DOE/CE/23810-79A
(JMC/ARTI-9611B - RDB6B41)

ARTI REFRIGERANT DATABASE

15 November 1996

prepared by

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MASTER

This report is one in a series prepared for the Materials Compatibility and Lubricant Research (MCLR) Program, under ARTI contract number 665-50000 for grant number DE-FG02-91CE23810 from the U.S. Department of Energy.

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INTRODUCTION

Purpose

The Refrigerant Database is an information system on alternative refrigerants, associated lubricants, and their use in air conditioning and refrigeration. It consolidates and facilitates access to property, compatibility, environmental, safety, application and other information. It provides corresponding information on older refrigerants, to assist manufacturers and those using alternative refrigerants, to make comparisons and determine differences. The underlying purpose is to accelerate phase out of chemical compounds of environmental concern.

Contents

The database provides bibliographic citations and abstracts for publications that may be useful in research and design of air-conditioning and refrigeration equipment. The complete documents are not included, though some may be added at a later date.

The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene). ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available even though standard designations may not have been assigned yet. It addresses lubricants including alkylbenzene, polyalkylene glycol, polyolester, and other synthetics as well as mineral oils. It also references documents addressing compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits.

Incomplete citations or abstracts are provided for some documents. They are included to accelerate availability of the information and will be completed or replaced in future updates.

Limitations

The Refrigerant Database is intended as a means to assist users in locating sources of information on alternative refrigerants. But, the database is:

- neither a comprehensive nor authoritative reference source,
- not a substitute for independent data collection by users,
- not a substitute for examination of the data, information on how they were arrived at, assumptions, and caveats in the cited documents, and
- not an endorsement of suitability or accuracy of referenced publications.

Materials compatibility, properties, safety considerations, and other characteristics affecting suitability or desirability may be influenced by a number of factors. Among them are specific application conditions, preparation such as drying before use, additives including fillers, impurities, catalytic interactions with other materials used, and changes in compounding between one source or batch and another. Similarly, new findings or corrections may supersede previously published data. The database is an aid in locating data that may be pertinent; it is not and should not be viewed as the source of data for research, design, analysis, or other purposes.

Manual Version

A listing of the database contents is provided in this document. Citations are grouped under the primary or first subject addressed, but are not cross-referenced under other topics. The computerized version, therefore, is better suited to search for information by subject.

Documents added since the July 1996 release of the database are flagged by a bar in the margin, as shown to the left. Users looking for new references, as well as added or substantively updated abstracts, will need to review only the citations so indicated.

Some superseded and older citations and abstracts have been removed from this document. They remain accessible through the computerized version, discussed below. A periodic report, containing the removed citations and abstracts for the *historic* documents, may be prepared if users indicate a need for it.

Computerized Version

A companion version of this listing is available in computerized form. It contains more than 4,200 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 474 specially-prepared data summaries,

including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. The refrigerant profiles cover designations, common uses, chemical and trade names, molecular mass, critical properties (pressure, temperature, specific volume, and density), physical and thermophysical properties for selected conditions, safety (toxicity and flammability) limits and classifications, atmospheric lifetime, ozone depletion potential, global warming potential, halogen global warming potential, commercialization, phaseout, and other data. Additional information and refrigerants will be added in future updates.

More than 5,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify use. They include optional prompting by search category, an automated "thesaurus" of synonyms and related terms, chain searches to broaden or narrow prior searches, a "wildcard" capability to allow entry of word segments, and a configuration capability to customize a number of options.

Distribution of the Refrigerant Database

	computerized (diskette)	manual (report)	documents (copies)
data summaries			
• refrigerants	yes	no	a
• compatibility	yes	no	a
• toxicity	yes	no	a
bibliographic citations and synopses (detailed abstracts)			
• current	yes	yes	a
• additions and changes flagged	no	yes	no
• historical and superseded	yes	no	a
• CDA sponsored supplement [b]	yes	b	a
search and retrieval software	yes [c]	no	no
distributed on cost-recovery basis			
• subscription (quarterly updates)	yes	yes	no
• as ordered	no	yes	yes [d]

a Data summaries, citations, and synopses may be printed with the computerized version.

b The Copper Development Association (CDA) sponsored supplement provides additional citations and synopses, most of which address compatibility with or use of copper in air-conditioning and refrigeration systems. The supplement is included and searchable with the computerized version, but published as a separate report (not part of the listing); please see page 423.

c Use of the search and retrieval software is subject to acceptance of the license agreement for it; both accompany the computerized version.

d Distribution is limited to documents in the public domain or for which authorization has been obtained. Others may be ordered from their publishers, which are identified in the bibliographic citations.

Prices and ordering instructions for the database are indicated on page 7.

A demonstration of the computerized version can be downloaded from the Internet, by entering http://www.ari.org and following the instructions. It also may be requested by sending a fax, with your full mailing address, to +1-703/524-6351. The demonstration includes samples of the data summaries.

Additions

Updates are planned for this database, with replacement releases scheduled four times a year. Please help in making the database more useful, and facilitating use of alternative refrigerants, by submitting the following:

- corrections to errors identified in the database,
- copies of helpful papers - whether your own or written by others - for citation, and
- suggestions for improving the database.

Authors or those holding rights to published or unpublished works pertinent to the database are invited - and encouraged - to authorize their reproduction and unrestricted distribution through the database. Product literature normally is not included, but studies providing relevant information, whether on proprietary or generic substances, will be considered.

Please send your inputs to:

James M. Calm
Engineering Consultant
10887 Woodleaf Lane
Great Falls, VA 22066-3003 USA

Thank you for your help with and use of the database. Its objective is to accelerate phase out of chemical compounds of environmental concern by sharing the information needed to do so.

Obtaining Documents

Documents indicated as *available from JMC* in their citations are available through the database and may be ordered used the form accompanying the installation diskettes. Other documents should be ordered from their publishers or alternative sources as identified in the database. Many of these documents also may be obtained from libraries. An effort will be made to secure permission for JMC to distribute additional documents, to facilitate access to them, but compliance with copyright provisions precludes doing so until appropriate arrangements are made. Reports from national laboratories and the Gas Research Institute may be ordered from the NTIS; most other publications from the U.S. Government may be obtained from the GPO. Addresses for several alternative sources follow:

ACGIH American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Suite 600, Cincinnati, OH 45240 USA; phone +1-513/742-2020, fax +1-513/742-3355

AIHA American Industrial Hygiene Association, 2700 Prosperity Avenue, Suite 250, Fairfax, VA 22031 USA; phone +1-703/849-8888, fax +1-703/207-3561

ASHRAE Publication Sales, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329 USA; phone +1-404/636-8400, fax +1-404/321-5478

CAS Chemical Abstracts Service, Document Delivery Department, Post Office Box 3012, Columbus, OH 43210-0012 USA; phone +1-614/447-3670 x2956 (from USA 800/848-6538), fax +1-614/447-3648

EPRI EPRI Distribution Center, 207 Coggins Drive, Post Office Box 23205, Pleasant Hill, CA 94523 USA; phone +1-510/934-4212

GPO Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 USA; phone +1-202/512-1800

IIR / IIF Institut International du Froid, 177, Boulevard Malesherbes, F-75017 Paris, France; phone +33-1/42.27.32.35, fax +33-1/47.63.17.98

JAR Japanese Association of Refrigeration, Nippon Reito Kyokai, 4th Floor, San-ei Building, 8 San-ei-cho, Shinjuku-ku, Tokyo 160, Japan; phone +81-3/3359-5231, fax +81-3/3359-5233

JMC James M. Calm, Engineering Consultant, 10887 Woodleaf Lane, Great Falls, VA 22066-3003 USA, fax +1-703/450-4313

LHL Linda Hall Library of Science, Engineering, and Technology, 5109 Cherry Street, Kansas City, MO 64110-2498 USA; phone +1-816/363-4600, fax +1-816/926-8785

NTIS National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 USA; phone +1-703/487-4780

SAE Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA

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REFRIGERANT DATABASE - CITATIONS AND ABSTRACTS

THERMOPHYSICAL PROPERTIES

E. M. Clark (DuPont Chemicals) and M. O. McLinden (National Institute of Standards and Technology, NIST), **Refrigerants**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 16, pages 16.1-16.10, 1993 (10 pages with 2 figures and 14 tables, RDB3A79)

This chapter summarizes information on common refrigerants, including designations, physical and electrical properties, performance, safety data, leak detection methods, and effects on construction materials. The refrigerants addressed include R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-22B1, R-23, R-30, R-31, R-32, R-40, R-41, R-50, R-110, R-111, R-112, R-112a, R-113, R-113a, R-114, R-114a, R-114B2, R-115, R-116, R-120, R-123, R-123a, R-124, R-124a, R-125, R-133a, R-134a, R-140a, R-141b, R-142b, R-143a, R-150a, R-152a, R-160, R-170, R-216ca, R-218, R-245cb, R-290, R-C316, R-C317, R-C318, R-400, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-600, R-600a, R-610, R-611, R-620, R-630, R-631, R-702, R-704, R-717, R-718, R-720, R-728, R-732, R-740, R-744, R-744A, R-764, R-1112a, R-1113, R-1114, R-1120, R-1130, R-1132a, R-1140, R-1141, R-1150, and R-1270. Molecular mass, normal (atmospheric) boiling point, freezing point, critical properties (temperature, pressure, and specific volume), and liquid refractive index are tabulated for most of these fluids. Dielectric constants, volume resistivity, velocity of sound, latent heat of vaporization, comparative performance, effects of temperature on performance, and safety classifications are presented for the more common fluids. Swell data are tabulated for R-11, R-12, R-13, R-13B1, R-21, R-22, R-30, R-40, R-113, R-114, R-502, and R-600 for eight elastomers. They include nitrile butyl rubber (Buna(TM) N), butadiene styrene (Buna(TM) S, GR-S), Butyl(TM) (GR-1), natural rubber, neoprene GN, polysulfide rubber (Thiokol(R) FA), fluoroelastomer (DuPont Viton(R) B), and silicone. Diffusion data are tabulated for water, R-12, and R-22 through neoprene, Buna N, synthetic rubber (DuPont Hypalon(R) 40), Butyl, Viton, polyethylene, and natural rubber. Mass density, specific heat, and viscosity are plotted for water/lithium bromide solutions (for absorption cycles) as functions of the mass fraction of lithium bromide.

P. E. Liley and P. D. Desai (Purdue University), **Thermophysical Properties of Refrigerants (SI Edition)**, publication 90375, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993 (296 pages with 230 tables, available from ASHRAE for $33 to members and $44 to nonmembers, RDB3A81)

This reference provides detailed specific heat, thermal conductivity, viscosity, velocity of sound, and surface tension data in tabular form in metric (SI) units. The refrigerants addressed include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50 (methane), R-113, R-114, R-115, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-C318, R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702p (para-hydrogen), R-704 (helium), R-717 (ammonia), R-718 (water), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). Empirical or semi-empirical property equations also are provided for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-142b, R-152a, R-500, R-502, R-503, R-717, and R-744. More than 200 references are cited to identify the data sources used.

please see pages 6-8 for ordering information

P. E. Liley and P. D. Desai (Purdue University), **Thermophysical Properties of Refrigerants (Inch-Pound Edition)**, publication 90373, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993 (292 pages with 230 tables, available from ASHRAE for $33 to members and $44 to nonmembers, RDB-3A82)

This reference provides detailed specific heat, thermal conductivity, viscosity, velocity of sound, and surface tension data in tabular form in inch-pound (IP) units. The refrigerants addressed include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50 (methane), R-113, R-114, R-115, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-C318, R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702p (para-hydrogen), R-704 (helium), R-717 (ammonia), R-718 (water), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). Empirical or semi-empirical property equations also are provided for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-142b, R-152a, R-500, R-502, R-503, R-717, and R-744. More than 200 references are cited to identify the data sources used.

M. O. McLinden (National Institute of Standards and Technology, NIST) and S. G. Penoncello (University of Idaho), **Refrigerant Properties**, *ASHRAE Handbook - Fundamentals* (published in separate editions with inch-pound and SI metric units), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, chapter 17, pages 17.1-17.86, 1993 (86 pages, RDB3A80)

This chapter provides pressure-enthalpy (Mollier) diagrams and tabulates thermodynamic and thermophysical properties for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-32, R-50 (methane), R-113, R-114, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (normal hydrogen), R-702p (parahydrogen), R-704 (helium), R-717 (ammonia), R-718 (water/steam), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). The tabular data include temperature, pressure, vapor volume, liquid density, enthalpy, entropy, specific heat, specific heat ratio, velocity of sound, viscosity, thermal conductivity, and surface tension. An enthalpy-concentration diagram and tabular data for the specific volume at saturation are presented for ammonia/water for absorption cycles. Enthalpy equilibrium and concentration diagrams are similarly provided for water/lithium bromide solutions.

B. Platzer et al, **Thermophysical Properties of Refrigerants**, Springer Verlag, Berlin, Germany, 1990 (probably in German, RDB4C09)

thermodynamic data, transport data

R. B. Stewart, R. T. Jacobsen, and S. G. Penoncello (University of Idaho), **ASHRAE Thermodynamic Properties of Refrigerants**, inch-pound (IP) version, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1986 (508 pages with 31 figures and 65 tables, RDB3208)

This book provides detailed thermodynamic property data for 31 refrigerants in inch-pound (IP) units of measure. An introductory section presents the equations of state, ancillary equations, and references for the data used. Appendices summarize the conversion factors and reference (datum) states for entropy and enthalpy. A sequence containing a pressure enthalpy diagram and two tables follows for each refrigerant. The first table presents saturated properties by temperature including pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second provides the density, enthalpy, and entropy at unsaturated conditions, by temperature and pressure. The refrigerants covered include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50 (methane), R-113, R-114, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702a (parahydrogen), R-704 (helium), R-717 (ammonia), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). Martin-Hou equations of state, or subsets or extensions thereto, were used for most of the fluorocarbon refrigerants. Detailed formulations were used for R-12 and R-22, and a truncated virial equation was used for R-13B1. Modified Benedict-Webb-Rubin (MBWR) equations were used for R-11, R-50, R-702, R-702a, R-720, R-728, R-732, R-1150, and R-1270. Specific formulations were used for the remainder, notably that by Haar and Gallagher for R-717.

R. B. Stewart, R. T. Jacobsen, and S. G. Penoncello (University of Idaho), **ASHRAE Thermodynamic Properties of Refrigerants**, metric (SI) version, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1986 (466 pages with 31 figures and 65 tables, RDB3209)

This book provides detailed thermodynamic property data for 31 refrigerants in metric (SI)

units of measure. An introductory section presents the equations of state, ancillary equations, and references for the data used. Appendices summarize the conversion factors and reference (datum) states for entropy and enthalpy. A sequence containing a pressure enthalpy diagram and two tables follows for each refrigerant. The first table presents saturated properties by temperature including pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second provides the density, enthalpy, and entropy at unsaturated conditions, by temperature and pressure. The refrigerants covered include R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-50 (methane), R-113, R-114, R-142b, R-152a, R-170 (ethane), R-290 (propane), R-500, R-502, R-503, R-600 (butane), R-600a (isobutane), R-702 (hydrogen), R-702a (parahydrogen), R-704 (helium), R-717 (ammonia), R-720 (neon), R-728 (nitrogen), R-729 (air), R-732 (oxygen), R-740 (argon), R-744 (carbon dioxide), R-1150 (ethylene), and R-1270 (propylene). Martin-Hou equations of state, or subsets or extensions thereto, were used for most of the fluorocarbon refrigerants included. Detailed formulations were used for R-12 and R-22, and a truncated virial equation was used for R-13B1. Modified Benedict-Webb-Rubin (MBWR) equations were used for R-11, R-50, R-702, R-702a, R-720, R-728, R-732, R-1150, and R-1270. Specific formulations were used for the remainder, notably that by Haar and Gallagher for R-717.

R-10

D. N. Seshadri, D. S. Vishwanath, and N. R. Kuloor, **Thermodynamic Properties of Carbon Tetrachloride**, *Journal of the Indian Institute of Science*, volume 48, number 2-3, pages 65-80, 1966 (RDB-4934)

R-10, thermodynamic properties, thermophysical data

R-11

R. T. Jacobsen, S. G. Penoncello, and E. W. Lemmon (University of Idaho), **A Fundamental Equation for Trichlorofluoromethane (R-11)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, number 11, pages 45-56, 1992 (12 pages, RDB3911)

equation of state, thermodynamic properties, thermophysical data

R-12

R. P. Kokernak and C. L. Feldman, **The Velocity of Sound in Liquid R12**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 13, pages 59 ff, 1971 (RDB4B74)

R-12, thermophysical properties

R. C. McHarness, B. J. Eiseman, Jr., and J. J. Martin, **The New Thermodynamic Properties of Freon-12**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 63, pages 31-44, September 1955 (RDB4653)

R-12, thermophysical data

S. G. Penoncello, R. T. Jacobsen, and E. W. Lemmon (University of Idaho), **A Fundamental Equation for Dichlorodifluoromethane (R-12)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, number 11, pages 57-70, 1992 (24 pages, RDB3912)

equation of state, thermodynamic properties, thermophysical data

J. T. R. Watson (National Engineering Laboratory, UK), **Thermophysical Properties of Refrigerant 12**, Her Majesty's Stationery Office (HMSO), Edinburgh, UK, 1975 (RDB2A25)

R-12, thermodynamic and transport data

Thermophysical Properties of Refrigerants (R-12, Dichlorodifluoromethane), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, August 1981 with errata dated 1986 (160 pages with 23 figures and 90 tables, in both Japanese and English, RDB0401)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-12. Included are tabular data and/or plots for PVT properties, enthalpy, entropy, isobaric and isochoric specific heat capacity, specific heat ratio, speed of sound, surface tension, viscosity, kinematic viscosity, thermal conductivity, thermal diffusivity, Prandtl number, solubility, refractive index, dielectric constant, volume resistivity, and dielectric strength. A 32-term polynomial equation of state is presented and compared to other equations and data. Relations also are presented for key equilibrium properties. Data are tabulated for the solubility of R-12 in water, moisture contents of saturated R-12 liquid and vapor, and R-12 in a naphthenic mineral oil. Data, including decomposition products by pyrolysis and hydrolysis rates, are pro-

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vided on the stability of R-12 in the presence of metals and oil. Linear swell, weight change, and observations are provided for R-12 with plastics including polytetrafluoroethylene (PTFE), tetrafluoroethylene-hexafluoropropylene copolymer, polyethylene, polyvinyl alcohol, polypropylene, polyvinylchloride (PVC), polyvinylidene chloride, nylon resin, acrylic resin (polymethacrylate), polystyrene, phenolic resin, epoxy resin, acetal resin, cellulose acetate, cellulose nitrate, acryl fiber, and polyester fiber. Linear swell data are tabulated for neat R-12, oil, and a 50/50 mixture with elastomers including neoprene W, neoprene GN, neoprene RT, Buna(TM) N, Buna(TM) S, natural rubber, polysulfide rubber, epichlorohydrin rubber, butyl rubber GR-I, chlorosulfonated polyethylene (DuPont Hypalon(R) 40), polyvinyl alcohol (PVA), fluoroelastomers (DuPont Viton(R) A and B), and urethane rubber. Published safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discussion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. An appendix summarizes quality requirements for compliance with the Japanese Industrial Standards (JIS) and specifically JIS K1517-1973.

R-13

L. F. Albright and J. J. Martin, **Thermodynamic Properties of Chlorotrifluoromethane**, *Industrial and Engineering Chemistry*, American Chemical Society (ACS), Columbus, OH, volume 44, 1952 (RDB4242)

R-13, thermophysical data

R-13B1

J. J. Martin, L. M. Welshans, C. H. Chou, and G. E. Gryka, **Data and Equations for Some Thermodynamic Properties of Freon-13B1 ($CBrF_3$)**, report on project M777, University of Michigan, Ann Arbor, MI, April 1953 (RDB3914)

R-13B1, equation of state, thermophysical data

Thermophysical Properties of Refrigerants (R-13B1, Bromotrifluoromethane), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, March 1989 (162 pages with 25 figures and 50 tables, in both Japanese and English, RDB0402)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-13B1. Included are tabular data and/or plots for PVT properties, enthalpy, entropy, isobaric and isochoric specific heat capacity, specific heat ratio, speed of sound, surface tension, viscosity, kinematic viscosity, thermal conductivity, thermal diffusivity, Prandtl number, solubility, refractive index, dielectric constant, volume resistivity, and dielectric strength. An equation of state is presented and compared to other equations and data. Relations also are presented for key equilibrium properties. Data are tabulated for the solubility of R-13B1 in both a naphthenic mineral oil and a synthetic polyglycol lubricant. Limited stability and compatibility data are outlined. Published safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discussion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. An appendix addresses compliance with the Japanese Industrial Standards (JIS), noting that the quality of R-13B1 is not covered; requirements for the quality of R-13B1 as a fire extinguishant, Halon 1301, under an ordinance of the Ministry of Home Affairs are summarized. R-13B1 also is regulated as a "liquified gas" by the Japanese Regulation on High-Pressure Gases.

R-22

D. R. Defibaugh and G. Morrison (National Institute of Standards and Technology, NIST), **Compressed Liquid Densities and Saturation Densities of Chlorodifluoromethane (R-22)**, *Journal of Chemical and Engineering Data*, volume 37, pages 107 ff, 1992 (4 pages, RDB4347)

thermodynamic properties, thermophysical data

D. E. Diller, A. S. Aragon, and A. Laesecke (National Institute of Standards and Technology, NIST), **Measurements of the Viscosity of Chlorodifluoromethane (R-22)**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, pages 19-22, 1993 (4 pages, RDB4349)

viscosity properties, thermophysical data

A. Kamei and S. W. Beyerlein, **A Fundamental Equation for Chlorodifluoromethane (R-22)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, number 11, pages 71-86, 1992 (16 pages, RDB-3915)

equation of state, thermodynamic properties, thermophysical data

R. Kohlen, **Das Fluide Zustandsgebiet von R-22: Berechnung, Korrelationen** [The Vapor-Phase Region of R-22: Calculations, Correlations], report series 19 number 14, Verein Deutscher Ingenieure (VDI) [Association of German Engineers] Verlag, Düsseldorf, Germany, 1987 (in German, RDB5492)

R-22, thermodynamic properties, thermophysical data

R. Kohlen, H. Kratzke, and S. Müller, **Thermodynamic Properties of Saturated and Compressed Liquid Difluorochloromethane**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 17, pages 1141-1151, 1985 (11 pages, RDB4142)

R-22, thermophysical data

B. Kruppa and J. Straub (Technische Universität München, Germany), **Thermal Diffusivity of Refrigerants**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 69-75, 1990 (7 pages with 4 figures and 2 tables, RDB-5623)

R-22, thermal diffusivity, transport data, photon correlation spectroscopy; presents results for R-22, but indicates that measurements also have been made for R-13, R-13B1, R-23, R-744, R-744A, R-7146, R-23/7146, and R-7146/13B1

E. F. Nielson and D. White, **The Heat Capacity, Heat of Fusion, Heat of Transition, and Heat of Vaporization of Chlorodifluoromethane Between 16 K and the Boiling Point**, *Journal of the American Chemical Society*, American Chemical Society (ACS), Columbus, OH, volume 79, pages 5618-5621, 1957 (4 pages, RDB4312)

R-22, thermodynamic properties, thermophysical data

K. Stephan and J. Biermann (Universität Stuttgart, Germany), **Thermal Diffusivity Measurement of Refrigerant 22 at Low Pressures Using the Photoacoustic Effect**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 149-156, July 1992 (8 pages with 5 figures and 2 tables, RDB2716)

R-22, thermodynamic properties, thermophysical data

M. Zander, **Pressure-Volume-Temperature Behavior of Chlorodifluoromethane (Freon 22) in the Gaseous and Liquid States**, *Proceedings of the Fourth Thermophysical Properties Symposium*, American Society of Mechanical Engineers (ASME), New York, NY, pages 114-123, 1968 (10 pages, RDB4325)

R-22, thermodynamic data, PVT

Thermophysical Properties of Refrigerants (R-22, Chlorodifluoromethane), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, November 1975 with errata dated 1986 (132 pages with 21 figures and 38 tables plus 16 page errata, in both Japanese and English, RDB-0403)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-22. Included are tabular data and/or plots for PVT properties, enthalpy, entropy, isobaric and isochoric specific heat capacity, specific heat ratio, speed of sound, surface tension, viscosity, kinematic viscosity, thermal conductivity, thermal diffusivity, Prandtl number, solubility, refractive index, dielectric constant, volume resistivity, and dielectric strength. A section on physical and chemical provides tabular data on the solubility of R-22 in water, miscibility diagrams for naphthenic and paraffinic mineral oils in R-22, and plots of the solubility in naphthenic mineral oil. It also identifies the decomposition products of R-22 in several heat sources and indicates the hydrolysis rate of R-22 in water alone and with several metal catalysts. The effects of R-22 on plastics are summarized, including polytetrafluoroethylene (PTFE), tetrafluoroethylene-hexafluoropropylene copolymer, poly(1-chloro-1,2,2-trifluoroethylene), polyvinyl alcohol, polyethylene, polyvinylchloride (PVC), polyvinylidene chloride, nylon resin, acrylic resin (polymethacrylate), polystyrene, phenolic resin, epoxy resin, acetal resin, cellulose acetate, cellulose nitrate, and acryl fiber. Linear swell data are tabulated for neat R-12, oil, and a 50/50 mixture with elastomers including Buna(TM) N, Buna(TM) S, neoprene W (type GN), butyl rubber, and natural rubber. The maximum temperature limit is provided for R-22 with several enamel (varnish) types, including acrylic, polyvinyl formal, isocyanate modified polyvinyl formal, polyamide imide, polyester imide, and polyimide. Published safety data, including toxicity and flammability, are summarized and explosion limit curves are provided for air mixtures. An equation of state is presented and compared to other equations and data. Relations also are presented for key equilibrium properties. Published safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discus-

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sion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. An appendix summarizes quality requirements for compliance with the Japanese Industrial Standards (JIS) and specifically JIS K1519-1973.

R-22/DTG (as Refrigerant/Absorbent)

F. P. L. M. Vissers (Technical University Delft, The Netherlands), **An Expression for the Excess Gibbs Function of the Liquid R-22/DTG Mixture**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 263-271, 1993 (9 pages with 1 figure and 1 table, RDB5322)

dimethylether tetraethyleneglycol (DTG), R-22/DTG refrigerant/absorbent, absorption systems

R-23

A. G. Aizpiri, A. Rey, J. Dávila, R. G. Rubio, J. A. Zollweg, and W. B. Streett, **Experimental and Theoretical Study of the Equation of State of CHF_3 in the Near-Critical Region**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 95, pages 3351-3357, 1991 (7 pages, RDB4A38)

R-23, thermodynamic properties, thermophysical data

J. L. Belzile, S. Kaliaguine, and R. S. Ramalho, **PVT Study of Trifluoromethane by the Burnett Method**, *Canadian Journal of Chemical Engineering*, Canadian Society for Chemical Engineering, Ottawa, ON, Canada, volume 54, pages 425-431, 1976 (7 pages, RDB4B28)

R-23, thermodynamic properties, thermophysical data

R. Döring and H. J. Löffler (Technische Universität Berlin, Germany), **Thermodynamische Eigenschaften von Trifluormethan (R23)** [Thermodynamic Properties of Trifluoromethane (R-23)], *Kältetechnik-Klimatisierung*, Germany, volume 20, pages 342-348, 1968 (7 pages, in German, RDB4307)

thermophysical data

K. Hori, S. Okazaki, M. Uematsu, and K. Watanabe (Keio University, Japan), **An Experimental Study of Thermodynamic Properties of Trifluoromethane**, *Proceedings of the Eighth Thermophysical Properties Symposium* (Gaithersburg, MD), American Society of Mechanical Engineers (ASME), New York, NY, volume 2, pages 380-386, 1982 (7 pages, RDB4309)

R-23, thermodynamic data

Y. C. Hou and J. J. Martin, **Physical and Thermodynamic Properties of Trifluoromethane**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 5, number 1, pages 125-129, 1959 (5 pages, RDB3916)

R-23, equation of state, thermophysical data

L. A. Kryukov, **Determination of Freon-23 Density at Room Temperatures at Near Atmospheric Pressures**, *Tr. Mosk. Energ. Inst.*, volume 104, pages 24-25, 1972 (2 pages, in Russian, RDB4B29)

R-23, thermodynamic properties, thermophysical data

A. Popowicz, T. Oi, J. Shulman, and T. Ishida (State University of New York), **Vapor Pressure Isotope Effects in Liquid Fluoroform**, *Journal of Chemical Physics*, American Institute of Physics (AIP), New York, NY, volume 76, number 7, pages 3732-3743, 1 April 1982 (12 pages with 6 figures and 7 tables, RDB4143)

R-23, thermodynamic properties, thermophysical data

D. S. Rasskazov, E. K. Petrov, G. A. Spiridonov, and E. R. Ushmaikin, **Investigation of the p,v,t-Dependence of Freon-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 8, pages 4-26, 1975 (23 pages, in Russian, RDB4B30)

R-23, PVT, thermodynamic properties, thermophysical data

D. S. Rasskazov, E. K. Petrov, and L. A. Kryukov, **Experimental Investigation of the Caloric Properties of Freon-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 8, pages 100-107, 1975 (8 pages, in Russian, RDB4B31)

R-23, thermodynamic properties, thermophysical data

D. S. Rasskazov, U. M. Babikov, and N. Y. Filatov, **Experimental Study of Viscosity of Freon-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov*

[Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 8, pages 142-147, 1975 (6 pages, in Russian, RDB4B32)

R-23, transport properties, thermophysical data

D. S. Rasskazov, E. K. Petrov, and E. R. Ushmaikin, **Experimental Study of Density of Freon-23 in the Liquid Phase**, *Tr. Mosk. Energ. Inst.*, volume 234, pages 52-57, 1975 (6 pages, in Russian, RDB4B33)

R-23, thermodynamic properties, thermophysical data

D. S. Rasskazov and L. A. Kryukov, **Properties of Gaseous Freon-23 at Subcritical Pressures**, *Tr. Mosk. Energ. Inst.*, volume 179, pages 108-112, 1974 (5 pages, in Russian, RDB4B34)

R-23, thermodynamic properties, thermophysical data

R. G. Rubio, J. A. Zollweg, and W. B. Streett, **A p-V-T Surface for Trifluoromethane**, *Berichte der Bunsengesellschaft für Physikalische Chemie*, volume 93, pages 791-800, 1989 (10 pages, RDB4316)

R-23, thermodynamic properties, thermophysical data, PVT

A. Takanuma, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of the Isobaric Specific Heat Capacity and Formulation of an Equation of State for Refrigerant 23 in the Gaseous Region**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 2, number 2, pages 61-68, 1985 (8 pages, RDB4B35)

R-23, thermodynamic properties, thermophysical data

N. I. Timenshenko, E. P. Kholodov, and A. L. Yamnov, **Refractive Index, Polarizability, and Density of Freon-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 8, pages 17-26, 1975 (10 pages, in Russian, RDB4B36)

R-23, transport properties, thermophysical data

R. H. Valentine, G. E. Brodale, and W. F. Giauque, **Trifluoromethane: Entropy, Low Temperature Heat Capacity, Heats of Fusion and Vaporization, and Vapor Pressure**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, volume 66, pages 392-395, 1962 (4 pages, RDB4321)

R-23, thermodynamic properties, thermophysical data

W. Wagner, **Thermodynamische Eigenschaften von Trifluormethan** [Thermodynamic Properties of Trifluoromethane], *Kältetechnik-Klimatisierung*, volume 20, number 8, pages 238-240, 1968 (3 pages, in German, RDB4322)

R-23, thermophysical data

Refrigerant Reclin(R) 23, product bulletin AFK2043E/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, March 1993 (12 pages with 6 figures and 7 tables, RDB4774)

This bulletin provides data for R-23 along with comparative data for R-13 and R-503 [R-23/13 (40.1/59.9)] in metric (SI) units of measure. The introduction describes R-23 as an alternative for R-13 and R-503 for low-temperature refrigeration. It outlines the environmental impetus to phase out R-13 and R-503 and typical uses for these refrigerants. They include applications with evaporating temperatures of -110 to -60 °C (-166 to -76 °F) such as laboratory cryostats, test facilities, and equipment for gas separation and process technologies. Such applications use cascaded equipment with R-22 or R-134a for the high stage. The bulletin reviews thermodynamic selection criteria. Four plots compare the compression ratios, compressor discharge temperatures, volumetric refrigerating effect, and coefficient of performance for R-13, R-23, and R-503 for -110 to -60 °C (-110 to -76 °F). These data also are tabulated. The bulletin then discusses lubricants, noting that only fully synthetic lubricants are suitable, since mineral oils and semisynthetic oils do not have adequate miscibility with R-13, R-23, and R-503 in their usual application temperature range. It suggests that polyalkylbenzene with solubizers, silicates (Bayer Fluisil(R) S 55 K), polysiloxanes (Bayer Baysilone(R)), or low viscosity esters (DEA Mineralöl Triton SEZ 22) may be suitable. A miscibility diagram is provided for R-23 with an ester from Deutsche Shell AG. Oil-free labyrinth piston compressors also offer solutions. The bulletin provides elastomer swell data for R-13 and R-23 with chloroprene (CR, Neoprene(R) GN), nitrile (NBR, Perbunan(R) N), styrene-butadiene (SBR, Buna(R) S), polysulfide (Thiokol(R)), natural (NR), butyl (IIR), chlorosulfonated polyethylene (CSM, Hypalon(R) 40), and fluorinated (FPM, DuPont Viton(R) A) rubbers. A table provides physical property information including the chemical formula and name, molecular mass, normal boiling and freezing points, critical parameters (temperature, pressure, and density), and latent heat of vaporization. It also gives the surface tension, vapor dielectric constant, and liquid viscosity,

please see pages 6-8 for ordering information

thermal conductivity, specific heat, and density at selected temperatures. The bulletin discusses differences in evaporator sizing for R-13, R-23, and R-503. Three tables then provide saturated property data for these refrigerants. The thermodynamic data include pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover the ranges of -130 °C (266 °F) to the critical points. The bulletin concludes with a pressure-enthalpy (Mollier) diagram for R-23 based on a Benedict-Webb-Rubin (BWR) equation of state. Hoechst Chemical's product name for R-23 is Reclin(R) 23.

R-32

D. R. Defibaugh, G. Morrison, and L. A. Weber (National Institute of Standards and Technology, NIST), **The Thermodynamic Properties of Difluoromethane**, *Journal of Chemical and Engineering Data*, 1993 (RDB4348)

R-32, thermophysical data

P. G. T. Fogg, P. A. Hanks, and J. D. Lambert, **Ultrasonic Dispersion in Halo-methane Vapours**, *Proceedings of the Royal Society*, volume 219, pages 490-499, 1953 (10 pages, RDB5484)

R-32, thermodynamic properties, thermophysical data

Y. Higashi, H. Imaizumi, and S. Usuba, **Measurement of the Critical Parameters for HFC-32**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 65-68, 1992 (4 pages in Japanese, RDB4B21)

R-32, thermodynamic properties, thermophysical data

A. Kanungo, T. Oi, S. Popowicz, and T. Ishida (State University of New York), **Vapor Pressure Isotope Effects in Liquid Methylene Difluoride**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 91, number 15, pages 4198-4203, 1987 (6 pages, RDB4144)

vapor pressures of isotopic R-32, thermodynamic properties, thermophysical data

S. Kuwabara, J. Tatoh, H. Sato, and K. Watanabe (Keio University, Japan), **Critical Parameters and Vapor-Liquid Coexistence Curve in the Critical Region for HFC-32**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 69-72, 1992 (4 pages, RDB-4B23)

R-32, thermodynamic data

D. R. Lide, **The Microwave Spectrum and Structure of Methylene Fluoride**, *Journal of the American Chemical Society*, American Chemical Society (ACS), Columbus, OH, volume 74, pages 3548-3552, 1952 (4 pages, RDB4361)

R-32

P. F. Malbrunot, P. A. Meunier, G. M. Scatena (Laboratoire des Hauts Pressions, France), W. H. Mears, K. P. Murphy, and J. V. Sinka (AlliedSignal Incorporated, then Allied Chemical Corporation), **Pressure-Volume-Temperature Behavior of Difluoromethane**, *Journal of Chemical and Engineering Data*, volume 13, number 1, pages 16-21, January 1968 (6 pages with 3 figures and 7 tables, RDB2310)

The pressure-volume-temperature (PVT) properties of R-32 are correlated using the Martin-Hou equation of state to within ±0.94% standard deviation over the experimental ranges: 25-200 °C (77-392 °F), 0.8-20 MPa (120-2900 psia), and 47-1.8 cc/g (0.75-0.03 cf/lb). Vapor pressures have been determined from -83 °C (-117 °F) to 78.4 °C (173 °F), the measured critical temperature. Using liquid densities measured between -25 and 78 °C (-13 and 172 °F) and densities of saturated vapor computed from the Martin-Hou equation, a rectilinear diameter line has been developed. The critical pressure and density are 5.830 MPa (846 psia) and 430 kg/m^3 (26.8 lb/cf), respectively.

A. Nishimura, Z-Y. Qian, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of HFC-32 at the Gaseous Phase and Saturated States**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 57-60, 1992 (4 pages, RDB4B24)

R-32, thermodynamic data

C-C. Piao, M. Noguchi (Daikin Industries, Limited, Japan), H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of a New Working Fluid, HFC-32**, *Proceedings of the 1993 Annual Conference*, Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 13-16, 1993 (4 pages, RDB4873)

R-32, thermophysical data

Z-Y. Qian, A. Nishimura, H. Sato, and K. Watanabe (Keio University, Japan), **Compressibility Factors and Virial Coefficients of Difluoromethane (HFC-32) Determined by the Burnett Method**, *JSME International Journal (series II: Fluids Engineering,*

Heat Transfer, Power, Combustion, and Thermophysical Properties), Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, volume 36, pages 665-670, 1993 (6 pages in English, available from ASME in the Americas and from Maruzen Company, Limited, elsewhere, RDB6448)

R-32, thermodynamic properties, thermophysical data

Z-Y. Qian, H. Matsunobe, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Property Measurements for Difluoromethane (HFC-32) by a Burnett Method**, paper B103, *Proceedings of the Twelfth Japan Symposium on Thermophysical Properties*, pages 73-76, 1991 (4 pages with 8 figures, RDB2428)

This paper summarizes measurements of vapor pressures of R-32 at temperatures of 300-330 K (80-134 °F) and compressibility factors for 300-350 K (80-170 °F) and 0.15-4.3 MPa (22-624 psia). The experimental apparatus used, based on a Burnett method, is briefly described. Second and third virial coefficients for property calculations are presented. A systematic error, related to an adsorption effect in the Burnett experimental procedure, and a correction are discussed.

T. Sato, H. Sato, and K. Watanabe (Keio University, Japan), **A Study of PVT Properties of HFC-32**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, 1992 (RDB4A43)

R-32, thermodynamic data

W. Tauscher, **Measurement of the Thermal Conductivity of Liquid Refrigerants by an Unsteady-State Hot Wire Method**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 11, number 1, pages 97-104, 1969 (8 pages, RDB-3917)

R-32, thermophysical properties, conductivity data

L. A. Weber and A. R. H. Goodwin (National Institute of Standards and Technology, NIST), **Ebulliometric Measurement of the Vapor Pressure of Difluoromethane**, *Journal of Chemical and Engineering Data*, volume 38, number 2, pages 254-256, 1993 (3 pages with 2 figures and 2 tables, available from JMC as RDB4910)

This paper presents measured vapor pressure data for R-32 at relatively low temperatures and pressures, between -65 and -36 °C (-85 and -33 °F). It describes a comparative ebulliometer used for the measurements. The paper shows and tabulates deviations of the measured data from fits to an Antoine equation and, combined with data from other researchers, to a Wagner equation. It compares the findings to those published by others. The results offer a means to calculate the vapor pressure of R-32 from -83 °C to the critical temperature, 78.21 °C (-118 to 172.78 °F). The paper then presents calculated thermodynamic properties, including liquid and vapor pressure, density, enthalpy, entropy, and specific heat at low temperatures, from -73 to -23 °C (-100 to -10 °F). It also presents estimates of the second virial coefficients for R-32.

M-S. Zhu, J. Li, and C-X. Lu (Tsinghua University, China), **Experimental Research on Vapor Pressure and Surface Tension of HFC-32**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 54-60, October 1993 (7 pages with 6 figures and 3 tables, RDB-3A26)

R-32, thermodynamic properties, thermophysical data

Genetron(R) **HFC-32**, technical bulletin 525-642, AlliedSignal Incorporated, Morristown, NJ, April 1991 (4 pages with 3 tables, RDB4105)

This bulletin provides physical property, comparative performance, and thermodynamic data on R-32, difluoromethane, in inch-pound (IP) units. It summarizes physical properties including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), and flammability. It also indicates the liquid density and specific heats of the liquid and vapor at 26.7 °C (80 °F) as well as the ozone depletion potential (ODP) and estimated global warming potential (GWP). It then presents a performance comparison for R-12, R-22, R-32, and R-502. The report tabulates thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -40 to 60 °C (-40 to 140 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. AlliedSignal's product name for R-32 is Genetron(R) 32.

Thermodynamic Properties of Klea(R) **32, British Units**, bulletin 620250270, ICI Klea, Wilmington, DE, July 1993 (56 pages with 2 tables, limited copies available from JMC as RDB4107)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-32 in inch-pound (IP) units of measure. It com-

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prises two tables. The first presents saturation properties by temperature (°F and °R) for -84 to 78 °C (-120 to 172 °F) and at the critical point, 78.35 °C (173.03 °F). The tabular data include absolute and gauge pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second table provides volume, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 14-5170 kPa (2-750 psia) to temperatures as high as 114 °C (238 °F). ICI's product name for R-32 is Klea(R) 32.

Thermodynamic Properties of Klea 32, SI Units, bulletin CP/30473/1Ed/152/1192, ICI Chemicals and Polymers Limited, Runcorn, Cheshire, UK, November 1992, (60 pages with 2 tables, RDB-6B28)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-32 in metric (SI) units of measure. It comprises two tables. The first presents saturation properties by temperature (°C and K) for -80 to 78 °C (-112 to 172 °F) and at the critical point, 78.35 °C (173.03 °F). The tabular data include absolute pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second table provides volume, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 20-5500 kPa (3-800 psia) to temperatures as high as 198 °C (388 °F). ICI's product name for R-32 is Klea(R) 32.

R-50 (Methane)

S. Angus, B. Armstrong, and K. M. de Reuck, **International Thermodynamic Tables of the Fluid State - 5: Methane**, Chemical Data Series Number 16, International Union of Pure and Applied Chemistry (IUPAC), Pergammon Press, Oxford, UK, 1978 (RDB3943)

R-50, equation of state, thermodynamic properties, thermophysical data

D. G. Friend, J. F. Ely, and H. Ingram (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Methane**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 18, pages 583-638, 1989 (56 pages, RDB4223)

R-50, thermodynamic properties

R. Kleinrahm and W. Wagner, **Measurement and Correlation of the Equilibrium Liquid and Vapor Densities and the Vapor Pressure Along the Coexistence Curve of Methane**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 18, pages 739 ff, 1986 (RDB3125)

R-50, thermodynamic properties, thermophysical data

V. G. Skripka et al, **Vapor-Liquid Equilibrium of Binary Systems of Natural Gas Components at Low Temperatures**, *Gazovaja Promyslennost'*, publication date unknown (in Russian, RDB5716)

R-50, R-290, R-600a, R-290/600a, thermodynamic properties, thermophysical data [referenced in RDB 5705]

R-112

Freon(R) 112 - Tetrachlorodifluoroethane, product information bulletin B-1, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, September 1969 (26 pages with 1 figure and 24 tables, RDB5161)

R-112, R-112a, R-112a/112, R-112/113, R-112a/112/113, properties, compatibility, stability, solubility, safety, toxicity, flammability

R-113

M. J. Mastroianni, R. F. Stahl, and P. N. Sheldon, **Physical and Thermodynamic Properties of 1,1,2-trifluorotrichloroethane (R-113)**, *Journal of Chemical and Engineering Data*, volume 23, number 2, pages 113-118, 1978 (6 pages, RDB3918)

1,1,2-trifluoro-1,2,2-trichloroethane, equation of state, thermodynamic properties

R-114

A. F. Benning and R. C. McHarness, **Thermodynamic Properties of Freon 114 Refrigerant**, technical bulletin T-114D, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1966 (RDB6810)

R-114, thermophysical data

K. R. Hules (Sperry Corporation) and D. P. Wilson (AlliedSignal Incorporated, then Allied Chemical Corporation), **An Interim Engineering Model of the Thermodynamic Properties of 1,2-Dichloro-**

tetrafluoroethane, Refrigerant R-114, *Proceedings of the Eighth Thermophysical Properties Symposium* (National Bureau of Standards, Gaithersburg, MD, 15-18 June 1981), edited by J. V. Sengers, American Society of Mechanical Engineers (ASME), New York, NY, volume II, pages 370-379, 1982 (12 pages with 11 figures and 5 tables, available from JMC as RDB3929)

R-114, modified Martin-Hou equation of state, 1,2-dichloro-1,1,2,2-tetrafluoroethane

M. Kriebel, H. J. Löffler, and H. Matthias, **Thermodynamic Properties of Binary Mixtures of Dichlorotetrafluoroethane and Lubricating Oil**, *Kältetechnik-Klimatisierung*, volume 18, number 7, pages 261-267, 1966 (7 pages, in German, RDB-3B60)

R-114, thermophysical data, 1,2-dichloro-1,1,2,2-tetrafluoroethane

J. J. Martin, *Journal of Chemical and Engineering Data*, volume 5, pages 334 ff, 1960 (RDB6811)

R-114, thermodynamic properties, thermophysical data

D. P. Wilson (AlliedSignal Incorporated, then Allied Chemical Corporation) and K. R. Hules (Sperry Corporation), **Experimental Study of the Thermodynamic Properties of 1,2-Dichlorotetrafluoroethane**, *Proceedings of the Eighth Thermophysical Properties Symposium* (National Bureau of Standards, Gaithersburg, MD, 15-18 June 1981), edited by J. V. Sengers, American Society of Mechanical Engineers (ASME), New York, NY, volume II, pages 361-369, 1982 (11 pages with 3 figures and 6 tables, RDB6812)

R-114 [actually R-114/114a (93/7)], measurements of pressure-volume temperature (PVT) properties at 17-234 °C (62-453 °F) and 0.2-10.4 MPa (24-1514 psia) using a high pressure, constant volume and mass apparatus, which is described; 13 isochores were generated in the vapor, supercritical dense gas, and compressed liquid regions; new critical constants were determined; reviews measurements by others, noting that most were on commercial R-114, actually and isomeric blend of R-114/114a (95/5); relations for liquid density, vapor pressure, and ideal gas heat capacity; modified Martin-Hou equation of state; vibrational fundamentals for the trans and gauche isomers of R-114

Thermophysical Properties of Refrigerants (R-114, 1,2-dichlorotetrafluoroethane), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, March 1986 (162 pages with 23 figures and 46 tables, in both Japanese and English, RDB0404)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-114 (1,2-dichloro-1,1,2,2-tetrafluoroethane). Included are tabular data and/or plots for PVT properties, enthalpy, entropy, isobaric and isochoric specific heat capacity, specific heat ratio, speed of sound, surface tension, viscosity, kinematic viscosity, thermal conductivity, thermal diffusivity, Prandtl number, solubility, refractive index, dielectric constant, volume resistivity, and dielectric strength. An extended Martin-Hou equation of state is presented and compared to other equations and data. Relations also are presented for key equilibrium properties. Data are tabulated for the solubility of R-114 in water, moisture contents of saturated R-114 liquid and vapor, and R-114 in both a naphthenic mineral oil and a synthetic polyperfluoroether lubricant. Limited data on hydrolysis rates, stability of R-114 in the presence of metals and oil, and compatibility with other materials are outlined. Published safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discussion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. An appendix summarizes quality requirements for compliance with the Japanese Industrial Standards (JIS) and specifically JIS K1528-1982. R-114 also is regulated as a "liquified gas" by the Japanese Regulation on High-Pressure Gases.

R-114B2

R-114B2

R. Döring, **Thermodynamische Eigenschaften des Kältemittels R114B2** [Thermodynamic Properties of Refrigerant R-114B2], *Die Kälte- und Klimatechnik*, Germany, volume 9 pages 348 ff, 1977 (in German, RDB4918)

R-114B2, thermophysical data

R-115

E. Hahne, U. Groß, and Y. W. Song (Universität Stuttgart, Germany), **The Thermal Conductivity of R115 in the Critical Region**, *International Journal of Thermophysics*, Plenum Publishing Corporation,

please see pages 6-8 for ordering information

Brugge, Belgium, volume 10, pages 687-700, 1989 (14 pages, RDB5641)

R-115, thermodynamic properties, thermophysical data

H. J. Löffler and W. Schulz, **Thermodynamische Eigenschaften binärer Gemische aus Pentafluormonochloräthan (R115) und Kältemachinenölen** [Thermodynamic Properties of Binary Mixtures of Chloropentafluoroethane (R-115) and Refrigeration Oils], *Kältetechnik-Klimatisierung*, Germany, volume 18, number 1, pages 9-15, 1966 (7 pages, in German, RDB4932)

thermophysical data, refrigerant-lubricant mixtures

W. H. Mears, E. Rosenthal, and J. V. Sinka (Allied-Signal Incorporated, then Allied Chemical Corporation), **Pressure-Volume-Temperature Behavior of Pentafluoromonochloroethane**, *Journal of Chemical and Engineering Data*, volume 11, number 3, pages 338-343, July 1966 (6 pages, RDB-4654)

R-115, thermodynamic properties, thermophysical data

R-123

A. R. H. Goodwin, D. R. Defibaugh, G. Morrison, and L. A. Weber (National Institute of Standards and Technology, NIST), **The Vapor Pressure of 1,1-dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 13, number 6, pages 999-1009, November 1992 (11 pages with 1 figure and 1 table, RDB3711)

R-123, thermodynamic properties, thermophysical data

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Isobaric Heat Capacity Data for Liquid HCFC-123 ($CHCl_2CF_3$, 2,2-dichloro-1,1,1-trifluoroethane)**, *Journal of Chemical and Engineering Data*, volume 36, number 2, pages 156-159, 1991 (4 pages, RDB4B67)

R-123, thermodynamic properties, thermophysical data

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of Isobaric Specific Heat of HCFC-123 in the Liquid State**, *Thermochimica Acta*, volume 163, pages 203-210, 1990 (8 pages, RDB5337)

R-123, thermodynamic properties, thermophysical data

K. Oguchi and Y. Takaishi (Kanagawa Institute of Technology, Japan), **Measurement of Saturated Liquid Density of HCFC-123**, *Proceedings of the Tenth Japan Symposium on Thermophysical Properties*, pages 55-58, 1989 (4 pages, RDB4313)

R-123, thermodynamic properties, thermophysical data

T. Okubo and A. Nagashima, **Measurement of the Viscosity of HCFC-123 in the Temperature Range 233-418 K and at Pressure up to 20 MPa**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 13, number 3, pages 401-410, 1992 (10 pages, RDB4881)

R-123 transport properties, thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Equation for a New Working Fluid HCFC-123**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 122-129, 1991 (7 pages, RDB5481)

R-123, thermodynamic properties, thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **PVT and Vapor Pressure Measurements on 1,1-dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane] **(HCFC-123)**, *Journal of Chemical and Engineering Data*, volume 36, pages 398-403, 1991 (RDB5462)

R-123, thermodynamic properties, thermophysical data

M. Takahashi, C. Yokoyama, and S. Takahashi, **Gas Viscosities of HCFC-123 and HCFC-123a**, *Proceedings of the Eleventh Japan Symposium on Thermophysical Properties*, pages 115-118, 1990 (4 pages, RDB3923)

R-123, R-123a, thermophysical properties, viscosity

S. Tanikawa, Y. Kabata, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Critical Parameters and the Vapor-Liquid Coexistence Curve in the Critical Region of HCFC-123**, *Journal of Chemical and Engineering Data*, volume 35, pages 381-385, 1990 (5 pages, RDB-5465)

R-123, thermodynamic properties, thermophysical data

S. Tanikawa, Y. Kabata, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve in the Critical**

Region of HCFC-123, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), pages 513-518, 1989 (8 pages, RDB4320)

R-123, thermodynamic data

L. A. Weber and J. M. H. Levelt Sengers (National Institute of Standards and Technology, NIST), **Critical Parameters and Saturation Densities of 1,1-dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 55, pages 241-249, 1990 (9 pages with 2 figures and 1 table, RDB0915)

This paper describes measurements to determine the critical parameters (temperature and density) as well as densities along the liquid-vapor phase boundary of R-123. It describes and schematically shows the optical cell employed. It also outlines the experimental procedures used for the measurements. The measured data are tabulated and an empirical correlation and uncertainty analysis are presented. The critical temperature and density were found to be 183.72 °C (362.70 °F) and 550 kg/m^3 (34.3 lb/cf), respectively. The critical pressure was calculated from vapor pressure data to be 3674 kPa (532.9 psia), which yields a value of 0.269 for the critical compressibility factor, Z_c. Measurement temperatures varied from 25 °C (77 °F) to the critical point for the saturated liquid and from 160 °C (320 °F) to the critical point for saturated vapor.

L. A. Weber (National Institute of Standards and Technology, NIST), **Vapor Pressures and Gas-Phase PVT Data for 1,1-dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], *Journal of Chemical and Engineering Data*, American Chemical Society (ACS), Columbus, OH, volume 35, number 3, pages 237-240, July 1990 (4 pages with 2 figures and 4 tables, available from JMC as RDB0910)

New data are presented for the vapor pressure and gas-phase PVT surface of R-123 in the temperature range 338-453 K (149-356 °F) at densities up to 0.67 mol/L. The data have been represented analytically to demonstrate the precision and to facilitate calculation of thermodynamic properties.

Forane(R) 123, technical digest, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1994 (4 pages with 4 tables, available from JMC as RDB4767)

This bulletin supplies information on R-123 for use in low-pressure chillers, both in new equipment and retrofit of R-11 equipment. It compares the physical and environmental properties of R-11 and R-123, and provides a tabular data summary for them in inch-pound (IP) units. The table lists the chemical formula, molecular weight, normal boiling and freezing points, heat of vaporization, vapor and liquid density at the boiling point and 27 °C (80 °F), critical parameters (temperature, pressure, and density), specific heat of the liquid at the same temperature and of the vapor at atmospheric pressure, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). The table also shows both fluids to be nonflammable. A second table gives the saturated vapor pressures of R-11 and R-123 for -40 to 93 °C (-40 to 200 °F). A third presents the saturated vapor pressure and liquid and vapor densities and enthalpies for the same temperature range. The document briefly reviews operating and retrofit considerations with attention to performance, lubrication, and material compatibility. It also comments on personal exposure and safe handling. The digest concludes with container identification for R-123 and other alternative refrigerants. Elf Atochem's product name for R-123 is Forane(R) 123.

Genetron(R) 123, technical bulletin B-525-646, AlliedSignal Incorporated, Morristown, NJ, February 1993, May 1993, September 1993, November 1993, and February 1994 (4 pages with 3 tables, RDB-3452)

This bulletin supplies information on R-123, described as a replacement for R-11 in centrifugal chillers. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 30 °C (86 °F). It then presents a tabular comparison of performance for R-11 and R-123. The report provides tabular thermodynamic properties (pressure, density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -18 to 71 °C (0 to 160 °F). Formulae are provided to calculate thermodynamic properties including vapor pressure, ideal gas heat capacity, and liquid density correlations. Estimated coefficients are presented for a Martin-Hou equation of state. AlliedSignal's product name for R-123 is Genetron(R) 123.

Hoechst Refrigerant R 123, product bulletin AFK2321E/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, January 1991 (12 pages with 1 figure and 4 tables, RDB4775)

This bulletin provides data for R-123, identified as a substitute for R-11 in refrigeration engi-

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neering, and specifically for turbo (centrifugal) compressor chillers, in metric (SI) units of measure. The introduction reviews the phaseout of chlorine-containing refrigerants and criteria for substitutes. A table summarizes physical and thermodynamic property data for R-123, including the chemical formula and name, molecular mass, normal boiling point, and critical parameters (temperature, pressure, and density). It also gives the liquid and vapor densities at 20 and 40 °C (68 and 104 °F). A second table compares the compression ratio, suction flow rate, compressor discharge temperature, volumetric cooling capacity, and coefficient of performance (COP) of R-11 and R-123. The bulletin then discusses compatibility with metals, recommending avoidance only of zinc, magnesium, lead, and aluminum alloys with more than 2% magnesium. It reports storage tests that showed good stability to hydrolysis and no corrosive attack on ferritic steel, V2A steel, copper, brass, and aluminum. The bulletin provides elastomer swell, extraction, and elongation data for R-123 with butyl (IIR), nitrile (NBR, Perbunan(R)), chloroprene (CR, Neoprene(R)), fluorinated (FPM, DuPont Viton(R) A), and natural (NR) rubbers. The bulletin reports that neither R-123 nor R-11 passed the Philipp test for thermal stability with mineral oil, but that the stability of R-123 appears to be comparable to that of R-11. Moreover, R-123 is indicated as miscible with both mineral oil and alkylbenzene lubricants. A table provides thermodynamic property data including pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-123 at saturated (wet vapor) conditions from -50 to the critical point of 183.79 °C (-58 to 362.82 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram based on a U.K. Rombusch equation of state. Hoechst Chemical's product name for R-123 is Hoechst Refrigerant R 123.

Thermodynamic Properties of HCFC-123 (2,2-dichloro-1,1,1-trifluoroethane), technical information report T-123-ENG (H-47753), DuPont Chemicals, Wilmington, DE, January 1993 (40 pages with 1 figure and 2 tables, available from JMC as RDB-3422)

This report provides thermodynamic property data for R-123 in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 183 °C (-150 to 362 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 7-3450 kPa (1-500 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product names for R-123 are Suva(R) 123 Refrigerant and Suva(R) Centri-LP Refrigerant.

Thermodynamic Properties of HCFC-123 (2,2-Dichloro-1,1,1-trifluoroethane), technical information report T-123-SI (H-47754), DuPont Chemicals, Wilmington, DE, January 1993 (32 pages with 1 figure and 2 tables, available from JMC as RDB3423)

This report provides thermodynamic property data for R-123 in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 183 °C (-148 to 362 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 10-3600 kPa (1-520 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product names for R-123 are Suva(R) 123 Refrigerant and Suva(R) Centri-LP Refrigerant.

R-124

R. Bender, K. Bier, and G. Maurer, **Heat Capacity at Constant Pressure and Joule-Thomson Coefficient of Monochloro-1,2,2,2-tetrafluoroethane** [2-chloro-1,1,1,2-tetrafluoroethane], *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 12, pages 335-341, 1980 (8 pages, RDB4222)

R-124, thermodynamic properties, thermophysical data

S. J. Boyes and L. A. Weber (National Institute of Standards and Technology, NIST), **Vapor Pressures and Gas-Phase PVT Data for 1-chloro-1,2,2,2-tetrafluoroethane** [2-chloro-1,1,1,2-tetrafluoroethane], *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 15, number 3, pages 443-460, May 1994 (18 pages with 4 figures and 6 tables, limited copies available from JMC as RDB4893)

This paper presents new, very precise, thermodynamic data on R-124 in the temperature range of 5-150 °C (41-302 °F). The measured data include vapor pressures and the gas-phase pressure-volume-temperature (PVT) surface. The paper explains the apparatus and measurement techniques. It describes and graphically shows the influence of a volatile impurity, determined to be R-32. Compensating corrections to the data are outlined. The paper tabulates the measured data, and provides a fit to a Wagner equation for vapor pressures and to a virial PVT surface equation. It compares the findings to existing data in the literature, and also presents calculated values of saturated vapor density.

H. Kubota, Y. Tanaka, T. Makita, H. Kashiwagi, and M. Noguchi, **Thermodynamic Properties of 1-chloro-1,2,2,2-tetrafluoroethane (R-124)** [2-chloro-1,1,1,2-tetrafluoroethane], *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 9, number 1, pages 85-101, 1988 (RDB2332)

thermophysical data

R. A. Perkins, L. J. van Poolen, J. B. Howley, and M. L. Huber (National Institute of Standards and Technology, NIST), **Thermal Conductivity of 2-chloro-1,1,1,2-tetrafluoroethane (R-124)**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, 1993 (RDB3924)

thermophysical properties, data

I. R. Shankland, R. S. Basu, and D. P. Wilson (AlliedSignal Incorporated), **Thermophysical Properties of HCFC-124: An Environmentally Acceptable Refrigerant**, paper 3418, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 2, pages 317-322, 1990; republished in *CFC Alternatives*, technical data bulletin 6(1), ASHRAE, pages 19-24, June 1990 (6 pages with 3 figures and 11 tables, RDB4123)

R-124, thermophysical data

M. Takahashi, C. Yokoyama, and S. Takahashi, **Gas Viscosity of HFC-124** [sic, HCFC-124] **at High Pressures**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 347-350, 1992 (4 pages, RDB3925)

R-124, HCFC-124, thermophysical properties, data

Thermodynamic Properties of HCFC-124 (2-chloro-1,1,1,2-tetrafluoroethane), technical information report T-124-ENG (H-47755), DuPont Chemicals, Wilmington, DE, January 1993 (36 pages with 1 figure and 2 tables, available from JMC as RDB3424)

This report provides thermodynamic property data for R-124 in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 122 °C (-150 to 252 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 7-3450 kPa (1-500 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-124 is Suva(R) 124 Refrigerant.

Thermodynamic Properties of HCFC-124 (2-chloro-1,1,1,2-tetrafluoroethane), technical information report T-124-SI (H-47756), DuPont Chemicals, Wilmington, DE, January 1993 (32 pages with 1 figure and 2 tables, available from JMC as RDB3425)

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This report provides thermodynamic property data for R-124 in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 122 °C (-148 to 252 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 10-3600 kPa (1-520 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-124 is Suva(R) 124 Refrigerant.

R-125

C. Baroncini, G. Giuliani, G. Latini, F. Polonara (Università degli Studi di Ancona, Italy), and R. Camporese (Consiglio Nazionale della Ricerche, CNR, Italy), **Experimental Evaluation of Thermodynamic Properties of Refrigerants R125 (CHF_2CF_3)**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 207-213, 1993 (7 pages with 3 figures and 2 tables, RDB5318)

R-125, thermophysical data, measurement, vapor pressure, PVT properties, Redlich-Kwong-Soave (RKS) equation of state

G. Bigolaro, R. Camporese (Consiglio Nazionale delle Ricerche, CNR, Italy), G. Cortella, P. Romagnoni (Università di Udine, Italy), and M. Scattolini (CNR), **Propriétés Thermodynamiques du Réfrigérant Pentafluoroethane (R125)** [Thermodynamic Properties of Refrigerant Pentafluoroethane (R-125)], *International Journal of Refrigeration* (IJR), Paris, France, volume 13, number 8, pages 44-49, November 1990 (6 pages, RDB5457)

thermophysical data

N. Cohen and S. W. Benson, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 91, 162-175, 1987 (14 pages, RDB5941)

R-125

D. R. Defibaugh and G. Morrison (National Institute of Standards and Technology, NIST), **Compressed Liquid Densities and Saturation Densities of Pentafluoroethane (R125)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 157-166, 1992 (10 pages RDB4B26)

R-125, thermodynamic properties, thermophysical data

M. Fukushima and S. Ohotoshi, **Thermodynamic Properties of HFC-125**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 49-52, 1992 (4 pages, RDB-4B25)

R-125

Y. Monluc, T. Sagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of HFC-125**, paper B101, *Proceedings of the Twelfth Japan Symposium on Thermophysical Properties*, pages 65-68, 1991 (4 pages with 5 figures and 1 table, RDB2427)

This paper reports experimental data for R-125, including vapor pressure and PVT properties in the vapor phase. Vapor pressures were measured for 303-339 K (86-151 °F) and correlated; the critical pressure (3.633 MPa, 527.3 psia) also was determined based on a critical temperature previously determined by M. O. McLinden of 339.4 K (151.3 °F). PVT properties were measured along five isochores for temperatures of 240-423 K (-27 to 302 °F), pressures of 1.5-8.6 MPa (220-1250 psia), and densities of 97-446 kg/m3 (6-28 lb/cf). The experimental approach and regression equation are presented and vapor pressure measurements are tabulated and plotted. The PVT properties for the vapor phase also are plotted and compared to other published data.

L. C. Wilson, W. V. Wilding, G. M. Wilson, R. L. Rowley, V. M. Felix, and T. Chisholm-Carter, **Thermophysical Properties of HFC-125**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, number 11, pages 167-178, 1992 (12 pages, RDB3927)

R-125, equation of state, thermodynamic data

R-134

T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Pressure-Volume-Temperature Properties of 1,1,2,2-tetrafluoroethane (HFC-134)**, *Journal of Chemical and Engineering Data*, volume 37, pages 216-219, 1992 (4 pages, RDB5478)

R-134, thermodynamic properties, thermophysical data

T. Tatoh, S. Kuwabara, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve in the Critical Region and Critical Parameters of 1,1,2,2-tetrafluoroethane (HFC-134)**, *Journal of Chemical and Engineering Data*, volume 38, pages 116-118, 1993 (3 pages, RDB5467)

R-134, thermodynamic properties, thermophysical data

R-134a

H. D. Baehr and S. Kabelac (Universität Hannover, Germany), **Vorläufige Zustandsgleichungen für das ozonunschädliche Kältemittel R 134a** [Preliminary Equation of State for the Ozone-Safe Refrigerant R-134a], *Ki Klima-Kälte-Heizung*, Verlag C. F. Müller, Karlsruhe, Germany, volume 17, number 2, pages 69-71, 1989 (3 pages, in German, RDB-5214)

C. Baroncini, G. Giuliani, M. Pacetti, and F. Polonara (Università degli Studi di Ancona, Italy), **Experimental Study of Thermodynamic Properties of 1,1,1,2-tetrafluoroethane (R134a)**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 83-88, 1990 (6 pages with 4 figures and 3 tables, RDB4B45)

R-134a, thermodynamic properties, thermophysical data

R. S. Basu and D. P. Wilson (AlliedSignal Incorporated), **Thermophysical Properties of 1,1,1,2-tetrafluoroethane (R-134a)**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Limited, Brugge, Belgium, volume 10, number 3, pages 591-603, May 1989 (13 pages, RDB0514)

thermophysical data

R. S. Basu, I. R. Shankland, and R. G. Richard (AlliedSignal Incorporated), **Thermodynamic and Transport Properties of 1,1,1,2-tetrafluoroethane (R-134a) - An Alternative CFC Substitute in Refrigeration and Air Conditioning**, presented paper (AIChE Winter Annual Meeting, Washington, DC, 1988), Buffalo Research Laboratory, AlliedSignal Incorporated, Buffalo, NY, November 1988 (26 pages, RDB0515)

thermophysical data

A. V. Dobrokhotov, A. G. Grebenkov, E. E. Ustjushanin, V. V. Altunin, V. P. Dzelezny, A. V. Maslennikov, and O. B. Tswetkov (Moscow Power Engineering Institute, Russia), **Equation of State and Thermophysic[al] Properties for HFC-134a at the Single-Phase Region**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 175-182, 1993 (8 pages with 1 table, RDB5314)

R-134a, thermodynamic properties, thermophysical data, density, isobaric heat capacity, sound velocity, viscosity, thermal conductivity

A. V. Dobrokhotov, A. V. Maslennikov, J. V. Semenuk, and E. E. Ustjushanin (Moscow Power Engineering Institute, Russia), **The Density of Refrigerant 134a - Experiment and Generalization**, *Kolloidnyi Tekhnika*, volume 7, pages 16-20, 1991 (5 pages, in Russian, RDB5441)

R-134a, thermodynamic properties, thermophysical data

A. R. H. Goodwin and M. R. Moldover (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Gaseous Refrigerants from Speed of Sound Measurements (Apparatus, Model, and Results for 1,1,1,2-tetrafluoroethane, R-134a)**, *Journal of Chemical Physics*, American Institute of Physics (AIP), Woodbury, NY, volume 93, number 4, pages 2741-2753, 15 August 1990 (13 pages with 10 figures and 4 tables, available from JMC as RDB0919)

The speed of sound in gaseous R-134a has been obtained between 233.16 and 340 K from measurements of the frequency of the radial acoustic resonances of a gas-filled spherical cavity. Perfect gas heat capacities and second and third acoustic virial coefficients are used to estimate the density virial coefficients B(T) and C(T) and an effective square-well potential. The estimates of B(T) are consistent with B(T) deduced from high-quality equation-of-state measurements; those for C(T) are slightly inconsistent. The apparatus and its calibration with argon are described.

H. J. R. Guedes and J. A. Zollweg, **Speed of Sound in Liquid R-134a**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, num-

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ber 6, pages 381-385, July 1992 (5 pages, RDB-4B52)

thermophysical properties

H. Hou, J. C. Holste, B. E. Gammon, and K. N. Marsh (Texas A&M University), **Experimental Densities for Compressed R-134a**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, pages 365-371, 1992 (17 pages, RDB-4A55)

thermodynamic properties, thermophysical data

M. L. Huber and J. F. Ely (National Institute of Standards and Technology, NIST), **An Equation of State Formulation of the Thermodynamic Properties of R-134a (1,1,1,2-tetrafluoroethane)**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, pages 393-400, July 1992 (8 pages with 10 figures and 10 tables, available from JMC as RDB3702)

thermophysical data

M. L. Huber and M. O. McLinden (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of R-134a (1,1,1,2-tetrafluoroethane)**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 453-462, July 1992 (10 pages with 4 figures and 9 tables, RDB2828)

Y. Kabata, S. Tanikawa, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve and the Critical Parameters for 1,1,1,2-tetrafluoroethane**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, number 3, pages 605-616, 1989 (12 pages, RDB4119)

R-134a, thermophysical properties

P. M. Kesselman, V. P. Dzelezny, and Y. V. Semenuk (Moscow Power Engineering Institute, Russia), **Thermal Properties of Refrigerant 134a in the Liquid Phase**, *Kolloidnyi Tekhnika*, volume 7, pages 9-11, 1991 (3 pages, in Russian, RDB5445)

R-134a, thermodynamic properties, thermophysical data

R. Krauss (Universität Stuttgart, Germany), J. Luettmer-Strathmann (University of Maryland, USA), J. V. Sengers (University of Maryland, USA, and National Institute of Standards and Technology, NIST, USA), and K. Stephan (Universität Stuttgart, Germany), **Transport Properties of 1,1,1,2-Tetrafluoroethane (R134a)**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 14, number 4, pages 951-988, July 1993 (38 pages with 23 figures and 6 tables, RDB6401)

This paper presents new equations for the thermal conductivity and viscosity of R-134a. The paper summarizes a critical evaluation of available experimental data, with emphasis on the vapor phase. It outlines the methodology used to correlate the data, which was based on a temperature-dependent dilute gas term, an excess or residual term that accounts for density dependence, and the critical enhancement around the vapor-liquid critical point. A crossover model is presented for the latter along with a new fundamental equation of state (EOS) for the critical region. Tables summarize the saturation properties as a function of temperature for -33 to 101 °C (-27 to 214 °F) and the viscosity and thermal conductivity as a function of pressure and temperature, for 0.1-30.0 MPa (1.5-44 psia) and 17-157 °C (62-314 °F) respectively.

A. Laesecke, R. A. Perkins (National Institute of Standards and Technology, NIST, USA), and C. A. Nieto de Castro (Universidade de Lisboa, Portugal), **Thermal Conductivity of R134a**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 263-274, 1992 (12 pages with 5 figures and 1 table, available from JMC as RDB3708)

R-134a, thermophysical properties

H. Lippold, **Die thermodynamischen Stoffwerte von R 134a** [The Thermodynamic Properties of R-134a], *Luft- und Kältetechnik*, Germany, number 4, pages 182-185, 1989 (4 pages, in German, RDB-5536)

thermophysical properties

J. W. Magee and J. B. Howley (National Institute of Standards and Technology, NIST), **Vapour Pressure Measurements on 1,1,1,2-tetrafluoroethane (R134a) from 180 to 350 K**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, pages 362-364, July 1992 (3 pages with 2 figures and 2 tables, available from JMC as RDB-3704)

This paper summarizes measurements of vapor pressure for R-134a for -93 to 177 °C (-136 to 350 °F) by using an automated static cell. Temperatures and pressures were measured with a platinum resistance thermometer and with calibrated, oscillating quartz-crystal pressure transducers, respectively. The paper reviews the experimental approach, presents the measured data, plots the pressure-temperature relationship, provides a regression equation, and examines the deviations to it. The results provide highly accurate measurements of vapor pres-

sure for purified R-134a. This work extends the range of available data for R-134a to lower temperatures, more than 60 °C (108 °F) below its normal boiling point.

J. W. Magee (National Institute of Standards and Technology, NIST), **Measurements of Molar Capacity at Constant Volume (C_v) for 1,1,1,2-tetrafluoroethane (R134a)**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, July 1992, pages 372-380 (9 pages with 4 figures and 3 tables, available from JMC as RDB3705)

T. Okubo, T. Hasuo, and A. Nagashima, **Measurement of the Viscosity of HFC-134a in the Temperature Range 213-423 K and at Pressure up to 30 MPa**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 13, number 6, pages 931-942, 1992 (12 pages, RDB4882)

R-134a

C. M. B. P. Oliveira and W. A. Wakeham, **The Viscosity of Liquid R134a**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 14, pages 33-44, 1993 (12 pages, RDB4A51)

R-134a, thermophysical properties, transport data

I. B. Parker, M. H. Barley, and R. W. Wheelhouse (ICI Chemicals and Polymers Limited, UK), **The Reconciling of Diverse Literature Sources of PVT Data on Klea(R) 134a**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 183-190, 1993 (8 pages with 4 figures and 2 tables, RDB5315)

R-134a, thermodynamic properties, thermophysical data, Martin-Hou equation of state, GFIT correlation

J. Petrak, **Kältemittel R 134a - h,lgp-Diagamm und die Bewertung des einstufigen Kältemittel-Kreisprozesses**, *Ki Klima-Kälte-Heizung*, Verlag C. F. Müller, Karlsruhe, Germany, volume 17, number 12, pages 556-570, 1989 (15 pages, in German, RDB5214)

R-134a, enthalpy-log pressure diagram

C-C. Piao, M. Noguchi (Daikin Industries, Limited, Japan), H. Sato, and K. Watanabe (Keio University, Japan), **An Improved Equation of State for R-134a**, paper 3771, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 1, pages 358-366, 1994 (9 pages with 16 figures and 1 table, RDB4872)

thermodynamic properties, thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Charts, Tables, and Equations for HFC-134a**, paper 3518, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, pages 268-284, 1991; republished in *Alternative Refrigerants*, technical data bulletin 7(3), ASHRAE, pages 28-44, October 1991 (17 pages with 15 figures and 4 tables, RDB2615)

R-134a, thermodynamic properties, equation of state

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Equation of State for HFC-134a**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, volume 3, pages 435-442, 1991 (8 pages, RDB4148)

R-134a, thermodynamic properties, thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Experimental Study for PVT Properties of CFC Alternative Refrigerant 1,1,1,2-tetrafluoroethane (R-134a)**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 1, pages 132-140, 1990; republished in *CFC Alternatives*, technical data bulletin 6(1), ASHRAE, pages 1-9, June 1990 (9 pages with 8 figures and 4 tables, RDB2334)

thermodynamic properties, thermophysical data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of HFC-134a**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), pages 531-536, 1989 (6 pages, RDB5461)

R-134a, thermodynamic data

C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **An Experimental Study for p,v,T Properties of CFC Alternative Refrigerant R 134a**, *Transactions* (ASHRAE Annual Meeting, Vancouver, BC, Canada, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 95, part 2, 1989 (RDB5618)

R-134a, thermodynamic properties, equation of state

please see pages 6-8 for ordering information

Z-Y. Qian, H. Sato, and K. Watanabe (Keio University, Japan), **Compressibility Factors and Virial Coefficients of HFC-134a by a Burnett Apparatus**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 78, pages 323-329, 1992 (7 pages, RDB5464)

R-134a, thermodynamic properties, thermophysical data

M. Ross, J. P. M. Trusler, W. A. Wakeham, and M. Zalaf (Imperial College, UK), **Thermal Conductivity of R-134a over the Temperature Range 240 to 373 K**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 103-108, 1990 (6 pages with 5 figures and 3 tables, RDB5489)

R-134a, transport properties, thermophysical data, -28 to 212 °F

G. Ya. Ruvinskij, G. K. Lavrenchenko, and S. V. Ijushenko (Institute of Energy Conversion Systems, Ukraine), **Thermophysical Properties of R-134a**, *Kolloidnyi Tekhnika*, volume 7, pages 20-26, 1990 (7 pages, in Russian, RDB4A42)

thermodynamic data

A. Saitoh, S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Isobaric Heat Capacity Data for Liquid HFC-134a**, *Journal of Chemical and Engineering Data*, volume 35, number 2, pages 107-110, 1990 (4 pages, RDB4B54)

R-134a, thermodynamic properties, thermophysical data

I. R. Shankland, R. S. Basu, and D. P. Wilson (AlliedSignal Incorporated), **Thermal Conductivity and Viscosity of a New Stratospherically Safe Refrigerant - 1,1,1,2-tetrafluoroethane (R-134a)**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, pages 305-314, July 1988; republished in *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 117-122, 1989 (9 pages with 6 figures and 2 tables, available from JMC as RDB0516, last page is very faint)

thermophysical properties

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **An Improved Equation of State for HFC 134a**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 157-165, 1993 (9 pages with 6 figures and 1 table, RDB5312)

R-134a, thermodynamic properties, thermophysical data

R. Tillner-Roth, H. D. Baehr, and F. Klobasa (Universität Hannover, Germany), **Measurements and Correlations of the Thermodynamic Properties of Refrigerant 134a**, paper 73, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 630-634, 1991 (5 pages with 6 figures and 1 table, RDB4407)

R-134a, thermodynamic properties, thermophysical data, equation of state based on Helmholtz function

O. B. Tzvetkov and A. G. Asembaev, **The Heat Conductivity of R134a at the State of Dilute Gas**, *Heat and Mass Transfer in Cryo-Engineering and Thermophysical Properties of Refrigerants*, LTIHP, Russia, pages 72-79, 1991 (8 pages, RDB5446)

R-134a, thermodynamic data, thermal conductivity

A. van Pelt, G. X. Jin (University of Maryland), and J. V. Sengers (University of Maryland and National Institute of Standards and Technology, NIST), **Critical Scaling Laws and a Classical Equation of State**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 15, number 4, pages 687-697, July 1994 (11 pages with 3 figures, RDB6402)

method to modify a classical equation of state (EOS) by incorporating nonclassical critical behavior, illustrated by application to the Carnahan-Starling-DeSantis (CSD) EOS, gives parameters and constants for renormalized CSD equation for R-134 and compares the results to published experimental data

L. A. Weber (National Institute of Standards and Technology, NIST), **Vapor Pressures and Gas-Phase PVT Data for 1,1,1,2-Tetrafluoroethane**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, number 3, pages 617-627, May 1989 (12 pages with 3 figures and 4 tables, RDB0909)

New data for the vapor pressure and PVT surface of R-134a in the temperature range of 40-150 °C (104-302 °F) are presented. The PVT data are for the gas phase at densities up to one-half critical. Densities of the saturated vapor are derived at five temperatures from the intersections of the experimental isochores with the vapor pressure curve. The data are repre-

sented analytically, in order to demonstrate experimental precision and to facilitate calculation of thermodynamic properties. The paper describes and schematically shows the Burnett apparatus, filling system, and pressure measuring system used to obtain the data. It identifies the chief impurities as R-125, R-143a, R-1122, and water, each present at approximately 100 ppm. The paper presents the raw data, equations used to fit the data, and a plot of deviations from the fit; previously published data are overlaid for comparison.

D. P. Wilson and R. S. Basu (AlliedSignal Incorporated), **Thermodynamic Properties of a New Stratospherically Safe Working Fluid - Refrigerant 134a**, paper OT-88-20-4, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, pages 2095-2118, 1988; republished in *CFCs: Time of Transition*, ASHRAE, pages 104-116, 1989 (13 pages with 6 figures and 6 tables, RDB2236)

R-134a

M-S. Zhu, L-Z. Han, Y-D. Fu, J. Wu, and C-X. Lu (Tsinghua University, China), **Research on PVT Properties, Vapor Pressure, and Surface Tension of HFC-134a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 499-509, July 1992 (11 pages with 5 figures and 8 tables, available from JMC as RDB2833)

thermodynamic properties, thermophysical data

M-S. Zhu, J. Wu, and Y-D. Fu, (Tsinghua University, China), **New Experimental Vapor Pressure Data and a New Vapor Pressure Equation for HFC-134a**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 99-105, 1992 (7 pages, RDB4B41)

R-134a, equation of state, thermodynamic properties, thermophysical data

M-S. Zhu, Y-D. Fu, and L-Z. Han, (Tsinghua University, China), **An Experimental Study of PVT Properties of CFC Alternative HFC-134a**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 149-156, 1992 (8 pages, RDB4B42)

R-134a, thermodynamic properties, thermophysical data

Forane(R) 134a, technical digest, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1994 (4 pages with 4 tables, available from JMC as RDB4768)

This bulletin supplies information on R-134a in traditional R-12 applications and as a component for blends targeted for R-22 and R-502 applications. It compares the physical and environmental properties of R-12 and R-134a, and provides a tabular data summary for the latter in inch-pound (IP) units. The table lists the chemical formula, molecular weight, normal boiling and freezing points, heat of vaporization, vapor and liquid density at the boiling point and 27 °C (80 °F), critical parameters (temperature, pressure, and density), specific heat of the liquid at the same temperature and of the vapor at atmospheric pressure, Workplace Environmental Exposure Level (WEEL), ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). The table also shows R-134a to be nonflammable. A second table gives the saturated vapor pressures of R-12 and R-134a for -46 to 93 °C (-50 to 200 °F). A third presents the saturated vapor pressure and liquid and vapor densities and enthalpies for the same temperature range. The document briefly reviews the performance and lubricant considerations of R-134a for climate control and refrigeration. It notes immiscibility with mineral oils, but polyolester and polyalkylene glycol lubricants have been recommended by various equipment manufacturers. The bulletin then discusses retrofitting centrifugal chillers, automotive air conditioners, and refrigeration systems with R-134a. The digest concludes with container identification for R-134a and other alternative refrigerants. Elf Atochem's product name for R-134a is Forane(R) 134a.

Genetron(R) 134a Product Brochure, bulletin G-525-009, AlliedSignal Incorporated, Morristown, NJ, May 1994 (14 pages with 5 figures and 7 tables, RDB6B26)

This bulletin supplies information on R-134a and application data in metric (SI) and inch-pound (IP) units. R-134a is described as a replacement for R-12 in automobile air conditioning; residential and commercial refrigeration; residential, commercial, and industrial air conditioning including centrifugal chillers; and as a blowing agent and aerosol propellant. The bulletin describes these applications and lists basic physical properties including the chemical name and formula, appearance, molecular weight, normal boiling and freezing points, and critical parameters (temperature, pressure, density, and specific volume). The property data also include the vapor density, latent heat of vaporization at the boiling point, flammability limits (none), autoignition temperature, ozone depletion poten-

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tial (ODP), and halocarbon global warming potential (HGWP). Representative data are provided for 25 °C (77 °F) including the liquid density; vapor pressure; solubility in and of water; and vapor and liquid heat capacity, thermal conductivity, and viscosity. The bulletin provides Mollier (pressure-enthalpy) charts, product purity specifications, a tabular comparison of performance with R-12, and tabular pressure-temperature data for -45 to 70 °C (-60 to 160 °F). It then discusses lubricant suitability with primary focus on polyalkylene glycol (PAG) and polyolester (POE) synthetics. Characteristic miscibility plots are shown. The document discusses copper plating with PAG and POE lubricants. It notes that plating levels are lower for R-134a with the cited lubricants than with R-12 and mineral oil. While plating does not appear in laboratory tests with two POEs (Castrol Icematic(R) SW32 and Mobil EAL Arctic(R) 22), field occurrence suggests that it may result in the presence of other materials. The bulletin tabulates stability data for the same POEs in the presence of aluminum, copper, and steel. It discusses the effects of chlorinated solvents and residual refrigerants, noting that R-134a is chemically compatible with chlorinated materials, but that the associated PAG and POE lubricants may not be. It notes, however, that R-12 and R-134a form a higher-pressure azeotrope. The bulletin then discusses materials compatibility and provides tabular, qualitative indications for elastomers and plastics. It discusses suitability with polyethylene terephthalate (PET) and desiccants, and also provides a plot of solubility of water in R-134a. The bulletin then discusses safety, including both toxicity and flammability. It describes the former as intrinsically low. While it suggests that R-134a is nonflammable, it notes that R-134a can become combustible at higher pressures when mixed with more than 60% v/v air. The bulletin discusses storage, handling, safety guidelines, and leak detection methods. It briefly outlines environmental considerations, reclamation, retrofit procedures for R-12 equipment, and R-134a packaging. AlliedSignal's product name for R-134a is Genetron(R) 134a.

Refrigerant Reclin(R) 134a, product bulletin AFK2322e(035), Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, April 1994 (12 pages with 6 figures and 4 tables, RDB4776)

This bulletin provides data for R-134a, identified as a substitute for R-12, in refrigeration engineering, in metric (SI) units of measure. The introduction reviews the phaseout of chlorine-containing refrigerants and criteria for substitutes. A table summarizes physical and thermodynamic property data for R-134a, including the chemical formula and name, molecular mass, normal boiling and freezing points, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, surface tension, liquid density, isentropic exponent, solubility of water, solubility in water, dynamic viscosity, and thermal conductivity at selected conditions. The bulletin reviews thermodynamic similarities of R-134a with R-12. Four plots compare their compression ratios, compressor discharge temperatures, volumetric refrigerating effect, and coefficient of performance for suction temperatures of -30 to 5 °C (-22 to 41 °F). The bulletin then discusses compatibility with metals, recommending avoidance only of zinc, magnesium, lead, and aluminum alloys with more than 2% magnesium. It reports storage tests that showed good stability to hydrolysis and no corrosive attack on ferritic steel, V2A steel, copper, brass, and aluminum. The bulletin provides elastomer swell, extraction, and elongation data for R-134a with butyl (IIR), acrylonitrile-butadiene (NBR, Perbunan(R)), hydrogenated nitrile butadiene rubber (HNBR), chloroprene (CR, Neoprene(R)), fluorinated (FPM, DuPont Viton(R) A), natural (NR), and ethylene propylene diene terpolymer (EPDM) rubbers. It notes suitability with polytetrafluoroethylene (PTFE, Hostaflon(R)), polyacetal (POM, Hostaform(R)), and polyamide (PA) thermoplastics, but cautions that lubricant influences also must be considered. R-134a is indicated as almost completely immiscible with conventional mineral oils and also with some synthetics lubricants such as alkylbenzenes. The bulletin discusses miscibility and considerations for polyalkylene glycol (PAG) and polyolester (POE) lubricants as well as consequences of residual paraffinic or naphthenic oils from retrofit or manufacturing. A plot shows conceptual mixing ranges for polyglycols and esters with R-134a. The bulletin reports that both R-134a and R-12 pass the Philipp test for thermal stability with mineral oil, and that the stability of R-134a appears to be better than that of R-12. The bulletin indicates that R-134a does not form flammable mixtures with air under normal conditions, but that flammable mixtures can form above atmospheric pressure if the air fraction exceeds 60%. It warns that mixtures of R-134a with air or oxygen must never be used for leak or pressure tests. It notes that R-134a has been found to be at least as safe as R-12 toxicologically and recommends a workplace exposure limit of 1000 ppm by volume on an eight-hour, time-weighted average basis. A table provides thermodynamic property data including pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-134a at saturated (wet vapor) conditions from -60 to the critical point of 101.15 °C (-76 to 214.07 °F). The

bulletin concludes with a pressure-enthalpy (Mollier) diagram based on a U.K. Rombusch equation of state. Hoechst Chemical's product name for R-134a is Hoechst Reclin(R) 134a.

Thermodynamic Properties of HFC-134a (1,1,1,2-tetrafluoroethane), technical information report T-134a-ENG (H-47751), DuPont Chemicals, Wilmington, DE, January 1993 (36 pages with 1 figure and 2 tables, available from JMC as RDB3426)

This report provides thermodynamic property data for R-134a in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 101 °C (-150 to 213 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product names for R-134a are Suva(R) 134a Refrigerant, Suva(R) Cold-MP Refrigerant, Suva(R) Trans-AC Refrigerant, Formacel(R) Z-4 Blowing Agent, Dymel(R) 134a Aerosol Propellant, and Dymel(R) 134a/P Aerosol Propellant.

Thermodynamic Properties of HFC-134a (1,1,1,2-tetrafluoroethane), technical information report T-134a-SI (H-47752), DuPont Chemicals, Wilmington, DE, January 1993 (36 pages with 1 figure and 2 tables, available from JMC as RDB3427)

This report provides thermodynamic property data for R-134a in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a modified Benedict-Webb-Rubin (MBWR) equation of state and an ideal gas heat capacity equation at constant pressure. It also gives a Martin-Hou equation of state, fit from MBWR data, and a corresponding ideal gas heat capacity equation at constant vapor. It supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (pressure and liquid and vapor volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 101 °C (-148 to 213 °F). A set of tables presents volume, enthalpy, entropy, heat capacity at constant pressure, heat capacity ratio (dimensionless Cp/Cv), and velocity of sound data for superheated vapor at constant pressure for 10-4000 kPa (1-580 psia). The new tables are based on experimental data from the National Institute of Standards and Technology, NIST). The report concludes with a pressure-enthalpy diagram. DuPont's product names for R-134a are Suva(R) 134a Refrigerant, Suva(R) Cold-MP Refrigerant, Suva(R) Trans-AC Refrigerant, Formacel(R) Z-4 Blowing Agent, Dymel(R) 134a Aerosol Propellant, and Dymel(R) 134a/P Aerosol Propellant.

Thermodynamic Properties of Klea(R) 134a, British Units, bulletin 620250011, ICI Klea, Wilmington, DE, March 1995 (48 pages with 2 tables, RDB6302)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-134a in inch-pound (IP) units of measure. It comprises two tables. The first presents saturation properties by temperature (°F and °R) for -101 to 100 °C (-150 to 212 °F) and at the critical point, 101 °C (213.80 °F). The tabular data include absolute and gauge pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second table provides volume, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 14-3790 kPa (2-550 psia) to temperatures as high as 159 °C (318 °F). ICI's product name for R-134a is Klea(R) 134a.

Thermodynamic Properties of Klea 134a, SI Units, bulletin CP/34421/30371/4ED/33/394, ICI Klea, Runcorn, Cheshire, UK, March 1994, (64 pages with 2 tables, RDB6B29)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-134a in metric (SI) units of measure. It comprises two tables. The first presents saturation properties by temperature (°C and K) for -80 to 101 °C (-112 to 214 °F) and at the critical point, 101 °C (213.8 °F). The tabular data include absolute pressure; liquid and vapor specific volume, density, enthalpy, and entropy; and the latent heat of vaporization. The second table provides volume, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 20-4000 kPa (3-580 psia)

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to temperatures as high as 218 °C (424 °F). ICI's product name for R-134a is Klea(R) 134a.

R-141b

D. R. Defibaugh, A. R. H. Goodwin, G. Morrison, and L. A. Weber (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of 1,1-dichloro-1-fluoroethane (R141b)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 85, pages 271 ff, 1993 (RDB4909)

R-141b, thermophysical data

A. R. H. Goodwin and M. R. Moldover (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Gaseous Refrigerants from Speed of Sound Measurements: II. Results for 1,1-dichloro-1-fluoroethane (CCl_2FCH_3)**, *Journal of Chemical Physics*, American Institute of Physics (AIP), Woodbury, NY, volume 95, number 7, pages 5230-5235, 1 October 1991 (6 pages with 5 figures and 4 tables, RDB-3105)

R-141b, thermodynamic properties

L. A. Weber (National Institute of Standards and Technology, NIST), **PVT and Thermodynamic Properties of R141b in the Gas Phase**, paper 69, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 616-625, August 1991 (12 pages with 4 figures and 5 tables, available from JMC as RDB3615)

R-141b, thermophysical properties

Genetron(R) 141b Bulletin, document B-525-647, AlliedSignal Incorporated, Morristown, NJ, October 1993 (4 pages with 4 figures and 7 tables, RDB-5A29)

This bulletin supplies information and application data on R-141b in inch-pound (IP) units. R-141b is described as a replacement for R-11 as a blowing agent, for insulation in construction, appliance, and vehicle applications. A table lists data including the appearance, odor, chemical formula, molecular weight, and normal boiling and freezing points. The properties listed include the specific gravity; vapor pressure, density, and thermal conductivity; liquid density; and solubility in and of water at or near 25 °C (77 °F). The bulletin also lists the autoignition temperature, flash point (none), and lower and upper flame limits (LFL and UFL). It briefly mentions compatibility with plastics including polytetrafluoroethylene (PTFE), polyethylene, polypropylene, polyvinylidene fluoride, and phenolic coatings. It also addresses elastomers including perfluoroelastomers, but notes unsatisfactory results with nitrile rubber, ethylene propylene rubber, and neoprene. The bulletin compares the flame limits measured by several test methods, and compares the findings to those for R-30, R-140a, and R-1120. It then tabulates the vapor pressure, vapor thermal conductivity, liquid viscosity, and liquid density of R-141b at temperatures between -18 and 93 °C (0 and 200 °F). These data are plotted with corresponding curves for R-11 for comparison. AlliedSignal's product name for R-141b is Genetron(R) 141b.

Genetron(R) 141b Bulletin, document B-525-647-SIU, AlliedSignal Incorporated, Morristown, NJ, October 1993 (4 pages with 7 tables, RDB5A30)

This bulletin supplies information and application data on R-141b in metric (SI) units. R-141b is described as a replacement for R-11 as a blowing agent, for insulation in construction, appliance, and vehicle applications. A table lists data including the appearance, odor, chemical formula, molecular weight, and normal boiling and freezing points. The properties listed include the specific gravity; vapor pressure, density, and thermal conductivity; liquid density; and solubility in and of water at or near 25 °C (77 °F). The bulletin also lists the autoignition temperature, flash point (none), and lower and upper flame limits (LFL and UFL). It briefly mentions compatibility with plastics including polytetrafluoroethylene (PTFE), polyethylene, polypropylene, polyvinylidene fluoride, and phenolic coatings. It also addresses elastomers including perfluoroelastomers, but notes unsatisfactory results with nitrile rubber, ethylene propylene rubber, and neoprene. The bulletin compares the flame limits measured by several test methods, and compares the findings to those for R-30, R-140a, and R-1120. It then tabulates the vapor pressure, vapor thermal conductivity, liquid viscosity, and liquid density of R-141b at temperatures between -10 and 90 °C (14 and 194 °F). AlliedSignal's product name for R-141b is Genetron(R) 141b.

Genetron(R) 141b Product Brochure, bulletin B-525-648, AlliedSignal Incorporated, Morristown, NJ, November 1993 (6 pages with 5 tables, RDB5A33)

This bulletin supplies information and application data on R-141b in metric (SI) and inch-pound (IP) units. R-141b is described as an interim replacement for R-11 as a blowing agent, for use in rigid polyurethane foams. The bulletin summarizes these applications and then outlines safety implications. It briefly reviews toxic-

ity testing for R-141b and recommended permissible exposure limits (PEL consistent and WEEL) of 500 ppm. It discusses flammability, compares the flame limits by several test methods, and compares the findings to those for R-30, R-140a, and R-1120. The discussion notes that while R-141b is flammable, it does not exhibit either an open- or closed-cup flash point and is not considered a flammable liquid for transportation. The bulletin discusses environmental aspects of R-141b use including its low ozone depletion potential (ODP) and disposal of wastes. It then reviews stability and compatibility data, and gives tabular test results (weight, hardness, and volume change) for polymers. The plastics include polyvinyl chloride (PVC), polyethylene, polypropylene, polyvinylidene fluoride (Elf Atochem Kynar(R)), vinylester (Dow Chemical Derekane(R) 411), and polyphenylene sulfide (Phillips Petroleum Ryton(R) R-7). The elastomers include DuPont Kalrez(R) and Viton(R) E60C, nitrile, neoprene, silicone, urethane, butyl rubber, and ethylene propylene rubber. The bulletin then addresses reactivity with emphasis on finely divided metals, storage, handling, and safety precautions for equipment maintenance. It lists product specifications and tabulates representative properties including the chemical name and formula, appearance, molecular weight, and normal boiling and freezing points. The property data also include the vapor density, flammability limit, and autoignition temperature. Representative data are provided at or near 25 °C (77 °F) including the liquid density, vapor pressure, specific gravity, and solubility in and of water. AlliedSignal's product name for R-141b is Genetron(R) 141b.

R-142b

K. Kumagai, N. Yada, H. Sato, and K. Watanabe (Keio University, Japan), **A Study of PVT Properties of HCFC-142b**, *Proceedings of the Tenth Japan Symposium on Thermophysical Properties*, pages 67-70, 1989 (4 pages, RDB4224)

R-142b, thermodynamic properties

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Liquid Densities and Vapor Pressures of 1-chloro-1,1-difluoroethane**, *Journal of Chemical and Engineering Data*, volume 36, pages 148-150, 1991 (5 pages, RDB5468)

R-142b, thermodynamic properties, thermophysical data

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities of HCFC-142b**, *Proceedings of the Tenth Japan Symposium on Thermophysical Properties*, pages 71-74, 1989 (4 pages, RDB4227)

R-142b, thermodynamic properties

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Measurement of Isobaric Heat Capacity of Liquid HCFC-142b**, *Proceedings of the Eleventh Japan Symposium on Thermophysical Properties*, pages 103-106, 1990 (4 pages, RDB-3930)

R-142b, thermophysical properties

S. Tanikawa, Y. Kabata, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Critical Parameters and the Vapor-Liquid Coexistence Curve and Critical Parameters of 1-chloro-1,1-difluoroethane (HCFC-142b)**, *Journal of Chemical and Engineering Data*, volume 37, pages 74-76, 1992 (3 pages, RDB5466)

R-142b, thermodynamic properties, thermophysical data

N. Yada, K. Kumagai, T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of the Thermodynamic Properties of HCFC-142b**, *Journal of Chemical and Engineering Data*, volume 36, pages 12-14, 1991 (3 pages, RDB5477)

R-142b, thermodynamic properties, thermophysical data

Genetron(R) 142b, technical bulletin B-525-649, AlliedSignal Incorporated, Morristown, NJ, September 1993 (4 pages with 3 tables, RDB3A58)

This bulletin supplies information on R-142b, described as a replacement for R-12 in rigid polyurethane, polystyrene, and polyethylene foam insulation applications for residential and commercial construction as well as process piping. It provides physical property data, in inch-pound (IP) units, including the chemical formula, molecular weight, atmospheric boiling and freezing points and vapor density, flash point, and autoignition temperature. It also indicates the specific gravity and vapor pressure at 21 °C (70 °F) and the vapor thermal conductivity and liquid density at 25 °C (77 °F). It briefly outlines materials interactions citing compatibility with carbon steel, stainless steel, phenolic coatings, polytetrafluoroethylene (PTFE), fluoroelastomer, polyethylene (PE), polypropylene, and polyvinylidenefluoride. The bulletin notes unsatisfactory results with nitrile rubber, ethylene propylene rubber, and neoprene. It then presents flammability information, including a comparison with pentane. It concludes with tabular and plotted vapor pressure, vapor thermal conductivity, liquid viscosity, and liquid

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density data. AlliedSignal's product name for R-142b is Genetron(R) 142b.

R-143a

D. Arnaud, S. Macaudiere, L. Niveau, and S. Wosinski (Atochem Groupe ELF Aquitaine, France), **Propriétés Thermophysiques d'un Nouveau Fluide Frigorigène: le 1,1,1-Trifluoroéthane (HFA-143a)** [Thermophysical Properties of a New Refrigerant: The 1,1,1-Trifluoroethane (HFA-143a)], paper 79, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 664-668, August 1991 (5 pages with 3 figures and 6 tables, RDB4A39)

R-143a, thermodynamic properties, thermophysical data

H. Russell, D. R. V. Golding, and D. M. Yost, **The Heat Capacity, Heats of Transition, Fusion and Vaporization, Vapor Pressure and Entropy of 1,1,1-trifluoroethane**, *Journal of the American Chemical Society*, American Chemical Society (ACS), Columbus, OH, volume 66, pages 16-20, 1944 (5 pages, RDB4317)

R-143a, thermodynamic properties, thermophysical data

R-152a

W. Blanke and R. Weiß, **Isochoric (pVT) Measurements on $C_2H_4F_2$ (R-152a) in the Liquid State from the Triple Point to 450 K and at Pressures up to 30 MPa**, *Proceedings of the 11th Thermophysical Properties Symposium* (Boulder, CO, 23-27 June 1991), American Society of Mechanical Engineers (ASME), New York, NY, 1991 (RDB4555)

thermodynamic data

Y. Higashi, M. Ashizawa, Y. Kabata, T. Majima, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of Vapor Pressure, Vapor-Liquid Coexistence Curve, and Critical Parameters of Refrigerant 152a**, *JSME International Journal (series II: Fluids Engineering, Heat Transfer, Power, Combustion, and Thermophysical Properties)*, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, volume 30, number 265, pages 1106-1112, 1987 (7 pages in English, available from ASME in the Americas and from Maruzen Company, Limited, elsewhere, RDB4121)

R-152a, thermodynamic properties, thermophysical data

T. Hozumi, I. Furutsuka, H. Sato, and K. Watanabe (Keio University, Japan), **Sound Velocity Measurements in Gaseous HFC-152a**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), pages 258-363, 1992 (6 pages, RDB5480)

R-152a, physical data

A. Iso and M. Uematsu (Keio University, Japan), **Thermodynamic Properties of 1,1-difluoroethane in the Super-Critical and High Density Regions**, *Physica A*, Elsevier Science B.V., Amsterdam, The Netherlands, volume 156, pages 454-466, 1989 (13 pages, RDB4A53)

R-152a, PVT data

R. Krauss (Universität Stuttgart, Germany), V. C. Weiss (University of Maryland, USA, and Universität Bremen, Germany), T. A. Edison, J. V. Sengers (University of Maryland, USA), and K. Stephan (Universität Stuttgart, Germany), **Transport Properties of 1,1-Difluoroethane (R152a)**, publication unknown, circa 1996 (44 pages with 12 figures and 8 tables, RDB6408)

R-152a, equations and data for thermal conductivity and viscosity, critical region

T. Majima, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of PVT Properties of Refrigerant 152a**, *Proceedings of the Eighth Japan Symposium on Thermophysical Properties*, pages 77-81, 1987 (5 pages, RDB4225)

R-152a, thermodynamic properties, thermophysical data

Z-Y. Qian, T. Majima, H. Sato, and K. Watanabe (Keio University, Japan), **Preliminary Determination of Virial Coefficients for HFC-152a**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), pages 346-351, 1992 (6 pages, RDB5463)

R-152a, thermodynamic properties, thermophysical data

H. Sato, M. Uematsu, and K. Watanabe (Keio University, Japan), **Saturated Liquid Density of 1,1-difluoroethane (R-152a) and Thermodynamic Properties Along the Vapor-Liquid Coexistence Curve**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 36, pages 167-181, 1987 (15 pages, RDB4122)

thermophysical properties, thermophysical data

A. van Pelt and J. V. Sengers (University of Maryland), **Thermodynamic Properties of 1,1-Difluoroethane (R152a) in the Critical Range**, *Journal of Supercritical Fluids*, PRA Press, volume 8, pages 81-99, 1995 (19 pages with 16 figures and 4 tables, RDB6403)

R-152a, theoretically-based crossover model to adapt a classical, analytic equation of state (EOS) in the critical region, gives parameters and constants for the crossover model for R-152a, summary of experimental data sets and calculated thermodynamic property data for R-152a

J. M. Yin, J. X. Guo, Z. Y. Zhao, L. C. Tan, and M. Zhao, **Thermal Conductivity of HFC-152a**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 297-303, 1992 (7 pages, RDB4B55)

R-152a, thermophysical properties

Z. Y. Zhao, J. M. Yin, and L. C. Tan, **Measurement of PVT Properties and Vapor Pressure for HFC-152a**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 191-202, 1992 (12 pages, RDB4B56)

R-152a, thermodynamic properties, thermophysical data

R-170 (Ethane)

R. D. Goodwin, H. M. Roder, and G. C. Straty, **Thermodynamic Properties of Ethane from 90 to 600 K at Pressures to 700 Bar**, NBS Technical Note 684, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, August 1976 (available from GPO, RDB3944)

R-170, equation of state, thermophysical data

R-225ca or R-225cb

J. V. Widiatmo, Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Liquid Densities and Vapor Pressures of HCFC-225ca and HCFC-225cb**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 227-238, 1992 (12 pages, RDB-5472)

R-225ca, R-225cb, thermodynamic properties, thermophysical data

R-227ea

M. L. Robin (Great Lakes Chemical Corporation), D. Young, and J. Casler (Fike Corporation), **FM-200: Recent Findings**, presentation charts, 1993 Halon Alternatives Technical Working Conference (Albuquerque, NM), Great Lakes Chemical Corporation, West Lafayette, IN, May 1993 (14 pages with 3 figures and 1 table, available from JMC as RDB3727)

R-227ea, thermodynamic properties

M. L. Robin, **Halon Alternatives: Recent Technical Progress**, unpublished presentation, 1992 Halon Alternatives Technical Working Conference (Albuquerque, NM), Great Lakes Chemical Corporation, West Lafayette, IN, May 1992 (22 pages with 3 figures and 11 tables, available - missing page 1 - from JMC as RDB3726)

R-227ea, thermodynamic properties

M. L. Robin, **Thermodynamic Properties of Halogenated Fire Extinguishing Agents**, paper FLUO-40, 203rd National Meeting of the American Chemical Society (San Francisco), reprint by Great Lakes Chemical Corporation, West Lafayette, IN, April 1992 (22 pages with 4 figures and 12 tables, available from JMC as RDB3725)

This paper presents the thermodynamic properties of R-22B1 (bromodifluoromethane) and R-227ea (1,1,1,2,3,3,3-heptafluoropropane). Both are under consideration as fire suppressants and the latter also is being considered as a refrigerant. The paper summarizes thermodynamic data for them along with coefficients for the Carnahan-Starling-DeSantis (CSD) equation of state. CSD coefficients also are presented for R-13B1 and R-12B1. A table summarizes physical properties of the four compounds, including their molecular weights, melting and boiling temperatures, and critical parameters (temperature, pressure, and density). Correlations are presented for vapor pressure and temperature and for liquid volume and temperature for R-22B1 and R-227ea. Tabular properties and enthalpy-pressure diagrams are provided for the four fluids. Great Lakes Chemical Corporation's product names for R-22B1 and R-227ea are FM-100 and FM-200, respectively.

H. Wirbser, G. Bräuning, J. Gürtner, and G. Ernst (Universität Karlsruhe, Germany), **Flow Calorimetric specific Heat Capacities of CF_3CHFCF_3 (R227) - a New Working Fluid in Energy Technics - at Pressures up to 15 MPa and Temperatures between 253 K and 423 K**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 24, pages 761-772, 1992 (12 pages, RDB3A20)

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R-227ea, thermodynamic properties, thermophysical data

Hoechst Refrigerant R 227, product bulletin AFK2323e/035, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, January 1991 (12 pages with 6 figures and 3 tables, RDB3A66)

This bulletin provides thermodynamic property and application data for R-227ea (1,1,1,2,3,3,3-heptafluoropropane) in metric (SI) units of measure. This hydrofluorocarbon (HFC) may be suitable as an alternative for R-12 and R-114 for some applications. The bulletin provides physical properties including the chemical formula and name, molecular mass, normal boiling point, critical parameters (temperature, pressure, and density), and liquid and vapor densities at 20 and 40 °C (68 and 104 °F). Four figures summarize comparative performance for R-12, R-114, and R-227ea for the range of -20 to 10 °C (-4 to 50 °F). The charts show compression ratios, volumetric cooling capacities, compressor discharge temperatures, and coefficients of performance (COPs). The compression ratio and cooling capacity of R-227ea lies between those of the other two refrigerants. The discharge temperature is nearly the same as for R-114, both below that of R-12. The COP, however, is 9-14% lower than the other two fluids. The bulletin then discusses materials compatibility with metals and elastomers, noting concerns with lead, magnesium, zinc, aluminum alloys containing more than 2% magnesium, and elastomeric hoses, the latter due to permeation differences. Tabular data are provided for weight change, extraction, and swell for R-227ea with butyl, acrylonitrilebutadiene, chloroprene, fluorinated, and natural rubbers (IIR, NBR, CR, FPM, and NR, respectively). R-227ea is noted as virtually immiscible with mineral oil and alkylbenzene lubricants, but adequately miscible with some polyglycols. Results of thermal stability tests with mineral oil are briefly outlined, indicating that R-227ea appears to be more stable than R-12 and at least comparable to R-114. Preliminary thermodynamic tables - giving pressure, specific volume, density, enthalpy, heat of vaporization, and entropy as functions of temperature - are provided for -40 to 99 °C (-40 to 210 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram based on the U.K. Rombusch equation of state. Hoechst Chemical's product name for R-227ea is R 227.

R-236ea

N. D. Smith, **Thermophysical Properties of HFC-236ea**, Environmental Research Brief EPA-600/S-92-066, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, October 1992 (5 pages with 5 tables, available from JMC as RDB-3403)

This synopsis summarizes properties of R-236ea (1,1,1,2,3,3-hexafluoropropane), a potential alternative for R-114. It notes that the thermophysical properties of the fluids closely match, and that modelling indicates acceptable performance. The efficiency of R-236ea is indicated as within 1% of that of R-114. Tables, in both inch-pound (IP) and metric (SI) units provide the freezing and boiling points, critical properties, heat of vaporization, and liquid specific heat capacity. Measured liquid densities are given at eight temperatures from 2-95 °C (35-202 °F) and vapor pressures for -14 to 141 °C (8-286 °F). Calculated liquid and vapor density as well as heat of vaporization are tabulated for -14 to 141 °C (8-286 °F) and the equations used are provided. The ideal gas heat capacity is similarly provided for 27-327 °C (80-620 °F). The methods used and estimated accuracy are indicated.

R-236fa

Hydrofluorocarbons HFG-3236 (R236fa), product bulletin 98-0211-8554-5(HB), 3M Specialty Chemicals Division, Saint Paul, MN, October 1996 (4 pages with 1 figure and 4 tables, RDB6B05)

R-236fa identified as a replacement for R-114 in centrifugal chillers and in high-temperature heat pump and cooling systems; notes planned use by the U.S. Navy in chillers on ships; gives the chemical formula and name, molecular weight, environmental properties, normal boiling point, critical parameters (temperature, pressure, and density), and the saturated liquid and vapor density and specific heat as well as the latent heat of vaporization at the boiling point; lists product specifications; cites an unreferenced study that shows R-236fa with an unidentified polyolester (POE) outperformed R-114 with mineral oil for miscibility, lubricity, stability, and metals and non-metals compatibility; discusses safety and handling; provides a table of thermodynamic properties and a pressure enthalpy chart in inch-pound units of measure

R-245ca

N. D. Smith, **Thermophysical Properties of HFC-245ca**, Environmental Research Brief EPA-600/S-92-038, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, August 1992 (4 pages with 5 tables, available from JMC as RDB-3402)

This synopsis summarizes properties of R-245ca (1,1,2,2,3-pentafluoropropane), a potential alternative for R-11 and R-123. It notes that the thermophysical properties of the fluids closely match, and that modelling indicates acceptable performance. The efficiency of R-245ca is indicated as 3-4% less than R-11 and 1-2% less than R-123. Tables, in both inch-pound (IP) and metric (SI) units provide the melting and boiling points, critical properties, heat of vaporization, and liquid heat capacity. Measured liquid densities are given at six temperatures from 22-140 °C (72-284 °F) and vapor pressures for -39 to 26 °C (-38 to 78 °F). Calculated liquid and vapor density as well as vapor pressure and heat of vaporization are tabulated for 5-178 °C (41-353 °F) and the equations used are provided. The ideal gas heat capacity is similarly provided for 27-327 °C (80-620 °F). The methods used and estimated accuracy are indicated.

R-245cb

R. L. Shank (Union Carbide Corporation), **Thermodynamic Properties of 1,1,1,2,2-pentafluoropropane (Refrigerant 245cb)**, *Journal of Chemical and Engineering Data*, American Chemical Society (ACS), Columbus, OH, volume 12, number 4, pages 474-480, October 1967 (7 pages with 4 figures and 5 tables, RDB2506)

Thermodynamic properties are presented for the saturated liquid and vapor of R-245cb from -40 °C (-40 °F) to the critical temperature, 106.96 °C (224.52 °F); a pressure-enthalpy diagram is included. The critical properties, coefficients for a Benedict-Webb-Rubin (BWR) equation of state, a vapor-pressure equation, a liquid-density equation, and a heat-capacity equation are given. Data also are provided for the superheated vapor from the saturation temperature to 371 °C (700 °F). The properties listed are volume, enthalpy, entropy, heat capacity at constant pressure, and heat capacity ratio as functions of temperature and pressure. Pressure-volume isotherms are plotted for both the high-density and critical regions. These properties were calculated from measured volumetric and spectral data; the experimental procedures and calculations are described.

R-245fa

HFC-245fa, bulletin G525-513, AlliedSignal Incorporated, Morristown, NJ, October 1996 (2 pages with 3 figures and 1 table, RDB6B20)

This preliminary bulletin introduces R-245fa as a potential replacement for R-141b and other chemicals. It is being developed for use as a blowing agent for rigid insulating foams. The preliminary bulletin presents selected data for R-245fa, described as a nonflammable liquid having a boiling point slightly below room temperature. A table lists physical properties including the molecular formula and weight, boiling point, and water solubility. It indicates the liquid density and vapor pressure at 20 °C (68 °F) and the vapor thermal conductivity at 40 °C (104 °F). It also states that R-245fa exhibits neither a flash point nor flame limits, based on identified tests. A discussion of toxicity notes that R-245fa is not currently listed on the U.S. EPA TSCA, European INEX, or Japanese MITI inventories, and therefore is classified as a research material that may not be used commercially. While a Permissible Exposure Limit (PEL) has been set, the bulletin cites tests that indicate R-245fa to have low toxicity by both dermal and inhalation routes of exposure. The bulletin reports tests that demonstrate no mutagenic activity in an *in vivo* micronucleus study and an Ames assay, and only weak activity in an *in vitro* cytogenetics test. A cardiac sensitization study was negative at concentrations up to 20,000 ppm v/v. Plots show the pressure-temperature relation and miscibility in polyether polyols (BASF Pluracol(R) 824 and 975, Dow Chemical Voranol(R) 390, Bayer Corporation Multranol(R) 4063, and Eastman Chemical Thanol(R) 470X) as well as aromatic polyester polyols (Hoechst Celanese Terate(R) 203, 254, and 2541 and Oxid Terol(R) 235). The bulletin briefly reviews the environmental benefits of the hydrofluorocarbon (HFC) and outlines laboratory stability tests, which showed high thermal and hydrolytic stability. It then indicates that compatibility tests are underway, with favorable results to date for neoprene, EPDM, nylon, polytetrafluoroethylene (PTFE, DuPont Teflon(R)), HIPS, and ABS. It suggests unfavorable findings for fluoroelastomers, nitrile, and HNBR. The bulletin concludes with recommendations for storage and handling.

R-290 (Propane)

N. S. Ersova, E. B. Petrunina, and A. V. Kleckij, **Equation of State and Thermodynamic Proper-**

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ties of Propane, *Kolloidnyi Tekhnika*, volume 1, pages 30-33, 1981 (4 pages, in Russian, RDB5710)

R-290, thermophysical data

R. D. Goodwin, **Provisional Thermodynamic Functions of Propane from 85 to 700 K at Pressures to 700 Bar**, report NBSIR 77-860, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, July 1977 (available from GPO, RDB-3945)

R-290, thermophysical properties, equation of state

R. H. P. Thomas and R. H. Harrison (Bartlesville Energy Technology Center), **Pressure-Volume-Temperature Relations of Propane**, *Journal of Chemical and Engineering Data*, volume 27, number 1, pages 1-11, 1982 (11 pages, RDB5718)

R-290, thermodynamic properties, thermophysical data

E. T. Vaskov, **Thermodynamic Properties of Propane at Saturation State**, *Inzhenerno-Fizicheskii Zhurnal* [Journal of Engineering Physics], Moscow, Russia (then USSR), volume 46, number 2, pages 272-275, 1984 (4 pages, in Russian, RDB-5719)

R-290, thermophysical data

R-C318

G. Bambach (Technische Universität Karlsruhe, Germany), **Octofluorocyclobutane C_4F_8**, *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 11, number 1, pages 334-339, 1956 (6 pages, RDB4117)

R-C318, octafluorocyclobutane, thermophysical properties

R. Cipollone (University of L'Aquila, Italy), **Thermodynamic Properties of Perfluorocyclobutane (C_4F_8)**, paper 3517, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, 1991; republished in *Alternative Refrigerants*, technical data bulletin 7(3), ASHRAE, pages 45-50, October 1991 (6 pages with 8 figures and 4 tables, RDB4116)

R-C318, octafluorocyclobutane, thermophysical data

H. Matthias and H. F. Löffler, **Thermodynamische Eigenschaften von Octofluorcyclobutan (C_4F_8)** [Thermodynamic Properties of Octofluorocyclobutane], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 6, pages 240-241, 1966 (2 pages, in German, RDB4118)

R-C318, octafluorocyclobutane, thermophysical data

R-400

H. H. Kruse, M. Küver, U. Quast, M. Schroeder, and B. Upmeier (Universität Hannover, Germany), **Theoretical and Experimental Investigations of Advantageous Refrigerant Mixture Applications**, *Transactions* (Annual Meeting, Honolulu, HI, 23-26 June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 2B, pages 1383-1418, 1985; republished in *Advances in Nonazeotropic Mixture Refrigerants for Heat Pumps*, technical data bulletin 1(9), ASHRAE, pages 96-131, 1985 (36 pages with 8 figures and 8 tables, RDB2351)

R-12, R-114; vapor-liquid equilibrium (VLE) data for R-400 (R-12/114), R-22/114, and R-13/12; R-13B1/114

R-401A

Thermodynamic Properties of Suva(R) MP39 Refrigerant [R-401 (53/13/34)], technical information report T-MP39-ENG (H-47764), DuPont Chemicals, Wilmington, DE, January 1993 (28 pages with 1 figure and 2 tables, available from JMC as RDB3430)

This report provides thermodynamic property data for R-401A, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (53/13/34) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 99 °C (-150 to 211 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401A is Suva(R) MP39.

Thermodynamic Properties of Suva(R) MP39 Refrigerant [R-401 (53/13/34)], technical information report T-MP39-SI (H-47765), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB-3431)

This report provides thermodynamic property data for R-401A, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (53/13/34) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 99 °C (-148 to 210 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401A is Suva(R) MP39.

R-401B

Thermodynamic Properties of Suva(R) MP66 Refrigerant [R-401 (61/11/28)], technical information report T-MP66-ENG (H-47759), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3432)

This report provides thermodynamic property data for R-401B, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (61/11/28) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 97 °C (-150 to 207 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401B is Suva(R) MP66.

Thermodynamic Properties of Suva(R) MP66 Refrigerant [R-401 (61/11/28)], technical information report T-MP66-SI (H-47760), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3433)

This report provides thermodynamic property data for R-401B, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (61/11/28), in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 97 °C (-148 to 207 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-4000 kPa (1-580 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401B is Suva(R) MP66.

R-401C

Thermodynamic Properties of Suva(R) MP52 Refrigerant [R-401 (33/15/52)], technical information report T-MP52-ENG (H-47769), DuPont Chemicals, Wilmington, DE, February 1993 (28 pages with 1 figure and 2 tables, available from JMC as RDB3428)

This report provides thermodynamic property data for R-401C, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (33/15/52) - in inch-pound IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 104 °C (-150 to 220 °F). A set of tables presents vol-

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ume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401C is Suva(R) MP52.

Thermodynamic Properties of Suva(R) MP52 Refrigerant [R-401 (33/15/52)], technical information report T-MP52-SI (H-47770), DuPont Chemicals, Wilmington, DE, February 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3429)

This report provides thermodynamic property data for R-401C, a blend of R-22, R-152a, and R-124 - R-22/152a/124 (33/15/52) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 104 °C (-148 to 220 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-4000 kPa (1-580 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-401C is Suva(R) MP52.

(-150 to 154 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-402A is Suva(R) HP80.

Thermodynamic Properties of Suva(R) HP80 Refrigerant [R-402 (60/2/38)], technical information report T-HP80-SI (H-47767), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3437)

This report provides thermodynamic property data for R-402A, a blend of R-125, R-290, and R-22 - R-125/290/22 (60/2/38) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 68 °C (-148 to 154 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-4000 kPa (1-580 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-402A is Suva(R) HP80.

R-402A

Thermodynamic Properties of Suva(R) HP80 Refrigerant [R-402 (60/2/38)], technical information report T-HP80-ENG (H-47766), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3436)

This report provides thermodynamic property data for R-402A, a blend of R-125, R-290, and R-22 - R-125/290/22 (60/2/38) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 68 °C

R-402B

Thermodynamic Properties of Suva(R) HP81 Refrigerant [R-402 (38/2/60)], technical information report T-HP81-ENG (H-47757), DuPont Chemicals, Wilmington, DE, January 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3434)

This report provides thermodynamic property data for R-402B, a blend of R-125, R-290, and R-22 - R-125/290/22 (38/2/60) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well

as latent heat of vaporization) for -101 to 75 °C (-150 to 167 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-402B is Suva(R) HP81.

Thermodynamic Properties of Suva(R) HP81 Refrigerant [R-402 (38/2/60)], technical information report T-HP81-SI (H-47758), DuPont Chemicals, Wilmington, DE, January 1993 (20 pages with 1 figure and 2 tables, available from JMC as RDB3435)

This report provides thermodynamic property data for R-402B, a blend of R-125, R-290, and R-22 - R-125/290/22 (38/2/60) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 74 °C (-148 to 165 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-4000 kPa (1-580 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-402B is Suva(R) HP81.

R-403A

R-403B

Isceon 69-L, information packet, National Refrigerants, Incorporated, Philadelphia, PA, March 1992 (16 pages containing 1 figure and 5 tables, RDB-3A64)

This set of documents includes physical, thermodynamic, and application data on R-403B, a ternary zeotropic blend of R-22, R-218, and R-290 (propane) formulated as R-290/22/218 (5/56/39). This alternative refrigerant is targeted as a "drop-in" replacement for R-502 in existing refrigeration systems. The packet provides physical property data and saturated vapor pressures, the latter from -62 to 57 °C (-80 to 135 °F), in inch-pound units. It also includes thermodynamic property (pressure, specific volume, density, enthalpy, and entropy as functions of temperature) tables for saturated conditions, from -50 to 89 °C (-58 to 192 °F), and for superheated vapor in metric (SI) units. A pressure-enthalpy diagram, in SI units, is provided. The information packet gives general guidelines for retrofit of R-502 systems to use the blend, a retrofit checklist, and a theoretical performance comparison for the two fluids. Rhône-Poulenc Chemical's product name for R-403B is Isceon 69-L; National Refrigerants is the exclusive distributor for North America.

R-404A

Forane(R) 404A, technical digest, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1994 (4 pages with 4 tables, available from JMC as RDB4769)

This bulletin supplies information on R-404A, a near-azeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4). R-404A was formulated to closely match the properties of R-502 for use in medium and low temperature refrigeration in both new systems and applications. A table provides physical and environmental property data for R-404A in inch-pound (IP) units. The table lists the chemical formulation, average molecular weight, normal boiling point, heat of vaporization, vapor and liquid density at the boiling point and 25 °C (77 °F), critical parameters (temperature, pressure, and density), specific heat of the liquid at the same temperature and of the vapor at atmospheric pressure, maximum temperature glide, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). The table also shows R-404A to be nonflammable at test temperatures up to 100 °C (212 °F). A second table gives the saturated vapor pressures of R-404A and R-502 for -51 to 54 °C (-60 to 130 °F). A third presents the bubble and dew point temperatures and the liquid and vapor densities and enthalpies for R-404A for pressures of 34-2760 kPa (5-400 psia). The document briefly discusses considerations for use of near-azeotropic blends with attention to temperature glide, composition changes, and charging implications. It also reviews performance, lubrication, and materials compatibility considerations for R-404A for new and retrofit systems. It notes immiscibility with mineral oils and the need for their replacement with polyolester lubricant. It also points out that pressure relief devices may need modification due to the higher operating pressures of R-404A compared to R-502. The digest concludes with container identification for R-404A and other alternative refrigerants. Elf

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Atochem identified R-404A as FX-70 for research and development; its product name for the blend is Forane(R) 404A.

Genetron(R) 404A, technical bulletin B-525-532, AlliedSignal Incorporated, Morristown, NJ, April 1995 (4 pages with 2 tables, RDB6102)

This bulletin supplies information on R-404A, described as a replacement for refrigerants 22 and 502 in low- and medium-temperature, commercial refrigeration applications. The document notes that R-404A is not a "drop in" because a polyolester (POE) lubricant should be used, for miscibility. It also advises that this refrigerant be charged with liquid refrigerant, since vapor charging could result in the wrong composition. The bulletin presents physical property data, in inch-pound (IP) units, including the composition, molecular weight, normal boiling point, corresponding heat of vaporization, critical parameters (temperature, pressure, and density), flammability, and ozone depletion potential. It also indicates the liquid density and specific heats of the liquid and vapor at 30 °C (86 °F). The report provides tabular thermodynamic properties (bubble- and dew-point pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -46 to 71 °C (-50 to 160 °F). AlliedSignal's product name for R-404A is Genetron(R) 404A.

Kältemittel Reclin(R) 404A [Refrigerant Reclin(R) 404A], product bulletin AF2634d, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, May 1994 (28 pages with 6 figures and 7 tables, in German, RDB4777)

This bulletin provides data for R-404A, identified as a near-azeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4), in metric (SI) units of measure. The blend is described as a substitute for R-22 and R-502 in low-temperature refrigeration. The introduction reviews the phaseout of chlorine-containing refrigerants and criteria for substitutes. A table summarizes physical and thermodynamic property data for R-404A, including the chemical formulation and name, molecular mass, normal boiling point, freezing range, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, liquid and vapor density, specific heat, isentropic exponent, flammability limits (none), thermal conductivity, and dynamic viscosity at selected conditions. The bulletin reviews thermodynamic similarities of R-404A with R-22 and R-502. Four plots compare their compression ratios, compressor discharge temperatures, volumetric refrigerating effect, and coefficient of performance for evaporating temperatures of -45 to -5 °C (-49 to 23 °F). The bulletin then discusses compatibility with metals, recommending avoidance of zinc, magnesium, lead, and aluminum alloys with more than 2% magnesium. It reports storage tests that showed good stability to hydrolysis and no corrosive attack on cast iron, refined steel, copper, brass, and aluminum. The bulletin provides changes in Shore hardness, elastomer swell, extraction, and elongation data for R-404A with ethylene propylene diene terpolymer (EPDM), fluorinated (FKM), hydrogenated nitrile butadiene rubber (HNBR), acrylonitrile-butadiene (NBR), and chloroprene (CR) rubbers. It notes suitability with polytetrafluoroethylene (PTFE, Hostaflon(R)), polyacetal (POM, Hostaform(R)), and polyamide (PA) thermoplastics, but cautions that lubricant influences also must be considered. R-404A is indicated as almost completely immiscible with conventional mineral oils and also with some synthetics lubricants such as alkylbenzenes. The bulletin discusses miscibility and considerations for polyalkylene glycol (PAG) and polyolester (POE) lubricants. A plot shows miscibility of R-404A with an ester lubricant (Fuchs Reniso E 32). The bulletin reports that the absence of chlorine atoms in hydrofluorocarbon (HFC) refrigerants leads to higher thermal stability. The bulletin outlines toxicity testing for R-125 and R-134a, and that recommended exposure limits of 1000 ppm have been set for R-125, R-134a, and R-143a (the components of R-404A), but that exposures should still be kept to a minimum. It also notes that R-134a does not form flammable mixtures with air under normal conditions, but that flammable mixtures can form above atmospheric pressure if the air fraction exceeds 60%. R-143a is indicated as flammable, but R-125 is not. The blend does not burn, even after fractionation by leakage. The bulletin warns that mixtures of R-404A with air or oxygen must never be used for leak or pressure tests. The bulletin discusses leakage, noting that even losses up to 70% by mass have small impacts and that the blend performs nearly the same way as an azeotrope. It also discusses recycling and notes that Hoechst will accept used R-404A for reclaim. Two tables provide thermodynamic property data. The first includes bubble and dew point pressures; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-404A at saturated (wet vapor) conditions from -60 to 65 °C (-76 to 149 °F). The second provides specific volume, enthalpy, and entropy data for the superheated vapor from -50 to 200 °C (-58 to 392 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram based on a Peng-Robinson-Stryjek-Vera (PRSV) equation of state. Hoechst

Chemical's product name for R-404A is Reclin(R) 404A.

Thermodynamic Properties of Suva(R) HP62 Refrigerant [R-404A (44/52/4)], technical information report T-HP62-ENG (H-49744-1), DuPont Chemicals, Wilmington, DE, December 1993 (24 pages with 1 figure and 2 tables, available from JMC as RDB3C04)

This report provides thermodynamic property data for R-404A, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, specific volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 66 °C (-150 to 150 °F). A set of tables presents specific volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3450 kPa (1-500 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-404A is Suva(R) HP62.

Thermodynamic Properties of Suva(R) HP62 Refrigerant, technical information report T-HP62-SI (H-49745), DuPont Chemicals, Wilmington, DE, June 1993 (20 pages with 1 figure and 2 tables, RDB3733)

This report provides thermodynamic property data for R-404A, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, specific volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -100 to 65 °C (-148 to 149 °F). A set of tables presents specific volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-3600 kPa (1-522 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-404A is Suva(R) HP62.

R-405A

R-406A

R. Döring (Fachhochschule Münster, Germany), **Thermodynamic Characteristics of R-406A - Results of Experimental and Theoretical Tests**, Solvay Specialty Chemicals, Incorporated, Greenwich, CT, undated circa 1994 (68 pages with 2 figures and 59 tables, in English with several labels in German, available from JMC as RDB5127)

This report provides detailed thermodynamic property data for R-406A, a zeotropic blend of R-22, R-600a (isobutane), and R-142b - R-22/600a/142b (55/4/41). It presents a tabular comparison of calculated performance of R-12 and R-406A in a simple process cycle, noting almost the same capacity, piping sizes, and power use, but a higher compression ratio and discharge temperature. The report briefly outlines the methods used to measure properties and calculate derived vapor pressures, liquid densities, and ideal gas specific heat capacities. Tables present physical data for the components, the blend, and R-12 for comparison, in metric (SI) and inch-pound (IP) units of measure. They include the normal bubble and dew point temperatures as well as critical parameters (pressure, temperature, density, and specific volume). The report presents a Martin-Hou equation of state (EOS) and a table showing deviations from measured data. It also provides enthalpy and entropy equations for the superheated region and coefficients to calculate the specific enthalpy, entropy, and exergy. The report concludes with a pressure-enthalpy (Mollier) diagram and detailed tabular data for saturated and superheated conditions in metric (SI) units. The former covers -40 to 100 °C (-40 to 212 °F) and the latter pressures from 20 to 3400 kPa (3-493 psia). Solvay's product name for R-406A is Solkane(R) 406A. [translated from RDB5219]

R. Döring (Fachhochschule Münster, Germany), **Thermodynamische Eigenschaften von GHG 12 - Ergebnisse experimenteller und theoretischer Untersuchungen** [Thermodynamic Properties of GHG 12 - Results of Experimental and Theoretical Investigations], Solvay Fluor und Derivate GmbH, Hannover, Germany, undated circa 1994 (68 pages

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with 2 figures and 59 tables, in German, available from JMC as RDB5219)

This report provides detailed thermodynamic property data for R-406A, a zeotropic blend of R-22, R-600a (isobutane), and R-142b - R-22/600a/142b (55/4/41). It presents a tabular comparison of calculated performance of R-12 and R-406A in a simple process cycle, noting almost the same capacity, piping sizes, and power use, but a higher compression ratio and discharge temperature. The report briefly outlines the methods used to measure properties and calculate derived vapor pressures, liquid densities, and ideal gas specific heat capacities. Tables present physical data for the components, the blend, and R-12 for comparison, in metric (SI) and inch-pound (IP) units of measure. They include the normal bubble and dew point temperatures as well as critical parameters (pressure, temperature, density, and specific volume). The report presents a Martin-Hou equation of state (EOS) and a table showing deviations from measured data. It also provides enthalpy and entropy equations for the superheated region and coefficients to calculate the specific enthalpy, entropy, and exergy. The report concludes with a pressure-enthalpy (Mollier) diagram and detailed tabular data for saturated and superheated conditions in metric (SI) units. The former covers -40 to 100 °C (-40 to 212 °F) and the latter pressures from 20 to 3400 kPa (3-493 psia). Solvay's product name for R-406A is Solkane(R) 406A.

R-406A Vapor Table and Mollier-Diagram, Solvay Performance Chemicals, Greenwich, CT, undated circa 1994 (4 pages with 1 figure and 1 table, available from JMC as RDB5128)

This information packet describes and provides data for R-406A, a zeotropic blend of R-22, R-600a (isobutane), and R-142b - R-22/600a/142b (55/4/41). R-406A is identified as an alternative for R-12 for small, hermetic, refrigerating systems such as domestic refrigerators, drink dispensers, and other fixed refrigerating or chilling equipment. The packet includes a table of saturated liquid and vapor data in metric (SI) units of measure for -40 to 100 °C (-40 to 212 °F). It includes liquid (bubble point) and vapor (dew point) pressures as well as liquid and vapor specific volume, density, enthalpy, and entropy. It concludes with a pressure-enthalpy (Mollier) diagram. Solvay's product name for R-406A is Solkane(R) 406A.

R-407A

Klea(R) 60 Data Sheet, bulletin 620250550, ICI Klea, Wilmington, DE, January 1994; republished as **Klea(R) 407A (Klea 60) Data Sheet**, December 1994 (8 pages with 5 tables, available from JMC as RDB4130)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407A, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (20/40/40) - in inch-pound (IP) units of measure. This formulation was selected to replace R-502 in new refrigeration equipment and also for retrofit in many existing systems. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 21 °C (70 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with four tables giving calculated values for these properties at representative pressures of 70-2760 kPa (10-400 psia) and temperatures of -51 to 49 °C (-60 to 120 °F). ICI's product name for R-407A is Klea(R) 60.

Klea 60 Physical Property Data Sheet, SI Units, bulletin CP/33529/1Ed/33/0194, ICI Klea, Runcorn, Cheshire, UK, January 1994 (8 pages with 5 tables, available from JMC as RDB4564)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407A, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (20/40/40) - in metric (SI) units of measure. The bulletin tabulates physical properties including the atmospheric bubble and dew point temperatures, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 25 °C (77 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductiv-

ity. The document concludes with four tables giving calculated values for these properties at representative pressures of 100-3000 kPa (15-435 psia) and temperatures of -50 to 50 °C (-58 to 122 °F). ICI's product name for R-407A is Klea(R) 60.

Thermodynamic Properties of Klea(R) 407A (Klea(R) 60), British Units, bulletin 620250371, ICI Klea, Wilmington, DE, March 1995 (28 pages with 1 figure and 3 tables, limited copies available from JMC as RDB6B30)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407A - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (20/-40/40) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 6.9-69 kPa (1-10 psi) increments for 70-3000 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 213 °C (415 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407A is Klea(R) 407A (formerly Klea(R) 60).

Thermodynamic Property Data for Klea 407A, SI Units, bulletin CP/33342/33524/1Ed/R1/43/594, ICI Klea, Runcorn, Cheshire, UK, May 1994 (32 pages with 1 figure and 3 tables, RDB6B31)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407A - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (20/-40/40) - in metric (SI) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 0.1 bar (10 kPa, 1.5 psi increments) for 70-3000 kPa (10-435 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-430 psia) to temperatures as high as 168 °C (334 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 100-560 kPa (15-80 psia). ICI's product name for R-407A is Klea(R) 407A (formerly Klea(R) 60).

R-407B

Klea(R) 61 Data Sheet, bulletin 620250580, ICI Klea, Wilmington, DE, January 1994; republished as **Klea(R) 407B (Klea 61) Data Sheet**, December 1994 (8 pages with 1 table, available from JMC as RDB4132)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407B, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (10/70/20) - in inch-pound (IP) units of measure. This formulation was selected to replace R-502 in existing, low-temperature refrigeration equipment for which R-407A is unsuitable. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 21 °C (70 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with four tables giving calculated values for these properties at representative pressures of 70-2760 kPa (10-400 psia) and temperatures of -51 to 49 °C (-60 to 120 °F). ICI's product name for R-407B is Klea(R) 61.

Klea 61 Physical Property Data Sheet, bulletin CP/33530/1Ed/33/0194, ICI Klea, Runcorn, Cheshire, UK, January 1994 (8 pages with 5 tables, available from JMC as RDB4565)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407B, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (10/70/20) - in metric (SI) units of measure. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 20 °C

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(68 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with four tables giving calculated values for these properties at representative pressures of 100-3000 kPa (15-435 psia) and temperatures of -50 to 50 °C (-58 to 122 °F). ICI's product name for R-407B is Klea(R) 61.

Thermodynamic Property Data for Klea(R) 407B (Klea(R) 61), British Units, bulletin 620250391, ICI Klea, Wilmington, DE, March 1995 (28 pages with 1 figure and 3 tables, limited copies available from JMC as RDB6B32)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407B - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (10/70/20) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-435 psia) to temperatures as high as 207 °C (405 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407B is Klea(R) 407B (formerly Klea(R) 61).

Thermodynamic Property Data for Klea 407B, SI Units, bulletin CP/33343/33525/1Ed/R1/43/594, ICI Klea, Runcorn, Cheshire, UK, May 1994 (32 pages with 1 figure and 3 tables, limited copies available from JMC as RDB6B33)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-407B - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (10/70/20) - in metric (SI) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 0.1-0.5 bar (10-50 kPa, 1.5-7 psi) increments for 100-3000 kPa (10-435 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-3000 kPa (15-435 psia) to temperatures as high as 164 °C (327 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 100-560 kPa (15-80 psia). ICI's product name for R-407B is Klea(R) 407B (formerly Klea(R) 61).

R-407C

Genetron(R) 407C Product Brochure, bulletin G525-013, AlliedSignal Incorporated, Morristown, NJ, May 1995 (16 pages with 1 figure and 7 tables, RDB5A31)

This bulletin supplies information on R-407C, a zeotropic blend of R-32, R-125, and R-134a - R-32/125/134a (23/25/52). It was designed to replace R-22 in existing and new equipment including unitary air-conditioners, chillers without flooded evaporators, and commercial refrigeration. The document outlines potential applications and provides physical property information. The data include the chemical name and formula, appearance, molecular weight, normal bubble and dew point temperatures, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. The data also include the bubble and dew point pressure, liquid density, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications, provides a pressure-temperature table, and reviews servicing considerations. It describes tests and indicates that R-407C is stable with metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers. It lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties

(bubble and dew point pressures, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F). The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-407C is Genetron(R) 407C.

Klea(R) 407C (Klea 66) Data Sheet, bulletin 620250610, ICI Klea, Wilmington, DE, December 1994 (8 pages with 1 table, RDB6B34)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-407C, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/125/134a (23/25/52) - in inch-pound (IP) units of measure. This formulation was selected to replace R-22 in new low temperature refrigeration equipment and also for retrofit in many existing systems. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical temperature, Trouton's constant, and coefficient of thermal expansion. It also indicates the bubble point pressure and latent heat of vaporization at 21 °C (70 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, speed of sound, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with four tables giving calculated values for these properties at representative pressures of 70-2760 kPa (10-400 psia) and temperatures of -51 to 49 °C (-60 to 120 °F). ICI's product name for R-407C is Klea(R) 407C (formerly Klea(R) 66).

Thermodynamic Properties of Klea(R) 407C (Klea(R) 66), British Units, bulletin 620250411, ICI Klea, Wilmington, DE, January 1994 (28 pages with 1 figure and 3 tables, limited copies available from JMC as RDB6B36)

This bulletin provides detailed thermodynamic properties for saturated and superheated conditions for R-407C, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/-125/134a (23/25/52) - in inch-pound (IP) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 216 °C (420 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407C is Klea(R) 407C (formerly Klea(R) 66).

Thermodynamic Properties of Suva(R) AC9000 Refrigerant, technical information report T-AC-9000-ENG (H-56606), DuPont Fluoroproducts, Wilmington, DE, April 1994 (24 pages with 1 figure and 2 tables, available from JMC as RDB4764)

This report provides thermodynamic property data for R-407C, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (23/25/-52) - in inch-pound (IP) units of measure. It provides physical properties including the chemical formula, molecular weight, normal boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, specific volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -101 to 79 °C (-150 to 175 °F). A set of tables presents specific volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-407C is Suva(R) AC9000.

Thermodynamic Properties of Suva(R) AC9000 Refrigerant, technical information report T-AC-9000-SI (H-56607), DuPont Fluoroproducts, Wilmington, DE, April 1994 (20 pages with 1 figure and 2 tables, available from JMC as RDB4765)

This report provides thermodynamic property data for R-407C, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (23/25/-52) - in metric (SI) units of measure. It provides physical properties including the chemical formula, molecular weight, normal boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Peng-Robinson-Stryjek-Vera (PRSV) equation of state and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate vapor pressure and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, specific volume, density, enthalpy, and entropy

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as well as latent heat of vaporization) for -100 to 79 °C (-148 to 174 °F). A set of tables presents specific volume, enthalpy, and entropy data for superheated vapor at constant pressure for 10-4000 kPa (1.5-580 psia). The report concludes with a pressure-enthalpy diagram. DuPont's product name for R-407C is Suva(R) AC9000.

Transport Properties of Suva 9000 Refrigerant, product information report ART-26 (H-60081), DuPont Chemicals, Wilmington, DE, November 1994 (28 pages with 22 figures, available from JMC as RDB5129)

This report provides plots and equations for estimation of transport properties for R-407C, a zeotropic blend of R-125, R-143a, and R-134a - R-125/143a/134a (23/25/52) - as functions of temperature. Saturated liquid viscosity, kinematic viscosity, thermal conductivity, and Prandtl number; vapor viscosity and thermal conductivity at atmospheric and high (100-3,000 kPa, 15-450 psia) pressures; vapor heat capacity; and vapor heat capacity ratio (C_p/C_v) are addressed. The plots and equations are repeated in inch-pound (IP) and metric (SI) units. The equations are based on curve fits of measured data. DuPont's product name for R-407C is Suva(R) 9000.

Thermodynamic Property Data for Klea(R) Klea(R) 66, SI Units, bulletin CP/34434/34214/-2Ed/43/3941, ICI Klea, Runcorn, Cheshire, UK, March 1994 (32 pages with 1 figure and 3 tables, limited copies available from JMC as RDB6B37)

This bulletin provides detailed thermodynamic properties for saturated and superheated conditions for R-407C, a zeotropic blend containing R-32, R-125, and R-134a - specifically R-32/-125/134a (23/25/52) - in inch-pound (IP) [contrary to the title] units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 7-69 kPa (1-10 psi) increments for 70-2960 kPa (10-430 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, enthalpy, and entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 70-2960 kPa (10-430 psia) to temperatures as high as 216 °C (420 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 70-690 kPa (10-100 psia). ICI's product name for R-407C is Klea(R) 407C (formerly Klea(R) 66).

R-408A

Forane(R) FX-10, technical digest, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1994 (4 pages with 4 tables, available from JMC as RDB4770)

This bulletin supplies information on R-408A, a near-azeotropic blend of R-125, R-143a, and R-22 - R-125/143a/22 (7/46/47). R-408A was formulated as a retrofit refrigerant in low and medium temperature refrigeration systems designed for R-502. The bulletin notes that R-404A is recommended to replace R-502 in new equipment. A table compares physical and environmental property data for R-408A and R-502 in inch-pound (IP) units. The table lists the chemical formulation, average molecular weight, normal boiling point, heat of vaporization, vapor and liquid density at the boiling point and 25 °C (77 °F), critical parameters (temperature and pressure), specific heat of the liquid at the same temperature and of the vapor at atmospheric pressure, maximum temperature glide, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). The table also shows R-408A to be nonflammable at test temperatures up to 100 °C (212 °F). A second table gives the saturated vapor pressures of R-408A and R-502 for -43 to 60 °C (-45 to 140 °F). A third presents the saturated liquid and vapor pressures, densities, and enthalpies for the same range. The document briefly discusses considerations for use of near-azeotropic blends with attention to temperature glide, composition changes, and charging implications. It also reviews performance, lubrication, and materials compatibility considerations for retrofit systems. It notes that R-408A can be used with mineral oil, alkylbenzene, or polyolester lubricants. It also outlines a nine-step retrofit procedure to convert equipment from R-502 to R-408A. The digest concludes with container identification for R-408A and other alternative refrigerants. Elf Atochem's product name for R-408A is Forane(R) FX-10.

R-409A

Forane(R) FX-56, technical digest, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1994 (4 pages with 2 figures and 4 tables, available from JMC as RDB4771)

This bulletin supplies information on R-409A, a zeotropic blend of R-22, R-124, and R-142b - R-22/124/142b (60/25/15). R-409A was formulated as a retrofit refrigerant for R-12 in low and medium temperature refrigeration systems where removal of mineral oil is difficult. A table

summarizes physical and environmental property data for R-409A in inch-pound (IP) units. The table lists the chemical formulation, average molecular weight, normal boiling (bubble) point, heat of vaporization, critical parameters (temperature and pressure), vapor and liquid density at the boiling point and 27 °C (80 °F) respectively, specific heat of the liquid at the same temperature and of the vapor at atmospheric pressure, maximum temperature glide, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP). The table also shows R-409A to be nonflammable. A second table gives the bubble and dew point pressures of R-409A and saturated vapor pressures of R-12 for -34 to 60 °C (-30 to 140 °F). The document briefly discusses retrofit, lubrication, charging procedures, and performance. It notes that R-409A can be used with mineral oil, alkylbenzene, or polyolester lubricants. It also notes that while evaporator pressures will be similar to those with R-12, condenser pressures will be 69-138 kPa (10-20 psi) higher. The bulletin then explains terminology associated with zeotropic blends, including *bubble point*, *dew point*, *fractionation*, and *glide*. It then reviews the typical behavior of R-409A in an evaporator, explaining how the composition changes during boiling. The bulletin outlines an eight-step retrofit procedure to convert equipment from R-12 to R-409A and provides guidance on setting system temperatures with the blend. The digest concludes with container identification for R-409A and other alternative refrigerants. Elf Atochem's product name for R-409A is Forane(R) FX-56.

R-410A

Genetron(R) AZ-20 (R-410A) Product Brochure, bulletin G-525-012, AlliedSignal Incorporated, Morristown, NJ, July 1996 (16 pages with 4 figures and 7 tables, RDB6B27)

This bulletin supplies information on R-410A, a patented blend of R-32 and R-125 - R-32/125 (50/50) - that behaves like an azeotrope. It was designed to replace R-22 in a variety of new equipment including unitary air-conditioners, chillers, and commercial refrigeration. The document outlines potential applications and provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications and provides both a pressure-temperature table and pressure-enthalpy (Mollier) diagrams. It reviews servicing considerations presents a tabular summary of the stability of R-410A with polyolester lubricants and metals (aluminum, copper, and steel). The text refers inquiries on desiccants to drier manufacturers, but provides a solubility plot for water in R-410A and lists suitability indications for 27 elastomers and plastics. The bulletin suggests use of polyolester lubricants, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 160 °F) [tables cover dissimilar ranges for the two sets of units]. Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-410A is Genetron(R) AZ-20.

R-410B

D. B. Bivens, A. Yokozeki (DuPont Chemicals), and V. Z. Geller (Thermophysics Research Center), **Thermodynamic Properties of R32/R125 Mixture**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 107-116, October 1995 (10 pages with 1 figure and 7 tables, available from JMC as RDB5A51)

R-410B, critical parameters, vapor pressure, saturated liquid and vapor densities, PVT measurements, Martin Hou equation of state (EOS)

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R-411A

R-411B

Other Zeotropes

R. S. Agarwal, M. Ramaswamy, and V. K. Srivastava, **Transport Properties of Ternary Near-Azeotropic Mixtures**, unpublished research paper, Indian Institute of Technology (IIT), New Delhi, India, October 1993 (18 pages with 6 figures and 11 tables, available from JMC as RDB3A70)

This paper presents transport properties for four ternary zeotropic formulations of R-22/152a/-124, namely 53/13/34 (R-401A), 61/11/28 (R-401B), 33/15/32 (R-401C), and 36/24/40. The properties were calculated, using estimation techniques documented in the paper. Correlations and plots summarizing the findings are presented, the latter for -53 to 97 °C (-63 to 207 °F). The paper addresses liquid and vapor thermal conductivity, specific heat, and viscosity. The estimation techniques used were evaluated by computing the properties of R-500 and comparing the results with published data. Potential applications of the four near-azeotropic blends are discussed briefly.

K. Arita, T. Tomizawa, Y. Nakagawa, and Y. Yoshida, **Vapor-Liquid Equilibrium of the Non-azeotropic Refrigerant Mixture Formed by Chlorofluoromethane and 1,1,1,2-tetrafluoroethane**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 63, pages 151-156, 1991 (6 pages, RDB4A40)

R-31, R-134a, zeotropic blend

M. Arnemann and H. Kruse (Universität Hannover, Germany), **Liquid Viscosities of the Nonazeotropic Binary Refrigerant Mixtures of R22/R114, R22/R152a, and R22/R142b: Measurement and Calculations**, paper 41, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 379-383, August 1991 (5 pages with 4 figures and 6 tables, RDB4A45)

R-22/114, R-22/152a, R-22/142b, zeotropic blends, thermodynamic properties, thermophysical data

J. R. Barker, W. B. Kay, and A. S. Teja, **A Study of the Volumetric and Phase Behavior of Binary Systems, Part I: Critical Properties of Propane-Perfluorocyclopropane Mixtures**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 28, number 1, pages 134-138, 1982 (7 pages, RDB5706)

R-C216, R-290, R-290/C216, thermodynamic properties, thermophysical data

M. Buschmeier, G. Herres, and D. Gorenflo (Universität Paderborn, Germany), **Prediction of P,V,T,X Data for Mixtures of New Refrigerants by Cubic Equations of State**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 251-262, 1993 (12 pages with 11 figures, RDB5321)

R-22/142b, R-227ea/123 (identified in the paper as R-227/123), thermodynamic properties, thermophysical data, equation of state

M. Buschmeier, W. Künstler, G. Herres, and D. Gorenflo (Universität Paderborn, Germany), **Phasengleichgewicht und Dichte der Stoffsysteme R22/R142b sowie R227/R123** [Phase Equilibria and Densities of R-22/142b and R-227ea/123 Blends], *DKV-Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 19, 1992 (RDB5494)

R-22/142b, R-227ea/123 (identified in the paper as R-227/123), thermodynamic properties, thermophysical data, equation of state

D. R. Defibaugh and G. Morrison (National Institute of Standards and Technology, NIST), **Compressed Liquid Densities, Saturated Liquid Densities, and Saturation Pressures of Mixtures: Difluoromethane + 1,1,1,2-tetrafluoroethane, Difluoromethane + 1,1-difluoroethane**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 473-478, July 1992 (6 pages with 8 figures, RDB2830)

R-32/134a, R-32/152a

K. Fujiwara, A. Sato, and S. Ide (Daikin Industries, Limited, Japan), **Vapor-Liquid Equilibria of HFC-23/32/134a Mixtures**, paper A101, *Proceedings of the 15th Japan Symposium on Thermophysical Properties*, Japan, pages 1-4, 1994 (4 pages with 4 figures and 4 tables; in Japanese with English abstract, equations, figures, and tables; RDB5A06)

This paper presents isothermal, vapor-liquid equilibrium data for the binary zeotropes of R-23/32, R-23/134a, and R-32/134a. Both tabular data and pressure-composition plots are pro-

vided. The apparatus used for the measurements is described and shown schematically. The critical parameters (temperature and pressure) and acentric factors are tabulated for R-23, R-32, and R-134a. Interaction parameters and averaged comparisons to measured data are then compared to measured data for both the Soave-Redlich-Kwong (SRK) [Redlich-Kwong-Soave (RKS)] and Peng-Robinson (PR) equations of state, for the three binary pairs. Deviations to the bubble and dew point pressures and densities are tabulated for three ternary blends of R-23/32/134a, namely (1.0/-29.7/69.3), (2.0/28.0/70.0), and (5.0/28.5/-66.5). The paper concludes that the two equations predict the saturated pressure and vapor density with almost the same accuracy, but that the PR equation of state is more accurate for the liquid density.

K. Fujiwara, H. Momota, and M. Noguchi (Daikin Industries, Limited, Japan), **Vapor-Liquid Equilibria of HFC-32 Mixtures**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 61-64, 1992 (4 pages, RDB-4875)

R-32 blends

J. S. Gallagher, **Thermodynamic Properties of a Geothermal Working Fluid: 90% Isobutane - 10% Isopentane**, NBS Technical Note 1234, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1987 (available from GPO, RDB-4C08)

R-600a/601a (90/10), R-600a, R-601a, thermophysical data

V. Z. Geller, **Thermophysical Properties of Multicomponent Refrigerants**, *Inzhenerno-Fizicheskii Zhurnal* [Journal of Engineering Physics], Minsk, USSR, volume 55, number 4, pages 620-624, 1988 (5 pages probably in Russian, RDB5486)

thermophysical data

N. Hasegawa, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of p, v, T, x Properties of the R22 + R114 System**, *Journal of Chemical and Engineering Data*, American Chemical Society (ACS), Columbus, OH, volume 30, pages 32-36, 1985 (5 pages, RDB4124)

R-22/114, pressure, volume, temperature, PVT, quality, thermodynamic, thermophysical, properties

G. Herres and D. Gorenflo (Universität Paderborn, Germany), **Calculations of the Vapour-Liquid Equilibrium of Some Binary Systems of Refrigerants by Various Cubic Equations of State**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 169-176, 1990 (8 pages with 3 figures and 4 tables, RDB5490)

R-22/114, R-22/115 [R-502], R-7146/12 (blend of SF_6 and R-12), R-7146/22, thermodynamic properties, thermophysical data, equation of state; Redlich-Kwong-Soave (RKS), Peng-Robinson (PR), Trebble-Bishnoi (TB), Schreiner equations of state

Y. Higashi, M. Uematsu, and K. Watanabe (Keio University, Japan), **Measurements of the Vapor-Liquid Coexistence Curve and Critical Locus for Several Refrigerant Mixtures**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 7, pages 128-133, 1986 (11 pages, RDB4125)

blends, thermodynamic properties, thermophysical data

Y. Higashi, Y. Kabata, and K. Watanabe (Keio University, Japan), **Thermodynamic Behavior of the Vapor-Liquid Coexistence Curve for Binary Refrigerant Mixtures**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, volume B, pages 128-133, 1987 (6 pages, RDB4108)

blends, thermodynamic properties, thermophysical data

H. Hipkin, **Experimental Vapor-Liquid Equilibrium Data for Propane-Isobutane**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 12, number 3, pages 484-487, 1966 (4 pages, RDB5711)

R-290, R-600a, R-290/600a, thermodynamic properties, thermophysical data

H. G. Hirschberg (Gebrüder Sulzer AG, Switzerland), **Kältemittel** [Refrigerants], Verlag C. F. Müller, Karlsruhe, Germany, 1966 (in German, RDB-5712)

refrigerant applications and data

Y. Ikeya, C-C. Piao, S. Yokota, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of Gaseous Isobaric Specific Heat Capacity of Alternative Refrigerants**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 119-121, 1991 (3 pages, RDB5474)

thermodynamic properties, thermophysical data

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Y. Kabata, Y. Higashi, and M. Uematsu (Keio University, Japan), **Correlation of the Vapor-Liquid Coexistence Curve for Binary Refrigerant Mixtures**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, volume B, pages 140-145, 1987 (6 pages, RDB4109)

blends, thermodynamic properties, thermophysical data

L. R. C. Kahre, **Liquid Density of Light Hydrocarbon Mixtures**, *Journal of Chemical and Engineering Data*, volume 18, number 3, pages 267-270, 1973 (4 pages, RDB5713)

R-290/600a and others, thermodynamic properties, thermophysical data

M. Kriebel and H. J. Löffler, **Thermodynamische Eigenschaften des binären Systems Difluormonochlormethan (R22) - Tetraäthylenglycoldimethyläther (E181)** [Thermodynamic Properties of Binary Mixtures of Chlorodifluoromethane (R-22) and Tetraethylene Glycol Dimethyl Ether (E-181) [possibly E-281], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 17, number 9, pages 266-271, 1965 (6 pages, in German, RDB4916)

R-22 blends, R-22/TGDME

K. Kumagai, N. Yada, H. Sato, and K. Watanabe (Keio University, Japan), **Measurements of PVT Properties for the Binary Refrigerant HCFC-142b + HCFC-22**, *Journal of Chemical and Engineering Data*, volume 36, pages 236-240, 1991 (5 pages, RDB5475)

R-22/142b, thermodynamic properties, thermophysical data

M. Küver and H. Kruse (Universität Hannover, Germany), **Thermodynamic Data of the Binary Mixture R22/R114**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, volume B, pages 152-158, 1987 (7 pages, RDB4110)

R-22/114 blends, thermophysical properties

H. B. Lange and F. P. Stein, **Volumetric Behavior of a Polar-Nonpolar Gas Mixture: Trifluoromethane-Tetrafluoromethane**, *Journal of Chemical and Engineering Data*, volume 15, pages 56-61, 1970 (6 pages, RDB4B37)

R-14, R-23, R-14/23, thermodynamic properties, thermophysical data

J. Luettmer-Strathmann and J. V. Sengers (University of Maryland), **The Transport Properties of Fluid Mixtures Near the Vapor-Liquid Critical Line**, *Journal of Chemical Physics*, American Institute of Physics (AIP), Woodbury, NY, volume 104, number 8, pages 3026-3047, 22 February 1996 (25 pages with 16 figures and 4 tables, RDB6404)

R-170/744 (ethane/carbon dioxide), mode-coupling theory for the dynamics of critical fluctuations to binary fluid mixtures near the vapor-liquid critical line, compares a proposed crossover model with experimental thermal conductivity data in the critical region, provides constants for the crossover model and critical parameters (temperature, pressure, and density) for 25/75, 26/74, 50/50, and 74/26 mixtures of R-170 and R-744 by mole fraction, compares calculated results with experimental data for thermal diffusivity, thermal conductivity, and viscosity

J. Luettmer-Strathmann, J. V. Sengers, and G. A. Olchowy (University of Maryland), **Non-asymptotic Critical Behavior of the Transport Properties of Fluids**, *Journal of Chemical Physics*, American Institute of Physics (AIP), Woodbury, NY, volume 103, number 17, pages 7482-7501, 1 November 1995 (20 pages with 15 figures and 3 tables, RDB6405)

R-170/744 (ethane/carbon dioxide), mode-coupling theory for the dynamics of critical fluctuations to fluids near the vapor-liquid critical line

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Binary HCFC-22 + HFC-152a System**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 61, pages 263-273, 1991 (11 pages, RDB4C05)

R-22, R-152a, R-22/152a, thermodynamic properties, thermophysical data

Y. Maezawa, J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Ternary HCFC-22/HFC-152a/HCFC-142b System**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 61, pages 203-212, 1991 (10 pages, RDB5470)

R-22, R-142b, R-152a, R-22/152a/142b, blend, thermodynamic properties, thermophysical data

Y. Maezawa, J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of the Binary HFC-152a + HCFC-142b System**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 12, pages 1029-1038, 1991 (10 pages, RDB5471)

R-142b, R-152a, R-152a/142b, blend, thermodynamic properties, thermophysical data

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Some Correlations for Saturated Liquid Density of Refrigerant Mixtures**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 10, number 1, pages 125-133, 1993 (9 pages, in Japanese, RDB4877)

blends, thermodynamic properties, thermophysical data

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Some Correlations for Saturated Liquid Density of Refrigerant Mixtures**, paper 533, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 644-647, August 1991 (4 pages with 3 figures and 6 tables, RDB4446)

R-11, R-22, R-114, R-134, R-142b, R-152a, R-22/12, R-22/114, R-22/142b, R-22/152a, R-22/-152a/142b, R-152a/114, R-152a/134, R-152a/-142b, blends, thermodynamic properties, thermophysical data

Y. Maezawa, H. Sato, K. Watanabe, and S. Oshima (Keio University, Japan), **Saturated Liquid Densities and Bubble-Point Pressures of Binary HFC-152a + HFC-134 System**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, volume 3, pages 443-450, 1991 (8 pages, RDB5469)

R-152a/134, thermodynamic properties, thermophysical data

C-C. Piao, M. S. Noguchi (Daikin Industries, Limited), H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Properties of HFC-32/-HFC-134a Binary System**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 37-42, July 1994 (6 pages with 5 figures and 2 tables, RDB4807)

R-32/134a (30/70), thermophysical data

T. Sato, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Property Evaluation for a Binary HFC-32 + HFC-134a Refrigerant Based on Experimental PVTx Data**, paper 93-WA/HT-25 (Winter Annual Meeting, New Orleans, LA, 28 November - 3 December 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (RDB4874)

R-32/134a, thermophysical data

F. L. Swinton, **Mixtures Containing a Fluorocarbon**, *Chemical Thermodynamics*, edited by M. L. McGlashan, The Chemical Society, London, UK, volume 2, pages 147-198, 1978 (52 pages, RDB-4C10)

azeotropes, blends, zeotropes

T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **PVTx Properties of Binary 1,1-difluoroethane + 1,1,2,2-tetrafluoroethane**, *Journal of Chemical and Engineering Data*, volume 37, pages 512-515, 1992 (4 pages, RDB5476)

R-152a/134, thermodynamic properties, thermophysical data

T. Tamatsu, H. Sato, and K. Watanabe (Keio University, Japan), **Determination of Virial Coefficients for Refrigerant Mixture HFC-152a (1,1-difluoroethane) + HFC-134 (1,1,2,2-tetrafluoroethane)**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), pages 334-339, 1992 (6 pages, RDB5479)

R-152a/134, thermodynamic properties, thermophysical data

L. C. Tan and J. M. Yin, **Thermodynamic Analysis of R22/R114 Refrigeration Cycle**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, volume B, pages 670-675, 1987 (6 pages, RDB4111)

R-22/114

A. Valts, S. Laugier, and H. Richon, **Bubble Pressures and Saturated Liquid Molar Volumes of Dichloromonofluoromethane-Fluorochloroethane Binary Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 9, pages 282-295, 1986 (4 pages, RDB4207)

R-21/151, R-21, R-151, blends, thermodynamic properties, thermophysical data

D. Vollmer (Forschungszentrum für Kälte- und Umwelttechnik GmbH, FKU, Germany) and E. Findeisen (Foron Hausgeräte GmbH, Germany), **Calculation of Thermodynamic and Thermophysical Properties of Binary Mixture Propane/Isobutane**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute

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of Refrigeration (IIR), Paris, France, pages 119-130, 1994 (12 pages with 7 figures and 5 tables, RDB-5705)

R-290, R-600a, R-290/600a, thermodynamic properties, Redlich-Kwong-Soave (RKS) and Lee-Kesler-Plöcker (LKP) equations of state, thermophysical data

W. Wei, **Studies on General Vapor Pressure of Equation of Fluids and Experimental Measurement of PVTx Properties for HFC134a/HFC152a**, masters degree dissertation, Xi'an Jiaotong University, China, 1995 (RDB6815)

R-134a/152a, thermodynamic properties, thermophysical data

N. Yada, M. Uematsu, and K. Watanabe (Keio University, Japan), **Study in the PVTx Properties for Binary R-152a + R-114 System**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 5, number 1, pages 107-115, 1988 (9 pages, in Japanese, RDB4230)

R-152a/114 blends, thermodynamic properties, thermophysical data

J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Measurement of the Liquid Densities of the Binary HFC-32 + HFC-134a System**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 99, pages 199-207, 1994 (9 pages with 7 figures and 2 tables, RDB4871)

R-32/134a blends, thermodynamic properties, thermophysical data

N. Yada and K. Watanabe (Keio University, Japan), **Correlations of Dew Point and Bubble Point Pressures for Binary Refrigerant Mixtures**, *Transactions of the JSME*, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, series B, volume 57, pages 4167-4173, 1991 (7 pages, RDB5483)

zeotropes, blends, thermodynamic properties, thermophysical data

FRIGC(R) FR-12(TM) Specifications, InterCool Energy Corporation, Latham, NY, 1995 (2 pages with 1 figure and 2 tables, limited copies available from JMC as RDB5A41)

This product specification sheet provides data on a ternary zeotropic blend of R-124, R-134a, and R-600 - R-134a/124/600 (59/39/2) - in inch-pound (IP) and metric (SI) units of measure. The blend is described as a replacement for R-12 in mobile air-conditioning (MAC) applications. The bulletin indicates that the blend operates in the same pressure range as R-12, even at high ambient temperatures, and is compatible the mineral oil used in MAC compressors. A table summarizes selected physical properties including the normal bubble and dew points, corresponding vapor densities, latent heat of vaporization, and critical parameters (temperature, pressure, and density). It also includes the vapor pressure, solubility in water, and the liquid and vapor thermal conductivities and heat capacities at 25 °C (77 °F). It concludes with the ozone depletion potential (ODP), global warming potential (GWP), and flammability limits (indicated as none). The product sheet then discusses service considerations including charging and recovery. It briefly reviews compatibility findings with plastics, elastomers, metals, desiccants, and lubricants as well as leak detection. A table and plot compare the vapor pressure for the blend at its bubble and dew points to that for R-12 at -7 to 93 °C (20-200 °F). InterCool Energy Corporation's product name for this blend is FRIGC(R) FR-12(TM).

Refrigerant Reclin(R) HX4, product bulletin AF2612e, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 22 February 1994 (8 pages with 3 figures and 3 tables, RDB4778)

This bulletin provides data for a tetrary zeotropic blend of R-32, R-125, R-143a, and R-134a - R-32/125/143a/134a (10/33/36/21) - in metric (SI) units of measure. The blend is described as a substitute for R-22 and R-502. A table summarizes physical and thermodynamic property data for R-22, R-502, and HX4, including the chemical formulation, molecular mass, normal freezing and boiling points, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, liquid density, isentropic exponent, and flammability limits (none) at selected conditions. The bulletin indicates that the blend is nonflammable and that it would be unlikely to fractionate to a flammable mixture with air in the event of leakage. It notes that toxicity testing is not complete for the components, but that no adverse toxicological properties are indicated. Ozone depletion and halocarbon global warming potentials (ODP and HGWP) of 0 and 0.73, respectively, are indicated. The bulletin notes that only ester lubricants are suitable for HX4. It then reviews the thermodynamic similarities of the blend with those of R-22 and R-502. Two plots compare their pressure-temperature and density-temperature relationships for -50 to 60 °C (-58 to 140 °F). A table provides thermodynamic property data including the bubble and dew point pressures; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover HX4 at satu-

rated (wet vapor) conditions from -50 to 70 °C (-76 to 158 °F). The bulletin concludes with a pressure-enthalpy (Mollier) diagram

R-500

J. V. Sinka and K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Pressure-Volume-Temperature Relations for a Mixture of Difluorodichloromethane and 1,1-difluoroethane**, *Journal of Chemical and Engineering Data*, volume 12, number 3, pages 315-316, 1967 (2 pages, RDB3933)

R-500, thermodynamic properties, equation of state, PVT

Freon(R) 500 - Tables of Thermodynamic Properties, technical bulletin T-500 (E-36103), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1988 (16 pages with 2 tables, RDB3C01)

This report provides thermodynamic property data for R-500 in inch-pound (IP) units of measure. It comprises two tables. The first presents pressure as well as liquid and vapor specific volume, density, enthalpy, heat of vaporization, and entropy at saturation conditions for temperatures of -51 to 104 °C (-60 to 220 °F). The second presents specific volume, enthalpy, and entropy for the superheated vapor at temperatures of -46 to 238 °C (-50 to 460 °F) and pressures of 55-2850 kPa (8-414 psia). DuPont Chemical's product name for R-500 is Freon(R) 500.

R-501

B. J. Eiseman, Jr., **Kinetic Technical Memorandum**, number KTM-7, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, June 1952 (RDB4919)

R-501, R-22/12

S. G. Kandlikar, C. A. Bijlani, and S. P. Sukhatme, **Predicting the Properties of Mixtures of R-22 and R-12**, *Transactions* (Semiannual Meeting, Atlantic City, NJ, 26-30 January 1975), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 81, part 1, pages 266-284, 1975 (19 pages, RDB5515)

R-501, R-22/12

S. G. Kandlikar, C. A. Bijlani, and S. P. Sukhatme, **Predicting the Properties of Mixtures of R-22 and R-12, Part II: Transport Properties**, paper 2343, *Transactions* (Semiannual Meeting, Atlantic City, NJ, 26-30 January 1975), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 81, part 1, pages 285-294, 1975 (10 pages, RDB5560)

R-501, R-22/12

H. J. Löffler, **Einige Eigenschaften des Binären Systems Frigen 12 - Frigen 22 und des Ternären Systems F 12 - F 22 - Naphthenbasisches Mineralöl** [Some Properties of the Binary System R-12 / R-22 and the Ternary System R-12 / R-22 / Naphthenic Mineral Oil], *Kältetechnik-Klimatisierung*, volume 12, number 9, pages 256-260, 1960 (5 pages with 6 figures and 3 tables, in German, RDB-4262)

This paper presents tabular data and a vapor-pressure diagram for R-22/12 mixtures at low temperatures based on new measurements and published data from other studies. It covers the temperature range of -80 to 50 °C (-112 to 122 °F). The paper also presents miscibility, low-temperature fluidity, viscosity, and vapor pressure data for high oil concentrations with R-501 [an azeotrope of R-22/12 (75/25)] and for up to 25% by weight R-12 in R-501.

D. Madinabeitia, **The Effect of Pressure and Temperature on the Azeotropic Composition of the R22 and R12 Binary System**, MS thesis, University of Delaware, Newark, DE, 1960 (RDB4C11)

R-12, R-22, R-22/12, R-501, thermophysical data, blends

J. Nagaoka and S. Takagi, **On the Characteristics of the Mixture of Refrigerants 12 and 22**, *Refrigeration Japan*, number 358, pages 1-9, June 1958 (RDB4920)

R-12, R-22, R-22/12, R-501, thermophysical data, blends

R-502

J. J. Martin (University of Michigan) and R. C. Downing (E. I. duPont de Nemours and Company), **Thermodynamic Properties of Refrigerant 502**, paper 2150, *Transactions* (Annual Meeting, Kansas City, MO, 28 June - 1 July 1970), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 76, part 2, pages 129-139, 1970 (11 pages with 14 tables, RDB3934)

R-502, equation of state, thermophysical data

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Thermophysical Properties of Refrigerants (R-502, Azeotrope of R-22 and R-115), *Nippon Reito Kyokai* [Japanese Association of Refrigeration, JAR], Tokyo, Japan, November 1986 (164 pages with 21 figures and 44 tables, in both Japanese and English, RDB0405)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-502, an azeotrope comprising 48.8% R-22 and 51.2% R-115 by weight. Included are tabular data and/or plots for PVT properties, enthalpy, entropy, isobaric and isochoric specific heat capacity, specific heat ratio, isentropic expansion exponent, speed of sound, surface tension, viscosity, kinematic viscosity, thermal conductivity, thermal diffusivity, Prandtl number, solubility, refractive index, and dielectric constant. An extended Benedict-Webb-Rubin (BWR) equation of state is presented and compared to other equations and data. Relations also are presented for key equilibrium properties. Data are tabulated for the solubility of water in R-502 and of R-502 in alkylbenzene lubricant. Limited data are provided on the stability of R-502 in the presence of metals and oil and on linear swell for neoprene GN, Buna(TM) N, natural rubber, GR-I, GR-S, and polysulfide rubber. Published safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discussion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. An appendix addresses compliance with the Japanese Industrial Standards (JIS), noting that the quality of R-502 is not covered; JIS K1528-1982 requirements for the quality of R-22 are summarized.

R-503

J. V. Sinka, E. Rosenthal, and R. P. Dixon (AlliedSignal Incorporated, then Allied Chemical Corporation), **Pressure-Volume-Temperature Relations for a Mixture of Monochlorotrifluoromethane and Trifluoromethane**, *Journal of Chemical and Engineering Data*, volume 15, number 1, pages 73-74, 1970 (2 pages, RDB3935)

R-503, thermodynamic properties, equation of state

Genetron(R) 503 Refrigerant for Cascade Systems, bulletin RTB-503B (22-503B), AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 1976 (16 pages with 7 figures and 2 table, RDB4104)

This bulletin presents physical property, performance, and application data for R-503, an azeotropic blend of R-23 and R-13 - R-23/13 (40.1/59.9). A table identifies the composition and lists key physical data including critical parameters, flammability, toxicity, color, and odor. Two tables provides performance data at saturated cycle conditions of -87 °C (-125 °F) evaporating and -34 °C (-30 °F) condensing for R-503, compared to -82 °C (-115 °F) and -29 °C (-20 °F) for R-13, and for both at -84 °C (-120 °F) evaporating and -34 °C (-30 °F) condensing. The bulletin describes use of R-503 as the low stage of a cascade system as an alternative to R-13, R-23, and R-170. It discusses system design and operation as well as lubricant considerations, citing addition of no more than 5-10% pentane to mineral oils for improved miscibility. It briefly covers water solubility, stability, compatibility, handling, charging, leak testing, and safety precautions. A series of figures in inch-pound units compare the vapor pressure and temperature relations or R-13, R-170, and R-503 as well as the compressor displacement, solubility of water, and thermal conductivity of R-13 and R-503. Two final plots show the vapor heat capacity ratio and sonic velocity of R-503.

Genetron(R) 503 Refrigerant, Thermodynamic Properties, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 1970 (6 pages with 1 figure and 1 table, RDB3A10)

This bulletin presents physical property, performance, and thermodynamic data for R-503, an azeotropic blend of R-23 and R-13 - R-23/13 (40.1/59.9). A table identifies the composition, lists key physical data including critical parameters, flammability, toxicity, color, and odor. A second table provides performance data at saturated cycle conditions of -84 °C (-120 °F) evaporating and -34 °C (-30 °F) condensing. A final table gives thermodynamic (temperature, pressure, vapor volume, liquid density, enthalpy, and entropy) at saturation conditions for -129 °C (-200 °F) to the critical temperature, 19.5 °C (67.1 °F). A pressure-enthalpy diagram is provided in inch-pound units of measure.

R-507A (R-507)

Genetron(R) AZ-50 Product Brochure, bulletin G-525-030, AlliedSignal Incorporated, Morristown, NJ, May 1995 (16 pages with 4 figures and 8 tables, RDB5546)

This bulletin supplies information on R-507A, a patented, azeotropic blend of R-125 and R-143a - R-125/143a (50/50). It was developed to replace R-502 in low- and medium-temperature

commercial refrigeration such as display cases, transport refrigeration, and ice machines. The document outlines potential applications. It provides physical property data including the chemical name and formula, appearance, molecular weight, normal boiling point, corresponding heat of vaporization and vapor density, critical parameters (temperature, pressure, specific volume, and density), and flammability. It also indicates the liquid density, vapor pressure, and the vapor and liquid heat capacity, thermal conductivity, and viscosity at 25 °C (77 °F). The bulletin then presents product specifications, performance data, a pressure-temperature table, and pressure-enthalpy (Mollier) diagrams. The bulletin suggests use of polyolester lubricants and provides a generic miscibility diagram, but indicates that compressor and lubricant manufacturers should be contacted for specific recommendations. A table summarizes the stability of R-507A with polyolester lubricants and metals (aluminum, copper, and steel). The document recommends against introduction of chlorinated materials in systems using R-507A with polyolester lubricants. It identifies potential sources and indicates that the lubricants may be incompatible with them. It also counsels against mixing R-502 and R-507A, since R-115 from the former and R-125 from the latter may form an azeotrope, making recycling and reclamation very difficult. The bulletin lists suitability indications for 29 elastomers and plastics, provides a solubility plot for water in R-507A, and offers recommendations on desiccant driers. It then reviews safety information, addressing general toxicity, inhalation effects, skin and eye contact, responses to leaks, flammability, combustibility, and thermal stability. The bulletin offers guidance for storage, handling, leak detection, retrofit, recycling, reclamation, and disposal. It also provides tabular thermodynamic properties (pressure, liquid density, vapor volume, liquid and vapor enthalpy and entropy, and latent heat of vaporization) for -30 to 70 °C (-60 to 158 °F). Formulae are presented to calculate thermodynamic properties, including vapor pressure, liquid density, and ideal gas heat capacity correlations. A Martin-Hou equation of state also is presented. The data are provided in both inch-pound (IP) and metric (SI) units. AlliedSignal's product name for R-507A is Genetron(R) AZ-50.

R-508A (R-508)

Klea 5R3 Physical Property Data Sheet, bulletin CP/10051/1Ed/33/994, ICI Klea, Runcorn, Cheshire, UK, October 1994 (6 pages with 3 tables, RDB5A09)

This bulletin provides summary property data and equations to calculate thermophysical properties for R-508A, an azeotropic blend containing R-23 and R-116 - specifically R-23/116 (39/61) - in metric (SI) units of measure. The bulletin tabulates physical properties including the atmospheric bubble and dew points, estimated critical parameters (temperature, pressure, and density), and latent heat of vaporization. It also indicates the bubble point pressure and latent heat of vaporization at -40 °C (-40 °F) and the saturated vapor density at 1 atmosphere (14.7 psia). The bulletin then presents a Martin-Hou equation of state and formulae to calculate the bubble, mid, and dew point temperatures for the saturation envelope. It also provides formulae for the latent heat of vaporization, ideal gas heat capacity, saturated liquid enthalpy, and liquid and vapor density, viscosity, and thermal conductivity. The document concludes with three tables giving calculated values for these properties at representative pressures of 100-2000 kPa (15-290 psia) and temperatures of -90 to -10 °C (-130 to 14 °F). ICI's product name for R-508A is Klea(R) 5R3.

Klea 5R3 Thermodynamic Property Data, SI Units, bulletin CP/10298/1Ed/33/1194, ICI Klea, Runcorn, Cheshire, UK, November 1994 (32 pages with 3 tables, RDB5A10)

This bulletin provides detailed thermodynamic properties for saturated and superheated R-508A, an azeotrope of R-23 and R-116 - specifically R-23/116 (39/61) - in metric (SI) units of measure. It comprises three tables, accompanied by notes on system performance with zeotropic blends and instructions to find the evaporator inlet and outlet temperatures based on expansion valve enthalpy and the evaporator pressure. The first presents saturation properties by pressure in 0.1 bar (10 kPa, 1.5 psi increments) for 100-2200 kPa (15-319 psia). The tabular data include the dew and bubble points as well as the liquid and vapor density, liquid and vapor enthalpy, and vapor entropy. The second table provides density, enthalpy, and entropy data for superheated vapor at constant pressure. The data span the range of 100-2200 kPa (15-319 psia) to temperatures as high as 98 °C (208 °F). The last table presents evaporator inlet temperatures as functions of pressure and enthalpy for 100-560 kPa (15-80 psia). ICI's product name for R-508A is Klea(R) 5R3.

Replacements for R-503: Klea(R) 5R3, bulletin TN06, ICI Klea, Wilmington, DE, undated circa 1995 (6 pages with 2 figures and 3 tables, RDB5A24)

This bulletin provides physical property and performance comparisons between R-503 and

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R-508A for very low temperature applications, such as medical storage and freeze drying. A table summarizes the compositions, boiling points and densities, latent heats of vaporization, critical parameters (temperature, pressure, and density), isentropic indices, flammabilities, and occupational exposure limits OELs) for the two azeotropes. Plots compare the vapor pressures and a set of tables contrast performance, based on simulated and experimental data. The bulletin concludes with a discussion of lubricants and materials compatibility, suggesting that R-508A generally can be used with the same materials as R-503. It notes that R-508A may be slightly less soluble than R-503, due to the lower solubility of R-116 compared to R-13, with polyalphaolefin (PAO), alkylbenzene (AB), and mineral oil (MO) lubricants. ICI's product name for R-508A is Klea(R) 5R3.

R-508B

Replacements for R-503 and R-13: Properties and Operating Characteristics of Suva(R) 95 Refrigerant, technical information bulletin ART-28 (H-60080-1), DuPont Chemicals, Wilmington, DE, April 1995 (2 pages with 2 tables, RDB5909)

This bulletin introduces R-508B, a 46:54 (by mass) blend of R-23 and R-116 previously identified as R-23/116 (46/54). It identifies potential applications as a replacement for R-13 and R-503 in very low temperature applications using cascaded compressors. The bulletin lists selected physical properties including the normal boiling point, corresponding latent heat of vaporization, critical temperature and pressure, and the saturated vapor density at -73.3 °C (-100 °F). It also indicates the ozone depletion potential (ODP) as zero, that the blend is nonflammable, and a recommended exposure limit. The bulletin outlines a performance comparison to R-13, R-23, and R-503 and provides a tabular summary of theoretical capacity, efficiency, and key operating parameters. The bulletin concludes by indicating that the components are listed both for TSCA in the United States and EINECS in Europe. DuPont's product name for R-508B is Suva(R) 95.

Thermodynamic Properties of Suva(R) 95 Refrigerant [R-508B (46/54)], technical information report T-95-ENG (H-65138), DuPont Chemicals, Wilmington, DE, October 1995 (24 pages with 2 tables, RDB5C07)

This report provides thermodynamic property data for R-508B, a 46:54 (by mass) blend of R-23 and R-116 previously identified as R-23/116 (46/54). It lists selected physical properties including molecular weight, atmospheric boiling point, and critical parameters (temperature, pressure, density, and specific volume). It then presents a Martin-Hou (MH) equation of state (EOS) and an ideal gas heat capacity equation at constant pressure. It also supplies equations to calculate the liquid enthalpy, latent enthalpy (heat of vaporization), liquid entropy, vapor pressure, and density of the saturated liquid. The report provides tabular saturation properties (liquid and vapor pressure, volume, density, enthalpy, and entropy as well as latent heat of vaporization) for -123 to 13 °C (-190 to 55 °F). A set of tables presents volume, enthalpy, and entropy data for superheated vapor at constant pressure for 7-3800 kPa (1-550 psia). Most of the summary data and property equations are presented in both in metric (SI) and inch-pound (IP) units of measure, but the detailed saturation and superheat property tables are in IP units only. DuPont's product name for R-508B is Suva(R) 95.

Other Azeotropes

G. K. Lavrenchenko, M. G. Khmelnuk, G. Ya. Ruvinskij, and S. V. Iljushenko (Institute of Energy Conversion Systems, Ukraine), **Thermodynamic Properties of a New Refrigerant: A Binary Azeotrope Based on R152a and R218**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 7, pages 461-468, September 1994 (8 pages with 3 tables and 9 figures, RDB4A07)

This article presents data on the phase equilibrium and thermal properties of a binary azeotrope of R-152a and R-218, R-218/152a, in the range of -70 to 40 °C (-94 to 104 °F) up to 2000 kPa (290 psia). Liquid-liquid coexistence curves and equilibrium isotherms, as functions of the R-218 concentration, are plotted. An equation of state, in polynomial form, and pressure-enthalpy (Mollier) diagram are presented. Saturation properties (temperature, pressure, latent heat of vaporization, and liquid and vapor density, enthalpy, and entropy) are tabulated for -50 to 70 °C (-58 to 158 °F). The paper provides detailed tabular comparisons of the efficiency and operating parameters of the blend with R-12, R-22, R-134a, and R-502. The blend is recommended as an alternative for R-12, R-22, and R-502. The authors identify it as "R-507" [a designation assigned to R-125/143a (50/50) by ANSI/ASHRAE Standard 34].

G. K. Lavrenchenko, M. G. Khmelnuk, and E. Tikhonova (Institute of Energy Conversion Systems, Ukraine), **Thermodynamical Aspects of Using Mixtures of Substances in Refrigerating**

Machines, *CFCs: The Day After* (proceedings of the IIR meeting, Padova, Italy, 1994), International Institute of Refrigeration (IIR), Paris, France, volume 9, pages 65-70, 1994 (6 pages with 2 tables, RDB-5849)

blends

P. B. Logsdon, E. A. E. Lund, I. R. Shankland, and R. R. Singh (AlliedSignal Incorporated), **Properties of a Zero ODP Azeotropic Refrigerant Blend, HFC-125/HFC-143a**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 47-54, September 1992 (10 pages with 1 figure and 7 tables, RDB2A02)

R-125/143a, thermophysical data

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M. B. Ewing, A. R. H. Goodwin, M. L. McGlashan, and J. P. M. Trusler, **Thermophysical Properties of Alkanes from Speeds of Sound Determined Using a Spherical Resonator - 2: n-Butane**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 20, pages 243-256, 1988 (14 pages, RDB5110)

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R-600a (Isobutane)

T. R. Das, O. Reed, and P. T. Eubank, **PVT Surface and Thermodynamic Properties of Isobutane**, *Journal of Chemical and Engineering Data*, volume 18, number 3, pages 253-262, 1973 (10 pages, RDB5708)

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R-717 (Ammonia)

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R. Krauss (Universität Stuttgart, Germany), **Ammoniak** [Ammonia], *VDI-Wärmeatlas* [Thermal Atlas of the Association of German Engineers], Sixth Edition, Verein Deutscher Ingenieure (VDI) Verlag, Düsseldorf, Germany, volume d, section b, pages 59-71, 1991 (RDB3937)

R-717, thermal conductivity, transport properties, thermophysical data

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J. T. R. Watson (National Engineering Laboratory, UK), **The Dynamic Viscosity of Ammonia**, paper presented to Transport Formulations Subcommittee, International Union of Pure and Applied Chemistry (IUPAC), 1983 (RDB3936)

R-717, transport properties, thermophysical data

Ammonia Data Book, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 1993 (204 pages, RDB3635)

This comprehensive reference provides information on R-717 (ammonia) and most facets of its application. It covers general information on ammonia use and production. The book provides detailed thermodynamic, transport, and application data for use of ammonia in refrigeration systems. It also covers safety data, including hazardous and common reactions, compatibility, flammability, safety classifications, identified health hazards, and exposure consequences. The reference book covers environmental cycles for natural production and destruction of ammonia, detection methods, sampling, dispersion, and effects. It also addresses regulations for transportation and use of ammonia and identifies state emergency contacts.

Ammonia Used as a Refrigerant (L'ammoniac utilisé comme frigorigène), International Institute of Refrigeration (IIR), Paris, France, 1994 (available from the IIR for $22.00 plus postage, RDB4201)

R-717, thermophysical data

R-717/718 (Ammonia/Water as Refrigerant/Absorbent)

N. C. Goomer et al, **Ammonia-Water Systems: Part I, Thermodynamic Properties**, Bhabha Atomic Research Center, Bombay, India, 1980 (RDB3235)

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P. C. Jain and G. K. Gable, **Equilibrium Property Data Equations for Aqua-Ammonia Mixtures**, paper 2180, *Transactions* (Semiannual Meeting, Philadelphia, PA, 24-28 January 1971), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 77, part 1, 1971 (RDB3233)

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D. A. Kouremenos, S. K. Kakatsios, and O. E. Floratos, **Description of the Real Gas Isentropic Changes for an Ammonia-Water Vapor Mixture**, *Acta Mechanica*, volume 116, number 1-4, pages 61-73, 1996 (13 pages, RDB6B08)

R-717/718 (ammonia-water binary mixture); calculated thermodynamic changes in the vapor phase for isentropic expansion starting at 800 °C (1472 °F) and initial pressures of 2,000, 3,000, 4,000, and 5,000 kPa (290, 435, 580, and 725 psia) with a computer program (ISENEXPR); thermodynamic relations used were obtained in terms of the Gibbs free energy equation for the gas phase of pure components; entropy was held constant; results are presented as diagrams showing the isentropic change of the gas phase mixture

R. A. Macriss, B. E. Eakin, R. T. Ellington, and J. Huebler, **Physical and Thermodynamic Properties of Ammonia-Water Mixtures**, research bulletin 34, Institute of Gas Technology (IGT), Chicago, IL, 1964 (RDB3232)

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Y. M. Park (A-Joo University, Korea) and R. E. Sonntag (University of Michigan), **Thermodynamic Properties of Ammonia-Water Mixtures: A Generalized Equation-of-State Approach**, paper 3319, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 1, 1990 (10 pages with 9 figures and 3 tables, RDB3227)

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E. P. Perlman, **Vapor Pressure of Aqueous Ammonia Solution, Part I**, *Journal of the Chemical Society*, volume 79, pages 718 ff, 1901 (RDB3228)

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S. C. G. Schulz, **Equations of State for the System Ammonia-Water for Use with Computers**, proceedings of the XIIth International Congress of Refrigeration, International Institute of Refrigeration (IIR), Paris, France, volume II, 1971 (RDB6928)

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G. Scratchard et al, **Thermodynamic Properties - Saturated Liquid and Vapor of Ammonia-Water Mixtures**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 53, pages 413 ff, 1947 (RDB3231)

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R-718, water, thermodynamic properties, thermophysical data, equation of state

J. V. Sengers and J. T. R. Watson (National Engineering Laboratory, UK), **Improved International Formulations for the Viscosity and Thermal Conductivity of Water Substance**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 15, pages 1291-1322, 1986 (RDB3939)

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R-718/LiBr (Water/Lithium Bromide as Refrigerant/Absorbent)

S. M. Jeter (Georgia Institute of Technology), J. P. Moran (CRS-Sirrine), and A. S. Teja (Georgia Institute of Technology), **Properties of Lithium Bromide/Water Solutions at High Temperatures and Concentrations - Part III: Specific**, paper 3556 (527-RP), *Transactions* (Winter Meeting, Anaheim, CA, 25-29 January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 137-149, 1992 (13 pages with 11 figures and 6 tables, RDB4435)

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98, part 1, pages 167-172, 1992 (6 pages with 5 figures and 3 tables, RDB4436)

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M. R. Patterson, R. N. Crosswhite, and H. Perez-Blanco, **A Menu-Driven Program for Determining Properties of Aqueous Lithium Bromide Solutions**, report ORNL/TM-11331, Oak Ridge National Laboratory, Oak Ridge, TN, January 1990 (38 pages with program diskette, available from NTIS, RDB1147)

This report contains a description of and user's guide for the computer program LIMENU for calculating the thermodynamic and transport properties of aqueous solutions of lithium bromide (LiBr).

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absorption, thermodynamic properties, thermophysical data

Secondary Properties of Aqueous Lithium Bromide Solutions, proposed research project 919-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0919)

This research will catalog existing property data for mixtures of water and lithium bromide. It also will evaluate the feasibility of using these properties for control applications and assess available sensor technologies for them. The project is sponsored by ASHRAE Technical Committee 8.3, *Absorption and Heat-Operated Machines*. Proposals were due at ASHRAE Headquarters by 12 January 1996. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

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R-720, neon, thermophysical data, equation of state

R-728 (Nitrogen)

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R-728, nitrogen, thermodynamic properties, thermophysical data, equation of state

K. Stephan, R. Krauss, and A. Laesecke (Universität Stuttgart, Germany), **Viscosity and Thermal Conductivity of Nitrogen for a Wide Range of Fluid States**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 16, number 4, pages 993-1023, 1987 (11 pages, RDB5532)

R-728, thermophysical properties, transport data

R-729 (Air)

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R-728, R-729, R-732, R-740, air, thermodynamic properties, thermophysical data, equation of state

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R-744, transport properties, thermophysical data, viscosity, thermal conductivity

R-764 (Sulfur Dioxide)

L. S. Philipp and B. E. Tiffany, **Thermodynamics of Sulfur-Dioxide-Oil Systems**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 27, pages 248 ff, May 1934 (RDB3736)

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R-7146 (sulfur hexafluoride)

J. A. Brown, **Sulfur Hexafluoride**, *Kirk-Othmer Encyclopedia of Chemical Technology* (Second Edition), John Wiley and Sons, Incorporated, New York, volume 9, pages 664 ff, 1966 (RDB5A37)

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W. H. Mears, E. Rosenthal, and J. V. Sinka (Allied-Signal Incorporated, then Allied Chemical Corporation), **Physical Properties and Virial Coefficients of Sulfur Hexafluoride**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 73, pages 2254 ff, 1969 (RDB5A38)

R-7146, physical and thermodynamic properties, thermophysical data

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R-1113, properties, application, handling and storage

R-1150 (Ethene)

R. D. McCarty and R. T. Jacobsen, **An Equation of State for Fluid Ethylene**, Technical Note 1045,

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National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, July 1981 (available from GPO, RDB3957)

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R-1270 (Propene)

S. Angus, B. Armstrong, and K. M. de Reuck, **International Thermodynamic Tables of the Fluid State - 7: Propylene**, International Union of Pure and Applied Chemistry (IUPAC), Pergammon Press, Oxford, UK, 1980 (RDB3958)

R-1270, propene, thermodynamic properties

Ethers

D. R. Defibaugh, K. A. Gillis, M. R. Moldover, G. Morrison, and J. W. Schmidt (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of CHF_2-O-CHF_2, Bis(difluoromethyl) Ether**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 81, pages 285-305, 1992 (21 pages, RDB-3327)

This paper reports on measurements and data reduction to provide thermodynamic property data for E-134, a candidate alternative refrigerant. It summarizes measurements of the refractive index of the saturated liquid and vapor as well as the speed of sound of the dilute vapor. These measurements provide the normal boiling point, critical parameters (temperature, pressure, and density), and ideal gas heat capacity. Vapor pressure measurements using a high-pressure ebulliometer are tabulated; the apparatus is depicted in a figure. Refractive index, speed-of-sound, results of acoustic isotherms, liquid density, and saturation data are tabulated; deviations with other measurements and data fits are plotted. Coefficients of a Carnahan-Starling-DeSantis (CSD) equation of state and a polynomial representation of the ideal gas heat capacity are derived and presented. The paper notes that samples of E-134 with impurities were found to be unstable during laboratory measurements. It also notes that an azeotrope of E-134 and R-143a was discovered during the investigation. Samples of E-134 were found to be soluble in several elastomers used in the measurement apparatus.

M. Salvi-Narkhede, J. L. Adcock, A. Gakh, and W. A. Van Hook (University of Tennessee), **Vapor Pressures, Liquid Molar Volumes, Vapor Non-Ideality, and Critical Properties of $CF_3OCF_2CF_2$-CF_3, c-$CF_2CF_2CF_2CF_2O$, $CF_3OCF_2OCF_3$, CF_3O-CF_2CF_2H**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 25, pages 643-647, 1993 (RDB4445)

$CF_3CF_2CF_2OCF_3$, R-CE318 (c-$CF_2CF_2CF_2O$-CF_2), R-E218ca12 ($CF_3OCF_2OCF_3$), R-E227ca2 ($CHF_2CF_2OCF_3$), thermodynamic properties, thermophysical data

M. Salvi-Narkhede, B-H. Wang, J. L. Adcock, and W. A. Van Hook (University of Tennessee), **Vapor Pressures, Liquid Molar Volumes, Vapor Non-Ideality, and Critical Properties of Some Partially Fluorinated Ethers ($CF_3OCF_2CF_2H$, CF_3OCF_2H, and CF_3OCH_3), Some Perfluoroethers (CF_3O-CF_2OCF_3, c-$CF_2OCF_2OCF_2$, and c-$CF_2CF_2CF_2$-O), and of CHF_2Br and CF_3CHFCF_3**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 24, pages 1065-1075, 1992 (RDB3728)

R-22B1, R-227ea, R-E125, R-E143a, R-E218ca, R-E227ca2, thermodynamic properties, thermophysical data

N. D. Smith, **Thermophysical Properties of HFE-125**, Environmental Research Brief EPA-600/S-93-001, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, February 1993 (4 pages with 4 tables, available from JMC as RDB-3404)

This synopsis summarizes properties of E-125 (pentafluorodimethyl ether), a potential alternative refrigerant for low-temperature applications. Tables, in both inch-pound (IP) and metric (SI) units provide the freezing and boiling points, critical properties, heat of vaporization, and liquid specific heat capacity. Measured liquid densities are given at eight temperatures from 10-61 °C (50-142 °F) and vapor pressures for -104 to 81 °C (-156 to 177 °F). Calculated liquid and vapor density as well as heat of vaporization are tabulated for -55 to 81 °C (-66 to 177 °F) and the equations used are provided. The methods used and estimated accuracy are indicated.

B-H. Wang, J. L. Adcock, S. B. Mathur, and W. A. Van Hook (University of Tennessee), **Vapor Pressures, Liquid Molar Volumes, Vapor Non-Idealities, and Critical Properties of Some Fluorinated Ethers: $CF_3OCF_2OCF_3$, $CF_3OCF_2CF_2H$, c-CF_2-CF_2CF_2O, CF_3OCF_2H, and CF_3OCH_3; and of CCl_3F and CF_2ClH**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 23, pages 699-710, December 1991 (12 pages with 8 tables, RDB2505)

Vapor pressures, compressibilities, expansivities, and molar volumes of the liquid phase are presented, based on measurements between room temperature and the critical temperature, for a series of fluorinated ethers. Critical temperatures and pressures and approximate melting and boiling temperatures are tabulated for R-E218ea12 (perfluorodimethoxymethane), R-E227ca2 (2-hydryl-F-ethyl F-methyl ether), R-CE216 (F-oxetane), and R-E125 (pentafluorodimethyl ether). These ethers are under investigation as potential refrigerants, blowing agents, and cleaning agents based on their physical and chemical similarity to present refrigerants. Equations are presented for determination of these properties. Vapor-phase nonidealities were measured for each compound, but only for samples of high vapor density. Apparatus calibrations were verified with measurements for R-11 and R-22.

General and Multiple Fluids

R. Afshar and S. C. Saxena, **Transport Properties of Freon 152a and Freon 142b in the Temperature Range of 280-510 K**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 1, pages 51-59, 1980 (9 pages, RDB4A37)

R-142b, R-152a, thermophysical data

V. V. Altunin and V. Z. Geller, **Thermophysical Properties of Freons**, Hemisphere Publishing Company, New York, NY, 1977 (RDB6328)

thermodynamic and transport data, refrigerants

M. A. Anisimov, E. E. Gorodetskii, V. D. Kulikov, A. A. Povodyrev, and J. V. Sengers (University of Maryland), **A General Isomorphism Approach to Thermodynamic and Transport Properties of Binary Fluid Mixtures Near Critical Points**, *Physica A*, Elsevier Science B.V., Amsterdam, The Netherlands, volume 220, pages 277-324, 1995, plus erratum, volume 223, page 272, 1996 (49 pages with 4 figures, RDB6407)

equation of state, critical point

D. Arnaud, L. Niveau, and S. Wosinski (Atochem Groupe Elf Aquitaine), **Comparison of Thermophysical Properties of HFC 125, 32, and 143a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 375-383, July 1992 (9 pages with 4 figures and 4 tables, available from JMC as RDB2820)

This paper provides property data for R-32, R-125, and R-143a. These data are provided to predict the properties of their mixtures as replacements for R-502, an azeotrope containing R-22 and R-115. Critical properties, solubility, flammability, ozone depletion potential (ODP), and global warming potential (GWP) are compared for the three hydrofluorocarbons (HFCs) to those of R-502. Transport properties, including thermal conductivity, viscosity, surface tension, and specific heat are similarly compared. Tabular data are provided for compatibility with polychloroprene (neoprene), nitrile butyl rubber (NBR), and polyethylene chlorosulfone (DuPont Hypalon(R)) elastomers. Miscibility also is compared for R-502 and the three HFCs with unidentified naphthenic mineral oil and neopentyl polyester and alkylbenzene lubricants in 80% and 5% lubricant concentrations. A series of plots provide the vapor pressure, saturated liquid density, liquid viscosity, and liquid thermal conductivity for -60 to 60 °C (-76 to 140 °F). The paper reviews the design changes required, but concludes that only few adaptations will be needed for either retrofit or new uses of these fluids.

D. Arnaud and J. C. Tanguy (Atochem Groupe Elf Aquitaine), **Propriétés Thermophysiques des Réfrigérants R 124 et R 134a** [Thermophysical Properties of Refrigerants R-124 and R-134a], *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, pages 159-166, 1987 (8 pages, RDB5534)

R-124, R-134a, thermophysical data

A. G. Asambaev, **The Heat Conduction of the Liquid and Gas Refrigerants and Their Solutions - Alternatives of Chlorofluorocarbons**, PhD dissertation, LTIHP, Russia, 1992 (RDB5447)

R-123, R-125, R-134a, transport properties, thermophysical data, thermal conductivity

M. J. Assael and E. Karagiannidis, **Measurements of the Thermal Conductivity of R22, R123, and R134a in the Temperature Range 250-340 K at Pressures up to 30 MPa**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 14, pages 183-197, 1993 (15 pages, RDB4968)

R-22, R-123, R-134a, thermodynamic properties, thermophysical data

H. D. Baehr and R. Tillner-Roth (Universität Hannover, Germany), **Thermodynamische Eigenschaften umveltvertraglicher Kältemittel: Zustandsgleichungen und Tafeln für Ammoniak, R 22, R**

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thermodynamic properties, thermophysical data

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D. B. Bivens and A. Yokozeki (DuPont Fluoroproducts), **Heat Transfer Coefficients and Transport Properties for Alternative Refrigerants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J.

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R-22, R-404A, R-32/125 (60/40), R-32/125/134a (30/10/60), R-32/134a, R-502, thermophysical data

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H. B. Chae, J. W. Schmidt, and M. R. Moldover (National Institute of Standards and Technology, NIST), **Surface Tension of Refrigerants R-123 and R-134a**, *Journal of Chemical and Engineering Data*, American Chemical Society (ACS), Columbus, OH, volume 35, number 1, pages 6-8, January 1990 (3 pages with 2 figures and 3 tables, available from JMC as RDB0917)

The surface tensions of two environmentally acceptable refrigerants (R-123 and R-134a) were measured with a differential capillary rise technique. Measurements span the temperature range -25 to 140 °C (-13 to 284 °F) for R-123 and -10 to 95 °C (14 to 203 °F) for R-134a.

H. B. Chae, J. W. Schmidt, and M. R. Moldover (National Institute of Standards and Technology, NIST), **Alternative Refrigerants R-123a, R-134, R-141b, R-142b, and R-152a: Critical Temperature, Refractive Index, Surface Tension, and Estimates of Liquid, Vapor, and Critical Densities**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 94, number 25, pages 8840-8845, 13 December 1990 (6 pages with 6 figures and 4 tables, RDB0918)

Differential capillary rise and refractive index data are reported for five alternative refrigerants: R-123a, R-134, R-141b, R-142b, and R-152a. This paper explains the selection of these fluids, describes the apparatus and analytical methods, and compares the findings with published reports by others. The data extend from approximately 25 °C (77 °F) to the critical point of each fluid and directly yield the critical temperature T_c and the temperature-dependent capillary length. The present data were combined with liquid density data (near ambient temperature) to determine the Lorentz-Lorenz constant. The Lorentz-Lorenz relation is used to estimate the liquid, vapor, and critical densities, and the surface tension. R-141b slowly decomposed when maintained near its critical point (in contact with gold, sapphire, stainless steel, and crown glass).

C. Y. Chan and G. G. Haselden (University of Leeds, UK), **Computer-Based Refrigerant Thermodynamic Properties, Part I: Basic Equations**, *International Journal of Refrigeration* (IJR), Paris, France, volume 4, number 1, pages 7-12, January 1981 (6 pages, RDB5459)

S. S. Chen, A. S. Rodgers, J. Chao, R. C. Wilhoit, and B. J. Zwolinski, **Ideal Gas Thermodynamic Properties of Six Fluoroethanes**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 4, pages 441-456, 1975 (16 pages, RDB4241)

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S. Corr, J. D. Morrison, and F. T. Murphy (ICI Chemicals and Polymers, Limited, UK), **An Evaluation of the Effects of Lubricants on the Thermodynamic Properties and Performance of Refrigerant Mixtures in Refrigeration and Air Conditioning Cycles**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 119-124, July 1996 (6 pages with 11 figures, RDB6821)

thermodynamic model based on the Wilson-MHV-2 methodology; property prediction for tetrary blends of R-32, R-125, R-134a, and a mixed-acid polyolester (POE) lubricant; vapor-liquid equilibrium (VLE) behavior of refrigerant-lubricant mixtures; the effects of the oil are ex-

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pected to be small, but may increase for those points in the cycle that are close to the dew point line of the oil-free refrigerant

F. de Rossi, R. Mastrullo, S. Sibilio (Università di Napoli "Frederico II", Italy), P. Mazzei, and M. Sasso (Università degli Studi di Salerno, Italy), **EASY: Exergetic Analysis of SYstems - Interactive Computer Code for Refrigerants Thermodynamic Properties Evaluation and Exergetic Analysis of Vapor Compression Systems**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 95-101, 1990 (7 pages with 8 figures, RDB5630)

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R-13B1, R-114, thermodynamic properties, thermophysical data

F. de Rossi, O. Manca, R. Mastrullo (Università di Napoli "Frederico II", Italy), and P. Mazzei (Università degli Studi di Salerno, Italy), **Exergy-Enthalpy Diagrams of R502 and R503 and their Application**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, 1988 (RDB5634)

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D. E. Diller, A. S. Aragon, and A. Laesecke (National Institute of Standards and Technology, NIST), **Measurements of the Viscosities of Saturated and Compressed Liquid 1-1-1,2-tetrafluoroethane (R-134a), 2,2-dichloro-1,1,1-trifluoroethane (R-123), and 1,1-dichloro-1-fluoroethane (R-141b)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 88, pages 251-262, 1993 (12 pages, RDB3922)

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This paper presents a sensitivity study of a vapor-compression cycle in the form of a heat pump operating in the cooling mode. The study was performed with the aid of a detailed simulation model; runs were made for different parametric values and the capacity and power input were compared with results of a run using an unchanged value of the parameters. The effects on evaporator and condenser pressures, and refrigerant mass flow rate are given. The independent variables include thermodynamic and transport properties, as well as the refrigerant flow, heat transfer, and pressure drop coefficients. The parameters which had the most effect on system performance were liquid transport properties, evaporative heat transfer coefficient, and vapor density.

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R. Döring (Fachhochschule Münster, Germany) and H. Buchwald (Kali-Chemie AG, Germany), **Experimentelle und theoretische Untersuchungen der Kältemittel R 134a (CH_2F-CF_3) und R 123 ($CHCl_2$-CF_3)** [Experimental and Theoretical Investigations of Refrigerants R-134a (CH_2FCF_3) and R-123 (CHCl2CF3)], *Ki Klima-Kälte-Heizung*, Verlag C. F. Müller, Karlsruhe, Germany, volume 18, number 3, pages 108-112, 1990 (5 pages with 7 figures and 7 tables, in German, RDB5220)

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R. Döring (Fachhochschule Münster, Germany) and H. Buchwald (Kali-Chemie AG, Germany), **Thermodynamische Eigenschaften der Kältemittel R 134a (CH_2F-CF_3) und R 123 ($CHCl_2$-CF_3)** [Thermodynamic Properties of Refrigerants R-134a (CH_2FCF_3) and R-123 (CHCl2CF3)], *Bericht über die Kälte-Klima-Tagung* [Proceedings of the Refrigeration and Air-Conditioning Conference] (Hannover, Germany, 22 November 1989), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 16, pages 225-246, 1989 (24 pages with 8 figures and 4 tables, in German, RDB5221)

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G. Ernst and J. Busser, **Ideal and Real Gas State Heat Capacities C_p of C_3H_8 and i-C_4H_{10}**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 6, pages 1027-1037, 1994 (11 pages, RDB5709)

R-290 (propane), R-600a (isobutane), thermodynamic properties, thermophysical data

B. R. Fellows, R. G. Richard, and I. R. Shankland (AlliedSignal Incorporated), **Electrical Characterization of Alternate Refrigerants**, paper 45, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 398-402, August 1991 (5 pages with 2 figures and 7 tables, 10 page reprint available from JMC as RDB2319)

R-11, R-12, R-22, R-32, R-114, R-115, R-123, R-123a, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-C318, R-502, R-7146; breakdown voltage, dielectric and resistivity data

S. K. Fischer and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Thermodynamic Calculations for Mixtures of Environmentally Safe Refrigerants Using the Lee-Kesler-Plöcker Equation of State**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 373-382, July 1990 (10 pages with 6 figures and 2 tables, available from JMC as RDB3910)

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D. G. Friend, M. L. Huber, and J. S. Gallagher (National Institute of Standards and Technology, NIST), **Thermophysical Property Computer Packages from NIST**, *Computerized Thermophysical Property Packages*, publication HTD-Vol. 225, American Society of Mechanical Engineers (ASME), New York, NY, pages 13-18, 1992 (6 pages with 11 tables, available from JMC as RDB-3713)

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M. Fukushima, **Saturated Liquid Densities of HCFC-123, HFC-134a, CFC-11, and CFC-12**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 8, number 1, pages 65-75, 1991 (11 pages, in Japanese, RDB4B49)

R-11, R-12, R-123, R-134a, thermodynamic properties, thermophysical data

M. Fukushima, **Measurements of the PVT Properties of HCFC-123 and HFC-134a**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 7, number 3, pages 243-256, 1990 (14 pages, in Japanese, RDB-4B50)

R-123, R-134a, thermodynamic properties, thermophysical data

M. Fukushima, N. Watanabe, and T. Kamimura, **Measurements of the Vapor-Liquid Coexistence Curves and the Critical Parameters of HCFC-123 and HFC-134a**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 7, number 2, pages 85-89, 1990 (5 pages, in Japanese, RDB4B51)

R-123, R-134a, thermodynamic properties, thermophysical data

C. L. Gage, **Equation-of-State Parameters for Potential CFC and HCFC Replacements**, Environmental Research Brief EPA-600/S-93-003, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, February 1993 (2 pages with 2 tables, available from JMC as RDB3406)

This summary presents coefficients to calculate thermodynamic properties for 11 potential alternative refrigerants. These data are provided for use with for the Carnahan-Starling-DeSantis equation of state. The summary also presents coefficients for a quadratic equation for the ideal gas heat capacity. The chemicals include nine hydrofluorocarbons (HFCs), namely R-227ca, R-227ea, R-236cb, R-236ea, R-236fa, R-245ca, R-245cb, R-245fa, and R-254cb. They also include two ethers, E-125 and E-143a.

J. S. Gallagher, M. O. McLinden, G. Morrison, and M. L. Huber, **NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)**, Standard Reference Database 23 version 4.0, National Institute of Standards and Technology (NIST), Gaithersburg, MD, November 1993 (software and 82 page documentation available from NIST for $465.00 or $100.00 to upgrade from previous versions, RDB4101)

Version 4.00 of REFPROP calculates properties for 38 pure refrigerants as well mixtures of up to five of them. Measured interaction parameters are provided 65 mixture pairs along with a method to estimate interaction parameters for others from a correlation. Highly accurate, multiparameter equations of state are available for 12 of the pure fluids; others are calculated using a modified Carnahan-Starling-DeSantis (CSD) equation of state. The refrigerants include R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-123a, R-124, R-125, R-134, R-134a, R-E134, R-141b, R-142b, R-143, R-143a, R-152a, R-218, R-227ea, R-236ea, R-245cb, R-E245 (incorrectly indicated as R-E224 in the documentation), R-C270 (cyclopropane), R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-744 (carbon dioxide), R-717 (ammonia), n-pentane, and isopentane. Fourteen thermodynamic properties can be calculated, in user-selected units of measurement, including temperature, pressure, density, specific volume, speed of sound, specific heats at constant volume and pressure, viscosity, and thermal conductivity. REFPROP also provides information on pure fluids, including the ASHRAE Standard 34 designation (*R number*), chemical formula and name, Chemical Abstract Service registry number, molecular mass, triple-point temperature if applicable, normal boiling point temperature, critical temperature and pressure, polarizability and dipole moment if measured, and estimated surface tension values at representative temperatures. This update replaces version 3.0 (see RDB2430).

J. S. Gallagher, M. O. McLinden, and G. Morrison (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **Thermodynamic Diagrams for Refrigerant Mixtures**, paper OT-88-20-5, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, pages 2119-2136, 1988 (18 pages, RDB5114)

zeotropic blends, properties

F. W. Gatecliff and E. R. Lady, **Explicit Representation of the Thermodynamic Properties of Re-**

frigerants 12 and 22 in the Superheat Region, *Proceedings of the 1974 Purdue Compressor Technology Conference*, Purdue University, West Lafayette, IN, pages 187-190, July 1974 (RDB6908)

R-12, R-22, thermodynamic properties, thermophysical data

V. Z. Geller, M. E. Paulaitis (University of Delaware), D. B. Bivens, and A. Yokozeki (DuPont Fluoroproducts), **Transport Properties of Some Alternative Refrigerants,** *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 227-234, 1993 (8 pages with 1 figure and 2 tables, RDB4A47)

This paper presents tabular data for the thermal conductivity and viscosity of R-23 for -103 to 147 °C (-154 to 296 °F) and pressures of 100 kPa to 20 MPa (14.5-2900 psi). It also presents correlations for thermal conductivity and viscosity of R-22, R-23, R-32, R-134a, R-143a, and R-152a. These estimation methods cover dilute gases, saturated liquids and vapors, and liquids and vapors well removed from saturation conditions. The paper comments on the status of thermophysical and specifically transport property data. It notes that data for R-134a published in other studies differ by more than 20% and that estimates of viscosity by the most reliable methods may deviate from measured data by up to 50%. The paper summarizes the experimental methods used, which were based on a modified hot-wire apparatus for thermal conductivity and a modified capillary-tube method for viscosity measurements. A plot shows the correlation between reduced dilute gas velocity and reduced temperature for R-22, R-23, R-32, R-134a, R-143a, and R-152a, to substantiate that deviations in the new experimental data from a regression curve do not exceed 1.5%.

V. Z. Geller, E. G. Porichanskii, P. I. Svetlichnyi, and Y. G. Elkin, **Density of Some Liquid Freons on the Saturation Line,** *Kolloidnyi Tekhnika*, volume 2, pages 42-44, 1980 (3 pages, in Russian, RDB4A48)

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V. Z. Geller, **Viscosity of Freon 21, Freon 22, and Freon 23,** *Kolloidnyi Tekhnika*, volume 22, pages 41-45, 1976 (5 pages, in Russian, RDB4A49)

R-21, R-22, R-23, thermodynamic properties, thermophysical data

V. Z. Geller and V. G. Peredrii, **Thermal Conductivity of Freon 13 and Freon 23,** *Izvestiya Vysshikh Uchebnykh Zavedenii Energetika*, volume 18, pages 113-116, 1975 (5 pages, in Russian, RDB4A50)

R-13, R-23, thermophysical properties, data

V. Z. Geller, **Thermophysical Properties of Working Fluids for Refrigerants,** Publ. High Education, Ukraine, Russia, 1986 (RDB6329)

thermodynamic and transport data, refrigerants

K. D. Gerdsmeyer and H. Kruse (Universität Hannover, Germany), **Comparison of Equations of State for Application to Nonazeotropic Refrigerant Mixtures,** *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, pages 53-62, July 1988 (10 pages with 10 figures, RDB4405)

thermodynamic properties

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R-22, R-134a, thermodynamic properties, thermophysical data

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R-113a, R-152, R-113, R-E245, thermophysical properties, data

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R-123, R-123a, thermophysical properties, data

D. T. Gordon, J. F. Hamilton, and W. E. Fontaine, **An Empirical Equation for Predicting the Vis-**

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R-134a, transport properties, thermophysical data, thermal conductivity

J. J. Grebner and R. R. Crawford, **The Effects of Oil on the Thermodynamic Properties of Dichlorodifluoromethane (R12) and Tetrafluoroethane (R134a)**, report TR-13, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, February 1992 (113 pages, RDB4B73)

R-12, R-134a

U. Groß, Y. W. Song, and E. Hahne (Universität Stuttgart, Germany), **Thermal Conductivity of the New Refrigerants R134a, R152a, and R123 Measured by the Transient Hot-Wire Method**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 13, pages 957-983, 1992 (27 pages, RDB4A46)

R-123, R-134a, R-152a, thermodynamic properties, thermophysical data

U. Groß, Y. W. Song, J. Kallweit, and E. Hahne (Universität Stuttgart, Germany), **Thermal Conductivity of Saturated R-123 and R-134a, Transient Hot Wire Measurements**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 103-108, 1990 (6 pages with 5 figures and 3 tables, RDB3921)

transport properties, thermophysical data

V. A. Gruzdev and A. I. Shumskaya, **Experimental Investigation of Isobaric Specific Heats of Vapors of Freons: F-11, F-12, F-13, F-21, F-22, and F-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 8, pages 108-129, 1975 (22 pages, in Russian, RDB4A59)

R-11, R-12, R-13, R-21, R-22, R-23, thermodynamic properties, thermophysical data

B. V. Gunchuk, V. P. Zheleznyi, I. A. Zhosul, L. Y. Lyasota, M. D. Potapov, and V. P. Eizenbeis, **Study of the Density, Viscosity, Thermal Conductivity, and Surface Tension of Coolants R116, R132B2, R318, and R329 as well as Azeotropic Mixtures of R23 + R116 and R116 + R13 at the Boiling Line**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 28, pages 99-118, 1989 (in Russian, RDB6813)

R-116, R-132B2, R-C318, R-329, R-23/116, R-13/116, thermodynamic and transport properties, thermophysical data

X. Guozhen, W. Yezheng, D. Kunxuan, and C. Zhong (Xi'an Jiaotong University, China), **The Relations Used to Analyze the Phase Equilibrium Properties of Binary Refrigerant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 425-432, July 1992 (8 pages with 2 figures and 4 tables, RDB2825)

E. Hahne and Y. W. Song (Universität Stuttgart, Germany), **Messung der Wärmeleitfähigkeit von R115 bei hohen Drücken mit der Heißdraht-Methode** [Measurements of the Thermal Conductivity of R-115 at High Pressures by the Transient Hot-Wire Method, *Wärme- und Stoffübertragung*, Germany, volume 24, pages 79-85, 1989 (7 pages, in German, RDB5642)

thermodynamic properties, thermophysical data

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of HCFC Alternatives**, report DOE/CE/23810-66A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1996 (36 pages with 4 figures and 4 tables, available from JMC as RDB6603)

This interim report summarizes progress in measuring primary thermodynamic data for seven binary and one ternary blends as potential replacements for R-22 or R-502. They include R-32/125/134a, R-32/143a, R-32/290, R-125/134a, R-125/143a, R-125/290, R-143a/-134a, and R-290/134a. Measurements also are being made for R-41 and R-41/744 as potential replacements for R-13. The work consists of simultaneous measurements of the coexisting liquid and vapor densities, compositions, and bubble point pressures over a wide range of temperatures and compositions. These data will be used to determine the mixing parameters, including any temperature and/or composition dependence, for the Carnahan-Starling-DeSantis (CSD) equation of state and an extended cor-

responding states (ECS) model. The R-41 measurements will address vapor pressure; liquid density; liquid, two-phase, and ideal gas heat capacities; vapor sound speed and virial coefficients; and the critical point parameters. The report describes completion of a new vapor-liquid-equilibrium (VLE) apparatus as well a measurement of coexisting densities, bubble point pressures, and liquid and vapor compositions of R-32/134a and R-32/125/134a. It also summarizes isochoric pressure-volume-temperature (PVT) and vapor pressure measurements for R-41 along with development of a new spherical resonator for sound speed measurements. Finally, it describes initiation of isochoric PVT measurements of R-41/744 and VLE and coexisting density measurements of R-32/125. Figures compare the new data and those published in prior, independent studies to calculated data from the ECS model in REFPROP for R-32/134a and R-32/125/134a. Another shows the locus of measurements for R-41. Tables present the compressed gas and liquid-phase PVT data for R-41, in metric (SI) and inch-pound (IP) units of measure. Two final tables present the vapor pressure measurements for the same refrigerant.

W. M. Haynes (National Institute of Standards and Technology, NIST), **Thermophysical Properties of HFC-143a and HFC-152a**, report DOE/CE/23810-39, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1994 (190 pages with including 27 figures and 47 tables, available from JMC as RDB4B09)

This report presents raw and smoothed data for the thermophysical properties of R-143a and R-152a. It also provides modified Benedict-Webb-Rubin (MBWR) equations of state and transport property models. The objective of the study was to fill gaps in current data and resolve problems and uncertainties that exist in and between such data. The report summarizes the measurement methods used and estimated precision. The apparatus included a Burnett apparatus for pressure-volume-temperature (PVT) relations; an isochoric apparatus for liquid density; an ebulliometer and Burnett apparatus for vapor pressure; an optical cell for refractive index, capillary rise, and indirectly the critical density; a cylindrical acoustic resonator for speed of sound; an adiabatic calorimeter for molar heat capacity; low- and high-temperature transient hot-wire instruments for thermal conductivity; a torsionally oscillating quartz crystal viscometer for shear viscosity; and a capillary viscometer for liquid viscosity. The ranges of measurements, representative data, and deviations from the MBWR equation and ancillary equations for vapor pressure and saturated liquid and vapor densities are plotted. An appendix presents the extensive measured data in a series of tables along with the equations of state, critical parameters, ideal gas heat capacity equations, and derived thermodynamic properties for both R-143a and R-152a. Except for the equations and critical parameters, all of the data are provided in both metric (SI) and inch-pound (IP) units. Derived tables give the pressure, liquid density, vapor specific volume, specific heat ratio for the vapor, and liquid and vapor enthalpy, entropy, specific heat, and velocity of sound from the triple to the critical points at 10 °C and 20 °F intervals. Equations and tabular data also are provided for thermal conductivity and viscosity. A second appendix describes a correlation technique used with the transient hot wire measurements.

R. Heide and H. Lippold, **Thermophysical Properties of the Refrigerants R 134a and R 152a**, *Progress in the Science and Technology of Refrigeration in Food Engineering* (proceedings of the IIR Conference, Dresden, Germany, 1990), International Institute of Refrigeration (IIR), Paris, France, pages 237-240, 1990 (4 pages, RDB5487)

R-134a, R-152a, thermophysical data

R. Heide, **Concerning the Viscosities of Liquid Refrigerants and Mixtures of Refrigerants**, *Luft- und Kältetechnik*, Germany, volume 16, number 1, pages 7-10, 1981 (4 pages, in German, RDB4611)

transport properties, thermophysical data

R. Heide (Technische Universität Dresden, Germany), **Die Oberflächenspannung von Halogenkältemitteln** [The Surface Tension of Halogenated Refrigerants], *Luft- und Kältetechnik*, Germany, volume 9, number 3, pages 125-127, 1973 (3 pages, in German, RDB4A61)

transport properties, thermophysical data

Y. Higashi (Iwaki Meisei University, Japan), **Critical Parameters for HFC-134a, HFC-32 and HFC-125**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 167-174, 1993 (8 pages with 5 figures and 2 tables, RDB5313)

R-32, R-125, R-134a

Y. Higashi (Iwaki Meisei University, Japan) and M. Okada (Tsukuba College of Technology, Japan), **Measurement of the Surface Tension for CFC Alternatives**, paper 83, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages

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675-679, August 1991 (5 pages with 12 figures and 2 tables, RDB4B22)

R-123, R-134a, R-142b, R-152a, R-225ca, R-225cb, surface tension, transport properties, thermophysical data

C. D. Holcomb, V. G. Niesen, L. J. van Poolen, and S. L. Outcalt (National Institute of Standards and Technology, NIST), **Coexisting Densities, Vapor Pressures, and Critical Densities of Refrigerants R-32 and R-152a at 300 to 385 K**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1993 (RDB4A44)

thermodynamic properties, thermophysical data

J. C. Holste (Texas A&M University), **Thermodynamic Properties of Refrigerants R-125 and R-141b**, final report for 654-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1993 (RDB4A54)

PVT, thermophysical data

L. H. Horsley, **Azeotropic Data** (revision), report 116, *Advances in Chemistry*, American Chemical Society, Washington, DC, 1973 (RDB5558)

M. L. Huber (National Institute of Standards and Technology, NIST) and J. F. Ely (Colorado School of Mines), **Prediction of Viscosity of Refrigerants and Refrigerant Mixtures**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 239-248, 1992 (10 pages with 4 figures and 2 tables, available from JMC as RDB3706)

transport properties; thermophysical data; extended corresponding states (ECS) model using a Benedict-Webb-Rubin (BWR) equation for R-134a, as a reference fluid; coefficients for R-11, R-12, R-13, R-22, R-23, R-113, R-114, R-115, R-123, R-141b, and R-152a

M. L. Huber (National Institute of Standards and Technology, NIST) and J. F. Ely (Colorado School of Mines), **Prediction of Thermal Conductivity of Refrigerants and Refrigerant Mixtures**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 249-261, 1992 (13 pages with 3 figures and 2 tables, available from JMC as RDB3707)

thermophysical data; extended corresponding states (ECS) model using a Benedict-Webb-Rubin (BWR) equation for R-134a, as a reference fluid

D. W. Hughes, J. T. McMullan, and R. Morgan (New University of Ulster, Northern Ireland, UK), **Determination of the Thermodynamic Properties of Refrigerant-Oil Mixtures**, *Proceedings of the 1982 Purdue Compressor Conference*, Purdue University, West Lafayette, IN, pages 214-221, July 1982 (8 pages with 7 figures, RDB3323)

thermophysical data

Y-T. Hwang, **The constant volume Heat Capacities of Gaseous Tetrafluoromethane, Chlorofluoromethane, Dichlorotetrafluoroethane, and Chloropentafluoroethane**, PhD dissertation, University of Michigan, Ann Arbor, MI, 1961 (RDB6809)

R-14, R-31, R-114, R-114a, R-115, thermodynamic properties, thermophysical data

P. Jany and J. Straub (Technische Universität München, Germany), **Thermal Diffusivity of Fluids in a Broad Region Around the Critical Point**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 8, pages 165-180, 1987 (16 pages, RDB5627)

transport properties, thermophysical data

P. Jany and J. Straub (Technische Universität München, Germany), **Thermal Diffusivity of Five Pure Fluids**, *Chemical Engineering Communications*, volume 57, pages 67-76, 1987 (RDB5626)

transport properties, thermophysical data

P. Jany, **Die Temperaturleitfähigkeit reiner Fluide im weiten Zustandsbereich um den kritischen Punkt** [Thermal Diffusivity of Pure Fluids in a Broad Region Around the Critical Point], thesis, Technische Universität München, Germany, 1986 (RDB5625)

transport properties, thermophysical data

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction of Thermophysical Properties of CFC-Free Refrigerants**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 199-206, 1993 (8 pages with 6 tables, RDB5317)

R-32, R-124, R-134a, thermodynamic data, specific volume, enthalpy, entropy

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction and Evaluation of the Thermophysical Properties of Monomethylamine and Dimethylamine**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 123-127, 1990 (5 pages, RDB5453)

R-630 (methylamine), dimethylamine, thermodynamic data, specific volume, enthalpy, entropy

M. Jelinek, N. C. Daltrophe, and I. Borde (Ben-Gurion University of the Negev, Israel), **Prediction of Thermophysical Properties on Few Alternative CFC-Free Refrigerants**, *Proceedings of the 24th Israel Conference on Mechanical Engineering*, pages 3.1.1-1 - 3.1.1-3, May 1992 (3 pages, RDB-5454)

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D. Jung and R. K. Radermacher (University of Maryland), **Transport Properties and Surface Tension of Pure and Mixed Refrigerants**, paper 3445, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, pages 90-99, 1991 (RDB3B48)

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D. Jung (University of Maryland) and D. A. Didion (National Institute of Standards and Technology, NIST), **Mixing Rule for Liquid Viscosities of Refrigerant Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 13, number 6, pages 243-247, July 1990 (5 pages with 2 figures and 2 tables, RDB6409)

R-500, R-502, R-503, R-504, R-506, R-32/12 (87/13), R-115/152a (69/31), mixing rules, Hildebrand's correlation, Grunberg and Nissan's correlation

C. Z. Kamien and O. W. Witzell, **Effects of Pressure and Viscosity of Refrigerants in the Vapor Phase**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 65, pages 663-674, 1959 (12 pages, RDB4A56)

thermophysical data

A. Kamei, C-C. Piao, H. Sato, and K. Watanabe (Keio University, Japan), **Thermodynamic Charts and Cycle Performance of [H]FC-134a and [H]FC-152a**, paper 3318, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990) American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 1, pages 141-149, 1990; republished in *CFC Alternatives*, technical data bulletin 6(1), ASHRAE, pages 10-18, June 1990 (9 pages with 13 figures and 5 tables, RDB3110)

thermodynamic properties and cycle performance for R-134a and R-152a

G. T. Kartsounes and R. A. Erth, **Computer Calculation of the Thermodynamic Properties of Refrigerants 12, 22, and 502**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 77, pages 88-103, 1971 (RDB6B13)

R-12, R-22, R-502, thermodynamic properties, thermophysical data

R. F. Kayser (National Institute of Standards and Technology, NIST), **Thermophysical Properties**, report DOE/CE/23810-16, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (242 pages, including 23 figures and 75 tables, available from JMC as RDB3860)

This report summarizes experimental measurements to provide highly accurate, thermophysical property data for R-32, R-123, R-124, and R-125. The report reviews the methods and apparatus used to complete data measurements, resolve problems and uncertainties that existed in prior data sets, fit equations of state, and develop transport property models for these fluids. Figures show the ranges of measured data, comparisons between the data and deviations from equation of state or regression values, and comparisons of the findings to results reported by other researchers. An appendix presents measured thermodynamic and transport data, in both metric (SI) and inch-pound (IP) units. The data addressed include measurements of Burnett vapor-phase pressure-volume-temperature (PVT) relations, vibrating-tube compressed liquid density, liquid PVT data, vapor pressures using both Burnett apparatus and an ebulliometer, saturated vapor and liquid densities, vapor pressure, liquid and two-phase heat capacity, viscosity, speed of sound, and derived ideal-gas heat capacity and acoustic virial coefficients. Coefficients are provided for modified Benedict-Webb-Rubin (MBWR) equations of state for the four refrigerants. A second appendix outlines a generalized correlation developed for thermal conductivity data. Conductivity data, measured with a transient hot-wire device, and correlation parameters are provided for R-32 and R-123.

E. L. Keating and R. A. Matula, **Correlation and Prediction of Viscosity and Thermal Conductivity of Vapor Refrigerants**, *Transactions* (Semiannual Meeting, Chicago, IL, 27-30 January 1969), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 75, part 1, 1969 (RDB4632)

transport properties, thermophysical data

M. S. Kim, T. S. Kim, and S. T. Ro (Seoul National University, Korea), **Estimation of Thermodynamic Properties of Refrigerant Mixtures Using a Modified Carnahan-Starling Equation of State**, *Trans-*

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actions, Korean Society of Mechanical Engineers (KSME), Seoul, Korea, volume 15, pages 2189-2205, 1991 (17 pages in Korean, RDB6767)

thermodynamic properties, thermophysical data

Y. Kim, R. E. Sonntag, and C. Borgnakke (University of Michigan), **Generalized Equation of State for Refrigerants**, paper 3833, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 3-16, 1995 (14 pages with 12 figures and 13 tables, RDB5229)

R-152a, R-600 (butane), R-740 (argon), thermodynamic properties, thermophysical data, equation of state (based on critical temperature, critical pressure, acentric factor, and polarity factor), methane- and ethane-series refrigerants

H. Knapp, R. Döring (Fachhochschule Münster, Germany), L. Oellrich, U. Plöcker, and J. M. Prausnitz, **Vapor-Liquid Equilibria for Mixtures of Low Boiling Substances**, *Chemistry Data Series VI*, Dechema, Frankfurt am Main, Germany, 1981 (RDB4360)

blends, thermodynamic properties, thermophysical data

R. Krauss and K. Stephan (Universität Stuttgart, Germany), **Thermal Conductivity of Refrigerants in a Wide Range of Temperature and Pressure**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 18, number 1, pages 43-76, 1989 (34 pages, RDB5533)

thermophysical properties, transport data

B. Kruppa, P. Jany, and J. Straub (Technische Universität München, Germany), **Experimental Apparatus for Measuring the Thermal Diffusivity of Pure Fluids at High Temperatures**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 9, pages 911-921, 1988 (11 pages, RDB5628)

transport properties, thermophysical data

H. Kubota, T. Yamashita, Y. Tanaka, and T. Makita, **Vapor Pressures of New Fluorocarbons**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, number 3, pages 629-637, 1989 (9 pages, RDB-4120)

thermodynamic properties, thermophysical data

A. Kumagai and S. Takahashi, **Viscosity of Saturated Liquid Fluorocarbon Refrigerants from 273 to 353 K**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 12, number 1, pages 105-117, 1991 (13 pages, RDB5485)

thermophysical properties

S. D. Labinov (Thermodynamic Center, Ukraine) and J. R. Sand (Oak Ridge National Laboratory, ORNL, USA), **An Analytical Method of Predicting Lee-Kesler-Plöcker Equation of State Binary Interaction Coefficients**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 16, number 6, pages 1393-1411, November 1995 (18 pages with 10 figures and 4 tables, RDB5C01)

This paper presents a method to calculate binary interaction coefficient (IC) values for hydrocarbon mixtures for the Lee-Kesler-Plöcker (LKP) equation of state (EOS). The method is based on solving simultaneous equations from Plöcker's mixing rules, for pseudocritical parameters of a mixture, and the Lee-Kesler equation for the saturation line. This approach allows determination of binary ICs for both polar and nonpolar substances, with a maximum deviation of 0.4%. The calculations require the critical parameters of the components and their normal boiling temperatures, but no experimental data for the mixtures. A table summarizes the interaction coefficients published in other studies for R-22/114, R-22/142b, and R-22/152a for the LKP equation of state. A second table compares experimental and calculated coefficients for R-170 (ethane) mixed with R-290 (propane), R-600 (n-butane), n-pentane, n-hexane, n-heptane, n-octane, and n-nonane. A figure compares calculated and experimental values of these coefficients. A second figure compares the experimental and calculated compressibility factors against the acentric factor for methane through n-decane (alkanes with 1-10 carbon atoms). A third figure compares reduced properties (normalized to critical parameters) for boiling temperature for the pure substances and mixtures of ethane with nonane and ethane with propane. The paper also presents a method to determine ICs for mixtures of polar substances such as the homologs of methane and ethane, which include the primary alternative refrigerants and blend components. The basic physical properties (molecular mass, normal boiling and critical point temperatures, critical pressure, critical molar volume, and dipole moments) needed are tabulated along with basic data for 12 mixtures. They include R-22/114, R-22/124, R-22/142b, R-22/152a, R-23/114, R-23/134a, R-23/22, R-32/134a, R-134a/124b, R-134a/134, R-152a/124, and R-152a/134. Calculated and experimental LKP ICs are plotted for these mix-

tures to show the inadequacies of the algorithm without consideration of polarity. A similar plot compares the calculated ICs, obtained by including parameters indicative of polarity based on component data, to measurements. The paper concludes with an equation that approximates this approach, and yields errors of less than 5%. The results allow thermodynamic property calculations for mixtures of polar substances with a minimum of experimental property information, which can be estimated from the chemical structures of the components when necessary.

P. A. LaRue, **Vapour-Liquid Equilibrium Measurements**, technical report 664-DE00521, Centre de Recherche Industrielle du Québec, Québec, Canada, 1990 (RDB4206)

thermodynamic properties, thermophysical data, VLE

G. Latini, P. Pierpaoli, and F. Polonara (Università degli Studi di Ancona, Italy), **Dynamic Viscosity and Thermal Conductivity Prediction of Refrigerants and Refrigerant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 489-498, July 1992 (9 pages with 7 tables, RDB2832)

transport properties, thermophysical data

A. D. Leu and D. B. Robinson (University of Alberta, Canada), **Vapor-Liquid Equilibrium in Selected Binary Systems**, AIChE Symposium Series paper 271, American Institute of Chemical Engineers (AIChE), New York, NY, volume 85, pages 44-50, 1989 (7 pages with 6 figures and 6 tables, RDB4C51)

This paper presents experimental vapor-liquid equilibrium (VLE) data on six binary mixtures at pressures from 24 to 2736 kPa (3-400 psia). They include R-22/218 for 0 and 25 °C (32 and 77 °F), R-116/22 for -10 and 25 °C (14 and 77 °F), R-E170 (dimethyl ether) with methyl tertiary butyl ether (MTBE) for 25 and 75 °C (77 and 167 °F), tertiary butanol with propionaldehyde, tertiary butanol with acrolein, and acetone with isobutyraldehyde. The data were developed to improve the performance and efficiency of industrial plants, primarily those involved in petroleum or petrochemical processing. The paper notes that the data also may be used to refine equations of state and property prediction methods for the blends examined. The paper reviews the experimental apparatus (based on a pistoned sapphire cell), instrumentation, and procedures used. Measured equilibrium properties are tabulated and plotted as pressure versus composition. The VLE plot for R-22/218 reveals azeotropic behavior at both temperatures.

J. M. H. Levelt Sengers (National Institute of Standards and Technology, NIST), **Solubility Near the Solvent's Critical Point**, *Journal of Supercritical Fluids*, PRA Press, volume 4, number 4, pages 215 ff, 1991 (RDB3126)

transport properties, thermophysical data

M. Lisal and V. Vacek (Academy of Sciences, Czechoslovakia), **Effective Potentials for Liquid Simulation of the Alternative Refrigerants HFC-32 (CH_2F_2) and HFC-23 (CHF_3)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 118, number 1, pages 61-76, 15 April 1996 (16 pages, RDB6B06)

site-site potentials for use in liquid simulations of R-23 and R-32 are constructed using effective interactions; these rigid molecules have interaction centers at the atomic sites coinciding with gas-phase monomer geometries; atomic interactions consist of van der Waals and Coulombic parts; the potential functions are adjusted to give simulated liquid properties for reduced temperatures (T/T_C) of 0.5-0.9 on the saturated liquid curves; proposed potentials are used in constant pressure and constant temperature and in constant temperature molecular dynamics simulations of the saturated liquids; the results are compared with experimental data

T. O. Luddecke and J. W. Magee (National Institute of Standards and Technology, NIST), **Molar Heat Capacity at Constant Volume of Difluoromethane (R32) and Pentafluoroethane (R125) from the Triple-Point Temperature to 345 K at Pressures to 35 MPa**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 17, number 4, pages 823-849, July 1996 (27 pages, RDB6B07)

molar heat capacities at constant volume (Cv) of R-32 and R-125 were measured with an adiabatic calorimeter; temperatures ranged from their triple points to 72 °C (161 °F) and pressures up to 35 MPa (5,100 psia); measurements were conducted on the liquid in equilibrium with its vapor and on compressed liquid samples; samples were of a high purity verified by chemical analysis; calorimetric results were obtained for two-phase saturated liquid and single-phase gas and liquid; these data were used to estimate vapor pressures for values less than 0.3 MPa (44 psia) by applying a thermodynamic relationship between the saturated liquid heat capacity and the temperature derivatives of the vapor pressure; the triple-point temperature and the enthalpy of fusion also were measured for each substance; principal sources of uncertainty are the temperature rise measurement and the change-of-volume work adjustment

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Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Liquid Densities and Vapor Pressures of 1,1,2,2-tetrafluoroethane (HFC-134) and 1,1-dichloro-1-fluoroethane (HCFC-141b)**, *Journal of Chemical and Engineering Data*, volume 36, pages 151-155, 1991 (5 pages, RDB4B53)

R-134, R-141b, thermodynamic properties

Y. Maezawa, H. Sato, and K. Watanabe (Keio University, Japan), **Saturated Liquid Densities of HCFC-123 and HFC-134a**, *Journal of Chemical and Engineering Data*, volume 35, number 3, pages 225-228, 1990 (4 pages, RDB4310)

R-123, R-134a, thermodynamic properties

T. Makita, Y. Tanaka, Y. Morimoto, M. Noguchi, and H. Kubota, **Thermal Conductivity of Gaseous Fluorocarbon Refrigerants R12, R13, R22, and R23 Under Pressure**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 2, pages 249-268, 1981 (20 pages, RDB4B38)

R-12, R-13, R-22, R-23, thermophysical properties

J. M. Martell and R. J. Boyd, **An Ab Initio Study of the Series of Fluorinated Ethanes C2Hn-F6-n (n=0-6): Geometries, Total Energies, and Carbon-Carbon Bond Dissociation Energies**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 96, number 15, pages 6287-6290, 1992 (4 pages, RDB5970)

R-116, R-125, R-134, R-134a, R-143a, R-152a, R-170, and others

J. J. Martin, **Equations of State**, *Industrial and Engineering Chemistry*, American Chemical Society (ACS), Columbus, OH, volume 59, pages 34-52, 1967 (19 pages, RDB4226)

thermodynamic properties, thermophysical data

J. J. Martin, R. M. Kapoor, and N. De Nevers, **An Improved Equation of State: Application to Eight Fluorine Compounds**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 5, pages 159-160, 1959 (2 pages, RDB-5622)

thermodynamic properties, thermophysical data

J. J. Martin and Y. C. Hou, **Development of an Equation of State for Gases**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 1, number 2, pages 142-151, 1955 (10 pages, RDB3967)

thermodynamic properties, thermophysical data

V. Marx, A. Pruß, and W. Wagner, **Neue Zustandsgleichungen für R12, R22, R11 und R113** [New Equations of State for R-12, R-22, R-11, and R-113], report series 19 number 57, Verein Deutscher Ingenieure (VDI) [Association of German Engineers] Verlag, Düsseldorf, Germany, 1992 (in German, RDB5493)

R-11, R-12, R-22, R-113, thermodynamic properties, thermophysical data

R. Mastrullo (Università di Napoli "Frederico II", Italy) and P. Mazzei (Università degli Studi di Salerno, Italy), **Programma interattivo per il calcolo della proprietà di refrigeranti e l'analisi di cicli inversi** [Interactive Computer Program for Calculation of Refrigerant Properties and Analysis of Reversed Cycles], *Il Freddo* [Refrigeration], Italy, volume 42, number 1 pages 61 ff and number 2 pages 203 ff, 1988 (RDB5631)

R-11, R-12, R-13, R-13B1, R-21, R-22, R-23, R-113, R-114, R-114B2, R-115, R-124a [probably R-124], R-134a, R-142b, R-152a, R-C318, R-500, R-502, R-503, R-717, thermodynamic properties, thermophysical data

R. C. McHarness and D. C. Chapman, **Refrigerating Capacity and Performance Data for Various Refrigerants, Azeotropes, and Mixtures**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 67, 1961; republished in *ASHRAE Journal*, ASHRAE, volume 4, number 1, pages 49-58, January 1962 (10 pages, RDB3213)

M. O. McLinden, M. L. Huber, and S. Outcalt (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Alternative Refrigerants**, paper presented at the Winter Annual Meeting (New Orleans, LA, 28 November - 3 December 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (16 pages with 7 figures and 11 tables, available from JMC as RDB4878)

This paper summarizes a survey of available thermophysical property data for seven hydrofluorocarbon (HFC) refrigerants: R-23, R-32, R-125, R-134, R-134a, R-143a, and R-152a. The paper discusses and tabulates the temperature at the triple point, temperature and liquid density at the NBP, and temperature, pressure, and density at the critical point. It then provides coefficients for vapor pressure data fits to Wagner or expanded Wagner equations. Coefficients also are provided for saturated-liquid density and ideal gas heat capacity fits to common equations. The paper tabulates and graphically shows the ranges of single-phase, pressure-volume-temperature (pVT) data available, for each of the refrigerants, to fit an equation of state. The tables and plots also identify the re-

searchers that provided the data. The availability of data at the triple and critical points as well as ranges of data for saturated liquid and vapor densities, ideal gas heat capacity, speed of sound, surface tension, dielectric constant, dipole moment, thermal conductivity, and viscosity are tabulated. The paper notes that while extensive property research has been conducted in the last three years, considerable differences remain between refrigerants in the quantity and quality of information. The paper includes an extensive list of references on published property data.

M. O. McLinden, J. G. Gallagher, M. L. Huber, and G. Morrison (National Institute of Standards and Technology, NIST), **REFPROP Refrigerant Properties Database: Capabilities, Limitations, and Future Directions**, *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 59-71, 1994 (13 pages with 20 figures and 1 table, RDB4520)

M. O. McLinden, J. S. Gallagher, L. A. Weber, G. Morrison, D. Ward, A. R. H. Goodwin, M. R. Moldover, J. W. Schmidt, H. B. Chae, T. J. Bruno, J. F. Ely, and M. L. Huber (National Institute of Standards and Technology, NIST), **Measurement and Formulation of the Thermodynamic Properties of Refrigerants 134a (1,1,1,2-tetrafluoroethane) and 123 (1,1-dichloro-2,2,2-trifluoroethane)**, paper 3282 (588-RP), *Transactions* (Annual Meeting, Vancouver, BC, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 95, part 2, pages 263-283, 1989 (21 pages, RDB0913)

Thermodynamic properties of R-134a and R-123 are formulated using a modified Benedict-Webb-Rubin (MBWR) equation of state fit to experimental measurements of the critical point, vapor pressure, saturated liquid and vapor volumes, superheated pressure-volume-temperature (PVT) behavior, and second virial coefficients derived from PVT and sound speed measurements. The heat capacity of the ideal gas reference state is determined from sound speed measurements on the low density vapor. Surface tensions are also presented. The experimental methods and results are summarized, compared to the property formulation, and compared to other sources in the literature. Tables and diagrams of the thermodynamic properties of R-123 and R-134a, prepared using the MBWR equation of state, are presented. While the various measurements cover different ranges of temperature and pressure, the MBWR formulation is applicable in both the liquid and vapor phases at pressures up to 10,000 kPa (1500 psia); the applicable temperature range is 233 to 450 K (-40 to 350 °F) for R-134a and 255 to 450 K (0 to 350 °F) for R-123. This paper summarizes the results of ASHRAE research project 588-RP.

W. H. Mears, R. F. Stahl, S. R. Orfeo, R. C. Shair, I. F. Kells, W. Thompson, and H. McCann (AlliedSignal Incorporated, then Allied Chemical Corporation), **Thermodynamic Properties of Halogenated Ethanes and Ethylenes**, *Industrial and Engineering Chemistry*, American Chemical Society (ACS), Columbus, OH, volume 47, number 7, pages 1449-1453, July 1955 (RDB3929)

R-114a, R-142b, and others, thermophysical properties; data for R-114a [as cited in RDB 6812]

C. W. Meyer and G. Morrison (National Institute of Standards and Technology, NIST), **Dipole Moments of Seven Partially Halogenated Ethane Refrigerants**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 95, number 9, pages 3860-3866, 1991 (7 pages with 5 figures and 6 tables, RDB4969)

R-124, R-125, R-134, R-134a, R-143, R-143a, R-152a, R-740 (argon), thermodynamic properties, thermophysical data, dielectric constant, molar polarization, refractive index

C. W. Meyer and G. Morrison (National Institute of Standards and Technology, NIST), **Dipole Moments of Seven Refrigerants**, *Journal of Chemical and Engineering Data*, volume 36, number 4, pages 409-413, 1991 (5 pages with 2 figures and 5 tables, RDB4970)

R-22, R-32, R-114, R-123, R-123a, R-E134, R-141b, thermodynamic properties, thermophysical data, dielectric constant, molar polarization, refractive index

R. C. Miller, A. D. Ceballos, K. R. Hall, and J. C. Holste (Texas A&M University), **Accurate Vapor Pressures for Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 479-487, July 1992 (9 pages with 3 figures and 2 tables, RDB2831)

thermodynamic properties, thermophysical data

G. Morrison (National Institute of Standards and Technology, NIST), **The Shape of the Temperature-Entropy Saturation Boundary**, *International Journal of Refrigeration* (IJR), Paris, France, vol-

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ume 17, number 7, pages 495-504, September 1994 (10 pages with 7 figures and 9 tables, RDB-4A58)

PVT, thermodynamic properties, thermophysical data

G. Morrison and M. O. McLinden (National Institute of Standards and Technology, NIST), **Azeotropy in Refrigerant Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 2, pages 129-138, February 1993 (10 pages with 7 figures and 4 tables, available from JMC as RDB-3701)

This paper presents a method to predict the existence of binary azeotropes, noted as attractive "because they behave very nearly as pure materials." The paper presents data for 25 selected refrigerants, from which the existence of 65 azeotropes is predicted in 300 binary mixtures examined. Extensive compilations of information exist for 23 of them. The authors suggest that there may be promise for the remainder, for which no experimental information was found. The paper notes that the azeotropes found in the literature also were predictable by the method presented. The refrigerants examined include R-11, R-12, R-13B1, R-14, R-21, R-23, R-32, R-113, R-114, R-115, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143, R-143a, R-152a, R-218, R-C270, R-C318, and isopentane-2-methylbutane. The predicted azeotropes are categorized as shallow expected near the boiling point of the more volatile component, azeotropy extending to higher temperatures, and one associated with a Bancroft Point (in which the vapor pressures of the components at a particular temperature are identical).

G. Morrison (National Institute of Standards and Technology, NIST), **Azeotropes in Refrigerant Mixtures**, Conference Report Number 18, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, pages 109 ff, 1991 (in English, RDB4438)

G. Morrison and M. O. McLinden, **Application of a Hard Sphere Equation of State to Refrigerants and Refrigerant Mixtures**, NBS Technical Note 1226, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, August 1986 (156 pages, available from JMC as RDB0911)

The Carnahan-Starling-DeSantis (CSD) equation of state is applied to halogenated hydrocarbon refrigerants and their mixtures. A set of thermodynamic functions is derived from the PVT equation of state and the ideal gas heat capacities. Reference states are discussed for both pure materials and mixtures. Although the model exhibits a critical point, it does not quantitatively represent properties in the critical region. Despite this limitation, this model can represent both liquid and gaseous mixtures away from their own critical points, even at conditions near to and above the critical points of their components. Algorithms and Fortran routines for the use of this model are presented along with the numerical coefficients for 11 pure refrigerants and 7 mixtures. Routines for evaluating the coefficients from saturation data are included. Several examples of the application of this equation of state are presented to demonstrate its versatility. The average deviation from the tabulated saturation properties of the 11 pure refrigerants is 0.54% for pressures, 0.09% for liquid volumes, and 0.50% for vapor volumes.

G. Morrison and M. O. McLinden (National Bureau of Standards, NBS), **Two Refrigerant Mixtures and the Hard Sphere Fluid**, paper HI-85-18-3, *Transactions* (ASHRAE Annual Meeting, Honolulu, HI, June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 2, pages 929-935, 1985 (14 pages with 9 figures and 1 table, available from JMC as RDB3509)

binary blends, azeotropes, zeotropes, equation of state

G. Morrison and D. K. Ward (National Institute of Standards and Technology, NIST), **Thermodynamic Properties of Two Alternative Refrigerants, 1,1-Dichloro-2,2,2-trifluoroethane (R-123) and 1,1,1,2-Tetrafluoroethane (R-134a)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 62, pages 65-86, 1991 (22 pages with 11 figures and 7 tables, preprint available from JMC as RDB0907)

This paper describes property measurements for R-123 and R-134a. A simple variable-volume sapphire cell was used to obtain vapor-liquid-equilibrium measurements. Vapor pressures and saturation liquid densities are presented for R-134a from -5 °C (23 °F) to the critical temperature, and for R-123 at 30-100 °C (85-210 °F). Saturation vapor density was also determined for R-134a from 35 °C (95 °F) to the critical point, where the critical conditions were measured. A mechanical oscillator densimeter was used to provide density measurements of the compressed liquids. These measurements are presented from the saturation pressure to 5.5 MPa (800 psi) for R-134a and to 3.5 MPa (500 psi) for R-123 at 5-95 °C (40-200 °F). Results are summarized and compared with similar measurements made by other groups.

G. Morrison (National Bureau of Standards, NBS), **The Importance of Including the Liquid Phase in Equations of State for Nonazeotropic Refrigerant Mixtures**, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 1B, pages 260-273, January 1985 (14 pages, RDB6431)

J. D. Morrison, M. H. Barley, F. T. Murphy, I. B. Parker, and R. W. Wheelhouse (ICI Chemicals and Polymers, Limited, UK), *Proceedings of the 12th Thermophysical Properties Symposium* (Boulder, CO, 19-24 June 1994), American Society of Mechanical Engineers (ASME), New York, NY, June 1994; republished in *CFCs: The Day After* (proceedings of the IIR meeting, Padova, Italy, 1994), International Institute of Refrigeration (IIR), Paris, France, pages 461 ff, 1994; republished in the *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 16, pages 1165 ff, 1995 (RDB6822)

thermodynamic properties, thermophysical data, Martin-Hou equation of state; model based on the MHV-2 methodology; property prediction for tetrary blends of R-32, R-125, and R-134a (R-407 series); R-407A, R-407B, R-407C, R-407D, R-32/125/134a; vapor-liquid equilibrium (VLE) behavior of refrigerant mixtures

T. E. Morsy, **Extended Benedict-Webb-Rubin Equation of State - Application to Eight Fluorine Compounds**, *Journal of Chemical and Engineering Data*, volume 2 (possibly volume 15, number 2), pages 256-265, 1970 (10 pages, RDB5215)

R-13B1, R-717, and others; Benedict-Webb-Rubin (BWR) equation of state

S. Nakagawa, T. Hori, H. Sato, and K. Watanabe (Keio University, Japan), **Isobaric Heat Capacity for Liquid 1-chloro-1,1-difluoroethane and 1,1-difluoroethane**, *Journal of Chemical and Engineering Data*, volume 38, pages 70-74, 1992 (5 pages, RDB5473)

R-142b, R-152a, thermodynamic properties, thermophysical data

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Isobaric Heat Capacity and Enthalpy for Liquid HFC-134a and HCFC-123**, *High Temperatures - High Pressures*, volume 23, pages 191-198, 1991 (8 pages, RDB5482)

R-123, R-134a, thermodynamic properties, thermophysical data

S. Nakagawa, H. Sato, and K. Watanabe (Keio University, Japan), **Specific Heat at Constant Pressure for Liquid New Refrigerants**, *Proceedings of the 27th National Heat Transfer Symposium of Japan*, Nagoya, Japan, pages 421-423, 1990 (RDB-5439)

NSRDS (USSR), **Thermophysical Properties of Freon, Methane Series**, edited by V. V. Altunin et al, Hemisphere Publishing Company, New York, 1987 (RDB5449)

transport properties, thermophysical data

K. Ohgaki, S. Umezono, and T. Katayama, **Pressure-Density-Temperature Relations of CHF_3, N_2O, and C_3H_6 in the Critical Region**, *Journal of Supercritical Fluids*, PRA Press, volume 3, pages 78-84, 1990 (13 pages, RDB4B39)

R-23, R-744A (nitrous oxide), R-1270 (propene, propylene), thermodynamic properties, thermophysical data

M. Okada and Y. Higashi, **Measurements of the Surface Tension for HCFC-124 and HCFC-141b**, *Proceedings of the 13th Japan Symposium on Thermophysical Properties*, Akita, Japan, pages 73-76, 1992 (4 pages, RDB3926)

R-124, R-141b

M. Okada, Y. Higashi, T. Ikeda, and T. Kuwana, **Measurements of the Surface Tension for HCFC-142b and HFC-152a**, *Proceedings of the 12th Japan Symposium on Thermophysical Properties*, pages 105-108, 1991 (4 pages, RDB3932)

R-142b, R-152a

M. Okada, T. Umayahara, M. Hattori (Nagaoka University of Technology, Japan), and K. Watanabe (Keio University, Japan), **Measurements of the Surface Tension of HCFC 123 and HFC 134a**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 69-75, 1990 (7 pages with 4 figures and 2 tables, RDB5629)

R-123, R-134a, transport properties, thermophysical data

C. M. B. P. Oliveira and W. A. Wakeham, **The Viscosity of R32 and R125 at Saturation**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, 1993 (RDB4A52)

R-32, R-125, thermophysical properties, transport data

D. Y. Peng and D. B. Robinson, **A New Two-Constant Equation of State**, *Industrial Engineering Chemistry Fundamentals*, volume 15, number 1, pages 59-64, 1976 (6 pages, RDB4876)

thermodynamic properties, thermophysical data

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S. G. Penoncello, R. T. Jacobsen, R. C. Williams, and E. W. Lemmon (University of Idaho), **Comparisons of Equations of State for HFC-134a and HCFC-123**, report on Annex 18, International Energy Agency (IEA) Heat Pump Center, Sittard, The Netherlands, 1993 (52 pages with 55 tables, RDB-5850)

R-123, R-134a, thermodynamic properties

R. A. Perkins, A. Laesecke (National Institute of Standards and Technology, NIST, USA), and C. A. Nieto de Castro (Universidade de Lisboa, Portugal), **Polarized Transient Hot Wire Thermal Conductivity Measurements**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 275-286, 1992 (12 pages with 5 figures and 3 tables, available from JMC as RDB3709)

R-134a, R-142b, thermodynamic properties, thermophysical data

D. R. Pesuit, **Binary Interaction Constants for Mixtures with a Wide Range in Component Properties**, *Industrial Engineering Chemistry Fundamentals*, volume 17, pages 235-242, 1978 (8 pages, RDB2355)

zeotropes, interaction coefficients, equation of state

T. W. Phillips and K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Liquid Viscosity of Halogenated Refrigerants**, paper 2152, *Transactions* (Annual Meeting, Kansas City, MO, 28 June - 1 July 1970), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 76, part 2, pages 146-156, June 1970 (12 pages with 5 figures and 3 tables, RDB2315)

Liquid viscosity data are tabulated for R-11, R-12, R-13, R-22, R-114, R-115, R-133a, R-152a, R-500, R-502, R-31/114, R-115/152a, R-503, R-504, and R-32/12; transport properties, thermophysical data

T. W. Phillips and K. P. Murphy (AlliedSignal Incorporated, then Allied Chemical Corporation), **Liquid Viscosity of Halocarbons**, *Journal of Chemical and Engineering Data*, volume 15, number 2, pages 304-307, February 1970 (4 pages with 5 figures and 5 tables, RDB2314)

transport properties, thermophysical data

C-C. Piao, Y. Ikeya, H. Sato, and K. Watanabe (Keio University, Japan), **An Experimental Study of Isobaric Specific Heats for CFC Alternatives**, *Proceedings of the 11th Japan Symposium on Thermophysical Properties*, 1990 (RDB4A57)

B. Platzer and G. Maurer, **Win Programmpacket zur Berechnung thermodynamischer Zustandsgrößen reiner Fluide mit Hilfe der Zustandsgleichung von Bender** [Software for Thermodynamic Property Calculations of Pure Fluids by the Bender Equation of State], *DKV Jahrestagung* [Proceedings of the DKV Annual Meeting] (Hannover, Germany, 1989), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), 1989 (in German, RDB5619)

thermodynamic properties, thermophysical data

K. Raznjevic, **Handbook of Thermodynamic Tables and Charts**, Hemisphere Publishing Corporation, Washington, DC, and McGraw-Hill Book Company, New York, NY, 1976 (RDB3211)

thermodynamic properties, thermophysical data

R. Reid, J. Prausnitz, and B. Poling, **The Properties of Gases and Liquids** (Fourth Edition), McGraw-Hill Book Company, New York, NY, 1987 (RDB-3239)

thermodynamic properties, thermophysical data

E. Reile, **Messung der Temperaturleitfähigkeit reiner Fluide und binärer Gemische mit Hilfe der dynamischen Lichtstreuung in der weiteren Umgebung des kritischen Punktes** [Measurements of Thermal Diffusivity of Pure Fluids and Binary Mixtures in a Wide Region around the Critical Point by Means of Dynamic Light Scattering], thesis, Technische Universität München, Germany, 1981 (RDB5624)

thermophysical property measurement and apparatus

K. Reuter, S. Rosenzweig, and E. U. Frank, **The Static Dielectric Constant of CH_3F and CHF_3 at 468 K and 2000 Bar**, *Physica A*, Elsevier Science B.V., Amsterdam, The Netherlands, volume 156, pages 294-302, 1989 (9 pages, RDB4B40)

R-23, R-41, physical properties

A. S. Rodgers, J. Chao, R. C. Wilhoit, and B. J. Zwolinski, **Ideal Gas Thermodynamic Properties of Eight Chloro- and Fluoromethanes**, *Journal of Physical Chemistry Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, volume 3, pages 117-140, 1974 (24 pages, RDB4315)

thermophysical data

U. K. Rombush, **Ein erweiteres Korrespondenzprinzip zur Bestimmung von Zustandgrößen** [An Extended Correspondence Principal for Determina-

tion of Properties], *Allg. Wärmetechnik*, volume 11, pages 133-145, 1962 (13 pages, RDB6907)

thermodynamic properties, thermophysical data

J. R. Sand, S. K. Fischer (Oak Ridge National Laboratory, ORNL), and J. A. Jones (Jet Propulsion Laboratory, JPL, California Institute of Technology), **Carnahan-Starling-Desantis and Lee-Kesler-Plöcker Interaction Coefficients for Several Binary Mixtures of Ozone-Safe Refrigerants**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 2, pages 123-129, February 1994 (7 pages with 2 figures and 3 tables, RDB4203)

Estimates of interaction coefficients (ICs) are provided for binary refrigerant blends for both the Carnahan-Starling-Desantis (CSD) and Lee-Kesler-Plöcker (LKP) equations of state (EOS). These IC values characterize the non-ideal behavior of mixtures, and are useful in calculating thermodynamic properties. The estimates were determined by least-squares fits of the CSD and LKP equations to previously measured, saturated vapor pressure (bubble point) data. 70 mixtures of 8 different refrigerants in 18 binary combinations were analyzed. The combinations included R-12/152a, R-22/124, R-22/134, R-22/134a, R-22/142b, R-22/152a, R-23/22, R-23/134a, R-124/142b, R-134/124, R-134/142b, R-134a/124, R-134a/134, R-134a/142b, R-134a/152a, R-152a/124, R-152a/134, and R-152a/142b. The paper describes the use of IC values, experimental apparatus used to measure the data, presents the resulting ICs, and discusses variances found with previously determined values. Good agreement was found for several known blends, but poor agreement resulted for the well characterized R-22/142b blend; further experimental verification is recommended. Comparisons between experimental ICs and those calculated from physical properties or critical constants of the components suggest that refinement of the property calculation algorithms may be desirable.

J. V. Sengers (University of Maryland), **Effects of Critical Fluctuations on the Thermodynamic and Transport Properties of Supercritical Fluids**, *Supercritical Fluids*, edited by E. Kiran and J. M. H. Levelt Sengers, Kluwer Academic Publishers, Dordrecht, The Netherlands, and Norwell, MA, USA, pages 231-271, 1994 (41 pages with 17 figures, RDB6406)

long-range density fluctuations in the critical phase transition, thermodynamic and transport properties around the critical point

I. R. Shankland, **Transport Properties of CFC Alternatives**, unpublished presentation (*Symposium on Global Climate Change and Refrigerant Properties*, AIChE Spring National Meeting, Orlando, FL, 1990), Buffalo Research Laboratory, AlliedSignal Incorporated, Buffalo, NY, March 1990 (31 pages with 13 figures and 12 tables, available from JMC as RDB0517)

This paper provides transport property data for alternative refrigerants. The data and correlations cover liquid viscosity for R-123, R-123a, R-124, R-125, R-134a, and R-141b; liquid thermal conductivity for R-123, R-123a, R-124, R-125, and R-134a; and vapor thermal conductivity for R-123, R-123a, R-124, R-141b, and R-141b. Comparative data are provided for R-11, R-12, R-22, R-114, and R-502. The data and correlations are plotted to facilitate comparisons and to illustrate the regression deviations. The paper describes the experimental procedures and estimated accuracies. Thermal conductivity measurements were performed using a transient hot-wire apparatus. Liquid viscosity measurements were performed using an Ubbelohde suspended level capillary type viscometer. The paper notes that the transport properties of the alternatives yield lower performance in some instances, such as foam blowing, when compared to chlorofluorocarbons. In other cases, the properties offer advantages, such as improved heat transfer characteristics for R-134a. One consequence is the need to redesign and optimize systems that utilize the new fluids.

A. M. Silva and L. A. Weber (National Institute of Standards and Technology, NIST), **Ebulliometric Measurement of the Vapor Pressure of 1-chloro-1,1-difluoroethane and 1,1-difluoroethane**, *Journal of Chemical and Engineering Data*, volume 38, number 4, pages 644-646, 1993 (3 pages with 4 figures and 3 tables, RDB4911)

This paper presents measured vapor pressure data for R-142b between -48 and 12 °C (-55 and 53 °F) and for R-152a between -53 and 0 °C (-64 and 32 °F). It describes a comparative ebulliometer used for the measurements. The paper shows and tabulates deviations of the measured data from fits to an Antoine equation and, for R-152a, also to a Wagner equation. It compares the findings to those published by others, some of which were used in fitting the new data. The results offer a means to predict the vapor pressure of R-142b from -73 to 27 °C (-100 to 80 °F) and of R-152a from -58 to the critical temperature, near 113 °C (-73 to 235 °F).

L. C. Singal, C. P. Sharma, and H. K. Varma, **Thermodynamic Property Charts and Cycle Analysis for Binary Refrigerant Mixtures**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-29 January 1981), American Society of Heating, Refrigerating,

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and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 87, part 1, pages 80-93, 1981 (14 pages with 7 figures and 3 tables, RDB5555)

blends, thermodynamic properties, thermophysical data

R. R. Singh, E. A. E. Lund, and I. R. Shankland (AlliedSignal Incorporated), **Thermophysical Properties of HFC-32, HFC-125, and HFC-32/HFC-125**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 451-459, 1991 (10 pages with 3 figures and 4 tables, available from JMC as RDB2234)

This paper provides a summary of thermodynamic data for the vapor, compressed liquid, and saturated regions of R-32, R-125, and R-32/125 (60/40). Correlations based on measured data and the Martin Hou equation of state are given for vapor pressure, liquid density, and ideal gas heat capacity. The paper briefly describes a pseudo-isochoric (constant mass) pressure-volume-temperature (PVT) apparatus; this new, automated apparatus was used to obtain some of the data presented. Tables present the boiling point temperature; critical point temperature, pressure, and density; and molecular mass. Pressure-enthalpy (Mollier) diagrams also are provided for the two single-compound refrigerants and their 60/40 blend.

D. C. Smith, G. M. Brown, J. R. Nielsen, R. M. Smith, and C. Y. Liang, **Infrared and Raman Spectra of Fluorinated Ethanes, III, the Series of CH_3CF_3, CH_3CF_2Cl, CH_3CFCl_2, and CH_3CCl_3**, *Journal of Chemical Physics*, American Institute of Physics (AIP), Woodbury, NY, volume 20, pages 473-486, 1952 (14 pages, RDB4318)

R-143a, R-142b, R-141b, and R-140a (methyl chloroform)

N. D. Smith, **New Chemical Alternatives for CFCs and HCFCs**, Environmental Research Brief EPA-600/F-92-012, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, 24 March 1992 (2 pages with 2 tables, available from JMC as RDB3405)

This summary outlines efforts to identify alternative refrigerants. It mentions a panel, convened to assess the potential for finding suitable alternative chemicals. It discusses the trade offs, in replacing one or more chlorine or bromine atoms in familiar refrigerants with hydrogen, between desired environmental characteristics and flammability, toxicity, and loss in efficiency. It reviews a search and cooperatively funded project, with the Electric Power Research Institute (EPRI), at Clemson University and the University of Tennessee. The goals were to synthesize and determine relevant physical properties of numerous fluorinated propanes, butanes, and ethers. Chemical formulae and normal boiling points are tabulated for 34 compounds considered. 11 are identified for further characterization; their chemical names and the refrigerants they might replace are tabulated. Additional testing of these 11 candidates is continuing. This research includes determination of atmospheric stability and tests of acute inhalation toxicity, materials compatibility, vapor thermal conductivity, and refrigeration performance. The 11 selected chemicals include nine hydrofluorocarbons (HFCs), namely R-227ca, R-227ea, R-236cb, R-236ea, R-236fa, R-245ca, R-245cb, R-245fa, and R-254cb. They also include two ethers, E-125 and E-143a.

G. Soave, **Rigorous and Simplified Procedures for Determining the Pure Component Parameters in the Redlich-Kwong-Soave Equation of State**, *Chemical Engineering Science*, number 35, pages 1725-1729, 1980 (5 pages, RDB5460)

RKS equation of state, thermodynamic properties, thermophysical data

C. F. Spencer and R. P. Danner, **Prediction of Bubble-Point Density of Mixtures**, *Journal of Chemical and Engineering Data*, volume 18, pages 230-234, 1973 (5 pages, RDB4C06)

blends, thermodynamic properties, thermophysical data

K. Stephan and T. Heckenberger (Universität Stuttgart, Germany), **Thermal Conductivity and Viscosity Data of Fluid Mixtures**, *Chemistry Data Series X*, Dechema, Frankfurt am Main, Germany, 1988 (RDB5530)

blends, thermophysical properties

D. R. Stull and H. Prophet, **JANAF Thermochemical Tables**, report NSRDS-NBS37, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1971 (available from GPO, RDB4C07)

thermophysical data

B. Sukornick, **Potentially Acceptable Substitutes for Chlorofluorocarbons: Properties and Performance Features of HFC-134a, HCFC-123, and HCFC-141b**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, number 3, pages 553-561, 1989 (9 pages, RDB4319)

R-123, R-134a, R-141b, thermodynamic properties, thermophysical data

W. Swietoslawski, **Azeotropy and Polyazeotropy**, edited by K. Ridgway, MacMillan Company, New York, NY, 1963 (RDB4606)

azeotropes, blends

M. Takahashi, C. Yokoyama, and S. Takahashi, **Viscosities of Gaseous R-13B1, R-142b, and R-152a**, *Journal of Chemical and Engineering Data*, volume 32, pages 98-103, 1987 (6 pages, RDB-3931)

thermophysical data

Y. Tanaka, M. Nakata, and T. Makita (Kobe University, Japan), **Thermal Conductivity of Gaseous HFC-134a, HFC-143a, HCFC-141b, and HCFC-142b**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 12, number 6, pages 949-963, 1991 (15 pages, RDB5488)

R-134a, R-141b, R-142b, R-143a, transport properties, thermophysical data

A. S. Teja and A. Singh, **Equation of State for Ethane, Propane, and n-Butane**, *Cryogenics*, volume 17, number 11, pages 591-596, 1977 (6 pages, RDB5717)

R-170, R-290, R-600, thermodynamic properties, thermophysical data

N. Thorp and R. L. Scott (University of California at Los Angeles), **Fluorocarbon Solutions at Low Temperatures. II. The Liquid Mixtures of C_2H_6-C_2F_6, C_2F_6-CHF_3, CH_2F_2-CHF_3, C_2H_6-CHF_3 and Xe-CHF_3**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, volume 60, pages 1441-1443, October 1956 (3 pages with 4 figures and 3 tables, RDB4A35)

R-170/116 (azeotropic), R-23/116 (azeotropic), R-23/32 (zeotropic), R-170/23, and, R-7131/23 (xenon/23); possibility of intermolecular hydrogen bonding in liquid R-23

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **Measurements of p,rho,T Properties in the Liquid, Near Critical and Supercritical Regions of 1,1,1,2-tetrafluoroethane (R-134a) and 1,1-difluoroethane (R-152a)**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 25, pages 227-292, 1993 (8 pages, RDB4408)

pressure, density, temperature, thermodynamic properties, thermophysical data

R. Tillner-Roth and H. D. Baehr (Universität Hannover, Germany), **Burnett Measurements and Correlations of Gas Phase of 1,1,1,2-tetrafluoroethane (R-134a) and 1,1-difluoroethane (R-152a)**, *Journal of Chemical Thermodynamics*, Academic Press Limited, New York, NY, volume 24, pages 413-424, 1992 (12 pages, RDB4409)

thermodynamic properties, thermophysical data

P. Tremaine and M. G. Robinson, **The Static Dielectric Constants of the Liquified Fluoromethanes**, *Canadian Journal of Chemistry*, National Research Council of Canada (NRCC), Ottawa, ON, Canada, volume 51, number 10, pages 1497-1503, 1973 (7 pages, RDB5353)

R-14, R-23, R-32, R-41, physical properties

O. B. Tswetkov, Y. A. Laptev, and A. G. Asambaev, **Thermal Conductivity of Refrigerants R123, R134a, and R125**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, 1993 (RDB4B27)

R-123, R-125, R-134a, transport properties, thermophysical data

Y. Uena, Y. Kobayashi, Y. Nagasaka, and A. Nagashima, **Thermal Conductivity of CFC Alternatives: Measurements of HCFC-123 and HFC-134a in the Liquid Phase by the Transient Hot Wire Method**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, volume 57, pages 3169-3175, 1991 (7 pages, in Japanese, RDB4B57)

R-123, R-134a, thermodynamic properties, thermophysical data

W. N. Vanderkooi and T. DeVries, **The Heat Capacity of Gases at Low Pressure Using a Wire-Ribbon Method**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, volume 60, pages 636-639, 1956 (4 pages, RDB4229)

thermophysical data

B. P. Vladimirov and Y. F. Shvets, **Saturated Vapor Pressure of R-218 and R-329 and Azeotropic Mixtures of R-116 and R-23**, *Teplofizicheskie Svoistva Veshchestv i Materialov* [Thermophysical Properties of Substances and Materials], Izdatel'stvo Standartov, Moscow, Russia, volume 28, pages 24-27, 1989 (in Russian, RDB3C11)

thermodynamic properties, thermophysical data

W. Wagner, **New Vapor Pressure Measurements for Argon and Nitrogen and a New Method for Establishing Rational Vapor Pressure Equations**,

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Cryogenics, volume 13, pages 470-482, 1973 (RDB4A41)

R-728, R-740, thermodynamic properties, thermophysical data

K. Watanabe and H. Sato (Keio University, Japan), **Recent Progress on Thermodynamic Property Studies of Alternatives to Replace HCFC-22**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 215-225, 1993 (11 pages with 3 figures and 1 table, RDB5319)

This paper summarizes research performed at Keio University to measure the thermodynamic properties of alternative refrigerants. The paper briefly reviews the phaseout of ozone-depleting substances and the resultant need to select the best hydrofluorocarbon (HFC) refrigerant, to replace R-22. It identifies the binary blends of R-32/125 and R-32/134a as well as ternary blends of R-32/125/134a as candidates. The paper outlines systematic series of measurements and analytical studies, including modelling associated with formulations and correlations of different thermodynamic properties. It discusses capabilities including a Burnett apparatus, magnetic densimeter incorporated into a variable-volume cell, separate apparatus for isobaric heat capacity measurements in the vapor and liquid phases, a constant-volume apparatus coupled with a sample expansion procedure for PVTx measurements, and a spherical resonator to measure sound velocity. The paper then discusses property measurements for R-32. Plots illustrate the range of measured PVT data and compare the second viral coefficient determined by the authors with those from under studies. A table compares the critical parameters (temperature, pressure, and density) from the subject research with those reported by others. The paper then discuses property measurements for R-125 and R-143a, and compares the former to a published correlation. It briefly cites investigations of R-32/134a and R-32/125 measurements. The paper lists 51 data references, most from studies by the authors and their students.

K. Watanabe, H. Sato, and Z-Y. Qian (Keio University, Japan), **Thermodynamic Properties of New Refrigerants - HFC-32 and HFC-125**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 443-452, July 1992 (10 pages with 9 figures, RDB2827)

R-32, R-125

L. A. Weber and D. R. Defibaugh (National Institute of Standards and Technology, NIST), **The Virial Coefficients of Five Binary Mixtures of Fluorinated Methanes and Ethanes**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, undated circa 1994 (28 pages with 6 figures and 2 tables, available from JMC as RDB4B68)

R-32/125, R-32/134a, R-125/134a, R-125/143a, R-134a/152a, thermodynamic properties, thermophysical data

L. A. Weber (National Institute of Standards and Technology, NIST), **Estimating the Virial Coefficients of Small Polar Molecules**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 15, number 3, pages 461-482, May 1994 (22 pages with 10 figures and 1 table, available from JMC as RDB4912)

This paper presents a physically based, semiempirical scheme for estimating the second and third virial coefficients of halogenated methanes and ethanes. The paper tabulates the critical parameters (temperature, pressure, and specific volume), reduced dipole moment, Pitzer acentric factor, and volume of a hard-sphere model for 18 refrigerants. They include R-11, R-12, R-13, R-14, R-22, R-23, R-32, R-41, R-114, R-115, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, and R-152a. The paper compares predicted and measured data, concluding that the model provides an accurate method of predicting densities. It outlines the development and presents equations and parameters for estimating the properties of pure refrigerants, and their mixtures, when thermodynamic data are not available.

L. A. Weber (National Institute of Standards and Technology, NIST), **Criteria for Establishing Accurate Vapor Pressure Curves**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 463-471, July 1992 (9 pages); republished in *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 2, pages 117-122, February 1994 (6 pages with 4 figures, available from JMC as RDB2829)

This paper uses standard thermodynamic relationships to demonstrate the accuracy of new vapor pressure measurements. Calculated, liquid-phase, heat capacities, based on data for R-123 and R-134a, are compared to published, experimental values. The paper describes and schematically illustrates a comparative ebulliometer apparatus used to measure vapor pressures. It contrasts the measured data to those obtained by others, noting that the new vapor pressure data tend to be systematically

lower than published values. It suggests that the deviations may derive from presence of a volatile impurity (air) in samples used in static measurements, overcome by the dynamic approach of the apparatus described. The paper presents relations, based on thermodynamic principles, to confirm assertion of volatile impurities and to select the most reliable vapor pressure curves. It then discusses plots of heat capacity deviations. The paper concludes that discrepancies between precise vapor pressure data, from different laboratories, can be explained by assumption of impurities, probably air. It notes that very small concentrations of air can have relatively large effects, which can affect calculated thermodynamic properties.

L. A. Weber (National Institute of Standards and Technology, NIST), **Ebulliometric Measurement of the Vapor Pressures of R-123 and R-141b**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, pages 141 ff, 1992 (RDB4565)

thermodynamic properties, thermophysical data

L. A. Weber (National Institute of Standards and Technology, NIST), **Thermophysical Properties of Some Selected Alternative Refrigerants**, presentation at the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference (Purdue University, West Lafayette, IN, July 1990); published in the *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 703-712, July 1992 (10 pages with 8 figures and 1 table, available from JMC as RDB0908)

Research on thermophysical properties for six candidate alternative refrigerants is summarized. Properties measured include gas- and liquid-phase PVT, vapor pressure, surface tension, index of refraction, dielectric constant, gas-phase speed of sound, critical parameters and materials compatibility. Results have been obtained for R-123, R-125, R-134, R-134a, and R-141b; some properties have been obtained for E-134.

L. A. Weber (National Institute of Standards and Technology, NIST), **Vapor-Liquid Equilibrium in Binary Systems of Chlorotrifluoromethane with n-Butane and Isobutane**, *Journal of Chemical and Engineering Data*, American Chemical Society (ACS), Columbus, OH, volume 34, pages 452-455, October 1989 (4 pages, RDB6706)

R-13/600, R-13/600a, thermodynamic properties fit to Peng-Robinson equation of state

W. Wei, T. Liancheng, and X. Hongwei (Xi'an Jiaotong University, China), **A Simple Vapor Pressure Equation for New Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 117-122c, October 1995 (8 pages with 3 tables, available from JMC as RDB5A52)

R-11, R-12, R-22, R-32, R-113, R-123, R-125, R-134a, R-142b, R-152a, R-290 (propane), R-600a (isobutane), R-1270 (propene), vapor pressure prediction, corresponding states

J. V. Widiatmo, H. Sato, and K. Watanabe (Keio University, Japan), **Measurement of Vapor Pressures and Liquid Densities of HFC-32 and HFC-125**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), pages 364-369, 1992 (6 pages, RDB5456)

R-32, R-125, thermodynamic properties, thermophysical data

E. G. Wright (E. I. duPont de Nemours and Company, Incorporated), **Prediction of Refrigerant Ternary Mixture Properties Using the Redlich-Kwong-Soave Equation of State**, *Advances in Nonazeotropic Mixture Refrigerants for Heat Pumps*, technical data bulletin 1(9), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 37-52, June 1985 (16 pages, RDB2331)

thermodynamic properties, thermophysical data

J. Xinqiao, X. Dazhong, and Z. Xinxi (Shanghai Jiao Tong University, China), **Performance Evaluation of Air-Condition**[ing] **System Using NARM by Equation of State**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 287-292, July 1994 (6 pages with 4 figures, RDB4836)

R-22, R-142, R-22/142, zeotropes, thermodynamic properties; Martin-Hou (MH) equation of state, cycle analysis

J. Xinqiao, Z. Xinxi, and X. Dazhong (Shanghai Jiao Tong University, China), **Comparing of Several EOS for Evaluation of NARMs' Thermodynamic Properties**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 55-60, July 1994 (6 pages with 3 tables, RDB4810)

R-12, R-22, R-142b, R-22/12, R-22/142, zeotropes, thermodynamic properties; Martin-Hou (MH), Starling-Han-Benedict-Webb-Rubin

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(SHBWR), Redlich-Kwong-Soave (RKS), equation of state (EOS)

T. Yamashita, H. Kubota, Y. Tanaka, T. Makita, and H. Kashiwaga, **Physical Properties of New Halogenated Hydrocarbons**, *Proceedings of the Tenth Japan Symposium on Thermophysical Properties*, pages 75-78, 1989 (4 pages, RDB4323)

thermodynamic properties, thermophysical data

T. Yamashita, H. Kubota, Y. Tanaka, T. Makita, and H. Kashiwaga, **Measurement of Physical Properties of New Fluorocarbons**, *Proceedings of the Ninth Japan Symposium on Thermophysical Properties*, pages 227-230, 1988 (4 pages, RDB4324)

thermodynamic properties, thermophysical data

J. Yata, M. Hori, T. Kurahashi, and T. Minamiyama, **Thermal Conductivity of Alternative Fluorocarbons in Liquid Phase**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 80, number 11, pages 287-296, 1992 (10 pages, RDB3928)

R-141b, R-142b, R-152a

J. Yata, **Thermal Conductivity of Alternatives to CFCs**, *Proceedings of the Eleventh Japan Symposium on Thermophysical Properties*, pages 143-146, 1990 (4 pages, RDB3920)

thermophysical data

J. Yata, M. Hori, and T. Minamiyama, **Refractive Index of HCFC-22 and HFC-134a**, *Proceedings of the Eleventh Japan Symposium on Thermophysical Properties*, 1990 (RDB4B43)

R-22, R-134a, transport properties, thermophysical data

J. Yata, C. Kawashima, M. Hori, and T. Minamiyama, **Thermal Conductivity of R123 and R134a in Liquid Phase**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), pages 201-205, 1989 (5 pages, RDB4B44)

R-123, R-134a, thermodynamic data

C. Yokoyama and S. Takahashi, **Saturated Liquid Densities of 2,2-dichloro-1,1,1-trifluoroethane (HCFC-123), 1,2-dichloro-1,2,2-trifluoroethane (HCFC-123a), 1,1,1,2-tetrafluoroethane (HFC-134a), and 1,1,1-trifluoroethane (HFC-143a)**, *Fluid Phase Equilibria*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 67, pages 227-240, 1991 (14 pages, RDB5440)

R-123, R-123a, R-134a, R-143a

S. Young, **The Vapour Pressures, Specific Volumes, Heats of Vaporization, and Critical Constants of Thirty Pure Substances**, *Scientific Proceedings of the Royal Dublin Society*, New Series 12, Dublin, Ireland, pages 374-443, 1909-1910 (70 pages, RDB4933)

thermodynamic properties, thermophysical data

Dampftaflen für Frigen 12, 22, 502 / Refrigerant Tables for Frigen 12, 22, 502, product bulletin AFK2074D/E, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, February 1992 (44 pages with 7 tables, in English and German, RDB4773)

This bulletin provides thermodynamic property data for R-12, R-22, and R-502 in metric (SI) units of measure. An introduction summarizes the units used, provides conversion factors from metric to inch-pound (IP) units, and outlines the reference states and adjustments for other selections. A table then summarizes basic physical data, including the chemical formula and name, molecular mass, normal boiling point, freezing point, critical parameters (temperature, pressure, and density), and latent heat of vaporization. It also gives the surface tension, liquid density, specific heat ratio, water solubility, refractive index, relative dielectric strength, and vapor and liquid dielectric constants at selected temperatures. Three tables then provide saturated property data including pressure; liquid and vapor specific volumes, densities, enthalpies, and entropies; and the heat of vaporization. These data cover R-12 from -60 to 112.0 °C (-76 to 233.6 °F), R-22 from -100 to 96.18 °C (-148 to 205.1 °F), and R-502 from -65 to 82.16 °C (-85 to 179.9 °F); the upper limits are the critical temperatures. Three additional tables give the specific volume, enthalpy, and entropy for superheated vapor for R-12 from -40 to 74 °C (-40 to 165 °F), R-22 from -60 to 62 °C (-76 to 144 °F), and R-502 from -60 to 62 °C (-76 to 144 °F). Hoechst Chemical's product names for R-12, R-22, and R-502 are Frigen(R) 12, 22, and 502.

Dymel(R) Aerosol Propellants, product information bulletin (240881D), DuPont Fluorochemicals, Wilmington, DE, August 1995 (10 pages with 1 figure and 3 tables, RDB6210)

R-134a, R-152a, R-E170 (DME), applications, properties, environmental impacts, stability, solubility, safety, toxicity, flammability, compatibility

Frigen(R) Primer for Refrigeration, Air Conditioning and Energy Technology, product bulletin AFK1479E/46, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, December 1981 (104 pages with 4 figures and 22 tables, RDB4779)

This bulletin provides information on the properties, application, and handling of R-11, R-12,

R-12B1, R-13, R-13B1, R-22, R-23, R-113, R-114, R-115, R-500, R-502, and R-503 in metric (SI) units of measure. Chemical names, formulae, container data, and valve information are discussed. The bulletin then reviews stability, moisture effects, compatibility with metals, seal materials, lubricants, safety precautions, and toxicity indicators for the subject refrigerants. It also discusses evacuation, leak detection, charging, leakage replenishment, moisture removal, and uses. A table summarizes physical and thermodynamic property data including the chemical formula and name, molecular mass, normal boiling point, freezing point, and critical parameters (temperature, pressure, and density). It also gives the heat of vaporization, surface tension, liquid specific heat, liquid density, specific heat ratio, solubility of water, liquid refractive index, relative dielectric strength, and dielectric constant at selected conditions. A plot compares the pressure-temperature curves. 13 tables provide thermodynamic property data at saturated (wet vapor) conditions. They indicate the saturation vapor pressure; liquid and vapor specific volumes and enthalpies; and the heat of vaporization. Hoechst Chemicals identifies its refrigerants with the trade name Frigen(R) and those that are chlorine free, and meet ecological and technical requirements, as Reclin(R).

Thermophysical Properties of Alternative Refrigerants, proposed research project 861-WS, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0861)

This research project is sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines*.

Thermophysical Properties of Environmentally Acceptable Fluorocarbons - HFC-134a and HCFC-123, Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR] and Japan Flon Gas Association, Tokyo, Japan, 1991 (304 pages with 83 figures and 99 tables, in both Japanese and English, RDB2235)

This comprehensive volume summarizes critical, thermodynamic, transport, physical, chemical, compatibility, and other data available on R-123 and R-134a. Included are tabular data and/or plots for solubility, refractive index, dielectric constant, dielectric strength, PVT properties and equations of state, enthalpy, entropy, isobaric and isochoric specific heat capacity, isentropic expansion exponent, speed of sound, surface tension, viscosity, kinematic viscosity, and thermal conductivity. Data on thermal and chemical stability are summarized, including weight and length changes with polypropylene, polystyrene, polyethylene, polyvinylchloride, polyamide, polyimide, chlorinated and chlorosulfonated polyethylene, nitrile butadiene rubber, Butyl(TM) rubber, fluorocarbon rubber, ethylene propylene diene terpolymer (EPDM), urethane rubber, and polychloroprene. Safety data, including toxicity and flammability, are summarized. The volume contains an extensive list of references as well as discussion of the ranges and differences among property sources identified. An introductory section outlines conversions among several metric systems, including SI, and inch-pound units. It also reviews the environmental concerns with chlorofluorocarbon (CFC) refrigerants.

Thermophysical Properties of Pure Substances and Mixtures for Refrigeration, proceedings (Meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, 1990 (278 pages with 33 papers, RDB1103)

thermodynamic data, transport properties

Thermophysical Properties of Refrigerants 123 and 134a, proposed research project 655A-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0655A)

This project is sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines*.

Thermophysical Properties of Refrigerants 125 and 141b, proposed research project 655B-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0655B)

This project is sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines*.

Transport Properties of Suva(R) Refrigerants: Suva(R) Cold-MP (HFC-134a), Suva(R) Trans A/C (HFC-134a), and Suva(R) Centri-LP (HCFC-123), product information report ART-1 (H-43855-1), DuPont Chemicals, Wilmington, DE, September 1992 (24 pages with 18 figures, available from JMC as RDB3438)

This report provides plots and equations for estimation of the transport properties of R-123 and R-134a. Liquid viscosity, liquid thermal conductivity, saturated liquid heat capacity, vapor viscosity at atmospheric pressure, vapor thermal conductivity at atmospheric pressure, vapor heat capacity, and vapor heat capacity ratio (C_p/C_v) are addressed. Corresponding data are plotted for R-11 and R-12 for all but the vapor heat capacity data for comparison. The plots and equations are repeated in inch-pound (IP) and metric (SI) units. The equations are based on curve fits of measured data.

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Transport Properties of Suva(R) Refrigerants: Suva(R) MP39, Suva(R) MP52, and Suva(R) MP66, product information report ART-10 (H-45949), DuPont Chemicals, Wilmington, DE, January 1993 (32 pages with 24 figures, available from JMC as RDB-3440)

This report provides plots and equations for estimation of transport properties for R-401A, R-401B, and R-401C. These refrigerants are zeotropic blends of R-22, R-152a, and R-124, namely R-22/152a/124 (53/13/34), (61/11/28), and (33/15/52), respectively. Saturated liquid viscosity, thermal conductivity, and heat capacity; vapor viscosity at atmospheric pressure; vapor thermal conductivity at atmospheric pressure; vapor heat capacity; and vapor heat capacity ratio (C_p/C_v) are addressed. Plots provide correction factors for vapor viscosity at higher pressures for vapor densities to 110 kg/m3 (7 lb/cf). The plots and equations are repeated in inch-pound (IP) and metric (SI) units. The equations are based on curve fits of measured data. DuPont's product names for R-401A, R-401B, and R-401C are Suva(R) MP39, Suva(R) MP66, and Suva(R) MP52, respectively.

Transport Properties of Suva(R) Refrigerants: Suva(R) HP62, Suva(R) HP80, and Suva(R) HP81, product information report ART-18 (H-49740), DuPont Chemicals, Wilmington, DE, May 1993 (40 pages with 34 figures, RDB3C03)

This report provides plots and equations for estimation of transport properties for R-402A and R-402B. These refrigerants are zeotropic blends of R-125, R-290 (propane), and R-22, namely R-125/290/22 (60/2/38) and (38/2/60), respectively. The report also covers R-404A, a zeotropic blend of three hydrofluorocarbons (HFCs) - R-125, R-143a, and R-134a - namely R-125/-143a/134a (44/52/4). Saturated liquid viscosity, thermal conductivity, and heat capacity; vapor viscosity at atmospheric pressure; vapor thermal conductivity at atmospheric and high pressure; vapor heat capacity; and vapor heat capacity ratio (C_p/C_v) are addressed. Most include curves for R-502 for comparison. The plots and equations are repeated in inch-pound (IP) and metric (SI) units. The equations are based on curve fits of measured data. DuPont's product names for R-402A, R-402B, and R-404A are Suva(R) HP80, Suva(R) HP81, and Suva(R) HP62, respectively.

MATERIALS COMPATIBILITY

E. G. Afanas'eva, **Chemical and Thermal Stability of Freons**, *Kolloidnyi Tekhnika*, volume 16, pages 80-81, 1973 (in Russian, RDB3518)

compatibility

J. T. Ashton et al, **The Solubility of Certain Gaseous Fluorine Compounds in Water**, *Journal of the Chemical Society, Inorganic Physical Theory*, pages 1793 ff, 1968 (RDB5A36)

solubility, compatibility

G. Bambach (Technische Universität Karlsruhe, Germany), **Testing Electrical Insulation Materials for Sealed Refrigeration Systems**, *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 8, pages 268 ff, 1956 (RDB6654)

compatibility, motor materials

E. A. Beacham and R. T. Divers (Carrier Corporation), **Some Practical Aspects of the Dielectric Properties of Refrigerants**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 63, pages 33-40 and 108-109, July 1955 (10 pages with 14 figures and 5 tables, RDB4562)

R-11, R-12, R-21, R-22, R-113, R-114, R-290, R-500, R-41-12; dielectric properties both alone and with water and oil contaminants

G. J. Bich, J. R. Kweicinski, and F. A. Sattler (Westinghouse Electric Corporation), **Effect of Composition of Polyester-Amide-Imide Wire Enamels on Refrigerant 22 Resistance**, paper 71C38EI-40, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 126-128, 1971 (3 pages with 6 figures and 2 tables, RDB6661)

R-22, compatibility, motor materials, test methods

H. J. Borchardt (E. I. duPont de Nemours and Company), **The Reaction of Fluorohydrocarbon Refrigerants with Refrigeration Machinery Oils**, *Kältetechnik-Klimatisierung*, volume 7, number 9, pages 345-347, 1979 (3 pages, RDB3515)

compatibility, lubricants

H. J. Borchardt, **New Findings Shed Light on Reactions of Fluorocarbon Refrigerants**, *DuPont Innovation*, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, volume 6, number 2, Winter 1975; republished as bulletin RT-58, DuPont,

May 1979 (6 pages with 4 figures and 2 tables, RDB3731)

R-11 (decomposes into chlorine and R-112); R-12 (forms chlorine and R-114 when initially pyrolyzed, then R-11 and R-13 a "disproportionation" reaction; the final products of long-term pyrolysis are R-13, chlorine, and carbonaceous solids); R-13 (decomposes into chlorine and R-116); R-22 (described as "one of the least stable" fluorocarbon refrigerants based on experimental tests; pyrolysis of R-22 to manufacture tetrafluoroethylene, the DuPont Teflon(R) monomer); R-114 (decomposes, in part, into R-12); and R-115 (decomposes, in part, into R-13); reactions with oil; reactions of aluminum with R-12 and oil; stabilization with 1% R-744A (nitrous oxide)

W. R. Brisken (General Electric Company), **Moisture Migration in Hermetic Refrigeration Systems**, national meeting paper (42nd Semiannual Meeting), *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 63, pages 42-49 and 109-110, July 1955 (RDB6616)

R-12, R-22; gravimetric, titrimetric (Karl Fischer), electric conductometric, and infrared-spectrophotometric methods

D. J. Bushouse (General Electric Company), **Degradation of Polyester Films by Alcohols when Used as Additives in Refrigeration Systems**, Annual Meeting (Denver, CO, June 1961), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA; republished in *ASHRAE Journal*, ASHRAE, volume 3, number 9, pages 61-64, September 1961 (4 pages with 7 figures and 2 tables, RDB2301)

R-12, R-22, naphthenic mineral oil (Witco Suniso(R) 3GS)

R. C. Cavestri and D. L. Schooley (Imagination Resources, Incorporated, IRI), **Compatibility of Manufacturing Process Fluids with R-134a and Polyolester Lubricant**, report DOE/CE/23810-55, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1996 (32 pages with 12 tables, available from JMC as RDB6805)

This report identifies processing fluids known to be used in the manufacture of compressors and other components for air-conditioning and refrigeration equipment. The objective was to investigate whether these fluids contribute to formation of acids might corrode metals or other materials that may block capillary tubes, expansion valves, filters, and desiccants. 64 fluids were tested for compatibility with R-134a and a dried, pentaerythritol ester mixed acid lubricant (ICI Emkarate(TM) RL 32H), indicated as containing no additives. Solutions or suspensions of the process fluid residues in the polyolester (POE) lubricant were heated for 14 days at 175 °C (347 °F) in evacuated, sealed glass tubes containing polished valve steel (Sandvik) coupons. The report outlines the methods used to prepare the residues or solutions of the fluids. Miscibility tests were performed in a 90/10 mixture by weight of R-134a and the POE with the fluid residue contaminants, and then scanned in 10 °C (18 °F) increments from -40 °C (-40 °F) for signs of turbidity, haze formation, or oil separation. Their observation was deemed a sign of immiscibility. Tables report the visual condition of the POE, soluble iron, total acid number (TAN), and critical miscibility of the aged mixtures for uncured and uncured sealants and the other fluids. No interpretations or conclusions are given for the data presented. The brazing fluxes tested were Lucas-Milhaupt Incorporated *Handy Flux D*, J. W. Harris *Stay Silv White*, and Novamax *No Rez 65*. Machining coolants included Solene Industrial Lubricants *1000*, Cincinnati Milacron *Cimstar 3700T* and *40 Pink*, Castrol Industrial Central Incorporated *Safety Cool 800 / Syntilo 9954*, Chemtool *CT500*, Oakite *Controlant 127S* and *3000ss*, and Diversey-Dubois *Lubricoolant Tec*. The detergents, degreasers, and cleaners examined included Brulin Corporation *815GD* and *815QR*; Solvox Manufacturing Company *Special 474*; Florida Chemical Company *D-Limonene*; Oakite *Okemclean*, *Improclean 1300*, *Rustripper*, *LSD*, *31*, and *77*; Parker-Amchem *Parco 142*; and Diversey-Dubois *Super Terj* and *ISW-29*. Iron phosphatizers included Oakite *Cryscoat 747*, *1127*, *2147*, and *Ultra Seal (Rinse)*. Tested lubricants were Schrader-Bellows *F4422 Oil*, Castrol *Honilo 480*, Etna Products *Master Draw 566* and *1969A1*, Witco *Suniso 160* and *3GS*, Oakite *Formula 59*, Benz Pol Company *Rex Draw 176*, and Oak International *11-B* and *Oil 50-5*. Rust inhibitors and preventatives included Birchwood Casey *Dri-Touch IRP1*, Castrol *Rustilo DW924*, Research Metal Fluids *Resco Oxy Kleen 4926A*, *Koate Syn*, and *Ultra Koate XP*, Almco *2420*, Novamax *R44*, Diversey-Dubois *E-314* and *ICS-423*, Quaker Chemical *Ferracote 368*, Chemical Technologies *Protech 1300*, Chem Tool *CT625*, Oakite *Inpro-tect 600* and *670*, *Renovator*, and *Special Protective Oil*, Puma Technologies *Meca Lube*, and Met-Chem *211*. Tested sealants were Loctite *515*, *640*, and *RC 1620* as well as Oakite *Renovator*. Eight appendices tabulate the published compositions and working concentrations for these fluids.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lu**

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bricants with Engineering Plastics, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, pages 349-360, May 1994 (12 pages with 1 table, RDB4566)

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Compatibility of Refrigerants and Lubricants with Engineering Plastics**, report DOE/CE/23810-15, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, September 1993 with December 1993 revisions (182 pages with 7 figures and 106 tables, available from JMC as RDB4103; type on page 74 is small and may be difficult to read)

This report provides extensive compatibility information on 23 engineering plastics with 10 refrigerants, 7 lubricants, and 17 refrigerant-lubricant combinations. An introduction notes the complexities of both materials selection and application-specific influences, such as changes in environmental conditions and residual molding stresses. A narrative outlines the experimental methods used, including modifications to standard test procedures. Six figures depict the apparatus used in the different tests. The report then presents significant findings. 23 summaries provide generic and trade names for the plastics, the molecular structure if published, a description, and tabular findings for total acid number (TAN), tensile change, and elongation change. The report concludes that the refrigerants and lubricants seemed to have no dramatic effects on most of the plastics tested. Most absorbed some refrigerant and lubricant, which softened the plastics slightly. The most prominent observation was a decrease in tensile strength and elongation due to heating alone. Had this effect not been observed by control tests with air, the study would have concluded that all of the plastics tested were incompatible. In fact, only three (acrylonitrile-butadiene-styrene terpolymer, polyphenylene oxide, and polycarbonate) were affected severely enough to be considered incompatible with HFC refrigerants and lubricants. The report also notes that the analyses would have been clearer with prior annealing and dehydration; special attention is suggested for PET and PBT. Finally, the report notes that some form of extractable component can be obtained whenever any plastic is used with polar refrigerants and lubricants. The plastics included polyphthalamide (Amoco Amodel(R) AD-1000 HS), acrylonitrile-butadiene-styrene terpolymer (ABS, GE Cycolac(R) GPM 4700), acetal (DuPont Delrin(R) II 11500), phenolic (Hooker Durez(R)), polyvinylidene fluoride (Atochem Kynar(R) 720), polycarbonate (GE Lexan(R) 161), modified polyphenylene oxide (PPO, GE Noryl(R) 731), polypropylene (Himont Profax(TM) 6331 NW), polyarylsulfone (Amoco Radel(R) A-200), polyethylene terephthalate (PET, DuPont Rynite(R) 530), polyphenylene sulfide (PPS, GE Supec(TM) G401), polytetrafluoroethylene (PTFE, DuPont Teflon(R)), high strength polyamide-imide (PAI, Amoco Torlon(R) 4203L), 12% graphite polyamide-imide (PAI, Amoco Torlon(R) 4301), polyetherimide (PEI, GE Ultem(R) 1000), modified polyetherimide (PEI, GE Ultem(R) CRS 5001), polyaryletherketone (PAEK, BASF Ultrapek(R)), polybutylene terephthalate (PBT, GE Valox(R) 325 PBT), polyimide-DF (PI-DF, DuPont Vespel(R) DF), polyimide-DF-ISO (PI-DF-ISO, DuPont Vespel(R) DF-ISO), poly(aryl ether ether ketone) (PEEK, ICI Victrex(TM) PEEK 450 G), liquid crystal polymer (LCP, Amoco Xydar(R) MG450), and polyamide nylon 6/6 (DuPont Zytel(R) 101). The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, and R-152a. The lubricants included a mineral oil (MO, BV Associates R0-15); an alkylbenzene (AB, Shrieve Zerol(R) 150); three polyalkylene glycols (PAGs), namely polypropylene glycol butyl monoether (ICI Emkarox(R) VG32), polypropylene glycol diol (Dow P-425), and a modified polyglycol (AlliedSignal BRL-150); and two polyolesters (POEs), namely pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), and pentaerythritol ester branched acid (Henkel Emery(R) 2927-A). Appendices provide further details. The first two list the commercial names of the products tested and summarize the molding specifications and conditions for the plastics. The next comprises seven tables that summarize the changes for immersions in the individual lubricants at 60 and 100 °C (140 and 212 °F). Observations of particulates, cracking, crazing, softening, and color change are presented. Quantitative data are provided for dimensional (length, width, and thickness) and weight changes. Ten tables then summarize corresponding changes following exposures to the refrigerants at room temperature and 60 °C (140 °F) for 14 days. 11 tables summarize the creep modulus of the plastics at 10-300 hours for immersions in air and the 10 refrigerants with POE branched acid. 36 tables summarize physical, tensile, and elongation changes following exposures to refrigerant-lubricant mixtures. The last three appendices document the TANs of thermally aged lubricants with and without plastics, tensile properties of plastics after lubricant immersions, and temperature and dehydrating effects on the plastics.

S. Corr, P. Dowdle, G. Tompsett, R. W. Yost, T. W. Dekleva (ICI Klea), J. Allison, and R. Brutsch (Von Roll Isola, Switzerland), **Compatibility of Non-Metallic Motor Components with R-22 and R-502**

Replacement Refrigerants, seminar presentation (ASHRAE Winter Meeting, New Orleans, LA, 24 January 1994), ICI Klea, Wilmington, DE, January 1994 (32 pages with 32 presentation charts, available from JMC as RDB4216)

These presentation charts provide information on materials compatibility tests of insulation materials, tapes, resins, laminates, cable sheaths and ties, and plastics for motors for hermetic compressors with refrigerants and lubricants. The tests performed gauged changes in appearance, weight, volume, and hardness following autoclave tests at 130 °C (266 °F) for 14 days. The charts outline the test procedures, provide details (composition and application) of the materials tested, and present the findings. The tested materials included a composite of polyethylene terephthalate (PET) between two polyester felts impregnated with resin (Myoflex PVS), a composite of PET between two pieces of polyamide paper impregnated with resin (Myoflex N), glass fiber tape impregnated with epoxy varnish (Vetroflex 253.13), glass fiber tape impregnated with polyurethane varnish (Vetroflex 253.10), composite of mica paper and glass fabric impregnated with epoxy resin (Samicatherm 366.28), polyester fleece tape impregnated with pigments and flexible epoxy resin (Epoflex 215.01), composite of mica, glass threads, and polyester film with impregnated with acrylic (Filosam 326.52-11), composite of mica, glass threads, and polyester film with impregnated with epoxy (Filosam 326.52-30), composite of mica and glass fabric impregnated with polyester-imide (Samicatherm 366.58 with resin 3308), composite of mica and glass fabric and polyester film impregnated with polybutadiene resin (Isomica 326.04), and composite of mica and glass fabric and polycarbonate film impregnated with polybutadiene resin (Isomica 326.95-66) insulations. They also included unsaturated polyester-imide resin containing styrene as a thinner (resin 3316), solventless unsaturated polyester-imide resin (resin 3305), unsaturated polyester-imide resin without styrene (resin 3350), modified epoxy resin with little solvent (resin 3405), and modified unsaturated polyester-imide without styrene (resin 3360) winding resins. They also included modified cross-linked polyolefin (Exar-500) and diacetate fibers, PET film, and polyamide paper coated with polyester/polyurethane (2MN-180) lead wires; silicone rubber and synthetic yarn braid impregnated with polyurethane (Siwo-Kul) cable; stabilized rayon impregnated with resin (RT8) tying tape; impregnated polyester braid (Siligaine) cable sleeving; polyester nonwoven fleece impregnated with carbon particles conductive tape; polyester fabric impregnated with silicone carbide and epoxy resin semiconductive tape; woven glass cloth laminated with epoxy resin (G11) dielectric laminate; and woven glass cloth laminated with polyester resin (GP03) laminate for terminal boards. They also included THEIC modified polyester (Thermex 180 PZ/2), polyester-imide coated with polyamide-imide (Thermex 200 PZ/2), two modified polyester-imide (Thermex 305-1 and 305-2), modified polyester-imide coated with polyamide-imide (Thermex 306), two self bonding, modified polyamide-imide (Thermibond 158 and 164) enameled motor winding wires; hard phenolic resin (Varnih 2004 HFP), modified alkyd polyester resin (Varnih 2005 HFP), and modified polyester-imide resin (Varnih 2053 HFP) winding varnishes; glass filament fused with synthetic yarn (Daglas) for use with enameled wire; polytetrafluoroethylene (PTFE) for gaskets, seals, and insulation; polyamide (nylon 6,6) molding material; and polybutyl terephthalate (PBT) for electrical terminal blocks. These 40 materials were tested with neat R-22, R-32, R-134a, and R-32/134a (30/70); R-22 with mineral oil (MO, Witco Suniso(R) 3GS); R-32 and R-32/134a with two ester lubricants (ICI Emkarate(TM) 68S and 32S); and R-22 with an ester (ICI Emkarate(TM) 32S). Eight tables present subjective observations ("ok" or "x") after exposures. 16 figures then show the weight, volume, and hardness changes as percentages. A final chart present three conclusions: 1) the materials generally performed as well or better in the hydrofluorocarbon (HFC)/ester exposures than in R-22/MO, 2) HFCs and esters appear compatible with many motor materials, and 3) accelerated thermal aging can be harsher than actual application.

S. Corr, T. W. Dekleva, P. Dowdle, G. Tompsett (ICI Klea), J. Allison, and R. Brutsch (Von Roll Isola, Switzerland), **Compatibility of Non-Metallic Motor Components with R22 and R502 Replacement Refrigerants**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, pages 507-512, October 1993 (6 pages with 20 figures and 3 tables, RDB3A24)

This paper presents materials compatibility data for motor insulation materials with hydrofluorocarbon (HFC) refrigerants R-32, R-125, and R-134a and a neopentyl polyolester lubricant (ICI Emkarate(TM), a mixed acid pentaerythritol ester). An introduction and table explain the need for HFCs to replace R-22 and R-502 and the associated need to change lubricants from traditional mineral oils. The tests performed gauged changes in appearance, volume, hardness, and weight following autoclave tests at 130 °C (266 °F) for 14 days at autogenous pressures; moisture content also was determined prior to the

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tests. The paper outlines the test procedures, provides details (composition and application) on the materials tested, and present the findings. The tested materials included a composite of polyethylene terephthalate (PET) between two polyester felts impregnated with resin (Myoflex PVS), a composite of PET between two pieces of polyamide paper impregnated with resin (Myoflex N), glass fiber tape impregnated with epoxy varnish (Vetroflex 253.13), glass fiber tape impregnated with polyurethane varnish (Vetroflex 253.10), composite of mica paper and glass fabric impregnated with epoxy resin (Samicatherm 366.28), polyester fleece tape impregnated with pigments and flexible epoxy resin (Epoflex 215.01), composite of mica, glass threads, and polyester film with impregnated with acrylic (Filosam 326.52-11), composite of mica, glass threads, and polyester film with impregnated with epoxy (Filosam 326.52-30), composite of mica and glass fabric impregnated with polyester-imide (Samicatherm 366.58 with resin 3308), composite of mica and glass fabric and polyester film impregnated with polybutadiene resin (Isomica 326.04), and composite of mica and glass fabric and polycarbonate film impregnated with polybutadiene resin (Isomica 326.95-66) insulations. They also included unsaturated polyester-imide resin containing styrene as a thinner (resin 3316), solventless unsaturated polyester-imide resin (resin 3305), unsaturated polyester-imide resin without styrene (resin 3350), modified epoxy resin with little solvent (resin 3405), and modified unsaturated polyester-imide without styrene (resin 3360) winding resins. They also included modified cross-linked polyolefin (Exar-500) and diacetate fibers, PET film, and polyamide paper coated with polyester/polyurethane (2MN-180) lead wires; silicone rubber and synthetic yarn braid impregnated with polyurethane (Siwo-Kul) cable; stabilized rayon impregnated with resin (RT8) tying tape; impregnated polyester braid (Siligaine) cable sleeving; polyester nonwoven fleece impregnated with carbon particles conductive tape; polyester fabric impregnated with silicone carbide and epoxy resin semiconductive tape; woven glass cloth laminated with epoxy resin (G11) dielectric laminate; and woven glass cloth laminated with polyester resin (GP03) laminate for terminal boards. They also included theic modified polyester (Thermex 180 PZ/2), polyester-imide coated with polyamide-imide (Thermex 200 PZ/2), two modified polyester-imide (Thermex 305-1 and 305-2), modified polyester-imide coated with polyamide-imide (Thermex 306), two self bonding, modified polyamide-imide (Thermibond 158 and 164) enameled motor winding wires; hard phenolic resin (Varnih 2004 HFP), modified alkyd polyester resin (Varnih 2005 HFP), and modified polyester-imide resin (Varnih 2053 HFP) winding varnishes; glass filament fused with synthetic yarn (Daglas) for use with enameled wire; polytetrafluoroethylene (PTFE) for gaskets, seals, and insulation; polyamide (nylon 6,6) molding material; and polybutyl terephthalate (PBT) for electrical terminal blocks. These 40 materials were tested with neat R-22, R-32, R-134a, and R-32/134a (30/70); R-22 with mineral oil (MO, Witco Suniso(R) 3GS); R-32 and R-32/134a with two ester lubricants (ICI Emkarate(TM) 68S and 32S); and R-22 with two same esters. A tables presents subjective observations ("ok" or "x") after exposures. 20 figures then show the hardness, volume, weight changes as percentages. The paper concludes that the materials appeared to perform as well or better in the HFC and HFC/ester exposures as in R-22 and R-22 with MO. Incomplete data for R-125 and R-125 with ester suggests comparable behavior to that with R-32 and R-134a. The paper comments further on the harshness of the tests and resulting impacts on resins and cables.

R. T. Divers (Carrier Corporation), **Electrical Insulation and the Hermetic Motor**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 65, number 8, pages 33-38 and 60-62, August 1957 (9 pages with 9 figures and 4 tables, RDB6638)

suitability and compatibility of motor materials, magnet wires, insulating sheet materials, varnishes and impregnants

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Electrical Sheet Insulation Under Retrofit Conditions**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 175-180, July 1996; republished as report DOE/CE/23810-72B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (10 pages with 2 tables, available from JMC as RDB6836)

This paper summarizes tests conducted on six electrical sheet materials used in hermetic motors for refrigeration compressors, to determine whether prior exposure to an original refrigerant and mineral oil would affect compatibility with an alternative refrigerant and lubricant after retrofit. The materials were exposed first to the original refrigerant and lubricant and then to the alternatives, for 500 hours at elevated temperature for each refrigerant-lubricant system. R-11, R-12, R-22, and R-502 were tested as original refrigerants; R-123, R-134a, R-245ca, R-404A, and R-407C were tested as retrofit alternatives,

the last four with polyolester (POE) lubricants. The test materials included a standard polyester film (DuPont Mylar(R) 900 MO), a low oligomer polyester film (ICI Melinex(R) 228), a polyester composite (Westinghouse Dacron-Mylar-Dacron(R)), an aramid fiber mat (DuPont Nomex(R) 410 10 mil), an aramid fiber mica mat (DuPont Nomex(R) Mica 418), and an aramid mat, polyester film composite (Westinghouse Nomex-Mylar-Nomex(R)). These insulation sheets were tested for tensile strength, elongation, and dielectric breakdown. The paper outlines the test methods and materials, provides a qualitative table of findings, and discusses the specific observations for each material tested. It concludes that the tested materials appeared to be as compatible with the alternatives as with the original refrigerants and lubricants. One exceptions was sheet insulation containing the aramid fibre mat, which showed delamination and blistering particularly after removal of absorbed refrigerant at high temperature. A second was polyethylene terephthalate (PET), which became embrittled. Subsequent tests, under extremely dry conditions, showed that embrittlement of the PET materials could be attributed to moisture present during the exposure.

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of R-245ca with Motor Materials Under Retrofit Conditions**, presentation (ASHRAE Annual Meeting, San Diego, CA, 24-28 June 1995), report DOE/CE/23810-62A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 28 June 1995 (4 pages with 20 presentation charts including 9 tables, available from JMC as RDB5802)

A series of presentation charts briefly outlines interest in R-245ca as a candidate to replace R-11 and R-123. It then relates the present compatibility study to prior, published work by the authors that used the same approach. The charts describe exposures of materials to R-11 or R-123 with mineral oil followed by R-245ca and an unidentified, polyolester lubricant. Data are tabulated for varnishes, magnet wire, sheet insulation, and nitrile and neoprene elastomers. The charts note that most materials appear compatible with R-245ca under retrofit conditions. Concerns are noted with aramid-polyethylene terephthalate (PET)-aramid sheet insulation due to blistering and to shrinkage of neoprene. The final chart notes that the flammability, toxicity, efficiency, and cost of R-245ca and/or blends containing it are unresolved.

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials Under Retrofit Conditions**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 159-168, October 1995; republished as paper DOE/CE/23810-65A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1995 (10 pages with 2 tables, available from JMC as RDB5A56)

This paper summarizes tests conducted on motor materials, to determine whether prior exposure to the original refrigerant and mineral oil would affect compatibility with an alternative refrigerant and lubricant after retrofit. The materials were exposed first to the original refrigerant and lubricant and then to the alternatives, for 500 hours at elevated temperature for each refrigerant-lubricant system. R-11, R-12, R-22, and R-502 were tested as original refrigerants; R-123, R-134a, R-245ca, R-404A, and R-407C were tested as retrofit alternatives, the last four with polyolester (POE) lubricants. The test materials included motor insulation, magnet wire varnishes, sleeving, tapes, and tie cord. The paper outlines the test methods and materials, provides a qualitative table of findings, and discusses the specific observations for each material tested. It concludes that the tested materials appeared to be as compatible with the alternatives as with the original refrigerants and lubricants. One exceptions was sheet insulation containing DuPont Nomex(R) sheet insulation, which showed delamination and blistering particularly after removal of absorbed refrigerant at high temperature. A second was polyethylene terephthalate (PET) sheet and sleeving insulation, which became embrittled. Subsequent tests, under extremely dry conditions, showed that embrittlement of the PET materials could be attributed to moisture present during the exposure.

R. G. Doerr and T. D. Waite (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials Under Retrofit Conditions**, report DOE/CE/23810-51B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 12 January 1995 (86 pages with 66 tables, available from JMC as RDB5511)

This interim report summarizes a study of the compatibility of materials used in motors, for hermetic compressors, with refrigerants and lubricants. These materials were tested by exposures first to "original" refrigerant-oil mixtures and then to alternative refrigerant-lubricants mixtures. The sequential, 500-hour exposures simulate the effects of retrofit. Some samples were exposed to the original refrigerant-oil mixture for a total of 1000 hours as a control. The

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report identifies the materials used, test procedures, and sample evaluations and quantities. It summarizes the status of the work, recommendations for further tests, and significant results. Testing was performed in accordance with UL Standard 2171. The original and retrofit combinations were R-11/paraffinic mineral oil (MO, Penreco Sontex 300LT) and R-123/mineral oil (same), R-12/naphthenic MO (Witco Suniso(R) 3GS) and R-134a/polyolester (POE, CPI(R) Soltest(R) 68), R-502/MO (Suniso(R) 3GS) and R-404A/POE branched acid (Castrol Icematic(R) SW32), and R-22/MO (Suniso(R) 3GS) and R-407C/POE mixed acids (ICI Emkarate(TM) RL 32H). The magnet wire insulations tested were a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a polyester imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical), and a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000). They were tested for dielectric breakdown and burnout strength. The varnishes included a water-base epoxy phenolic (Schenectady Isopoxy(R) 800), a solvent epoxy phenolic (P. D. George 923), and a solvent epoxy (Sterling(R) U-475 EH). Coated helical coils tested for bond strength. The sheet insulations tested were a standard polyester film (DuPont Mylar(R) 900 MO), a low oligomer polyester film (ICI Melinex(R) 228), a polyester composite (Westinghouse Dacron-Mylar-Dacron(R)), an aramid fiber mat (DuPont Nomex(R) 410 10 mil), an aramid fiber mica mat (DuPont Nomex(R) Mica 418), and an aramid mat, polyester film composite (Westinghouse Nomex-Mylar-Nomex(R)). These insulation sheets were tested for tensile strength, elongation, and dielectric breakdown. The spiral-wrapped sleeving materials tested were a polyester film (Insulations Sales Mylar(R)) and an aramid mat, polyester film composite (Insulations Sales Nomex-Mylar(R)). The lead wires tested were a polyester composite (A. O. Smith Dacron-Mylar-Dacron(R)) and a polyester, fluoropolymer composite (A. O. Smith Dacron-Teflon-Dacron(R)). The sleeving and lead wires were tested for dielectric breakdown. Other materials tested were a polyester tie cord (Ludlow Textiles); braided polyester, acrylic binder assembly tape; and polyester mat assembly tape. They were tested for tensile strength and elongation. Assembled motorettes with the three wire types were tested for their ability to withstand applied voltages. In addition, all materials were inspected visually. The tests performed to date generally found the materials exposed to be compatible. Concerns are noted with embrittlement of polyethylene terephthalate (PET) sheet and sleeving insulation as well as delamination and blistering of the Nomex sheet insulation in R-12, R-22, and R-502. Also, the solvent epoxy varnish separated from the metal surface in R-123, possibly due to the condition of the metal surface. The causes of these problems are being investigated; an appendix in the report indicates that some of materials may have been inadequately dried in testing.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Electrical Sheet Insulation**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, pages 493-504, May 1994 (12 pages with 9 tables, RDB4A28)

This paper summarizes an investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on sheet insulation materials for hermetic compressor motors. The introduction outlines the mechanisms by which insulation properties are impacted, including absorption of refrigerants, subsequent desorption, and solvent extraction. It notes that absorption may change the dielectric strength or physical integrity. Absorption can cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from dissolving of unpolymerized materials to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. The paper outlines the experimental procedures followed, which comprised immersions in liquid refrigerant or refrigerant-lubricant pairs at 2068 kPa (300 psia). Properties were measured immediately after 500 hr exposures and again after baking at 150 °C (302 °F) in air, to remove absorbed refrigerant. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca. The lubricants included naphthenic mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), POE branched acid (Henkel Emery(R) 2927), a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32), PAG modified with a fluoroalkyl group (AlliedSignal BRL-150), and a PAG diol (Dow Chemical P425). The sheet insulations tested were Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) 900 MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. Tabular results are presented and discussed for weight changes for 17 refrigerant-lubricant pairs, tensile strength, moisture changes as an

indication of potential hydrolysis and embrittlement, weight and flexibility changes, and effects on dielectric strength. The paper concludes that the combinations of R-22 with mineral and alkylbenzene lubricants have the greatest effects on motor materials. Whereas these systems have an excellent history of reliability with many of the materials tested, the alternative refrigerants and lubricants tested are expected to be reliable with most materials.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Alternative Refrigerants with Varnished Magnet Wire**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, pages 513-517, October 1993; republished as paper DOE/CE/23810-23, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, October 1993 (5 pages with 4 tables, available from JMC as RDB3A22)

This paper summarizes an investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on varnished magnet wires for hermetic compressor motors. The introduction discusses refrigerant compatibility with polymeric insulation material, citing absorption and extraction as the primary modes of interaction. It notes that absorption may change the dielectric strength or physical integrity. Absorption can cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from embrittlement to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. A table gives the change in weight of varnish disks following 500 hour exposures in the refrigerants (and nitrogen as a control) and a subsequent air bake. Three additional tables summarize change in bond, burnout, and dielectric strength following similar exposures of varnish-coated magnet wire. The paper notes that absorption of R-123 by most motor materials was higher than for other refrigerants. However, absorption of R-22, R-32, R-134, and R-152a followed by desorption, at higher temperatures, resulted in greater damage. These results suggest that high internal pressures and the desorption rate are as important as the amount of refrigerant absorbed. These changes decreased bond strength by as much as 95%, dielectric strength by as much as 70%, and decreased the physical integrity of the materials. Polyester-glass served magnet wire showed the highest burnout resistance and was influenced less by the refrigerants. Of the refrigerants tested, R-22 produced the greatest effects on the motor materials. Because R-22 has an excellent reliability history with many of them, the article concludes that the alternative refrigerants tested are expected to be compatible with most materials. Exposures were at 90 °C (194 °F) for R-22, R-123, R-124, R-134, R-134a, R-142b, and R-152a; R-32, R-125, R-143a were tested at 60 °C (140 °F) and R-245ca at 121 °C (250 °F). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide imide and epoxy saturated glass, and polyester imide overcoated with polyamide-imide, though the paper presents data only for the first.

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 8, pages 42-47, August 1993 (6 pages with 3 tables, RDB3A04)

This article summarizes a detailed investigation (see RDB3857) of the effects of 11 refrigerants and 17 refrigerant-lubricant combinations on 24 insulating materials for hermetic compressor motors. The introduction identifies absorption, extraction, and/or chemical dissolution as the primary deterioration mechanisms. It notes that absorption may change the dielectric strength or physical integrity or cause excessive swelling, softening, or decreased strength. Rapid desorption may cause blisters, crazing, surface craters, delamination, or bubbles within the insulating materials. Extraction of materials may result in a range of effects from embrittlement to complete dissolution. Extraction and dissolution, in turn, may cause other components to stick or lead to clogging of passage such as capillary tubes. Three tables classify motor materials as *compatible*, indicating a *concern*, or *incompatible* with pure refrigerants or refrigerant/lubricant mixtures. The effects of the pure refrigerants generally were greater than in combination with lubricants. The article notes that absorption of R-123 was higher than for other refrigerants by most motor materials. However, absorption of R-22, R-32, R-134, and R-152a followed by desorption, at higher temperatures, resulted in greater damage. These results suggest that high internal pressures and

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the desorption rate are as important as the amount of refrigerant absorbed. These changes decreased bond strength by as much as 95%, dielectric strength by as much as 70%, and decreased the physical integrity of the materials. Magnet wire with polyester-glass serving showed the highest burnout resistance and was influenced less by the refrigerants. Of the refrigerants tested, R-22 produced the greatest effects on the motor materials. Because R-22 has an excellent reliability history with many of them, the article concludes that the alternative refrigerants tested are expected to be compatible with most materials. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca. The lubricants included naphthenic mineral oil (Wit-co Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), polyolester (POE) mixed acid (ICI Em-karate(TM) RL 22H, formerly RL 244), POE branched acid (Henkel Emery(R) 2927), a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32), PAG modified with a fluoroalkyl group (AlliedSignal BRL-150), and a PAG diol (Dow Chemical P425). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and polyester imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical). The sheet insulations tested were Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) 900 MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. The spiral-wrapped sheet insulations tested were Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R). The lead wires tested were A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R). Other materials tested were woven glass tape (Carolina Narrow Heat Cleaned Fiberglass), heat shrinkable braided polyester tape (Electrolock), and glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles).

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, final report DOE/CE/23810-13 volume I, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1993 (166 pages with 118 tables, available from JMC as RDB3857)

This report presents very detailed compatibility information for 24 materials used in hermetic compressor motors with 11 refrigerants and 17 refrigerant-lubricant combinations. Volume I outlines the project, documents the test procedures, identifies the materials tested, discusses the findings, and provides both compatibility charts (*yes*, *concern*, *incompatible*) and summary tables of measured results. Companion volumes (see RDB3858 and RDB3859) supply the recorded data (approximately 40,000 measurements) for the exposures, and an unpublished volume contains photographs of the motor materials after exposures. The report concludes that the alternative refrigerants tested are expected to be compatible with most materials. This finding is based on comparisons to R-22, which produced the greatest effects on motor materials, but has an excellent reliability history with many of them. The report notes that absorption of R-123 by most motor materials was higher than for other refrigerants. However, absorption of R-22, R-32, R-134, and R-152a followed by desorption, at higher temperatures, resulted in greater damage. These results suggest that high internal pressures and the desorption rate are as important as the amount of refrigerant absorbed. Desorption caused blisters, cracks, internal bubbles, and delamination in some materials. These changes decreased bond strength by as much as 95%, dielectric strength by as much as 70%, and decreased the physical integrity of the materials. Magnet wire with polyester-glass serving showed the highest burnout resistance and was influenced less by the refrigerants. The refrigerant-lubricant combinations generally had less effect on the motor materials than the pure refrigerants. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca. The lubricants included mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150), polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244), POE branched acid (Henkel Emery(R) 2927), a polyalkylene glycol (PAG) butyl monoether (ICI Emkarox(R) VG32), modified PAG (AlliedSignal BRL-150), and a PAG diol (Dow Chemical P425). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and

polyester imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical). The sheet insulations tested were Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) 900 MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228. The spiral-wrapped sheet insulations tested were Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R). The lead wires tested were A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R). Other materials tested were woven glass tape (Carolina Narrow Heat Cleaned Fiberglass), heat shrinkable braided polyester tape (Electrolock), and glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles).

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials - Effects of Refrigerant Exposures on Motor Materials**, final report DOE/-CE/23810-13 volume II, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1993 (270 pages with 234 tables, available from JMC as RDB3858)

This report provides detailed compatibility information for 24 materials used in hermetic compressor motors with 11 refrigerants and 17 refrigerant-lubricant combinations. Volume II contains the recorded measurements before exposures, after exposures to the pure refrigerants, and before and after a subsequent 24-hour bake out, at 150 °C (302 °F), to remove absorbed refrigerant. The refrigerants tested included R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, R-152a, and R-245ca. All exposures were at 90 °C (194 °F) except for R-32 and R-125 at 60 °C (140 °F) and R-245ca at 121 °C (250 °F). The effects of heat alone were gauged by similar exposure to nitrogen (R-728) at both 60 and 90 °C (140 and 194 °F). The data are organized into 13 appendices for nitrogen at each exposure temperature and for each refrigerant. Each appendix contains 18 detailed tables providing measurements before and after exposures and before and after bake out; visual observations also are indicated. Triplicate measurements, except for weights, and average results are indicated for each test. Bond strength is compared to unexposed values for dipped coats of each of six varnishes on each of three magnet wires. The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide-imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and polyester-imide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and waterborne epoxy (Schenectady Isopoxy(R) 800). Burnout resistance and dielectric strength are compared to unexposed values for each varnish on each of the magnet wires and also to unvarnished specimens. Weight change is reported for exposed disks of the varnishes. Weight, tensile strength, elongation, and dielectric strength are compared to unexposed values for six sheet insulations (Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228). Weight change is tabulated for Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R) spiral-wrapped sleeving insulation. Changes in weight and dielectric strength are presented for A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R) lead wire insulations. Weight and breaking load changes are supplied for woven glass tape (Carolina Narrow), heat shrinkable braided polyester tape (Electrolock), glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles). [see RDB-3857 for a summary and RDB3859 for data on exposures to the refrigerant-lubricant combinations]

R. G. Doerr and S. A. Kujak (The Trane Company), **Compatibility of Refrigerants and Lubricants with Motor Materials**, final report DOE/CE/23810-13 volume III, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1993 (370 pages with 324 tables, available from JMC as RDB3859)

This report provides detailed compatibility information for 24 materials used in hermetic compressor motors with 11 refrigerants and 17 refrigerant-lubricant combinations. Volume III contains the recorded measurements before exposures, after exposures to the refrigerant-lubricant mixtures, and before and after a subsequent 24-hour bake out at 150 °C (302 °F), to remove absorbed refrigerant. The measurements are tabulated for exposures at 127 °C (260 °F) to 17 refrigerant-lubricant combinations. R-22 was tested with mineral oil (Witco Suniso(R) 3GS). R-124, R-142b, and R-152a were tested with alkylbenzene (Shrieve Zerol(R) 150). R-134a was tested with a polyolester (POE) mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244); and R-32, R-125, R-134, R-134a, R-143a, and R-245ca with a POE branched acid (Henkel Emery(R) 2927 ISO 32). R-32, R-125, and R-134a were tested with a polyalkylene glycol (PAG) butyl monoether (ICI

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Emkarox(R) VG32); R-125 and R-134a with a modified PAG (AlliedSignal BRL-150); and R-134a with a PAG diol (Dow Chemical P425). The effects of heat alone were gauged by similar exposure to nitrogen (R-728). The data are organized into 18 appendices, covering nitrogen and for each refrigerant. Each appendix contains 18 detailed tables providing measurements before and after exposures and before and after bake out; visual observations also are indicated. Triplicate measurements, except for weights, and average results are indicated for each test. Bond strength is compared to unexposed values for dipped coats of each of six varnishes on each of three magnet wires. The magnet wires included a modified polyester base overcoated with polyamide imide (Phelps Dodge Armored Poly-Thermaleze 2000), a modified polyester base overcoated with polyamide-imide and epoxy saturated glass (Phelps Dodge Armored Poly-Thermaleze Daglass 2000), and polyesterimide overcoated with polyamide-imide (Phelps Dodge / Schenectady Chemical). The varnishes included two solvent epoxies (P. D. George Sterling(R) U-475 EH and 923), a solvent epoxy phenolic (Sterling(R) Y-390 PG), 93% solids epoxy (Sterling(R) ER-610), and 100% solids VPI epoxy (Sterling(R) Y-833), and waterborne epoxy (Schenectady Isopoxy(R) 800). Burnout resistance and dielectric strength are compared to unexposed values for each varnish on each of the magnet wires and also to unvarnished specimens. Weight change is reported for exposed disks of the varnishes. Weight, tensile strength, elongation, and dielectric strength are compared to unexposed values for six sheet insulations (Westinghouse Nomex-Mylar-Nomex(R), Westinghouse Dacron-Mylar-Dacron(R), DuPont Mylar(R) MO, DuPont Nomex(R) 410, DuPont Nomex(R) Mica 418, and ICI Melinex(R) 228). Weight change is tabulated for Insulations Sales Nomex(R), Mylar(R), and Nomex-Mylar(R) spiral-wrapped sleeving insulation. Changes in weight and dielectric strength are presented for A. O. Smith Dacron-Mylar-Dacron(R) and Dacron-Teflon-Dacron(R) lead wire insulations. Weight and breaking load changes are supplied for woven glass tape (Carolina Narrow), heat shrinkable braided polyester tape (Electrolock), glass-acrylic tape (Essex Permacel P247), and polyester tie cord (Ludlow Textiles). [see RDB-3857 for a summary and RDB3858 for data on exposures to the neat refrigerants]

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J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 149-158, Oc-

tober 1995 (10 pages with 8 figures and 4 tables, available from JMC as RDB5A55)

This paper outlines a project and presents selected data from a study of the compatibility of bead and molded-core desiccants with 13 refrigerant-lubricant combinations. The investigation used sealed-tube tests with aluminum, copper, and steel catalysts to gauge desiccant changes. The paper introduces the test materials generically and briefly outlines the methods used. A table compares the results for R-12 and R-134a, showing total acid number (TAN) as well as fluoride, chloride, and organic acid content after aging for eight desiccants. The same data are plotted. The 16 desiccants include samples from two suppliers for each of eight types, namely 3Å and 4Å molecular sieves, alumina, silica gel, and four core types. They include 10-25% molecular sieve and alumina with carbon and 15-30% molecular sieve and alumina without carbon, each with type 3Å and 4Å molecular sieves. The lubricants include a naphthenic mineral oil (MO), alkylbenzene (AB), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). The refrigerant lubricant combinations examined included R-11, R-12, R-22, and R-123 with MO; R-32, R-125, and R-134a with both POE-BA and POE-MA; R-124 with AB; R-143a with POE-BA; and R-152a with AB (or with POE-MA). The paper concludes that R-22 and R-32 decomposed at nearly the same levels and that the polyolester (POE) lubricant decomposed more than did the mineral oil. The paper notes that 3Å molecular sieves performed slightly better than 4Å except in the presence of R-32.

J. E. Field (Spauschus Associates, Incorporated), **Sealed Tube Comparisons of the Compatibility of Desiccants with Refrigerants and Lubricants**, report DOE/CE/23810-54, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, May 1995 (98 pages with 67 tables, available from JMC as RDB5932)

This report presents data necessary to assess the compatibility of bead and molded-core desiccants with 13 refrigerant-lubricant combinations. It is based on sealed-tube tests with aluminum, copper, and steel catalysts. The report generically identifies the test materials, outlines the preparation and analysis methods, and summarizes the desiccant specifications for as-received samples. The moisture content and contaminants of the refrigerant specimens and the moisture content, total acid number (TAN), and ion content of the lubricants are tabulated. A table for each desiccant summarizes findings before and after aging, with both 50 and 1000 ppm of added moisture. These results include liquid and desiccant colors, copper plating, solids formation, steel corrosion, crush strength, fraction of reacted refrigerant based on gas chromatography, TAN, fluoride and chloride ion content in the liquid phase and retained in the desiccant, and organic acid retained in the desiccant. Additional tables detail the crush strength results and the acid anion and gas chromatographic analyses. The 16 desiccants include samples from two suppliers for each of eight types, namely: 3Å and 4Å molecular sieves, alumina, silica gel, and four core types. They include 10-25% molecular sieve and alumina with carbon and 15-30% molecular sieve and alumina without carbon, each with type 3Å and 4Å molecular sieves. The lubricants include a naphthenic mineral oil (MO), alkylbenzene (AB), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). The report presents compatibility data for each of the desiccants with the following refrigerant-lubricant combinations: R-11, R-12, R-22, and R-123 with MO; R-32, R-125, and R-134a with both POE-BA and POE-MA; R-124 with AB; R-143a with POE-BA; and R-152a with AB (or with POE-MA). It also presents a number of conclusions: Addition of 1000 ppm moisture produces no significant difference. The desiccant solid phase contains most of the chloride and fluoride ions for molecular sieves, but not always with alumina and silica gel desiccants. All of the desiccants tested contained chloride, fluoride, and - for most - sulfate and other ions when received, and they do not perform as well in retaining organic anions as they do for inorganic anions. The crush strength was reduced approximately 20% after aging. None of the desiccants tested are compatible with R-32, and steel corrosion seems to be prevalent with the core-type desiccants when aged with POE lubricants. The report notes, however, that the elevated test temperatures may have induced reactions that would not occur in actual systems at lower temperatures.

R. Foon and K. P. Schug, symposium paper E3, *Molecular Rate Processes*, Royal Australian Chemical Institute, Warburton, Australia, August 1975 (possibly 1995) (RDB5213)

decomposition kinetics of various chlorofluorocarbons (CFCs), formation of free radicals as a halocarbon breakdown mechanism

R. Hall, **Magnet Wire in Hermetic Motors, Part II**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 11, number 12, pages 53 ff, December 1969 (RDB6649)

please see pages 6-8 for ordering information

G. R. Hamed, R. H. Seiple, and O. Taikum (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, report DOE/CE/-23810-14, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1994 (538 pages with 519 figures and 117 tables, available from JMC as RDB4501)

This report provides extensive data on the swell behavior of 95 elastomeric gasket and seal materials in 10 refrigerants and 7 lubricants. It also details tensile strength, hardness, weight, and dimensional changes for 25 selected elastomers after thermal aging in refrigerant-lubricant mixtures. The report describes the selections as well as sample verifications for the elastomers, refrigerants, and lubricant. It then discusses resistance to solvent uptake - and resultant swell - based on the degree of crosslinking, the degree of interaction with a solvent (based on the Flory-Rehner equation), the roles of cure level and filler content, and tradeoffs with hardness and brittleness. R-123 generally resulted in the greatest swelling, but EPDM/PP/TPE, butyl rubber/PP TPE, and several vendor-supplied compositions swelled little in this refrigerant. The HFCs generally gave much less swelling than the HCFCs, though the fluoroelastomers and fluorosilicones exhibit high swelling in them. Some vendor compositions are identified that resisted swelling in all refrigerants and lubricants tested. The refrigerants tested included both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, and R-152a). The lubricants included a naphthenic mineral oil (MO, Witco Suniso(R) 3GS), alkylbenzene (AB, Shrieve Zerol(R) 150), and three polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether (ICI Emkarox(R)), a polypropylene glycol diol (Dow P425), and a modified polyglycol (AlliedSignal BRL-150). Two polyolester (POE) lubricants also were included, namely a pentaerythritol ester branched acid (Henkel Emery(R) 2927-A) and a pentaerythritol ester mixed acid (ICI Emkarate(TM) RL 22H, formerly RL 244). Appendices describe the test methodology and identify the elastomer formulations. They include polyisoprene (Natsyn(TM) 2200), polychloroprene (Neoprene(TM) W), isobutyl isoprene (Polysar Butyl), bromobutyl (Polysar X2), chlorobutyl 1068, styrene butadiene rubber (SBR 1502 and Stereon 730A and 840A), nitrile (Chemigum(TM) N206, N300, N615B, and N917), hydrogenated nitrile (Polysar Tomac(TM) A3850 and A4555), fluoroelastomers (DuPont Viton(R) A, B, and GF), fluorinated/chlorinated rubber (KEL-F(TM) 3700), epichlorohydrin homopolymer (Hydrin(TM) H-65), epichlorohydrin copolymer (Hydrin(TM) C-65 and T-75), methyl vinyl silicone (SE-33(TM)), dimethyl silicone (SE-436U(TM)), methyl vinyl phenyl silicone (SE-565U(TM)) silicone (SE-3808U(TM)), fluorinated silicone (LS-63U(TM)), EPDM/polypropylene thermoplastic elastomer (TPE, Santoprene(TM) 201-87, 201-73, 203-40, and 203-50), nitrile/polypropylene TPE (Geolast(TM) 701-87, 701-80, and 701-40), copolyester TPE (Hytrel(TM) 4056, 5526, G6356, and 7246), polysulfide rubber (FA(TM) and ST(TM)), polyurethane (Airthane(TM) PET-95A and PET-60D, Cyanaprene(TM) A-8 and D-55, Millathane(TM) 76 and E-34), chlorosulfonated polyethylene (Hypalon(TM) 20, 40, and 4085), ethylene propylene (EPM, Vistalon(TM) 404 and 707), ethylene acrylic (Vamac(TM) G and B-124MB), chlorinated polyethylenes (Dow CM0136(TM) and 4211P(TM)), ethylene propylene diene (EPDM, Royalene(TM) 552, 525, and 359), and EPDM/butyl TPE (Trefsin(TM)). Another appendix identifies ten gasket materials supplied by ARTI including filled chloroprene (Precision Rubber 2167), acrylonitrile (Precision Rubber 7507), neoprene (Garlock 2930), non-asbestos (Armstrong N-8092, Specialty Paperboard NI-2085G, Victopac 69, and Klinger C-4401), nitrile-aramid (Specialty Paperboard 2099), fluorocarbon (Parker V747-75), and neoprene (Greene, Tweed and Company 956). 95 tables present data on swell after immersions of 1, 3, and 14 days, weight change after 14 days, diameter and weight after removal, and shore hardness after 1 day of drying. 18 figures for each refrigerant and lubricant illustrate diameter changes for the exposed elastomers. Oscillating disk rheometer (ODR) curves are provided for 68 curable elastomers and thermogravimetric analysis (TGA) plots for 94 elastomers. Physical property data before exposures also are given, including modulus, tensile strength elongation at break, and hardness. Infrared (IR) and gas chromatographic (GC) analyses are summarized for the refrigerants and lubricants. A set of tables then identifies the specific refrigerant-lubricant combinations tested and changes in weight, width, thickness, tensile strength, and hardness after aging; the changes in tensile strength also are plotted.

G. R. Hamed and R. H. Seiple (University of Akron), **Compatibility of Refrigerants and Lubricants with Elastomers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 8, pages 173-176, August 1993 (4 pages with 4 tables, RDB3A05)

This article summarizes swell measurements for elastomer compounds comprising various base polymers, filler contents, and cure systems (see RDB3202). The introduction distinguishes between highly-filled gaskets, which require significant compressive forces to be effective, and

more elastic polymers, which depend on internal restoring forces to seal mating components. The article outlines swell measurements on nearly 100 elastomers after submersion in refrigerants and lubricants for 14 days at 60 °C (140 °F). It identifies a second phase of the research, to determine strength retention following extended exposures, for materials found to best resist swelling. The article reviews the theoretical background for solvent uptake and interaction, based on the degree of crosslinking and filling in the material structure. Swell behavior is qualitatively (*good* or *poor*) tabulated for common elastomer classes, including polyisoprene, silicone, polychloroprene, thermoplastic elastomer (TPE), butyl rubber, polysulfide rubber, styrene butadiene rubber (SBR), polyurethane, nitrile, chlorosulfonated and chlorinated polyethylene (PE), fluorinated rubber, epichlorohydrin, ethylene propylene rubber (EPR), ethylene propylene diene monomer (EPDM), and ethylene acrylic. A number of gasket materials supplied by industry also were examined. The refrigerants included both hydrochlorofluorocarbons (HCFCs R-22, R-123, R-124, and R-142b) and hydrofluorocarbons (HFCs R-32, R-125, R-134, R-134a, R-143a, and R-152a). The lubricants included a naphthenic mineral oil, alkylbenzene, and three polyalkylene glycols (PAGs), namely a polypropylene glycol butyl monoether, a polypropylene glycol diol, and a modified polyglycol. Two polyolester (POE) lubricants also are included, namely a pentaerythritol ester branched acid and a pentaerythritol ester mixed acid. The article notes that R-123 generally gave the greatest swelling and HFCs, as a group, the least. Some industrial gasket samples resisted swelling in all refrigerants. The lubricants that showed the most swell for the greatest number of elastomers were mineral oil and alkylbenzene. Outgassing of high pressure refrigerants (e.g., R-22, R-32, and R-125) following exposures may produce surface cracking, surface bubbling, and internal flaws. The article notes that gaskets using a wider, less-expensive range of polymers may be engineered for HFCs because of the limited swell found with them.

J. P. Harrington and R. J. Ward, **Polyester Film Insulation for Hermetic Motors**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 1, number 4, pages 75 ff, April 1959 (RDB-2302)

compatibility, motor materials

J. F. Harris and C. B. Sonnino, **New Insulating Media for Hermetic Motors Require New Tests**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 1, pages 49 ff, 1959 (RDB6652)

compatibility, motor materials

R. Hawley-Fedder, D. Goerz, C. Koester, and M. Wilson (Lawrence Livermore National Laboratory, LLNL), **Investigation of the Breakdown Products Produced from Electrical Discharge in Selected CFC Replacement Fluids**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 163-168, July 1996; republished as report DOE/CE/23810-72C, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (10 pages with 1 figure and 3 tables, available from JMC as RDB6833)

evaluation of R-22, R-134a, and R-507A under simulated alternating current (AC), direct current (DC), and pulsed breakdown conditions; energy deposition into each fluid; major breakdown products after electrical testing under ambient and elevated pressure and temperature and after an AC carryover arc condition in hermetic motors

R. Hawley-Fedder (Lawrence Livermore National Laboratory, LLNL), **Products of Motor Burnout**, report DOE/CE/23810-59D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 April 1995 (16 pages with 4 figures and 4 tables, available from JMC as RDB5814)

This interim report summarizes progress to identify and quantify the products of motor failures in hermetic and semihermetic refrigeration compressors. The study also will assess their corrosive effects on power-supply terminals, evaluate the efficacy of current clean-up procedures, and assess whether hydrofluorocarbon (HFC) refrigerants will increase or decrease the incidence of motor burnouts. The primary focus of this report is on quantitation of breakdown products formed during atmospheric pressure testing. Plots are included of the breakdown fraction as a function of energy deposition for R-22, R-134a, and R-507A. They show the total decomposition products as well as the key products for each of these refrigerants. Tabular data, indicating the identified breakdown products and quantities, also are given. The report notes continued monitoring of literature on chlorofluorocarbon (CFC) refrigerant degradation and breakdown by thermal and electrical mechanisms. It also describes the electrical breakdown tests at atmospheric pressure and describes preparations for similar tests elevated pressures an temperatures as well as during induced motor burnouts.

please see pages 6-8 for ordering information

J. E. Hoffman (Sporlan Valve Company), **Caution: Alcohol at Work**, *RSC*, pages 18-20, August 1971 (3 pages with 1 figure, RDB6668)

clean up of systems that have been saturated with water by flushing with methyl alcohol, cautions for flammability, toxicity, and compressor damage

J. P. Hurtgen (General Electric Company), **Hermetic Motor Life Tests**, paper 71C38EI-36, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 113-116, 1971 (4 pages with 7 figures and 3 tables, RDB6663)

R-22, compatibility, motor materials, test methods

J. P. Hurtgen and A. R. Mounce (General Electric Company), **New Insulation Systems for Hermetic Refrigeration Motors**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 1, number 7, pages 60-62, July 1959 (3 pages, RDB6630)

compatibility, motor materials

T. Iizuka, A. Ishiyama, H. Hata, and T. Sugano (Hitachi Limited, Japan), **Study of Technology for Refrigerant Applications 1. Materials Compatibility for HCFC-22 Alternative Refrigerants**, unpublished paper presented at the Fifth International Refrigeration Conference (Purdue University, West Lafayette, IN), July 1994 (6 pages with 6 figures and 5 tables, limited copies available from JMC as RDB-4866)

This paper presents the findings of materials compatibility tests of R-32, R-125, and R-134a with basic fabrication materials for refrigerators, air conditioners, and other refrigeration systems. A table compares the minimum chemical bond strength, ozone depletion potential (ODP), global warming potential (GWP), and flammability of the three refrigerants and R-22, R-32/134a (30/70), and R-407C [R-32/125/134a (23/25/-52)]. Based on these data, the paper notes that all hydrofluorocarbons (HFCs) are thermally more stable than R-22. A second table gives the viscosity at 40 and 100 °C (104 and 212 °F), pour point, and lower critical solution temperature (LCST) in R-32, R-125, and R-134a for eight polyolester (POE), two carbonate or polycarbonate, and one mineral oil lubricants. The POEs include trimethylolpropane (TMP), pentaerythritol, and neopentylglycol types. Their miscibilities with the cited HFCs and total acid number (TAN) values are plotted, the latter as functions of water and epoxy additive contents. Tables summarize the results of sealed-tube tests of R32, R-125, and R-134a in the presence of aluminum, copper, and iron catalysts. The paper then discusses hydrolysis of the POEs into carboxylic acid and alcohol. It also discusses prevention methods, including drying and use of epoxy-type catchers. Plots show the relative oligomer extraction and tensile strength change of polyethylene terephthalate (PET) motor insulating films. Two tables summarize tests of modified ester-imide, polyamide imide, double coated magnet wires and of six molecular sieve desiccants (UOP 4A-NRG, XH-5, XH-6, XH-7, XH-9, and XH-10C). The paper concludes that TMP ester with epoxy-type acid catcher offers good miscibility with HFCs and improved hydrolytic stability. Further, motor materials for insulating film and magnet wires for R-22 can be used in HFC systems without modification. Developmental molecular sieve XH-10C is the indicated as the best choice at low temperatures with R-32, and drop-in tests with the cited materials yielded satisfactory results.

A. Ishiyama, T. Iizuka, K. Kawashima, K. Sekigami, H. Hata, and T. Sugano (Hitachi Limited, Japan), **Study of Technology for Refrigerant Applications 2. Lubrication of Rotary Compressors in HFC-Based Alternatives**, unpublished paper presented at the Fifth International Refrigeration Conference (Purdue University, West Lafayette, IN), July 1994 (6 pages with 6 figures and 5 tables, limited copies available from JMC as RDB4867)

J. E. Korleski (E. I. duPont de Nemours and Company), **The Performance of PET Motor Insulation in CFC-Free Refrigerant Systems**, *Proceedings of the 20th Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA, Boston, MA, 7-10 October 1991), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, page 190, 1991 (RDB3C15)

The rapid conversion to chlorofluorocarbon (CFC) free refrigerants has prompted reexamination of the performance of polyethylene terephthalate (PET) insulating materials in the presence of the new refrigerant-lubricant systems. Several PET motor films were subjected to sealed-tube aging tests in the presence of CFC-free refrigerants and lubricants. The effects of the type of lubricant, level of moisture, temperature, and time on the physical properties of the motor films were examined. The factors which dominate the motor film's performance were considered. The performance of the films in sealed-tube tests was compared to their performance in other aging tests, such as hydrolytic stability, thermal aging at 160 °C (320 °F), and oligomer extraction, to obtain a correlation of the later test's relative predictive value.

D. E. Kvalnes and H. M. Parmelee (E. I. duPont de Nemours and Company), **Behavior of Freon-12 and Freon-22 in Sealed Tube Tests**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 65, number 11, pages 40-42, 82, 84, and 86, November 1957; republished as bulletin 25, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE (6 pages, RDB2322)

R-12, R-22, factors that influence refrigerant-oil reactions

S. A. Kujak and T. D. Waite (The Trane Company), **Compatibility of Motor Materials with Polyolester Lubricants: Effect of Moisture and Weak Acids**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 425-429, July 1994 (5 pages with 6 tables, RDB4857)

compares results for R-134a with polyolester lubricant to results for R-22 with mineral oil

G. A. Lamont and H. Kumar (APV Baker Therm Division), **Advances in Elastomer Materials for Use in Plate Heat Exchangers**, 29th National Heat Transfer Conference (Atlanta, GA, 8-11 August 1993), American Society of Mechanical Engineers (ASME), New York, NY, 1993 (RDB3B68)

compatibility

R. L. Mays, **Molecular Sieve and Gel-Type Desiccants for Refrigerants 12 and 22**, presented at the Semiannual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (Miami, FL, 25-27 June 1962), ASHRAE, Atlanta, GA, volume 68, pages 330 ff, 1962 (RDB-4922)

R-12, R-22

D. L. McClenahan, **The Significance of Hydrolysis Tests on Film-Insulated Magnet Wire in Predicting Suitability in Hermetically-Sealed Units**, paper CP63-500, *IEEE Conference*, Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 1963 (RDB6636)

compatibility with motor materials, hydrolytic stability

W. McMahon, H. A. Birdsall, G. R. Johnson, and C. T. Camilli (Bell Telephone Laboratories, Incorporated), **Physical Properties Evaluation of Compounds and Materials, Part II: Degradation Studies of Polyethylene Terephthalate**, *Journal of Chemical and Engineering Data*, volume 4, number 1, pages 57-69, January 1959 (13 pages with 23 figures and 22 tables, RDB6628)

compatibility, motor materials, rates of hydrolysis, oxidation, and thermal degradation of PET as functions of temperature, relative humidity, and film thickness; hydrolysis found to be faster than the other two reactions; provides a relation between extents of chemical and physical degradation to determine the time required for the polymer to reach a given degree of degradation; identifies materials and experimental methods with data for DuPont Mylar(R) film and Dacron(R) yarn

G. E. Millward and E. Tschuikow-Roux, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 76, number 3, pages 292-298, 1972 (7 pages, RDB6861)

decomposition kinetics of various chlorofluorocarbons (CFCs), formation of free radicals as a halocarbon breakdown mechanism

Mitsubishi Heavy Industries, Limited, **Prevention of Oxidative Degradation of Lubricating Oils for Refrigeration Compressors**, *Kokai Tokkyo Kono*, Japan, February 1985 (RDB4B19)

lubricant stability

D. Miyatani, K. Shinoda, T. Nakamura, M. Ohta, and K. Yasuda, *Chem. Letters*, pages 795-798, 1992 (4 pages, RDB5253)

decomposition of R-12 over iron catalyst

S. Nishizaki and A. Muramoto, **Evaluation of Hermetic Motor Insulation Systems**, *Proceedings of the Ninth Electrical Insulation Conference* (EIC, Boston, MA, 8-11 September 1969), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 250-253, 1969 (4 pages, RDB2918)

compatibility, motor materials

F. J. Norton (General Electric Company), **Rates of Thermal Decomposition of $CHClF_2$ and CF_2Cl_2**, Contaminants Conference (53rd Annual Meeting, Miami Beach, FL, 4-5 June 1957) American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA; republished in *Refrigerating Engineering*, ASRE (ASHRAE), volume 65, number 9, pages 33-34 and 62-63, September 1957 (4 pages with 4 figures and 4 tables, RDB4114)

R-12 (CCl_2CF_2), R-22 ($CHClCF_2$), stability: decomposition rates for 175-570 °C (347-1048 °F); influences of air, water, metal catalysts (aluminum, copper, and iron), and glass

please see pages 6-8 for ordering information

S. Okada, K. Asano (Hitachi Cable Limited, Japan), Y. Mukoyama, and Y. Osada (Hitachi Chemical Limited, Japan), **A New Class 200°C Enameled Wire**, paper CH1717-8/81, Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 121-125, 1981 (5 pages with 8 figures and 6 tables, RDB6665)

R-12, R-22, compatibility, motor materials: properties of polyester (terephthalic), ester-imide, ester-imide THEIC, amide-imide, poly-imide, amide-imide/ester-imide, and ester-imide/amide-imide

H. M. Parmelee (E. I. duPont de Nemours and Company), **Sealed-Tube Stability Tests on Refrigeration Materials**, paper 1924, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 154-161 and 167-168, 1965 (10 pages with 29 tables, RDB0013)

This paper summarizes an investigation into the stability of fluorocarbon refrigerants alone and in the presence of oils, metals, nonmetallic components of refrigeration systems, and residual cleaning and degreasing agents. It is based on sealed-tube stability tests, performed at elevated temperatures, for periods as long as three years. Results are reported for R-11, R-12, R-13B1, R-22, R-113, R-114, R-115, R-124, R-216, R-C318, R-500, and R-502. The testing included examination of decomposition products, specifically including the fraction converted into other refrigerants. The metals tested included aluminum, brass, cadmium, copper, iron, lead, magnesium, mercury, steel, and zinc. The effects of selected additives and inhibitors, including phenyl alpha naphthylamine, molybdenum disulfide, and tricresyl phosphate (TCP), also were examined. The paper concludes that the life of a system should be longer if made chemically simpler, because every added material provides a possibility of increased chemical reactions.

H. M. Parmelee (E. I. duPont de Nemours and Company), **Permeability of Plastic Films to Refrigerant 12 and Nitrogen**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 66, number 2, pages 35 ff, February 1958 (RDB6646)

R-12, R-728

H. M. Parmelee (E. I. duPont de Nemours and Company), **Solubility of Air in Freon-12 and Freon-22**, presentation (ASRE Spring Meeting, Detroit, MI, 27-30 May 1951); republished in the *Journal of the ASRE*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, pages 573-577, June 1951 (5 pages with 11 figures and 1 table, RDB5702)

This article presents a method to measure small amounts of noncondensable material in liquified gases and applies it to measurement of air solubility in R-12 and R-22. Plots show the solubility of air as functions its partial pressure and temperature for these refrigerants. The solubility relationship is shown to obey Henry's Law; the solubility coefficients are tabulated. Further plots and empirical relations examine the variability of solubility with total pressure, variability with temperature, and distribution of air between the vapor and liquid phases - the last based on Raoult's Law. The article then examines the effect of the liquid discharge rate on air concentration in the liquid and the rate at which air dissolves in the refrigerants, the latter occurring very slowly. The article describes and schematically shows a method and apparatus to analyze air concentrates in refrigerants. Plots show the time required for air to mix with R-12 without agitation and the radical acceleration achieved with agitation by the apparatus presented. The article concludes that the solubility of air in R-12 and R-22 is proportional to the partial pressure of the air and to the total pressure. Moreover, the solubility coefficient increases with decreasing temperature. The findings and apparatus developed afford a practical means to determine small concentrations of air from refrigerant samples.

K. S. Sanvordenker (Tecumseh Products Company), **Materials Compatibility Concerns for Refrigerator-Freezers - A Historic Perspective and a Look to the Future**, paper 3.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 39-44, February 1993 (8 pages with 2 tables, preprint available from JMC as RDB3116)

The paper traces compatibility concerns for refrigerator-freezers, from historic use of R-764 (sulfur dioxide) and R-40 (methyl chloride) to present use of R-12. Sludge deposition with oils led to an oil-free, belt-driven model, using R-764, as early as 1913. R-764 achieved 90% penetration around 1925, but was limited to open-drive compressors. The driving force for hermetic systems was the problem of leaks, particularly with sulfur dioxide. Identification of an appropriate lubricant led to introduction of hermetic compressors. The initial solution was a highly

refined mineral oil, referred to as *white oil*. The paper reviews introduction of R-40 in the 1930s, in both open and hermetic compressors, reaching a peak of 20% penetration. It avoided subatmospheric operation, thereby eliminating introduction of air and moisture. The required compressor displacement was smaller, discharge temperatures much lower, and compatibility with mineral oils higher; but it was flammable and toxic. Incompatibility with aluminum, particularly in dry systems, led to demise of R-40 use. R-12 came in as the successor fluid in the late 1930s, though the paper also cites early use of R-21 and R-114. R-12 became dominant because of its thermodynamic properties, positive pressure operation, full miscibility with mineral oils, and compatibility with metals and other materials of construction. Compatibility problems resulted later, in seeking smaller compressors and associated increases in discharge temperatures. The paper briefly outlines the resolution of these problems. It then turns to recent environmental concerns with chlorofluorocarbon refrigerants, and introduction of R-134a. Compatibility issues are discussed, with emphasis on lubricant interactions. Tables are included to summarize the effects of temperature and metals (steel, copper, and aluminum) on decomposition for both polyalkylene glycol (PAG) and polyolester (POE) lubricants. The role of metal passivation is outlined, particularly for POEs with steel. Chemical reactivity, miscibility, solubility, lubricity, suitability with motor materials, and contaminant issues are reviewed. The paper cites consideration of R-152a, particularly in developing countries, and future refrigerant candidates. Compatibility is indicated as manageable with R-152a, partly based on experience with R-500 of which it is a component; flammability is cited as a concern. The paper concludes by noting the role of the Materials Compatibility and Lubricant Research (MCLR) Program.

I. Sauerbrunn, **Elastomere in Kälteanlagen mit halogenierten Kohlenwasserstoffen als Kältemittel** [Elastomers in Refrigeration Equipment with Halogenated Hydrocarbons as Refrigerant], *BBC-Nachtrichten*, Brown, Boveri und Cie AG, Mannheim, Germany, volume 1, pages 10 ff, 1960 (RDB-6660)

compatibility

I. Sauerbrunn (Brown, Boveri und Cie AG, Germany), **Methods of Testing and Selection of Non-cellulosic Insulating Materials to be Used in Hermetically-Sealed Refrigerating Machinery**, *Proceedings of the XIIth International Congress of Refrigeration* (Copenhagen, Denmark), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 76 ff, 1959 (RDB6655)

compatibility, motor materials

K. P. Schug, H. G. Wagner, and F. Zabel, *Berichte der Bunsengesellschaft für Physikalische Chemie*, volume 83, number 2, pages 167-175, 1979 (9 pages, RDB6834)

decomposition kinetics of various chlorofluorocarbons (CFCs), formation of free radicals as a halocarbon breakdown mechanism

M. S. Sefton, S. V. Mortlock, M. A. Harding (ICI Films) S. Corr, and G. Tompsett (ICI Chemicals and Polymers, Limited, UK), **Polyester Insulation Materials, HFC Refrigerants, and Ester Lubricants**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, pages 505-506, October 1993 (2 pages with 2 figures and 1 table, RDB3A23)

This paper presents compatibility tests of polyethylene terephthalate (PET) insulating materials with R-32, R-125, and R-134a with mixed-acid, polyolester (POE) lubricants (ICI Emkarate(TM) RL 22H and 32S). Comparative data also are presented for R-12 and R-22 with mineral oils (MO, Shell Clavus 32 and Witco Suniso(R) 3GS). The tests examined both standard and low oligomer PET films (ICI Melinex(R) 226 and 228, respectively), used as insulation materials in motors for hermetic compressors. The paper outlines autoclave tests at 140 °C (284 °F) for 14 and 28 days at autogenous pressures (approximately 4 MPa, 600 psig) followed by tensile testing and oligomer extraction analysis. The results indicate that the R-134a/POE mixture is considerably more aggressive in terms of oligomer extraction than R-12/MO or R-22/MO mixtures. However, low oligomer PET films show similar behavior for the same refrigerant/lubricant systems. Two figures compare oligomer extraction for standard and low oligomer films in R-12/MO, R-22/MO, R-32/-POE, R-125/POE, and R-134a/POE. A table summarizes changes in tensile strength and extension to break for the two PET types for R-32, R-125, and R-134a with POEs.

K. L. Snider (Union Carbide Corporation), **Thermal Stability of Several Fluorocarbons**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 9, number 11, pages 54-58, November 1967 (5 pages, RDB3A06)

reactivity

H. O. Spauschus (Spauschus Associates, Incorporated), **Compatibility Requirements for CFC Al-**

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ternatives, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 33-38, 1990; *International Journal of Refrigeration* (IJR), Paris, France, volume 13, number 3, pages 73-78, March 1990 (6 pages, RDB1101)

This paper reviews the materials compatibility and fluid property information required for design and successful commercial application of air-conditioning and refrigeration equipment. Information on alternative refrigerants, including the leading candidates, future prospects, and long-term possibilities, are summarized. Methods of predicting compatibility based on structural information and modeling are proposed.

H. O. Spauschus (Georgia Institute of Technology), **Factors Affecting the Reliability of Hermetic Compressors**, *Proceedings of the 1982 Purdue Compressor Conference*, Purdue University, West Lafayette, IN, July 1982 (RDB3514)

R-12, R-22, refrigerant-lubricant stability

H. O. Spauschus and R. A. Sellers (General Electric Company), **Aging of Hermetic Motor Insulation**, paper 68C6EI-89, *Proceedings of the Eighth Electrical Insulation Conference* (EIC, Los Angeles, CA, 9-12 December 1968), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 156-161, 1968; republished in *Transactions of Electrical Insulation*, IEEE, volume EI-4, number 4, December 1969 (6 pages with 7 figures and 4 tables, RDB6627)

compatibility, motor materials

H. O. Spauschus and R. A. Sellers (General Electric Company), **Electrical Properties of Wire Enamels in Refrigerant Environments**, paper 3.04, *Progress in Refrigeration Science and Technology* (proceedings of the XIIth International Congress of Refrigeration, Madrid, Spain, 30 August - 6 September 1967), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 1153-1160, 1969 (8 pages with 2 figures and 2 tables including discussion, RDB4A30)

R-12, R-22, polyvinyl formal, isocyanate modified polyvinyl formal, polyamide-imide, polyester-imide, polyimide

H. O. Spauschus and R. A. Sellers (General Electric Company), **Effect of Atmosphere on Aging of Electrical Insulation**, *Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena*, publication 1578, National Academy of Sciences (NAS), Washington, DC, pages 132 ff, 1968 (RDB6659)

compatibility, motor materials

H. O. Spauschus, G. C. Doderer, R. S. Olsen, and R. A. Sellers (General Electric Company), **Material Stabilities in Vapor-Compression Refrigeration Systems**, paper 111-3, *Proceedings of the XIth International Congress of Refrigeration* (München, Germany, 3 September 1963), International Institute of Refrigeration (IIR), Paris, France, 1963 (RDB-4115)

R-12, R-22

H. Steinle (Robert Bosch GmbH, Germany), **Prüfung und Auswahl von Kunstoffen zur verwendung in gekapselten Kältemaschinen** [Test and Selection of Plastics for Use in Hermetic Refrigeration Machines], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 16, number 11, pages 334-341, 1965 (8 pages with 8 figures and 5 tables in German, RDB6643)

R-12, R-22, laboratory tests of plastics

H. Steinle (Robert Bosch GmbH, Germany), **Examinations on the Behavior of Plastics in Hermetic Units**, paper III-8, *Proceedings of the XIth International Congress of Refrigeration* (München, Germany, September 1963), International Institute of Refrigeration (IIR), Paris, France, 1963 (5 pages with 1 table, RDB6637)

R-12, R-22, compatibility tests with esters of terephtalic acid (Mylar(R), Hostaphan(R), Terafilm(R), and Diolen(R)), polycarbonate (Makrolon(R)), polyamide (Durethan(R) BK 40 f), polyformaldehydes (Delrin(R), Hostaform(R) C), and phenolic resins (Bakelite(R), Resitex(R))

H. Steinle (Robert Bosch GmbH, Germany), **Zersetzung der Kältemittel R 12 und R 22 in Berührung mit Linde-Molekularsieben A4** [Decomposition of Refrigerants R-12 and R-22 in Contact with Linde Molecular Sieve A4], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 13, number 4, pages 150 ff, 1961 (in German, RDB6643)

R-12, R-22, 4Å molecular sieve desiccants

H. Steinle (Robert Bosch GmbH, Germany), **Wassergleichgewichte in gekapselten Kältemaschinen** [Water Equilibria in Hermetic Refrigeration Machines], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 11, number 10, pages 336 ff, 1959 (in German, RDB6639)

moisture effects on the electrical insulating materials used in motors of hermetic units

H. Steinle (Robert Bosch GmbH, Germany), **Water Equilibria in Hermetic Refrigeration Machines**, *Proceedings of the XIIth International Congress of Refrigeration* (Copenhagen, Denmark), Interna-

tional Institute of Refrigeration (IIR), Paris, France, 1959 (RDB6680)

moisture effects on the electrical insulating materials used in motors of hermetic units, other water-related materials compatibility issues

H. Steinle (Robert Bosch GmbH, Germany), **Die Temperaturbeständigkeit nichtmetallischer Stoffe in Kältemaschinen** [The Thermal Stability of Nonmetallic Materials in Refrigeration Machines], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 4, pages 28 ff, February 1952; republished in *Werkstoffe und Korrosion*, volume 3, pages 419 ff, 1952 (in German, RDB6622)

compatibility with nonmetallic materials

H. Steinle (Robert Bosch GmbH, Germany), **Prüfung der Kältemittel-Beständigkeit nichtmetallischer Stoffe in Kältemaschinen** [Stability Testing of Nonmetallic Materials in Refrigerants in Refrigeration Machines], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 3, number 5 pages 110 ff and number 6 pages 139 ff, 1951 (in German, RDB6641)

testing of refrigerant compatibility with nonmetallic materials in refrigeration systems

G. A. Sturrock, P. G. Simmonds, G. Nickless, and D. Zweip, *Journal of Chromatography*, volume 648, pages 423-431, 1993 (9 pages, RDB5212)

gas chromatography of various chlorofluorocarbons (CFCs)

M. V. Thierry (Anaconda Wire and Cable Company), **Choice of a Magnet Wire for Hermetic Motors**, paper 71C38EI-54, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 171-174, 1971 (4 pages with 2 figures and 6 tables, RDB6664)

R-22, compatibility, motor materials, apparatus for adhesion twist test, test methods

J. S. Thrasher, R. Timkovich, H. P. S. Kumar, and S. L. Hathcock (University of Alabama), **Moisture Solubility in Refrigerant 123 and Refrigerant 134a**, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 1, 1994 (RDB4A32)

R-123, R-134a

Thornton, Bury, and Schlesinger, **The Behavior of Dichlorodifluoromethane and of Chlorotrifluoromethane in the Electric Discharge**, *Journal of the American Chemical Society*, American Chemical Society (ACS), Columbus, OH, pages 55 ff, 1933 (RDB6645)

R-12, R-13

Trump, Safford, and Cloud, **DC Breakdown Strength of Air and of Freon in a Uniform Field at High Pressures**, *Transactions*, American Institute of Electrical Engineers (AIEE), volume 60, 1941 (RDB6623)

dielectric strength of refrigerants

F. F. Trunzo, G. J. Bich, and G. W. Hewitt [Westinghouse Electric Corporation), **Repeated Scrape Abrasion Testing of Enameled Wires in Gaseous and Liquid Refrigerants**, *Transactions* (Annual Meeting, Lake Placid, NY, 22-24 June 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 74, number 2, pages 675 ff, 1968 (RDB-6653)

compatibility, motor materials, test methods

I. M. Wade, **Accelerated Test Performance of Imide-Modified Magnet Wire Insulations for Hermetic Motors**, *Proceedings of the Eighth Electrical Insulation Conference* (EIC, Los Angeles, CA, 9-12 December 1968), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 127-131, 1968 (5 pages, RDB6647)

compatibility, motor materials

W. O. Walker, S. Rosen, and S. L. Levy, **Stability of Mixtures of Refrigerants and Refrigerating Oils**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 68, pages 360-389, 1962; republished in *ASHRAE Journal*, volume 4, number 8, pages 59-72, 1962 (30/14 pages, RDB-4650)

R-11, R-12, R-22, R-113, R-114, R-114a, R-500, naphthenic and paraffinic mineral oils, lubricants, aluminum, copper, steel, metal catalysts, compatibility

W. O. Walker, S. Rosen, and S. L. Levy, **A Study of the Factors Influencing the Stability of the Mixtures of Refrigerant 22 and Refrigerating Oils**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 66, pages 445 ff, 1960 (RDB-2323)

R-22, compatibility, lubricants

C. L. Yaws, H. C. Yang, J. R. Hopper, and K. C. Hansen, **Organic Chemicals: Water Solubility Data**, *Chemical Engineering*, pages 115-118, July 1990 (RDB5C35)

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R-32 and others

Develop Corrosion Data with Metals of Construction and New Refrigerant/Lubricants at Various Moisture and Organic Acid Levels, research project, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1995 - October 1996 (ASH0887)

This research project will determine the corrosion rates for selected metals in the presence of low molecular weight, organic acids. These acids result from hydrolysis of polyolester lubricants and subsequent reactions. The study also will quantify the concentrations of reacting acids and reaction products as functions of exposure times. The contractor for the project is Spauschus Associates, Incorporated, led by J. E. Field; it is sponsored by Technical Committee 3.2, *Refrigerant System Chemistry*.

Equilibrium Water Capacity of Desiccants in Mixtures of HFC Refrigerants and Appropriate Lubricants, research project 867-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1995 - July 1995 (ASH0867)

This research project measured the equilibrium water capacity of three desiccants in contact with R-134a and a polyolester lubricant at 24 and 54 °C (75 and 125 °C). The contractor for the project was Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it was sponsored by ASHRAE Technical Committee 3.2, *Refrigerant System Chemistry*.

Handbook for Rubber Materials in Automotive Air Conditioning Applications, *Rubber Handbook*, Santech Industries, Incorporated, Fort Worth, TX, November 1993 (24 pages with 11 figures and 11 tables, available from JMC as RDB4139)

This bulletin presents the uses of and considerations for rubber in mobile air-conditioning (MAC) applications, noting that all applications are static. It illustrates the sealing mechanisms of o-rings and outlines the temperatures encountered - as high as 149 °C (300 °F) - in representative systems. It then identifies R-12 and R-134a as the refrigerants used by original equipment manufacturers, but notes that R-22 or other refrigerants are used in some truck and trailers systems. It suggests three refrigerant-lubricant combinations as the most common, namely R-12 with mineral oil (MO), R-134a with polyalkylene glycol (PAG), and for retrofit of existing systems R-134a with polyolester (POE). The remainder of the brochure discusses compatibility for them with three rubber materials that account for almost all rubber used in automotive applications: nitrile butadiene rubber (NBR, nitrile or Buna-N), hydrogenated nitrile butadiene rubber (HNBR also including highly saturated nitrile, HSN), and chloroprene rubber (CR including neoprene, neoprene W, and polychloroprene). The bulletin lists the ingredients of a simple NBR, but points out that there are thousands of compounds tailored for different applications. After discussing seal force, the bulletin compares the three rubbers after aging at 100 and 148 °C (212 and 300 °F) for 70 hours. The bulletin describes ASTM D395 compression set (heat aging), ASTM D471 fluid immersion, and Santech internal QP409 refrigerant-lubricant immersion test methods. It then presents test results for sample o-rings made of HNBR (Santech ST7470), HNBR (Santech ST4470), and CR (an unidentified neoprene compound). The bulletin also discusses comparative costs of the three elastomers and outlines rubber uses by major automobile and MAC compressor manufacturers. The bulletin concludes with recommendations for rubber material selections.

Quality Specifications and Methods of Analysis for the Freon Fluorocarbon Refrigerants, technical bulletin B-8, E. I. duPont de Nemours and Company, Wilmington, DE, November 1960 (RDB-6625)

R-11, R-12, R-22, R-113, R-114: specifications, water content, nonadsorbable gases, boiling range, high-boiling impurities, chloride ion content, cloud point

Solubility Relationships of the Freon Fluorocarbon Compounds, technical bulletin B-7, E. I. duPont de Nemours and Company, Wilmington, DE, September 1961 (RDB6624)

R-11, R-12, R-21, R-22, R-113, R-114: solubility in and with water, organic compounds; liquid miscibility with other compounds

Stability of Several 'Freon' Compounds at High Temperatures, technical bulletin XIA, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1969 (RDB3867)

fluorocarbon refrigerants

R-12

T. Aida, R. Higuchi, and H. Niyama, *Chem. Letters*, pages 2247-2250, 1990 (4 pages, RDB5252)

decomposition of R-12 over gold catalyst

H. J. Borchardt (E. I. duPont de Nemours and Company, Incorporated), **The Reaction of Aluminum with Refrigerant 12 and Oil**, *Transactions*

(Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 78, part 2, 1972; republished in *Lubricants, Refrigerants, and Systems - Some Interactions*, symposium bulletin NA-72-5, ASHRAE, June 1972; republished as Product Information Bulletin RT-61, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1972 (8 pages with 1 figure and 6 tables, RDB3B64)

R-12, materials and experimental procedures, aluminum reactions at various temperatures, chemical reaction preceding aluminum attack, nature of the reaction, oil cracking, R-12 disproportionation: reaction between aluminum and R-12 was reproducibly initiated at 149 °C (300 °F) and higher, but the R-12/oil had to be degraded - resulting in high acid levels - before the reaction would start; partial removal of the protective aluminum oxide layer by severely degraded refrigerant-lubricant mixture, permitting direct contact between the refrigerant and the metal, may be necessary; reaction products included aluminum halides, carbonaceous matter, and R-13; overall stability was limited by the stability of the refrigerant oil mixture and not by the aluminum

R. M. Buffington and H. M. Fellows, **The Stability and Corrosive Properties of Freon-12**, technical paper 5, Kinetic Chemicals Incorporated, 1931 (RDB6669)

R-12, compatibility

M. Chaigneau and D. Barthes (Laboratoire Chimique Anal. Fac. Pharm., France), **Action of Dichlorodifluoromethane on Nickel, Aluminum, and Raney Nickel**, *Compte Rendu de l'Académie de Science*, Paris, France, series C, volume 170, number 7, pages 624-626, 1970 (3 pages in French, RDB6683)

R-12 reactions, compatibility

H. M. Elsey and L. C. Flowers, **Equilibria in Freon-12 Water Systems**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 57, page 153 ff, 1949 (RDB6605)

R-12, water content

A. Factor and P. M. Miranda (General Electric Company), **An Investigation of the Mechanism of the R12-Oil-Steel Reaction**, *Wear*, Elsevier Sequoia, Lausanne, Switzerland, volume 150, pages 41-58, 1991 (18 pages with 3 figures and 12 tables, RDB2309)

A study of chemical interactions between R-12, hydrocarbon lubricating oils, and steel is summarized. While R-12 is quite stable thermally, it decomposes rapidly when heated above 150 °C (300 °C) in the presence of oils and metals, such as iron or aluminum. Sealed-tube tests were performed for 3 days at 200 °C (392 °F), using a naphthenic mineral oil (Witco Suniso(R) 3GS), to simulate conditions in an operating hermetic refrigeration compressor. The mechanism of the degradation reaction was explored by testing the effect of the presence of various probe and model compounds. The paper reviews prior studies, presents the experimental approach, and summarizes the subsequent analyses. It identifies the additives, free radical initiators, and inhibitors used to explore reactions and to passivate steel surfaces. The results of gas chromatography and GPC analyses are tabulated. The results indicate that except for formation of some $FeCl_3$ and R-22, free radical reactions do not appear to play a major role. The preponderance of the data indicates that Friedel-Crafts reactions, especially alkylation, play a key role in the decomposition.

V. Gustafsson (Danfoss Compressors GmbH, Germany), **Decomposition of Refrigerant in Household Refrigerators**, *Proceedings of the 1978 Purdue Compressor Technology Conference*, Purdue University, West Lafayette, IN, pages 105 ff, July 1978 (RDB4907)

R-12, mineral oil

J. P. Hurtgen (General Electric Company), **Aluminum Magnet Wire in R12 Systems**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 11, number 11, pages 45-47, November 1969 (3 pages with 4 figures, RDB4112)

This article presents materials compatibility findings for use of aluminum magnet wire for hermetic compressor motors in R-12 refrigeration systems. It focuses on wire coated with polyvinyl formal phenolic resin in windings of motor stators. The article notes that the change from copper magnet wire is complex, involving both motor design and manufacturing techniques, but that aluminum has been used in rotor windings, compressor parts, and evaporators. It cites aluminum incompatibility with R-14, R-40, and uninhibited R-140a as well as rapid and destructive exothermic reactions of R-12 with aluminum impellers where melting or abrasion could expose a fresh, film-free surface. The document also reviews published studies of aluminum chloride formation, and its function as catalyst to convert R-12 into R-11 and R-13, following R-12 reactions with oil. The article describes sealed-tube tests of enameled wire he-

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lixes with R-12 and oil. Tests at 150 and 170 °C (302 and 338 °F) indicated that aluminum wire ages more rapidly than copper in R-12, as evidenced by greater R-22 formation. The R-22 formation and reaction rates are plotted. Tests by other researchers are cited, for as long as 360 days at 130 °C (266 °F) and at 170 °C (338 °C) for more than two years; no significant differences between aluminum and copper wire systems were found. New tests of dielectric strength retention at 170 °C (338 °C) for 14-450 days are described. The plotted results showed gradual decline, but the author concludes that reactions will be very low and approximately equal for the two magnet wire types. Hermetic units tests performed for verification are summarized. Complete analyses did not disclose significant differences between the copper and aluminum units. Field trials, the longest of which exceeded four years, support the findings.

S. Shiono, T. Imamura, J. Enomoto, and K. Kuyama, **A Study of the Reaction Rate of Refrigerant 12 and Refrigerant Oils and the Effect of Aluminum on the Reaction as a Catalyst**, *Reito* [Refrigeration], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 51, number 583, pages 361-368, 1976 (8 pages, RDB4A23)

R-12, mineral oil

H. O. Spauschus and G. C. Doderer (General Electric Company), **Reaction of Refrigerant 12 with Petroleum Oils**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 3, number 2, pages 65-69, February 1961 (5 pages, RDB-2526)

R-12, naphthenic mineral oil, valve steel as catalyst: identification of R12-oil reactions

R. I. Thompson, **The Chemical Activity of Freon-12**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 29, pages 139 ff, 1935 (RDB6673)

R-12, compatibility

Compatibility of Elastomers with CFC-12 and/or Paraffinic Oil, report ARTD-16 (H-26830), DuPont Chemicals, Incorporated, Wilmington, DE, 7 May 1990 (16 pages with 1 figure and 12 tables, available from JMC as RDB3124)

This report summarizes an investigation of the compatibility of 11 elastomers at 25 and 80 °C (77 and 176 °F) with R-12, an unidentified paraffinic mineral oil, and a 50/50 mixture of them. This refrigerant-lubricant pair is widely used in automotive air conditioners; the measurements were made for comparison with similar data for alternative refrigerants and lubricants. The data presented were taken after 27 days of immersion ("temporary") and also after subsequent drying in air at 25 °C (77 °F) for 14 days ("final"). The elastomers also are rated on a scale of 0 ("no change") to 5 ("severe, unacceptable change") based on the "temporary" data. The "final" data are suggested as a guide for seal replacement after equipment tear down. The report outlines the experimental approach and presents a table with the ratings. Eleven subsequent tables present measured changes in length, weight, and Shore A hardness as well as elasticity and visual (both the liquid and the polymer) ratings. The elastomers tested include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). A figure shows the scale used for swell and hardness ratings. The report cautions that the effects of refrigerants on elastomers depend on the nature of the polymer, the compounding formulation used, the curing or vulcanizing condition, the presence of plasticizers or extenders, and other elastomer variables. While the data serve as a guide, generalizations from the results are difficult to make.

R-22

R. T. Divers and W. West (Carrier Corporation), **Hermetic Compressors in Modern Applications**, *Transactions* (Semiannual Meeting, New Orleans, LA, 27-29 January 1964), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 70, 1964; republished in *ASHRAE Journal*, ASHRAE, volume 6, number 4, pages 55-61, April 1964 (7 pages with 9 figures and 3 tables, RDB6634)

R-22, motor cooling methods in reciprocating compressors, motor insulation materials

J. P. Hurtgen (General Electric Company), **R22 Blister Testing of Magnet Wire**, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 183-185, 1971 (3 pages with 5 figures and 5 tables, RDB2917)

R-22, compatibility with motor materials, varnish

K. Mall, **Studies on Aged Refrigerating Machine Oils and Gaseous Reaction Products from Motor Compressors**, *Kältetechnik-Klimatisierung*, volume 23, number 2, pages 58-63, 1971 (5 pages, in German, RDB3513)

R-22, lubricants

R. D. Petry (A. O. Smith Corporation), **Hermetic Insulation Tests Using Motorettes in Autoclave**, paper 71C38EI-37, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL, 20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 116-119, 1971 (4 pages with 4 figures and 4 tables, RDB6631)

R-22, compatibility with motor materials, hydrolytic stability, vibration, heat shock, rapid heat rise,

H. O. Spauschus and G. C. Doderer (General Electric Company), **Chemical Reactions of Refrigerant 22**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 162-168, 1965 (7 pages, RDB2327)

R-22; stability; literature review on reactions; decomposition mechanisms; experimental study of decomposition in the presence of lubricants and metals (aluminum, copper, and iron); effect of temperature

R-40

W. O. Walker and K. S. Willson (Ansul Chemical Company), **The Action of Methyl Chloride on Aluminum**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, pages 89, 90, 126 ff, August 1937 (RDB6632)

R-40, compatibility, reactivity

R-114

J. A. Callighan (Union Carbide Corporation), **The Thermal Stability of Fluorocarbons 114 and 216**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 11, number 9, pages 65-69, September 1969 (5 pages with 5 figures and 4 tables, RDB3A02)

This article presents stability tests of R-114 and R-216. These fluids are noted as candidate turbine motive fluids [e.g., for organic Rankine cycles] based on cited characteristics: low toxicities, no appreciable odor, non-flammable, low freezing point, high liquid and vapor densities, and low corrosion rates in metal systems. Stability tests for 200-500 °C (392-932 °F) are described. The test approaches included thermal aging in a steel bomb, decomposition analyses after flow through a heated quartz tube (with and without metal coupons), and cycled vaporizing and condensing in steel dynamic test apparatus. Summary physical properties are tabulated and decomposition products indicated, based on mass spectroscopic analysis of fragmentation patterns. The paper concludes that R-114 and R-216 have about the same thermal stability, which increases exponentially with decreasing temperature in the range of 316-426 °C (600-800 °F). It further notes that the presence of oxygen, moisture, and hydrocarbon oils all decrease the thermal stability, but that corrosion rates on commonly used metals are generally low when the decomposition rates are low. Tables summarize the decomposition data by the tests performed and the corrosion rates with cast iron, mild steel, AOS stainless steel, and iconel metal. A plot relates the decomposition fraction to refrigeration oil concentration, but shows greatly reduced reactivity with polychlorotrifluoroethylene (PCTFE) lubricants. The presence of steel is shown to influence the decomposition rates, but insufficient data were obtained to prove a relation between exposed surface area and decomposition rates.

J. E. Goodson, Jr., D. F. Nowicki, R. J. Thibeau, B. Toekes, and D. P. Wilson, **System Component Compatibility and R-114 Stability**, report DOE/ET/27125-T4 Volume 2 (also designated as SRC-CR-81-75-Vol. 2), U.S. Department of Energy (DOE), Washington, DC, 1981 (available from NTIS, RDB4335)

thermal stability

R-123

R. G. Doerr (The Trane Company), **Absorption of HCFC-123 and CFC-11 by Epoxy Motor Varnish**, paper 3621, *Transactions* (Annual Meeting, Baltimore, MD, June 1992; previously presented at Annual Meeting, Indianapolis, IN, June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 227-234, 1992 (8 pages with 9 figures, RDB2606)

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This paper summarizes a study to determine the parameters that influence absorption of R-11 and R-123 by varnishes and the effect of the absorbed refrigerants on chemical and physical properties. These varnishes hold motor windings together and act as secondary electrical insulation, filling in voids created during the winding process. Interest in the subject stems from observations that motor varnishes can absorb considerable amounts of R-123 with varying effects. The effects of cyclic and continuous exposures at high temperature and pressure, relative rates of absorption and desorption, existence of an equilibrium absorption value, and effects of temperature on the rate of absorption and the equilibrium are discussed. The experimental procedure, based on weight gain during thermal aging followed by drying, is outlined. Four varnishes were tested; they are identified as a recently introduced solventless type, a common solvent-based type, a 100% solids type, and a water-borne epoxy. The paper concludes that absorption is the same for cyclic and continuous exposures, that desorption is extremely slow to nonexistent at 21 °C (70 °F), and that full desorption would require in excess of 1000 hours at 121 °C (250 °F). It also notes that absorption increases until an equilibrium is established; while the rate differs widely for different varnishes, the rate is more rapid at higher temperatures. The equilibrium value is linearly dependent on temperature, with greater absorption at lower temperatures, for R-123, but relatively independent of temperature for R-11. The paper outlines two key implications for compatibility testing: 1) low temperature and pressure may be a more severe environment for materials than high temperature and pressure, and 2) tests must be continued long enough to be certain that equilibrium is reached at lower temperatures.

H. B. Ginder, **Compatibility Test - 15# Carbon Bursting Disk (2.5")**, York International Corporation, York, PA, July 1989 (1 page, available from JMC as RDB0011)

A 64 mm (2½") carbon bursting disk was immersed in R-123 at room temperature for 16 days. Subsequent testing for leaks and porosity, using R-22, indicated that the disk did not develop leaks.

H. B. Ginder, **Compatibility Test - O-Rings, Gasket, Oil Filter, Etc.**, York International Corporation, York, PA, July 1989 (1 page with 1 table, available from JMC as RDB0009)

A table summarizes the swelling of various materials immersed in R-123 and R-11. The materials include elastomeric (DuPont Viton(R), Buna(TM) N, and neoprene) o-rings, a Buna(TM) N bushing, and components of a Kaydon oil-line filter (cork and Buna(TM) N gaskets, pleated paper, and adhesive). Quantitative results are presented after a two week exposure at room temperature in a mixture of 90% refrigerant and 10% naphthenic oil. The R-123 test samples swelled considerably more than the R-11 samples. The Buna N bushing swelled 79% in R-123, as compared to 7.1% in R-11. The document concludes that Buna N formulations are not too compatible with R-123, but that Viton and neoprene appear to be acceptable. Compatibility concerns also are cited for the gaskets and adhesive in the oil filter.

T. P. Gross, **Compatibility Test - Green-Colored Viton O-Ring**, York International Corporation, York, PA, July 1989 (1 page, available from JMC as RDB-0012)

Swell data are presented for green-colored fluoroelastomeric (DuPont Viton(R) o-rings) immersed in R-123 and R-11 for three weeks at room temperature. The o-rings showed initial linear swell of 19.8% in R-123, which changed to 4.4% after drying overnight. Samples exposed to R-11 showed initial linear swell of 3.0%. The elastomers exhibited no significant loss in physical properties in either fluid.

T. P. Gross, **Compatibility Test - Loctite Sealants (Pipe Sealant with Teflon, Grade AV)**, York International Corporation, York, PA, July 1989 (1 page, available from JMC as RDB0010)

Two Loctite(R) compounds (pipe sealant with DuPont Teflon(R) and Grade AV) were applied to threaded fittings and tested with liquid R-123. The report indicates that they appear to be compatible with R-123, based on a seven-day period of exposure and curing. The test procedure and curing considerations for sealants are discussed.

Compatibility of Alternative Refrigerants with Elastomers, report NIST-11, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1989 (3 pages available from JMC as RDB0307)

This report summarizes an investigation to determine the compatibility of two elastomers, Neoprene W and Buna(TM) N, with R-123 and R-124. Swell data are tabulated after immersions for 1 hour and 1, 2, and 3 days at room temperature. Qualitative observations on discoloration of the refrigerant also are reported. Based on a criterion of swell substantially exceeding 10%, both elastomers were deemed incompatible with R-123 and Buna N was judged incompatible with R-124. The experimental procedure is outlined.

Decomposition Rates of R-11 and R-123, Carrier Corporation, Syracuse, NY, September 1989 (3 pages with 3 figures, available from JMC as RDB-0019)

The fraction of R-123 that decomposes in solution with alkylbenzene lubricant after 14 days is plotted as a function of temperature. Less than 1% decomposition was measured at 82 and 121 °C (180 and 250 °F), but this increased to 6.2% at 177 °C (350 °F). Decomposition of R-11 and R-123 after 4 and 14 days, respectively, at 121 °C (250 °F) is compared for mixtures of 5% lubricant by weight. One alkylbenzene (Zerol(R) 300) and four mineral oils (Mobil DTE Heavy Medium, Mobil DTE 26, Rando HD-68, and Witco Sunisо(R) 4GS) were tested.

Elastomer Immersion Tests for Fluorocarbon-123, technical report NIST-8, Freon(R) Products Laboratory, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1988 (5 pages with 2 tables, available from JMC as RDB0304)

Results are summarized for immersion tests of 13 elastomers in R-123 for up to seven days at 75 and 130 °F (24 and 54 °C). Quantitative results of the linear-swell tests are provided, including intermediate and final changes in length and weight as well as the fraction of extractables. Qualitative changes in appearance and physical properties of the elastomers and in the appearance of the liquid are tabulated. The tested elastomers were two urethane rubbers (Uniroyal Adiprene(R) C and Adiprene(R) L), a hydrocarbon rubber (DuPont Nordel(R)), a fluoroelastomer (DuPont Viton(R) A), a silicone rubber (General Electric SE-361), a nitrile silicone rubber (NSR-X5602), a synthetic rubber (DuPont Hypalon(R) 40), natural rubber, polysulfide rubber (Thiokol(R) FA), Buna(TM) N, Buna(TM) S, chloroprene (neoprene W), and Butyl(TM). Of those tested, only Thiokol FA appears suitable for use and prolonged contact with R-123.

Evaluation of Epoxy Varnish Materials for Alternative Refrigerant HCFC-123, report NIST-13, Chemistry Laboratory, The Trane Company, La Crosse, WI, 25 August 1989 (9 pages with 8 tables, available from JMC as RDB0034)

This report presents measured and observed findings for sealed-tube tests varnishes used as insulation for motors in hermetic compressors. Results are tabulated before and after thermal aging in air, R-11, and R-123 for P. D. George Sterling(R) 364, water-borne epoxy (Schenectady Isopoxy(R) 800), Schenectady 8620, Epoxylite 477, and solvent epoxy (Sterling(R) 923) varnishes. The exposures were made at 121 °C (250 °F) for 168 hours (1 week). Changes to the pre-exposure conditions are reported immediately after exposures and after drying for different periods, depending on the material. A final table summarizes extraction measurements on the varnishes after exposures. The preparatory curing conditions for the samples also are documented.

HCFC-123 Compatibility with Teflex NPG V-214 O-Rings Covered with High Density Teflon, report NIST-11, Chemistry Laboratory, The Trane Company, La Crosse, WI, 16 March 1989 (1 page, available from JMC as RDB0032)

Results of swell testing tetrafluoroethylene (TFE, DuPont Teflon(R)) coated DuPont Viton(R) o-rings in R-123 at 100 °C (212 °F) are reported. The Teflon(R) coating was permeated, causing the Viton core to swell. Testing stopped after 72 hours due to o-ring failure.

HCFC-123 Refrigerant Analyses, report NIST-9, Chemistry Laboratory, The Trane Company, La Crosse, WI, 24 November 1988 (1 page with 1 table, available from JMC as RDB0030)

A table compares the purity of new, used, and distilled-used specimens of R-123. No change from new R-123 was found by gas chromatography after use in model CVHE hermetic centrifugal chillers. Quantitative results are compared for moisture content and high-boiling residue. The high-boiling residues increased from 6 to 1591 ppm in use, but dropped to 1 ppm after redistillation. Moisture content decreased from 36 to 21 ppm, but increased to 31 ppm after redistillation.

Material Compatibility of Alternative Refrigerants: Usability/Compatibility of R-123 Received from Refrigerant Suppliers, report NIST-2, Chemistry Laboratory, The Trane Company, La Crosse, WI, 15 April 1988 (2 pages with 1 table, available from JMC as RDB0023)

This report of chemical analyses addresses the compatibility of R-123 samples from AlliedSignal and DuPont Chemicals with red neoprene 2337 elastomer material. Test rings were exposed to R-123 in both vapor and liquid phases for 168 hours at 77 °C (170 °F) using Trane Standard Test Method 3.7-04. Control samples were similarly exposed to R-11. Cross-sectional diameter, volume swell, and durometer hardness are tabulated before and after exposures. Some extraction of processing and/or base oils was observed with all three refrigerant samples. No precipitation of waxlike materials, cracks, or blisters were evident in any of the refrigerants. The increases in diameter and volume and decreases in durometer hardness were lower in R-123 than in R-11. The differences between results from the two R-123 samples were minor.

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Material Compatibility of Alternative Refrigerants: Usability/Compatibility of R-123 Received from Refrigerant Suppliers, report NIST-3, Chemistry Laboratory, The Trane Company, La Crosse, WI, 15 April 1988 (4 pages with 2 tables, available from JMC as RDB0024)

Swell tests of elastomeric compounds in R-11 and R-123 at 77 °C (170 °F) for 72 hours are reported. The elastomers included yellow nitrile 7507, red neoprene 2337, and green neoprene 2167. Quantitative data are presented for volume swell, cross-sectional diameter, and durometer hardness. Nitrile swelled 400-600% more in R-123 than in R-11. The neoprene samples exposed to R-123 exhibited less or comparable swelling to those exposed to R-11.

Material Compatibility of Alternative Refrigerants: Usability/Compatibility of R-123 Received from Refrigerant Suppliers with Elastomer Materials, report NIST-4, Chemistry Laboratory, The Trane Company, La Crosse, WI, 10 May 1988 (3 pages with 2 tables, available from JMC as RDB-0025)

Swell and durometer test data are tabulated for yellow nitrile 7507, red neoprene 2337, and green neoprene 2167 test rings exposed to 50/50 mixtures of R-11 and R-123 with 250 SUS white oil. The tests were repeated for separate samples of R-123 from AlliedSignal and DuPont Chemicals. Samples were aged in stainless steel test vessels for 3 days (72 hours) at 77 °C (170 °F). Cross-sectional diameter, volume swell, and durometer hardness were measured both before and after exposures, for both the vapor and liquid phases of the refrigerants, and compared. The hardness measurements were repeated after 2-3 days of drying to allow off-gasing.

Material Compatibility of Alternative Refrigerants: Compatibility of R-123 Received from Refrigerant Suppliers with Proposed Elastomer Materials, report NIST-5, Chemistry Laboratory, The Trane Company, La Crosse, WI, 6 June 1988 (2 pages with 1 table, available from JMC as RDB-0026)

Measurements of weight, volume, density, dimensions, and durometer hardness are reported for polysulfide rubber (Morton Thiokol(R) ST). Data are compared before and after exposures to both the vapor and liquid phases of R-123. Aging was performed in stainless steel test vessels for 3 days (72 hours) at 77 °C (170 °F). The tabulated data summarize measurements for tests in the refrigerant alone and in a 50/50 mixture with 250 SUS white oil. The tests were repeated for separate samples of R-123 from AlliedSignal and DuPont Chemicals. Data for exposures to the AlliedSignal R-123 refrigerant without lubricant were lost, due to an experimental problem, and were not remeasured. The document concludes that this rubber formulation would not be acceptable as an elastomer for use in a R-123 environment, but it does not rule out use of other polysulfide rubbers. The test data suggest that this rubber compound is affected more severely by 100% R-123 than by the mixture of R-123 and lubricant.

Material Compatibility of Alternative Refrigerant 123: Elastomer Chemistry of and Specifications for Chloroprene, report NIST-8, Chemistry Laboratory, The Trane Company, La Crosse, WI, 10 November 1988 (2 pages with 1 table, available from JMC as RDB0029)

This document compares the elastomer chemistry of chloroprene rubber for use in R-123. The formulations tested included 2337 (red dot), 2167 (green dot), and 2347 (new compound) o-rings as well as 2167 (green dot) cord ring. Chemical properties obtained from infrared spectra, volumetric swell, and durometer hardness were compared as received, after heat aging in air for 168 hr at 100 °C (212 °F), and after thermal aging at the same conditions in ASTM #3 oil, 250 SUS white oil, and R-123 vapor. Tests also were performed after immersion in R-11 liquid, R-11 vapor, and R-123 liquid for neoprene 2347. The resulting data are tabulated.

Material Compatibility of Alternative Refrigerant 123: Physical Properties of O-Rings for Applicability in Alternative Refrigerant 123 and Refrigerant 11, report NIST-7, Chemistry Laboratory, The Trane Company, La Crosse, WI, 27 October 1988 (2 pages with 2 tables, available from JMC as RDB-0028)

The tensile strength, elongation, and fluid resistance of neoprene 2347 (size 222) o-rings were tested. Measured values were compared for materials as received, after heat aging in air for 168 hr at 100 °C (212 °F), and after thermal aging at the same conditions in ASTM #3 oil, 250 SUS white oil, R-11, and R-123. Heat aging was performed and fluid resistance was measured in accordance with ASTM D573 and D471, respectively. The tabulated data indicate less change for R-123 than for R-11, and that the decrease in tensile strength and elongation for R-123 is similar to that after immersion in ASTM #3 oil.

Material Compatibility of Alternative Refrigerant 123: Short Term Suitability of Chloroprene Sheet Gasket Material, report NIST-6, Chemistry Laboratory, The Trane Company, La Crosse, WI, 7 October 1988 (1 page, available from JMC as RDB-0027)

Results are qualitatively summarized for compression and flexibility tests of Reinz chloroprene sheet gasket material exposed to R-123. The exposures were for 24 hour at 25 °C (77 °F) and at 100 °C (212 °F). All samples (hot and cold) failed when folded before reaching a 180° angle.

Metal Corrosion Tests with [HC]FC-123 and Distilled Water, report NIST-10, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated (5 pages with 2 tables, available from JMC as RDB0306)

Compatibility results of R-123 and distilled water with cold-rolled steel 1020, stainless steel 304, nickel, monel, copper, aluminum 2S, zinc, and magnesium alloy FS-1 are reported for dry and wet conditions. Results are tabulated at the liquid boiling point after exposure for 100 hours and after 100 days at 55 °C (130 °F). Decomposition of the R-123, metal corrosion rates, and the appearances of the liquid and metal are presented. R-123 was judged suitable with all of the metals under dry-test conditions, but suitable only with the stainless steel after 100-day wet exposure. Additionally, only the stainless steel, nickel, and monel showed no corrosion after the 100-day wet-exposure test.

Motor Insulations in R-123 and R-134a, Carrier Corporation, Syracuse, NY, September 1989 (2 pages with 2 figures, available from JMC as RDB-0015)

Two charts show the effects of R-123 and R-134a on cured motor insulations. XV-572, XV-587, water-borne epoxy (Schenectady Isopoxy(R) 800), solvent epoxy (P. D. George Sterling(R) U-475), and polyester (Dolphon) varnishes were tested for weight change, percent extractables, and Shore D hardness loss. Quantitative data, after aging for ten days at 93 °C (200 °F) for R-123 and at 38 °C (100 °F) for R-134a, are given.

Mutual Solubilities of Water with Fluorocarbons and Fluorocarbon-Hydrate Formation, report NIST-12, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated (16 pages with 4 figures and 7 tables, available from JMC as RDB0308)

Test procedures and results are described for an investigation of the mutual solubility of water and of solid hydrate formation with R-123, R-124, and R-125. Measured and calculated solubility data are tabulated in the temperature range of 77-167 °C (171-333 °F) for R-123 and R-124 and 77-138 °C (171-280 °F) for R-125. Regression equations and plots of the data are provided to compare the data to prior measurements for R-22, R-113, and an unidentified fluid. Solubility coefficients are plotted for these fluorocarbons in water for 0-120 °C (30-250 °F) at saturated vapor pressure conditions. The fraction of fluorocarbon by weight in water are similarly presented and plotted at saturated vapor and atmospheric pressures. The results coupled with those of earlier work indicate that R-125, R-134a, R-142b, and R-152a form solid water hydrates, but that R-123 and R-124 do not. The document discusses implications of the findings on specifications for water content in the refrigerants examined.

Plastic Immersion Tests in Fluorocarbon-123, report NIST-7, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated (5 pages with 2 tables, available from JMC as RDB-0303)

Results of compatibility tests are presented for 13 plastics, after immersion for four hours at 24 °C (75 °F) and after thermal-aging for 100 hours at 54 °C (130 °F) in R-123. The plastics included linear polyethylene (Alathon(R) 7050), polypropylene (Alathon(R) 9140), cast methylmethacrylate resin (Lucite(R)), nylon (DuPont Zytel(R) 101), tetrafluoroethylene (TFE, DuPont Teflon(R) type 1), polycarbonate resin (GE Lexan(R)), ABS polymer (Kralastic(R)), polystyrene (Styron(TM) 475), epoxy (G-10-3675), ethyl cellulose, acetal resin (DuPont Delrin(R) 500X), polyvinyl alcohol, and unplasticized polyvinyl chloride. Quantitative data are presented for length change, weight change, and for percent extractables. The appearances of the plastic and liquid R-123 are described. The linear polyethylene, nylon, epoxy, acetal, and polyvinyl chloride plastics tested were judged to be compatible with R-123.

Polymer/Elastomer Performance in R-123 and R-134a, Carrier Corporation, Syracuse, NY, September 1989 (4 pages with 3 figures, available from JMC as RDB0018)

Two graphs compare swell for polymers and elastomers in R-11 and R-123 at room temperature and at 93 °C (200 °F). The materials include a nitrile copolymer, fluoroelastomer (DuPont Viton(R) A), isoprene (neoprene), nylon, phosphazene (Eypel-F), polytetrafluoroethylene (PTFE, Gylon), polyolefin (Alcryn), polypropylene, olefinic thermoplastic (Geolast(R)), and polyester thermoplastic (DuPont Hytrel(R)). R-123 produced much greater swelling than did R-11. Quantitative values are given for swell and extractables of elastomeric materials in R-134a at 93 °C (200 °F) for ten days. These materials include Gylon, neoprene, nitrile, nylon 6/6, polypropylene, and Viton A.

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[R-]**123 Refrigerant Analyses**, report NIST-1, Chemistry Laboratory, The Trane Company, La Crosse, WI, 14 March 1988 (1 page with 1 table, available from JMC as RDB0022)

A table compares the chemical purity of R-123 samples, from AlliedSignal and DuPont Chemicals, with distilled R-11. Results are tabulated for chloride-ion content, high boiling temperature impurities, neutralization value, moisture content, and organic purity determined by gas chromatography. The moisture content in the R-123 samples was higher than expected, but not judged to be significant.

Refrigerant Breakdown Voltage, AlliedSignal Incorporated, Buffalo, NY, 1 May 1990 (1 page with 1 table, available from JMC as RDB0512)

Refrigerant breakdown voltages, as determined by ASTM D-2477-84, are tabulated for R-11, R-12, R-22, R-123, and R-134a at 21 °C (70 °F) and 93 °C (200 °F).

Sealed-Tube Stability Test Results: Alternative Refrigerants, Carrier Corporation, Syracuse, NY, September 1989 (1 page with 1 table, available from JMC as RDB0020)

A table summarizes the decomposition fraction of R-11, R-12, R-123, and R-134a with Witco Suniso(R) 3GS and Mobil DTE 26 mineral oils and with Zerol(R) 150 and Zerol 300 alkylbenzene lubricants. No decomposition was detected for R-134a; some R-12 decomposed into R-22. R-123 decomposed less than R-11 for all four lubricants.

Stability of CFC-11 and HCFC-123, report NIST-12, Chemistry Laboratory, The Trane Company, La Crosse, WI, 17 April 1989 (3 pages with 1 table, available from JMC as RDB0033)

Sealed-tube test results are compared for R-11 and R-123 after exposure to 250 SUS white mineral oil and metallic catalysts (aluminum, copper, and steel). Qualitative and quantitative decomposition effects are presented after 168 hours at 100 °C (212 °F), 121 °C (250 °F), and 150 °C (302 °F). The thermal stability of R-123 and oil was judged to be greater than the thermal stability of R-11 and oil.

Teflex O-Rings, Size 214, Sealmore Industries, report NIST-10, Chemistry Laboratory, The Trane Company, La Crosse, WI, 27 January 1989 (1 page with 1 table, available from JMC as RDB0031)

A table compares the swell properties of Teflex o-rings in R-11, R-123, and in 250 SUS white oil with each refrigerant in a 50% refrigerant mixture. Quantitative results are presented after a 70-hour exposure at 77 °C (170 °F). The R-123 samples exhibited a volume change three-times higher than those of the R-11 samples. However, the o-ring density changes were comparable for the R-11 and R-123 refrigerant-lubricant mixtures.

Viton O-Ring and Cord Ring Swell Data in Both R-11 and HCFC-123, report NIST-14, Chemistry Laboratory, The Trane Company, La Crosse, WI, 13 September 1989 (1 page with 1 table, available from JMC as RDB0035)

Comparisons are presented for immersion of fluoroelastomer (DuPont Viton(R)) o-rings and cord rings in R-11 and R-123. Data are tabulated for 70-hour exposures at 77 °C (170 °F). The volume change of the Viton materials in R-123 was found to be approximately three times that for R-11.

UL 984 Tests with R-123 and Oils, Carrier Corporation, Syracuse, NY, undated circa September 1989 (1 page with 1 table, available from JMC as RDB0016)

A table summarizes modified UL 984 tests of motor materials aged at 82 °C (180 °F) for 60 days. Control results are compared to those after separate exposures to R-11 and R-123 mixed with 5% Mobil DTE 26 mineral oil, Zerol(R) 150 alkylbenzene oil, and Rando HD-68. Insulation failures (1 ma current leakage to ground after 1 minute at 1.5 kV) and breakdown voltages are reported. Results are summarized for polyester-imide magnet wire, Dacron-Valox(R) lead wire, DuPont Teflon(R) wire sleeving, DuPont Mylar(R) end cap, Mylar-Dacron(R) thermosleeve, Mylar(R) and Melinex(R) slot liners, and Mylar and Melinex phase separators. Breakdown voltages of 2.7-17.0 kV, but no current leakage failures, are indicated.

R-124

P. R. Reed (DuPont Chemicals) and H. O. Spauschus (Spauschus Associates, Incorporated), **HCFC-124: Applications, Properties, and Comparisons with CFC-114**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 34, number 2, February 1992 (RDB4931)

R-114, R-124

P. R. Reed (DuPont Chemicals) and H. O. Spauschus (Spauschus Associates, Incorporated), **HCFC-124 Applications and Properties: Comparisons with CFC-114**, presentation charts prepared by Spauschus Associates, Incorporated, for E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated (22 pages with 9

figures and 1 table, available from JMC as RDB-1206)

The stability, miscibility, and lubricity of R-124 are compared to those of R-114. Qualitative data are presented for sealed-tube tests with metals (copper and steel) and unspecified 300 SUS mineral oils (paraffinic and naphthenic) and with an alkylbenzene lubricant after 14 days at 175 °C (350 °F). The effects of high moisture content and of lubricant additives on refrigerant stability also are discussed. Alkylbenzene lubricants were judged to be the most suitable for use with R-124.

R-134a

S. Corr, P. D. Guy, R. D. Gregson, N. M. Sammes, G. Tompsett (ICI Chemicals and Polymers, Limited, UK), and T. W. Dekleva (ICI Americas, Incorporated), **Materials Compatibility and System Stability Studies with R-134a and Alternative Lubricants**, seminar presentation at the ASHRAE Annual Meeting (St. Louis, MO), ICI Americas Incorporated, New Castle, DE, 12 June 1990 (30 pages with 23 charts, RDB2523)

P. D. Guy, G. Tompsett (ICI Chemicals and Polymers, Limited, UK), and T. W. Dekleva (ICI Americas, Incorporated), **Compatibilities of Nonmetallic Materials with R-134a and Alternative Lubricants in Refrigeration Systems**, paper AN-92-5-4, *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 804-816, 1992 (13 pages with 17 tables, RDB2104)

This paper reviews the compatibility of nonmetallic materials with R-134a and associated lubricants, based on sealed-tube tests as well as analytical investigations of compressor life tests and field evaluations. The test and analytical methods used also are reviewed. The materials addressed include ethylene propylene dimer monomer (EPDM) rubber, fluorinated polymer, natural rubber, nitrile rubber, nylon, and polyethylene terephthalate (PET). Data on weight, volume, tensile-strength, and elongation change as well as on hardness are compared to those for R-12 with naphthenic mineral oil. The paper notes that while an enormous amount of information has been developed by industry for compatibility of alternative refrigerants with associated lubricants and materials, most of it has not been published.

J. G. Johnson and T. E. Watson (McQuay International, then SnyderGeneral Corporation), **Refrigerant 134a Compatibility with Centrifugal Chillers**, paper 5.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 83-88, February 1993 (6 pages with 4 figures and 6 tables, preprint available from JMC as RDB-3117)

This paper reviews requirements for use of R-134a in chillers with centrifugal compressors. The paper compares the thermodynamic properties of R-134a to those of R-12 and R-500. Data are tabulated to substantiate 4% lower mass flow, but higher isentropic lift requirements. Heat transfer characteristics also are compared, noting an overall improvement of 12% in condensers for R-134a over R-12 and 2-10% in evaporators. A plot compares the film coefficients for pool boiling for a range of typical heat fluxes. Scaling opportunities through dimensional analysis, to attain a range of capacities and accommodate different refrigerants, are illustrated. Tabular data compare efficiency with R-134a or R-500 to that with R-12. The paper then reviews materials compatibility issues, with attention to elastomers, plastics, metals, and motor materials. A plot compares swell for three nitriles with R-134a, polyolester mixed acid, polyolester branched acid, and naphthenic mineral oils. Stability data based on sealed-tube tests, are compared for R-12, R-22, R-123, R-134a, and R-500 with associated lubricants. The paper addresses lubricant solubility, miscibility, and lubricity. A plot shows oil return with R-12 and R-134a, with mineral oil and pentaerythritol ester respectively, for a flooded evaporator. Test results are tabulated for a retrofit from R-500 to R-134a, showing a 10% loss in capacity and 2% increase in efficiency. Conversion requirements are outlined from R-12 to R-134a. A final table compares pool boiling for R-12 with mineral oil, R-134a with ester, and the latter pair with 5% residual mineral oil. The paper concludes that R-134a with ester lubricants offers similar or improved compatibility and better oil return and heat transfer. The efficiency is nearly the same for R-12, R-134a, and R-500. Conversions of R-500 machines can achieve 90% of original capacity without hardware changes. Retrofit of R-12 chillers requires changing the gear set and impeller, but results in comparable efficiency.

J. G. Johnson, **R-134a, R-123, and Mineral Oil Compatibility with Steel, Aluminum, and Copper**, McQuay International (then SnyderGeneral Corporation), Staunton, VA, 4 September 1990 (4 pages with 1 figure and 1 table, available from JMC as RDB0902)

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The chemical and thermal stability of R-123 and R-134a with Witco Suniso(R) 4GS mineral oil in the presence of ferrous and nonferrous metals were compared to that of R-12 and R-500 under the same conditions. Stability was gauged using sealed-tube tests for 14 days at 175 °C (350 °F); test results are compared by gas chromatography, to identify decomposition products, and by visual analysis. The metals used for the tests were Sandvik valve steel, OFHC copper wire, and aluminum 85 bearing material. R-134a was found to be superior to R-12 and R-500 in stability and reactivity, but immediate decomposition was evident for R-123.

E. D. Lawler, **HFC-134a and Mineral Oil Materials Compatibility with Hermetic Motor Insulation System for McQuay PEH048/050 Centrifugal Water Chillers**, McQuay International (then SnyderGeneral Corporation), Staunton, VA, 29 August 1990 (2 pages with 4 tables, available from JMC as RDB0901)

The compatibility of R-134a and mineral oils (both naphthenic and paraffinic) with the hermetic motor insulation materials used in centrifugal water chillers are examined. Baseline tests were run with R-12 and naphthenic oil for comparison purposes. Results are presented for varnish bonding for amide-imide-polyester film and dielectric retention of copper magnet wire with and without varnish treatment. Results also are summarized for retention of flexibility for DuPont Mylar(R), DuPont Nomex(R), and Dacron(R)-Mylar(R)-Dacron(R) sheet insulation, as well as for dielectric retention of flexible hermetic lead wire. The materials were generally unaffected. One exception was a weakening of epoxy varnish in the presence of R-134a and naphthenic oil (reduced 13.5% compared to the mixture of R-12 and naphthenic oil). Flexibility of film insulation was adequately maintained and retained dielectric was acceptable.

E. D. Lawler, **Compatibility of Various Elastomers in Refrigerant HFC-134a with Several Lubricants**, McQuay International (then SnyderGeneral Corporation), Staunton, VA, 5 September 1990 (3 pages with 3 tables, available from JMC as RDB0903)

Results of materials compatibility testing of o-rings with R-134a and naphthenic mineral oil, alkylbenzene, and polyalkylene glycol (PAG) lubricants are presented. The elastomers evaluated were nitrile HSN, nitrile ASM 3215, and neoprene ASM 3209. Thermal aging tests were conducted separately for the refrigerant and lubricants and for refrigerant-lubricant mixtures. Changes are noted for hardness, tensile strength, elongation, and volume. The property changes experienced by the elastomers were no greater than, and generally less than, those experienced when aged in the presence of either R-12 or R-22. Nitrile, however, appears to shrink slightly when soaked in alkylbenzene. The neoprene swelled slightly when subjected individually to either R-134a or the PAG, and there was an unacceptable amount of shrinkage when aged in a mixture of R-134a and 5% PAG.

K. S. Sanvordenker (Tecumseh Products Company), **Materials Compatibility of R-134a in Refrigerant Systems**, *Transactions* (Annual Meeting, Vancouver, BC, 24-28 June 1989), volume 95, part 2; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 211-216, January 1989 (6 pages with 5 figures and 1 table, 20 page preprint available from JMC as RDB0001)

Miscibility and pressure-temperature solubility diagrams are presented for R-134a with polyglycol (butyl monoether, polyoxyethylene-propylene, and polyoxypropylene glycol) and polyolester (dibasic acid ester and neopentyl ester) lubricants. The effects of R-134a on two magnet-wire insulations (polyester-imide and polyester enamel overcoated with amide-imide), two unidentified anaerobic adhesives, three elastomeric o-rings (chloroprene, ethylene propylene rubber, and nitrile), and a type 4A molecular-sieve desiccant are addressed. Compressor and refrigerator-freezer tests with R-134a and selected lubricants are described.

S. G. Sundaresan (Copeland Corporation), J. F. Judge, W. Chu, and R. K. Radermacher (University of Maryland), **A Comparison of the Oil Return Characteristics of R-22/Mineral Oil and its HFC Alternatives (R-407C & R-410A) with Mineral Oil and POE in a Residential Heat Pump**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 187-192, July 1996 (6 pages with 7 figures, RDB6920)

steady state, cyclic, and simulated oil pump out tests of R-407C and R-410A with a mineral oil and with a polyolester (POE) lubricant to examine oil return in a 10.6 kW cooling (3 ton) single-speed, split-system heat pump; comparison to R-22 with mineral oil; concludes that R-407C and R-410A have reliable oil return characteristics with POE, but not with the mineral oil

S. G. Sundaresan and W. R. Finkenstadt (Copeland Corporation), **Polyalkylene Glycol and Polyol Ester Lubricant Candidates for Use with HFC-134a in Refrigeration Compressors**, paper AN-92-5-3, *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASH-

RAE), Atlanta, GA, volume 98, part 1, pages 796-803, 1992 (8 pages with 4 figures and 6 tables, RDB2103)

This paper addresses polyalkylene glycol (PAG) and ester lubricants for use with R-134a in refrigeration compressors, with emphasis on lubricity and materials compatibility. The PAGs include diols (having two free hydroxyl groups), monoethers (one hydroxyl group), and end-capped PAGs (no free hydroxyl groups). The esters include dibasic (DBE), pentaerythritol (PE), trimethylolpropane (TMP), and neopentyl glycol (NPG). Properties of 17 PAG and 22 ester candidates are presented along with miscibility profiles for five of them. Sealed-tube test results are tabulated for four lubricants with metals (aluminum, stainless steel, and copper), magnet wire enamel, epoxy, PET film and fiber, polyamide (nylon 6/6), polyimide, polyetherketone (PEK), chloroprene o-ring, and nonasbestos (nitrile binder with clay silicate filler) gasket material. Hygroscopicity and wear from life testing, in semihermetic reciprocating-piston compressors, are summarized. While the exact cause-and-effect mechanisms leading to failure of a connecting rod in one test and wrist pin distress in others have not been established, noticeable differences are reported for the several lubricants. The results indicate that end-capped PAGs and PEs are viable candidates. Esters are preferred over PAGs for retrofit due to their miscibility with hydrocarbon lubricants and compatibility with residual chlorine.

S. G. Sundaresan and W. R. Finkenstadt (Copeland Corporation), **Degradation of Polyethylene Terephthalate Films in the Presence of Lubricants for HFC-134a: A Critical Issue for Hermetic Motor Insulation Systems**, *International Journal of Refrigeration* (IJR), Paris, France, volume 14, number 8, pages 317-320, November 1991 (4 pages with 3 figures and 2 tables, RDB2202)

An investigation of polyethylene terephthalate (PET) embrittlement mechanisms with lubricants is summarized. PET is widely used as an insulating material in motors for hermetic compressors. The paper reviews related studies and summarizes both the experimental approach and findings. Degradation was measured after thermal-aging in sealed tubes at 130, 150, and 175 °C (166, 302, and 347 °F) for 7, 14, and 28 days. The effects of drying the PET film and lubricants were evaluated. Three polyalkylene glycols (PAGs) were studied including monol, diol, and end-capped (modified) polypropylene glycols. A pentaerythritol (PE) ester and a blend of PAG-monol and PE-ester also were investigated. All five lubricants were ISO 32 (150 SUS) viscosity for use with R-134a. The effects of moisture content, temperature, and lubricant structure were examined. The results were compared to those of PET in R-12 with mineral oil. The study confirmed earlier findings that PET films must be dried, to less than 0.1% moisture content by weight, to minimize embrittlement by moisture. Residual water in the PET, even after drying, may exceed ten times that contributed by the lubricant and has a greater effect. The extent of embrittlement increases with the number of free hydroxyl groups in PAGs, and neither the monol nor diol was found to be acceptable. The end-capped PAG and ester lubricants showed no adverse reaction with dried PET film.

S. G. Sundaresan and W. R. Finkenstadt (Copeland Corporation), **Status Report on Polyalkylene Glycol Candidates with HFC-134a in Refrigeration Compressors**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 138-144, July 1990 (7 pages with 3 figures and 6 tables, RDB4355)

R-134a, PAG lubricants

S. G. Sundaresan and W. R. Finkenstadt (Copeland Corporation), **Evaluation of Polyalkylene Glycol Candidates with HFC-134a in Refrigeration Compressors**, unpublished presentation at ASHRAE's CFC Technology Conference, National Institute of Standards and Technology, Gaithersburg, MD, September 1989 (22 pages with 2 figures and 6 tables, available from JMC as RDB4305)

This paper summarizes miscibility, compatibility, and stability data for R-134a with a series of four unidentified, polyalkylene glycol (PAG) lubricants for refrigeration systems. It also addresses the findings of compressor durability testing with them. The paper outlines both the tests procedures and findings. A table summarizes viscosity, miscibility, moisture content, and acid number measurements; a figure compares the miscibility profiles of the PAGs as functions of temperature and concentration in R-134a. A second table reports the effects of metals on chemical stability of R-134a/lubricant mixtures for two of the PAGs at four moisture levels, both with and without test coupons of aluminum, copper, and steel. No refrigerant or lubricant degradation was detected by gas chromatography or visual appearance, and there was no sign of metal corrosion, rusting, or copper plating. The findings of sealed tube tests at 175 °C (347 °F) are reported for several materials used in system construction. They include magnet wires, polyethylene terephthalate (PET) insulating materials, polyamide (nylon 6,6), polyimide, polyetherketone (PEK), a nitrile-based nonas-

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bestos gasket, and a chloroprene o-ring. Of the findings, the most negative observation involved PAG effects on PET films, attributed both to hydrolysis and alcoholysis (or glycolysis) degradation and to PET embrittlement by hydrolytic cleavage. The paper then reports on tests of lubricity, including both bench and compressor-life tests. The former group included pin and v-block, pin-on-disk, four ball, and other screening tests. The latter comprised a regimen of break-in, normal loading, start/stop, high load, high compression ratio, and flooded start tests. The lubricity and durability findings are tabulated and discussed, noting failures and evidence of component distress for all four PAGs. The authors state that the results are more indicative of early development than of the true potential for R-134a/PAG systems. They conclude that the screening tests have delineated the key issues as: 1) the effects of PAGs on the stability of PET, epoxy varnishes, and polyamide-based polymers, 2) the effects of PAGs on aluminum corrosion and/or wear, and 3) the effects of moisture on PET films and fibers and on aluminum corrosion and/or wear.

S. G. Sundaresan and W. R. Finkenstadt, **Evaluation of Polyalkylene Glycol Candidates with HFC-134a in Refrigeration Compressors**, presentation charts (ASHRAE Annual Meeting, Vancouver, BC, Canada, 24-28 June 1989), Copeland Corporation, Sidney, OH, June 1989 (25 pages with 2 figures and 7 tables, available from JMC as RDB-0529)

Miscibility is shown for 55-100% R-134a with four unidentified polyalkylene glycol (PAG) lubricants (150-180 SUS). Compatibility of the refrigerant-polyglycol mixtures with metals, motor materials, and structural polymers are qualitatively presented. The metals include copper, aluminum, and stainless steel. The motor materials include two magnet-wire insulations (epoxy coated and polyester enamel overcoated with polyamide-imide), a polyethylene terephthalate (PET) slot liner, and an unspecified lead wire insulation. The structural polymers include a chloroprene seal, nonasbestos gasket (nitrile binder and clay silicates as filler), nylon 6/6, polyetherketone (PEK), and polyimide. Effects of the refrigerant-lubricant mixtures on compressor durability were quantitatively reported for test conditions of break-in, normal load, start/stop, high load, high compression ratio, and flooded start.

Y. Takahashi, T. Komatsubara, and T. Sunaga, **Development of Compressor Material Technology for HFC-134a Use**, *Proceedings of the 1994 International Compressor Engineering Conference at Purdue*, edited by W. Soedel, Purdue University, West Lafayette, IN, July 1994 (RDB6915)

R-134a, materials compatibility

R. H. P. Thomas and H. T. Pham (AlliedSignal Incorporated), **Evaluation of Environmentally Acceptable Refrigerant-Lubricant Mixtures for Refrigeration and Air Conditioning**, paper 891967 (Passenger Car Meeting, Dearborn, MI), Society of Automotive Engineers, Warrendale, PA, September 1989 (9 pages with 6 tables and 5 figures, available from JMC as RDB0503)

Laboratory data on the compatibility of R-134a with lubricants and the compatibility of the refrigerant-lubricant mixtures with elastomers and other materials are reviewed. Miscibility of R-134a in three polyglycols, a dihydroxy and two butyl-capped monhydroxy polyalkylene glycols (PAGs), and solubility for R-134a with the first of these are discussed. Stability, dry and with moisture present, also is addressed by comparing copper plating at 149 °C (300 °F) for the systems with R-134a and PAGs to R-12 with mineral oil. Tests of fluoride-ion production in sealed-tube tests, to determine the effects of air and water, are presented. Hose permeability with the refrigerant alone and with the refrigerant-lubricant mixtures, lubricity test using pin and v-block (Falex machine) tests, and swell tests with elastomers are described. The elastomers tested include three nitriles, epichlorohydrin, two neoprenes, a chlorosulfonated polyethylene, and a chlorinated polyethylene. The basic finding is that the combination of R-134a and PAGs is workable.

Compatibility of Elastomers with HFC-134a, report ARTD-5, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 7 November 1989 (16 pages with 12 tables and 1 figure, available from JMC as RDB0538)

This report summarizes an investigation of the compatibility of 11 elastomers at 25, 80, and in some cases at 141 °C (77, 176, and 286 °F) with R-134a. The data presented were taken after 27 days of immersion ("temporary") and also after subsequent drying in air at 25 °C (77 °F) for 14 days ("final"). Comparative data are presented for R-12 immersions under the same conditions. The elastomers also are rated on a scale of 0 ("no change") to 5 ("severe, unacceptable change") based on the "temporary" data. The "final" data are suggested as a guide for seal replacement after equipment tear down. The report outlines the experimental approach and presents a table with the ratings. Eleven subsequent tables present measured changes in length, weight, and Shore A hardness as well as elasticity and visual (both the liquid and the

polymer) ratings. The elastomers tested include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). A figure shows the scale used for swell and hardness ratings. The report cautions that the effects of refrigerants on elastomers depend on the nature of the polymer, the compounding formulation used, the curing or vulcanizing condition, the presence of plasticizers or extenders, and other elastomer variables. While the data serve as a guide, generalizations from the results are difficult to make.

Compatibility of Elastomers with HFC-134a and/or Ucon(R) 50HB660 (RO-W-6602) Plus Additives, report ARTD-18 (H-26845), DuPont Chemicals, Incorporated, Wilmington, DE, 12 July 1990 (16 pages with 12 tables, available from JMC as RDB2112)

This report summarizes an investigation of the compatibility of 11 elastomers at 25 and 80 °C (77 and 176 °F) with a polyalkylene glycol (PAG) lubricant, R-134a, and with a 50/50 refrigerant-lubricant mixture. The data presented were taken after 27 days of immersion ("temporary") and also after subsequent drying in air at 25 °C (77 °F) for 14 days ("final"). The elastomers also are rated on a scale of 0 ("no change") to 5 ("severe, unacceptable change") based on the "temporary" data. The "final" data are suggested as a guide for seal replacement after equipment tear down. The report outlines the experimental approach and presents a table with the ratings. Eleven subsequent tables present measured changes in length, weight, and Shore A hardness as well as elasticity and visual (both the liquid and the polymer) ratings. The lubricant is identified as Ucon(R) 50HB660 (RO-W-6602) with a proprietary additive. The elastomers tested include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). The report concludes that R-134a and the tested lubricant have been demonstrated to be an effective combination for automotive air conditioning. It cautions that the effects of refrigerants on elastomers depend on the nature of the polymer, the compounding formulation used, the curing or vulcanizing condition, the presence of plasticizers or extenders, and other elastomer variables. While the data serve as a guide, generalizations from the results are difficult to make.

Compatibility of [H]FC-134a with Refrigeration System Materials, report NIST-4, Freon(R) Products Laboratory, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 14 December 1976 (7 pages with 3 tables, available from JMC as RDB0534)

R-134a

Elastomer Compatibility with HFC-134a: Experimental Details, report NIST-1, Freon(R) Products Laboratory, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1989 (2 pages with 2 tables, available from JMC as RDB0531)

Compatibility tests of elastomers with R-134a and a naphthenic mineral oil (Witco Suniso(R) 5GS) are summarized. Duplicate samples of two neoprene W samples, National O-Ring and Parker, were exposed for 18 days. Lengths and weights were measured before exposure, immediately after removal, and after storage in ambient air for an additional 15 days. No color change or particulate residue were noted. Temporary and final linear swelling by 4.43-5.76% and 3.07-4.37% was measured. Weight changes of -0.77 to 1.86% were noted upon removal, but they changed to -3.71% to -1.01% after drying.

The Compatibility of Polymeric / Elastomeric Materials with Klea(TM) 134a and Polyalkylene Glycol (PAG) Based Lubricants, technical note 1, ICI Americas Incorporated, New Castle, DE, USA, August 1990 (8 pages with 5 tables, RDB2515)

Test results are tabulated to summarize changes in weight, volume, length, thickness, strength, elongation to break, and hardness for polymeric and elastomeric materials exposed to refrigerants and lubricants for 14 days. These tests are based on immersions at 130 °C (266 °F) with 50 ppm water for R-12 and mineral oil and at 85 °C (185 °F) with 200 ppm water for R-134a with Emkarox(R) RL 68 PAG. The materials tested include chloroprene (chlorinated isoprene, neoprene W), chlorinated rubber (neoprene), ethylene propylene diene monomer (EPDM), fluorinated propylene monomer (FPM) copolymer, FPM terpolymer, hydrogenated nitrile (HN) rubber N grade, HN rubber E grade, HN butyl rubber, HN green rubber, natural rubber, nitrile butyl rubber (Buna(TM) N), butadiene-acrylonitrile copolymer (Buna(TM) N), nylon 6/6, polybutylene terephthalate (PBT), PBT with 10% glass, polyether ether ketone (PEEK), poly ether sulfone (PES 75), polyethylene terephthalate (PET), polyimide 75 (ICI Upilex(R) R), polyimide 50 (ICI Upilex(R) S), polyimide (DuPont Kapton(R)), poly phenyl sulfone (PPS), and fluorinated copolymer of vinylidene fluoride and hexafluoropropylene (DuPont Viton(R)). Addi-

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tional data are provided for R-134a and four PAGs (Emkarox(R) RL) for EPDM, natural, and nitrile rubbers as well as for nylon, and Viton. These lubricants include a monol PAG ISO 22 with 65 ppm water, modified PAG ISO 22 with 165 ppm water, modified PAG ISO 32 with 190 ppm water, and modified PAG ISO 70 with 85 ppm water. The second set of tests were for thermal aging at 130 °C (266 °F) for 14 days. The experimental approach is briefly outlined.

The Compatibility of Polymeric / Elastomeric Materials with Klea(TM) 134a and Ester Based Lubricants, technical note 2, ICI Americas Incorporated, New Castle, DE, USA, August 1990 (6 pages with 4 tables, RDB2516)

Test results are tabulated to summarize changes in weight, volume, length, thickness, strength, elongation to break, and hardness for polymeric and elastomeric materials exposed to refrigerants and lubricants for 14 days. These tests are based on immersions at 130 °C (266 °F) with 50 ppm water for R-12 and mineral oil and with 180 ppm water for R-134a with Emkarate(TM) RL 32S (formerly RLE DE 184). The materials tested include chloroprene (chlorinated isoprene, neoprene W), chlorinated rubber (neoprene), ethylene propylene diene monomer (EPDM), fluorinated propylene monomer (FPM) copolymer, FPM terpolymer, hydrogenated nitrile (HN) rubber N grade, HN rubber E grade, HN butyl rubber, HN green rubber, natural rubber, nitrile butyl rubber (Buna(TM) N), butadiene-acrylonitrile copolymer (Buna(TM) N), nylon 6/6, polybutylene terephthalate (PBT), PBT with 10% glass, polyether ether ketone (PEEK), poly ether sulfone (PES 75), polyethylene terephthalate (PET), polyimide 75 (ICI Upilex(R) R), polyimide 50 (ICI Upilex(R) S), polyimide (DuPont Kapton(R)), polyphenyl sulfone (PPS), and fluorinated copolymer of vinylidene fluoride and hexafluoropropylene (DuPont Viton(R)). Additional data are provided for R-134a and Emkarate(TM) RL 15S (formerly RLE DE 212) with 180 ppm water for EPDM, natural, and nitrile rubbers as well as for nylon, PBT, and Viton. The experimental approach is briefly outlined.

Disassembly and Inspection of Compressor in Laboratory Refrigerator Charged with R-134a, report NIST-13, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1988 (40 pages with 50 figures and 3 tables, available from JMC as RDB0309)

This report documents a detailed inspection of a hermetic compressor, operated for 8.7 years with R-134a and a polyalkylene glycol (PAG) lubricant, Union Carbide UCON LB-525. An unmodified Frigidaire refrigerator was charged with R-134a in November 1977, but the compressor failed a month later. The failure analysis was not located, but the cause is believed to have been a manufacturing defect. The compressor was replaced and the refrigerator returned to service in July 1978; it operated without incident until March 1987. The refrigerator was functioning normally when shut down for compressor disassembly, to determine the long-term effects of this refrigerant-oil system. This report provides a photographic record of the disassembly, summarizes detailed chemical and metallurgical analyses, and includes profilometer readings to evaluate the effect of slight copper plating on steel bearing surfaces. A hardened steel vane spring, which broke when dropped, had been severely fatigued during service. The polyethylene slot liner insulation showed embrittlement, but was not analyzed. Very limited refrigerant decomposition was found, and the report concludes that R-134a use had very little effect on the metal parts of the compressor. Particles trapped in the oil produced slight scars on metallic contact surfaces. The molecular sieve drier contained 5% residual water, compared to a saturation value of 19-20%. Unanswered questions remain concerning the refrigerant-lubricant stability; addition of an oil stabilizer or use of a different oil may be indicated. General Electric Company and Tecumseh Products Company assisted in disassembling the compressor and interpreting the visual evidence. Further examination of the desiccant used, Union Carbide molecular sieve type 4A-XH-6, is reported in document RDB-0003.

Polyglycol Sealed-Tube Tests, Carrier Corporation, Syracuse, NY, September 1989 (1 page with 1 table, available from JMC as RDB0021)

A table compares tests of R-12 and R-134a with two polyalkylene glycol (PAG) lubricants (Nippon RS680 and Glygoyle 11). No decomposition was detected for R-134a with either oil. R-12 decomposition was reported at 75-90% with the two lubricants.

UL 984 Tests with R-134a and Oils, Carrier Corporation, Syracuse, NY, undated circa September 1989 (1 page with 1 table, available from JMC as RDB0017)

A table summarizes UL 984 tests of motor materials aged at 110 °C (230 °F) for 60 days. Control results are compared to those after separate exposures to R-12 mixed with mineral oil (Witco Suniso(R) 3GS) and R-134a mixed with the same oil and with alkylbenzene oil (Zerol(R) 150). Insulation failures (1 ma current leakage to ground after 1 minute at 1.5 kV) and breakdown voltages are reported. Results are summarized

for polyester-imide magnet wire, Dacron-Valox(R) lead wire, DuPont Teflon(R) wire sleeving, DuPont Mylar(R) end cap, Mylar-Dacron(R) thermosleeve, Mylar(R) and Melinex(R) slot liners, and Mylar(R) and Melinex(R) phase separators. Breakdown voltages of 0.7-15.5 kV are indicated; current leakage failures resulted only for the polyesterimide magnet wire.

E-134

T. P. Gross, **Sealed-Tube Tests - Grace Ether (E-134)**, York International Corporation, York, PA, 28 March 1990 (2 pages with 3 tables, available from JMC as RDB0904)

This memo summarizes sealed-tube tests to compare the stability of R-114 and E-134 when aged for up to 72 hours with several lubricants at temperatures as high as 182 °C (360 °F). The lubricants tested included York C, Zerol(R) 300 alkylbenzene, and UCON LB-165 polyglycol. Aluminum, copper, and iron wires were included as catalysts. E-134 was found to be somewhat less stable than R-114.

R-141b

Isotron R-141b Foam Blowing Agent: Material Compatibility, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 table, available from JMC as RDB0519)

A table provides quantitative and qualitative data on weight change and swelling for common elastomers, plastics, refrigerator liner materials, and roofing membrane materials after a two-week exposure to R-11 and R-141b. The elastomeric materials include neoprene, Butyl(TM), Buna(TM) N, and fluoroelastomer (DuPont Viton(R)). The plastics and refrigerator liner materials include ABS polymer, FEP, Kynar PVDF, polyethylene, polypropylene, polystyrene, polytetrafluoroethylene (PTFE), and polyvinyl chloride (PVC). The ABS polymer, Buna N, Viton, and PVC materials exhibited much greater swelling and weight gain after exposure to R-141b than to R-11. The other materials exhibited results lower than, or comparable to, R-11 after R-141b exposures.

R-142b

K. S. Sanvordenker, **Materials Compatibility of R-142b for Hermetic Units**, Tecumseh Products Company, Ann Arbor, MI, June 1989 (7 pages with 2 figures and 5 tables, available from JMC as RDB-0002)

Two figures compare the miscibility of R-142b and R-22 with Capella B and Calumet R015 mineral oils. The miscibility of R-142b with Zerol(R) 150 alkylbenzene lubricant also is discussed. Quantitative data on two magnet wire insulations (polyester-imide and polyester enamel overcoated with amide-imide) with R-142b and R-22 are given for refrigerant absorption, softening, blistering, and retained dielectric strength. R-142b and R-22 effects on the core-bond tensile strength of two unidentified solvent-based epoxy-type varnishes also are presented. Additionally, swell tests of R-142b with four elastomeric (neoprene, EPR, nitrile, and fluoroelastomeric (DuPont Viton(R) B) o-rings are given. In each investigation, R-142b exhibited characteristics comparable to, or better than, R-22.

R-245ca

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability and Compatibility Studies of R-245ca, $CHF_2CF_2CH_2F$, A Potential Low-Pressure Refrigerant**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 147-152, September 1992 (6 pages with 1 figure and 4 tables, available from JMC as RDB2A10)

This paper reviews the selection of R-245 isomers as low-pressure refrigerant candidates. This series offers the highest number of hydrogen atoms without becoming flammable and, therefore, the best potential among fluoropropanes. R-245ca was selected for further examination, based on performance modelling and its reported synthesis. Slightly lower efficiency is expected compared to R-123. Physical and chemical properties are tabulated for R-11, R-123, R-134a, and R-245ca for comparison. R-245ca is expected to be nontoxic, and it is indicated to be very similar to R-11 in terms of molecular weight, boiling point, and critical temperature. Its ozone depletion potential (ODP) is zero, but its 5.5 year atmospheric lifetime leads to a global warming potential (GWP) higher than for R-123 but lower than for R-134a. [Newer data indicate an atmospheric lifetime of 7.0 years.] The paper summarizes stability and compatibility studies. Sealed-tube tests, with

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and without lubricants, indicate that R-245ca is extremely stable; no evidence of decomposition was noted after 500 hours at 175 °C (347 °F). Parr bomb compatibility tests with electric motor materials and elastomers showed lower refrigerant absorption than for R-11 and R-123. The compatibility of R-245ca was found to be very similar to R-134a toward both motor materials and elastomers; no degradation was found for the materials tested. They included varnishes, slot liners, DuPont Mylar(R) sheet and tape, Dacron-Mylar-Dacron(R) and DuPont Nomex(R) wedges, DuPont Dacron(R) tape and cord, and reinforced tape. The varnishes tested included solvent epoxy (P. D. George Sterling(R) U-475 EH), 100% solids epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Weight, volume, and hardness change results are tabulated for a proprietary, chloroprene, and nitrile elastomers. The results suggest further investigation of R-245ca as a potential refrigerant. Commercialization is not expected for a number of years pending flammability, toxicity, and other testing as well as development of a competitive manufacturing process. [see RDB2A11 for presentation charts]

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability and Compatibility Studies of R-245ca, $CHF_2CF_2CH_2F$, A Potential Low-Pressure Refrigerant**, presentation charts (International CFC and Halon Alternatives Conference, Washington, DC), September 1992 (4 pages, available from JMC as RDB2A11)

This presentation reviews the selection of R-245 isomers as low-pressure refrigerant candidates. This series offers the highest number of hydrogen atoms without becoming flammable and, therefore, the best potential among fluoropropanes. R-245ca was selected for further examination, based on performance modelling and its reported synthesis. Slightly lower efficiency is expected compared to R-123. Physical and chemical properties are tabulated for R-11, R-123, R-134a, and R-245ca for comparison. R-245ca is expected to be nontoxic, and it is indicated to be very similar to R-11 in terms of molecular weight, boiling point, and critical temperature. Its ozone depletion potential (ODP) is zero, but its 5.5 year atmospheric lifetime leads to a global warming potential (GWP) higher than for R-123 but lower than for R-134a. [Newer data indicate an atmospheric lifetime of 7.0 years.] The presentation summarizes stability and compatibility studies. Sealed-tube tests, with and without lubricants, indicate that R-245ca is extremely stable; no evidence of decomposition was noted after 500 hours at 175 °C (347 °F). Parr bomb compatibility tests with electric motor materials and elastomers showed lower refrigerant absorption than for R-11 and R-123. The compatibility of R-245ca was found to be very similar to R-134a toward both motor materials and elastomers; no degradation was found for the materials tested. They included varnishes, slot liners, DuPont Mylar(R) sheet and tape, Dacron-Mylar-Dacron(R) and DuPont Nomex(R) wedges, DuPont Dacron(R) tape and cord, and reinforced tape. The varnishes tested included solvent epoxy (P. D. George Sterling(R) U-475 EH), 100% solids epoxy (Sterling(R) Y-833), and water-borne epoxy (Schenectady Isopoxy(R) 800). Weight, volume, and hardness change results are tabulated for a proprietary, chloroprene, and nitrile elastomers. The results suggest further investigation of R-245ca as a potential refrigerant. Commercialization is not expected for a number of years pending flammability, toxicity, and other testing as well as development of a competitive manufacturing process. [see RDB2A10 for text]

N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, A. S. Ng, M. W. Tufts, A. M. Drago, and K. Ratanaphruks (Acurex Environmental Corporation), **Evaluation of HFC-245fa as a Potential Alternative for R-11 in Low-Pressure Chillers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 894-901, October 1994 (8 pages with 4 figures and 4 tables, available from JMC as RDB5805)

R-245fa, R-245ca, R-11, R-123, thermophysical properties, chiller performance modelling, flammability, miscibility, stability, materials compatibility, atmospheric stability, global warming potential (GWP)

N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, M. W. Tufts, and A. S. Ng (Acurex Environmental Corporation), **R-245ca: A Potential Far-Term Alternative for R-11**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 2, pages 19-23, February 1993 (5 pages with 3 tables, RDB-3301)

This article summarizes tests and modelling of R-245ca, a candidate refrigerant to eventually replace R-11 and R-123. Thermophysical properties measurements are described. The results and findings of performance modelling are compared to data for R-11 and R-123; the efficiency of R-245ca is indicated to be 3-4% lower than for R-11. Flammability measurements based on the ASTM E681-85 procedure are described. The flammability was found to be sensitive both to the presence of moisture and the

ignition source. Lower and upper flammability limits (LFL and UFL) of 7.0-14.4% are reported at 30 °C (84 °F) for 43.5% relative humidity; the fluid was nonflammable in dry air. Tests of miscibility with two unidentified polyolester (POE) lubricants are discussed, indicating complete miscibility, insensitive to moisture content, for -30 to 125 °C (-22 to 257 °F) for concentrations of 10, 20, and 30% lubricant by weight. Sealed-tube tests to gauge compatibility with aluminum, copper, valve steel, fluoroelastomer (DuPont Viton(R)), nitrile butyl rubber (Buna(TM) N), neoprene, DuPont Nomex(R), and DuPont Mylar(R) are described. Observations, results of gas chromatography and infrared spectrometry, acidity, weight change, and swell are summarized. The paper indicates that R-245ca with a POE lubricant is compatible with the metals tested, Mylar, Viton; possibly compatible with Buna N and Nomex; and incompatible with neoprene. As a chlorine- and bromine-free compound, R-245ca is expected to have an ozone depletion potential (ODP) of zero. Its atmospheric lifetime was estimated as 6.4 years by measuring its reaction rate with atmospheric hydroxyl radicals; its global warming potential (GWP) was estimated to be one-third that of R-134a. Very preliminary testing of acute inhalation toxicity tests are outlined; no signs of concern were identified at a concentration level of 993 ppm. The paper concludes that R-245ca has been shown to be a good candidate for replacement of R-11 or R-123 in the far-term.

R-E245

R. G. Doerr, D. Lambert, R. Schafer, and D. Steinke (The Trane Company), **Stability Studies of E-245 Fluoroether, CH_3-CH_2-O-CHF_2**, paper DE-93-20-3, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 1137-1140, 1993 (4 pages with 1 figure and 3 tables, RDB3626)

R-E245 compatibility

R. G. Doerr, R. Schafer, D. Lambert, and D. Steinke (The Trane Company), **Stability Studies of E-245 Fluoroether $CF_3CH_2OCHF_2$**, presentation at the International CFC and Halon Alternatives Conference (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, 1991 (4 pages with 14 charts, available from JMC as RDB-2811)

These presentation charts summarize an investigation into the use of E-245, a proposed low-pressure refrigerant for centrifugal chillers. The charts summarize properties of this fluid and sealed-tube tests to determine its stability. Tests in glass tubes, both with and without an unidentified oil, resulted in violent explosions. Tests of R-123 and E-245 with copper and iron coupons in Parr bombs are presented, indicating stable results. Repetition of the E-245 tests with copper, iron, and glass coupons led to reactions. Analyses of the pressure build-up as well as a gas chromatogram and quantitative analysis of the reaction products are presented. Further tests with glass are outlined to examine the role of water, air, oxygen, and peroxide. The charts note that E-245 can react autocatalytically with glass to produce high pressures, hydrogen fluoride, and 2,2,2-trifluoroethyl ether (a convulsant). This reaction is accelerated by air (oxygen) and peroxide. The fraction of E-245 remaining after exposures at 121 °C (250 °F) for 14 days are tabulated to indicate the effects of various materials. They included elastomers, motor materials, copper, iron, water, glass-like materials. Tests with copper, iron, and aluminum at 166 and 177 °C (330 and 350 °F) also are presented. E-245 was found to be unstable with fiberglass motor materials.

R-717 (Ammonia)

G. D. Short (CPI Engineering Services, Incorporated), **Refrigeration Lubricants Update: Synthetic and Semi-Synthetic Oils Are Solving Problems with Ammonia and Alternative Refrigerants**, *Technical Papers of the 12th Annual Meeting* (Memphis, TN, 4-7 March 1990), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 19-53, March 1990 (36 pages with 12 figures and 4 tables, available from JMC as RDB2203)

This paper reviews bench tests and field experience with synthetic lubricants. The first part addresses semi-synthetic, high-viscosity index (HVI), hydrocracked lubricants for improved performance with ammonia. These lubricants also are referred to as "hydrocracked paraffinic oils" and as "restructured, semi-synthetic lubricants" to distinguish them from hydrogen finished oils, which contain more aromatic components. The paper discusses the benefits of these lubricants and briefly reviews case histories for two applications. Advantages cited, leading to longer drain intervals, include good thermal and chemical stability, lower mutual solubility, low foaming and volatility, excellent low-temperature fluidity, high viscosity, and good demulsibility. The hydrotreating process also removes nearly all aromatics, including carcinogenic polynuclear aromatics found in

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some lubricants. The second part addresses polyalkylene glycols (PAGs) and esters in positive displacement compressors for R-134a and refrigerant blends. Previously documented concerns with PAGs and low-viscosity, neopentyl esters are outlined. A new complex ester, which yields improved energy efficiency in screw compressors and superior miscibility with R-22, is discussed. The composition of naphthenic, solvent-refined paraffinic, and hydrocracked paraffinic lubricants are tabulated for comparison. Similar data are provided on oxidation resistance and emulsion characteristics. Plots of viscosity and antioxidant level, as functions of time in use, are provided for the lubricants discussed. Solubility with ammonia, volatility, and viscosity are plotted for the hydrocracked oils. The miscibility of two complex esters are shown for R-134a, and the viscosity-temperature relationships are graphically compared for R-22 with a complex ester and a naphthenic oil. A figure compares the isentropic efficiency of complex esters with R-22 to that for a polyalphaolefin (PAO) lubricant for a range of pressure ratios.

G. D. Short (CPI Engineering Services, Incorporated), **Hydrotreated Oils for Ammonia Refrigeration**, *Technical Papers of the 7th Annual Meeting* (10-13 March 1985, San Antonio, TX), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 149-176, March 1985 (28 pages with 8 figures and 4 tables, available from JMC as RDB2204)

R-717, lubricants

Others

H. Steinle (Robert Bosch GmbH, Germany), **Schwefeldioxyd-Beständigkeit und Harzgehalt von Kälternachinenölen** [Stability with Sulfur Dioxide and Resin Content of Refrigeration Machine Lubricants], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 1, pages 14 ff, 1949 (in German, RDB6676)

R-7146, mineral oil

Blends

Water Solubility in HFC Refrigerant Blends, research project 923-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1996 - April 1997 (ASH0923)

This project will measure the solubility of water in R-23, R-32, R-125, R-143a, and R-152a at temperatures of -73 to 71 °C (-100 to 160 °F), or 8 °C (15 °F) below the critical temperature. It also will investigate the solubility of water in mixtures of these compounds and verify the projections with measurements on three or more ternary blends of them. The contractor for the project is Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it is sponsored by ASHRAE Technical Committee 3.3, *Contaminant Control in Refrigerating Systems*.

Azeotropes

R. H. P. Thomas and R. Robinson, **The Solubility of Air in HFC Refrigerants**, unpublished presentation (ASHRAE Annual Meeting, San Diego, CA, 24-28 June 1995), AlliedSignal Incorporated, Buffalo, NY, June 1995 (9 pages with 4 figures, available from JMC as RDB5701)

This set of presentation charts addresses the effects of air as a refrigerant contaminant, with emphasis on hydrofluorocarbon (HFC) refrigerants. The introduction indicates that air raises the system pressure, reduces efficiency, causes oxidation of lubricants and metallic components, and interacts with water to enhance reactions. A figure schematically shows a vessel with gas and liquid sample cylinders and a stirrer, used to measure pressure variations. A plot illustrates the variation of pressure with air concentrations of 0-4% at 10 and 20 °C (50 and 68 °F); the influence is more pronounced at the higher temperature. A chart notes an earlier study by H. M. Parmelee in 1951. It found the solubility of air to obey Henry's Law for R-12 and R-22, with similar solubility coefficients. A plot combines new data for R-134a with Parmelee's for R-12 and R-22. It suggests that the solubility coefficient is a linear or near-linear function of temperature. The authors conclude that chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), and HFC refrigerant behave similarly with respect to air, based on the three representative refrigerants. They also show more detailed data for R-507A, and conclude that it behaves like a single-compound refrigerant with regard to air solubility. AlliedSignal's product name for R-507A is Genetron(R) AZ-50.

Isotron 22/142b Blends for Refrigeration: Material Compatibility, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 table, available from JMC as RDB0520)

This bulletin summarizes the procedure and findings for two-week exposures of selected re-

frigeration system materials both to R-12 and to a blend of R-22/142b (55/45). The materials tested included copper wire, polyimide insulation, and several plastics and elastomers. The plastics included nylon (DuPont Zytel(R) 101), polytetrafluoroethylene (PTFE), FEP, PVDF (Kynar), PVC, low-density polyethylene, polypropylene, polystyrene, high-impact polystyrene, and high-gloss ABS. The elastomers included neoprene, Butyl(TM), Buna(TM) N, and fluoroelastomer (DuPont Viton(R)). Swell (length increase percentage), weight gain (percentage), and appearance (including qualitative observations on hardness and embrittlement) are tabulated.

Zeotropes

Y. Obokata, M. Hagiwara, and T. Komatsubara (Sanyo Electric Company, Limited, Japan), **Reliability Study on a Rotary Compressors for HFC Refrigerants Mixture**, paper 6.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 145-149, December 1994 (5 pages with 12 figures and 8 tables; in Japanese with abstract, figures, and tables in English; RDB5427)

R-22, R-32, R-125, R-134a, and R-407C; alkylbenzene, polyolester, and carbonate lubricants, compatibility

Measurement of Solubility, Viscosity, and Density of R-32/125 (R-410 Series) Refrigerant-Lubricant Mixtures, proposed research project 928-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0928)

This project will investigate the solubility, viscosity, and density of R-410A and R-410B mixtures with polyolester (POE) lubricants. It is sponsored by ASHRAE Technical Committees 8.1, *Positive Displacement Compressors*, and 3.4, *Lubrication*. Proposals were due at ASHRAE Headquarters by 12 January 1996. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

LUBRICANTS AND TRIBOLOGY

A. Ali, F. Lockwood, J. L. Duda, and E. J. Tewksbury, **The Chemical Degradation of Ester Lubricants**, *Transactions*, American Society of Lubricating Engineers (ASLE), volume 22, number 3, pages 267 ff, 1978 (RDB6376)

polyolester (POE) lubricants

D. J. Alofs, M. M. Hasan, and H. J. Sauer, Jr. (University of Missouri at Rolla), **Influence of Oil on Pressure Drop in Refrigerant Compressor Suction Lines**, *Transactions* (Winter Meeting, Atlanta, GA, 10-14 February 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, volume 96, part 1, 1990 (RDB-4603)

K. Benke and J. Reichelt, **Synthetische Flüssigschmiermittel für Tieftemperatur-Kälteanlagen** [Synthetic Lubricants for Low-Temperature Refrigeration Installations], *Die Kälte- und Klimatechnik*, Germany, volume 5 pages 172-176 and volume 6, pages 208-214, 1975 (12 pages, in German, RDB-4918)

J. Bougard and R. Jadot (Polytechnique de Mons, France), **Modelisation des Équilibres Réfrigérant-Huile** [Modeling of Refrigerant-Oil Equilibria], *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 149-156, 1993 (8 pages with 9 figures and 1 table, in French, RDB5311)

R-22 with mineral oil and unidentified synthetic lubricant, R-134a with polyalkylene glycol (PAG) lubricant, solubility, vapor pressure

M. Burke and H. Kruse (Universität Hannover, Germany), **Solubility and Viscosity of New Oil/Ammonia-Systems**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 133-139, 1993 (7 pages with 4 figures and 1 table, RDB5309)

R-717, polyolester (POE), polyalkylene glycol (PAG), ethylene oxide (EO) and propylene oxide (PE) compositions, additives

M. Burke and H. Kruse (Universität Hannover, Germany), **Das Ölverhalten der chlorfreien Kältemittel R23, R134a, und R152a** [Oil Retention in Chlorine-Free Refrigerants R-23, R-134a, and R-152a], *Ki Klima-Kälte-Heizung*, volume 19, number 9, pages 348-351, September 1991 (4 pages, in German, RDB4531)

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Potentially Useful Polyolester Lubricant Additives. An Overview of Antioxidants, Antiwear and Antisieze Compounds**, *Proceed-*

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ings of the 1996 International Refrigeration Conference at Purdue (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 169-174, July 1996; republished as report DOE/CE/23810-72D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (10 pages, available from JMC as RDB6835)

results of a literature search; discussion of additives known to be used in refrigeration compressor lubricants, their modes of action, additive chemistry, thermal stability; antioxidant, antiwear, and antisieze additives for synthetic, polyolester (POE) lubricants

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Viscosity, Density, and Gas Solubility of Refrigerant Blends and Azeotropes in Selected Refrigerant Lubricants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 413-418, July 1994 (6 pages with 12 figures, RDB4855)

R-404A [R-125/143a/134a (44/52/4)], R-507A [R-125/143a (50/50)], polyolester branched acid, polyolester mixed acid

R. C. Cavestri, J. Munk, and M. Menning (Imagination Resources, Incorporated, IRI), **Solubility, Viscosity, and Density Measurements of Refrigerant-Lubricant Mixtures - Part I: Branched Acid Pentaerythritol Polyolesters with R-134a**, paper 3804 (716-RP), *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 220-230, 1994 (11 pages with 11 figures, RDB4716)

This paper presents data on the equilibrium gas solubility, viscosity, and density of R-134a in branched acid, pentaerythritol polyolester (POE) lubricants. It covers dissolved gas ranges of 2% to more than 65% by weight for pressures up to 3445 kPa (500 psia). The two lubricants tested were 32 and 100 ISO viscosity grade POEs (Henkel Emery(R) 2927-A and Castrol Icematic(R) SW-100). The paper reviews prior research of refrigerant-lubricant properties, noting that little is known about the hydrodynamic lubricant film-forming qualities of synthetic lubricants with refrigerant mixtures. It describes and schematically illustrates the oscillating-body viscometer used. This apparatus accurately determines density as well as viscosity, under identical elevated pressure and temperature conditions. Two pairs of figures present smoothed viscosity and pressure data, in modified Daniel plots, and density and pressure data for temperatures of -25 to 125 °C (-13 to 257 °F) for the two viscosity grades. Additional plots show the miscibility ranges of R-134a with the 100 ISO POE as well as the isothermal viscosity and concentration curves for each lubricant at 40 and 100 °C (104 and 212 °F). A final plot shows the kinematic viscosities of both lubricants for the same temperature range. The paper notes that the relative viscosity change with 10% refrigerant dilution is dramatic for the 32 ISO lubricant.

R. C. Cavestri, J. Munk, and M. Menning (Imagination Resources, Incorporated, IRI), **Solubility, Viscosity, and Density Measurements of Refrigerant-Lubricant Mixtures - Part II: Polyalkylene Glycols with R-134a**, paper 3805 (716-RP), *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 231-238, 1994 (8 pages with 11 figures, RDB4717)

This paper presents data on the equilibrium gas solubility, viscosity, and density of R-134a in polyalkylene glycol (PAG) lubricants. It covers dissolved gas ranges of 1% to more than 70% by weight for pressures up to 3445 kPa (500 psia). The two lubricants tested were a 32 ISO viscosity grade, polypropylene glycol monobutyl ether (ICI Emkarox(R) VG32) and an 80 cSt, polyoxypropylene diol (Dow Chemical P1200). The paper briefly outlines the experimental approach used and presents plots based on fits of the measured data to an equation of state. Two pairs of figures present viscosity and pressure data in modified Daniel plots along with and density and pressure data for the two PAGs. These plots cover temperatures of -25 to 125 °C (-13 to 257 °F). The paper discusses the enhancements made to the conventional form for the Daniel charts. Additional plots show the miscibility ranges of R-134a and the isothermal viscosity and curves for each lubricant. A final plot shows the kinematic viscosities of both lubricants for the same temperature range.

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of Viscosity, Density, and Gas Solubility of Refrigerant Blends in Selected Synthetic Lubricants**, report DOE/CE/-23810-46, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 May 1995 (198 pages with 192 figures and 20 tables, available from JMC as RDB5603)

This report summarizes measurements of viscosity, density, and solubility for mixtures two 32 ISO VG, polyolester (POE) lubricants with three refrigerant blends and with the components of those blends. They included R-32, R-125, R-134a, R-143a, R-404A, R-407C, and R-507A. They were tested with branched- and

mixed-acid POEs (Henkel Emery(R) 2968A and ICI Emkarate(TM) RL 32S, respectively). Data on R-22 and R-502 with a naphthenic mineral oil (MO, Witco Suniso(R) 3GS) are included for comparison. The report describes the measurement methods and schematically illustrates the oscillating body viscometer, blend sampling apparatus, and hydraulic cylinder (to assure uniform composition) used. The results for each refrigerant-lubricant pair are summarized with three figures. They show viscosity as a function of temperature for representative isobars, viscosity and pressure at constant concentrations as functions of temperature in modified Daniel plots, and density as a function of temperature at constant concentrations. Each series is supported by an appendix that contains a table of raw viscosity, density, and solubility data as well as plots of the viscosity and gas solubility at representative temperatures. Gas fractionation also is shown for the blends. Additionally, the plots for R-407C are repeated with and without use of the zero-head, hydraulic injection cylinder; it was introduced to minimize composition changes with successive sampling from a single container. The report findings show the reduction in lubricant viscosity due to gas dissolved in the lubricant. An appendix describes selection of the fluids based on miscibility evaluations for R-32/125 (60/40), R-32/125/-134a (30/10/60), R-32/125/290/134a (20/55/-5/20), R-32/134a (30/70), R-125/143a (45/55), and R-404A. Their miscibilities are plotted for five lubricants, including two branched-acid POEs (Castrol Icematic(R) SW32 and Henkel Emery(R) 2968a), two mixed-acid POEs (ICI Emkarate(TM) RL 32S and Mobil Arctic(R) EAL 224R), and an alkylbenzene (AB, Shrieve Zerol(R) 150).

R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Measurement of the Solubility, Viscosity, and Density of Synthetic Lubricants with R-134a**, final report for 716-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 17 April 1993 (72 pages with 58 figures and 4 tables, RDB4618)

This report presents data on the equilibrium gas solubility, viscosity, and density of R-134a in synthetic polyolester (POE) and polyalkylene glycol (PAG) lubricants. It covers dissolved gas ranges of 2% to more than 65% by weight for temperatures of -25 to 125 °C (-13 to 257 °F) and pressures up to 3445 kPa (500 psia). The POEs tested included 32 and 100 ISO VG branched acid, pentaerythritols (Henkel Emery(R) 2927-A and Castrol Icematic(R) SW-100). The PAGs were a 32 ISO viscosity grade, polypropylene glycol monobutyl ether (ICI Emkarox(R) VG32) and an 80 cSt, polyoxypropylene diol (Dow Chemical P1200). The introduction briefly reviews the role of lubricants, noting that little is known about the hydrodynamic lubricant film-forming qualities of synthetic lubricants with refrigerant mixtures. It also reviews prior research of refrigerant-lubricant properties. The report then describes the oscillating-body viscometer used, provides a schematic for it, and details the experimental procedures. This apparatus accurately determines density as well as viscosity, under identical elevated pressure and temperature conditions. The pressure-viscosity-temperature relationships are presented for R-134a with each lubricant at its individual isothermal measurement temperatures. These modified Daniel plots detail the composition of the equilibrium gas solubility, vapor pressure, concentration, and viscosity in both metric (SI) and inch-pound (IP) units of measure. An appendix shows the miscibility ranges of R-134a with the 100 ISO POE and the two PAGs. A second appendix presents plots of the kinematic viscosities of both lubricants. Four final appendices show the isothermal viscosity and concentration curves and tabulate the raw data for measurements at -25, -15, -7, 0, 20, 40, 60, 80, 100, and 125 °C (-13, 5, 19, 32, 68, 104, 140, 176, 212, and 257 °F).

K. W. Cooper and A. G. Mount, **The Effect of Oil Circulation on Compressor Capacity**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 39-42, October 1972 (RDB3322)

W. D. Cooper, R. C. Downing, and J. B. Gray (E. I. duPont de Nemours and Company, Incorporated), **Alkyl Benzene as a Compressor Lubricant**, *Proceedings of the 1974 Purdue Compressor Technology Conference*, Purdue University, West Lafayette, IN, pages 88 ff, July 1974 (RDB4350)

alkylbenzene

S. Corr, S. Randles, and A. Stewart (ICI Chemicals and Polymers, Limited), **Synthetic Lubricants for R134a - A Replacement Gas for R12**, Lubricants of the Future and Environment, Brussels, September 1993 (RDB5124)

R-12, R-134a

S. Corr, F. T. Murphy (ICI Chemicals and Polymers, Limited), B. E. Gilbert, and R. W. Yost (ICI Americas, Incorporated), **Characteristics of Refrigerant Lubricant Mixtures Containing R-32 and R-32 Blends**, paper DE-93-20-1, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 1123-1128, 1993 (6 pages with 5 figures and 3 tables, RDB3624)

please see pages 6-8 for ordering information

S. Corr, P. D. Guy, A. A. Lindley, F. T. Murphy, G. Tompsett (ICI Chemicals and Polymers, Limited), and T. W. Dekleva (ICI Americas, Incorporated), **The Effect of Miscibility on Performance of R-134a and Alternative Lubricants**, seminar presentation at the ASHRAE Annual Meeting (Indianapolis, IN), ICI Americas Incorporated, New Castle, DE, 24 June 1991 (20 pages with 24 charts, RDB-2521)

S. Corr (ICI Chemicals and Polymers, Limited), **Solubility and Miscibility - Relevance to Klea(TM) 134a Refrigeration Systems**, ICI Americas Incorporated, Wilmington, DE, USA, 8 February 1991 (11 pages with 8 figures, RDB2520)

This document explains the meaning and relevance of solubility and miscibility within refrigeration systems. It notes that the solubility of refrigerant gas in the lubricant usually is an important lubricant feature. In general, lubricants that display miscibility with the refrigerant liquid over a wide range of conditions will also have good refrigerant gas solubilities, but the reverse is not necessarily true. Although the solubility of refrigerant gas in liquid lubricant is important in determining the viscosity of fluid at the evaporator outlet, other factors also are likely to have an effect. An example is the lubricant structure (e.g., polarity or hydrogen bonding). The viscosity of the circulating liquid phase and the velocity of the driving gas are the two most important considerations for lubricant return to the compressor. Lubricant viscosity and the solubility-related viscosity of the refrigerant-lubricant mixture would be expected to govern lubricant holdup, a measure of the lubricant quantity available to interfere with heat transfer. Experience indicates that the concentration of lubricant in the liquid refrigerant phase is below 1% over the majority of the evaporation process, so lubricant miscibility actually does not appear to be significant in determining oil holdup. Separate liquid phases for the refrigerant and lubricant will be present only over a very short length of the evaporator. Plots and tabular data are provided for low-temperature miscibility for ester lubricants (Emkarate(TM) RL) in R-134a. The fraction of lubricant in refrigerant also is plotted for the evaporator length.

R. L. Covington and H. L. Ravner, **Interactions in Neopentyl Polyol Ester-Tricresyl Phosphate-Iron Systems at 500 °F**, *Transactions*, American Society of Lubricating Engineers (ASLE), volume 12, pages 280-286, 1969 (RDB4563)

polyolester, POE, TCP

G. Daniel, M. J. Anderson, W. Schmid, and M. Tokumitsu (Mobil Oil), **Performance of Selected Synthetic Lubricants in Industrial Heat Pumps**, paper B3, *Proceedings of the International Symposium on the Industrial Application of Heat Pumps* (University of Warwick, UK, 24-26 March 1982), BHRA Fluid Engineering, Cranfield, Bedford, UK, pages 41-53, 1982; republished in *Journal of Heat Recovery Systems*, Pergamon Press Limited, UK, volume 2, number 4, pages 359-368, 1982 (12 pages with 3 figures and 4 tables, RDB2210)

This paper reviews lubrication requirements at high condensing temperatures (120-130 °C, 248-266 °F), typical of those encountered in industrial heat pumps. Potential limitations of mineral oils are examined and physical data are reviewed for synthetic lubricants, particularly synthetic hydrocarbon fluids (SHF) of the polyalphaolefin type and selected polyglycols. Viscosity, vapor pressure, and stability data are reviewed for selected synthetic lubricants with halogenated refrigerants. The field results in several installations with R-12 and R-114 are examined, to document satisfactory operation under the severe conditions encountered. The viscosity and solubility data are presented as plots [subsequently referred to by other researchers as Daniel Charts.]

K. E. Davis and J. N. Vinci (Lubrizol Corporation), **Formulation of Polyol Ester Lubricants for Use with HFC Refrigerants**, paper 1.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 15-20, February 1993 (6 pages with 9 tables, RDB3308)

polyolester

K. E. Davis and J. N. Vinci (Lubrizol Corporation), **Effect of Additives in Synthetic Ester Lubricants Used with HFC-134a Refrigerant**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 125-133, September 1992 (9 pages with 5 figures); reprinted by Lubrizol Corporation, Wickliffe, OH, 1992 (20 pages with 5 figures, RDB2A08)

This paper reviews tests of antiwear additives with synthetic ester lubricants, for use with R-134a in automotive and stationery compressors. The lubricants addressed are polyol-carboxylic acid condensation products. The additive screening and tests focused on suitability for wear protection of aluminum on steel, steel on steel, and bronze on steel. The advantages of R-12 lost in conversion to R-134a are outlined; they include inherent antiwear properties, associated with formation of metal-chloride boundary layers, and miscibility with mineral oils. The R-134a advantages, specifically avoidance of

ozone depletion and high relative stability, also are noted. A need for a balanced additive approach, respecting both protection of contacting surfaces and low aggressivity toward copper and aluminum design components, is cited. The paper notes that the issue of copper plating is a selection constraint, in light of its prominence with R-134a and use of polar, potentially active lubricants. The paper reviews a screening protocol based on Falex pin and v-block tests. Results are plotted for R-12 with mineral oil, R-134a with the ester, and the latter pair with six unidentified additive systems. The most promising of the additive packages was further tested with three polyolester lubricants for viscosities of 15-130 cSt. This additive is described as carefully balanced for multi-metal compatibility, namely sufficiently active for antiwear protection yet relatively inactive toward aluminum and copper-containing components. The findings of the compressor tests, including visual examination for distress, deposit formation, and copper plating are reviewed. A figure qualitatively compares the Falex and compressor results. The figure show the Falex test to be a good predictor, though it indicates greater bronze-on-steel concern for the optimized additive than was experienced in the compressor tests.

D. L. Dick, J. N. Vinci, K. E. Davis, G. R. Malone, and S. T. Jolley, **Polyol Ester Interactions with Additives and Desiccants**, Lubrizol Corporation, Wickliffe, OH, 1996 (5 pages with 2 figures, available from JMC as RDB6902)

This paper presents experiments to investigate factors that govern polyolester (POE) lubricant stability. It also discusses stabilization of additized POEs at extreme temperatures. Duplicate sealed-tubes containing the lubricant specimens were aged at 130 or 180 °C (266 or 356 °F) for 1-3 weeks. The samples then were assayed for water, via the Karl Fischer method, and total acid number (TAN). The lubricants comprised *conventional* and *hindered* base esters, formulated esters, and each of them with an antiwear additive, a hydrolysis inhibiting agent, and both of these additives. Plots compare the hydrolytic stability of the unadditized and five formulated POEs alone, with added desiccant, with the hydrolysis inhibitor, and with the desiccant and inhibitor for both *conventional* and *hindered* POEs. The paper presents the sample preparation, test procedures, and discussion of the results. It concludes that the *hindered* POE is more resistant to hydrolysis than the *conventional* counterpart, even with additives present. Further, both the molecular sieve desiccant and hydrolysis inhibiting chemical markedly enhance the stability of unadditized and additized lubricants. Their combined effect produced a substantial enhancement, particularly for the hydrolytically less stable, *conventional* POE. While the paper shows differences in hydrolysis potential among the different formulations, the desiccant-inhibitor combination held acidity to very low levels with all of the additives tested.

K. Doya, Y. Aoki, and M. Onoyama (Showa Shell Sekiyu Company, Limited, Japan), **Refrigerant Oil for Alterable Refrigerant 134a**, *Reito* [Refrigeration], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 65, number 756, pages 47-52 also numbered as 1047-1052, October 1990 (6 pages with 3 figures and 10 tables, in Japanese with summary in English, RDB-3C12)

This paper addresses polyalkylene glycol (PAG) lubricants for use with R-134a, as an alternative for R-12, in mobile air-conditioning (MAC) systems. It discusses lubricity for aluminum-aluminum and/or aluminum-steel contacts, miscibility with R-134a, and compatibility with nonferrous metals. The paper presents data from a study of two PAGs and a *hindered* polyolester (POE) for automotive air conditioners. Among the topics presented are miscibility, thermal stability, effects of additives, hydrolysis resistance, and corrosion.

F. Espinoux, G. Bardy, B. Constans, P. Sanvi, and N. Genet (Elf Research Center, France), **Lubricity Evaluation for Lubricants Used in Refrigeration with HFC-134a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 405-414, July 1992 (10 pages with 6 figures and 3 tables, RDB2823)

R-134a

K. F. Fung (Tyler Refrigeration Corporation) and S. G. Sundaresan (Copeland Corporation), **Study of Oil Return Characteristics in a Display Case Refrigeration System - Comparison of Different Lubricants for a HFC-Blend Refrigerant**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 121-128, July 1994 (8 pages with 4 figures and 6 tables, RDB4815)

R-404A, R-502, naphthenic mineral oil, polyolester

V. Z. Geller (Thermophysics Research Center), A. Yokozeki, and D. B. Bivens (DuPont Chemicals), **Solubility and Viscosity of Alternative Refrigerant/Lubricant Oil Mixtures**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference,

please see pages 6-8 for ordering information

Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 59-67, October 1995 (9 pages with 5 figures and 3 tables, available from JMC as RDB5A46)

R-32, R-125, R-410B, polyolester (POE) lubricant, vapor pressure, density, viscosity

V. Z. Geller, M. E. Paulaitis (University of Delaware), D. B. Bivens, and A. Yokozeki (DuPont Fluoroproducts), **Viscosities for R22 Alternatives and Their Mixtures with a Lubricant Oil**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 49-54, July 1994 (6 pages with 3 figures and 5 tables, RDB4809)

R-32, R-125, R-134a, R-143a, polyolester lubricant

V. Z. Geller, M. E. Paulaitis (University of Delaware), D. B. Bivens, and A. Yokozeki (DuPont Chemicals), **Viscosity of HFC-32 and HFC-32/Lubricant Mixtures**, *Proceedings of the 12th Thermophysical Properties Symposium* (Boulder, CO, 19-24 June 1994), American Society of Mechanical Engineers (ASME), New York, NY, pages 477-486, June 1994 (10 pages, RDB5B25)

R-32, lubricants, properties

W. C. Gergel, **Lubricant Additive Chemistry**, Lubrizol Corporation, Wickliffe, OH, 21 January 1992 (16 pages with 27 figures and 7 tables, RDB3906)

This bulletin reviews the market for, functions of, and types of lubricant additives. It covers diverse applications, but portions also apply to air conditioning and refrigeration. The document summarizes consumption statistics for formulated lubricating oils, noting total annual demand of 34 million metric tons on a worldwide basis. It also discusses uses and the specifications set for key applications. It presents lubricant functions, including contaminant containment, heat removal, and friction reduction. It then discusses additive types including detergents, dispersants, inhibitors, pour point depressants, foam inhibitors, and viscosity modifiers. It also reviews additive types used in automotive transmissions as well as industrial oils and associated additive groups.

B. D. Greig, A. M. Smith, and A. P. Swallow (Castrol International), **Household Compressor Manufacturers Adopting HFC Refrigerants; Compressor Lubricants and Manufacturing Fluids Compatibility**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, October 1993), Alliance for Responsible CFC Policy, Arlington, VA, pages 100-108, October 1993 (9 pages with 10 tables, RDB3A32)

This paper discusses the compatibility and performance of polyolester (POE) lubricants with R-134a as well as compatibility issues arising from manufacturing residues and moisture. It specifically addresses Castrol Icematic SW, a family of synthetic POE lubricants formulated with a low treat, ashless additive package. The additives improve hydrolytic stability, inhibit copper plating, and reduce compressor component wear. The paper notes that tests, including field trials, have found wear comparable or lower than with R-12 and mineral oil, but that problems remain. One source identified is residual mineral oil lubricants from manufacturing processes, which act as contaminants. These residues contain paraffins that form insoluble flocs when mixed with liquified R-134a in condensers. The flocs cause system blockage, especially in capillary tubes. The paper cites efforts with equipment manufacturers to identify compatible alternatives, nonchlorinated cleaners, and corrosion preventives. They include an ester wax to replace paraffinic wax as the motor winding lubricant, a multipurpose lubricant that functions as a hydraulic oil for automated post-cleaning assembly equipment, compressor oil for air compressors supplying dried air to the factory, and a component assembly lubricant. The paper notes that POE lubricants were successfully employed for many years in several applications involving high temperatures. New POEs were synthesized for miscibility with R-134a. A table presents the viscosities, pour points, flash points, and critical solution temperatures with R-134a for three viscosity grades. The paper then discusses inhibition of copper plating. A table compares the condition of aluminum, copper, and steel specimens following sealed-tube tests at 175 °C (347 °F) for 14 days for both a nonformulated base stock and fully formulated Icematic SW22 with 50, 250, and 500 ppm of water. The results suggest that plating increases with moisture, but can be partially or fully inhibited with additives depending on the moisture level. The paper notes the need to dry POE lubricants, typically to 50 ppm or even 20 ppm, and that care is required to minimize exposures to atmospheric moisture. The paper then discusses hydrolytic stability, noting that ester base stocks are produced by a reversible reaction of acid(s) and alcohol(s) to yield an ester and water. A table provides total acid number (TAN) data from turbine and oxidation stability tests (TOST) for selected POEs, including a neat base stock. The discussion indicates that the true level of breakdown is likely to be higher, due to losses from the volatility of many of the acid breakdown products. The paper

then addresses compressor wear, noting that chlorinated additive compounds and chlorine from refrigerants have historically provided excellent anti-wear properties. Falex pin and v-block wear data are tabulated for naphthenic mineral oil alone and with R-12 as well as for ester base stock and formulated POEs alone, with R-12, and with R-134a. The data suggest that R-134a with the formulated POE results in the lowest wear. A separate table compares compressor efficiency for R-134a with POE in three viscosity grades and for R-134a with an unidentified naphthenic oil. Discussion of the data suggests that the lower viscosities will be preferred for higher compressor efficiency. The paper then reviews chemical cleaners and corrosion preventives used in the manufacture of compressors. Data are provided for Castrol Careclean MP and Rustilo DWX; Rustilo DWX 30 is designed as an ester-based corrosion preventive for compatibility with R-134a and POEs. The paper similarly discusses effects of residual honing oils for compressor component machining and hydraulic oils for assembly. Tabular data show the reduction in lower solution temperature with ester honing and hydraulic oils, such as Castrol CareTech and Hyspin SW32, compared to mineral oils. The paper concludes that system compatibility with R-134a involves consideration of the motor winding wax, corrosion preventives, honing and hydraulic oils, and cleaners in addition to the selection and additives for the POE lubricant.

B. D. Greig (Castrol Limited), **Formulated Polyol Ester Lubricants with HFC-134a: The Role of Additives and Conversion of Existing CFC-12 Plant to HFC-134a**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 135-145, September 1992 (11 pages with 3 figures and 3 tables, RDB-2A09)

R-12, R-134a, polyolester

T. Hamada and N. Nishiura (Mitsubishi Oil Company, Limited, Japan), **Refrigeration Lubricant Based on Polyolester for Use with HFCs and Prospect or Its Application with R-22 (Part 2) Hydrolytic Stability and Compressor Endurance Test Results**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 279-284, July 1996 (6 pages with 11 figures and 3 tables, RDB6917)

tribological behavior for a pentaerythritol type polyolester (POE) base and formulated oils as a lubricant for use with both R-22 and hydrofluorocarbon (HFC) refrigerants including R-134a, R-404A and R-407C; hydrolytic and thermal stability; moisture removal effect; reliability tests; compressor endurance tests; roles of additives including epoxy type, antiwear (aryl phosphate and sulfur phosphorous), and others

P. E. Hansen (Danfoss-Flensburg GmbH, Germany), **On the Oil Selection Methodology for New Refrigerants for Small Hermetic Compressors**, paper 3.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 45-50, February 1993 (6 pages with 3 figures and 3 tables, RDB3312)

T. Hayashi, M. Tanaka, K. Takeuchi, K. Takahata, and N. Sakamoto (Mitsui Petrochemical Industries, Limited, Japan), **Carbonate Oils for Unitary Air Conditioners with R-410A**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 285-290, July 1996 (6 pages with 5 figures and 7 tables, RDB6918)

R-410A; synthetic carbonate lubricants containing a ß-hindered alkyl and alkylbenzene groups; miscibility with R-410A; thermal stability; lubricity; drop-in test in a rotary, rolling-piston compressor; properties

R. Heide (Forschungszentrum für Luft- und Kältetechnik, Dresden, Germany), **Ein Beitrag zur Viskosität von Öl-Kältemittel-Gemischen** [A Contribution on the Viscosity of Oil-Refrigerant Mixtures], *Luft- und Kältetechnik*, Germany, volume 6, number 6, pages 308-310, 1970 (3 pages with 3 figures, in German, RDB4249)

This paper provides plots of and regressions to estimate the kinematic viscosities of three mixtures of synthetic lubricants with refrigerants. They included 51KM33 oil with R-11, 51KM33 with R-12, and KM30 with R-22 for 50-100% concentrations for -40 to 60 °C (-40 to 140 °F). The refrigerants were obtained from VEB Fluorwerke Dohna and the three synthetic lubricants from VEB Leuna-Werke, both in the German Democratic Republic. The paper reviews prior measurements by others and outlines the experimental approach using falling-ball and rotating rheostat viscometers.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant/Lubricant Mixtures**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 419-424,

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July 1994 (6 pages with 12 figures and 1 table, RDB4856)

Density is plotted as a function of temperature for R-32 with ISO 100 POE-BA, R-125 with ISO 22 POE-MA and with ISO 32 POE-BA, and R-152a with ISO 68 AB. Daniel Charts are provided for R-32 with ISO 100 POE-BA, R-124 with ISO 68 AB, R-134a with ISO 22 POE-MA, R-143a with ISO 32 POE-BA, and R-152a with ISO 68 AB.

D. R. Henderson (Spauschus Associates, Incorporated), **Solubility, Viscosity, and Density of Refrigerant/Lubricant Mixtures**, report DOE/CE/-23810-34, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1994 (150 pages with 142 figures and 77 tables, available from JMC as RDB4889)

This report presents the findings of a study of the solubility, viscosity, and density of 35 refrigerant-lubricant mixtures. It addresses low (0, 10, 20, and 30% by weight) and high (80, 90, and 100%) refrigerant concentrations. It summarizes results for R-12, R-22, R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, and R-152a with mineral oil (MO), alkylbenzene (AB), polyalkylene glycol (PAG), and two classes of polyolester (POE) lubricants - pentaerythritol ester branched acid (POE-BA) and pentaerythritol ester mixed acid (POE-MA). Data are provided for the following combinations: R-12 with ISO 32 and 100 MO; R-22 with ISO 32 MO; R-32 with ISO 22 and 68 POE-MA and with ISA 32 and 100 POE-BA; R-123 with ISO 32 and 100 MO and with ISO 32 and 68 AB; R-124 with ISO 32 and 68 AB; R-125 with ISO 22 and 68 POE-MA and with ISO 32 and 100 POE-BA; R-134a with ISO 68 PAG, ISO 22, 68, and 100 POE-BA, and ISO 22, 32, 68, and 100 POE-MA; R-142b with ISO 32 and 78 AB; R-143a with ISO 22 and 68 POE-MA and ISO 32 and 100 POE-BA; and R-152a with ISO 32 and 68 AB and with ISO 22 and 68 POE-MA. Equations and regression coefficients are tabulated for solubility (expressed as vapor pressure), dynamic and kinematic viscosity, and density for each mixture. These results also are shown as plots of density versus temperature and as Daniel Charts, showing kinematic viscosity and solubility versus temperature. The measurements for the low refrigerant concentrations covered 0-100 °C (32-212 °F), except that measurements for R-32, R-125, and R-143a were capped at 75, 65, and 70 °C (167, 149, and 158 °F), respectively. Those for high concentrations covered -40 to 40 °C (-40 to 104 °F), except for R-32, R-123, and R-143a for which the low end of the ranges were changed to -50, -20, and -45 °C (-58, -4, and -49 °F). An appendix explains the experimental technique. It also outlines the theoretical basis for corrections made for vapor space volume in the test apparatus. A second appendix summarizes the lubricant purities, including moisture content, total acid number (TAN), and iron and copper contents. A final appendix identifies the specific lubricants tested, including AB (Shrieve Chemical Zerol(R) 150 and 300), naphthenic MO (Witco Suniso(R) 3GS and 5GS), PAG (ICI Emkarox(R) DGLP 103), POE-BA (Henkel Emery(R) 2966A, 2968A, 2942A, and 2928A), and POE-MA (Mobil EAL Arctic(R) 22 and 32; Castrol Icematic(R) SW32, SW68, and SW100; and ICI Emkarate(R) RL-375). The report includes an interpretive discussion of the findings by refrigerant.

N. J. Hewitt, J. T. McMullan, N. E. Murphy, and N. Shafaghian (University of Ulster, UK), **A Solubility Equation for R-22/Oil Mixtures**, *International Journal of Energy Research*, volume 15, number 9, pages 763-768, December 1991 (6 pages, RDB-4C21)

refrigerant-lubricant properties

H. Hirano, H. Kawano, Y. Watanabe, H. Fukuoka, and A. Miyazaki (Matsushita Electric Industrial Company, Limited, Japan), **Evaluation of Lubricants for HFC Refrigerants**, paper 6.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 150-155, December 1994 (6 pages with 13 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5428)

naphthenic mineral oil, alkylbenzene, polyolester, ether, and carbonate lubricants, additives, lubricity, rotary rolling-piston compressor

H. G. Hirschberg (Gebrüder Sulzer AG, Switzerland), **Zur Ermittlung der Viskosität von Mineralöl-Kältemittel-Gemischen**, *Technische Rundschau Sulzer*, Winterthur, Switzerland, volume 46, number 2, pages 89-93, February 1964; republished in English as **Determining the Viscosity of Mixtures of Mineral Oil and Refrigerants**, *Sulzer Technical Review*, Winterthur, Switzerland, volume 46, number 2, pages 89-92, February 1964; republished in *Modern Refrigeration*, pages 711-713 (3 pages with 4 figures, RDB2501)

The viscosity of lubricating oils is substantially lowered by dissolved hydrocarbons. Determination of viscosity for refrigerant-lubricant mixtures, therefore, is very important in equipment and application design. The need is heightened by variations in the hydrocarbon content, related to the origin of the crude oil used, and the way in which it is refined. This paper outlines

calculation methods to determine the viscosity based on ring analysis, mean molecular weight, viscosity-temperature relation, and density. The ring analysis determines the paraffins, cyclic paraffins (naphthenic substances, and benzene derivatives (aromatics) present in the oil. The molecular weight is a measure of the size of the oil molecules. The viscosity index, or alternative viscosity pole height, may be obtained from manufacturer data. The paper discusses viscosity equations developed by a number of investigators, including Arrhenius, E. R. Epperson and H. L. Dunlap, L. Grunberg and A. H. Nissan, and H. Umstätter. It illustrates comparative results based on a mixture of R-114 and mineral oil. It concludes that a modified version of the Grunberg and Nissan equation is useful for representing and calculating the viscosities of refrigerant-lubricant mixtures.

D. F. Huttenlocher (Spauschus Associates, Incorporated), **Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals**, report DOE/CE/23810-5, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 9 October 1992 (126 pages with 75 figures and 27 tables, available from JMC as RDB3608; several of the figures, specifically the IR spectra, are difficult to read)

This report presents stability data, based on sealed tube tests, for 21 mixtures of refrigerants and lubricants in the presence of a valve steel strip, as catalyst. Tables present results for R-11 with mineral oil (MO) and with a white naphthenic MO; R-22 with MO; R-32 with pentaerythritol ester mixed acid and with polypropylene glycol (PPG) butyl monoether; R-123 with MO and with white naphthenic MO; R-124 with alkylbenzene (AB); R-125 with PPG butyl monoether, modified polyglycol, and pentaerythritol ester mixed acid; R-134 with pentaerythritol ester mixed acid; R-134a with PPG butyl monoether, PPG diol, modified polyglycol, three pentaerythritol esters (two of them mixed acids); R-142b with alkylbenzene; R-143a with pentaerythritol ester mixed acid; and R-152a with AB. Each test mixture was aged at three temperature levels, generally 150, 175, and 200 °C (221, 302, and 347 °F); tests were performed at other temperatures when warranted. The information provided includes the specific materials and aging conditions for each combination tested, visual observations on the aged sealed tubes, and results of chemical analyses. The last includes gas chromatograms of the vapor-phase contents as well as chloride and fluoride ion contents for mixtures containing hydrochlorofluorocarbons (HCFCs) hydrofluorocarbon (HFCs), respectively. Total acid number (TAN) values and infrared analyses (IR) are presented; size exclusion chromatography (SEC) is summarized for mixtures including polyalkylene glycol (PAG) lubricants. The findings indicate that the HFCs tested and R-22 are very stable and do not undergo measurable chemical reactions or thermal decomposition, even in the presence of lubricants, for the conditions tested. R-124 and R-142b have stability properties intermediate between the HFCs and R-12. R-123 is more reactive, but offers stability improvement by a factor of ten over R-11. All of the pentaerythritol ester and PAG fluids showed changes in chemical structure after exposures at 200 °C (347 °F), and in some cases at 150 °C (302 °F) and 175 °C (347 °F). An appendix summarizes the test results, including tabulated findings and gas chromatograms. A second presents IR spectra and SECs of the lubricants before and after aging. A third appendix recaps the refrigerants and lubricants tested as well as purity measurements taken. Gas chromatograms are provided for each of the refrigerants. Acidity, water content, and metal content are tabulated for each of the lubricants. The MOs tested were Witco Suniso(R) 3GS (ISO VG32) and Freezene Naphthenic Heavy white oil (ISO VG46). The AB was Shrieve Zerol(R) 150. The PAGs included ICI Emkarox(R) PPG butyl monoether (ISO VG32) and Dow Chemical P245 PPG diol (ISO VG22). The pentaerythritol esters (PEs) included Castrol Icematic(R) SW32 branched acid (ISO VG32), ICI Emkarate(TM) RL mixed acids (ISO VG22), and Henkel Emery(R) 4078X (2928 ISO VG100) 100 cSt.

K. Inoue, M. Sunami, and A. Nakao (Nippon Oil Company, Limited, Japan), **Mutual Solubility of Refrigerants and Polyol Esters**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 147-152, July 1994 (6 pages with 6 figures and 2 tables, RDB4819)

R-32, R-125, R-134a, R-143a, tetraesters, pentaerythritol, polyolesters

K. Inoue and A. Iwamoto (Nippon Oil Company, Limited, Japan), **Mutual Solubility of HFC-134a (1,1,1,2-tetrafluoroethane) and Synthetic Ester Base Stocks**, *Sekiyu Gakkaishi*, Japan, volume 35, number 1, pages 76-83, 1992 (8 pages, RDB4B18)

R-134a, polyolester (POE) lubricants

B. Jacobson (SKF Engineering & Research Centre B.V, Nieuwegein, The Netherlands), **Lubrication of Screw Compressor Bearings Used in the Presence of Refrigerants**, *Proceedings of the 1994 International Compressor Engineering Conference at Purdue*, edited by W. Soedel, Purdue University, West Lafayette, IN, volume I, pages 115-120, July

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1994 (6 pages with 3 figures and 3 tables, RDB-5A03)

R-22 and naphthenic mineral oil; R-134a and polyolester lubricant, EHL theory

H. P. Jaeger, **Design of a Viscometer for Measuring the Viscosity of Multiple Component Blends with High Vapor Pressure**, *Technisches Messen Atm.*, Germany, volume 45, number 5, pages 161 ff, 1978 (in German, RDB4252)

H. P. Jaeger, **Calculation of the Viscosity of Oil and Refrigerant Mixtures**, *Il Freddo* [Refrigeration], Italy, volume 31, number 5, pages 376-386, 1977 (in Italian, RDB4614)

H. P. Jaeger, **Calculation of the Viscosity of Fluid Oil-Coolant Mixtures**, *Kälte.*, Hamburg, Germany, volume 28, number 9, pages 332-340, 1975 (in German, RDB4615)

H. P. Jaeger, **Synthetic Oils for Refrigerating Machines**, *Klima-Kältetechnik*, Germany, volume 16, 1974 (in German, RDB4616)

R-11, R-12, R-13, R-13B1, R-22

H. P. Jaeger (Technische Universität Braunschweig, Germany), **The Pattern of Solubility Limits of Oil-Refrigerant Mixtures in the Critical Range**, *Kältetechnik-Klimatisierung*, Germany, volume 25, number 3, pages 73-74, 1973 (2 pages, in German, RDB4253)

H. P. Jaeger (Technische Universität Braunschweig, Germany), **Empirische Methoden zur Vorausberechnung thermodynamischer Eigenschaften von Öl-Kältemittel-Gemischen** [Empirical Methods for Predicting Thermodynamic Properties of Oil-Refrigerant Mixtures], *Kältetechnik-Klimatisierung*, Germany, volume 25, number 2, pages 35-38, 1973 (4 pages, in German, RDB4254)

H. P. Jaeger, **Empirische Methoden zur Vorausberechnung thermodynamischer Eigenschaften von Öl-Kältemittel-Gemischen** [Empirical Methods for Predicting the Thermodynamic Properties of Oil-Refrigerant Mixtures], dissertation, Technische Universität Braunschweig, Germany, 1972; published by Verein Deutscher Ingenieure (VDI, Association of German Engineers) Verlag, Düsseldorf, Germany, volume 115, number 15, pages 1239 ff, 1973 (in German, RDB4255)

H. P. Jaeger and H. J. Löffler (Technische Universität Braunschweig, Germany), **Concerning the Behavior of R-22/Oil Mixtures**, *Kältetechnik-Klimatisierung*, volume 23, number 10, pages 305-309, 1971 (5 pages, in German, RDB4256)

R-22

H. P. Jaeger and H. J. Löffler (Technische Universität Braunschweig, Germany), **Thermodynamischer Eigenschaften von Öl-Kältemittel-Gemischen** [Thermodynamic Properties of Oil-Refrigerant Mixtures], *Kältetechnik-Klimatisierung*, volume 22, number 8, pages 246-256, 1970 (11 pages with 10 figures and 38 tables, in German, RDB4257)

This paper provides solubility, density, vapor pressure, viscosity, and specific volume data for mixtures of R-10, R-12, R-13, R-13B1, and R-22 with five lubricants. They include naphthenic and paraffinic mineral oils, a synthetic lubricant, and a mixture of a mineral oil and a synthetic. The paper summarizes the experimental methods used and compares the findings to those from prior studies.

H. P. Jaeger (Technische Universität Braunschweig, Germany), **Thermodynamischer Eigenschaften binärer Gemische aus Kältemischinenölen und Monofluortrichlormethan (R11)** [Thermodynamic Properties of Binary Mixtures of Mineral Oils and Trichlorofluoromethane (R-11)], *Kältetechnik-Klimatisierung*, volume 21, number 10 pages 302-306 and number 12 pages 367-369, 1969 (8 pages, in German, RDB4258)

S. T. Jolley, K. E. Davis, and G. R. Malone, **The Effect of Desiccants in HFC Refrigeration Systems Using Ester Lubricants**, Lubrizol Corporation, Wickliffe, OH, 1996 (12 pages with 8 figures, available from JMC as RDB6903)

investigation of moisture impacts with use of polyolester (POE) lubricants; potential for acid contamination of systems using hydrofluorocarbon (HFC) refrigerants and POEs from the lubricant and additive hydrolysis; water potential and role of desiccants in refrigeration systems; bench and accelerated compressor testing shows that hydrolysis increases, as evidenced by a decrease in water and increase in total acid number (TAN); role of the carboxylic acid from POE hydrolysis over a 5000 hr test; experiments show that moisture can be transferred from desiccants to lubricants and that the water content of lubricants reaches an equilibrium with other parts of the system; capillary tube blockage tests with wet and dry systems, each with and without a desiccant show low blockage in dry systems, but a quick increase when doped with carboxylic acid; the paper concludes that moderate water contamination of refrigeration systems may be less of a long-term problem than perceived; it further concludes that while POEs can undergo hydrolysis with sufficient water, the combination of desiccant use and affinity of refrigerants to associate with water reduce its contact with the lubricant; finally, that use of POEs prepared with α-branched acids and use of hydrolysis inhibiting

additives further reduce the potential for lubricant degradation

R. L. Jones, H. L. Ravner, and R. L. Cottington, **Inhibition of Iron-Catalyzed Neopentyl Polyolester Thermal Degradation Through Passivation of the Active Metal Surface by Tricresyl Phosphate**, American Society of Lubricating Engineers (ASLE) / American Society of Mechanical Engineers (ASME) Lubrication Conference (Houston, TX), 1969 (RDB4928)

POE, TCP

U. J. Jonsson and E. B. Höglund (Luleå University, Sweden), **Determination of Viscosities of Oil-Refrigerant Mixtures at Equilibrium by Means of Film Thickness Measurements**, paper DE-93-20-2, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 1129-1136, 1993 (8 pages with 11 figures and 1 table, RDB3625)

S. T. Jolley, **The Performance of Synthetic Ester Lubricants in Mobile Air-Conditioning Systems**, unpublished presentation at the Society of Automotive Engineers (SAE) Passenger Car Meeting and Exposition (Nashville, TN, 16-19 September 1991); unpublished presentation repeated at the International CFC and Halon Alternatives Conference (Baltimore, MD, 3-5 December 1991); Lubrizol Corporation, Wickliffe, OH, 1991 (14 pages with 3 figures and 6 tables, available from JMC as RDB-2C07)

The publication reviews polyolester chemistry and the reactions of alcohol and carboxylic acid to produce them. The variety of lubricants that can be produced from neopentylglycol (NPG), glycerine (GLY), trimethylolpropane (TMP) and pentaerythritol (PER) polyols (alcohols with multiple hydroxyl reaction sites) is illustrated. A table demonstrates the influence of the alcohol type on viscosity and miscibility using the same carboxylic acid. A second table shows that when similar lubricants, with the same viscosity are prepared, differences occur in miscibility with R-134a. GLY and NPG fluids exhibit the poorest and highest solubility, respectively. Tabulated results of sealed-tube tests of R-134a and lubricant in the presence of iron, copper, and aluminum show high thermal stability for a number of polyolesters, generally superior to that of R-12 with mineral oil. The more reactive systems tended to be those with high water content or residual carboxylic acid. Data are presented on the same refrigerant-lubricant pairs with addition of controlled amounts of water, to examine hydrolytic stability. Resultant increases in acid number are discussed, but caveated that higher acid levels might occur with additives instead of the base lubricants tested. A figure summarizes elastomer swell for mineral oil as well as NPG, TMP, and PER esters for NBR, H-NBR, EPDM, nitrile, neoprene, and Butyl; the paper notes that further testing is needed. It then discusses miscibility with mineral oil, a concern for retrofit of automobile air conditioners with R-134a and esters. TMP and PER esters are indicated to be fully compatible with both residual R-12 and mineral oil. Compressor tests are summarized, to address the influence of viscosity on durability and the role of unidentified additives. The paper indicates that equivalent performance to R-12 and mineral oil can be obtained with polyolesters and appropriate additive packages. The paper concludes that polyolesters appear ideal for use in automobile air conditioner systems, and that they can be tailored for specific needs.

S. T. Jolley, **New and Unique Lubricants for Use in Compressors Utilizing R-134a Refrigerant**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 145-152, July 1990 (8 pages with 1 figure and 5 tables, RDB2C06)

H. M. Lee Kang, S. C. Zoz and M. B. Pate (Iowa State University of Science and Technology), **Solubility of HFC-32, HFC-125, and HFC-134a with Three Potential Lubricants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 437-442, July 1994 (6 pages with 9 figures and 1 table, RDB-4859)

R-32, R-125, R-134a

R. E. Kauffman and W. E. Rhine (University of Dayton Research Institute), **Development of a Useful Lubricant Life Evaluation Technique, Part I: Differential Scanning Calorimetric Techniques**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 44, number 2, pages 154-161, February 1988 (8 pages, RDB3961)

S. Kitaichi, S. Sato, R. Ishidoya, and T. Machida (Toshiba Corporation, Japan), **Tribological Analysis of Metal Interface Reactions in Lubricant Oils/CFC-12 and HFC-134a System**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 153-162, July 1990 (10 pages with 13 figures and 3 tables, RDB4C23)

R-12, R-134a

please see pages 6-8 for ordering information

S. Komatsuzaki, Y. Homma, Y. Itoh, and K. Kawashima (Hitachi Limited, Japan), **Polyol Esters as HFC-134a Compressor Lubricants**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 50, number 10, pages 801-807, 1994 (7 pages, RDB6370)

R-134a, polyolester (POE) lubricants

S. Komatsuzaki and Y. Homma (Hitachi Limited, Japan), **Lubricants for HFC Refrigerant Compressors**, *Sekiyu Gakkaishi*, Japan, volume 37, number 3, pages 226-235, 1994 (10 pages, RDB6371)

polyalkylene glycol (PAG) polyolester (POE) lubricants

S. Komatsuzaki and T. Iizuka (Hitachi Limited, Japan), **Miscibility and Lubricity of Polyol Ester-Based Refrigerator Lubricants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 92-99, October 1993 (8 pages with 9 figures and 1 table, available from JMC as RDB3A31)

This paper provides data on the miscibility and lubricity of mixtures of R-134a with polyolester (POE) lubricants, including neopentyl glycol (NPG), pentaerythritol (PE), and trimethylol propane (TMP) esters. It briefly reviews the rationale for transition to hydrofluorocarbon refrigerants and the accompanying introduction of new lubricants and other materials. It cites the dependence on hydrogen bonding between the refrigerant and lubricant for miscibility, and discusses the influence of the lubricant's molecular structure on miscibility. The paper reviews the manufacture of esters from reactions of alcohols with fatty acids. Figures show the miscibility of R-134a with TMP and PE esters as well as with fatty acids as functions of temperature and lubricant fraction for straight- and branched-chain acids. The paper then discusses and shows plots of the upper critical solution temperature (UCST) dependence on the number of carbon atoms in the acids for NPG, PE, and TMP esters. The paper discusses the anticipated use of R-32 in blends and tabulates the viscosity of eight POEs and their UCSTs with R-32 and R-134a. It discusses lubricity tests and notes that measured results were entirely different in refrigerant and air environments. It describes lubricity tests with refrigerant lubricant mixtures and gives plots for R-12 with alkylbenzene and for R-134a with an unidentified, additized, TMP ester. A final plot shows the seizure load dependance of these mixtures on the refrigerant-lubricant ratio. The paper concludes that better miscibility can be achieved with branched acids and that higher lubricity is needed with R-134a than with R-12, since the refrigerant offers no lubricity itself. Further, the use of extreme pressure (EP) additives allows R-134a/POE mixtures to match the lubricity of R-12 with mineral oils or alkylbenzenes. The paper notes, however, that the lubricity of R-134a/POE drops sharply when the refrigerant exceeds 50% of the mixture by volume.

S. Komatsuzaki, Y. Homma, K. Kawashima, and Y. Itoh (Hitachi Limited, Japan), **Polyalkylene Glycol as Lubricant for HFC-134a Compressors**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 47, number 12, pages 1018-1025, December 1991 (8 pages, RDB2212)

R-134a, PAG

S. Komatsuzaki and Y. Homma (Hitachi Limited, Japan), **Antiseizure and Antiwear Properties of Lubricating Oils Under Refrigerant Gas Environments**, paper 90-AM-6C-1 (45th Annual Meeting, Denver, CO, 7-10 May 1990), Society of Tribologists and Lubrication Engineers (STLE), May 1990; republished in *Lubrication Engineering*, STLE, volume 47, number 3, pages 193-198, 1991 (6 pages, RDB2213)

S. Komatsuzaki, T. Tomobe, and Y. Homma (Hitachi Limited, Japan), **Additive Effects on Lubricity and Thermal Stability of Refrigerator Oils**, *Lubrication Engineering*, American Society of Lubrication Engineers (ASLE), volume 43, number 1, pages 31-36, January 1987 (6 pages, RDB2423)

M. A. Krevalis, C. B. Duncan, and G. W. Davis, **The Effect of Structure on the Performance of Polyol Esters as Synthetic Lubricants**, 49th Annual Meeting, Pittsburgh, PA, May 1994), Society of Tribologists and Lubrication Engineers (STLE), 1994 (RDB5125)

polyolester, POE

H. H. Kruse and F. Wrede (Universität Hannover, Germany), **Possibilities of Energy Saving in Compressors for Refrigeration Systems**, *Proceedings of the XVth International Congress on Refrigeration* (Venice, Italy, 23-29 September 1979), pages 7-15, 1979 (9 pages, RDB4626)

lubricant impacts performance

S. Kussi, **Polyethers as Base Fluids to Formulate High Performance Lubricants**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 47, number 11, pages 926-933, November 1991 (8 pages, RDB6913)

chemistry of polyalkylene glycol (PAG) lubricants

K. C. Lilje, M. Sabahi (Albermarle Corporation), and S. Hamid (Hüls America Incorporated), **Polybasic Esters: Novel Synthetic Lubricants Designed for Use in HFC Compressors**, paper SD-95-8-2, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 935-939, 1995 (5 pages with 1 figure and 12 tables, RDB6369)

polybasic ester (PBE) lubricants resulting from reactions of acrylate esters with malonate-esters (malonate-acrylate Michael adducts)

K. C. Lilje and M. Sabahi (Albermarle Corporation), **A Novel Class of Synthetic Lubricants Designed for HFC Compressors**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 145-153, October 1994 (9 pages, RDB6914)

polybasic ester (PBE) lubricants resulting from reactions of acrylate esters with malonate-esters (malonate-acrylate Michael adducts)

F. Lockwood and E. E. Klaus, **Ester Oxidation - The Effect of an Iron Surface**, *Transactions*, American Society of Lubricating Engineers (ASLE), volume 25, number 2, pages 236-244, 1981 (9 pages, RDB4929)

H. J. Löffler and H. P. Jaeger, **Wie Verhalten Sich Öl-R23-Gemische in Kältemaschinen?** [How Do R-23/Oil Mixtures Behave in Refrigeration Machines?], *Kältetechnik-Klimatisierung*, volume 19, number 8, pages 237-240, 1967 (4 pages, in German, RDB4308)

R-23, lubricants

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Die Viskosität von Öl-Kältemittel-Gemischen** [Viscosity of Oil-Refrigerant Mixtures], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 12, number 3, pages 71-75, 1960 (5 pages with 12 figures, in German, RDB4263)

This paper presents viscosity data for R-11, R-12, and R-22 with five different lubricants. The experimental apparatus used to measure the viscosities is described and shown schematically. Plots show the kinematic viscosity of oil-refrigerant mixtures for the three refrigerants with 75-100% mineral oil by weight and for R-22 with a synthetic silicate lubricant (Bayer Fluisil(R) S 55 K), at temperatures of -20 to 70 °C (-4 to 158 °F). Additional plots show the relationship between solution vapor pressure and concentration for the same temperatures. The results are compared with those published by other investigators. Based on the comparisons, the paper presents a simple method to estimate the viscosities of oil-refrigerant mixtures containing R-11, R-12, or R-22.

H. J. Löffler (Kältetechnischen Institut der Technischen Hochschule Karlsruhe, Germany), **Die Mischbarkeit der synthetischen Öle 'Fluisil S55K' und 'Polyran M15' mit den Kältemitteln Frigen 13, Frigen 22, bzw. mit Gemischen as Frigen 13 und Frigen 22** [The Mixing Abilities of the Synthetic Oils Fluisil S55K and Polyran M15 with Refrigerants R-22, R-13, or Mixtures of R-22 and R-13], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 9, number 5, pages 135-137, 1957 (3 pages with 2 figures and 1 table, in German, RDB4268)

R-13, R-22, R-13/22, synthetic silicate butyl ester (polykieselsäurebutylester) lubricant (Bayer Fluisil(R) S 55 K), synthetic polyether (Bayer Polyran M15)

W. L. Martz and A. M. Jacobi, **Refrigerant-Oil Mixtures and Local Composition Modeling**, report TR-68, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, October 1994 (RDB5B24)

T. Matsuzaki and M. Akei (Calsonic Corporation), **The Friction and Wear Behavior in Refrigerant Atmosphere**, paper 2.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 27-32, February 1993 (6 pages with 13 figures, RDB3310)

H. H. Michels and T. H. Sienel (United Technologies Research Center), **Solubility Modeling of Refrigerant/Lubricant Mixtures**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 49-58, October 1995; republished as report DOE/CE/23810-65B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1995 (10 pages with 6 figures, available from JMC as RDB5A45)

general model (NISC) for predicting the solubility properties of refrigerant-lubricant mixtures, Wohl model, excess Gibb's energy of nonideal solutions, R-407C, R-410A, polyolester lubricant

K. Mizuhara, M. Akei, and T. Matsuzaki, **The Friction and Wear Behavior in a Controlled Alternative Refrigerant Atmosphere**, *Tribology Transactions* (ASME/STLE Tribology Conference, San Diego, CA, 18-21 October 1992), paper 92-TC-3B-3, Society of Tribologists and Lubrication Engineers

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(STLE), volume 37, number 1, pages 120-128, 1994 (RDB4C26)

lubricant performance

K. Mizui, M. Tanaka, T. Hayashi, K. Takahata, and N. Sakamoto (Mitsui Petrochemical Industries, Limited, Japan), **New Lube Oil for Unitary Air Conditioner**, paper 5.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 119-123, December 1994 (5 pages with 2 figures and 9 tables; in Japanese with abstract, figures, and tables in English; RDB5422)

R-407C; carbonate, ester, and ether synthetic lubricants; hindered and nonhindered carbonates; lubricity, viscosity, miscibility, stability with metals

M. Muraki, K. Takagawa (Mitsubishi Oil Company, Limited, Japan), and D. Dong (Sanseki Techno Company, Limited, Japan), **Refrigeration Lubricant Based on Polyolester for Use with HFCs and Prospect or Its Application with R-22 (Part 1) Tribological Considerations**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 273-278, July 1996 (6 pages with 10 figures and 3 tables, RDB6916)

tribological behavior for a pentaerythritol type polyolester (POE) base and formulated oils and an alkylbenzene having a branched alkyl substituent with R-22, R-134a, R-404A, and R-407C; effects of refrigerants and additives; surface observations and analysis

M. Muraki (Mitsubishi Oil Company, Limited, Japan), **Refrigeration Lubricants Based on Polyolester for Alternative Refrigerants**, paper 5.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 101-106, December 1994 (6 pages with 16 figures, in Japanese with abstract and figures in English, RDB5419)

miscibility, hydrolytic stability, tribology, wear, rotary rolling-piston compressor, R-134a, R-32/125/134a

S. K. Naidu, E. E. Klaus, and J. L. Duda, **Thermal Stability of Esters Under Simulated Boundary Lubrication Conditions**, *Wear*, Elsevier Sequoia, Lausanne, Switzerland, volume 121, pages 211-222, 1988 (12 pages, RDB4930)

polyolester, POE

Y. Natsume (Nippondenso Company, Limited), **Refrigerating Machine Lubricants for New Refrigerants**, paper 2.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 21-26, February 1993 (6 pages with 11 figures and 1 table, RDB3309)

J. C. Nieuwoudt (Shell Development Company) and I. R. Shankland (AlliedSignal Incorporated), **Oscillating Body Viscometers**, *Experimental Thermodynamics*, edited by W. A. Wakeham, A. Nagashima, and J. V. Sengers, Blackwell Scientific Publishers, UK, volume III, pages 9-48, 1991 (40 pages, RDB4655)

M. Nomura, K. Sakitani, S. Hiodoshi, M. Minowa, and T. Kato (Daikin Industries, Limited, Japan), **Evaluation of Oil Applicable to HFC-134a**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 135-140, July 1994 (6 pages with 2 figures and 2 tables, RDB4817)

R-134a, polyolester

F. G. Oberender, **Refrigerant and Refrigeration Oil Trends**, *Lubrication*, Texaco Publications, volume 79, number 3, pages 1-16, 1993 (16 pages, RDB6372)

lubricants

M. B. Pate, S. C. Zoz, and L. J. Berkenbosch (Iowa State University of Science and Technology), **Miscibility of Lubricants with Refrigerants**, report DOE/CE/23810-18, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 1993 (262 pages with 73 figure and 151 tables, available from JMC as RDB4502)

This report provides detailed miscibility data for 10 alternative refrigerants with 14 lubricants, based on experiments conducted in two phases. The first involved screening using refrigerant concentrations of 10, 50, and 95%. The second entailed further measurements at 20, 35, 65, 80, and 90%. The report presents the methods, apparatus based on test cells in temperature-controlled baths, and significant results. Ten tables summarize the miscibility data for each refrigerant by nominal concentration in each of 14 lubricants. 72 plots show the miscible and immiscible regions by mass fraction (0.0 to 1.0) and temperature (-50 to 60 °C, -58 to 140

°F); plots are omitted for combinations exhibiting full miscibility. The refrigerants are R-22, R-32, R-123, R-124, R-125, R-134, R-134a, R-142b, R-143a, and R-152a. The lubricants include two naphthenic mineral oils (Witco Suniso(R) 3GS and 4GS) and two alkylbenzenes (Shrieve Zerol(R) 150 and 300). They also included five polyalkylene glycol (PAG) samples: two polypropylene glycol butyl monoethers (ICI Emkarox(R) VG32 and VG58), two polypropylene glycol diols (Dow Chemical P425 and P1200), and a modified polyglycol (AlliedSignal BRL-150). Five polyolesters (POE) were tested, all pentaerythritol esters: three mixed acids (ICI Emkarate(TM) RL 22H, formerly identified as RL 244, and Castrol Icematic(R) SW32 and SW100) and two branched acids (Henkel Emery(R) E2927 and E2928). Each of the refrigerants tested is miscible with at least one of the lubricants, with the exception of R-143a, which exhibits partial miscibility with each of the lubricants. The moisture, iron, and copper contents as well as acid numbers are tabulated for the test lubricants. An appendix comprising 140 tables provides a summary of qualitative observations (two phase, clear, slightly hazy, or hazy) by nominal temperature and concentration as well as the precise measurements of the mass fractions and actual temperatures.

A. P. Perekrestov, M. A. Lyustig, and I. V. Gerasimova, **Determination of the Viscosity of an Oil-Freon Mixture of New Synthetic Oils Under Thermodynamic Equilibrium Conditions**, *Kolloidnyi Tekhnika*, volume 31, pages 57-59, 1980 (3 pages, in Russian, RDB4278)

T. Pyziak and D. W. Brinkman, **Recycling and Re-Refining Used Lubricating Oils**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 49, number 5, pages 339 ff, 1993 (RDB6382)

lubricant recovery, disposal and reuse of oils

S. J. Randles and M. G. Penman (ICI Chemicals and Polymers Limited, UK), **Handling and Disposal of Polyol Ester Refrigeration Lubricants**, paper SD-95-8-4, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 947-957, 1995 (11 pages with 8 figures and 4 tables, RDB6375)

polyolester (POE) lubricants, storage, handling, safety, additives, disposal and reuse of oils

J. Reyes-Gavilán, T. Flak, and T. Tritcak (Witco Corporation), **Lubricants for Refrigeration Compressor Applications**, unpublished paper presented at the International CFC and Halon Alternatives Conference (Washington, DC), October 1993 (13 pages with 4 figures and 3 tables, available from JMC as RDB3A55)

This paper presents an experimental study to evaluate oil return in domestic refrigerator-freezers using R-134a. A refrigerant immiscible, naphthenic mineral oil (Witco Suniso(R) 1GS) was tested in a 0.6 m³ (20 cf) side-by-side refrigerator and in a 0.4 m³ (14.6 cf) top-mount unit for 22 months. The aim was to demonstrate suitability of the lubricant and that proper oil return results. The same lubricant type was compared to a fully miscible polyolester (POE, Suniso(R) 1GS SL-10) in a test stand, designed with a difficult oil-return configuration. Tabular data are presented to compare the cabinet and freezer temperatures for drop-in evaluation of the mineral oil with R-12 and R-134a and to compare the typical properties of the mineral oil and POE. A third table summarizes the test conditions for the oil-return test stand. Plots show the gas solubility and viscosity curves for each lubricant in R-134a at -23 and 0 °C (-10 and 32 °F). The experimental procedures and findings are discussed. The paper concludes that oil return to the compressor is very similar for both lubricants at typical suction conditions similar for domestic refrigerators. Refrigerant gas velocity is noted as playing an important role in lubricant return for poor oil return configurations. The results also show that differences in cabinet and freezer temperatures, between the two refrigerant/lubricant systems, are not due to oil trapping in the heat exchangers.

J. Reyes-Gavilán (Witco Corporation), **Lubricants for Refrigeration Compressor Applications**, seminar presentation charts (Annual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Denver), Witco Corporation, Oakland, NJ, June 1993 (19 pages with 3 figures and 9 tables, available from JMC as RDB3A01)

These charts summarize an unpublished presentation on possible lubricant choices for use with hydrochlorofluorocarbon (HFC) refrigerants. The provide bench test and performance evaluation findings on polyolester (POE), dibasic acid ester, and naphthenic mineral oil (MO) lubricants. Two charts summarize typical properties of seven POEs (Witco Suniso(R) SL10, SL15, SL22, SL32, SL46, SL68, and SL100) and three dibasic acid esters (Witco R-72-0A, R-72-0B, and R-84-0). Stability test results in the presence of R-134a, steel, copper, and aluminum at 175 ° (347 °F) for up to 56 days and Falex wear evaluations are presented for four base and four additized POEs and the three dibasic acid esters. Hydrolytic stability test

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findings also are tabulated. A table summarizes miscibility ranges for four of the POEs with R-125, R-134a, R-404A, R-125/143a (45/55), R-32/125 (60/40), and R-32/125/134a (formulation unspecified). Viscosity and solubility with R-134a are plotted for SL10 and SL32 at 125 °C (257 °F) and for a mineral oil (Witco Suniso(R) 1GS) at 0 °C (32 °F).

J. Reyes-Gavilán (Witco Corporation), **Performance Evaluation of Naphthenic and Synthetic Oils in Reciprocating Compressors Employing R-134a as the Refrigerant**, paper 3656, *Transactions* (Winter Meeting, Chicago, IL, 23-27 January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 349-360, 1993 (12 pages with 12 figures and 6 tables, RDB4C35)

mineral oil, alkylbenzene, polyalkylene glycol (PAG), and polyolester (POE) lubricants; wear, copper plating, discoloration, compatibility

D. R. Riffe (Americold / White Consolidated Industries, Incorporated) and T. W. Dekleva (ICI Americas, Incorporated), **Effects of Lubricants on the Energy Efficiency of R-134a in Home Appliances**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), ICI Americas Incorporated, Wilmington, DE, 1991 (RDB5123)

literature survey, mineral oil (MO), polyolester (POE), polyalkylene glycol (PAG), compressor losses, effects of solubility and viscosity

P. Sanvi, N. Genet, F. Espinoux, and G. Bardy, **Lubrication for HFC-134a Compressor in Home Appliances**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), Elf Atochem S.A., Paris - La Défense, France, December 1991 (RDB-6326)

R-134a, lubricants

K. S. Sanvordenker (Tecumseh Products Company), **Durability of HFC 134a Compressors - the Role of the Lubricant**, *Proceedings of the 42nd Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, May 1991), IATC, Batavia, IL, pages 37-50, 1991; reprint by Tecumseh Products Company, Tecumseh, MI, 1991 (8 pages with 2 figures and 2 tables, RDB-2216)

Properties of polyalkylene glycol (PAG) and polyolester lubricants are examined, with emphasis on inherent thermal stability and suitability for use with R-134a in refrigeration compressors. The PAGs addressed include diols, monoethers, ester-ethers, and diethers, all stabilized with 200 ppm BHT. Plots of hygroscopicity and miscibility of PAGs with mineral oils are provided. The decomposition kinetics, based on sealed-tube tests, are tabulated. The effects summarized include temperature (177-260 °C, 350-500 °F), presence of metals (steel, copper, and aluminum) or R-134a, and PAG type. Problems of hygroscopicity, incomplete miscibility with mineral oils, and incompatibility with chlorinated solvents exist, but they can be handled by proper housekeeping procedures. Lack of thermal stability, even in the absence of metals, at 177-204 °C (350-400 °F) is identified as a key shortcoming for the PAG candidates. The effects of time, metal catalysts, and initial moisture are tabulated for polyolesters, again at elevated temperatures (204-260 °C, 400-500 °F). Pentaerythritol tetraester is emphasized due, in part, to its better miscibility with R-134a compared to other neopentyl esters. Decomposition also was observed, but only in the presence of steel. A metal passivator specific to steel was found to provide a simple remedy.

K. S. Sanvordenker (Tecumseh Products Company), **Mechanism of Oil-R12 Reactions - the Role of Iron Catalyst in Glass Sealed Tubes**, paper 2881, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 1A, pages 356-369, January 1985 (14 pages with 7 figures and 1 table, RDB2217)

This frequently cited paper presents the chemistry of oil and R-12 reactions in sealed-tube tests in detail. The paper reviews the mechanisms postulated in earlier publications [see RDB2326 and RDB2526] and observations based on infrared absorbance. The paper concludes that iron acts as a participant in the reaction, rather than as a catalyst. Large amounts can be solubilized, and the process of solubilization begins early. The iron-oil molecule and R-12 react with the glass; this reaction also starts much earlier than previously indicated. The reaction forms boron-hydrogen and silicone fluorine compounds, while precipitating out the solubilized iron. Based on gas analysis by infrared, a criterion is defined to identify the entry of glass in sealed-tube reactions. The paper traces through the postulated reactions and experiments conducted, to identify actual reactions by elimination of participating materials. Based on the finding that reactions involving glass start at an early stage in systems containing R-12, oil, and steel, data in prior publications that show large amounts of reaction products need to be reexamined.

K. S. Sanvordenker (Tecumseh Products Company), **Lubrication by Oil-Refrigerant Mixtures:**

Behavior in the Falex Tester, paper KC-84-14-3, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 90, part 2, pages 799-805, 1984; republished in *ASHRAE Journal*, ASHRAE, volume 26, pages 59 ff, 1984 (7 pages with 2 figures and 3 tables, RDB2422)

The effects of test parameters, with reference to the fundamentals of boundary lubrication, are discussed for Falex pin and v-block tests. Such tests are widely used by equipment manufacturers and lubricant suppliers to simulate lubrication in refrigerant compressors and to screen refrigeration lubricants. When modified to provide a closed, pressure-tight chamber, the Falex machine permits laboratory simulation of lubricants in hermetic compressors. The paper review fundamental theories of boundary lubrication and wear to explain laboratory data that may appear to be anomalous. In doing so, the paper explains that trouble-free operation of hermetic compressors under high-oil dilution conditions of liquid feedback has been simulated. The unanticipated result is explained on the basis of dissipation of frictional heat from the rubbing surfaces. The behavior of additive-free lubricants is described and compared to that with antiwear additives, such as tricresyl phosphate (TCP).

K. S. Sanvordenker and M. W. Larime (Tecumseh Products Company), **A Review of Synthetic Oils for Refrigeration Use**, *Transactions* (Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 78, part 2, 1972; republished in *Lubricants, Refrigerants, and Systems - Some Interactions*, symposium bulletin NA-72-5, ASHRAE, pages 14-19, June 1972, June 1972 (6 pages with 1 table, RDB2218)

A. Schelling, H. H. Kausch, and A. C. Roulin, **Friction Behavior of Polyetherketone Under Dry Reciprocating Movement**, *Wear*, Elsevier Sequoia, Lausanne, Switzerland, volume 151, number 1, pages 129-142, 30 November 1991 (14 pages, RDB4C37)

PEK

R. H. Schlosberg, A. Kurs, G. D. Dupre, and R. J. Pancirov, **Thermal Chemistry of Esters and Ketones**, *Liquid Fuel Technology*, volume 3, number 4, pages 465 ff, 1985 (RDB4356)

thermal degradation of ester lubricants

R. C. Schwing, **Polyisobutyl Benzenes and Refrigeration Lubricants**, paper 2063, *Transactions* (Semiannual Meeting, Columbus, OH, 5-8 February 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 74, part 1, pages III.I.1 ff, 1968 (RDB-4639)

synthetic lubricants, polyisobutylbenzene

T. K. Sheiretov and C. Cusano, **Tribological Evaluation of Compressor Contacts - Retrofitting and Materials Studies**, report ACRC-TR-46, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, July 1993 (149 pages, RDB4C41)

G. D. Short, T. E. Rajewski, and J. E. Oberle (CPI Engineering Services, Incorporated), **Refrigeration Lubricants - Current Practice and Future Development**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 265-271, July 1996 (7 pages with 6 figures and 1 table, RDB6912)

overview of synthetic lubricants including alkylbenzene (AB), carbonates, fluorosilicones, mineral oil, perfluoroethers, polyalphaolefin (PAO), polyalkylene glycol (PAG), polyolester (POE), PAG-ester blends, and other esters; table showing use of these lubricants for R-22, R-23, R-123, and R-134a; miscibility, solubility, viscosity, stability, system cleanliness, and wear and compressor durability tests with hydrofluorocarbon (HFC) refrigerants; reviews options for R-717 (ammonia) and hydrocarbons; miscibility of difunctional PAGs of differing average molecular weight (AMU) with R-134a; miscibility changes of POEs from different starting alcohols (dipentaerythritol, pentaerythritol, and trimethylol propane bases); comparative miscibility of three experimental lubricants with R-23, R-134a, R-404A, and R-410A; Daniel Plots with R-134a and R-404A; relative dilution of three POE lubricants with R-404A

G. D. Short and T. E. Rajewski (CPI Engineering Services, Incorporated), **Lubricants for Use With Highly Fluorinated Refrigerants**, *Technical Papers of the 15th Annual Meeting* (21-24 March 1993, Vancouver, BC, Canada), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 139-169 as misnumbered, March 1993 (31 pages with 4 figures and 6 tables, RDB3410)

This paper provides an update on lubricants for use with hydrofluorocarbon (HFC) refrigerants and HFC blends. It also summarizes evaluations of several synthetic lubricants and the tests necessary to insure that a lubricant will provide expected durability and performance with refrigerants. The paper identifies near-term alternatives for common chlorofluorocarbon

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(CFC) refrigerants, and provides tabular summaries of both candidate refrigerants and recommended lubricant types for use with R-22, R-23, R-123, and R-134a. The paper describes the derivation, applications, characteristics, and experience with several lubricants. They include polyolester (POEs), polyalkylene glycols (PAGs), modified PAGs, diesters, PAG esters, carbonates, fluoroethers, fluorosilicones, and alkylbenzenes. Tables provide recommended viscosity ranges for different compressor types, refrigerant-lubricant miscibility data for R-22 and replacement candidates, lubricity findings (based on Falex pin and v-block tests) for ester lubricants and mineral oil with steel on steel, and the effects of additives on lubricant stability. The paper discusses miscibility, viscosity dilution, lubricity tests, chemical and thermal stability, and compatibility of refrigerant-lubricant combinations with other materials. Four figures illustrate the viscosity-temperature-pressure relations for R-22 with a 32 ISO alkylbenzene, R-134a with a 68 ISO PAG, R-134a with a 68 ISO POE, and R-134a and R-12 with a 46 ISO POE. The paper briefly cites findings with retrofits and field experience of PAGs and POEs, and notes that neither are suitable for use with R-717 (ammonia). The paper concludes that POEs appear to be the choice for HFCs and dialkylbenzenes with HCFC-123 and HFC/HCFC blends. It notes that POEs are preferred over PAGs for retrofit due to their miscibility and their compatibility with residual chlorine.

G. D. Short (CPI Engineering Services, Incorporated) and R. C. Cavestri (Imagination Resources, Incorporated, IRI), **High-Viscosity Ester Lubricants for Alternative Refrigerants**, paper AN-92-5-2, *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 789-795, 1992 (7 pages with 3 figures and 5 tables, RDB-2102)

This paper describes the development of high-viscosity (ISO 68 and above), modified polyolester lubricants and their interactions with refrigerants. Typical properties are presented for 11 conventional and modified pentaerythritol (PE) esters, including several di- and tri-PEs, as well as for a modified trimethylolpropane (TMP) ester. Data are reported with R-123, R-134a, R-152a, E-134, and E-245. The apparatus used to measure viscosity and density is described. The viscosity of a modified, high-viscosity ester with R-134a is presented for evaluation of the hydrodynamic lubrication and sealing of compression areas. Chemical and thermal stability and lubricity test results are provided for durability considerations.

G. D. Short (CPI Engineering Services, Incorporated) and R. C. Cavestri (Imagination Resources, Incorporated, IRI), **Selection and Performance of Synthetic and Semi-Synthetic Lubricants for Use with Alternative Refrigerants in Refrigeration Applications**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 163-172, July 1990 (10 pages with 10 figures, RDB2220)

G. D. Short (CPI Engineering Services, Incorporated), **Synthetic Lubricants and Their Refrigeration Applications**, paper 89-AM-7A-1 (44th Annual Meeting, Atlanta, GA, 1-4 May 1989), *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 46, number 4, pages 239-247, April 1990 (12 pages with 9 figures and 1 table, RDB2221)

This paper reviews the requirements and use of synthetic fluids as lubricants for refrigeration systems. R-12, R-13, R-22, R-114, R-134a, R-502, R-503, propane (R-290), and ammonia (R-717) are addressed. Requirements are discussed for thermal and chemical stability, miscibility, solubility, and viscosity. Failure mechanisms including improper viscosity, dilution, loss or breakdown of lubricant, failure of hydrodynamic lubrication, foaming, and starvation related to solubility and miscibility characteristics are reviewed for rotary screw, reciprocating piston, and rotary vane (both fixed and rotating) compressors. Petroleum-based, including both naphthenic and high-viscosity index (HVI) paraffinic mineral oils, and synthetic lubricants are discussed. The synthetics are grouped as polyalphaolefin (PAO), alkylbenzene, and polyalkylene glycol (PAGs) synthetic hydrocarbon (SHC) oils. They also include esters such as diesters (or dibasic acid esters), neopentyl (or polyol) esters, and modified complex esters. The chemical structures and characteristics of these lubricants are reviewed, and viscosity and miscibility plots are provided for representative refrigerant-lubricant systems. Typical properties are tabulated for complex esters of ISO 150 and 320 viscosity. The unique requirements for R-134a, propane (R-290), and ammonia (R-717) are outlined, concluding that the synthetic lubricants described offer a major contribution for system advancement.

R. L. Shubkin, **Polyalphaolefins**, *Synthetic Lubricants and High Performance Functional Fluids*, Marcel Dekker, Incorporated, New York, NY, 1993 (RDB4646)

PAO lubricants; review of polyolester (POE) lubricants made by combining neopentyl alcohols with organic acids; alcohols include neopentyl glycol (NPG), trimethylol propane (TMP), pen-

taerythritol (PE), and dipentaerythritol (Di-PE) types

H. W. Sibley (Carrier Corporation), **Oil Foaming Characteristics - The Forgotten Design Parameter with HFC-134a**, paper 5.4, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 101-104, February 1993 (4 pages with 5 figures, RDB3319)

This paper addresses differences in interactions between R-134a with synthetic lubricants and chlorofluorocarbons (CFCs) with mineral oils. The discussion notes the importance of refrigerant-lubricant solubility for oil return to the compressor. The consequent role of the refrigerant as a lubricant contaminant, and specifically reduction in viscosity and hydrodynamic lubrication, is examined. The effect of rapid refrigerant vapor release, called foaming, is explained. A plot compares the vapor pressure of R-134a in a polyolester (POE) to R-12 in a mineral oil (MO) at 27 and 79 °C (80 and 174 °F) with 10-70% refrigerant. The nature of the resultant foams are characterized, that for R-12/MO as a stable froth and that of R-134a/POE as an unstable or quick breaking foam. Comparative foam heights are plotted and contrasted for oil-rich conditions, as in compressor crankcases, and oil-lean conditions, as in evaporators of centrifugal chillers. Significant differences are noted for the former. Desorption dynamics of the two refrigerant-lubricant pairs are discussed and plotted under driving temperature differences of 37 and 171 °C (67 and 308 °F). R-134a is shown to desorb more rapidly at common thermal gradients. The paper concludes that vapor-venting needs to be altered in R-134a compressors. While the change can be readily dealt with in new designs, the difference in venting must be considered in equipment conversions. The paper notes a need to examine effects of different foaming characteristics on heat transfer.

L. I. Sjöholm (Teknikgruppen AB) and G. D. Short (CPI Engineering Services, Incorporated), **Twin-Screw Compressor Performance and Complex Ester Lubricants with HCFC-22**, *Proceedings of the 1990 International Compressor Engineering Conference at Purdue*, edited by W. Soedel, Purdue University, West Lafayette, IN, pages 724-732, July 1990 (9 pages with 8 figures, RDB2222)

L. I. Sjöholm (Teknikgruppen AB) and G. D. Short (CPI Engineering Services, Incorporated), **Twin-Screw Compressor Performance and Suitable Lubricants with HFC-134a**, *Proceedings of the 1990 International Compressor Engineering Conference at Purdue*, edited by W. Soedel, Purdue University, West Lafayette, IN, pages 733-740, July 1990 (8 pages with 7 figures (RDB2223)

H. O. Spauschus, D. R. Henderson, and D. F. Huttenlocher (Spauschus Associates, Incorporated), **Boundary Lubrication Properties of Alternative Working Fluids**, paper 3.1, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 33-38, February 1993 (6 pages with 7 figures and 2 tables, RDB3311)

H. O. Spauschus, D. R. Henderson, and R. Rohatghi (Spauschus Associates, Incorporated), **SAE Cooperative Research Program: HFC-134a Lubricant Study, Final Report**, Society of Automotive Engineers (SAE), Warrendale, PA, 6 November 1992 (130 pages with 105 figures and 49 tables, RDB3107)

R-134a

H. O. Spauschus and L. M. Speaker (Georgia Institute of Technology), **A Review of Viscosity Data for Oil-Refrigerant Solutions**, technical paper 3094 (444-RP), *Transactions* (Annual Meeting, Nashville, TN, 27 June - 1 July 1987), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 93, part 2, pages 667-681, 1987 (15 pages, RDB2224)

H. O. Spauschus (Georgia Institute of Technology), **Evaluation of Lubricants for Refrigeration and Air-Conditioning Compressors**, *Transactions* (Annual Meeting, Kansas City, MO, 17-20 June 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 90, part 2B, pages 784-798, 1984; republished in *ASHRAE Journal*, volume 26, number 5, pages 59 ff, 1984 (15 pages with 4 figures, RDB-2225)

R-12, R-22, petroleum-based and synthetic lubricants, bench and compressor tests

H. O. Spauschus (General Electric Company), **Migration Rates for Refrigerant 22**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 7, number 10, pages 77 ff, October 1965 (RDB4233)

R-22

H. O. Spauschus (General Electric Company), **Vapor Pressures, Volumes, and Miscibility Limits of Refrigerant 22-Oil Solutions**, *Transactions*, American Society of Heating, Refrigerating, and Air-

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Conditioning Engineers (ASHRAE), Atlanta, GA, volume 70, pages 306-311, 1964 (6 pages, RDB-2226)

R-22

H. O. Spauschus (General Electric Company), **Thermodynamic Properties of Refrigerant-Oil Solutions: Dichlorodifluoromethane (R12) and Petroleum Oil**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 5, number 8, pages 63-71, August 1963 (9 pages, RDB2227)

R-12

H. O. Spauschus (General Electric Company), **Thermodynamic Properties of Refrigerant-Oil Solutions**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 5, number 4, pages 47-52, April 1963 (6 pages, RDB4652)

H. Steinle (Robert Bosch GmbH, Germany), **Development and Testing of Lubricants for Refrigerating Machines**, paper 1879, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 195-202; republished in *ASHRAE Journal*, ASHRAE, 1964 (8 pages with 17 figures, RDB6644)

history of mineral oil lubricant standards in Germany, Philipp test for stability, copper plating, life test, wear test: high temperatures in compressor bearings, discharge valves, and motor windings promote chemical reactions of refrigerants and lubricants; the reactivity of oil mixtures, metal corrosion, and copper plating are caused by oleoresins; DIN standard 51 503 prescribes tests for these phenomena; includes discussion by H. O. Spauschus (General Electric Company, USA)

H. Steinle (Robert Bosch GmbH, Germany), **Bestimmung des Flockpunktes von Kältemaschinenölen, Entwurf DIN 51351** [Determination of the Floc Point of Refrigeration Lubricants, Procedure DIN 51351], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 14, number 4, pages 126 ff, 1962 (in German, RDB6642)

oil floc points in refrigerants

H. Steinle (Robert Bosch GmbH), **Über der Oberflächenpannung von Kältemitteln, Kältemaschinenölen, und deren Gemischen** [On the Surface Tension of Refrigerants, Refrigeration Lubricants, and their Mixtures], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 12, number 11, pages 334-339, 1960 (6 pages, in German, RDB4913)

H. Steinle (Robert Bosch GmbH), **Schmiermittel für Kältemaschinen mit Frigen 22** [Lubricants for Refrigerating Machines with R-22], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 8, number 1, pages 12-14, 1956 (3 pages, in German, RDB4286)

F. S. Stevens, **Oil with Common Refrigerants**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, September 1934 (RDB3737)

R. Stirling and F. G. Drakesmith (Electricity Council Research Centre, ECRC, UK), **Refrigerant 114: Viscosity and Solubility Measurements in Hydrocarbon and Synthetic Lubricants**, paper B1-38, *Proceedings of the XVth International Congress of Refrigeration* (Venice, Italy, 23-29 September 1979), International Institute of Refrigeration, Paris, France, 1979 (6 pages with 8 figures and 1 table, RDB4287)

R-114, naphthenic mineral oil, polyperfluoroether, fluorosilicone

M. Stolarski and M. Zak, **A New Compression Cycle for Refrigerant-Oil Solution**, *Sci. Tech. Froid*, volume 1, pages 187-193, 1980 (RDB4558)

N. Stosic, L. J. Milutinovic, K. Hanjalic, and A. Kovacevi, **Investigation of the Influence of Oil Injection upon the Screw Compressor Working Process**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 4, pages 206-220, 1992 (15 pages, RDB4C38)

M. Sunami, M. Saito, K. Takigawa, S. Suda, and U. Sasaki (Nippon Oil Company Limited, Japan), **Lubricity of AB and AB Derivates in Compressor Durability Tests**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 303-308, July 1996 (6 pages with 4 figures and 12 table, RDB6921)

evaluation of the antiwear properties of alkylbenzene (AB) lubricants with a phosphate additive in rotary, rolling-piston compressors; solubility R-134a with AB and mineral oil; kinematic viscosity of AB with R-601 (n-pentane), added for oil return for immiscible AB lubricants

M. Sunami, K. Takigawa, S. Suda, and U. Sasaki (Nippon Oil Company Limited, Japan), **New Immiscible Refrigeration Lubricant for HFCs**, paper SD-95-8-3, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2,

pages 940-946, 1995 (7 pages with 4 figures and 8 tables, RDB6374)

low viscosity alkylbenzene (AB) lubricants, solubility with refrigerants, oil return, miscibility at high temperatures, effects of impurities, chemical stability, lubricity

M. Sunami (Nippon Oil Company, Limited, Japan), **New Immiscible Refrigeration Lubricant for HFCs**, paper 5.5, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 124-129, December 1994 (6 pages with 2 figures and 8 tables; in Japanese with abstract, figures, and tables in English; RDB5423)

R-134a, R-407C, alkylbenzene (AB) in rotary, rolling-piston compressors

M. Sunami, K. Takigawa, and S. Suda (Nippon Oil Company, Limited, Japan), **New Immiscible Refrigeration Lubricant for HFCs**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 129-134, July 1994 (6 pages with 6 figures and 9 tables, RDB4816)

alkylbenzene (AB) in rotary, rolling-piston compressors

M. Sunami, K. Takigawa, and S. Suda (Nippon Oil Company, Limited, Japan), **Optimization of POE Type Refrigeration Lubricants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 153-158, July 1994 (6 pages with 6 figures and 9 tables, RDB4820)

S. G. Sundaresan (Copeland Corporation), **Compressor Tribology and Other System Requirements for POE Lubricants with HFC Refrigerants**, paper 6.5, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 156-161, December 1994 (6 pages with 5 tables, available from JMC as RDB5429)

tribology, polyolester lubricants, oil return, heat transfer

T. Suzuki, Y. Kai, S. Enomoto, and T. Sakai, **Refrigerator Lubricating Oil**, *Kokai Tokkyo Kono*, Japan, December 1989 (RDB4B20)

A. Swallow, A. Smith, and B. Greig (Castrol International, UK), **Control of Refrigerant Vapor Release from Polyol Ester/Halocarbon Working Fluids**, paper SD-95-8-1, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 929-934, 1995 (6 pages with 6 figures and 4 table, RDB6368)

polyolester (POE) lubricants, outgassing of refrigerants, lubrication failure due to vapor lock of the oil pump or degreasing of contact surfaces

M. Takagi (Idemitsu Kosan Company, Limited, Japan), **New Non-Ester Type Lubricants for Alternative Refrigerants**, paper 5.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 113-118, December 1994 (6 pages with 6 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5421)

R-22 with mineral oil, R-134a with new non-ester synthetic lubricant, lubricity, contamination, stability with metals

H. Takahashi and T. Kaimai (Japan Energy Corporation, Japan), **New Type Lubricant for Ammonia Refrigerating Systems**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 309-314, July 1996 (6 pages with 5 tables, RDB-6922)

R-717, miscible polyalkylene glycol (PAG) lubricant; stability; lubricity; comparisons to alkylbenzene (AB), naphthenic mineral oil, and polyolester (POE) lubricants; properties

K. Takahata, M. Tanaka, T. Hayashi, K. Mizui, and N. Sukamoto (Mitsui Petrochemical Industries, Limited, Japan), **New Lube Oil for Stationary Air Conditioner**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 141-146, July 1994 (6 pages with 4 figures and 7 tables, RDB4818)

carbonate lubricants, R-407C

Y. Takaishi, M. Izumi, and K. Oguchi (Kanagawa Institute of Technology, Japan), **Measurements of the Solubility for the System of HFC-125 and Polyol Ester Lubricant**, *CFCs: The Day After* (pro-

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ceedings of the IIR meeting, Padova, Italy, 1994), International Institute of Refrigeration (IIR), Paris, France, pages 99-105, September 1994 (7 pages, RDB5B26)

R-125, polyolester (POE) lubricant, properties

Y. Takaishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Solubility of the Solutions of HFC-134a and Polyolester Based Oil**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 141-148, 1993 (8 pages with 5 figures and 2 tables, RDB-5310)

R-134a, polyolester (POE) lubricant

Y. Takaishi, H. Nakagawa, and K. Oguchi (Kanagawa Institute of Technology, Japan), **Vapor Pressure of the Solutions of HFC-134a and Ester Oil**, *Proceedings of the Third Asian Thermophysical Properties Conference* (Beijing, People's Republic of China), pages 321-326, 1992 (6 pages, RDB5434)

R-134a, polyolester (POE), solubility

Y. Takaishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Vapor Pressures of R12/Oil and R22/Oil Mixtures**, *Nippon Reito Kyokai Ronbunshu* [Transactions of the JAR], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 7, pages 75-84, 1990 (10 pages, in Japanese, RDB5435)

R-12, R-22, mineral oil

Y. Takaishi and K. Oguchi (Kanagawa Institute of Technology, Japan), **Measurements of Vapor Pressures of R22/Oil Solutions**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, volume B, pages 217 ff, 1987 (RDB5438)

R-22, mineral oil

M. Tanaka, T. Hayashi, K. Takeuchi, K. Takahata, and N. Sakamoto (Mitsui Petrochemical Industries, Limited, Japan), **New Non-POE Lube Oil with Low Viscosity for Refrigerators**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 291-296, July 1996 (6 pages with 2 figures and 5 tables, RDB6919)

synthetic, ether-type lubricant (Mitsui RE-5210) for use with R-134a; thermal stability determined with a differential scanning calorimeter; thermal decomposition and oxidation temperatures for RE-5210, an unidentified polyolester (POE), and a naphthenic mineral oil (Witco Suniso(R) 4GS); chemical stability comparisons of RE-5210 to the POE and a naphthenic mineral oil (Witco Suniso(R) 3GS), the latter with R-12; compatibility with polyethylene terephthalate (PET); lubricity by Falex and four-ball tests; water absorption; properties

Y. Tanaka, H. Kawachi, C. Takata, H. Kubota, and T. Makita (Kobe University, Japan), **Solubility of 1,1,1,2-tetrafluoroethane (R-134a) in Refrigeration Oils**, *Proceedings of the Second Asian Thermophysical Properties Conference* (Sapporo, Japan), pages 375-379, 1989 (6 pages with 6 figures, available from JMC as RDB2B11)

This paper discusses the solubility of R-134a in lubricants at temperatures of 303-363 K (86-194 °F) and pressures up to 2.5 MPa (360 psia). It describes experimental apparatus, procedures, and calculations to determine solubility. The lubricants tested included a naphthenic mineral oil (Witco Suniso(R) 4GS), perfluoropolyether (Daikin Demnum(R) S-65), polyethylene glycol (Wako), and polypropylene glycol (Wako). R-134a was found to be completely miscible with the perfluoropolyether, partially miscible with the two polyglycols, and almost immiscible with the naphthenic oil. Solubility plots are presented.

A. Tanka, **Effects of Alternative Refrigerants on Friction and Wear of Nylon and Polyacetar**, paper E-20, *Proceedings of the JAST Tribology Conference*, Tokyo, Japan, May 1991 (RDB4C39)

A. Thelen and H. J. Löffler, **Die Schmierung von zylindrischen Gleitlagern mit Öl-Kältemittel-Gemischen** [Lubrication of Cylindrical Bearings with Oil-Refrigerant Mixtures], report 15, *Abhandlung des DKV* [DKV Transactions], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Verlag C. F. Müller, Karlsruhe, Germany, 1960 (in German, RDB4665)

R. H. P. Thomas and H. T. Pham (AlliedSignal Incorporated), **Solubility and Miscibility of Environmentally Safer Refrigerant-Lubricant Mixtures**, paper AN-92-5-1, *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 783-788, 1992 (6 pages with 9 figures and 1 table as RDB2101)

Solubility and miscibility data are presented for R-134a with two polyalkylene glycol (PAG) lubricants (AP-150 and AP-500) and three modified PAGs (BRL-150, BRL-300, and BRL-500). Solubility was determined by measuring the equilibrium vapor pressure of mixtures of 10-

90% refrigerant (by weight) in the lubricants for 10-70 °C (50-158 °F). Miscibility was determined by visual observation of a sealed sample immersed in a thermostated bath for a range of -60 to 70°C (-76 to 158 °F). Differences in miscibility curve characteristics are contrasted to mineral oils. The paper examines occurrence of lower critical solution temperatures (LCSTs). Similarities of refrigerant-oil systems to solvent-polymer solutions are addressed, leading to correlations of the solubility data using the Flory-Huggins theory. While further analysis is indicated, Flory-Huggins type plots allow deduction of composition in a refrigerant-lubricant system, given the temperature and pressure and assuming equilibrium.

R. H. P. Thomas, R. P. Robinson, R. H. Chen, and W-T. Wu (AlliedSignal Incorporated), **The Solubility of R-32/125 in Modified Polyalkylene Glycols**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 375-383, 1991 (9 pages with 2 figures and 2 tables, RDB2228)

This paper provides solubility data on a mixture of 60.32% R-32 and 39.68% R-125, by weight, with two synthetic lubricants. This nonsegregating refrigerant blend is proposed as a candidate replacement for R-22 in medium- and high-temperature applications, with evaporator temperatures of -23 to 4 ° C (-10 to 40 °F). The lubricants examined were a modified polyalkylene glycol (PAG) and a PAG diol, BRL-150 and AP150 respectively. Tests also were made with mineral oils and alkylbenzene lubricants, but the refrigerant mixture was found to be immiscible with them. By contrast, the refrigerant was found miscible in the two PAGs from -60 to at least 55 °C (-76 to 131 °F). The same lubricants also are suitable for use with R-134a. The miscibility of the refrigerant-lubricant mixture was determined by sealing samples in thermostated glass tubes and visually observing the contents. The solubility was studied by determining the equilibrium vapor pressure at constant compositions as a function of temperature. The experimental apparatus and procedure is described. Measured vapor-pressures are tabulated, compared to earlier data, and extrapolated using Flory-Huggins theory. The relative pressure is tabulated at different temperatures for fixed fractions of lubricant by volume for verification. Plots are provided for both pressure and relative pressure versus volume fraction of lubricant, from 0.0 to 1.0, for R-32/125 in the modified PAG. The text observes that the solubility for the PAG diol is of the same order.

R. H. P. Thomas, W-T. Wu, and H. T. Pham (AlliedSignal Incorporated), **The Solubility and Viscosity of Mixtures of R-134a with Modified Polyglycols**, paper 48, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 412-415, August 1991 (4 pages with 7 figures, RDB-2229)

The solubilities and viscosities of mixtures of R-134a with two modified polyalkylene glycol (PAG) lubricants are reported. The piston-cylinder type viscometer and apparatus for measuring solubility are described. The solubility of R-134a in BRL-150 (a 150 SUS experimental lubricant) is plotted for 10-70 °C (50-158 °F) in concentrations of 0-100%. Its viscosity in BRL-150 and BRL-300 (300 SUS) is plotted both as functions of temperature for -20 to 80 °C (-4 to 176 °F) and pressure. Analysis of the solubility shows that it can be described by the Flory-Huggins theory.

R. H. P. Thomas, W-T. Wu, and H. T. Pham (AlliedSignal Incorporated), **Solubility and Viscosity of R-134a Refrigerant-Lubricant Mixtures**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 33, number 2, pages 37-38, February 1991 (2 pages with 3 figures, RDB-2230)

U. Todsen, **Refrigerating Machinery Oil - Better Performance with Synthetic Lubricants? Investigations Concerning Thermal Stability of Refrigerator Oils**, *Ki Klima-Kälte-Heizung*, Verlag C. F. Müller, Karlsruhe, Germany, volume 15, number 4, pages 186-189, April 1987 (4 pages, in German, RDB4C32)

This article reviews the requirements for lubricants for trouble-free refrigerator operation. It examines commercially-available oils and summarizes an investigation into their thermal stability.

J. C. Tolfa, **Synthetic Lubricants Suitable for Use in Process and Hydrocarbon Compressors**, *Lubrication Engineering*, Society of Tribologists and Lubrication Engineers (STLE), volume 47, number 4, pages 289-295, April 1991 (7 pages, RDB4C40)

S. I. Tseregounis (General Motors Corporation), **Wear and Galling of 356-T6 Aluminum-on-Steel in Low Amplitude Reciprocating Sliding in the Presence of Synthetic Lubricants in HFC-134a Atmosphere**, paper 95-AM-1C-1 (50th Annual Meeting, Chicago, IL, 14-19 May 1995), Society of Tribologists and Lubrication Engineers (STLE), 1995 (RDB5A08)

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This paper presents bench tests of wear and galling of aluminum (A356-T6) against steel (SAE 4620 carburized) in refrigerant-lubricant atmospheres. The tests were performed using a Falex test machine, modified to provide low-amplitude reciprocating motion with 5° oscillation, in a block-on-ring test arrangement. R-12 was examined with a mineral oil (GM M100), containing minimal antioxidant, as a reference. R-134a was tested with seven lubricants including the same mineral oil, five polyalkylene glycols (PAGs), and a polyolester (MO2D) containing tricresyl phosphate (TCP) and antiwear and extreme pressure (EP) additives. The PAG lubricants included a 50/50 ethylene oxide/propylene oxide, butanol initiated polyglycol (50HB); the same base stock with phosphate and triazole-derivative antiwear additives and amine corrosion inhibitors (U8); an esterified polypropylene oxide glycol (D1); and additized version (G551) of it; and a blended polyglycol (B0354). Of these, M100 and U8 are indicated to be the factory fill used in production of R-12 and R-134a automotive air conditioners, respectively. The paper summarizes background studies, wear mechanisms, preventive measures, and the experimental details. The test arrangement is shown schematically. The paper then identifies the materials tested in tables and presents the investigation. The extents of galling and wear are shown in plots, photographs, SEM analyses, and electron microprobe (EMP) analyses. The R-12/M100 case resulted in the lowest wear and almost no galling, attributed to formation of halide (mainly chloride) antiwear and EP films that protect the aluminum surface. The R-134a/M100 case also resulted in low wear and galling, possibly because the low solubility of R-134a in the oil prevented removal of the lubricant film. High wear and galling with R-134a is attributed to the absence of oil or antiwear films. The paper notes that fluorine-containing films do not offer any protection against wear and galling under the conditions examined. It concludes that the presence of a lubricant film and/or EP or antiwear films (chlorides primarily) prevent metal-to-metal contact and damage of the aluminum surface.

K. Ueshima (ICI, Japan), **Properties of Polyol Ester Oil and Examples of Retrofit Applications**, paper 5.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 107-112, December 1994 (6 pages with 3 figures and 6 tables; in Japanese with abstract, figures, and tables in English; RDB5420)

R-22, 32, R-134a, R-502, R-407A, R-407B, R-407C, polyolester (POE), retrofit, viscosity, refractive index, compatibility with elastomers, performance

N. A. Van Gaalen, S. C. Zoz, and M. B. Pate (Iowa State University of Science and Technology), **The Solubility and Viscosity of Solutions of R-502 in a Naphthenic Oil and in an Alkylbenzene at High Pressures and Temperatures**, paper 3519 (580-RP), *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, pages 285-292, 1991 (8 pages with 14 figures and 2 tables, RDB2344)

N. A. Van Gaalen and M. B. Pate, **Methods of Measuring the Solubility and Viscosity of Lubricating Oil/Refrigerant Mixtures**, report ISU-ERI-Ames-91191, Iowa State University of Science and Technology, Ames, IA, 1991; final report for 580-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1991 (RDB2345)

R-22, R-502, lubricants

N. A. Van Gaalen, S. C. Zoz, and M. B. Pate (Iowa State University of Science and Technology), **The Solubility and Viscosity of Solutions of HCFC-22 in a Naphthenic Oil and in Alkylbenzene at High Pressures and Temperatures**, paper 3446 (580-RP), *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, pages 100-108, 1991 (9 pages with 15 figures and 2 tables, RDB5548)

R-22, naphthenic mineral oil, lubricants

N. A. Van Gaalen, M. B. Pate, and S. C. Zoz (Iowa State University of Science and Technology), **The Measurement of Solubility and Viscosity of Oil/Refrigerant Mixtures at High Pressures and Temperatures: Test Facility and Initial Results for R-22/Naphthenic Oil Mixtures**, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 2, pages 183-190, 1990 (RDB2231)

N. A. Van Gaalen, M. B. Pate, and S. C. Zoz (Iowa State University of Science and Technology), **The Solubility and Viscosity of Solutions of HCFC-22 in Naphthenic Oil and in Alkylbenzene at High Pressures and Temperatures**, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990),

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 2, pages 100 ff, 1990 (RDB2232)

R-22, lubricants

G. van der Waal (Unichema Chemie BV), **The Relationship Between the Chemical Structure of Ester Base Fluids and Their Influence on Elastomer Seals, and Wear Characteristics**, Journal of Synthetic Lubricants, volume 1, pages 280-301, 1985 (22 pages with 20 figures and 4 tables, RDB2233)

J. N. Vinci and D. L. Dick (Lubrizol Corporation), **Polyol Ester Lubricants for HFC Refrigerants: A Systematic Protocol for Additive Selection**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 78-86, October 1995 (9 pages with 4 figures and 6 tables, available from JMC as RDB5A48)

polyolester (POE), synthetic ester, thermal stability, wear, hydrolytic stability, desiccant compatibility, capillary tube blockage, endurance capillary tube flow, miscibility, antiwear, load bearing

F. P. Wardle, B. Jacobson, H. Dolfsma (SKF Engineering & Research Centre B.V, Nieuwegein, The Netherlands), E. Höglund, and U. Jonsson (University of Luleå, Sweden), **The Effect of Refrigerants on the Lubrication of Rolling Element Bearings Used in Screw Compressors**, *Proceedings of the 1992 International Compressor Engineering Conference at Purdue*, edited by J. F. Hamilton, Purdue University, West Lafayette, IN, volume II, pages 523-534, July 1992 (12 pages with 20 figures and 1 table, RDB5A04)

R-22 and naphthenic mineral oil; R-134a and two polyolester lubricants

F. P. Wardle, B. Jacobson, and H. Dolfsma, **Rolling Bearing Lubrication in the Presence of Refrigerants**, unpublished paper for the SRM Licensee Conference (Stockholm, Sweden), SKF Engineering & Research Centre B.V, Nieuwegein, The Netherlands, May 1992 (10 pages with 12 figures, RDB5A05)

This paper reviews the lubrication parameters that influence rolling-bearing performance and examines the effect of refrigerant on the lubricant film thickness and performance. It briefly reviews the differences in lubrication requirements for hydrodynamic and rolling bearings. The paper then outlines the operating characteristics of rolling bearings, with attention to the stresses induced at contacting surfaces and fatigue life. The latter is presented as a ratio of minimum film thickness to composite surface roughness. The paper discusses the rheological properties of lubricants, addressing the dependence of viscosity on both temperature and pressure. A formula is presented for lubricant film thickness based on dimensionless speed, materials, load, and surface size parameters. The paper then describes a test rig built to simulate bearing operating conditions in a screw compressor; the apparatus and a detail of the bearing test head are shown schematically. The paper presents and discusses typical refrigerant concentration in the rig's lubricant "bath" (sump), the refrigerant concentration normalized to the equilibrium concentration based on pressure-temperature-solubility data, and the comparative viscosity of a naphthenic mineral oil and R-22/oil mixture as a function of pressure. It then explains the effect of refrigerant on the pressure-viscosity coefficient and on the viscosity of the lubricant. The effective viscosity is plotted for R-22 with a mineral oil and for R-134a with an unidentified polyolester lubricant, as functions of the refrigerant concentrations. The paper concludes that the thickness of lubricant films can be predicted at the highly-stressed contacts in rolling bearings. For oil rich (less than 20% refrigerant by weight) solutions, the primary effect of the refrigerant is viscosity reduction. The reduction in the pressure-viscosity coefficient becomes progressively more significant as the refrigerant concentration increases. Performance also depends on whether a single or multiple phases are present, the refrigerant-lubricant temperature, and the pressure.

C. L. Wellman and R. W. Yost (ICI Klea), **The Solubility of Refrigerant Blends in Synthetic Polyol Ester and Alkylbenzene Refrigeration Lubricants and the Effect of Viscosity**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 68-77, October 1995 (10 pages with 10 figures and 1 table, available from JMC as RDB5A47)

R-22, R-32, R-125, R-134a, R-407C, R-410A, polyolester (POE, ICI Emkarate(R) RL) and alkylbenzene (AB) lubricants

T. Yanagisawa, T. Shimizu, and M. Fukuta, **Foaming Characteristics of an Oil-Refrigerant Mixture**, *International Journal of Refrigeration* (IJR), Paris, France, volume 14, number 3, pages 132-136, May 1991 (5 pages, RDB4C29)

S. Yokoo, K. Doi, T. Takano (Nissan Motor Company, Limited, Japan), and T. Kaimai (Kyodo Oil

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Technical Research Center Company, Limited, Japan), **Development of a Lubricant for Retrofitting Automotive Air Conditioners for Use with HFC-134a**, *Climate Control and Automotive Cabin Air Filtration*, publication SP-1040, Society of Automotive Engineers (SAE), Warrendale, PA, pages 57-61, 1994; republished as paper 940594 (SAE International Congress and Exposition, Detroit, MI, 28 February - 3 March 1994), SAE, 1994 (8 pages with 4 figures and 5 tables, RDB4B01)

This paper introduces a new lubricant for use with R-134a, for retrofit of mobile air-conditioning (MAC) systems originally designed for R-12 with mineral oils. The lubricant is described as a block polymer polyalkylene glycol (PAG). The paper briefly reviews the introduction of R-134a for use in new and retrofit MAC applications. It notes that the chlorine in R-12 helps to lubricate compressors, by acting as an extreme pressure (EP) agent. Consequently, retrofit with chlorine-free R-134a requires a lubricant with high enough lubricity to compensate for this lack of a lubricating agent. Moreover, the lubricant also must be suitable in the retrofit environment. The paper indicates that antiwear additives in the retrofit lubricant may transfer to residual mineral oil, thereby reducing lubricity since the mineral oil would be insoluble in R-134a. Further, residual R-12 or moisture may degrade the chemical stability of PAG lubricants. Metal chlorides formed from prior operation with R-12 may be hydrolyzed by moisture from the lubricant, producing hydrochloric acid and resultant chemical attack. The paper outlines the development of the new lubricant specifically for wobble-plate, variable displacement compressors. A table compares the structures, lubricity, hygroscopicity, and R-134a miscibility of three PAG classes comprising alkyl, propylene oxide, and ethylene oxide groups. It also discusses use of a benzotriazole (BTA) derivative, as an antiwear additive and corrosion preventive agent to protect copper alloys. The antiwear effect is attributed to adsorption of the BTA element on copper surfaces and to the friction-reducing action of the long-chain alkyl groups, which form the oil film. Figures show pin and bearing wear as functions of the BTA quantity added in Falex pin and v-block tests and compressor tests. Oiliness and phosphate additives, to protect aluminum anti-rotation mechanisms, also are discussed. The use of an organic molybdenum compound as an EP agent was tested, but not selected to avoid degradation of the lubricant stability. Acceptance criteria and data on compatibility with organic materials, based on sealed-tube and autoclave tests, are tabulated for the new lubricant.

S. C. Zoz and M. B. Pate (Iowa State University of Science and Technology), **Critical Solution Temperatures for Ten Different Non-CFC Refrigerants with Fourteen Different Lubricants**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 431-436, July 1994 (6 pages with 3 tables, RDB4858)

S. C. Zoz, L. J. Berkenbosch, and M. B. Pate (Iowa State University of Science and Technology), **Miscibility of Seven Different Lubricants with Ten Different Refrigerants**, paper 3802, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 197-207, 1994 (11 pages with 1 figure and 11 tables, RDB4715)

Boundary Lubrication of Ternary Blends (KCD-9430 and 9433), document ARTD-12, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1990 (3 pages with 1 table, available from JMC as RDB0541)

This document summarizes a study to determine the lubricity of a 150 SUS viscosity alkylbenzene (Shrieve Zerol(R) 150) lubricant with two developmental refrigerants, KCD-9430 and KCD-9433. Both are ternary zeotropic blends, R-22/152a/114 (36/24/40) and R-22/152a/124 (36/24/40), respectively. Measurements were made using a modified Falex pin and v-block test machine, with refrigerant bubbled through the lubricant; the test procedure is outlined. Failure loads are tabulated for the lubricant alone, with R-12 for comparison, and with the two blends. Data are provided for the neat lubricant, with two unidentified additives, and with both additives together. The document concludes that the alkylbenzene lubricant with additives provides acceptable lubrication with either blend. The refrigerant-lubricant mixtures were deemed suitable for further compressor durability testing.

Moisture Content and Emkarate(TM) RL ester Lubricants, bulletin 62-0170-160, ICI Americas Incorporated, Wilmington, DE, January 1994 (8 pages with 3 figures, RDB6B38)

introductory discussion of the hygroscopicity (affinity for moisture) of ester lubricants; plot of typical water absorption rate for polyolester (POE), polyalkylene glycol (PAG), modified PAG, and mineral oils; ways water enters refrigeration systems; water uptake; consequences including loss of performance, ice deposition, corrosion of metals, blockage of expansion devices, copper plating, and poor lubrication; hydrolysis; water pull-down (drying) rates for ester

and PAG lubricants with driers; handling and housekeeping recommendations

Real Time Determination of Lubricant Concentrations Dissolved in Alternative Refrigerants, research project 761-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, December 1995 - June 1996 (ASH0761)

This project will evaluate three means of measuring the concentration of lubricants circulating in refrigeration systems. The apparatus to be addressed include a viscometer, a densimeter, and an acoustic velocity sensor. The project is a follow-up to a prior project, *Real Time Determination of Concentration of Oil Dissolved in Refrigerant Flow Stream Without Sample Removal* (365-RP, see ASH0365), completed in January 1988. Three alternative refrigerants will be evaluated, including R-123, R-134a, and a third to be determined. Each will be tested with two lubricants in concentrations of 0-6% at temperatures representative of condenser outlets, namely 24-49 °C (75-120 °F). The contractor for the project is Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it is sponsored by ASHRAE Technical Committee 1.2, *Instruments and Measurements*.

Refrigeration Compressor Lubrication with Synthetic Fluids, publication 801201, Mobil Oil Corporation, Fairfax, VA, 1980 (40 pages with 28 figures and 4 tables, RDB3510)

This bulletin reviews the fundamentals of refrigeration systems, discusses the roles of lubricants, identifies benefits of synthetic lubricants, and provides data on Mobil lubrication products. The introduction discusses the attributes sought in a lubricant and comparative qualities of conventional mineral oils (MOs), synthesized hydrocarbon fluids (SHFs), and polyglycols. It notes that low viscosity, naphthenic MOs have dominated to meet the need for low pour points, but that the final viscosity is lower than for the neat lubricant due to refrigerant dilution. The synthetic lubricants can be selected for specific refrigerants and applications with fluidity over a wide range, not encumbered by wax content at low temperatures, and high viscosity index (VI). The effects of refrigerant solubility in lubricants on viscosity, vapor pressure, and specific gravity as well as refrigerant-lubricant system performance are discussed. The bulletin reviews refrigeration cycles, common refrigerants, system components, and the roles of lubricants in wear reduction and sealing. It provides solubility plots of R-12, R-13, R-13B1, and R-22 in mineral oil; R-22 in mineral oil, SHF, and polyglycol; and R-290 (propane) in a polyglycol. It then provides a series of plots to show the estimated viscosity-diluting effect of refrigerants in lubricants. They include plots for R-12 with Gargoyle Arctic SHC 226, SHC 230, and Glygoyle 80; R-22 with SHC 226, SHC 234, and Glygoyle 11; R-114 with Gargoyle Arctic SHC 230 and SHC 234; and R-290 with Mobil Glygoyle 30. The report discusses solubility and miscibility, noting that the lubricating fluid in the compressor is a solution of refrigerant vapor in lubricant. In other parts of the system, such as the condenser, the fluid may be a solution of lubricant in liquid refrigerant. Thus the mixture may be in two phases, termed "mutual solubility," which is the basis for classification as completely miscible, partially miscible, and immiscible. The report describes miscibility characteristics and identifies typical miscibility in mineral oils for R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-113, R-114, R-115, R-152a, R-C318, R-500, R-501, R-502, R-717, and R-744. It discusses and provides miscibility plots for mineral oil, polyglycol, and SHF with R-22 and for polyglycol with R-12, R-13, R-13B1, and R-290. It then briefly discusses floc and cloud points, specific gravities of refrigerant-lubricant mixtures, stability of lubricants, VI and cold starting, copper plating, and compatibility. It also discusses lubricant influences on power consumption and describes applications in compressors, reliquification systems, and heat pump systems. The report concludes with a summary of Mobil lubricant products, including tables of physical characteristics and recommended type(s). An appendix provides a trouble shooting guide for lubricants. Mobil's product names are Gargoyle Arctic Oil for mineral oils, for Gargoyle Arctic SHC for SHFs, and Mobil Glygoyle for polyglycols.

Solubility of R-123 and R-134a in Oils, Carrier Corporation, Syracuse, NY, September 1989 (3 pages with 3 figures, available from JMC as RDB-0014)

Two figures summarize the solubility of R-123 with Mobil DTE 26 and Mobil DTE Heavy Medium mineral oils for -29 to -23 °C (-20 to -10 °F). Critical solution temperatures are shown for solutions of 70-95% R-134a in unidentified 300 and 750 SUS polyglycol lubricants.

Solubility of Refrigerant in Lubricants: HFC-134a, report NIST-3, Freon(R) Products Laboratory, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, undated circa 1989 (3 pages with 2 tables, available from JMC as RDB0533)

Solubility data for R-134a are presented for a range of lubricants based on tests run from -50 to 93 °C (-58 to 199 °F). Mixtures of 30, 60, and 90% refrigerant by weight were tested with the lubricants in air-free sealed tubes. Solubility

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was determined, following a minimum of 15 minutes with agitation at each temperature; the blends were considered immiscible when they acquired and retained *schlieren* lines, formed floc, or formed two liquid layers. The lubricants include a polychlorotrifluoroethylene (Halocarbon blend 700/95-6.7/93.3 500 SUS), four perfluorinated polyalkyl ether oils (Krytox(R) GPL 150 and 480 SUS and Fomblin(R) Y 25/5 and Z-15, both 417 SUS), and Daikin Demnum(R) S-65 300 SUS), dipentaerythritol esters of fatty acids (Hercules 240 and 290 SUS), PEG esters of fatty acids (CPI Engineering 144, 620, and 830 SUS), naphthenic oils (Witco Suniso(R) 5GS 500 SUS 38% aromatic, Witco 500 SUS and two experimental oils at 520 SUS 47% aromatic and 529 SUS 75% aromatic), paraffinic oil (BVM-100N 500 SUS), three alkylbenzenes (Zerol(R) 300 SUS, Conoco DN600 125 SUS, and Nippon Oil Atmos HAB15F 78 SUS), and three silicone oils (Union Carbide L-45 163, 231, and 462 SUS).

Study of the Segregation or Fractionation of Refrigerant Blends in Contact with Lubricants and Measurement of Viscosity, Solubility, and Density, research project 779-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1995 - April 1996 (ASH0779)

This project will measure the solubility, viscosity, and density of refrigerant blends comprising hydrofluorocarbons (HFCs) with a representative lubricant. An additional objective is to determine the influence, if any, of the lubricant on segregation and fractionation of the refrigerant mixtures. R-32, R-134a, R-32/134a (30/70), and R-32/134a (70/30) will be examined with a 32 ISO polyolester lubricant in compositions of 0-100%, vapor pressures of 70-2350 kPa (10-500 psia), and -40 to 125 °C (-40 to 257 °F). The miscibility and composition, in the gas and liquid phases (dissolved in the lubricant or as a separate liquid phase), of the cited fluids and of R-134a also will be measured. The results will be plotted. The contractor is Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; the project is sponsored by ASHRAE Technical Committees 3.4, *Lubrication*, and 8.1, *Positive Displacement Compressors*.

APPLICATION DATA

R. C. Downing (Consultant, formerly DuPont Chemicals), **Fluorocarbon Refrigerants Handbook**, Prentice Hall, Englewood Cliffs, NJ, 1988 (416 pages with 124 figures and 177 tables, RDB3960)

This popular handbook provides a general review of refrigerants and application data. It briefly outlines the history, nomenclature, manufacture, and applications of fluorocarbon refrigerants and then covers refrigeration, refrigerant properties, and mixtures (including azeotropes). It continues with the effects of water including solubility, drying, and hydrolysis; solubility of air and other gases; oil relationships including solubility and viscosity; the effects on polymers including both elastomers and plastics; and stability. It also addresses leak detection, solar applications (as heat transfer fluids), conversion factors, shipping data, and safety parameters and classifications. A final chapter provides pressure-enthalpy (Mollier) diagrams for R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-113, R-114, R-115, R-C318, R-502, and R-503. It also provides equations to calculate liquid density; vapor pressure; pressure-volume-temperature (PVT) data (equations of state); heat capacity, enthalpy, and entropy of the vapor; velocity of sound; and latent heat of vaporization for R-11, R-12, R-13, R-14, R-21, R-22, R-23, R-113, R-114, R-C318, R-500, and R-502.

L. A. Orth, D. C. Zeitlow, and C. O. Pedersen (University of Illinois at Urbana-Champaign), **Predicting Refrigerant Inventory of R-134a in Air-Cooled Condensers**, paper CH-95-23-1, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 1367-1375, 1995 (9 pages with 7 figures and 1 table, RDB5240)

R-134a

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R-11, R-12, R-13B1, R-21, R-22, R-113, R-114, R-C318, R-500, R-502, history, application, materials compatibility, properties, stability, safety, pressure drop, density, color coding, evacuation, water effects, drying, service recommendations, brazing and soldering, motor burnouts, charging refrigerants

Heat Transfer

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H. Cawte (Portsmouth Polytechnic, UK), **Effect of Lubricating Oil Contamination on Condensation in Refrigerant R22**, *International Journal of Energy Research*, volume 16, number 4, pages 327-340, June 1992 (14 pages, RDB3B73)

This paper summarizes measurements of heat transfer coefficients in convective condensation of R-22, both oil-free and with three concentrations of mineral oil (Shell Clavus 32). It describes an experimental facility for measurement of evaporation and condensation heat transfer coefficients in refrigerant-oil mixtures flowing in a horizontal tube. A 9.5 mm (3/8") outside diameter copper tube, 1.8 m (5.9') long, was used at condensation temperatures of 40 and 50 °C (104 and 122 °F). Heat flux and mixture mass velocity were kept constant at 2.5 kW/m^2 (794 Btu/(h·ft^2)) and 155 kg/m^2·s (32.8 lb/(ft^2·s)), respectively, and measured coefficients were in the range 1350-2850 W/(m^2·K) (502 Btu/(h·ft^2·°F)). Results showed that the heat transfer coefficient is reduced nonlinearly by the presence of oil, the reduction reaching 25% when the oil concentration is 5% by mass, and 28% at an oil concentration of 10%. An assessment showed that the effect of this reduction in the condensation heat transfer coefficient on the predicted performance of a heat pump is small. The paper presents a new correlation for the heat transfer coefficient in convective condensation of refrigerant-oil mixtures, which predicts the results of the present study to within approximately plus or minus 18%. The correlation is compared with those proposed by other researchers.

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E. Granryd (Kungl Tekniska Högskolan, KTH, Sweden), **Heat Transfer in Flow Evaporation of Nonazeotropic Refrigerant Mixtures - A Theoretical Approach**, paper 251, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume III, pages 1330-1334, August 1991 (5 pages with 6 figures, RDB2409)

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E. Granryd (Kungl Tekniska Högskolan, KTH, Sweden) and J. C. Conklin (Oak Ridge National Laboratory, ORNL), **Thermal Performance Analysis for Heat Exchangers Using Nonazeotropic Refrigerant Mixtures**, *Heat Transfer in Advanced Energy Systems*, American Society of Mechanical Engineers (ASME), New York, NY, Heat Transfer Division volume 151 and Advanced Energy Systems Division volume 18, pages 25-32, November 1990 (8 pages with 10 figures, available from JMC as RDB2330)

K. E. Gungor and R. H. S. Winterton, **Simplified General Correlation for Saturated Flow Boiling and Comparisons of Correlations with Data**, *Chemical Engineering Research and Design* (Journal of the Institution of Chemical Engineers, Rugby, UK), Pergamon Press Limited, London, UK, volume 65, pages 148-156, 1987 (9 pages, RDB5247)

K. E. Gungor and R. H. S. Winterton, **A General Correlation for Flow Boiling in Tubes and Annuli**, *International Journal of Heat and Mass Transfer*, Pergamon Press Limited, United Kingdom, volume 29, pages 351-358, 1986 (8 pages, RDB5248)

N. S. Gupte (Carrier Corporation) and R. L. Webb (Pennsylvania State University), **Convective Vaporization of Refrigerants in Tube Banks**, paper BA-92-4-4, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 411-424, 1992 (14 pages with 27 figures and 2 tables, RDB2607)

S. Ha (Goldstar Company Limited, Korea) and A. E. Bergles (Rensselaer Polytechnic Institute, RPI), **The Influence of Oil on Local Evaporation Heat Transfer Inside a Micro-Fin Tube**, paper CH-93-14-5, *Transactions* (Winter Meeting, Chicago, IL, 23-27 January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 1244-1255, 1993 (12 pages with 17 figures and 1 table, RDB3113)

E. Hahne and A. Noworyta, **Calculation of the Heat Transfer Coefficients for Nucleate Boiling in Binary Mixtures of Refrigerant-Oil**, *International Communications in Heat and Mass Transfer*, volume 106, number 1, pages 417-429 (13 pages, RDB4742)

K. Hambraeus (Kungl Tekniska Högskolan, KTH, Sweden), **Two Phase Flow Boiling of an Oil-HFC134a Mixture**, paper 91, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 499-503, August 1991 (5 pages with 4 figures and 2 tables, RDB4938)

heat transfer coefficients for two-phase boiling R-134a/lubricant mixtures; the tested lubricants are experimental oils (CPI 0275 and 0323),

K. Hashizume, **Flow Pattern and Void Fraction of Refrigerant Two-Phase Flow in a Horizontal Pipe**, *Bulletin of the Japan Society of Mechanical Engineers* (JSME), volume 26, number 219, pages 1597-1602, 1983 (6 pages, RDB6395)

heat transfer, refrigerant flow: modified Baker flow pattern map based on adiabatic horizontal flow for R-12 and R-22

H. Henrici and G. Hesse, **Untersuchungen über den Wärmeübergang beim Verdampfen von R114 und R114-Öl-Gemischen an einem horizontalen Glattrohr** [Investigation of the Evaporating Heat Transfer of R-114 and R-114/Oil Mixtures on a Horizontal Plain Tube], *Kältetechnik-Klimatisierung*, Germany, volume 23, pages 54-58, 1971 (5 pages, in German, RDB4547)

K. Hijata, **Forced Convective Condensation of a Nonazeotropic Binary Mixture on Vertical and Horizontal Tubes**, *Proceedings of the Ninth International Heat Transfer Conference* (Jerusalem, Israel), volume 3, pages 271-276, 1990 (6 pages, RDB6705)

zeotropic blends, heat transfer

D. L. Hinton (Tennessee State University), J. C. Conklin, and E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **Evaporation of an R143a and R124 NARM Inside Smooth and Corrugated Tubes**, paper 92-WA/HT-5, American Society of Mechanical Engineers (ASME), New York, NY, November 1992 (6 pages with 8 figures, RDB3339)

D. L. Hinton (Tennessee State University), J. C. Conklin, and E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **Evaporation Characteristics of R-22 Flowing Inside a Corrugated Tube**, *Enhanced Heat Transfer* (proceedings of the 28th National Heat transfer Conference, San Diego, CA), edited by M. B. Pate and M. K. Jensen, American Society of Mechanical Engineers (ASME), New York, NY, Heat Transfer Division volume 202, pages 127-132, August 1992 (6 pages with 12 figures, available from JMC as RDB2902)

This paper compares the boiling performance of two tubes, one smooth and one with corrugated (also called spirally indented) heat transfer enhancement for R-22. The investigation serves as the reference case for future work on zeotropic mixtures. The experimental apparatus and instrumentation are described; the former comprises a variable-speed compressor, variable-orifice flow-metering device, and two sets of counterflow, concentric-tube heat exchangers with different tube-side surfaces. The measurements reflect use of an alkylbenzene lubricant, with an estimated circulation concentration of the order of 1%. Two temperature levels were investigated, corresponding to those for the heating and cooling modes of air-source heat pumps at standard rating conditions. The measured heat transfer coefficient (HTC) for evaporation is compared to predictions, based on correlations from prior studies. HTC is then plotted versus heat flux and quality; both HTC and pressure drop are plotted against mass flux. The paper concludes that the corrugated tube geometry does enhance heat transfer over a wide range of mass and heat fluxes, with the most significant increase occurring at low qualities. The paper discusses suppression of nucleate boiling in the corrugated tube at lower mass fluxes; it suggests that evaporator designs be split to use corrugated tubes where the heat transfer is highest, at low qualities, and some other geometry for the intermediate and high quality regions.

H. Honda, B. Uchima, S. Nozu, E. Torigoe, and S. Imai (Okayama University, Japan), **Film Condensation of Downward Flowing R-113 Vapour on Staggered Bundles of Horizontal Finned Tubes**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, and Japan Society of Mechanical Engineers (JSME), Tokyo, Japan,

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volume 2, pages 487-494, 1991 (8 pages, RDB-5732)

R-113, heat transfer, enhanced tubes

H. Honda, B. Uchima, S. Nozu, H. Nakata, and E. Torigoe (Okayama University, Japan), **Film Condensation of Downward Flowing R113 Vapour on In-Line Bundles of Horizontal Finned Tubes**, *Heat Transfer with Phase Change* (Winter Annual Meeting, San Francisco, CA, 10-15 December 1989), edited by I. S. Habib and R. J. Dallman, publication HTD-Vol. 108, American Society of Mechanical Engineers (ASME), New York, NY, pages 117-125, 1989 (9 pages, RDB5733)

R-113, heat transfer, enhanced tubes

H. Honda, B. Uchima, S. Nozu and T. Fujii (Okayama University, Japan), **Effect of Vapour Velocity on Film Condensation of R113 on Horizontal Tubes in a Crossflow**, *International Journal of Heat and Mass Transfer*, Pergamon Press Limited, United Kingdom, volume 29, pages 429-438, 1986 (10 pages, RDB5734)

R-113, heat transfer

D. W. Hughes, J. T. McMullan, K. A. Mawhinney, and R. Morgan, **Influence of Oil on Evaporator Heat Transfer (Results for R-12 and Shell Clavus 68)**, *International Journal of Refrigeration* (IJR), Paris France, volume 7, number 3, pages 150-158, May 1984 (10 pages, RDB0923)

Experiments to investigate the influence of lubricating oil on heat transfer and refrigerant flow in evaporators are described. R-12 and Shell Clavus 68 oil were used. Efforts were made to model actual operation as closely as possible. The oil was found to have a significant effect on refrigerant flow and pressure drop. Measurements made on the heat transfer coefficient indicated that the oil had different effects depending on the fluid flow regime. No effect was apparent for annular-wavy regimes, but the presence of oil significantly reduced the heat transfer coefficient for annular-film flows.

M. K. Jensen and B. Shome (Rensselaer Polytechnic Institute, RPI), **Literature Survey of Heat Transfer Enhancement Techniques in Refrigeration Applications**, report ORNL/Sub/91-SL794, Oak Ridge National Laboratory, Oak Ridge, TN, May 1994 (394 pages with 77 figures, available from JMC as RDB4892)

M. K. Jensen and H. P. Bensler, **Saturated Forced-Convective Boiling Heat Transfer with Twisted-Tape Inserts**, *Journal of Heat Transfer*, American Society of Mechanical Engineers (ASME), New York, NY, volume 108, pages 93-99, 1986 (7 pages, RDB6415)

blend heat transfer

M. K. Jensen and D. L. Jackman, **Prediction of Nucleate Pool Boiling Heat Transfer Coefficients of Refrigerant-Oil Mixtures**, *Journal of Heat Transfer*, American Society of Mechanical Engineers (ASME), New York, NY, volume 106, number 1, pages 184-190, 1984 (7 pages, RDB3B24)

D. L. Jackman and M. K. Jensen, **Nucleate Pool Boiling of Refrigerant-Oil Mixtures**, paper 82-WA/HT-45, American Society of Mechanical Engineers (ASME), New York, NY, 1982 (RDB2403)

I. Jonsson, **Plate Heat Exchangers as Evaporators and Condensers for Refrigerants**, *Australian Refrigeration, Air Conditioning, and Heating*, Australia, volume 39, number 9, pages 19-31, 1985 (13 pages, RDB6435)

use of compact brazed-plate heat exchangers

D. Jung (Inha University, Korea) and R. K. Radermacher (University of Maryland), **Prediction of Evaporation Heat Transfer Coefficient and Pressure Drop of Refrigerant Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 5, pages 330-338, June 1993 (9 pages with 6 figures and 5 tables, RDB4420)

This article presents a study of the heat transfer coefficient (HTC) and pressure drop of refrigerant mixtures. Predicted HTCs and pressure drops are reported for blends under consideration as R-12 and R-22 alternatives. The article reviews heat transfer correlations with measured data, and conceptually illustrates the dependence of HTC on heat flux and quality in the nucleate boiling regime, and on quality in the convective evaporation regime. The results indicate that nucleate boiling is suppressed at qualities greater than 20% for all mixtures, and evaporation becomes the main heat transfer mechanism. The article then reviews the pressure drop correlation used and discusses alternative comparisons for mixtures to pure fluids. It concludes that equivalent cooling capacity offers a more meaningful basis than equivalent mass flow rates. Differences in respective volatilities of the mixture components are discussed. Predicted HTC values are tabulated for R-12, R-22, R-32, R-123, R-141b, R-142b, and R-152a and given as ratios to the HTC of R-12 over a quality range of 20-90% at evaporator temperatures of -10, 0, and 10 °C (14, 32, and 50 °F). Similar data are presented for R-12 alternatives including R-22/123 (60/40), R-22/141b (70/30), R-22/142b (50/50), R-22/152a (20/80), R-32/141b (20/80), and R-32/152a (10/90) and for R-22 substitutes, R-32/142b (50/50) and R-32/152a (40/60). Predicted pressure drops are plotted for the same fluids. A table compares the overall HTC

for mixtures of R-22/123 (60/40) and R-12 in air and water systems. A figure illustrates the predicted pressure drop of the cited blends and of R-12 and R-22 at -10, 0, and 10 °C (14, 32, and 50 °F). The paper notes that HTC values are sensitive to liquid viscosity and thermal conductivity; 10% uncertainty in them results in a 6% change in HTC. The paper concludes that nucleate boiling is fully suppressed for pure and mixed refrigerants and that HTC increases monotonically with quality in the evaporating range discussed. Further, while some mixtures exhibit as much as 90% higher HTC than R-12 and R-22 at uniform mass flow rates, mixtures containing R-32 and R-152a show only 8-10% increase for the same cooling capacity because of reduced mass flow rates. Mixtures of components with large volatility differences show up to 55% HTC reduction. The significance depends on the heat transfer fluid; the overall reduction is less than 1.5% in air-to-refrigerant heat exchangers, but as much as 20% in water-to-refrigerant exchangers. The pressure drops of all the mixtures examined are smaller due to the lower mass flows.

D. Jung and R. K. Radermacher (University of Maryland), **Prediction of Heat Transfer Coefficients of Various Refrigerants During Evaporation**, paper 3492, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, pages 48-53, 1991 (6 pages with 7 figures and 3 tables, RDB2347)

D. Jung and R. K. Radermacher (University of Maryland), **Prediction of Pressure Drop During Horizontal Annular Flow Boiling of Pure and Mixed Refrigerants**, *International Journal of Heat and Mass Transfer*, Pergamon Press plc, United Kingdom, volume 32, number 12, pages 2435-2446, 1989 (12 pages, RDB3B50)

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland), and D. A. Didion (NIST), **A Study of Flow-Boiling Heat Transfer with Refrigerant Mixtures**, *International Journal of Heat and Mass Transfer*, Pergamon Press plc, United Kingdom, volume 32, number 9, pages 1751-1764, September 1989 (14 pages, RDB2348)

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland), and D. A. Didion (NIST), **Horizontal Flow Boiling Heat Transfer Experiments with a Mixture of R-22/114**, *International Journal of Heat and Mass Transfer*, Pergamon Press plc, United Kingdom, volume 32, number 1, pages 131-145, 1989 (15 pages, RDB2903)

D. Jung (National Institute of Standards and Technology, NIST), **Horizontal-Flow Boiling Heat Transfer Using Refrigerant Mixtures**, report ER-6364, Electric Power Research Institute (EPRI), Palo Alto, CA, May 1989 (236 pages with 62 figures, 14 tables, and two appendices, RDB2B08)

This report documents a study of horizontal, convective, boiling heat transfer, including experiments to measure two-phase heat transfer coefficients of refrigerant mixtures. The report reviews the properties of mixtures, including those unique to azeotropes, and associated heat transfer. It then describes experimental apparatus designed to simulate evaporator conditions in heat pump and refrigeration systems. Measurement approaches are presented both for heat transfer and composition determination. Measured data are summarized for zeotropic mixtures of R-12 and R-114, both an azeotropic and zeotropic mixtures R-12 and R-152a, and their pure components for ranges of heat flux and mass flow rates. Differences in bubble growth are discussed between pure and mixed fluids. The results indicate two distinct regions of heat transfer, namely partial boiling and convective evaporation, the former governed by suppression of nucleate boiling. The report reviews analytical studies to predict the transition quality. Measured, local heat transfer coefficients were as much as 36% lower than the weighted average of the components for mixtures in the convective region. The study attributes this reduction to observed differences in composition in the annular liquid film for mixtures with large difference in component volatilities, such as R-22/114. An approach is proposed to account for mixture effects based on phase-equilibrium information.

D. Jung (University of Maryland), M. O. McLinden (National Institute of Standards and Technology, NIST), R. K. Radermacher (University of Maryland), **Measurement Techniques for Horizontal Flow Boiling Heat Transfer with Pure and Mixed Refrigerants**, *Experimental Heat Transfer*, Hemisphere Publishing Corporation, Washington, DC, volume 2, number 3, pages 237-255, 1989 (19 pages with 10 figures and 1 table, RDB6424)

R-12, R-22, R-114, R-152a, R-12/152a [R-500], R-22/114; pressure, composition, and temperature measurement; flow boiling of pure and mixed refrigerants in a horizontal, tube

D. Jung, **Mixture Effects on Horizontal Convective Boiling Heat Transfer**, doctoral dissertation, Department of Mechanical Engineering, University

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of Maryland, College Park, MD, May 1988 (RDB-2346)

S. G. Kandlikar, **A General Correlation for Saturated Two Phase Boiling Heat Transfer Inside Horizontal and Vertical Tubes**, *Journal of Heat Transfer*, American Society of Mechanical Engineers (ASME), New York, NY, volume 112, pages 219-228, February 1990 (10 pages, RDB3B44)

H. Kawahira, Y. Kubo, T. Yokoyama (Tokyo Electric Power Company, Japan), and J. Ogata (Mitsubishi Heavy Industries, Limited, Japan), **The Effect of an Electric Field on Boiling Heat Transfer of Refrigerant-11 - Boiling on a Single Tube**, paper IUSD 87-61, *IEEE Transactions on Industry Applications* (Industry Applications Society Annual Meeting, Atlanta, GA, 19-23 October 1989), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, volume 26, number 2, pages 359-365, March/April 1990 (7 pages with 9 figures, RDB3C20)

This paper summarizes an experimental investigation of the effect of an electric field on pool boiling of R-11 on a single, smooth tube with several rows of electrodes. It reviews prior studies and describes, and illustrates the experimental apparatus. The paper discusses the influences of 0-2% (by weight) mineral oil (Witco Suniso(R) 4GS), the surface roughness of the test tube, and the strength and polarity of an applied voltage. The paper concludes that: 1) the number of boiling bubbles decreases but the heat transfer coefficient increases as the applied voltage increases; 2) the polarity of the applied voltage affects the boiling heat transfer (a negative direct current electric field yields better heat transfer with neat refrigerant), and 3) a negative field does not adversely affect heat transfer for a refrigerant-oil mixture, but enhanced transfer results in a positive field.

M. A. Kedzierski, **Effect of Inclination on the Performance of a Compact Brazed Plate Condenser and Evaporator**, report NISTIR 5767, National Institute of Standards and Technology, Gaithersburg, MD, November 1995 (38 pages with 10 figures and 6 tables, available from NTIS, RDB6433)

This report summarizes tests to measure performance changes associated with tilting a compact brazed plate heat exchanger (CBE) from a vertical orientation. It summarizes tests, using R-22 in a CBE (SWEP B15x36) rotated in clockwise and counterclockwise directions, to assess the influence of gravity. The report recaps published studies of performance and growing use of CBEs in refrigeration. It describes and schematically illustrates the test apparatus used, outlines the analysis methods, and presents the findings. The study found a substantial performance penalty when the evaporator was rotated past 30° from the vertical. The capacity in the horizontal position was 62-74% of the vertical value. For a rotation angle of 30°, the degradation performance was within 5% of the vertical value. Rotation direction and entering refrigeration state had little effect on performance for rotation less than 60°. Only when the evaporator was rotated to the horizontal position did rotation direction and refrigerant state have much effect. At the horizontal position, a subcooled entering refrigerant and a counterclockwise rotation both tended to lessen the capacity degradation. Rotation of the CBE condenser to the horizontal position improve the overall heat transfer coefficient by approximately 25%. Rotation direction had a negligible effect on the performance of the condenser. No mention is made of lubricant presence or interactions for these tests.

M. A. Kedzierski and M. P. Kaul, **Horizontal Nucleate Flow Boiling Heat Transfer Coefficient Measurements and Visual Observations for R12, R134a, and R134a/Ester Lubricant Mixtures**, report NISTIR 5144, National Institute of Standards and Technology, Gaithersburg, MD, March 1993 (36 pages with 10 figures and 1 table, available from NTIS, RDB3419)

This report presents a calorimetric and visual investigation of nucleate flow boiling of R-12 and R-134a inside horizontal tubes. Mixtures of R-134a with 0.9% polyolester lubricant (Castrol Icematic(R) SW100) and 0.9 and 2.3% neopentyl polyolester (ICI Emkarate(TM) 213b, a developmental lubricant) also were investigated. The report documents both calorimetric measurements of the local two-phase heat transfer coefficients and simultaneous visual measurements, using high-speed photography. Derived bubble diameters and densities are presented. The test apparatus, instrumentation procedures, and calorimetric and visual results are described. Plots are provided of the heat transfer coefficient measurements for a range of heat fluxes for Reynolds numbers of zero to approaching 10,000. Good agreement was achieved with the Borishanskii-Minchenko equation. For both R-12 and R-134a, an increase in either the heat flux or Reynolds number of the flow increases the heat transfer coefficient, though the former has a larger effect. Visual observations of the bubble density and size are used to explain the heat transfer trends. Faster bubble formation by R-134a correlated with superior heat transfer. The authors offer a probable explanation for observed heat transfer enhancement of neopentyl polyolester mixture over pure R-134a. They attribute it to canceling effects of drastic reduction in bubble diameters and significant increase in

site density. Boiling appeared to occur from lubricant-rich clouds, acting like porous surfaces, on the heater portion of the tube.

M. A. Kedzierski, J. H. Kim, and D. A. Didion (National Institute of Standards and Technology, NIST), **Causes of the Apparent Heat Transfer Degradation for Refrigerant Mixtures**, *Two-Phase Flow and Heat Transfer* (proceedings of the 28th National Heat Transfer Conference, San Diego, CA, 9-12 August 1992), publication HTD-Vol. 197, American Society of Mechanical Engineers (ASME), New York, NY, pages 149-158, 1992 (10 pages, RDB3B22)

M. A. Kedzierski and D. A. Didion (National Institute of Standards and Technology, NIST), **A Comparison of Experimental Measurements of Local Flow Boiling Heat Transfer Coefficients for R-11 and R-123**, *Proceedings of the Third ASME/JSME Thermal Engineering Joint Conference* (Reno, NV, 17-22 March 1991), American Society of Mechanical Engineers (ASME), New York, NY, Japan Society of Mechanical Engineers (JSME), Tokyo, Japan, volume 3, pages 243-250, 1991 (8 pages, RDB-3B23)

J. A. Khan and J. H. Morehouse (University of South Carolina), **A Metal Matrix for Heat Transfer Enhancement During Phase-Change Processes**, paper OR-94-7-1, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 707-714, 1994 (8 pages with 6 figures and 1 table, RDB4710)

V. V. Klimenko and M. Fyodorov, **Prediction of Heat Transfer for Two-Phase Forced Flow in Channels of Different Orientation**, *Proceedings of the Ninth International Heat Transfer Conference* (Jerusalem, Israel), volume 5, pages 65-70, 1990 (6 pages, RDB4973)

mechanistic method to predict the transition from stratified to unstratified flow during boiling

X. Liu (Carrier Corporation), **LMTD Applications in Two-Phase Heat Transfer and Two-Phase Heat Exchangers**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 145-150, July 1996 (6 pages with 1 table, RDB6828)

J. R. Lloyd and P. J. Marto, **A Predictive Model to Describe the Pool Boiling Behavior of Refrigerant-Oil Mixtures**, technical report NPS ME-90-07, Naval Postgraduate School, Monterey, CA, 31 December 1990 (42 pages with 4 figures, RDB3B28)

P. Lundqvist (Kungl Tekniska Högskolan, KTH, Sweden), **Analysis of Plate Type Heat Exchangers with Zeotropic Refrigerant Blends**, proceedings (Winter Annual Meeting, San Francisco, CA), American Society of Mechanical Engineers (ASME), New York, NY, volume AES-34, pages 37-58, 1995 (RDB4759)

S. P. Manwell and A. E. Bergles (Rensselaer Polytechnic Institute, RPI), **Gas-Liquid Flow Patterns in Refrigerant-Oil Mixtures**, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 2, pages 456-464, 1990 (9 pages, RDB-4971)

J. T. McMullan, N. J. Hewitt, A. J. Masson, and N. E. Murphy (University of Ulster, UK), **Influence on Oil Viscosity and Refrigerant Quality on Evaporator Performance**, *International Journal of Energy Research*, volume 16, number 7, pages 567-581, September 1992 (15 pages, RDB4C22)

heat transfer

C. Möller, U. Groß, and E. Hahne (Universität Stuttgart, Germany), **Einfluß von Öl auf den Wärmeübergang beim Sieden von R134a** [Influence of Oil on Boiling Heat Transfer for R-134a], Conference Report Number 18, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, pages 93-108, 1991 (16 pages with 14 figures, in German, RDB4221)

This paper summarizes a study of the heat transfer of mixtures of R-134a with a polyolester lubricant (ICI Emkarate(TM)) using an electrically-heated platinum wire. The dependence of the heat transfer coefficient on the heat flux density was measured for temperatures varying between -16 and 32 °C (3 and 90 °F) and lubricant concentration from 0 to 15% by mass. The results are compared to those for R-12 with a mineral oil (Shell Clavus 129).

C. Möller, K. Shi, U. Groß, and E. Hahne (Universität Stuttgart, Germany), **Einfluß von Öl auf den Wärmeübergang beim Sieden von neuer Kältemittel** [Influence of Oil on Boiling Heat Transfer for New Refrigerants], *DKV-Statusbericht* [Status Report] 6, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, pages 73-76, 1990 (4 pages, in German, RDB4937)

R. W. Murphy and A. E. Bergles, **Subcooled Flow Boiling of Fluorocarbons**, report DSR/71903-72, Massachusetts Institute of Technology (MIT), Cambridge, MA, 1971 (RDB3B61)

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J. Ogata, Y. Iwafuji, Y. Shimada (Mitsubishi Heavy Industries, Limited, Japan), and T. Yamazaki (Tokyo Electric Power Company, Japan), **Boiling Heat Transfer Enhancement in Tube-Bundle Evaporators Utilizing Electric Field Effects**, paper BA-92-5-2, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 435-444, 1992 (10 pages with 10 figures and 3 tables, RDB2609)

M. M. Ohadi, S. Dessiatoun, A. Singh, and M. A. Fanni (University of Maryland), **EHD Enhancement of Pool and In-Tube Boiling of Alternative Refrigerants**, final report DOE/CE/23810-17, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1993 (62 pages with 13 figures, available from JMC as RDB3A16)

M. M. Ohadi, R. A. Papar, A. Kumar, and A. I. Ansari (University of Maryland), **Some Observations on EHD-Enhanced Boiling of R-123 in the Presence of Oil Contamination**, *Pool and External Flow Boiling* (proceedings of the Engineering Foundation Conference Pool and External Flow Boiling, Santa Barbara, CA, 22-27 March 1992), edited by V. K. Dhir and A. E. Bergles, American Society of Mechanical Engineers (ASME), New York, NY, pages 387-396, 1992 (10 pages with 26 figures and 1 table, RDB3C16)

M. M. Ohadi, R. A. Papar, T. L. Ng, M. A. Faani, and R. K. Radermacher (University of Maryland), **EHD Enhancement of Shell-Side Boiling Heat Transfer Coefficients of R-123/Oil Mixture**, paper BA-92-5-1, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 427-434, 1992 (8 pages with 10 figures and 1 table, RDB2608)

C. Pais and R. L. Webb (Pennsylvania State University), **Literature Survey of Pool Boiling on Enhanced Surfaces**, technical paper 3444 (392-RP), *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, pages 79-89, 1991 (RDB2405)

heat exchangers, heat transfer

J. S. Panek, **Evaporation Heat Transfer and Pressure Drop in Ozone-Safe Refrigerants and Refrigerant Oil Mixtures**, MS thesis (Department of Mechanical Engineering), University of Illinois at Urbana-Champaign, 1992 (RDB3B51)

R. A. Papar, M. M. Ohadi, A. Kumar, and A. I. Ansari (University of Maryland), **Effect of Electrode Geometry on EHD-Enhanced Boiling of R-123/Oil Mixture**, paper CH-93-14-4, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 1237-1243, 1993 (11 pages with 5 figures, RDB3112)

M. B. Pate (Iowa State University of Science and Technology), **Evaporation and Condensation Heat Transfer Coefficients for HCFC-124/HCFC-22/HFC-152a**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, July 1990 (RDB2240)

B. Pierre, **Flow Resistance with Boiling Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 6, pages 58-77, 1964 (20 pages, RDB5113)

mass flow, heat transfer, heat exchanger, evaporator

B. Pierre, **The Coefficient of Heat Transfer for Boiling Freon-12 in Horizontal Tubes**, *Heating and Air Treatment Engineer*, pages 302-310, December 1956 (9 pages, RDB3B45)

mass flow, heat transfer, heat exchanger, evaporator

R. K. Radermacher, H. D. Ross (University of Maryland), and D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **Experimental Determination of Forced Convection Evaporative Heat Transfer Coefficients for Nonazeotropic Refrigerant Mixtures**, paper 83-WA/HT-54 (Winter Annual Meeting), American Society of Mechanical Engineers (ASME), New York, NY, 1983 (RDB6420)

zeotropic blends

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mass flow, heat transfer, heat exchanger, evaporator

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R-22/114

C. K. Rice (Oak Ridge National Laboratory), **Influence of HX Size and Augmentation on Performance of Mixtures in Air-to-Air Heat Pumps**, paper DE-93-6-4, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 665-679, 1993 (15 pages with 9 figures and 2 tables, RDB3619)

S. T. Ro, H. S. Jun, Y. S. Chang, and J. Y. Shin (Seoul National University, Korea), **Condensation Heat Transfer of a Heat Pump System Using the Refrigerant Mixture of R-32/R-134a**, paper OR-94-7-2, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 715-720, 1994 (6 pages with 7 figures and 1 table, RDB4711)

R-32/134a

P. Rohlin (Kungl Tekniska Högskolan, KTH, Sweden), **Coefficients of Performance and Local Heat Transfer Coefficients for Flow Boiling Inside Horizontal Tubes with Nonazeotropic Refrigerant Mixtures in a Small Exhaust Air Heat Pump**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 157-166, July 1992 (10 pages with 8 figures and 1 table, RDB2717)

Test results are presented for three refrigerant blends in an exhaust-air heat pump, with a heating capacity of 1050-1450 W (3600-4950 Btu/hr). Such heat pumps are used, widely in Sweden, to recover heat from exhaust air to heat service hot water, particularly for large multifamily residential buildings. Heating coefficients of performance (COPs), capacities, and local heat transfer coefficients in the evaporator are compared to those for R-12. Data for R-22/-152a/124 (36/24/40) and two blends of R-22/-142b (45/55 and 60/40) are plotted and discussed. The experiments indicate that use of these zeotropic mixtures can increase both the COP and capacity despite a large reduction in the local heat transfer coefficient. The reduction is large with the binary mixtures and is compounded by suppression in nucleate boiling, also observed by other referenced investigations. Both the experimental apparatus and analytical methods used are described.

H. D. Ross (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), R. K. Radermacher, M. di Marzo (University of Maryland), and D. A. Didion (NBS), **Horizontal Flow Boiling of Pure and Mixed Refrigerants**, *International Journal of Heat and Mass Transfer*, Pergamon Press Limited, United Kingdom, volume 30, number 5, pages 979-992, 1987 (RDB5115)

R-13B1, R-152a, R-13B1/152a (18/82), (37/63), (58/42), and (80/20), experimental determination of heat transfer coefficients (HTCs): blends yielded sharply lower HTCs than either component tested as a single-compound refrigerant, attributed to circumferential gradient in concentration and interfacial temperature, data suggest that full suppression of nucleate boiling is easier to achieve with mixtures than single compounds

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heat transfer, blends

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single-compound refrigerants, azeotropic and zeotropic blends, heat transfer in tubes

J. M. Saiz Jabardo (University of Illinois at Urbana-Champaign, USA) and C. L. da Silva (Universidade Estadual Paulista, Brazil), **Modeling of the Nucleate Boiling of Refrigerant-Oil Mixtures**, paper 155, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 514-518, August 1991 (5 pages with 5 figures, RDB3B27)

R-11, R-113, R-114, heat transfer coefficients, heat exchangers, heat transfer

S. M. Sami, J. Schnotale (University of Moncton, New Brunswick, Canada), and J. G. Smale (DuPont Canada, Incorporated), **Prediction of the Heat Transfer Characteristics of R-22/152a/114 and R-22/152a/124**, paper 3602, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 51-58, 1992 (8 pages with 10 figures and 1 table, RDB2601)

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please see pages 6-8 for ordering information

actions (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, 1991 (RDB2241)

L. M. Schlager, M. B. Pate, and A. E. Bergles, **Performance of Micro-Fin Tubes with Refrigerant 22 and Oil Mixtures**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 31, number 11, pages 17-28, November 1989 (12 pages with 8 figures and 2 tables, RDB2243)

R-22, naphthenic mineral oil, copper tubes, micro fin and low fin surface enhancement, heat transfer

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R-22 with naphthenic mineral oil

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R-22 with naphthenic mineral oil

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R-290 (propane), R-602 (n-hexane), steel tube, heat transfer, surface enhancement

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blends

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heat exchanger, heat transfer, design, simulation

M. M. Shah, **A New Correlation for Heat Transfer During Boiling Flow Through Pipes**, *Transactions* (Annual Meeting, Seattle, WA, 27 June - 1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 82, part 2, pages 66-86, 1976 (21 pages, RDB3B47)

W. Shao and E. Granryd (Kungl Tekniska Högskolan, KTH, Sweden), **Flow Condensation of Pure and Oil Contaminated Refrigerant HFC-134a in a Horizontal Tube**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 317-322, July 1994 (6 pages with 5 figures, RDB4840)

R-134a, Castrol ester-based lubricant

K. Shi, E. Hahne, and U. Groß (Universität Stuttgart, Germany), **Pool Boiling Heat Transfer in HFC-134a, HFC-152a, and Their Mixtures**, paper 59, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 459-463, 1991 (5 pages with 10 figures and 2 tables, RDB54A5)

nucleate pool boiling of R-134a, R-152a, and R-134a/152a on a platinum wire; scaling of the heat transfer coefficients to tubes; comparison to prior data for R-12

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R-22, R-32, R-125, R-134a, R-290, R-600a, R-32/134a, R-290/600a, modification to Chen's correlation to predict heat transfer coefficients (HTCs)

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heat transfer

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heat transfer, fluid flow, blends

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R-12, R-13

A. Singh, M. M. Ohadi, S. Dessiatoun, and W. Chu (University of Maryland), **In-Tube Boiling Heat Transfer Enhancement of R-123 Using the EHD Technique**, paper OR-94-10-3, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 818-825, 1994 (8 pages with 12 figures, RDB4725)

electrohydrodynamic enhancement, evaporation, heat transfer

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M. K. Smith, J. P. Wattelet, and T. A. Newell (University of Illinois at Urbana-Champaign), **A Study of Evaporation Heat Transfer Coefficient Correlations at Low Heat and Mass Fluxes for Pure Refrigerants and Refrigerant Mixtures**, *Heat Transfer with Alternate Refrigerants* (proceedings of the 29th National Heat Transfer Conference, Atlanta, GA, 8-11 August 1993), edited by H. J. Sauer, Jr., and T. H. Kuehn, publication HTD-Vol. 243, American Society of Mechanical Engineers (ASME), New York, NY, pages 19-26, 1993 (8 pages with 8 figures, RDB3B18)

This paper presents an average heat transfer correlation for R-12 evaporation for the mass flux range of 25-100 kg/m²·s (5-20 lb/sf·s) and heat fluxes of 2-10 kW/m² (630-3200 Btu/(h·sf)). It also provides local correlations for mixtures of R-22/123 (65/35) and R-22/141b (80/20) for the mass flux ranges of 25-85 and 27-42 kg/m²·s (5-17 and 6-9 lb/sf·s) and heat fluxes of 1.2-2.8 and 1.0-4.2 kW/m² (380-890 and 320-1300 Btu/(h·sf)), respectively. These low mass and heat conditions are characterized as predominantly wavy/stratified flow and typical of those found in refrigerator evaporators. A plot contrasts the present work to the flow regimes examined by other researchers, which generally are for higher fluxes. The paper describes a horizontal-tube test stand used to measure heat transfer for neat refrigerants and energy balances performed for a full evaporator for the refrigerant mixtures. Heat transfer coefficients for the latter were found to be approximately 50% lower than predicted coefficients for R-12, for corresponding ranges of mass and heat flux.

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Germany, volume 17, number 2, pages 323-339, 1990; translated by Quest Technology, Incorporated (file QU0467), Arlington Heights, IL (24 pages with 8 figures and 4 tables, RDB3A18)

R-12, R-22, R-113, R-114, R-123, R-134a, R-227ea

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **An Experimental Evaluation of the Heat Transfer Coefficients of R-134a Relative to R-12**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 225-233, July 1990 (9 pages with 8 figures, RDB0501)

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void fraction and pressure drop of R-12 in forced, convective boiling; prediction model based on drift flux

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R-717

K. E. Starner, **Summary of Pool Boiling Test Results for R-134a, R-22, and R-12 with Oils**, York International Corporation, York, PA, 22 July 1992 (1 page, available from JMC as RDB2808)

This document summarizes tests to compare heat transfer characteristics of R-12, R-22, and R-134a, with and without lubricants, for Wolverine Turbo-B(R) enhanced-surface tubes. Turbo-B(R) tube is enhanced on both the inside and outside surfaces to increase the overall heat transfer coefficient; its primary use is as a boiling tube for evaporators in chillers. Quantitative results are presented for a heat flux of 17.3 kW/m^2 (5500 Btu/h·ft^2) for nominal 19 mm (3/4") outside-diameter tubes in a 60 cm (2'), 8-tube bundle at 4.4 °C (40 °F). Differences are presented between the wall temperature and the refrigerant saturation temperature at the measured pressure. Results are compared between refrigerant-lubricant mixtures, with 1.5% mineral oil by volume, and those for pure refrigerants. Additional data are provided for R-134a with miscible lubricants, including an unidentified polyalkylene glycol (PAG) and ester. For pure refrigerants, the measured temperature difference is 0.14 °C (0.25 °F) lower for R-22 and 0.06 °C (0.1 °F) higher for R-12 compared to that for R-134a. The document reports penalties, compared to pure refrigerants, of 0.53, 0.31, 2.78, 0.19, and 0.33 °C (0.95, 0.55, 5.00, 0.35, and 0.60 °F) for mixtures with 1.5% lubricant for R-12 with mineral oil, R-22 with mineral oil, R-134a with mineral oil (nonmiscible), R-134a with PAG, and R-134a with ester, respectively. Additional penalties of 0.17 and 0.39 °C (0.30 and 0.70 °F) are reported for mixtures of 0.08 and 0.15% mineral oil with 1.5% ester-based lubricant above that for the refrigerant-ester mixture alone.

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azeotropic and zeotropic blends

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R-12, R-22

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W. F. Stoecker and E. Kornota (University of Illinois at Urbana-Champaign), **Condensing Coefficients When Using Refrigerant Mixtures**, *Transactions* (ASHRAE Annual Meeting, Honolulu, HI, June 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 2B, pages 1351-1367, 1985 (17 pages with 20 figures and 4 tables, RDB5116)

heat transfer, condensation

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heat transfer, condensation, blends, azeotropic, zeotropic

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heat transfer, effect of lubricants

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R-12, mineral oil, heat transfer

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blends, heat transfer

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heat transfer, effects of lubricants

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R-11, R-12, R-21, R-22, R-113, R-717 (ammonia), R-718 (water, steam), heat transfer, effects of noncondensable gases and lubricants, tube bundle design, tube surface enhancement

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R-12, spine-fin circular tube

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R-22, R-410A

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R-22, R-410A

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R-12

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C. Y. Yang and R. L. Webb (Pennsylvania State University), **Condensation of R-12 in Small Hydraulic Diameter Extruded Aluminum Tubes With and Without Micro-Fins**, *Journal of Enhanced Heat Transfer*, American Society of Mechanical Engineers (ASME), New York, NY, 1995 (RDB-6393)

R-12, heat transfer

T. Yokoyama (Tokyo Electric Power Company, Japan), **The Effect of an Electric Field on Boiling Heat Transfer of Fluorocarbon R-11**, XVII International Conference for Heat and Mass Transfer, Dubrovnik, Yugoslavia, 1986 (RDB3C19)

S. Yoshida, T. Matsunaga, H-P. Hong, and M. Miyazaki (Kyushu University, Japan), **An Experimental Investigation of Oil Influence on Heat Transfer to a Refrigerant Inside Horizontal Evaporator Tubes**, *Nippon Kikai Gakkai Ronbunshu* (Transactions of the Japan Society of Mechanical Engineers, JSME), JSME, Tokyo, Japan, series B, volume 55, number 513, pages 1410-1416, 1989 (in Japanese); republished in *Heat Transfer - Japanese Research*, Scripta Technica, Incorporated (Wiley Company), volume 20, number 2, pages 113-129, May 1991 (17 pages with 14 figures, in English, RDB2905)

S. M. You, T. W. Simon, A. Bar-Cohen, and W. Tong, **Experimental Investigation of Nucleate Boiling Incipience with a Highly-Wetted Dielectric Fluid (R-113)**, *International Journal of Heat and Mass Transfer*, Pergamon Press plc, United Kingdom, volume 33, number 1, pages 105-117, 1990 (13 pages, RDB3B62)

X. Zeng, M. C. Chyu (Texas Tech University), and Z. H. Ayub (Ayub and Associates, Incorporated), **Evaporative Heat Transfer Performance of Nozzle-Sprayed Ammonia on a Horizontal Tube**, paper 3845 (725-RP), *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 136-149, 1995 (13 pages with 16 figures, RDB5239)

R-717

Applicability, Design Aspects, and Long-Term Effects of EHD Enhanced Heat Transfer of Alternative Refrigerants and Refrigerant Mixtures for HVAC Applications, research project 857-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1995 - April 1997 (ASH0857)

This project will investigate enhancement of boiling heat transfer by electrohydrodynamic (EHD) effects. The research focuses on concept testing, including experimentation and demonstration, and system design, including

optimum electrode design and system design guidelines. The contractor is Texas A&M University led by J. Seyed-Yagoobi; the project is sponsored by ASHRAE Technical Committee 8.5, *Liquid to Refrigerant Heat Exchangers*.

Effects of Inundation and Miscible Oil Upon the Condensation Heat Transfer Performance of R-134a, proposed research project 984-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, approved for bidding October 1996 (ASH0984)

This project is sponsored by ASHRAE Technical Committee 8.5, *Liquid to Refrigerant Heat Exchangers*. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

EHD-Enhanced Condensation Heat Transfer of Alternate Refrigerants and Refrigerant Mixtures for HVAC Applications, research project 922-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1994 - April 1998 (ASH0922)

This research will investigate the performance of electrohydrodynamic (EHD) techniques to enhance heat transfer with alternative refrigerants and blends. It also will provide data on pressure drop, electrical power requirements, electrode geometries, and operating conditions for air-conditioning and refrigeration applications. Utilizing these and other published data, the work will develop design correlations for feasibility and economic evaluation of EHD-enhanced condensation. The contractor for the project is the University of Maryland led by M. M. Ohadi; it is sponsored by ASHRAE Technical Committee 8.5, *Liquid-to-Refrigerant Heat Exchangers*.

Evaporation of Ammonia Outside Smooth and Enhanced Tubes With Miscible and Immiscible Oils, proposed research project 977-TRP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, approved for bidding October 1996 (ASH0977)

This project is sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

Experimental Determination of Heat Transfer in Water-Cooled Condensers and Direct Expansion Water Coolers Using Brazed Plate Heat Exchangers, research project 752-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1994 - April 1996 (ASH0752)

This project will determine average heat transfer coefficients for R-22 and R-134a for counterflow plate heat exchangers. Two or more commercially-available, brazed-plate heat exchangers will be tested. Heat transfer coefficients will be measured for the refrigerants for condensing at 41 °C (105 °F) and evaporating at 2 °C (35 °F). Water-side coefficients also will be determined. The coefficients and associated pressure drops will be presented as functions of the mass flow rates, which will be varied over the full range of commercial applications. Superheating and subcooling effects also will be investigated. The overall goal is to provide basic information to permit potential users to evaluate counterflow, brazed-plate heat exchangers as refrigerant evaporators and condensers. The contractor is the University of Missouri at Columbia led by W. E. Stewart, H. J. Sauer, Jr., and B. R. Becker; the project is sponsored by ASHRAE Technical Committee 8.5, *Liquid to Refrigerant Heat Exchangers*.

Experimental Determination of the Effect of Oil on Heat Transfer in Flooded Evaporators with Refrigerants HCFC-123 and HFC-134a, research project 751-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1993 - April 1996 (ASH-0751)

This project will determine average shell-side boiling coefficients for R-123 and R-134a with compatible lubricants for finned and other enhanced tube surfaces, as used in flooded evaporators. The work will expand on that addressed in ASHRAE 392-RP, by covering the influences of the lubricants. Heat flux, mass flux, and vapor quality will cover typical conditions for air conditioning and refrigeration for lubricant concentrations of 0-10% at evaporator temperatures of approximately 4 °C (40 °F). The contractor is the Northern Illinois University, led by P. Payvar; it is sponsored by ASHRAE Technical Committee 8.5, *Liquid to Refrigerant Heat Exchangers*.

Freon(R) Fluorocarbons Properties and Applications, bulletin G-1 (document E-03528-1), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, March 1985 (12 pages with 1 figure and 8 tables, RDB3511)

This brochure summarizes physical, thermodynamic, safety, and application data for R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-113, R-114, R-115, R-116, R-500, R-502, and R-503. Key physical parameters are tabulated for application of these refrigerants. The brochure reviews safety considerations for refrigerant use, noting that none of the compounds addressed are flammable or explosive though mixtures with other gases may be flammable. Health effects are reviewed with attention to relative toxicity

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and exposure limits, dermal effects (skin and eye contact), oral toxicity, central nervous system (CNS) effects, and cardiac sensitization. The brochure briefly discusses thermal decomposition products and handling of major spills and releases. Stability and decomposition data are provided for R-11, R-12, R-13, R-22, R-113, R-114, and R-115. Hydrolysis data with water, alone and in solution with sodium hydroxide, are presented for R-22 and R-23. The brochure discusses compatibility with commonly-used construction metals including aluminum, cast iron, brass, copper, lead, steel, and tin. It notes that some of the metals may act as catalysts for refrigerant breakdown at high temperatures. Alkali, and alkaline earth metals (sodium, potassium, barium, etc.), magnesium, and finely ground or powdered aluminum may be reactive with some or all refrigerants. Swell data with elastomers are tabulated for R-11, R-12, R-13, R-13B1, R-22, R-30 (methylene chloride), R-40 (methyl chloride), R-113, R-114, R-115, R-140a (methyl chloroform), and R-502 with neoprene GN, butadiene acrylonitrile (Buna(TM) N), butadiene styrene (Buna(TM) S), isoprene isobutylene (Butyl(TM)), and polysulfide and natural rubbers. Compatibility data are discussed with lubricants and plastics. A vapor pressure-temperature chart is included.

Heat Transfer and Pressure Drop Characteristics During In-Tube Gas Cooling of Supercritical Carbon Dioxide, proposed research project 913-URP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0913)

R-410A, R-410B: The project is being evaluated by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

Heat Transfer and Pressure Drop in the Dry-Out Region of In-Tube Evaporation with Refrigerant-Lubricant Mixtures, research project 800-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1993 - March 1996 (ASH0800)

This research will focus on heat transfer in the final stage of in-tube evaporation, where the annular liquid film thins and dries out. The work will formulate a generalized heat transfer coefficient in this dry-out region, where significant area is required to achieve desired levels of superheating. Unusual behavior or refrigerant-lubricant mixtures also may occur in this region. Heat transfer and pressure drop will be measured in both smooth and enhanced tubes with R-22 and R-134a, or an appropriate alternative, as a function of lubricant content. Mixtures containing 0, 1, 2, 3, and 5% lubricant will be tested, for conditions determined through a literature search and examination of the energy transfer process in qualities exceeding 90%. The contractor for the project is the École Polytechnique Fédérale de Lausanne (ÉPFL), Ecublens, Switzerland, led by J. R. Thome; it is sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*.

In-Tube Evaporation of Ammonia in Smooth and Enhanced Tubes With and Without Miscible Oils, research project 866-RP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1995 - April 1997 (ASH0866)

This research project will investigate local, two-phase heat transfer and pressure drop during in-tube evaporation of R-717 (ammonia). Performance will be quantified for both a smooth tube and an enhanced-surface, micro-fin tube. The study also will examine the effect of miscible lubricants on evaporation performance. Correlations will be developed for use in design. The contractor for the project is Kansas State University (KSU) led by D. Fenton; it is sponsored by ASHRAE Technical Committee 1.3, *Heat Transfer and Fluid Flow*.

Fractionation, Leakage, and Detection

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, report DOE/CE/-23810-51C (UTRC R94-970566-3), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (26 pages with 14 figures and 1 table, available from JMC as RDB5602)

This report summarizes the progress of research to investigate composition changes in refrigerant blends. The project entails four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. The report outlines contractual compliance and work status. It describes a model based on nonideal, Wohl solution theory to assess lubricant-solubility effects. Figures illustrate model predictions of vapor pressure and R-32 mass fraction with liquid R-32/134a (25/75) as functions of the mass fraction of oil in the sump and sump temperature. Three others show the vapor pressure and vapor mass fraction versus mass fraction of oil and R-32 liquid mass fraction at representative temperatures. The report then summarizes modelling of fractionation within components for

a typical heat pump; the model currently addresses the evaporator, condenser, compressor, expansion valve, and accumulator. A figure shows the extreme operating conditions of constant temperature and constant mass fraction conditions. Four figures show the R-32 concentration by component and the refrigerant location with time, after starting, with 0 and 100% temperature glide. Three schematics illustrate an experimental facility and equipment that will be used to conduct verification tests. The heat pump and instrumentation are described. Planned tests are outlined and the specific sequence and operating conditions are summarized in a table. Presentation charts on the objectives, deliverables, and schedule are appended.

F. R. Biancardi (United Technologies Research Center, UTRC), **Investigation into the Fractionation of Refrigerant Blends**, presentation (ARI Alternative Refrigerants Evaluation Program, AREP, Meeting, Chicago, IL, 27 January 1995), report DOE/CE/23810-52B, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (24 pages with 14 figures, available from JMC as RDB5257)

This report comprises presentation charts on research to investigate composition changes in refrigerant blends. The charts outline the work scope, deliverables, and schedule. They identify four technical tasks addressing lubricant solubility effects, fractionation effects from successive charges, fractionation within system components, and fractionation during leaks. Charts show the binary activity coefficients, predicted vapor pressures, and experimental and measured vapor pressures for R-32/134a (25/75) with a polyolester (POE) lubricant (Castrol Icematic(R) SW68). Four figures summarize analyses of fractionation based on both an isothermal, static equilibrium model and a more rigorous, dynamic simulation model. They include a sample mass loss and composition plot with the static model, a schematic and corresponding thermal circuit diagram for the transient model, plots of mass loss, and temperature, and composition plots for discharges at constant temperature and with a temperature change. Five additional plots show predicted internal fractionation for these components during start-up and at steady state, assuming 0 and 100% of maximum glide and for a system with half the initial refrigerant charge for 0% glide. A summary chart indicates that different solubility of blend components can affect fractionation, but modelling predicts trends accurately. Further, tank charging effects can be modelled with verified accuracy, but verification of modelling for fractionation inside systems is more difficult. The summary also notes that the work performed has been limited to a single blend with moderate glide.

D. B. Bivens, M. B. Shiflett, C. C. Allgood, and A. Yokozeki (DuPont Fluoroproducts), **Zeotropic Mixture Separations Analyses**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 113-118, July 1996 (6 pages with 10 figures, RDB6820)

thermodynamic model to simulate a slow vapor leak, comparison to experimental data for R-401A, R-404A, R-407C, R-125/143a (45/55); comparison to NIST REFLEAK model for R-401A and R-407C

F. C. Chen, S. L. Allman, and C. H. Chen (Oak Ridge National Laboratory, ORNL), **New Concepts for Refrigerant Leak Detection and Mixture Measurement**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 211-217, October 1993 (7 pages with 4 figures, RDB3A44)

S. Esslinger, **The True Cost of Refrigerant Leaks**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 30, number 11, pages 27-29, November 1988 (3 pages, RDB4237)

M. R. Harrison (Radian Corporation), R. C. Keeney (Jones Nuese), and T. P. Nelson (Radian Corporation), **Pilot Survey of Refrigerant Use and Emissions from Retail Food Stores**, paper 3835, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 25-33, 1995 (9 pages with 6 tables, RDB5231)

R-12, R-22, R-502

M. S. Kim (Seoul National University, Korea) and D. A. Didion (National Institute of Standards and Technology, NIST), **Simulation of Isothermal and Adiabatic Leak Processes of Zeotropic Refrigerant Mixtures**, *HVAC&R Research*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 1, number 1, pages 3-20, January 1995 (18 pages with 17 figures, RDB5201)

This article presents a study of the composition shifts of zeotropic blends during refrigerant leaks. The simulations addressed cover both slow and fast leaks, characterized by isothermal and adiabatic processes, respectively. The article summarizes interest in zeotropic blends and concerns such as fractionation to or of a

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flammable composition. Leak modes from container tops and bottoms, representing initial vapor and liquid leaks, are presented. The model is described as a quasi-steady state process with finite time increments, in each of which mass escapes and a new thermodynamic equilibrium is reached. The model uses the NIST REFPROP program to calculate refrigerant properties. The model is presented along with schematic diagrams of pressure and composition changes for both isothermal and adiabatic leaks. The results are illustrated with plots of mass fraction by component as a function of mass percentage lost. Results are shown for R-32/134a (30/70) and R-32/125/134a (30/10/60) for both vapor and liquid leaks. A sensitivity study shows the influence of temperature on leakage of the ternary mixture. The remaining fraction of the more or most volatile component decreases for either a vapor or liquid leak in the isothermal process. Also, the mass fraction changes at low temperature are greater than those at high initial temperature. The mass fraction of the more volatile component increases in the vapor and decreases in the liquid for the adiabatic process in both the vapor and liquid loss modes. The results show that the refrigerant left in the container remains nonflammable for both blends in isothermal vapor leaks, but could become flammable in the adiabatic process, since the R-32 fraction is highest in the final state. The authors note that the refrigerant charging process is close to the adiabatic process addressed, and that the model can be used to estimate the amount of refrigerant leaked from a system by measuring the pressure and using the equations presented.

T. Lemmons and R. Bradow, **Refrigerant 12 Leakage in Automobile Air Conditioner Systems**, paper 810506, Society of Automotive Engineers (SAE), Warrendale, PA, February 1981 (RDB2443)

R-12

R. E. Low, B. E. Gilbert, M. Davies (ICI Klea, USA), J. D. Morrison, and F. T. Murphy (ICI Klea, United Kingdom), **Handling Zeotropic Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 216-224, October 1995 (9 pages with 2 figures and 1 table, available from JMC as RDB5A62)

azeotropes, zeotropes, glide, differential leakage, R-407A, R-407B, R-407C

J. R. Parsnow, **Monitoring Instruments for HCFC-123**, publication 819-060, Carrier Corporation, Syracuse, NY, April 1992 (8 pages with 2 figures and 1 table, RDB2915)

R-123, leak detection

R. R. R. Scharf, V. W. Goldschmidt, and L. White (Purdue University), **Measurement of Refrigerant Leakage in Reversing Valves**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 90, part 1A, pages 185-195, 1984 (11 pages with 7 figures and 1 table, RDB5614)

describes a test method and measurements of flow leakage in heat pump reversing valves

T. C. Sorensen (Thermal Gas Systems, Incorporated), **Seeking Out Chiller Leaks**, *Refrigerating Service and Contracting* (RSC), Business News Publishing, Troy, MI, July 1995 (3 pages with 1 figure, limited copies available from JMC as RDB-5C09)

This article provides an overview of refrigerant leak detection devices and their application. It cites the requirement for them in ANSI/ASHRAE Standard 15-1994, identifies data sources for detection levels, and outlines factors that facility managers, suppliers, and technicians need to know for installations. The article then describes common monitoring technologies including ceramic metal oxide semiconductor (CMOS) and infrared (IR) devices. It describes both and gives typical cost ranges. It then reviews instrument sensitivity, selectivity, speed of response, and location. It also describes two approaches, one that locates sensors where refrigerants are likely to concentrate and another that draws air samples to the sensor. The article concludes with recommended installation, calibration, and service practices.

S. Stanbouly and A. Wesolowski (York International Corporation), **Serviceability Issues Associated with R407C Refrigerant**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 125-132, July 1996 (8 pages with 10 figures, RDB-6823)

R-407C, performance, leakage, fractionation: laboratory tests in a 10.6 kW cooling (3 ton) single-speed, split-system heat pump found a 3-4% decrease in capacity and performance in the cooling mode and 4-9% increase in capacity and 3-4% loss in efficiency in the heating mode; when 50% of the refrigerant charge was leaked by a simulated slow, isothermal leak and recharged to the nameplate amount, the capacity dropped 3-4% and efficiency by 5% due to a significant change in composition; the leaked

gas is noted as rich in R-32, which is flammable; performance, service, design, manufacturing, and safety issues are outlined issues

S. G. Sundaresan and R. J. Watkins (Copeland Corporation), **Study of Liquid and Vapor Composition During Calorimetry**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 234-237, October 1995 (9 pages with 2 figures and 1 table, available from JMC as RDB5A64)

R-404A, R-407C, R-410A, fractionation of refrigerant blends during secondary calorimetry testing

A. Yokozeki (DuPont Fluoroproducts), **Characteristics of Alternative Refrigerant Mixtures**, paper 1.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 12-16, December 1994 (5 pages with 12 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5403)

This paper examines the composition change and temperature glide of azeotropic and zeotropic refrigerant blends with and without oil present. It also addresses the oil viscosity and solubility of refrigerant-oil mixtures. The paper notes that azeotropic blends may undergo composition shifts due to differences in solubility of the components in lubricants. Pressure-composition plots depict the bubble and dew point curves at -30, 0, and 30 °C (-22, 32, and 86 °F) for R-22/115, R-125/143a, R-32/125, and R-32/134a. Plots illustrate the composition shifts of R-407C with vapor leakage and successive recharging. Four further plots show the vapor composition shift of R-407C, R-410B, R-502, and R-507A in unidentified polyolester (POE) lubricants. Two final figures show the viscosity-temperature-pressure-composition relations of R-407C and R-32/125 (60/40) with a POE. A table give the normal boiling point and maximum temperature glide (dew minus bubble point temperatures) for R-22, R-404A, R-407A, R-407B, R-407C, R-410A, R-502, R-507A, and R-32/134a (25/75) and (30/70). A second table contrasts the performance of R-22, R-410A, and R-410B. A final table shows the composition and pressure changes with 50% vapor leakage at 20 °C (68 °F) for R-404A, R-407C, R-410A, R-410B, R-502, R-507A, and R-32/134a (30/70).

Leak Detectors for Alternative Refrigerants, document ARTD-27 (H-31753-2), DuPont Chemicals, Wilmington, DE, December 1992 (8 pages, available from JMC as RDB4508)

Glide Matching and Lorenz Cycles

P. A. Domanski, W. J. Mulroy, and D. A. Didion (National Institute of Standards and Technology, NIST), **Glide Matching with Binary and Ternary Zeotropic Refrigerant Mixtures - Part 2: A Computer Simulation**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 354-363, 1993; republished in *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 4, pages 226-230, April 1994 (10/5 pages with 8 figures and 1 table, RDB5326)

R-22, R-142b, R-23/142b, R-23/22/142b, Lorenz cycle

A. Lorenz and K. Meutzner, **On Application of Nonazeotropic Two Component Refrigerants in Domestic Refrigerators and Home Freezers**, *Proceedings of the XIVth International Congress of Refrigeration* (Moscow, USSR, August 1975), International Institute of Refrigeration, Paris, France, August 1975 (RDB3217)

W. J. Mulroy, P. A. Domanski, and D. A. Didion (National Institute of Standards and Technology, NIST), **Glide Matching with Binary and Ternary Zeotropic Refrigerant Mixtures - Part 1: An Experimental Study**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 343-353, 1993; republished in *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 4, pages 220-225, April 1994 (11/6 pages with 7 figures and 1 table, RDB5327)

R-23/142b, R-23/22/142b, Lorenz cycle

J. R. Sand, E. A. Vineyard, and V. D. Baxter (Oak Ridge National Laboratory, ORNL), **Laboratory Evaluation of an Ozone-Safe Nonazeotropic Refrigerant Mixture in a Lorenz-Meutzner Refrigerator Freezer Design**, paper CH-93-20-4, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, 1993, pages 1467-1481 (14 pages with 8 figures and 12 tables, RDB2412)

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Operation and Maintenance

M. M. Bagaman (Southland Industries Services Company, SISCO), **After CFCs: What a Changeover Means for Maintenance**, *Maintenance Solutions*, pages 10 and 12, July/August 1994 (2 pages, RDB5126)

This article reviews requirements for record keeping, system maintenance and monitoring, and refrigerant safety and handling, including training of personnel. The discussion of record keeping centers on compliance with regulations promulgated in May 1993, pursuant to Section 608 of the U.S. Clean Air Act Amendments. Six top record types are listed, namely those covering service, maintenance, repair, or disposal; copies of service invoices; and indications of the quantities of appliances serviced, maintained, repaired, or disposed. They also include records of the amount of refrigerant used, recovered, or recycled; the equipment used to recover or recycle refrigerants; and of other methods used to prevent releases into the atmosphere. The article summarizes guidelines for maintenance and monitoring, dominantly focusing on the recommendations of ASHRAE Guideline 3-1990. It identifies parameters to be checked and logged routinely. Turning to safety, the article outlines training requirements and identifies responsibilities for maintenance managers. The latter include providing a safe workplace, compliance with laws, and attention to the interests of facility owners. The article stresses the importance of regulatory and code compliance as well as attention to safety in improving the environment.

Guidelines for Start-Up, Inspection and Maintenance of Ammonia Mechanical Refrigerating Systems, bulletin 110, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, March 1993 (60 pages with 7 tables, RDB4759)

This bulletin outlines basic requirements for the safe start-up, inspection, and maintenance of R-717 (ammonia) refrigerating systems. The maintenance focus is on steps to promote safety, to supplement manufacturer instructions. The guide provides definitions and a section on ammonia characteristics, properties, hazards, specifications for refrigerant grade ammonia, and general precautions. It then identifies essential records and documentation to be obtained and maintained by the user. A section on start-up covers an advance safety review, process hazard analysis, operating procedures, training, initial status and safety provisions, electrical equipment, evacuation, dehydration, leak checking, charging, and testing of protection devices. A section on inspection and maintenance covers general considerations, keeping of a system log, compressors, other system components, ammonia pumps, valves and sensing devices, piping, oil maintenance and removal, and motors and other drives. Appendices identify minimum design pressures, information to be provided on component name plates, a check list for start-up, and requirements for machinery rooms and auxiliary safety equipment. A separate appendix reviews stress corrosion cracking (SCC), inspection, and preventive measures. Additional appendices cover pressure tests and typical schedules for inspection and maintenance. The document concludes with sample forms for pressure vessel records and system logs.

Guidelines for Identification of Ammonia Refrigeration Piping and System Components, IIAR bulletin 114, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, September 1991 (20 pages with 2 figures and 1 table, RDB4761)

This bulletin provides guidance for uniform labeling of R-717 (ammonia) piping and components for refrigeration systems. Its objective is to promote safety, facilitate maintenance, and provide vital information to emergency service personnel. It stipulates standardized identification of the physical state, relative pressure level, and direction of flow of the refrigerant for piping mains, headers, and branches. It also provides for identification of components, including receivers, heat exchangers, and accumulators. The bulletin prescribes standard piping and component markers with specific attention to content, arrangement, approved abbreviations, dimensions, and colors. It also prescribes marker locations and provides for posting of reference charts.

Pipe Sizing and Flow

D. A. Aaron and P. A. Domanski, **An Experimental Investigation and Modeling of the Flow Rate of Refrigerant 22 Through the Short Tube Restrictor**, report NISTIR 89-4120, National Institute of Standards and Technology (NIST), Gaithersburg, MD, July 1989 (106 pages with 32 figures and 3 tables, available from NTIS, RDB4730)

R-22

A. Abdul-Razzak, M. Shoukri, and J. S. Chang (McMaster University), **Characteristics of Refrigerant R-134a Liquid-Vapor Two-Phase Flow in a Horizontal Pipe**, paper CH-95-12-1, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta,

GA, volume 101, part 1, pages 953-964, 1995 (12 pages with 11 figures and 1 table, RDB5233)

T. Atwood (AlliedSignal Incorporated), **Pipe Sizing and Pressure Drop Calculations for HFC-134a**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 32, number 4, pages 62-66, April 1990 (5 pages, RDB0513)

R-134a

J. Barnhart, **An Experimental Investigation of Flow Patterns and Liquid Entrainment in a Horizontal Tube Evaporator**, PhD thesis (Department of Mechanical Engineering), University of Illinois, December 1992 (RDB3B49)

J. B. Chaddock and H. Lau, and E. Skuchas, **Pressure Drop in Two-Phase Flow Application of Refrigerant Recirculation Systems**, report DME/TR 75-01, Duke University, Durham, NC, 1974 (RDB-5105)

N. E. Hopkins, **Rating the Restrictor Tube**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, pages 1087-1095, November 1950 (RDB3417)

M. L. Jacobs (Carnegie-Mellon University, CMU), F. C. Scheideman (Carrier Corporation), F. C. Kazem (Kabul University, Afghanistan), and N. A. Macken (Rensselaer Polytechnic Institute, RPI), **Oil Transport by Refrigerant Vapor**, paper 2423, *Transactions* (Annual Meeting, Seattle, WA, 27 June - 1 July 1976), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 82, part 2, pages 318-327, 1976 (10 pages with 8 figures and 2 tables, RDB4631)

This paper presents correlations to determine the flow velocity needed for oil entrainment by refrigerant vapor in suction and hot gas risers. Oil transport was determined in vertical tubes, for R-12 with 150 and 300 SUS naphthenic mineral oils and for R-22 with 150 SUS oil. The tests were conducted in an all-vapor loop driven by a reciprocating compressor. The paper summarizes the experimental apparatus and procedures, flow theory involved, and analysis of the data. Figures depict the apparatus and test section. The findings are reduced to correlations for the minimum mass flux and tonnage for entrainment. Calculated values based on the refrigerant saturation temperature and common pipe sizes, from 13-105 mm (½ to 4 1/8"), are tabulated.

N. A. Macken (Rensselaer Polytechnic Institute, RPI), F. C. Scheideman (Carrier Corporation), and M. L. Jacobs (Carnegie-Mellon University, CMU), **An Experimental Study of Pressure Drop and Liquid Transport of Oil-Refrigerant Mixtures**, paper 75-WA/HT-26 (Winter Annual Meeting, Houston, TX, 30 November - 4 December 1975), American Society of Mechanical Engineers (ASME), New York, NY, 1975 (12 pages with 16 figures, RDB-5206)

Y. Kim, D. L. O'Neal (Texas A&M University), and X. Yuan (Xi'an Jiatong University, China), **Two-Phase Flow of HFC-134a and CFC-12 Through Short-Tube Orifices**, paper OR-94-2-2, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 582-591, 1994 (10 pages with 7 figures and 4 tables, RDB4707)

S. J. Kuehl (Whirlpool Corporation) and V. W. Goldschmidt (Purdue University), **Flow of R-22 Through Short-Tube Restrictors**, paper 3603, *Transactions* (Annual Meeting, Baltimore, MD, 27 June - 1 July 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 59-64, 1992 (6 pages, RDB3215)

D. K. Miller (York International Corporation), **Sizing Dual-Suction Risers in Liquid Overfeed Refrigeration Systems**, *Chemical Engineering*, 24 September 1979 (RDB4560)

pipe sizing

K. J. Riedle (Siemens AG, Germany), N. A. Macken, and S. W. Gouse, Jr. (Carnegie-Mellon University, CMU), **Oil Transport by Refrigerant Vapor: A Literature Survey and Proposed Analytical Model**, paper 2246 (109-RP), *Transactions* (Annual Meeting, Nassau, Bahamas, 25-29 June 1972), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1972 (10 pages with 11 figures, RDB5207)

K. J. Riedle, N. A. Macken, and S. W. Gouse, Jr. (Carnegie-Mellon University, CMU), **Oil Transport by Refrigerant Vapor**, report number CMU-40203-1, final report for 109-RP Phase I, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, June 1971 (94 pages with 36 figures, RDB5205)

F. C. Scheideman (Carrier Corporation), M. L. Jacobs (Union Carbide Corporation), S. M. Kazem (Kabul University, Afghanistan), and N. A. Macken (Rensselaer Polytechnic Institute, RPI), **Pressure Loss of Oil-Refrigerant Mixtures in Suction and Discharge Lines**, paper 2463 (109-RP), *Transactions* (Annual Meeting, Halifax, NS, Canada, 26-30

please see pages 6-8 for ordering information

June 1977), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 83, part 2, 1977 (18 pages with 15 figures and 5 tables, RDB5209)

This paper documents research of pressure drops for suction and discharge lines for R-12 and R-22 with mineral oil. It also presents correlations and tabular data to allow use of the results in system design. The paper describes and schematically illustrates the test apparatus. It entailed a closed refrigerant loop with oil injection and separation means as well as both horizontal and vertical test sections. The loop was an oil-vapor system with pressure and flow maintained by a 37.3 kW (50 hp) compressor. The horizontal test sections comprised three parallel tubes, 3 m (10') in length, of 12.7, 25.4, and 76.2 mm (½, 1, and 3") diameter, with valves to enable selection. The vertical test section was a 25.4 mm (1") tube. The paper explains the test procedure, instrumentation, and theoretical derivation for the form of the correlations used. R-12 was tested with both 150 and 300 SUS mineral oil (unidentified) and R-22 with the former. Tests were performed at six temperatures from -40 to 38 °C (-40 to 100 °F) with 11-56 °C (20-100 °F) of superheat; the oil fraction ranged from 0.1 to 5% by weight. Figures show the solubility of the refrigerants in the lubricants, the viscosity of the mixtures, and defined Lockhart-Martinelli and Chisholm correlations for the horizontal and vertical pressure drops. Four tables provide refrigerant capacities in tons that result in a 1.1 °C (2 °F) pressure drop per 30 m (100') equivalent length of piping for horizontal suction and discharge lines and for suction and hot gas risers. They cover 12.7-105 mm (½-4¼") pipes for 1% oil. The paper concludes that oil causes a significant and predictable increase in the pressure drop, which can be estimated with the data and correlations provided.

F. C. Scheideman (Carrier Corporation) and N. A. Macken (Carnegie-Mellon University, CMU), **Pressure Loss of Refrigerant-Oil Mixtures in Horizontal Pipes**, paper 2341 (109-RP), *Transactions* (Semiannual Meeting, Atlantic City, NJ, 26-30 January 1975), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 81, part 1, pages 235-241, 1975 (12 pages with 11 figures, RDB4A10)

mass flow, oil return

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Selecting the Size of Pipes Carrying Hot Gas to Defrost Evaporators**, *International Journal of Refrigeration* (IJR), Paris, France, volume 7, number 4, pages 225-228, May 1984 (4 pages, RDB4633)

pipe sizing

M. L. Timm, **An Improved Method for Calculating Refrigerant Line Pressure Drops**, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, pages 194-203, January 1991 (10 pages, RDB4634)

H. A. Whitesel, **Capillary Two-Phase Flow, Part II**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 65, number 9, pages 35-40, September 1957 (RDB3416)

H. A. Whitesel, **Capillary Two-Phase Flow, Part I**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 65, number 4, pages 42-44, April 1957 (RDB3415)

H. Wijaya (AlliedSignal Incorporated), **Adiabatic Capillary Tube Test Data for HFC-134a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 63-71, July 1992 (9 pages with 9 figures and 3 tables, RDB2714)

R-134a

D. D. Wile, **Refrigerant Line Sizing**, publication 90250, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1977 (48 pages, RDB4635)

This document provides charts to simplify sizing of refrigerant lines. It covers suction, discharge, and liquid lines for both copper tubes and steel pipes with R-12, R-22, and R-502 as well as for steel pipes with R-717 (ammonia).

Charge Inventory Calculations for Evaporating and Condensing Refrigerants Inside Tubes, proposed research project 758-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH-0758)

This research project is sponsored by ASHRAE Technical Committee 8.4, *Air-to-Refrigerant Heat Transfer Equipment*. Proposals were due at ASHRAE Headquarters by 12 January 1996.

Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

Fundamental Study of Refrigerant Line Transients, research project 736-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1993 - June 1994 (ASH0736)

This research project will identify causes and consequences of pressure transients, induced by condensation during hot-gas defrost, in refrigerant piping. The underlying goal is to develop means to prevent their occurrence, either by appropriate design or operation. The problem induces hydraulic shock and vapor-propelled liquid slugging. The work will involve a literature search, documentation of critical flow regimes, and analysis of both condensation-induced hydraulic shock and vapor-propelled liquid slugs. The contractor is the University of Illinois, led by A. M. Jacobi; it is sponsored by ASHRAE Technical Committees 10.3, *Refrigerant Piping* and 10.1, *Engineered Refrigeration Systems*.

ICI Klea Engineers' Tables: KLEA 407B, Version 1.0 SI Units, bulletin CP/10150/1Ed/23/994, ICI Klea, Runcorn, Cheshire, UK, September 1994 (24 pages with 1 figure and 23 tables, RDB6B39)

This bulletin provides detailed data for systems design using R-407B - a zeotropic blend containing R-32, R-125, and R-134a, specifically R-32/125/134a (10/70/20) - in metric (SI) units of measure. An introductory section explains the use of the data and how they were derived. The first tables give the evaporator pressure from the liquid temperature and mean evaporating temperature, the mean evaporator and dew-point temperatures from the pressure and liquid temperature, the mean condenser pressure and dew- and bubble-point temperatures from the mean temperature, and the condenser bubble-point, mean, and dew-point temperatures from pressure. They cover evaporating temperatures of -40 to +5 °C (-40 to +41 °F) and condensing temperatures of 10-60 °C (50-140 °F). The next set of tables give the maximum recommended suction line capacities for varying suction gas conditions for 10-105 mm (0.4-4.1") type L copper tube and 10-100 (0.4-3.9") schedule 40 steel pipe. Further tables give the discharge and liquid line capacities, and recommended minimum capacities for oil entrainment in suction lines for the same line sizes and types. Two final tables provide correction factors to use the capacity tables at other conditions. A chart correlates refrigerant flow rate and unit capacity for mean evaporating and condensing temperatures of -40 to +5 °C (-40 to 41 °F) and condensing temperatures of 20-50 °C (68-122 °F), respectively.

ICI's product name for R-407B is Klea(R) 407B (formerly Klea(R) 61).

Performance of a Suction-Line Capillary Tube Heat Exchanger with Alternative Refrigerants, proposed research project 948-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, approved for bidding October 1996 (ASH0948)

This project is sponsored by ASHRAE Technical Committee 8.8, *Refrigerant System Controls and Accessories*. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

Pressure Drop in Refrigerant Suction Lines at High Refrigerant Flux with Oil in Circulation, proposed research project 731-TRP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0731)

This research project is sponsored by ASHRAE Technical Committee 10.3, *Refrigerant Piping*.

Performance

D. Arnaud (Elf Atochem S.A., France) and J. P. Caillie, **Comparative Performance of HFA-134a and CFC-12 in a Reciprocating Water Chiller**, *Proceedings of the 1990 USNC/IIR Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 354-364, July 1990 (11 pages, RDB6325)

R-12, R-134a

J. C. Bare (U.S. Environmental Protection Agency, EPA), **Simulation of Performance of Chlorine-Free Fluorinated Ethers and Fluorinated Hydrocarbons to Replace CFC-11 and CFC-114 in Chillers**, paper 3661, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 397-407, 1993 (11 pages with 4 figures and 4 tables, RDB3407)

R-11 and R-114 alternatives

J. P. Barger, W. M. Rohsenow, and K. M. Treadwell, **A Comparison of Refrigerants When Used in Vapor Compression Cycles over an Extended Temperature Range**, *Transactions of the ASME*, American Society of Mechanical Engineers (ASME), New York, NY, volume 79, pages 681 ff, April 1957 (RDB4352)

please see pages 6-8 for ordering information

D. J. Bateman (DuPont Chemicals), **Performance Comparison of HFC-134a and CFC-12 in Automotive Air-Conditioning Systems**, paper 890305 (SAE International Congress and Exposition, Detroit, MI, February-March 1989), Society of Automotive Engineers (SAE), Warrendale, PA, February 1989 (RDB4231)

R-12, R-134a

D. B. Bivens, R. A. Gorski, W. D. Wells, A. Yokozeki (DuPont Chemicals), R. A. Lindstrom, and R. L. Shimon (Tecumseh Products Company), **Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants**, paper 890306 (SAE International Congress and Exposition, Detroit, MI, February-March 1989), Society of Automotive Engineers (SAE), Warrendale, PA, February 1989 (RDB4232)

S. Corr, P. D. Guy, F. T. Murphy, G. Tompsett (ICI Chemicals and Polymers, Limited), and T. W. Dekleva (ICI Americas, Incorporated), **Performance Characteristics of R-134a and Alternative Lubricants**, seminar presentation at the ASHRAE Winter Meeting (New York, NY), ICI Americas Incorporated, New Castle, DE, USA, 22 January 1991 (26 pages with 19 charts, RDB2522)

P. A. Domanski, **Theoretical Evaluation of the Vapor Compression Cycle With a Liquid-Line/-Suction-Line Heat Exchanger, Economizer, and Ejector**, report NISTIR 5606, National Institute of Standards and Technology, Gaithersburg, MD, March 1995 (42 pages with 27 figures and 1 table, available from JMC, RDB6436)

This report presents a theoretical analysis of three vapor-compression cycles that incorporate a liquid-line/suction-line heat exchanger (LSHX), economizer, or ejector. These enhancements reduce throttling losses by different principles, but they also increase complexity and costs. The analyses compared the variations to basic reverse Carnot and Rankine cycles for 38 refrigerants. They included R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-123a, R-124, R-125, R-134, R-E134, R-134a, R-141b, R-142b, R-143, R-143a, R-152a, R-218, R-227ea, R-236ea, R-245cb, R-E245, R-C270, R-290, R-C318, R-600, R-600a, R-601 (pentane), R-601a (isopentane), R-717, and R-744. The benefits of the cycle modifications generally increase with the amount of throttling losses realized by the refrigerant in the reverse-Rankine cycle. The study found that the LSHX cycle offers the smallest improvement. The ejector cycle offers the highest, but requires an ejector efficiency beyond that practically demonstrated. The performance of the ejector cycle is comparable to that of the single-stage economizer cycle for typical ejector efficiencies. The report includes a tabular summary of selected properties (critical temperature, molecular mass, latent heat of vaporization, and vapor and liquid molar heat capacities).

P. A. Domanski, **Modelling of a Heat Pump Charged with a Nonazeotropic Refrigerant Mixture**, NBS Technical Note 1218, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1986 (available from GPO, RDB6856)

cycle analysis, zeotropic blend

T. Ebner and H. Halozan (Technische Universität Graz, Graz, Austria), **Testing the Available Alternatives - An Examination of R-134a, R-152a, and R-290**, *IEA Heat Pump Newsletter*, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, volume 12, number 1, 1994 (RDB5721)

D. S. Godwin and M. S. Menzer (Air Conditioning and Refrigeration Institute, ARI), **HCFC-22 Phase Out in North America - Impact on Future Equipment Protection**, *IEA Heat Pump Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 29-31. March 1995 (3 pages with 2 figures and 1 table, RDB5689)

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K. Hachisuka, M. Kawada, and N. Ohya (Mitsubishi Heavy Industries, Limited, Japan), **Performance of R-125/143a/134a Low Temperature Refrigeration**, paper 3.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 52-56, December 1994 (5 pages with 12 figures and 2 tables; in Japanese with abstract, figures, and tables in English; RDB5411)

R-125/143a/134a (44/52/4) [R-404A], condensing unit with scroll compressor

G. H. Haines, T. W. Dekleva, and R. E. Low (ICI Klea), **Performance Testing of R-502 Replacements Based on R-32/R-125/R-134a**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 395-400, July 1994 (6 pages with 10 figures, RDB-4852)

R-407A [R-32/125/134a (20/40/40)], R-407B [R-32/125/134a (10/70/20)]

H. T. Haukås (Norgest Tekniska Högskole, NTH, Norway), **Practical Performance of Alternatives to R-12 and R-502 in Refrigerators and Freezers**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and Institute of Refrigeration, London, UK, 11 November 1992 (7 pages with 9 figures and 2 tables, RDB3333)

M. Kurokawa, K. Nasako, M. Honjo, and M. Osumi (Sanyo Electric Company, Limited, Japan), **An Experimental and Theoretical Study on System Performance of Refrigeration Cycle Using Alternative Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 217-222, July 1996 (6 pages with 9 figures and 3 tables, RDB6854)

R-410A, pressure loss in grooved tube evaporators, capillary tube characteristics, system simulation, seasonal performance, comparison to R-22 concludes that efficiency is better at low loads, worse at high loads, and nearly the same on a seasonal basis

R. E. Low, J. D. Morrison, and F. T. Murphy (ICI Klea, UK)), **Performance Testing of R-22 and R-502 Alternatives Based on R-32/R-125/R-134a**, paper 1.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 7-11, December 1994 (5 pages with 4 figures and 2 tables, RDB5402)

R-407A, R-407B, R-407C, R-32/125/134a, zeotropic blends, fractionation, performance, thermodynamics, servicing

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Summary of Test Data from Several Drop-In, Compressor Calorimeter, Soft-Optimized Compressor, and Soft-Optimized System Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 123, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (14 pages with 10 figures and 1 table, available from JMC as RDB3D23)

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **R-22, R-502 Alternative Refrigerants Evaluation Program in Japanese Industry**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 31-39, 1994 (9 pages with 19 figures and 3 tables, RDB4518)

B. Ouazia and W. K. Snelson (National Research Council, Canada, NRCC), **Predicting System Performance of Alternative Refrigerants Using a Water-Water Heat Pump**, paper 3797, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 140-147, 1994 (8 pages with 8 figures, RDB4708)

R-134a

J. Pettersen and H. Rekstad (Norgest Tekniska Högskole, NTH, Norway), **The Practical Performance of R-134a in Motorcar Air-Conditioning**, paper 225, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume III, pages 1155-1160, 1991 (6 pages with 7 figures and 3 tables, RDB-5B27)

R-134a with an unidentified polyoxalkylene glycol ether lubricant, capacity and efficiency in mobile air conditioning (MAC) system; laboratory measurements

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Is There a Relationship Between the Ideal Carnot Cycle and the Actual Vapor-Compression Cycle?**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 205-212, July 1994 (8 pages with 12 figures and 1 table, RDB4826)

theoretical performance, refrigeration effect, isentropic compression efficiency, coefficient of performance, COP, R-12, R-22, R-115, R-124, R-134, R-134a, R-142b, R-143a, R-152a, R-218, R-C270, R-290, R-C318, R-600a

T. Yamaguchi (Mitsubishi Electric Corporation, Japan), **Characteristics of Scroll Condensing Units for R125/143a/134a**, paper 3.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 63-67, December 1994 (5 pages with 13 figures and 1 table; in Japanese with abstract, figures, and table in English; RDB5413)

please see pages 6-8 for ordering information

R-125/143a/134a (44/52/4) [R-404A], composition shift, equilibrium composition, discharge temperature, cooling capacity and efficiency

Cycle Analyses

C. P. Aroa, **Power Savings in Refrigerating Machines Using Mixed Refrigerants**, *Progress in Refrigeration Science and Technology* (proceedings of the XIIth International Congress of Refrigeration, Madrid, Spain, 30 August - 6 September 1967), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 397-409, 1969 (RDB6410)

blends, performance

P. K. Bansal, T. Dutto, and B. Hivet, **Performance Evaluation of Environmentally Benign Refrigerants in Heat Pumps: A Simulation Study**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, pages 340-348, June 1992 (19 pages, RDB2C03)

alternative refrigerants, efficiencies

J. C. Bare, C. L. Gage (U.S. Environmental Protection Agency, EPA), D. Jung, and R. K. Radermacher (University of Maryland), **Simulation of Nonazeotropic Mixtures for Use in a Dual-Circuit Refrigerator/Freezer with Countercurrent Heat Exchangers**, paper IN-91-14-3(3540), *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, pages 447-454, 1991 (9 pages with 3 figures and 3 tables, RDB4419)

zeotropic blends,

S. Chen, J. F. Judge, E. A. Groll, and R. K. Radermacher (University of Maryland), **Theoretical Analysis of Hydrocarbon Mixtures as a Replacement for HCFC-22 for Residential Uses**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 225-230, July 1994 (6 pages with 4 figures and 2 tables, RDB4827)

R-22, R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601a (isopentane), R-290/600, R-290/600a, R-290/601a

M. A. Comeau, **Numerical and Experimental Analysis of the Dynamic Behavior of a Heat Pump Working with Nonazeotropic Refrigerant Mixtures**, MScA thesis, Mechanical Engineering Department, University of Moncton, Moncton, Canada, 1991 (RDB6717)

lumped parameter model to predict the dynamic behavior of heat pumps using zeotropic blends as refrigerants; R-22/114 (80/20) and (60/40); R-22/152a (80/20)

P. A. Domanski, D. A. Didion, W. J. Mulroy (National Institute of Standards and Technology, NIST, USA), and J. A. R. Parise (Pontifícia Universidade Católica do Rio de Janeiro, Brazil), **A Simulation Model and Study of Hydrocarbon Refrigerants for Residential Heat Pump Systems**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 339-354, 1994 (16 pages with 5 figures and 7 tables, RDB5B28)

R-22, R-32/125 (49/51), R-290, R-290/600a (70/30), simulated performance

P. A. Domanski and D. A. Didion (National Institute of Standards and Technology, NIST), **Thermodynamic Evaluation of R-22 Alternative Refrigerants and Refrigerant Mixtures**, paper DE-93-6-2, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 636-648, 1993 (13 pages with 18 figures and 3 tables, RDB3617)

This paper evaluates performance of candidate refrigerants to replace R-22, including R-32/125 (60/40), R-407B [R-32/125/134a (10/70/20)], R-32/125/134a (30/10/60), R-32/125/290/-134a (20/55/5/20), R-32/134a (25/75), R-32/-134a (30/70), R-32/227ea (35/65), R-134a, and R-290 (propane). The analyses are based on a semi-theoretical model, CYCLE-11, with cross-flow heat transfer in the evaporator and condenser. Thermodynamic properties were calculated using the Carnahan-Starling-DeSantis (CSD) equation of state. The conditions examined approximate outdoor rating conditions for residential heat pumps, namely 27.8 and 35 °C (82 and 95 °F) for cooling and -8.3 and 8.3 °C (17 and 47 °F). Calculated volumetric capacities, coefficients of performance (COPs), pressure lift, and compressor discharge temperatures and pressures are plotted. The analyses are presented for "drop-in" conditions (constant heat exchangers), constant heat exchanger loading, and with addition of a liquid-suction heat exchanger. Summary fluid properties and results for the constant exchanger loading cases are tabulated. They indicate efficiency losses of 1-16% for the R-22 alternatives. Corresponding changes in volumetric capacity range from 31% lower to 55% higher. The paper notes, however, that these findings would change with consideration of differences in transport properties. The paper abstractly discusses the influence of critical temperature on performance and unavoidable trade off between

COP and volumetric capacity. It also reviews the impacts of heat capacity, liquid thermal conductivity, and liquid viscosity; neither these transport properties nor toxicity and flammability were otherwise addressed. An appendix describes the CYCLE-11 model. [See RDB3305 for a more complete summary, from which this paper was extracted.]

P. A. Domanski and D. A. Didion (National Institute of Standards and Technology, NIST), **Theoretical Evaluation of R22 and R502 Alternatives**, report DOE/CE/23810-7, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1993 (32 pages with 19 figures and 7 tables, available from JMC as RDB3305)

This report evaluates performance of candidate refrigerants to replace R-22 and R-502. The alternatives compared to R-22 include R-32/125 (60/40), R-407B [R-32/125/134a (10/70/20)], R-32/125/134a (30/10/60), R-32/125/290/-134a (20/55/5/20), R-32/134a (25/75), R-32/-134a (30/70), R-32/227ea (35/65), R-134a, and R-290 (propane). The analyses are based on a semi-theoretical model, CYCLE-11, with cross-flow heat transfer in the evaporator and condenser. Thermodynamic properties were calculated using the Carnahan-Starling-DeSantis (CSD) equation of state. The conditions examined approximate outdoor rating conditions for residential heat pumps, namely 27.8 and 35 °C (82 and 95 °F) for cooling and -8.3 and 8.3 °C (17 and 47 °F). Calculated volumetric capacities, coefficients of performance (COPs), pressure lift, and compressor discharge temperatures and pressures are plotted. The analyses are presented for "drop-in" conditions (constant heat exchangers), constant heat exchanger loading, and with addition of a liquid-suction heat exchanger. The alternatives compared to R-502 are R-32/125/143a (10/45/45), R-125/143a (45/55), and R-125/143a/134a (44/52/4) [R-404A]. These fluids are examined at typical conditions for commercial refrigeration, namely -23.3 and 35 °C (-10 and 95 °F) for the fluid entering the evaporator and condenser, respectively. Simulation cases and results similar to those for the R-22 alternatives are presented. Summary fluid properties and results for the constant exchanger loading cases are tabulated. They indicate efficiency losses of 1-16% for the R-22 alternatives and 3-7% for the R-502 alternatives. Corresponding changes in volumetric capacity range from 31% lower to 55% higher and from 8% lower to 13% higher than R-22 and R-502, respectively. The report notes, however, that these findings would change with consideration of differences in transport properties. The report abstractly discusses the influence of critical temperature on performance and unavoidable trade off between COP and volumetric capacity. It also reviews the impacts of heat capacity, liquid thermal conductivity, and liquid viscosity; neither these transport properties nor toxicity and flammability were otherwise addressed. Two appendices summarize the nomenclature used in the report and describe the CYCLE-11 model. A third tabulates vapor heat capacity, liquid and vapor thermal conductivity, and liquid and vapor viscosity for the fluids addressed.

I. W. M. Eames (University of Nottingham, UK) and M. Naghashzadegan (University of Sheffield, UK), **Comparison Study of Isceon 49 (A Drop-In Replacement for R12) with R12 and R-134a**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 259-264, July 1996 (6 pages with 8 figures and 1 table, RDB6911)

R-12, R-134a, R-413A, cooling capacity, coefficient of performance, cycle analysis, experimental validation in a refrigerator; concludes that retrofit from R-12 to R-413A does not result in a significant loss in overall performance

T. Fukushima, A. Arai, et al, **Simulation of Refrigeration Cycle for Air Conditioners**, *Reito* [Refrigeration], Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, volume 52, number 593, pages 19 ff, 1977 (RDB6855)

cycle analysis for refrigerants

D. Jung and R. K. Radermacher (University of Maryland), **Performance Simulation of a Two-Evaporator Refrigerator-Freezer Charged with Pure and Mixed Refrigerants**, *International Journal of Refrigeration* (IJR), Paris, France, volume 14, number 7, pages 254-263, September 1991 (10 pages with 10 figures and 4 tables, RDB4418)

D. Jung and R. K. Radermacher (University of Maryland), **Performance Simulation of Single-Evaporator Domestic Refrigerators Charged with Pure and Mixed Refrigerants**, *International Journal of Refrigeration* (IJR), Paris, France, volume 14, number 6, pages 223-232, July 1991 (10 pages with 8 figures and 5 tables, RDB4417)

G. S. Kazachki (Acurex Environmental Corporation), **Derivation of Dimensionless Parameters for Thermodynamic Evaluation of Refrigerants in Vapor-Compression Cycles**, paper 106, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 597-601, 1991 (5 pages with 1 figure, RDB6317)

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outlines a method to estimate the basic characteristics of a vapor-compression cycle from refrigerant properties and to configure the cycle for optimal performance for specific refrigerants; cycle analysis; performance analysis

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection Agency, EPA), **Thermodynamic Evaluation of Five Alternative Refrigerants in Vapor Compression Cycles**, paper 535, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration (IIR), Paris, France, volume II, pages 611-615, 1991 (5 pages, RDB6324)

performance comparisons for R-12, R-22, R-32, R-125, R-134a, R-143a, R-152a, and R-502; cycle analysis; plots of efficiency as functions of evaporating temperature with throttling expansion, superheating, and both

T. P. McDowell (Thermal Storage Applications Research Center, TSARC), J. W. Mitchell, and S. A. Klein (University of Wisconsin), **Investigation of Ammonia-Secondary Fluid Systems in Supermarket Refrigeration Systems**, paper 3923, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 486-496, 1995 (11 pages with 9 figures and 2 tables, RDB6361)

R-717, indirect systems, optimization, performance comparison with R-22 systems

D. Parent and P. A. LaRue (Centre de Recherche Industrielle du Québec, Canada), **Testing and Modelling of a Water-to-Air Heat Pump Operating with a Nonazeotropic Refrigerant Mixture**, *Transactions* (Annual Meeting, Vancouver, BC, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 95, part 2, pages 405-410, 1989 (6 pages with 19 figures and 5 references, RDB5611)

R-13B1/152a, R-22/114, R-23/22, zeotropic blends, Simpac program, simulation

C. K. Rice, L. S. Wright (Oak Ridge National Laboratory, ORNL), and P. K. Bansal (University of Auckland, New Zealand), **Thermodynamic Cycle Evaluation Model for R-22 Alternatives in Heat Pumps - Initial Results and Comparisons**, *Heat Pumps in Cold Climates* (proceedings of the Second International Technical Conference, Moncton, NB, Canada, 16-17 August 1993), Caneta Research, Incorporated, Mississauga, ON, Canada, pages 81-96, January 1994 (17 pages with 7 figures and 5 tables, RDB4869)

"Bicycle" model, R-32/125 (60/40), R-32/134a (30/70), R-32/125/134a (30/10/60), R-32/-227ea (35/65)

S. T. Ro, J. Y. Shin, and Y. S. Chang (Seoul National University, Korea), **Cycle Performance of the Refrigeration System Using Alternatives to R-12 and R-22**, *Heat Pumps in Cold Climates* (proceedings of the Second International Technical Conference, Moncton, NB, Canada, 16-17 August 1993), Caneta Research, Incorporated, Mississauga, ON, Canada, pages 71-80, January 1994 (10 pages, RDB4885)

S. M. Sami and Y. Zhou (University of Moncton, Canada), **Numerical Prediction of Heat Pumps' Dynamic Behavior Using Ternary Nonazeotropic Refrigerant Mixtures**, *International Journal of Energy Research*, volume 18, 1995 (RDB4C12)

zeotropic blends, performance

S. M. Sami and M. A. Comeau (University of Moncton, Canada), **Development of a Simulation Model for Predicting Dynamic Behaviour of Heat Pump with Nonazeotropic Refrigerant Mixtures**, *International Journal of Energy Research*, John Wiley and Sons, Limited, volume 16, pages 431-444, 1995 (14 pages with 11 figures, RDB6716)

lumped parameter model to predict the dynamic behavior of heat pumps using zeotropic blends as refrigerants; presents the mathematical formulation of the model based on mass, momentum, and energy balances; effects of flow regimes and dynamic phase changes; comparison of predicted and experimental power consumption, pressures, and temperatures for R-22/114 (80/20) and (60/40) and for R-22/152a (80/20)

S. M. Sami (University of Moncton, Canada) and T. N. Duong (University of Sherbrooke, Canada), **Dynamic Performance of Heat Pumps Using Refrigerant R-134a**, *Transactions* (Annual Meeting, Indianapolis, IN, 22-26 June 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 2, pages 41-47, 1991; republished in *Alternative Refrigerants*, technical data bulletin 7(3), ASHRAE, pages 21-27, October 1991 (7 pages with 15 figures, RDB2614)

R-134a, performance

Compressor Calorimeter Tests

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 182, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May

1994 (14 pages with 8 figures and 2 tables, available from JMC as RDB5682)

R-410A compared to R-22, with a polyolester (POE) lubricant (CPI(R) Soltest(R) 120), in a gas cycle test of a semihermetic, twin-screw compressor (Dunham-Bush 1615DHR4VOEOEM)

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 132, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (14 pages with 8 figures and 2 tables, available from JMC as RDB3D32)

This report presents results of calorimeter (gas-cycle) testing for two refrigerants in an open-drive, large twin screw compressor (Dunham-Bush model 1610FHF4VOE). R-22 was tested as a reference with a mineral oil (Witco Suniso(R) 4GS); R-134a was tested with a polyolester (CPI(R) Soltest(R) 120). The report summarizes the test conditions and provides a schematic of the test system. Three appendices present the tabular data, derived performance curves, and a plot comparing the relative efficiencies for R-134a to those with R-22. The tabular data for the tests include capacity, input shaft power, energy efficiency ration (EER), coefficient of performance (COP), and relative COP (R-134a to R-22). The tests were performed at saturated suction temperatures of -7, -1, and 4 °C (20, 30, and 40 °F) and saturated discharge temperatures of 35 and 52 °C (95 and 125 °F). Capacity, input power, and COP are plotted for the same conditions. The resultant data for R-134a show 17% lower to 5% higher efficiency, depending on the suction and discharge temperatures. The relative COP appears to decrease with increasing lift. No source is indicated for the thermodynamic properties used.

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 133, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (14 pages with 8 figures and 2 tables, available from JMC as RDB3D33)

This report presents results of calorimeter (gas-cycle) testing for two refrigerants in a hermetic, vertical, twin screw compressor (Dunham-Bush model 1210NUF6V5KBJOC). R-507A was tested with a polyolester (CPI(R) Soltest(R) 120); R-502 was tested with a mineral oil (Witco Suniso(R) 4GS) as a reference. The report summarizes the test conditions and provides a schematic of the test system. Three appendices present the tabular data, derived performance curves, and a plot comparing the relative efficiencies for R-507A to those with R-502. The tabular data for the tests include capacity, mass flow rate, compressor speed, current draw, input power, energy efficiency ratio (EER), coefficient of performance (COP), and relative COP (R-507A to R-502). The tests were performed at saturated suction temperatures of -40, -32, and -18 °C (-40, -25, and 0 °F) and saturated discharge temperatures of 35, 41, and 52 °C (95, 105, and 125 °F). Capacity, input power, and COP are plotted for the same conditions. The resultant data for R-507A show 4-9% lower efficiency, depending on the suction and discharge temperatures. The relative COP appears to decrease with increasing discharge temperature. No source is indicated for the thermodynamic properties used.

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 160, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (14 pages with 8 figures and 2 tables, available from JMC as RDB5660)

R-404A, twin-screw compressor

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 122, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (14 pages with 8 figures and 2 tables, available from JMC as RDB3D22)

R-404A

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 90, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (10 pages with 8 figures and 1 table, available from JMC as RDB3C90)

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 26, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (36 pages with 15 figures and 9 tables, available from JMC as RDB3826)

This report presents results of calorimeter (gas-cycle) testing for two refrigerants in a vertical, twin screw compressor (Dunham-Bush model 1212BHF6W4KBJOC). R-134a was tested with a polyolester (CPI(R) Soltest(R) 120); R-22 was tested with a mineral oil (Witco Suniso(R) 4GS) as a reference. R-22 testing was performed using a 134 kW (100 HP) compressor motor, reduced to 107 kW (80 HP) for R-134a. The tests and resulting comparisons were repeated with-

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out and with vapor injection. The test conditions and a schematic of the test system are documented. Five appendices present the tabular data, a polynomial regression to them, derived performance curves, and a plot comparing the relative efficiencies with R-134a to those with R-22. The tabular data for the gas-cycle tests include capacity, mass flow rate, speed, current draw, input power, efficiency, and relative efficiency. The R-22 tests were performed at saturated suction temperatures of -7, -1, and 4 °C (20, 30, and 40 °F); those for R-134a were at -7, 2, and 10 °C (20, 35, and 50 °F). The saturated discharge temperature for both were 35, 41, and 46 °C (95, 105, and 115 °F). Capacity, input power, and COP are plotted for the same data ranges. The resultant data for R-134a show 13-17% lower efficiency, depending on the discharge temperature, without vapor injection and 4-10% lower with vapor injection at low suction temperatures. The efficiencies were similar to or as much as 10% higher at high suction temperatures. No source is indicated for the thermodynamic properties used, but the plots are noted as *based on preliminary data*.

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 31, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (22 pages with 8 figures and 5 tables, available from JMC as RDB3831)

This report presents results of calorimeter (gas-cycle) testing for two refrigerants in the same semihermetic, reciprocating piston compressor (Dunham-Bush model 201PHFOEMBJ6C). R-134a was tested with a polyolester (CPI(R) Soltest(R) 32); R-22 was tested with a mineral oil (Witco Suniso(R) 4GS) for reference. The 27 kW (20 HP) compressor motor was replaced with a 15 kW (11 HP) motor for the R-134a tests. The test conditions and a schematic of the test system are documented. Three appendices present the tabular data, a polynomial regression to them, derived performance curves, and a plot of relative efficiencies (comparing the COP of R-134a to that of R-22). The tabular data for the gas-cycle tests include capacity, mass flow rate, speed, current draw, input power, efficiency, and relative efficiency at saturated suction temperatures of -12, 2, and 10 °C (10, 35, and 50 °F) and saturated discharge temperatures of 35, 41, 52, and 63 °C (95, 105, 125, and 145 °F). Capacity, input power, and COP are plotted for the same data ranges. The resultant data for R-134a show 2-6% lower efficiency, depending on the discharge temperature, at low suction temperatures and higher efficiency at high suction temperatures. No source is indicated for the thermodynamic properties used, but the plots are noted as *based on preliminary data*.

R. R. Angers (Dunham-Bush, Incorporated), **Compressor Calorimeter Test of Refrigerant R-717 (Ammonia)**, Alternative Refrigerants Evaluation Program (AREP) report 61, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (16 pages with 12 figures and 3 tables, available from JMC as RDB3C61)

This report presents results of calorimeter (gas-cycle) testing for R-717 (ammonia) in medium and large screw compressors. The actual tests were performed by Svenska Rotor Maskiner AB (SRM) in Sweden, using compressors with 127 and 204 mm (5 and 8") rotors. The report describes the test setup and shows it schematically. Appendices present the test results including reference data with R-22. Saturated discharge temperature, saturated suction temperature, volumetric and adiabatic efficiency, brake horsepower, capacity, and coefficient of performance (COP) are tabulated for both compressors. The results show 8% lowered COP with R-717 at low suction temperatures improving to 5% better at high suction temperatures for the larger compressor size. The relative COP was 3-6% lower with R-717 in the smaller compressor. A second appendix indicates the lubricant content circulated, substantially higher with R-717. A third appendix provides 12 plots of the measured data including capacity, input power, and COP as functions of suction temperature for both refrigerants for both compressors.

J. C. Bare (U.S. Environmental Protection Agency, EPA), **Program to Determine Performance of Fluorinated Propanes and Fluorinated Ethers in a Compressor Calorimeter**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December, 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 418-427, December 1991 (10 pages, RDB-6327)

HFC and HFE refrigerants, performance

B. Carter (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 157, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (16 pages with 3 figures and 4 tables, available from JMC as RDB5657)

R-410A with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a hermetic, compliant scroll compressor (Copeland ZR18K1-PFV)

B. Carter, P. Dexter, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blends R-32/125**

(60/40), R-32/134a (25/75), R-32/134a (30/70), R-32/125/134a (10/70/20) [R-407B], and R-32/-125/134a (30/10/60), Alternative Refrigerants Evaluation Program (AREP) report 29, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (50 pages with 13 figures and 24 tables, available from JMC as RDB3829)

B. Carter, P. Dexter, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blends R-32/125 (60/40), R-32/134a (25/75), R-32/134a (30/70), R-32/125/134a (10/70/20) [R-407B], and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 30, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (62 pages with 17 figures and 31 tables, available from JMC as RDB-3830)

B. Carter, S. Kulkarni, E. B. Muir, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blends R-125/143a/-134a (44/52/4) [R-404A], R-125/143a (45/55), and R-32/125/143a (10/45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 53, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (36 pages with 9 figures and 15 tables, available from JMC as RDB3853)

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 17, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (12 pages with 7 figures and 2 tables, available from JMC as RDB3817)

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 18, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (12 pages with 7 figures and 2 tables, available from JMC as RDB-3818; table 1 contains type that is small and may be difficult to read)

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 19, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 4 December 1992 (14 pages with 8 figures and 2 tables, available from JMC as RDB3819; table 2 contains type that is small and may be difficult to read)

R. E. Cawley (The Trane Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 20, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 4 December 1992 (14 pages with 8 figures and 2 tables, available from JMC as RDB3820; table 2 contains type that is small and may be difficult to read)

C. Ellis (Lennox International, Incorporated), **Compressor Calorimeter and Drop-In Tests of Refrigerant R-290 (Propane)**, Alternative Refrigerants Evaluation Program (AREP) report 3, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 23 September 1992 (48 pages with 5 figures and 7 tables, available from JMC as RDB3803)

This report summarizes a test of R-290 (propane) as an alternative to R-22 in unitary air-conditioners and heat pumps. It documents comparative performance; flammability and safety concerns are acknowledged and noted as separately addressed in other work. The report reviews the Alternative Refrigerants Evaluation Program (AREP) objectives and rationale for nomination of R-290 by Lennox International. The test procedure, instrumentation, and test equipment are described. The basic test machine used was a 10.6 kW cooling (3 ton) single-speed, medium-efficiency heat pump. Performance was measured with a standard scroll compressor (Copeland ZR34K1-PFV) for R-22 and with a second compressor, for R-290, with 14.5% greater volumetric displacement (Copeland ZRK40K1-PFV). The latter was specially prepared with motor thermocouples. Testing followed ASHRAE standards 37-1988 and 116-1989 and ARI standard 210/240. The lubricant used was a conventional white oil (Penreco Sontex 200LT); a solubility plot is presented for R-290 in mineral oil (Witco Suniso(R) 3GS). Measured increases in the heating and cooling capacities with R-290 are noted as resulting from the difference in compressors. System efficiencies were indicated as comparable, within ±2%. Appendices provide measured performance data and comparative plots of capacity, input power, efficiency, and efficiency ratio for evaporator temperatures of -18 to 16 °C (0-60 °F) and condenser temperatures of 32-60 °C (90-140 °F). Simulated and measured data are tabulated in both inch pound and metric (SI) units. The report concludes that performance with propane is predictable, despite small inconsistencies in thermodynamic data for it, that few equipment changes are needed to switch to R-290, and that retrofit may be possible. The report recommends that R-290 be further considered until another candidate becomes an "obvious choice" or ongoing safety evaluations and related efforts prove ineffective.

J. Gephart, E. B. Muir, P. Naculich, and S. G. Sundaresan (Copeland Corporation), **Compressor Calorimeter Test of Refrigerant Blends R-**

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125/143a (45/55), R-125/143a/134a (44/52/4) [R-404A], and R-32/125/143a (10/45/45), Alternative Refrigerants Evaluation Program (AREP) report 28, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (44 pages with 9 figures and 25 tables, available from JMC as RDB-3828; available copy is difficult to read)

D. S. Godwin (Air-Conditioning and Refrigeration Institute, ARI), **Alternative Refrigerants Evaluation Program (AREP) Compressor Calorimeter and System Drop-In Tests with R-22 Alternatives**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, pages 375-386, May 1994 (12 pages with 9 figures and 2 tables, available from JMC as RDB4554)

This paper summarizes results of calorimeter tests to measure performance of alternative refrigerants in compressors for air conditioners, heat pumps, and refrigeration equipment. It also addresses laboratory "drop-in" (unoptimized) tests in equipment. The tests were performed by companies participating in the Alternative Refrigerants Evaluation Program (AREP), established by the Air-Conditioning and Refrigeration Institute (ARI). The paper reviews the development of AREP and lists the 39 companies - in Europe, Japan, and North America - participating in this effort. It also lists the 14 candidate refrigerants selected for testing as potential replacements for R-22. They include R-134a; R-290 (propane); R-717 (ammonia); R-32/125 (60/40); R-32/134a (20/80), (25/75), (30/70), and (40/60); R-32/227ea (35/65); R-125/143a (45/55); R-32/125/134a (10/70/20) [R-407B], (24/16/60), and (30/10/60); and R-32/125/290/134a (20/55/5/20). The candidates also include four for R-502, namely R-125/143a (45/55), R-32/125/134a (20/40/40) [R-407A]; R-125/143a/134a (10/45/45), and R-125/143a/134a (44/52/4) [R-404A]. The paper summarizes the results for R-32/125 (60/40); R-32/125/134a (30/10/60), R-32/134a (25/75), and R-32/134a (30/70). Four plots show the efficiencies and capacities measured in calorimeter tests relative to evaporating temperatures. Five additional plots, for the same candidates plus R-134a, map the efficiencies and capacities found in system "drop-in" tests as ratios to those for R-22. The paper concludes that several non-ozone depleting candidates offer performance approaching those of R-22. While most of the candidates resulted in a loss of capacity, efficiency, or both, some yielded improvements in either capacity or efficiency. The paper notes that efforts to standardize the test conditions led to good agreement in the calorimeter tests, but that higher scatter was found in the system tests. The cause is suggested as the result of differences in the specific equipment tested. The paper notes that performance is likely to improve with full optimization of the compressors and equipment for these fluids, but that such optimization is left to the individual companies. It also cites international cooperation as a significant and advantageous accomplishment.

D. S. Godwin and M. S. Menzer (Air-Conditioning and Refrigeration Institute, ARI), **Results of Compressor Calorimeter Tests in ARI's R-22 Alternative Refrigerants Evaluation Program**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 109-118, October 1993 (10 pages with 11 figures, available from JMC as RDB3A33)

D. S. Godwin and M. S. Menzer (Air-Conditioning and Refrigeration Institute, ARI), **Results of Compressor Calorimeter Tests in ARI's R-22 Alternative Refrigerants Evaluation Program**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/-NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 1-18, 1994 (18 pages with 12 figures and 14 tables; 25 page preprint available from JMC as RDB3862)

This paper summarizes results of calorimeter tests to measure performance of alternative refrigerants in compressors for air conditioners, heat pumps, and refrigeration equipment. The tests were performed by companies participating in the Alternative Refrigerants Evaluation Program (AREP) established by the Air-Conditioning and Refrigeration Institute (ARI). The paper reviews the development of AREP and lists the 39 companies participating in this international effort. It also lists the 14 candidate refrigerants selected for testing as potential replacements for R-22. They include R-134a; R-290 (propane); R-717 (ammonia); R-32/125 (60/40); R-32/134a (20/80), (25/75), (30/70), and (40/60); R-32/227ea (35/65); R-125/143a (45/55); R-32/125/134a (10/70/20) [R-407B], (24/16/60), and (30/10/60); and R-32/125/-290/134a (20/55/5/20). The candidates also include four for R-502, namely R-125/143a (45/55), R-32/125/134a (20/40/40) [R-407A]; R-125/143a/134a (10/45/45), and R-125/-143a/134a (44/52/4) [R-404A]. The paper briefly outlines three facets of the program, including calorimeter, drop-in, and heat transfer testing. The test conditions and reporting requirements for the compressor calorimeter tests are outlined. The measured capacities and efficiencies are tabulated as ratios to those for the reference (R-22 and R-502) fluids for 12 of the

candidates. The results also are plotted relative to the evaporating temperatures of the tests, accompanied by an explanation of the data and variances. The paper concludes that several non-ozone depleting candidates offer performance approaching those of R-22 and R-502, and some offer better capacity and/or efficiency. Moreover, performance is likely to improve with full optimization of the compressors for these fluids.

M. Hayano and T. Kobuna (Toshiba Corporation, Japan), **Calorimeter Test of Rotary Compressors with HFC-Blend Refrigerants**, paper 6.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 135-138, December 1994 (4 pages with 12 figures and 1 table; in Japanese with abstract, figures, and table in English; RDB5425)

R-22, R-407C, R-410A, two-cylinder rotary rolling-piston compressor

K. E. Hickman (York International Corporation), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 1, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (10 pages with 6 figures, available from JMC as RDB-3801)

This report provides summary plots based on calorimeter test results for a large semihermetic (accessible hermetic), reciprocating piston compressor. The plots present capacity and input power multipliers, for converting from R-22 to R-134a, as functions of saturated suction and discharge temperatures. One set of figures for operation at 1750 rpm shows the effect on performance of retaining the same motor for both refrigerants, namely oversizing the motor for R-134a. The second set shows the benefits of changing the motor to suit the reduced power requirements with R-134a, by changing the speed from 1750 to 1775 rpm. Modelled compressor data, based on measurements for a single 9.53 cm (3.75") bore and 7.87 cm (3.10") stroke, are presented. The results cover -29 to 21 °C (-20 to 70 °F) saturated suction and 27-68 °C (80-155 °F) saturated discharge conditions.

K. Hossner and H. Renz (Bitzer Kühlmaschinenbau GmbH, Germany), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 15, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (10 pages with 6 figures and 2 tables, available from JMC as RDB3815)

T. Iizuka and A. Ishiyama (Hitachi Limited, Japan), **Reliability of Compressors for HFC-Based Refrigerants**, paper 6.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 139-144, December 1994 (6 pages with 15 figures and 7 tables; in Japanese with abstract, figures, and tables in English; RDB5426)

R-22, R-32, R-125, R-134a, R-32/134a (50/50) and (30/70), and R-407C; polyolester and carbonate lubricants, compatibility

H. Kanno (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 41, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3841)

H. Kanno (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 56, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (10 pages with 2 figures and 1 table, available from JMC as RDB3856)

N. Kanzaki (Kobe Steel, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 43, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (10 pages with 3 tables, available from JMC as RDB3843)

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 67, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 2 tables, available from JMC as RDB3C67)

O. Kataoka (Daikin Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 68, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 3 figures and 2 tables, available from JMC as RDB3C68)

O. Kataoka (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 38, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA,

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January 1993 (12 pages with 4 figures and 1 table, available from JMC as RDB3838)

O. Kataoka (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 39, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 4 figures and 1 table, available from JMC as RDB3839)

G. S. Kazachki (Acurex Environmental Corporation), C. L. Gage, and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Evaluation of HFE-125 as an R-502 Replacement in Supermarket Low Temperature Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 238-247, October 1995 (10 pages with 16 figures and 1 table, available from JMC as RDB5A65)

R-E125, theoretical evaluation, compressor calorimeter tests

G. S. Kazachki (Acurex Environmental Corporation) and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Performance Testing of a Semi-Hermetic Compressor with HFC-236ea and CFC-114 at Chiller Conditions**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 407-411, July 1994 (5 pages with 12 figures, RDB4854)

R-114, R-236ea

G. S. Kazachki (Acurex Environmental Corporation) and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Calorimeter Tests of HFC-236ea as a CFC-114 Alternative and HFC-245ca as a CFC-11 Alternative**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 158-166, October 1993 (9 pages with 7 tables, RDB3A38)

H. Kitayama (Matsushita Refrigeration Company, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 119, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 13 figures and 1 table, available from JMC as RDB-3D19)

rotary rolling-piston compressor

H. Kitayama (Matsushita Refrigeration Company, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 120, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 11 figures and 1 table, available from JMC as RDB-3D20)

scroll compressor

Y. Kiyokawa (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blends R-32/125 (60/40) and R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 35, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (14 pages with 5 figures and 2 tables, available from JMC as RDB3835)

S. Komatsu (Sanden Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a**, Alternative Refrigerants Evaluation Program (AREP) report 146, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB5646)

This report summarizes performance measurements of R-125/143a (45/55) with an unidentified ester lubricant in a rotary, rolling-piston compressor.

S. Komatsu (Sanden Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a**, Alternative Refrigerants Evaluation Program (AREP) report 147, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB5647)

This report summarizes performance measurements of R-404A [R-125/143a/134a (44/52/4)] with an unidentified ester lubricant in a rotary, rolling-piston compressor. Note that the title disagrees with the report on the refrigerant tested.

S. Komatsu (Sanden Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 121, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 tables, available from JMC as RDB3D21)

This report summarizes performance measurements of R-125/143a (45/55) with an unidentified ester lubricant in a rotary, rolling-piston compressor. The test rig is shown schematically. A table presents the evaporating and condensing temperatures and pressures as well as the superheat. It also gives the capacity, input power, and coefficient of performance (COP) normalized to those with R-502 at corre-

sponding conditions. Measurements were made for -30, -25, -20, and -15 °C (-22, -13, -4, and 5 °F) evaporating and 45 °C (113 °F) condensing. The capacities and COPs increased by 1-12% and 13-22%, respectively, with R-125/143a (45/55). The report notes that the discharge temperature seemed to be lower than with R-502.

J. W. Linton, W. K. Snelson, P. F. Hearty, A. R. Triebe (National Research Council, Canada, NRCC) F. T. Murphy, R. E. Low (ICI Klea, UK), and B. E. Gilbert (ICI Klea, USA), **Comparison of R-407C and R-410A with R-22 in a 10.5 kW (3.0 TR) Residential Central Heat Pump**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 1-6, July 1996 (6 pages with 4 figures and 2 tables, RDB6746)

performance comparison for both heating and cooling with partial optimization, concludes that capacities with R-407C and R-410A were 91-101% and 98-107%, respectively of that with R-22 depending on the operating conditions and modifications to the indoor heat exchanger

K. Matsuo (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-32/125 (60/-40)**, Alternative Refrigerants Evaluation Program (AREP) report 114, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 figures and 1 table, available from JMC as RDB3D14)

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Compressor Calorimeter Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 34, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (22 pages with 1 figure and 7 tables, available from JMC as RDB-3834)

This document outlines uniform test procedures used for compressor calorimeter tests for the Japanese Alternative Refrigerants Evaluation Program (JAREP). The procedures were developed and the cooperative program is conducted by the Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), in coordination with the U.S. Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP). The procedure addresses refrigerant blends. It prescribes test conditions (evaporator, condenser, and ambient temperatures as well as superheat and subcooling) for air-conditioning and heat pump applications. It also specifies test conditions (evaporator, condenser, and ambient temperatures as well as suction temperature and subcooling) for medium- and low-temperature applications. The procedure indicates test requirements to measure input power, for the power supply, for verification of blend compositions, and for data presentation. It identifies reference data to be taken with R-22 or R-502, selection of lubricants, and procedures for azeotropes. A single figure illustrates the temperatures points defined by the procedure. Appendices tabulate thermodynamic property data for R-32/134a (30/70) and R-32/125 (60/40). NIST REFPROP version 3 is identified for data for R-125/143a (45/55) and R-404A [R-125/143a/134a (44/52/4)]. The report provides data forms to report general and compressor information as well as the findings. A final table indicates the specific tests and refrigerants to be performed by participating companies. They include Daikin, Hitachi, Kobe Steel, Mayekawa, Matsushita, Matsushita Refrigeration, Mitsubishi Electric, Mitsubishi Heavy, Sanden, Sanyo, Sharp, and Toshiba.

K. W. Mumpower (Bristol Compressors, Incorporated) and M. B. Shiflett (DuPont Fluoroproducts), **Calorimeter Experiments with Suva(R) AC9000**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 61-66, July 1994 (6 pages with 6 figures and 1 table, RDB4811)

R-407C [R-32/125/134a (23/25/52)]

K. W. Mumpower (Bristol Compressors, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (10/70/20)**, Alternative Refrigerants Evaluation Program (AREP) report 4, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (44 pages with 5 figures and 23 tables, available from JMC as RDB3804)

This report summarizes calorimeter test data for R-22 and R-407B [R-32/125/134a (10/70/20)] for a hermetic, reciprocating piston compressor (Bristol Inertia(R) model H25A353CBC). Performance tables, calculated with thermodynamic data supplied by the refrigerant manufacturer, and a revision, based on data from NIST REFPROP 3x, are provided; the latter indicate increased capacity over the former. Raw and regressed performance (capacity, power, current, mass flow, and efficiency) tables are provided for -7 to 13 °C (-20 to 55 °F) evaporating and 27-66 °C (80-150 °F) condensing temperatures, based on 8 °C (15 °F) subcooling and 11 °C (20 °F) superheat. Plots compare the capacity and efficiency of the blend versus R-22. A performance plot depicts the motor characteristics and small shift in the torque range required (and corresponding efficiencies) for the two refriger-

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ants. A table summarizes the blend pressures at test temperatures. Tests were performed with mineral oil (Witco Suniso(R) 3GS). The test conditions and instrumentation accuracy are indicated. The report concludes that the blend yielded significantly higher capacities at condensing temperatures below 54 °C (130 °F), but lower capacities at higher temperatures. Similarly, the blend was less efficient than R-22 except at condenser temperatures below 38 °C (100 °F).

K. Mumpower (Bristol Compressors, Incorporated), **Compressor Calorimeter Test of Refrigerant R-290**, Alternative Refrigerants Evaluation Program (AREP) report 21, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (30 pages with 5 figures and 11 tables, available from JMC as RDB3821)

K. Mumpower (Bristol Compressors, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 54, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (28 pages with 4 figures and 12 tables, available from JMC as RDB3854)

K. Mumpower (Bristol Compressors, Incorporated), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 55, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (32 pages with 4 figures and 13 tables, available from JMC as RDB3855)

R-404A

N. Murata (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 115, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 2 figures and 2 tables, available from JMC as RDB3D15)

R-404A

N. Murata (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 64, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 1 figure and 3 tables, available from JMC as RDB3C64)

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 145, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB4745)

This report summarizes performance measurements of R-134a with an unidentified mineral oil in a reciprocating piston compressor. The test rig is shown schematically. Two tables present evaporating and condensing temperatures and pressures. They also give the capacity, input power, and coefficient of performance (COP) normalized to those with R-22 at corresponding conditions. Measurements were made for -21, -9, and 8 °C (-6, 16, and 46 °F) evaporating and 33, 43, 53, and 57 °C (91, 109, 127, and 135 °F) condensing. Two plots show the dependence of the normalized COPs on the evaporating and condensing temperatures. The COPs decreased by 5-15% with R-134a, and were most sensitive to decreasing evaporating temperature.

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 79, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (10 pages with 3 figures and 3 tables, available from JMC as RDB3C79)

This report summarizes performance measurements of a twin-screw compressor with R-134a and an unidentified polyolester lubricant. The test rig is shown schematically. Two tables present evaporating and condensing temperatures and pressures. They also give the capacity, input power, and coefficient of performance (COP) normalized to those with R-22 at corresponding conditions. Measurements were made for -15, -5, 0, and 7 °C (5, 23, 32, and 45 °F) evaporating and 35 and 45 °C (95 and 113 °F) condensing. Two plots show the dependence of the normalized COPs on the evaporating and condensing temperatures. The COPs decreased by 10% at low evaporating temperatures, but increased by up to 10% at high evaporating temperatures. The decreased slightly with increasing condensing temperature.

T. Nitta (Mitsubishi Heavy Industries, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 141, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (6 pages with 2 figures and 1 table, available from JMC as RDB-4741)

R-404A, ester lubricant, rotary rolling-piston compressor

M. Ozu (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/-**

125/134a (30/10/60) and R-32/125 (60/40), Alternative Refrigerants Evaluation Program (AREP) report 69, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (16 pages with 6 figures and 4 tables, available from JMC as RDB-3C69)

M. Ozu (Toshiba Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 37, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3837)

C. K. Rice and J. R. Sand (Oak Ridge National Laboratory, ORNL), **Compressor Calorimeter Performance of Refrigerant Blends - Comparative Methods and Results for a Refrigerator Freezer Application**, paper CH-93-20-3, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, 1993, pages 1447-1466 (20 pages with 7 figures and 5 tables, RDB3115)

K. Sakaino (Mitsubishi Electric Corporation, Japan), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 77, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (10 pages with 4 figures and 2 tables, available from JMC as RDB3C77)

K. Sakaino (Mitsubishi Electric Corporation, Japan), **Compressor Calorimeter Test of Refrigerant R-134a and Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 42, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (34 pages with 17 figures and 9 tables, available from JMC as RDB3842)

K. S. Sanvordenker (Tecumseh Products Company), **Experimental Evaluation of an R-32/134a Blend as a Near Drop-In Substitute for R-22**, paper DE-93-9-3, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 773-778, 1993 (5 pages with 5 figures and 1 table, RDB3622)

> This paper summarizes evaluation of R-32/134a (30/70) as a substitute for R-22 for use in unitary hermetic compressors. It reviews a cooperative industry effort to test new refrigerants, the Alternative Refrigerants Evaluation Program (AREP), and the author's rationale for selecting the R-32/134a blend for testing (see RDB3802). The paper then summarizes calorimeter tests for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor. Plots present efficiency and capacity ratios, to compare performance for R-32/134a (30.1/69.9) and R-22, as functions of evaporator and condensing temperatures. The ranges covered are -26 to 13 °C (-15 to 55 °F) and 32-66 °C (90-150 °F), respectively. The tests were performed using a fully-formulated, polyolester lubricant. The paper notes that above -12 °C (10 °F) evaporator temperature, the efficiencies of the blend slightly exceed those with R-22. Below this temperature, the blend suffers compared to R-22. The capacity is shown to be slightly lower with the blend at almost all conditions plotted, though the same trend in worse comparative performance is evident at low suction temperatures. The paper then discusses materials compatibility considerations. It presents miscibility diagrams for R-32, R-134a, and the R-32/134a blend in polyolester and a solubility plot to compare R-22 in alkylbenzene against R-32/134a in polyolester. Turning to compatibility, the paper notes that R-134a is relatively benign, but that R-32 behaves more like R-22 in softening and blistering magnet wire. A table compares the effects of R-22, R-32, and R-134a on and their absorption by wire enamel. The discussion concludes that the R-32/134a blend is expected to have less or comparable effect than R-22 alone. The paper notes concern with desiccants, since activated alumina will become fully loaded by absorbing polyolester and commercially-available molecular sieves will adsorb R-32. The paper then address flammability considerations. It notes disagreement on classification of the blend, since it could become flammable at low, -20 °C (-4 °F) ambient conditions or if tested above 80 °C (176 °F). The author indicates an urgent need for consensus on acceptable criteria for flammability. The paper concludes that R-32/134a (30/70) is as close as can be expected to a drop-in replacement for R-22, but that its use could be impeded by the definition of, and therefore potential labeling of the blend as, flammable.

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 181, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, August 1994 (14 pages with 4 figures and 4 tables, available from JMC as RDB-5681)

> This report compares the performance of R-407C to that with R-22 and that with R-32/125/-134a (30/10/60) in an 8.8 kW (2½ ton) hermetic, reciprocating piston compressor (Tecumseh AW5530G). A polyolester (POE) lubricant (Mo-

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bil EAL Arctic(R) 32) was used for these tests, which were performed using secondary refrigerant calorimetry. The report summarizes the evaluation purpose and experimental details. Two tables show the calorimeter parameters for representative evaporator and condenser test conditions. Two additional tables compare the measured capacity and efficiency of R-407C to those of R-22 and R-32/125/134a (30/10/60). Four plots show the capacity and energy-efficiency ratios for the same comparisons as functions of the evaporator and condensing temperatures, for ranges of -12 to 13 °C (10-55 °F) and 32-54 °C (90-130 °F) respectively. The report concludes that R-407C and R-22 have identical capacities at 7 °C (45 °F) evaporating and 54 °C (130 °F) condensing, but that R-407C is more favorable at lower condensing temperatures. Further, R-407C offers marginally lower performance compared to R-32/125/134a (30/10/-60), but the differences are within the range of experimental uncertainty. It recommends further evaluation of R-407C based on its nonflammability compared to the other blend formulation.

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Calorimeter Test of Refrigerant Blends R-32/134a (30/70), R-32/134a (25/75), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 32, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (14 pages with 7 tables, available from JMC as RDB3832)

This report summarizes calorimeter test results for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor (Tecumseh model AW5530F). Tabular data are provided to compare the capacity and efficiency for R-22, R-32/134a (30/70), R-32/134a (25/75) and R-32/125/134a (30/10/60) as functions of evaporator and condensing temperatures. The ranges covered are -15 to 13 °C (5 to 55 °F) and 32-66 °C (90-150 °F), respectively. The last two blends were tested to supplement earlier data (see RDB3802), based on indications that R-32/134a (30/70) might be flammable. The tests were performed with the same compressor and lubricant, a fully-formulated, polyolester (Mobil EAL Arctic(R) 322 R, ISO viscosity grade 22). Four tables compare the measured capacity and efficiency of each blend to that with R-22 and to compare the two R-32/134a blends to each other. These tables show the blend capacities to be slightly lower and efficiencies slightly higher, compared to R-22, for common application conditions of air-conditioners and heat pumps. The composition shift from R-32/134a (30/70) to (25/75) yields consistent further drops in capacity. The author deems the 25/75 blend as not even a *near drop in* substitute, since it would require redesign of the compressor. The ternary blend shows a persistent improvement in both capacity and efficiency compared to R-22, and is described as deserving more attention as a substitute for R-22. An addendum tabulates refrigerant conditions for the condenser, evaporator, subcooled liquid, and compressor inlet, calculated for each blend with NIST REFPROP 3.04a.

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 2, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, August 1992 (22 pages with 10 figures and 4 tables, available from JMC as RDB3802)

This report summarizes calorimeter test results for a nominal 8.8 kW (30,000 Btu/hr), hermetic reciprocating piston compressor (Tecumseh model AW5530F). Plots present efficiency and capacity ratios, to compare performance for R-32/134a (30.1/69.9) and R-22, as functions of evaporator and condensing temperatures. The ranges covered are -26 to 13 °C (-15 to 55 °F) and 32-66 °C (90-150 °F), respectively. The tests were performed using a fully-formulated, polyolester lubricant (Mobil EAL Arctic(R) 322 R, ISO viscosity grade 22). Tables and plots summarize the compressor performance (capacity, input power, current draw, mass flow, and efficiency) and coefficients per ARI standard 540-91. The report notes that above -12 °C (10 °F) evaporator temperature, the efficiencies of the blend exceed those with R-22 by less than 5%. Below this temperature, the blend suffers compared to R-22. The effect is described as real, because the compression ratios are significantly higher, but exaggerated, because there may be large errors in measurements at these conditions. The capacity is shown to be slightly lower with the blend at almost all conditions plotted. The report also notes that the same gain in efficiency was not found for a different compressor, using thermodynamic data from a separate source (NIST REFPROP 3.04a versus DuPont Chemicals data), though the trends are the same. (also see RDB3622)

N. Sawada (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 143, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (12 pages with 5 figures and 1 table, available from JMC as RDB-4743)

R-407C, polyolester lubricant, rotary rolling-piston compressor

N. Sawada (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 116, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 4 figures and 1 table, available from JMC as RDB-3D16)

K. Sawai (Matsushita Electric Industrial Company Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 72, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (10 pages with 4 figures and 2 tables, available from JMC as RDB3C72)

M. B. Shiflett and A. Yokozeki (DuPont Fluoroproducts), **Compressor Calorimeter Experiments on R-502 and R-22 Alternatives**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 401-406, July 1994 (6 pages with 7 figures, RDB4853)

R-404A [R-125/143a/134a (44/52/4)], R-407C (R-32/125/134a (23/25/52)]

H. W. Sibley (Carrier Corporation), **Compressor Calorimeter Tests of Refrigerant Blends R-32/-125/134a (30/10/60), R-32/134a (25/75), R-125/143a (45/55), and R-32/125 (60/40); and Drop-In Tests of Refrigerant Blends R-32/125/-134a (30/10/60), R-32/134a (25/75), R-125/143a (45/55), and R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 22, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (34 pages with 6 figures and 19 tables, available from JMC as RDB3822)

K. Tojyo (Mitsubishi Electric Corporation, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 78, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 1 figure and 2 tables, available from JMC as RDB3C78)

R-404A

Y. Seyama (Sanyo Electric Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 171, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1994 (10 pages with 3 figures and 1 table, available from JMC as RDB-5671)

R-404A with an unidentified ester lubricant compared to R-22 in a reciprocating piston compressor

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Near-Azeotropic Refrigerant Mixtures as Potential Drop-in Substitutes for R-502**, paper 3695, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 60-68, 1993 (9 pages with 17 figures, RDB3636)

J. P. Soley (Unidad Hermética, S.A., Spain), **Compressor Calorimeter Test of Refrigerant Blend R-125/143a/134a (45/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 158, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1994 (8 pages with 2 figures and 1 table, available from JMC as RDB5658)

This report compares the measured performance of R-404A and an unidentified polyolester (POE) lubricant to that of R-502 and mineral oil. The tests were made with a reciprocating-piston compressor (Unidad Hermética model MR22FB). The document lists the compressor characteristics and presents the test conditions and results in a table. Plots show the performance with R-404A and R-502. The capacity was approximately 4% lower with R-404A at the lowest evaporator temperature, -40 °C (-40 °F), but increased to 10% higher at -10 °C (14 °F). The efficiency was lower by 9 and 7% at the same two points for condensing at 55 °C (131 °F).

J. P. Soley (Unidad Hermética, S.A., Spain), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 23, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (10 pages with 6 tables, available from JMC as RDB3823)

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **R-22 Alternative Refrigerants: Performance in Unitary Equipment**, paper DE-93-9-4, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 779-785, 1993 (7 pages with 1 figure and 3 tables, RDB3623)

K. Tojo (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-125/143a/-134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 140, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (6 pages with 2 figures and 1 table, available from JMC as RDB4740)

R-404A, scroll compressor

K. Tojo (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-32/125/134a**

please see pages 6-8 for ordering information

(23/25/52), Alternative Refrigerants Evaluation Program (AREP) report 153, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 2 figures and 1 table, available from JMC as RDB4753)

R-407C with an unidentified polyolester lubricant, rotary rolling-piston compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (23/25/53)**, Alternative Refrigerants Evaluation Program (AREP) report 144, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 4 figures and 2 tables, available from JMC as RDB4744)

R-407C, rotary, rolling-piston compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 117, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 1 table, available from JMC as RDB3D17)

rotary, rolling-piston compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 118, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 1 table, available from JMC as RDB3D18)

scroll compressor

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 36, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 3 figures and 1 table, available from JMC as RDB3836)

H. Yasuda (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 57, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (6 pages with 2 figures and 1 table, available from JMC as RDB3C57)

This report summarizes calorimeter tests of R-134a in a 1-10 kW (0.3-2.8 ton) rotary, rolling-piston compressor using an unidentified polyolester (POE) lubricant. The charge and lubricant quantities, motor characteristics, and test conditions are indicated. A table presents evaporator and condenser temperatures and pressures along with compressor speed and discharge temperature. The capacity, input, and efficiency are tabulated relative to performance with R-22. Plots compare the coefficient of performance (COP) and capacity ratio at 46 °C (115 °F) for compressor speeds of 2000-6000 rpm and for evaporating temperatures of 5.5-11 °C (42-52 °F). The efficiency and capacity are indicated to be approximately 5-8% and 32-38% lower, respectively.

H. Yasuda (Hitachi, Limited, Japan), **Compressor Calorimeter Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 40, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 1 figure and 2 tables, available from JMC as RDB3840)

This report summarizes calorimeter tests of R-32/134a (30/70) in a 1-10 kW (0.3-2.8 ton) rotary, rolling-piston compressor and in a 2.5-25 kW (0.7-7.1 ton) scroll compressor using an unidentified polyolester (POE) lubricant. The charge and lubricant quantities, motor characteristics, and test conditions are indicated. A table presents evaporator and condenser temperatures and pressures along with compressor speed and discharge temperature. The capacity, input, and efficiency are tabulated relative to an undescribed base performance, presumed to be that with R-22. The efficiencies and capacities are indicated to be approximately 3-6% and 7-12% lower, respectively, for the rotary compressor and 10% lower to 1% higher and 5-13% lower, respectively, for the scroll compressor. A schematic shows the calorimeter arrangement and instrumentation.

Drop-In Tests

M. Barreau, P. Weiss, and P. Fauvarque (Elf Atochem, S.A., France), **Field Testing Using HCFC-22 Replacements**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 21-30, October 1995 (10 pages with 5 figures and 2 tables, available from JMC as RDB5A42)

R-22, R-407C, R-23/32/134a (4.5/21.5/742) [FX-220], laboratory performance tests

K. Beermann and H. Kruse (Universität Hannover, Germany), **Experiences with the Refrigerant R-134a as a 'Drop-In' Replacement in a Large Water-Water Heat Pump**, *Proceedings of the 1992 International Refrigeration Conference - Energy Ef-*

ficiency and New Refrigerants, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 211-219, July 1992 (9 pages with 4 figures and 4 tables, RDB2723)

J. Berge, S. L. Kwon, and L. Naley (Thermo King Corporation), **Drop-In Test of Refrigerant Blends R-125/143a (45/55) and R-125/143a (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 156, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (14 pages with 8 figures and 10 tables, available from JMC as RDB4756)

R-125/143a (45/55) and R-125/143a (50/50) with an unidentified polyolester compared to R-502 with an unidentified alkylbenzene and with an unidentified polyolester in a transport refrigeration unit with a reciprocating piston compressor

J. Berge, S. L. Kwon, and L. Naley (Thermo King Corporation), **Drop-In Test of Refrigerant Blends R-32/125/143a (10/45/45) and R-32/125/134a (20/40/40)**, Alternative Refrigerants Evaluation Program (AREP) report 87, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 4 figures and 2 tables, available from JMC as RDB3C87)

R-32/125/143a (10/45/45) and R-407A

J. Berge, S. L. Kwon, and L. Naley (Thermo King Corporation), **Drop-In Test of Refrigerant Blends R-125/143a/134a (44/52/4)** [R-404A] **and R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 51, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (12 pages with 4 figures and 5 tables, available from JMC as RDB3851)

D. Clodic (École des Mines de Paris, France), **Comparison of Performance between R404A and AZ50 Used in Commercial Refrigeration**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 73-78, July 1994 (6 pages with 1 figure and 2 tables, RDB4813)

R-404A [R-125/143a/134a (44/52/4)], R-507A [R-125/143a (50/50), AZ-50], R-502

M. S. Collins, **An Experimental Study of the Performance of R-32/134a, R-32/125/134a, and R-134a as Drop-In Replacements for R-22 in Air Conditioning Applications**, MS thesis, Iowa State University of Science and Technology, Ames, IA, 1994 (RDB6337)

drop-in performance tests

S. W. Crown, **An Experimental Study of Thermal Performance of R-134a and Refrigerant Blends in an Air Conditioning System**, PhD dissertation, Iowa State University of Science and Technology, Ames, IA, 1993 (RDB6338)

performance comparison of R-134a and refrigerant to R-12

S. W. Crown, H. N. Shapiro, M. B. Pate (Iowa State University of Science and Technology), **A Comparison Study of the Thermal Performance of R-12 and R-134a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 187-196, July 1992 (10 pages with 11 figures and 2 tables, RDB2720)

This paper compares the performance of a 10 kW (3 ton) refrigeration system with R-134a to R-12. The equipment tested, instrumentation, and test conditions are described. Both the capacity and coefficient of performance (COP) are plotted as functions of the condenser water temperature for representative evaporator temperatures. COP and capacity ratios for R-134a to R-12 are similarly plotted with varying R-134a charges. System performance was shown to be less sensitive to the charge for R-12. Experimental results show that R-134a yielded higher efficiency and cooling capacity for almost all tests, especially with subcooling of 5.6-7.5 °C (10-15 °F). COPs are compared to pressure ratios for the two refrigerants, leading to a conclusion that the system can operate at a higher pressure ratio with R-134a and yet have a higher COP than with R-12. The effects of operating conditions are presented in detail.

S. Corr, B. E. Gilbert, R. Low, F. T. Murphy (ICI Klea), and G. Davies (Cadbury Limited), **Trials with Zeotropic Refrigerants as Replacements for R-22 in an Instrumented Glycol/Water Chiller**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 13-18, July 1994 (6 pages with 6 figures, RDB4803)

R-32/134a (25/75), R-32/134a (30/70), R-32/-125/134a (30/10/60), R-407C [R-32/125/134a (23/25/52)]

J. L. Cox (Rheem Manufacturing Company), **Drop-In Test of Refrigerant Blend R-32/134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 25, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, November 1992 (6 pages with 3 tables, available from JMC as RDB3825)

ETL Testing Laboratory, Incorporated, **Drop-In Test of Refrigerant R-290 (Propane)**, Alternative Refrigerants Evaluation Program (AREP) report 33,

please see pages 6-8 for ordering information

Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (28 pages with 17 tables, available from JMC as RDB3833)

C. Ellis, O. Hanson, and L. J. Van Essen (Lennox Industries, Incorporated), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 177, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, July 1994 (6 pages with 2 tables, available from JMC as RDB5677)

R-32/125 (60/40) compared to R-22 both with an unidentified ester lubricant in a 10.6 kW (3 ton), split-system heat pump using a scroll compressor in both the cooling and heating modes

J. N. Friedman, **Experimental Evaluation of Alaskan Air Conditioning Company's Mixed Refrigerant R-176**, Carrier Corporation, Syracuse, NY, 17 August 1984 (13 pages with 2 figures and 4 tables, available from JMC as RDB1B01)

The measured performance of a zeotropic ternary blend, R-22/12/142b (25/15/60) is compared to that of R-22 for two residential heat pumps. The units tested included an air-to-water heating-only model and an air-to-air heating-and-cooling model. The charge and expansion device orifice (Accurator(R) piston size) were optimized for capacity and efficiency. The heating capacity and coefficient of performance (COP) were approximately 52 and 15% lower, respectively, with the refrigerant blend than with R-22 in the air-to-water heat pump. The heating and cooling capacities were approximately 35 and 46% lower, respectively, in the air-to-air heat pump, but the efficiency increased by approximately 10% in the cooling mode and was nearly the same for heating. The test procedures and conditions are described in the report. The study concluded that the mixture is not a viable replacement in Carrier heat pump systems operating in the heating mode. Additional testing is recommended to determine if increases in efficiency can be achieved with the mixture in the cooling mode, based on further capillary tube and refrigerant charge optimization, despite the decreased cooling capacity.

K. Furuhama (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 172, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (16 pages with 4 figures and 7 tables, available from JMC as RDB5672)

R-407C with an unidentified ester lubricant compared to R-22 with mineral oil in an air-to-air, multicoil heat pump using an adjustable-speed rotary, rolling piston compressor in both the cooling and heating modes; composition shift

D. S. Godwin, **Results of System Drop-In Tests in ARI's R-22 Alternative Refrigerants Evaluation Program**, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1 December 1993 (10 pages with 7 figures and 2 tables, available from JMC as RDB4868)

P. R. Glamm and E. F. Keuper (The Trane Company), **Drop-In Test of Refrigerant R-134a and Refrigerant Blends R-32/125/134a (24/16/60), R-32/134a (30/70), and R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 16, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (14 pages with 6 tables, available from JMC as RDB3816)

I. Haider, K. E. Simmons, K. Kim, and R. K. Radermacher (University of Maryland), **Independent Compartment Temperature Control of a Modified Lorenz-Meutzner-Cycle Refrigerator with a Hydrocarbon Mixture**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 206-215, October 1995 (10 pages with 5 figures and 2 tables, available from JMC as RDB5A61)

R-12, R-290/600 (70/30)

Y. Hara (Sanyo Electric Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 74, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (14 pages with 9 figures and 3 tables, available from JMC as RDB3C74)

P. F. Hearty, J. W. Linton, A. R. Triebe, W. K. Snelson (National Research Council, Canada, NRCC), **Performance Comparison of R-502 Replacements in a Commercial Scale Low Temperature Refrigeration Plant with a Two Stage Compressor**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 51-56, July 1996 (6 pages with 4 figures and 1 table, RDB6757)

R-404A, R-407A, R-507A

P. F. Hearty, J. W. Linton, W. K. Snelson, and A. R. Triebe (National Research Council, Canada, NRCC), **Drop-In Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 52, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 25 February 1993 (18 pages with 4 figures and 4 tables, available from JMC as RDB3852)

R-404A and R-502

F. Hill (Dunham-Bush, Incorporated), **Drop-In Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 50, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (6 pages, available from JMC as RDB3850)

This report summarizes a performance test of R-134a in a water-cooled chiller (Dunham-Bush model WCFX20), to compare capacity and efficiency to those with R-22 for a drop-in (no components changed) substitution. This chiller employs two twin screw compressors (Dunham-Bush model 1210BHF6W4JBJ0C), a flooded evaporator with interior and exterior tube enhancement, and a shell-and-tube condenser with integral-finned tubes. R-22 was tested with an unidentified mineral oil as a reference; R-134a was tested with a lubricant containing 85% unidentified ISO 150 polyolester and 15% mineral oil. The mineral oil content in the latter was residual from the first test. A table compares entering and leaving water temperatures and flow rates in the heat exchangers, capacity, input power, approach temperatures, subcooling and superheat. The report notes that the capacity and input power with R-134a were 68.0 and 68.4%, respectively, of those with R-22. The efficiency was, therefore, unchanged within the instrumentation accuracy. Oil return and evaporator performance were both satisfactory in the R-134a test despite the residual mineral oil.

T. Itami (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 12, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (5 pages with 2 tables, available from JMC as RDB3812)

H. Kanno (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-125/143a**, Alternative Refrigerants Evaluation Program (AREP) report 47, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (20 pages with 6 figures and 9 tables, available from JMC as RDB3847)

N. Kanzaki (Kobe Steel, Limited, Japan), **Drop-In Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 109, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1993 (4 pages with 2 tables, available from JMC as RDB3D09)

This report summarizes a performance test of R-134a in a 40 hp, 207 kW (59 ton), water-cooled chiller with a twin-screw compressor and shell-and-tube heat exchangers. The results are tabulated for R-134a along with corresponding data for R-22. Both refrigerants were tested with an unidentified polyolester lubricant. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show decreases of 34.3 and 29.0% in capacity and increases of 2.1 and 5.1% in efficiency, with and without an economizer, compared to R-22.

H. Kasahara, M. Nakamura, and S. Watabe (Mitsubishi Heavy Industries, Limited, Japan), **Packaged Air Conditioner with a Refrigerant Mixture of R-32/125/134a**, paper 2.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 33-37, December 1994 (5 pages with 5 figures and 4 tables; in Japanese with abstract, figures, and tables in English; RDB5407)

R-32/125/134a (30/10/60) and (23/25/52) [R-407C]

M. Katayama (Fujitsu General Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/-134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 170, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (16 pages with 9 figures and 2 tables, available from JMC as RDB5670)

R-407C with an polyolester lubricant (JS-4156A1) compared to R-22 with mineral oil (Witco Suniso(R) 4GSD) in a room heat pump, with and adjustable-speed rotary, rolling-piston compressor, in both the cooling and heating modes

M. Katayama (Fujitsu General Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/-40)**, Alternative Refrigerants Evaluation Program (AREP) report 113, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1993 (10 pages with 5 figures and 2 tables, available from JMC as RDB3D13)

T. Kato (Sanden Corporation, Japan), **Drop-In Test of Refrigerant Blends R-125/143a (45/55) and R-32/125/134a (10/45/45)**, Alternative Refrigerants Evaluation Program (AREP) report 112, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 tables, available from JMC as RDB3D12)

This report summarizes performance tests of two refrigerant blends, R-125/143a (45/55) and R-32/125/134a (10/45/45), in a 175 W (600 Btu/hr) chest freezer with a rotary, rolling-piston compressor. The results are tabulated along

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with corresponding data for a mixture of R-502 and propane, R-290/22/115 (6.0/45.9/48.1) identified as "R-502P". The blends were tested with an unidentified ester lubricant and R-502 with an unidentified mineral oil. Tests were performed at an ambient temperature of 34.7 °C (94.5 °F). Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show decreases of 8.4 and 6.3% in efficiency for the binary and ternary blends, respectively, compared to "R-502P". The report notes that the discharge pressure with the two alternatives was slightly higher than with "R-502P", but the discharge temperature was slightly lower. It also suggests that the charge quantity can be reduced with the alternatives.

K. Kawamura (Mayekawa Manufacturing Company, Limited, Japan), **Drop-In Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 14, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (2 pages with 1 table, available from JMC as RDB-3814)

H. Kitayama (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 111, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (16 pages with 16 figures and 4 tables, available from JMC as RDB3D11)

Y. Kiyokawa (Sanyo Electric Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 44, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (10 pages with 2 figures and 4 tables, available from JMC as RDB3844)

S. Komatsu and K. Yamamoto (Sanden Corporation, Japan), **Performance of Chest Freezer with R125/143a/134a**, paper 3.5, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 68-71, December 1994 (4 pages with 13 figures and 2 tables; in Japanese with abstract, figures, and tables in English; RDB5414)

R-125/143a/134a (44/52/4) [R-404A]

S. Komatsu (Sanden Corporation, Japan), **Drop-In Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 173, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (10 pages with 5 figures and 1 table, available from JMC as RDB5673)

This report compares performance measurements of R-404A with an unidentified ester lubricant to those for R-502 with mineral oil in a chest freezer using a rotary, rolling-piston compressor.

S. N. Kondepudi (Electric Power Research Institute, EPRI), **Drop-In Testing of R-32 Blends as R-22 Alternatives in a Split-System Air Conditioner**, paper DE-93-9-2 (3733), *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 406-413, 1993 (8 pages with 2 figures and 8 tables, RDB3621)

This paper summarizes capacity and efficiency tests of five zeotropic blends in a 2 ton, split-system air conditioner. The refrigerants included three mixtures of R-32 and R-134a, with 20, 30, and 40% R-32 by mass, and two of R-32 and R-152a, with 30 and 40% R-32. The five blends were selected as candidate R-22 replacements based on prior studies. Testing was performed by an independent testing laboratories, and confirmed by separate tests by the manufacturer of the air conditioner; both were performed in accordance with standard rating test procedures. The fluids were tested under near "drop-in" conditions, without equipment modification except for substitution of a manual expansion device and replacement of the refrigerant and lubricant. An unidentified polyolester lubricant was used. The paper summarizes the need for R-22 alternatives, candidates identified in prior and ongoing studies, testing and equipment details, and measured results. It also compares the findings to simulations. Measured capacity and efficiency fell below simulated results, but the test system had not been optimized for the alternative refrigerants. The blends tested generally showed steady-state efficiency to be within 2% of that of R-22, but offered lower capacity. R-32/134a (40/60) was identified as a promising retrofit fluid since it yielded steady state efficiency and capacity 1% higher than R-22, though the seasonal performance (SEER) was 1% lower. The paper concludes with recommendations to better evaluate the refrigerant blends tested.

S. N. Kondepudi (Drexel University), **Experimental Investigation of R-22 Replacement Refrigerants in a Split-System Residential Air Conditioner**, report EPA/430/R-92/007, U.S. Environmental Protection Agency (EPA), Washington, DC, September

1992 (30 pages with 4 figures and 12 tables, RDB-2B09)

This report summarizes capacity and efficiency tests of five zeotropic blends in a Lennox, 2 ton, split-system air conditioner. The refrigerants included three mixtures of R-32 and R-134a, with 20, 30, and 40% R-32 by mass, and two of R-32 and R-152a, with 30 and 40% R-32. The five blends were selected as candidate R-22 replacements based on prior studies. Testing was performed by ETL Testing Laboratories, and confirmed by independent tests by Lennox Industries; both were performed in accordance with standard rating test procedures. The fluids were tested under near "drop-in" conditions, without equipment modification except for substitution of a manual expansion device and replacement of the refrigerant and lubricant. An unidentified polyolester lubricant was used. The report summarizes the need for R-22 alternatives, candidates identified in prior and ongoing studies, testing and equipment details, and measured results. It also compares the findings to simulations. Measured capacity and efficiency fell below simulated results, but the test system had not been optimized for the alternative refrigerants. The blends tested generally showed steady-state efficiency to be within 2% of that of R-22, but offered lower capacity. R-32/134a (40/60) was identified as a promising retrofit fluid since it yielded steady state efficiency and capacity 1% higher than R-22, though the seasonal performance (SEER) was 1% lower.

M. Kurachi (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/-134a (25/75)**, Alternative Refrigerants Evaluation Program (AREP) report 75, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (16 pages with 11 figures and 1 table, available from JMC as RDB3C75)

M. Kurachi (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/-125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 169, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (14 pages with 12 figures and 3 tables, available from JMC as RDB5669)

R-407C with an unidentified polyolester (POE) lubricant compared to R-22 with mineral oil in an air-to-air, multicoil heat pump using a scroll compressor in both the cooling and heating modes; internal composition change

M. Kurachi (Matsushita Refrigeration Company, Japan), **Drop-In Test of Refrigerant Blend R-32/-125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 76, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (16 pages with 11 figures and 1 table, available from JMC as RDB3C76)

X-Z. Leng (Beijing Research Institute of Household Electric Appliances, China), **Testing Study About HFC-152a and the Mixture of HFC-152a with HCFC-22**, publication unknown, circa 1991 (8 pages with 8 figures and 1 table, available from JMC as RDB2513)

This paper analyzes use of R-152a and blends of R-152a with R-22, as substitutes for R-12 for domestic refrigerator/freezers. The freezer and food-section temperatures, suction and discharge pressures, run time, power, and energy use are compared for R-12, R-152a and three compositions of R-22/152a, namely 14, 22, and 33% by mass. These data were measured using an instrumented refrigerator/freezer (Hang-Tian model BCD-177A), reported as having the highest efficiency in the Chinese market. A blend containing approximately 14% R-22 by mass offered the lowest energy use, 8.2% less than with R-12; R-152a alone resulted in a savings of 1.0%. The study found that the freezer evaporator needs to be enlarged to use R-152a. Additional tests were performed changing the lubricant from mineral oil to an alkylbenzene, resulting in slightly higher energy use; compatibility was not addressed. The impacts of leakage were assessed based on compliance with the Chinese requirement (standard GB 8059.1-3.86) that refrigerant losses not exceed 0.5 g/yr (0.02 oz/yr). Assuming that all refrigerant lost is R-22, an R-22/152a (30/70 by mass) blend would fractionate to 25.3% R-22, improving performance slightly. The paper concludes that R-22/152a results in lower energy use than for R-12 without change in construction or performance.

A. T. Lim (Inter-City Products Corporation), **Drop-In Test of Refrigerant Blends R-32/125/134a (10/-70/20)** [R-407B], **R-32/125/290/134a (20/55/5/-20), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 24, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, March 1993 (8 pages with 5 tables, available from JMC as RDB3824)

M. Lindsay and D. Shapiro (Hussmann Corporation), **Drop-In Test of Refrigerant Blend R-125/-143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 58, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (8 pages with 3 figures and 1 table, available from JMC as RDB3C58)

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This report summarizes drop-in testing of R-404A in a low- and two medium-temperature display cases (Hussmann G6FA129 and FHMG12U, respectively). They were tested with an indoor condensing unit, including a Copeland Discus (reciprocating semi-hermetic) compressor, and an air-cooled condenser. The lubricant used both for the R-404A and R-502 reference tests was Mobil EAL Arctic(R) 22. The test setup is described and shown schematically. The results are tabulated and plotted both for medium- and low-temperature display cases. The relative power use was 10% higher with R-404A at 35 °C (95 °F) outdoor temperature, but nearly the same or 4% lower at 10 °C (50 °F). Comparative run time data also are provided.

J. W. Linton, W. K. Snelson, A. R. Triebe, and P. F. Hearty (National Research Council, Canada, NRCC), **System Performance of Some Long Term R-502 Replacements**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 383-388, July 1994 (6 pages with 8 figures and 2 tables, RDB4850)

R-404A [R-125/143a/134a (44/52/4)], R-407A [R-32/125/134a (20/40/40)], R-407B [R-32/-125/134a (10/70/20)], R-507A [R-125/143a (50/50)]

J. W. Linton, W. K. Snelson, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **System Performance of Near Azeotropic Mixtures of R-134a and R-152a**, paper DE-93-9-1 (3732), *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 400-405, 1993 (6 pages with 9 figures, RDB3620)

J. W. Linton, W. K. Snelson, and P. F. Hearty (National Research Council, Canada, NRCC), **Effect of Condenser Liquid Subcooling on System Performance for Refrigerants CFC-12, HFC-134a, and HFC-152a**, paper 3558, *Transactions* (Winter Meeting, Anaheim, CA, 25-29 January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 160-166, 1992 (7 pages with 12 figures and 1 table, RDB4432)

R-12, R-134a, R-152a

B. Y. Liu, M-L. Tomasek, and R. K. Radermacher (University of Maryland), **Experimental Results with Hydrocarbon Mixtures in Domestic Refrigerator/Freezers**, paper CH-95-24-1, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 1415-1421, 1995 (7 pages with 6 figures and 1 table, RDB5244)

R-12, R-290/600 (70/30)

Z. Liu, I. Haider, and R. K. Radermacher (University of Maryland), **Simulation and Test Results of Hydrocarbon Mixtures in a Modified-Lorenz-Meutzner-Cycle Domestic Refrigerator**, *HVAC&R Research*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 1, number 2, pages 127-142, April 1995 (16 pages with 6 figures and 6 tables, RDB5C08)

R-22/123, R-290/600, R-290/41-12 (R-290/n-C5)

M. Masuda (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 59, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (6 pages with 4 figures and 2 tables, available from JMC as RDB3C59)

R-22 with mineral oil (Witco Suniso(R) 4GDID), R-32/134a (30/70) with an unidentified ester lubricant; room air conditioner/heat pump, rotary rolling-piston compressor

A. Matsui (Kobe Steel, Limited, Japan), **As to Drop-In Test of R-32/125/134a in Screw Chiller**, paper 3.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 47-51, December 1994 (5 pages with 10 figures and 1 table; in Japanese with abstract, figures, and table in English; RDB5410)

This paper summarizes a drop-in performance test of R-32/125/134a (32/10/60) (sic, probably 30/10/60) in a water-cooled chiller, with and without an economizer. The zeotropic hydrofluorocarbon (HFC) blend yielded a 10% lower coefficient of performance (COP) than R-22, attributed to degraded heat exchanger performance. Plots show the chiller configuration, flow schematic, compressor volumetric and adiabatic efficiency as functions of the entering temperature, and the overall heat transfer coefficients, heat fluxes, and superheat for the condenser and evaporator. Additional plots compare the R-22 and blend capacities, input powers, and COPs as functions of the chilled water temperature both with and without a single-stage economizer. Ratios are tabulated for these data at 7 °C (45 °F). The economizer appears to increase capacity and performance by

5.7 and 3.4%, respectively, with the blend and 3.4 and 1.7% with R-22.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 110, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 1 figure and 4 tables, available from JMC as RDB3D10)

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 6, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3806)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 2.7 kW cooling (3/4 ton) air-to-air, room heat pump using a variable-speed, rotary rolling-piston compressor. R-22 was tested with ISO viscosity grade 56 mineral oil; the blend was tested with an ISO viscosity grade 32 ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser exit, inlets to the expansion device and evaporator, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 8 and 3% decreases for the blend in heating capacity and efficiency at the same speeds and 6% reductions in cooling capacity and efficiency. With speed increases of 8% for heating and 12% for cooling, to restore the capacities with the blend, the efficiencies were reduced by 10 and 12% in the heating and cooling modes, respectively, compared to the R-22 reference.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 7, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3807)

Two tables summarize tests to compare performance of R-22 and R-134a through drop-in tests in a 3.1 kW cooling (0.9 ton) air-to-air, room heat pump using a variable-speed, rotary rolling-piston compressor. R-22 was tested with an ISO viscosity grade 56 mineral oil; R-134a was tested with an ISO viscosity grade 15 ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser exit, expansion device inlets and outlets, and evaporator inlets and outlets. Data are presented for both the heating and cooling modes. The results with R-134a show a 33% capacity decrease and 14% efficiency increase in the heating mode, at the same speeds, and 25% capacity decrease and 20% efficiency increase in the cooling mode. With speed increases of 33% for heating and 64% for cooling, to partially restore the capacities with R-134a, the four corresponding changes were decreases of 6, 6, 12, and 27%, respectively.

K. Matsuo (Hitachi, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 8, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3808)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 7.0 kW cooling (2 ton) air-to-air, packaged heat pump using a scroll compressor. R-22 was tested with a mineral oil; the blend was tested with an unidentified ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the suction line and compressor shell outlets, condenser inlet, saturated vapor and liquid states in the condenser, condenser and liquid line exits, expansion device outlet, evaporator inlet, saturated vapor state in the evaporator, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 3 and 6% decreases for the blend in heating capacity and efficiency and 1 and 2% reductions in cooling capacity and efficiency, respectively.

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Drop-In Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 60, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (14 pages with 2 figures and 4 tables, available from JMC as RDB3C60)

This document outlines uniform test procedures to be used for drop-in performance tests for the Japanese Alternative Refrigerants Evaluation Program (JAREP). The procedures were developed and the cooperative program is conducted by the Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), in coordination with the U.S. Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP). The procedure addresses three replacement candidates for R-22 including R-32/125 (60/40), R-32/134a

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(30/70), and R-134a. It identifies three systems for testing, including a 1 HP "room air conditioner (RAC)" (split-system heat pump with inverter-driven hermetic rotary, rolling-piston compressor), a 3-5 HP "packaged air conditioner (PAC)" (split-system heat pump with hermetic scroll compressor), and a 40 HP chiller (shell-and-tube heat exchangers with a screw compressor). Photographs are provided to illustrate the first two system types. The report then identifies the participating companies and specific systems and refrigerants to be tested. They companies include Daikin, Hitachi, Mayekawa (Mycom), Matsushita (Panasonic), Mitsubishi Heavy, Sanyo, and Toshiba. The report specifies indoor and outdoor dry and wet bulb temperatures for testing, based on the JIS C9612-1989 test standard for RACs. It also prescribes use of thermophysical property data from Daikin Industries for calculations, with compositions verified by gas chromatography. It identifies 5 test points to be measured in the refrigeration cycle and three to be calculated. Tables are provided to report both heating and cooling performance data, including reporting of performance relative to that with R-22, as a reference.

N. Murata (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 65, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (12 pages with 7 figures and 3 tables, available from JMC as RDB3C65)

T. Nagai (Sanyo Electric Company. Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 13, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3813)

T. Nitta (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 136, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 1 figure and 4 tables, available from JMC as RDB4736)

This report summarizes performance measurements of R-407C, with an unidentified ester lubricant, in a 2.4 kW (8300 Btu/hr) split-system room air conditioner (RAC) / heat pump with a scroll compressor. The results are compared to corresponding data for R-22 with alkylbenzene. A schematic illustrates the refrigerant circuit. The data for the cooling and heating modes are summarized in two tables. The charge and lubricant quantities are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show decreases of 7 and 1% in the cooling and heating modes, respectively, with corresponding decreases in the coefficient of performance (COP) of 13 and 12%. The report notes that the discharge pressure with R-407C is 6-13% higher than with R-22, but the discharge temperature is 0.5-3 °C (0.9-5.4 °F) lower.

M. Ohta (Mitsubishi Heavy Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 5, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (5 pages with 2 tables, available from JMC as RDB3805)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 12.6 kW cooling (3.6 ton) packaged, air-to-air heat pump using a scroll compressor. R-22 was tested with an alkylbenzene lubricant (ISO viscosity grade 32); the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, saturated condensing vapor and liquid conditions, condenser exit, liquid line inlet and exit, inlets to the expansion device and evaporator, saturated evaporating condition, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results show 4 and 1% decreases for the blend in heating capacity and efficiency and 7 and 6% reductions in cooling capacity and efficiency; the latter were lowered to 4 and 2%, respectively, with optimized charge and capillary-tube selection.

H. Ohnishi (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blends R-32/134a (25/75), R-32/134a (30/70), R-32/134a (40/60), and R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 66, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (12 pages with 9 tables, available from JMC as RDB3C66)

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/-10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 70, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 3 tables, available from JMC as RDB-3C70)

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 71, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 4 tables, available from JMC as RDB3C71)

M. Ozu (Toshiba Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 46, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (10 pages with 4 tables, available from JMC as RDB3846)

K. Sakuma (Mitsubishi Electric Corporation, Japan), **Drop-In Test of Refrigerant R-134a and Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 48, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (28 pages with 4 figures and 18 tables, available from JMC as RDB-3848)

S. M. Sami and B. Song (University of Moncton, Canada), **Performance Evaluation of a New Four-Component HFC Blend in a Vapour-Compression Heat Pump System**, *Energy*, Pergamon Press Limited / Elsevier Sciences Limited, UK, volume 21, number 5, pages 361-369, 1996 (9 pages with 13 figures and 3 tables, RDB6745)

performance test results for R-32/125/143a/134a (40/25/25/10), proposed as a replacement for R-502; laboratory test rig and comparative tests for R-407B, R-502, and R-507A are outlined; plots show the comparative heating and cooling coefficients of performance (COP), capacities, compression pressure ratios, discharge temperatures, and mass flow rates, as functions of the evaporator temperature; also presents comparative tests of the tetrary blend and R-502 performed by the National Research Council of Canada (NRCC)

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **A Drop-In-Replacement Blend for Air-Refrigerant Equipment**, *International Journal of Energy Research*, John Wiley and Sons, Limited, volume 20, pages 787-796, 1996 (20 pages with 10 figures and 1 table, RDB6744)

performance evaluation of R-23/22/152a in three different compositions (not disclosed in this paper) identified as *NARM-12*, *NARM-22*, and *NARM-502*; outlines the experimental approach and provides plots of the coefficients of performance (COPs) in a prototype air-to-air heat pump, home refrigerator, and four commercial refrigeration machines; a plot compares the pressure-temperature relationships for R-22, *NARM-502*, and R-502; concludes that the three tested blends offer similar pressure-temperature relations to R-12, R-22, and R-502, respectively, and potential to enhance performance by 7-30%

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **Performance of Residential Refrigerators with Ternary Blends**, *International Journal of Energy Research*, John Wiley and Sons, Limited, volume 19, pages 631-637, 1995 (RDB6742)

drop-in performance tests of R-22/152a/114 (53/19/28) identified as *MP33*, R-22/152a/124 (47.4/15.7/36.9) identified as [a developmental formulation of] *MP39*, R-23/22/152a (5/65/30) identified as *NARM-12*, R-23/22/124 (5/60/35), identified as *NARM-12/124*, R-23/22/134a (5/-40/55) identified as *NARM-12/134a* in a domestic refrigerator using a mineral oil lubricant; provides plots of and discusses operating parameters and performance; concludes that R-23/22/152a (5/65/30) "could be considered as a 'drop-in replacement' for CFC-12, in domestic refrigerators"

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **Performance Analysis of a Drop-In Replacement Blend for CFC-12, CFC-502, and HCFC-22**, *International Journal of Energy Research*, John Wiley and Sons, Limited, volume 18, pages 49 ff, 1994 (RDB4C16)

R-12, R-22, and R-502 alternatives; zeotropic blends

S. M. Sami, J. Schnotale (University of Moncton, Canada), and J. G. Smale (DuPont Canada Incorporated, Canada), **A Comparative Performance Study of CFC502, HCFC22 and HFC125**, *International Journal of Energy Research*, John Wiley and Sons, Limited, volume 17, pages 143-151, 1993 (9 pages with 12 figures, RDB6741)

drop in performance test of R-125 with comparative measurements for R-22 and R-502 [HCFC/CFC-502] under a range of operating conditions; plots compare the operating parameters of the three refrigerants with both reciprocating piston and scroll compressors; concludes that R-125 degrades performance compared to R-22 as candidate R-502 replacements

J. R. Sand, E. A. Vineyard (Oak Ridge National Laboratory, ORNL), and R. J. Nowak (Purdue University), **Experimental Performance of Ozone-Safe Alternative Refrigerants**, paper 3399, *Transactions* (Annual Meeting, St. Louis, MO, 9-13 June 1990), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 96, part 2, pages 173-182, 1990 (10 pages with 1 figure and 8 tables, RDB4129)

performance comparisons for R-12, R-22, R-32, R-114, R-124, R-125, R-134, R-134a, R-142b, R-

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143, R-143a, R-152a, R-218, and R-C318 at four standard heat pump rating conditions

K. Sawai (Matsushita Electric Industrial Company Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 73, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1993 (8 pages with 1 figure and 4 table, available from JMC as RDB3C73)

M. Seki, A. Osajima, Y. Nakane, H. Sato, K. Watanabe (Keio University, Japan), N. Kagawa (National Defense Academy, Japan), and T. Yajima (Toshiba Corporation, Japan), **Performance of Refrigeration Cycle with R-32/134a and R-32/125 Based on the Reliable Thermodynamic Property Data**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 67-72, July 1994 (6 pages with 6 figures and 2 tables, RDB4812)

M. B. Shiflett (DuPont Fluoroproducts), **HCFC-22 Alternatives for Air Conditioners and Heat Pumps**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 1-6, July 1994 (6 pages with 5 figures, available from JMC as RDB4801)

This paper discusses alternative refrigerants for R-22 in unitary air conditioners and heat pumps, with emphasis on R-407C - R-32/125/134a (23/25/52). The paper notes that while R-134a and R-410A also were in the focus of interest in the Alternative Refrigerants Evaluation Program (AREP), both would require system redesign due to capacity and efficiency differences with R-22. R-407C is suggested as offering the closest performance match to R-22 in existing equipment. The paper notes that R-407C was formulated for similar capacity, highest efficiency, and to be nonflammable under both normal and abnormal operating conditions. The paper then outlines tests of R-407C in an 8.8 kW (2½ ton), air-to-air, split-system heat pump. The paper describes and schematically shows the instrumentation; it also outlines the test procedures. The results are presented and compared for both R-22 and R-407C, with the same reciprocating piston compressor and an unidentified polyolester lubricant. A series of four plots compare capacity, efficiency, compressor discharge temperature and pressure for cooling at 28 and 35 °C (82 and 95 °F) and heating at -8 and 8 °C (17 and 47 °F). The paper also discusses system modifications to improve the capacity and efficiency, including use of a suction line accumulator to allow composition shifting for improved heating capacity. Estimated improvements are discussed with counterflow heat exchangers and a liquid-suction heat exchanger. The paper concludes that R-407C offers similar heating and cooling capacity to R-22 with a 3-4% loss in efficiency. Gains of up to 6% in heating capacity or 8-10% in cooling efficiency and capacity are suggested for optimized systems. DuPont's product name for R-407C is Suva(R) AC9000.

C. N. Shores (York International Corporation), **Drop-In Test of Refrigerant Blend R-32/134a**, Alternative Refrigerants Evaluation Program (AREP) report 134, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (6 pages with 1 table, available from JMC as RDB5645)

R-32/134a (30/70), R-22 for reference, mineral oil, water-cooled reciprocating piston chiller

C. N. Shores and H. B. Ginder (York International Corporation), **Drop-In Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 89, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (4 pages with 2 tables, available from JMC as RDB3C89)

This report summarizes "drop-in" performance tests of R-134a in a water-cooled, centrifugal chiller with a nominal capacity of 3.2 MW (900 tons) for R-22. The report describes the test equipment and conditions. The entering and leaving water temperatures, flow rates, refrigerant pressures and subcooling are tabulated along with comparative R-22 measurements. A second table gives the capacity, input power, and specific power (reciprocal of efficiency) for R-134a normalized to those for R-22. The report concludes that the chiller capacity and efficiency dropped by 30% and 4.5% respectively when run with R-134a. The report discusses these decreases, attributing them to differences in both thermodynamic properties and the operating point in the compressor performance map. R-22 was tested with a mineral oil and R-134a with a polyolester, both unidentified. The impeller speed was held constant between the two refrigerants.

H. W. Sibley (Carrier Corporation), **Drop-In Tests of Refrigerant Blends R-32/125/134a (30/10/60), R-32/125/134a (25/20/55), and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 178, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 2 figures and 6 tables, available from JMC as RDB5678)

R-32/125/134a (30/10/60), (25/20/55), and (23/25/52) [R-407C] with a polyolester (POE) lubricant (Mobil EAL Arctic(R) 32) compared to R-22 with an alkylbenzene (AB) lubricant (Shrieve Zerol(R) 150) in a 0.9 kW (8000 Btu/hr)

window air conditioner (Carrier 51AGA108111) using a hermetic, rotary rolling-piston compressor

H. W. Sibley (Carrier Corporation), **Drop-In Tests of Refrigerant Blends R-32/125/134a (30/10/60) and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 179, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (16 pages with 4 figures and 8 tables, available from JMC as RDB5679)

R-32/125/134a (30/10/60) and (23/25/52) [R-407C] with a polyolester (POE) lubricant (Mobil EAL Arctic(R) 32) compared to R-22 with an alkylbenzene (AB) lubricant (Shrieve Zerol(R) 150) in a 17.6 kW (5 ton) split-system heat pump (Carrier 58YKB060) using a hermetic scroll compressor in both the cooling and heating modes

H. W. Sibley (Carrier Corporation), **Drop-In Tests of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 180, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (10 pages with 2 figures and 4 tables, available from JMC as RDB5680)

R-407C with a polyolester (POE) lubricant (Mobil EAL Arctic(R) 32) compared to R-22 with an alkylbenzene (AB) lubricant (Shrieve Zerol(R) 150) in a 17.6 kW (5 ton) split-system heat pump (Carrier 58YKB060) using a hermetic scroll compressor in the cooling mode with nominal and 30% higher charge of lubricant

W. K. Snelson, J. W. Linton, A. R. Triebe, and P. F. Hearty (National Research Council, Canada, NRCC), **System Drop-In Tests of Refrigerant Blend R-125/R-143a/R-134a (44%/52%/4%) Compared to R-502**, paper 3834, *Transactions* (Winter Meeting, Chicago, IL, 28 January - 1 February 1995), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 1, pages 17-24, 1995 (8 pages with 12 figures, RDB5230)

R-404A [R-125/143a/134a (44/52/4)] and R-502

W. K. Snelson, J. W. Linton, P. F. Hearty (National Research Council, Canada, NRCC), and T. N. Duong (University of Sherbrooke), Canada, **Some Thermodynamic Performance Test Results of Refrigerant 134a**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 344-353, July 1990 (10 pages with 10 figures and 1 table, RDB4433)

K. E. Starner (York International Corporation), **Drop-In Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 88, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (6 pages with 2 tables, available from JMC as RDB3C88)

This report summarizes "drop-in" performance tests of R-134a in two water-cooled chillers with nominal capacities of 1.4 and 2.3 MW (390 and 650 tons) for R-22. Both employed open-drive, screw compressors (Frick). Approximately 39% of the evaporator and condenser tubes were plugged in the larger chiller for R-134a tests, to simulate down-sized heat exchangers. The report describes the test equipment and conditions and provides tabular results and comparative R-22 measurements. The entering and leaving water temperatures, flow rates, refrigerant pressures, and subcooled-refrigerant temperature are provided. A second table gives the capacity, input power, specific power (reciprocal of efficiency), and compressor isentropic and volumetric efficiencies for R-134a normalized to those for R-22. The report concludes that the chiller capacities were 33% lower, isentropic compressor efficiencies 2% lower, volumetric efficiencies 2% higher, and overall efficiency within approximately 2% for R-134a compared to R-22. Even with the reduced heat transfer surface area, the large chiller efficiency fell only slightly, approximately 2%. The R-134a tests were performed with a polyolester lubricant (CPI(R) Soltest(R)).

Y. Sumida (Mitsubishi Electric Corporation, Japan), **Drop-In Test of Refrigerant Blend R-125/143a/-134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 49, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (20 pages with 11 figures and 7 tables, available from JMC as RDB3849)

R-404A

H. Sumimoto (Kobe Steel, Limited, Japan), **Drop-In Test of Refrigerant R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 135, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, November 1993 (4 pages with 1 tables, available from JMC as RDB3D35)

This report summarizes a performance test of R-32/125/134a (30/10/60) in a 40 hp, 207 kW (59 ton), water-cooled chiller with a twin-screw compressor and shell-and-tube heat exchangers. The results are tabulated for R-32/125/-134a (30/10/60) along with corresponding data for R-22. Both refrigerants were tested with an unidentified polyolester lubricant. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of

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the compressor, condenser, expansion device, and evaporator. The results show changes of -1.4 and +4.8% in capacity and decreases of 8.5 and 7.2% in efficiency, with and without an economizer, compared to R-22.

Y. Tanimura (Mitsubishi Electric Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/-125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 137, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (8 pages with 5 figures and 2 tables, available from JMC as RDB4737)

This report summarizes performance measurements of R-407C [R-32/125/134a (23/25/52)] and R-32/125/134a (30/10/60) with an unidentified ester lubricant. They were tested in a 2.6 kW (8900 Btu/hr) split-system room air conditioner (RAC) / heat pump with a rotary, rolling-piston compressor. The results are compared to corresponding data for R-22 with an unidentified mineral oil. Schematics illustrate the refrigerant circuits in both the heating and cooling modes. The data for the two modes are tabulated. The charge and lubricant quantities as well as the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results for both refrigerants show capacity changes of less than 1% in either the cooling and heating modes. The coefficients of performance (COPs) dropped by 3% and less than 1% in the cooling mode, with R-407C and R-32/125/134a (30/10/60). The heating COPs decreased by 7 and 4%, respectively. The report notes that the compressor discharge pressures is higher in both modes with both blends, but the discharge temperatures are lower.

S. Uemura (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 9, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3809)

Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 7.6 kW cooling (2.1 ton) air-to-air, packaged heat pump using a scroll compressor. R-22 was tested with a mineral oil; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, condenser and liquid line exits, evaporator inlet, and the evaporator outlet. Data are presented for both the heating and cooling modes. The results for the blend show a 3% decrease to a 1% gain in capacity, depending on superheating and subcooling, and corresponding 2 and 1% efficiency increases in the heating mode. The results also show a 1% decrease to 1% gain in capacity, again depending on superheating and subcooling, and corresponding 3% gain and 1% loss in efficiency in the cooling mode.

S. Uemura (Daikin Industries, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 10, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3810)

Two tables summarize tests to compare performance of R-22 and R-32/125 (60/40) through drop-in tests in a 2.7 kW cooling (3/4 ton) air-to-air, room heat pump with a variable-speed, rotary rolling-piston compressor. R-22 was tested with a mineral oil; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser exit, liquid line inlet, and the evaporator inlet and outlet. Data are presented for both the cooling and heating modes. With a speed adjustment (to 77% of the R-22 reference case) to match capacity, the cooling efficiency dropped by 18% with the blend; a further speed reduction (to 73% of the reference) yielded a 4% loss in capacity and 16% increase in efficiency, both relative to the reference case. With a speed adjustment (to 73% of the R-22 reference case) to match capacity, the heating efficiency dropped by 5% with the blend; a further speed reduction (to 64% of the reference) yielded a 10% loss in capacity and 3% increase in efficiency, both relative to the reference case. Corresponding changes in superheating and subcooling are noted.

E. A. Vineyard, J. R. Sand, and W. A. Miller (Oak Ridge National Laboratory, ORNL), **Refrigerator-Freezer Energy Testing with Alternative Refrigerants**, *Transactions* (ASHRAE Annual Meeting, Vancouver, BC, Canada, 24-28 June 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 95, part 2, 1989; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, ASHRAE, pages 205-210, 1989 (6 pages with 2 figures and 3 tables, RDB2121)

R-134a, R-22/142b, R-12/DME, R-500

H. Wakabayashi and A. Aoki (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 138, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (12 pages with 3 figures and 7 tables, available from JMC as RDB4738)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 45, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1993 (10 pages with 1 figure and 5 tables, available from JMC as RDB3845)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 11, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1992 (4 pages with 2 tables, available from JMC as RDB3811)

> Two tables summarize tests to compare performance of R-22 and R-32/134a (30/70) through drop-in tests in a 2.5 kW cooling (3/4 ton) air-to-air, room heat pump with a variable-speed, rotary rolling-piston compressor. R-22 was tested with an unidentified synthetic lubricant; the blend was tested with an ester lubricant. The refrigerant charge amounts, lubricant quantities and circulated fractions, and test conditions are indicated. Temperature and pressure data are tabulated at the compressor shell inlet and outlet, condenser inlet, saturated vapor and liquid states in the condenser, condenser exit, liquid line inlet, expansion device inlet, evaporator inlet, saturated vapor state in the evaporator, and the evaporator outlet. Data are presented for both the cooling and heating modes. With an unspecified speed adjustment to match capacity, the cooling efficiency dropped 6% with the blend; other (unspecified) adjustments yielded a 1% increase in capacity at 6% loss in efficiency or 3% loss in capacity and efficiency. Set to match heating capacity, the efficiency dropped less than 1% with the blend. Other, unspecified adjustments yielded a 3% increase in capacity at 3% loss in efficiency or 1% loss in capacity and negligible drop in efficiency.

K. Wakahara (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blends R-32/125/134a (30/-10/60) and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 174, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 1 figure and 4 tables, available from JMC as RDB-5674)

> R-407C and R-32/125/134a (30/10/60) with an unidentified ester lubricant compared to R-22 with mineral oil in a room heat pump using a rotary, rolling-piston compressor in both the cooling and heating modes

K. Wakahara (Sharp Corporation, Japan), **Drop-In Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 139, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 2 tables, available from JMC as RDB4739)

P. Weiss, M. Barreau, and S. Macaudiere (Elf Atochem S.A., France), **Field Tests Using HCFC-22 Replacements**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, August 1995), International Institute of Refrigeration (IIR), Paris, France, volume IVa, pages 606-613, 1995 (8 pages with 6 figures and 1 table, RDB5A07)

> This paper summarizes a laboratory comparison of the performance of four potential R-22 replacements in a water-to-water heat pump, for both the heating and cooling modes. R-22 was tested with an alkylbenzene lubricant as a reference. R-134a, R-404A, R-407C, and R-23/32/-134a (4.5/21.5/72) [FX220, believed to be (4.5/-21.5/74)] were tested with an unidentified polyolester lubricant. The paper shows a schematic of the test system and describes the test conditions and measured data points. The evaporator inlet and outlet temperatures, suction and discharge temperatures and pressures, and flow rates are tabulated for all five refrigerants for condenser water temperatures of 30 and 50 °C (86 and 122 °F). Plots compare the capacities and efficiencies of the five refrigerants in both the heating and cooling modes. A final plot shows the discharge pressures for a range of condenser water temperatures. The paper concludes that R-407C or the R-23/32/134a blend offer the best match for R-22 for air-cooled systems. It notes that R-134a is an attractive candidate for large chillers, but that R-404A is the optimum choice for smaller chillers when a high cooling capacity is one of the key criteria. The tests were performed at the TNO Institute of Environmental and Energy Technology in the Netherlands.

G. B. Wetzel (McQuay International, then Snyder-General Corporation), **Drop-In Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 27, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1992 (14 pages with 7 tables, available from JMC as RDB3827)

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R. Yajima and O. Kataoka (Daikin Industries, Japan), **Drop-In Test of Refrigerant Blends R-23/-32/134a (1.5/27/71.5), R-23/32/134a (1.5/20/-78.5), and R-23/32/134a (2/29.4/68.6)**, Alternative Refrigerants Evaluation Program (AREP) report 168, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 5 figures and 4 tables, available from JMC as RDB5668)

R-23/32/134a (1.5/27/71.5), (1.5/20/78.5), and (2/29.4/68.6) with an unidentified polyolester (POE) lubricant compared to R-22 with a mineral oil and to R-32/134a with a POE in a room heat pump using a rotary, rolling-piston compressor

R. Yajima and O. Kataoka (Daikin Industries, Japan), **Drop-In Test of Refrigerant Blends R-32/134a (30/70) and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 152, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 1 figure and 2 tables, available from JMC as RDB4752)

This report summarizes performance tests of R-32/134a (30/70) and R-407C with an unidentified ester lubricant. They were tested in an unmodified 7.6 kW (2 ton) split-system, unitary heat pump with a 2.2 kW (3 hp) scroll compressor. The equipment is shown schematically. The results are tabulated with corresponding data for R-22 with an unidentified mineral oil. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor and evaporator as well as the outlets from the condenser and expansion device. The results show capacity and efficiency losses of 1.4 and 5.8%, respectively in the cooling mode, and a capacity increase of 4% and efficiency decrease of 3.5% in the heating mode, for R-32/134a (30/70). They also show a capacity increase of 1.2% and efficiency decrease of 1% in the cooling mode, and capacity and efficiency increases of less than 1% in the heating mode, for R-407C.

Optimized Compressor Tests

N. Kanzaki (Kobe Steel, Limited, Japan), **Soft-Optimized Compressor Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 85, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (12 pages with 8 tables, available from JMC as RDB3C85)

K. Furuhama (Toshiba Corporation, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 163, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (18 pages with 7 figures and 6 tables, available from JMC as RDB5663)

R-410A compared to R-22 in a rotary, rolling-piston compressor with an unidentified polyolester lubricant

O. Kataoka (Daikin Industries, Limited, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 103, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 figures and 2 tables, available from JMC as RDB3D03)

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Soft-Optimized Compressor Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 81, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 2 tables, available from JMC as RDB3C81)

T. Sano (Toshiba Corporation, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 98, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 5 figures and 3 tables, available from JMC as RDB3C98)

T. Sano (Toshiba Corporation, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 99, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 2 figures and 4 tables, available from JMC as RDB3C99)

H. W. Sibley (Carrier Corporation), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 91, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, September 1993 (14 pages with 6 figures and 9 tables, available from JMC as RDB3C91)

This report summarizes performance tests of R-32/125 (60/40) in a three-phase, hermetic scroll compressor (Carrier SR40) with a nominal capacity of 11.7 kW (3.3 ton). Tests were performed using a polyolester lubricant (Mobil EAL Arctic(R) 32). The operating conditions and measured results of the calorimeter tests are tabulated. The capacity, coefficient of performance (COP), mass flow rate, input power, and current draw are plotted as functions of saturated suction and condensing temperatures for suction temperatures of -32 to 13 °C (-25 to 55

°F). A plot summarizes the relative capacities and COPs are plotted for three further comparative tests in scroll compressors: R-22 with an alkylbenzene lubricant (Chevron Zerol(R) 150) in a Carrier SRD600AA, R-32/125 (60/40) in a "drop-in" test with a Copeland ZR61K2 compressor, and the same blend in an optimized Carrier SR40 compressor. The compressor operating conditions and R-22 measurements are tabulated. The comparisons show 50% higher capacity and approximately 10% lower efficiency for the "drop-in" compressor and slightly higher capacity and lower efficiency for the optimized compressor using the blend.

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized Compressor Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 105, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 4 tables, available from JMC as RDB3D05)

Optimized System Tests

R. S. Agarwal, M. Ramaswarmy, A. Kant, V. Agarwal, and V. K. Srivastava (Indian Institute of Technology, India), **Evaluation of Hydrocarbon Refrigerants in Single Evaporator Domestic Refrigerator-Freezers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 248-257, October 1995 (10 pages with 10 figures and 4 tables, available from JMC as RDB5A66)

R-12, R-134a, R-600a, R-290/600a (50/50), capacity, efficiency, run time, pull down, ice making

J. Berge, S. L. Kwon, and L. Naley (Thermo King Corporation), **Soft-Optimized System Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 176, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (20 pages with 4 figures and 5 tables, available from JMC as RDB5676)

R-404A with an unidentified polyolester (POE) lubricant compared to R-502 with an alkylbenzene (AB) lubricant in a 14 kW (4 ton) transport refrigeration unit using an engine-driven, reciprocating piston compressor

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125/143a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 127, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (22 pages with 3 figures and 8 tables, available from JMC as RDB3D27)

This report summarizes a performance test of R-R-32/125/143a (30/10/60), with a polyolester lubricant (Mobil EAL Arctic(R) 22), in a 7 kW (2 ton) unitary, split-system heat pump. The system consisted of an outdoor unit (Trane TWR-024C100A), with a reciprocating-piston compressor (Trane Climatuf CP223-BC1-GA), matched to an indoor air handler (Trane TWV-036B140A). Performance was measured in an unmodified system, with the indoor heat exchanger recircuited for cross-counter flow in the cooling mode, with addition of a liquid-suction coaxial heat exchanger (LSHX), and with both recircuiting and an LSHX. The modifications are shown schematically in three figures. Eight tables summarize the test conditions, charge and lubricant quantities, operating parameters, capacity, input power, and efficiency in both metric (SI) and inch-pound (IP) units of measure. The data also are expressed as ratios to corresponding measurements with R-22 in the same system with the same lubricant. The report indicates that the capacity increased by 1% while the seasonal energy efficiency ratio (SEER) dropped 5% in the cooling mode. The capacity was nearly the same, but the heating season performance factor (HSPF) decreased by 6%. With recircuiting, the SEER and HSPF decreased by 2% and 14%, respectively, with corresponding changes in capacity of +1 and -19%. With recircuiting combined with the LSHX, the HSPF decreased by 6% while the capacity increased by 4%. With the LSHX alone, the SEER was restored and the cooling capacity decreased by 5%. Detailed test data are provided.

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 128, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (10 pages with 4 tables, available from JMC as RDB3D28)

This report summarizes a performance test of R-R-32/125 (60/40), with a polyolester lubricant (Mobil EAL Arctic(R) 22), in a 10.6 kW (3 ton) unitary, split-system heat pump. The system consisted of an outdoor unit (Trane TWX036-C100A), with a reciprocating-piston compressor (Trane Climatuf CP223-BC1-GA for the blend and GP343-FG1-GA for R-22), matched to an indoor air handler (Trane TWE042C140A). Performance was measured with adjusted expansion devices and a substituted compressor. Four tables summarize the test conditions,

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charge and lubricant quantities, operating parameters, capacity, input power, and efficiency in both metric (SI) and inch-pound (IP) units of measure. The data also are expressed as ratios to corresponding measurements with R-22 with the same lubricant. The report indicates that the capacity increased by 0-2% depending on the outdoor temperature while the energy efficiency ratio (EER) dropped 0-2% in the cooling mode. The heating capacity increased by 3%, but the coefficient of performance (COP) decreased by 1-2%. Detailed test data are provided.

S. Chen and T. Kennedy (The Trane Company), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 129, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (16 pages with 2 figures and 6 tables, available from JMC as RDB3D29)

J. L. Cox and Q. Wang (Rheem Manufacturing Company), **Soft-Optimized System Test of Refrigerant Blends R-32/125 (60/40) and R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 93, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (20 pages with 9 tables, available from JMC as RDB3C93)

N. Downs and M. Lindsay (Hussmann Corporation), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 159, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 2 figures and 2 tables, available from JMC as RDB5659)

R-410B compared to R-502 with a polyolester lubricant (Mobil EAL Arctic(R) 22) in a commercial refrigeration system

A. Fujitaka, N. Yamaguchi, and Y. Watanabe (Matsushita Electric Industrial Company Limited, Japan), **Experimental Evaluation of Room Air Conditioner Using R-32/125/134a Blend**, paper 2.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 17-22, December 1994 (6 pages with 20 figures and 4 tables; in Japanese with abstract, figures, and tables in English; RDB5404)

R-22, R-407C

A. Fujitaka (Matsushita Electric Industrial Company Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 164, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (12 pages with 4 figures and 5 tables, available from JMC as RDB5664)

R-407C compared to R-22 and to R-32/125/-134a (30/10/60) with an unidentified polyolester (POE) lubricant in an air-source, room heat pump with a rotary, rolling-piston compressor in both the cooling and heating modes

A. Fujitaka (Matsushita Electric Industrial Company Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 165, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (10 pages with 2 figures and 4 tables, available from JMC as RDB5665)

R-407C compared to R-22 and to R-32/125/-134a (30/10/60) with an unidentified polyolester (POE) lubricant in an air-source, room heat pump with a scroll compressor in both the cooling and heating modes

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 154, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (16 pages with 5 tables, available from JMC as RDB4754)

R-125/143a (45/55) compared to R-502 with polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a commercial refrigeration system

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 124, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (24 pages with 3 figures and 8 tables, available from JMC as RDB3D24)

R-125/143a (45/55) compared to R-502 with polyolester lubricant (Mobil EAL Arctic(R) 22 CC) in a commercial refrigeration system

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 125, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (20 pages with 3 figures and 5 tables, available from JMC as RDB3D25)

This report summarizes a performance test of R-R-125/143a (45/55), with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC), in a commercial refrigeration system with compressor speed and

control optimization. The system consisted of a display case (Tyler D5FG 12'), a reciprocating-piston compressor (Copeland 2DB3-0600-TFC) with an adjustable-speed drive (Magnetek L710 type GPD 502 frequency inverter), and a water-cooled condenser (Standard Refrigeration T7-500D). Performance was measured at compressor speeds of 1070, 1217, 1379, 1584, and 1789 with a varied heater load, to maintain uniform evaporating temperature. The report outlines the test procedures and presents tabular results in both metric (SI) and inch-pound (IP) units of measure. Five tables summarize test conditions, charge and lubricant quantities, measured capacity, input power, and efficiency at each speed. The data also are expressed as ratios to corresponding measurements with R-502 in the same system with the same lubricant. Three plots show the capacities, input power, and coefficients of performance (COP) at the five tested speeds normalized to those for R-502 at 1760 RPM. The capacity ratios ranged from 0.92 to 1.40 and the efficiency ratios from 1.038 to 1.089.

K. K. Fung (Tyler Refrigeration Company), **Soft-Optimized System Test of Refrigerant Blend R-125/143a (45/55)**, Alternative Refrigerants Evaluation Program (AREP) report 126, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (6 pages with 1 table, available from JMC as RDB3D26)

This report summarizes a performance test of R-R-125/143a (45/55), with a polyolester lubricant (Mobil EAL Arctic(R) 22 CC), in a commercial refrigeration system with heat exchanger and control optimization. The system consisted of a display case (Tyler D5FG 12'), a reciprocating-piston compressor (Copeland 2DB3-0600-TFC), and a water-cooled condenser (Standard Refrigeration T7-500D). Performance was measured with a regenerator-type heat exchanger, with twice the normal length, for the evaporator. The report outlines the test procedures and presents tabular results in both metric (SI) and inch-pound (IP) units of measure. A table summarizes test conditions, charge and lubricant quantities, measured capacity, input power, and efficiency. The data also are expressed as ratios to corresponding measurements with R-502 with a standard evaporator and the same lubricant. The capacity increased by 4.8%, but the efficiency dropped by 0.25%. Compared to another test of R-125/143a (45/55) with a standard evaporator, the coefficient of performance (COP) was 4.2% lower.

K. Furuhama and M. Komazaki (Toshiba Corporation, Japan), **Performance Evaluation of Residential Air Conditioner with HFC32/125 Mixture**, paper 2.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 23-26, December 1994 (4 pages with 5 figures and 2 tables; in Japanese with abstract, figures, and tables in English; RDB5405)

R-22; R-32; R-125; R-32/125 (40/60), (50/50), (60/40), and (80/20); zeotrope, blend composition, efficiency, COP

P. R. Glamm, E. F. Keuper, and F. B. Hamm (The Trane Company), **Evaluation of HFC-245ca for Commercial Use in Low Pressure Chillers**, report DOE/CE/23810-67, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, March 1996 (96 pages with 46 figures and 16 tables, available from JMC as RDB6501)

This report summarizes theoretical and experimental performance comparisons of R-245ca with both R-11 and R-123, for which it is a a potential replacement, in a multistage, centrifugal chiller. It also addresses environmental advantages and safety concerns, notably including the marginal flammability of R-245ca. The report outlines the theoretical approach used and comments on the lubricant impacts, operating range, impeller selection, compressor performance, and heat exchanger differences for R-245ca substitution. It also discusses attempts to use a blend of R-245ca and a mix of perfluorohexane isomers, proposed to suppress flammability. This blend was found to be unsatisfactory due to reduced surface tension and resultant liquid carryover. The study concludes with an assessment of commercial viability for both retrofit and new applications. The report provides detailed plots and tabular data for component operating characteristics and performance. An appendix addresses surge limits for the three refrigerants. A second appendix provides detailed records of operating parameters, in both inch-pound (IP) and metric (SI) units of measure, for three selections of impellers, sized for each of the refrigerants. The report concludes that R-245ca will not perform satisfactorily in retrofits of equipment designed for R-11 and R-123, due to surge concerns, without a compressor replacement and, in most cases, a larger motor and drive system. The expense would be prohibitive except in special cases. R-245ca can match the performance of R-123 in new equipment with a small increase in heat transfer surface, but this change is not currently viable since R-245ca is not commercially produced. Moreover, concerns with flammability would result in market resistance. Blending

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R-245ca with flammability-suppressants would degrade performance and complicate heat exchanger design. The report recommends that industry continue to investigate cost-effective means to use marginally flammable refrigerants that offer high performance.

P. R. Glamm, E. F. Keuper, and F. B. Hamm (The Trane Company), **Evaluation of HFC-245ca for Commercial Use in Low Pressure Chillers, Volume II: Chiller Test Data**, report DOE/CE/23810-67, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, March 1996 (414 pages all tables, available from JMC as RDB6502)

This report provides detailed chiller test data for R-11 with a mineral oil and a polyolester (POE) lubricant (CPI Soltest 68) and for R-123 and R-245ca with the same POE in a three-stage, centrifugal chiller (Trane CenTraVac CVHE). R-11 and R-245ca were run with two sets of impeller selections, and R-123 with three; these selections include optimized choices for each of the three refrigerants. The test data cover multiple runs to optimize the charge size and test different operating and load conditions. Curve fits are provided for motor efficiency and speed. These detailed measurements substantiate the data plots and comparisons provided in volume 1 of this report.

P. R. Glamm (The Trane Company), **Water-Source Heat Pumps with HFC Refrigerants**, *IEA Heat Pump Center Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 25-28, March 1995 (4 pages with 3 figures and 5 tables, RDB5688)

R-407C and R-410A performance in a 10.6 kW (3 ton) water-source heat pump compared to R-22

D. S. Godwin (Air-Conditioning and Refrigeration Institute, ARI), **Results of Soft-Optimized System Tests in ARI's R-22 Alternative Refrigerants Evaluation Program**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 7-12, July 1994 (6 pages with 4 figures; 8 page reprint available from JMC as RDB4802)

AREP

Y. H. Hwang, J. F. Judge, and R. K. Radermacher (University of Maryland), **An Experimental Evaluation of Medium and High Pressure HFC Replacements for R-22**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 41-48, October 1995 (8 pages with 7 figures and 9 tables, available from JMC as RDB5A44)

R-407C, R-410A, R-410B, laboratory performance test

S. Ishigaki (Sanyo Electric Company, Limited, Japan), **Performance Improvement of 1 HP RAC with Refrigerant Mixture R-32/125/134a**, paper 2.5, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 38-41, December 1994 (4 pages with 6 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5408)

R-32/125/134a (23/25/52) [R-407C]

O. Kataoka (Daikin Industries, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 104, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 1 figure and 3 tables, available from JMC as RDB3D04)

M. Katayama (Fujitsu General Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 167, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (16 pages with 10 figures and 2 tables, available from JMC as RDB5667)

R-407C with an polyolester lubricant (JS-4156A1) compared to R-22 with mineral oil (Witco Suniso(R) 4GSD) in a room heat pump, with and adjustable-speed rotary, rolling-piston compressor, in both the cooling and heating modes

M. Kurachi (Matsushita Refrigeration Company, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 166, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1994 (10 pages with 1 figure and 4 tables, available from JMC as RDB5666)

R-407C with an unidentified polyolester lubricant compared to R-22 with mineral oil in a room heat pump, with and adjustable-speed scroll compressor, in both the cooling and heating modes

M. Kurachi (Matsushita Refrigeration Company, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 83, Air-Conditioning and Refrigeration Institute (ARI),

Arlington, VA, June 1993 (6 pages with 1 figure and 3 tables, available from JMC as RDB3C83)

R-32/125/134a (30/10/60) with an unidentified polyolester lubricant compared to R-22 with mineral oil in a room heat pump, with and adjustable-speed scroll compressor, in both the cooling and heating modes

A. T. Lim (Inter-City Products Corporation), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 162, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (4 pages with 1 table, available from JMC as RDB5662)

This report consists of a single table that compares the measured performance and operating parameters of R-407C and R-22 in a packaged-terminal air conditioner. The zeotropic blend was tested in drop-in and three soft-optimized modes. They included matching of the superheat and subcooling, coil modification for recircuiting, and coil modification for counterflow circuiting. An unidentified polyolester (POE) lubricant was used with both refrigerants. The blend results show steady state losses of 7.3-10.8% in efficiency and 2.5-6.0% in capacity. The report gives the measured temperatures and pressures for key locations, power draw, sensible and latent cooling capacities, and counts of expansion valve openings.

J. W. Linton, W. K. Snelson, A. R. Triebe, and P. F. Hearty (National Research Council, Canada, NRCC), **System Performance Comparison of R-507 with R-502**, paper 3925, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 502-510, 1995 (9 pages with 13 figures, RDB6363)

R-502, R-507, experimental comparison

J. W. Linton, W. K. Snelson, A. R. Triebe, and P. F. Hearty (National Research Council, Canada, NRCC), **Soft-Optimization Test Results of R-32/-R-125/R-134a (10%/70%/20%) Compared to R-502**, paper OR-94-1-4, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 558-565, 1994 (8 pages with 13 figures, RDB4704)

R-407B [R-32/125/134a (10/70/20)]

K. Matsuo (Hitachi, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/-125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 97, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 3 tables, available from JMC as RDB3C97)

M. Mårtensson and E. Skoglund, **Cycle Performance Test of R404A and R407A Using a Scroll Compressor**, MS thesis, Kungl Tekniska Högskolan (KTH), Stockholm, Sweden, 1996 (RDB6760)

R-404A, R-407A

V. C. Mei, F. C. Chen, D. T. Chen (Oak Ridge National Laboratory, ORNL) and E-P. HuangFu (U.S. Department of Energy, DOE), **Performance Tests of R-22 and R-32/R-125/R-134a Mixture for Baseline Air Conditioning and Liquid Over-Feeding Operations**, paper SD-95-12-3, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 1072-1077, 1995 (6 pages with 8 figures, RDB6393)

R-22, R-32/125/134a (30/10/60), performance tests in room (window) air conditioner, modification to flooded evaporator with liquid overfeed (LOF): drop-in cooling capacity was 7.7% lower with the blend, 1.1% lower with the LOF modification

Y. Morikawa (Matsushita Electric Industrial Company Limited, Japan), **Procedure and Report Format for Soft-Optimized System Tests Performed by JRAIA Member Companies**, Alternative Refrigerants Evaluation Program (AREP) report 80, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (10 pages with 4 tables, available from JMC as RDB3C80)

AREP

F. T. Murphy, R. E. Low, B. E. Gilbert (ICI Klea), J. W. Linton, W. K. Snelson, and P. T. Hearty (National Research Council, Canada, NRCC), **Comparison of R-407C and R-410A with R-22 in a 10.5 kW (3.0 TR) Residential Central Air-Conditioner**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 31-40, October 1995 (10 pages with 5 figures and 3 tables, available from JMC as RDB5A43)

R-22, R-407C, R-410A, polyolester lubricant, laboratory performance test

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 108, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA,

please see pages 6-8 for ordering information

October 1993 (4 pages with 2 tables, available from JMC as RDB3D08)

This report summarizes a performance test of R-134a in a 40 hp, 174 kW (49 ton), water-cooled chiller with a twin-screw compressor. The results are tabulated for R-134a along with corresponding data for R-22. Both refrigerants were tested with an unidentified synthetic lubricant and R-134a also was tested with an unidentified polyalkylene glycol (PAG). The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor and evaporator as well as the outlets from the condenser and expansion device. The results show decreases of 37 and 39% in capacity and 6 and 2% in efficiency for the synthetic and PAG lubricants, respectively, compared to R-22.

T. Nitta (Mitsubishi Heavy Industries, Limited, Japan), **Soft-Optimized Test of Refrigerant R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 148, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (8 pages with 3 figures and 3 tables, available from JMC as RDB4748)

This report summarizes performance measurements of R-32/125/134a (30/10/60) with an unidentified ester lubricant in a 2.75 kW (3/4 ton) split-system room air conditioner (RAC) / heat pump with a rotary rolling-piston compressor. The results are compared to corresponding data for R-22 with alkylbenzene. Two schematics illustrate the refrigerant circuit and modifications to the heat exchangers for the zeotropic blend. The data for the cooling and heating modes are summarized in two tables. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor, condenser, expansion device, and evaporator. The results show a 1% increase in capacity for both cooling and heating and decreases of 5 and 4% in efficiency for the cooling and heating modes, respectively, compared to R-22. These findings are plotted. The report notes that the discharge pressure with R-32/125/134a (30/10/60) is approximately 10% higher than with R-22, but the discharge temperature is approximately 7% lower.

M. Ozu (Toshiba Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/-125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 149, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 3 figures and 3 tables, available from JMC as RDB4749)

This report summarizes a performance test of R-407C with an unidentified ester lubricant in a 2.3 kW (8000 Btu/hr) room air conditioner (RAC) / heat pump. The results are tabulated with corresponding data for R-22 with an unidentified mineral oil.

M. Ozu (Toshiba Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/-125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 82, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 2 figures and 4 tables, available from JMC as RDB3C82)

M. Pande, Y. H. Hwang, J. F. Judge, and R. K. Radermacher (University of Maryland), **An Experimental Evaluation of Flammable and Nonflammable High Pressure HFC Replacements for R-22**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 21-26, July 1996 (6 pages with 4 figures and 7 tables, RDB6752)

performance comparison of R-32, R-410A, and R-410B with R-32 in a residential, air-to-air heat pump; indicates 5.1% and 2.5-4% improvement in cooling and heating seasonal performance, respectively, for R-32, but notes that it is flammable; indicates a 2-3% improvement for R-410A and R-410B for cooling and similar performance for heating; summarizes tests at standard rating conditions and provides plots of efficiency and capacity relative to charge amount; tabulates seasonal performance for heating (for the six standard rating regions for the United States) and cooling for the cited refrigerants

K. Sakuma (Mitsubishi Electric Corporation, Japan), **Soft-Optimized System Test of Refrigerant R-134a**, Alternative Refrigerants Evaluation Program (AREP) report 84, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 4 figures and 2 tables, available from JMC as RDB3C84)

K. Sakuma (Mitsubishi Electric Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 102, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 6 figures and 2 tables, available from JMC as RDB3D02; available copy is difficult to read)

N. Sawada (Sanyo Electric Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 150, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (10 pages with

3 figures and 5 tables, available from JMC as RDB-4750)

This report summarizes a performance test of R-407C with an unidentified polyester lubricant in a 2.6 kW (9400 Btu/hr) room air conditioner (RAC) / heat pump. The results are tabulated with corresponding data for R-22 with a mineral oil (Witco Suniso(R) 4GSD-T).

N. Sawada (Sanyo Electric Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 100, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 5 tables, available from JMC as RDB-3D00)

H. W. Sibley (Carrier Corporation), **Soft-Optimized System Test of Refrigerant Blends R-32/125 (60/40) and R-32/125 (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 95, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (6 pages with 2 tables, available from JMC as RDB3C95)

R-32/125 (50/50) [R-410A] and R-32/125 (60/-40)

H. W. Sibley (Carrier Corporation), **Soft-Optimized System Test of Refrigerant Blends R-32/125/-134a (30/10/60), R-32/125/134a (25/20/55), and R-32/125/134a (23/25/52)**, Alternative Refrigerants Evaluation Program (AREP) report 96, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (8 pages with 3 tables, available from JMC as RDB3C96)

R-32/125/134a (30/10/60), R-32/125/134a (25/20/55), and R-32/125/134a (23/25/52) [R-407C]

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized System Test of Refrigerant Blend R-23/32/125 (5/25/70)**, Alternative Refrigerants Evaluation Program (AREP) report 161, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, May 1994 (16 pages with 6 figures and 4 tables, available from JMC as RDB5661)

R-23/32/125 (5/25/70) [identified in the report as "R-32/125/23 (25/70/5)"] compared to R-502 in a test loop using a reciprocating-piston compressor with an unidentified polyolester (POE) lubricant

W. K. Snelson, J. W. Linton, P. F. Hearty and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized Test Results of R-32/-125/134a (20/40/40)**, Alternative Refrigerants Evaluation Program (AREP) report 155, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (18 pages with 5 figures and 4 tables, available from JMC as RDB4755)

R-407A with unidentified ester lubricant compared to R-502 with unidentified alkylbenzene in a test loop with a reciprocating-piston compressor

W. K. Snelson, J. W. Linton, P. F. Hearty and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized Test Results of R-125/143a (50/50)**, Alternative Refrigerants Evaluation Program (AREP) report 130, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (16 pages with 5 figures and 4 tables, available from JMC as RDB3D30)

R-507A with unidentified ester lubricant compared to R-502 with unidentified alkylbenzene in a test loop with a reciprocating-piston compressor

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (10/70/20)**, Alternative Refrigerants Evaluation Program (AREP) report 94, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (44 pages with 4 figures and 16 tables, available from JMC as RDB-3C94)

R-407B

W. K. Snelson, J. W. Linton, P. F. Hearty, and A. R. Triebe (National Research Council, Canada, NRCC), **Soft-Optimized System Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 92, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (16 pages with 5 figures and 4 tables, available from JMC as RDB-3C92)

R-404A and R-502

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **Experimental Evaluation of R-22 Alternative Refrigerants in Unitary Air Conditioning Equipment**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 19-24, July 1994 (6 pages with 2 tables, RDB4804)

R-134a, R-410A [R-32/125 (50/50)], R-407C (R-32/125/134a (23/25/52)], AZ-20

M. W. Spatz and J. Zheng (AlliedSignal Incorporated), **Performance of Alternative Refrigerants in Heat Pumps and Air Conditioners**, presented at the 1992 International Refrigeration Conference

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(Purdue University, West Lafayette, IN, July 1992), published in *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 465-475, July 1994 (11 pages with 3 figures and 4 tables, RDB4862)

R-134a, R-152a, R-32/125 (60/40), R-32/134a (25/75)

Y. Sumida (Mitsubishi Electric Corporation, Japan), **Soft-Optimized System Test of Refrigerant Blend R-125/143a/134a (44/52/4)**, Alternative Refrigerants Evaluation Program (AREP) report 101, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (12 pages with 8 figures and 4 tables, available from JMC as RDB3D01)

R-404A

L. J. Swatkowski, Jr. (Appliance Industry-Government CFC Replacement Consortium), **Energy Efficiency of HFC-134a versus HFC-152a**, *Proceedings of the 44th Annual International Appliance Technical Conference* (University of Ohio, Columbus, OH, 11 May 1993), IATC, Batavia, IL, May 1993; reprint published by the Association of Home Appliance Manufacturers (AHAM), Chicago, IL, May 1993 (9 pages, available from JMC as RDB3722)

This paper summarizes a project to evaluate the relative efficiencies of R-134a and R-152a in household refrigerators and freezers typical of those used in the United States. The project was conducted by the Appliance Industry-Government CFC Replacement Consortium, also known as the *Appliance Research Consortium* (ARC). The paper reviews the organization and membership of ARC and mentions that 21 projects have been initiated and three of them completed since 1989. It reviews the history of the present project, noting a 1991 comparison showing higher efficiency for R-152a in unoptimized, *drop-in* comparisons. Those findings were challenged by another study (see RDB-2728). The paper outlines testing by the Environmental Protection Agency (EPA) and six equipment manufacturers, using refrigerator-freezers incorporating compressors optimized for each refrigerant. The paper reviews test unit criteria, test methods, refrigerant supply, and lubricant and desiccant selection. It presents arguments for and against adjusting the measured data, and notes a conclusion by the program participants not to do so. The paper gives the study's conclusion, that no statistically significant difference in efficiency was found between R-134a and R-152a.

N. Takahasi (Hitachi, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/-125 (60/40)**, Alternative Refrigerants Evaluation Program (AREP) report 86, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1993 (8 pages with 2 figures and 3 tables, available from JMC as RDB3C86)

K. Takaichi, O. Asakawa, Y. Masatoki, R. Fujimoto (Matsushita Refrigeration Company, Japan), Y. Yoshida (Matsushita Electric Industrial Company, Limited, Japan), **New Application of R502 Substitute Refrigerant into Freezer-Refrigerator**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 389-394, July 1994 (6 pages with 3 figures and 3 tables, RDB4851)

R-502/13 (87/13), R-22/115/12 (42.5/44.5/13), R-125/143a/134a (40/50/10), R-404A [R-125/-143a/134a (44/52/4)], R-507A [R-125/143a (50/50)], R-32/125/134a (20/40/40) and (30/-10/60)], R-32/125/134 (20/50/30), R-134a

D. W. Treadwell (Lennox International, Incorporated), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 62, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, April 1993 (4 pages with 2 tables, available from JMC as RDB3C62; available copy is difficult to read)

The report presents the test conditions and results for laboratory tests of a 10.5 kW (3 ton), split-system, air-to-air heat pump using a hermetic scroll compressor (Copeland ZR34K1-PFV) and thermostatic expansion valves. The title indicates that the equipment was soft-optimized for use of R-32/125/134a (30/10/60), though the specific changes are not identified. The report consists of two tables, for the cooling and heating modes, that compare performance with this blend and R-22 at identified, standard rating conditions. All tests were performed using an unidentified ester lubricant. The refrigerant charge amount, total and sensible (cooling mode only) capacities, input power, resultant efficiency, cycling degradation factor, and calculated seasonal performance are presented. Refrigerant temperatures and pressures also are tabulated for compressor suction and discharge; condenser inlet, midpoint, and leaving; expansion device inlet; and evaporator inlet, midpoint, outlet, and leaving conditions. The refrigerant subcooling, superheat, and flow rates also are given. The cooling-mode results indicate 1 and 1% losses in capacity at 35 and 28 °C (95 and 82 °F) "outdoor" ambient temperatures, respectively, with 7 and 1% losses in efficiency; the calculated seasonal efficiency was 3.1% lower with the blend. The heating-mode measurements show a 4% increase and slight de-

crease in capacities at +8 and -8 °C (47 and 17 °F) with 4 and 6% losses in efficiency; the calculated seasonal efficiency was 7.6% lower with the blend. The compressor discharge pressure was higher in both modes.

A. R. Triebe, W. K. Snelson, P. F. Hearty, J. W. Linton (National Research Council, Canada, NRCC), F. T. Murphy, and S. Corr (ICI Klea, UK), **System Performance Comparison of R-407A and R-502 in Parallel and Counter-flow Heat Exchangers**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 45-50, July 1996 (6 pages with 6 figures, RDB6756)

performance comparison of R-407A and R-502 based on measurements in a test loop; performance with R-407A was found to be 96-105% and 96-99% that of R-502 by switching from a parallel to counter-flow heat exchanger at -15 °C (5 °F) and -25 °C (-13 °F) evaporating temperature, respectively; the maximum performance increase with a counter-flow condenser was found to be 3%

E. A. Vineyard (Oak Ridge National Laboratory, ORNL) and L. J. Swatkowski, Jr. (Appliance Industry-Government CFC Replacement Consortium), **Energy Efficiency of HFC-134a versus HFC-152a**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 86-91, October 1993 (6 pages with 1 figure and 1 table, RDB3A30)

R-134a, R-152a, performance

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 106, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 4 figures and 6 tables, available from JMC as RDB3D06)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 107, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (10 pages with 2 figures and 6 tables, available from JMC as RDB3D07)

Q. Wang and J. L. Cox (Rheem Manufacturing Company), **Soft-Optimized System Test of Refrigerant Blends R-32/125 (50/50) and R-32/125/134a (23/25/53)** (sic), Alternative Refrigerants Evaluation Program (AREP) report 131, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1993 (16 pages with 7 tables, available from JMC as RDB3D31)

R-407C [R-32/125/134a (23/25/52)] and R-410A

G. B. Wetzel (McQuay International), **Soft-Optimized System Test of Refrigerant Blend R-32/125/134a (30/10/60)**, Alternative Refrigerants Evaluation Program (AREP) report 175, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, June 1994 (14 pages with 7 tables, available from JMC as RDB5675)

R-32/125/134a (30/10/60) with a polyolester (POE) lubricant (Mobil EAL Arctic(R) 22 CC) compared to R-22 in water-source heat pump (McQuay model CCH-036) using a hermetic, reciprocating piston compressor (Copeland model CR32K6-TFD) in both the cooling and heating modes

R. Yajima, S. Taira, and I. Tarutani (Daikin Industries Limited, Japan), **The Performance Evaluation of Various HFC Refrigerant Mixtures**, paper 2.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 27-32, December 1994 (6 pages with 9 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5406)

R-22; R-32; R-125; R-134a; R-32/134a (30/70); R-32/125 (60/40); R-125/134a (40/60); R-32/125/134a (30/10/60), (23/25/52) [R-407C], and (18/40/42)

R. Yajima and O. Kataoka (Daikin Industries Limited, Japan), **Soft-Optimized System Test of Refrigerant Blend R-32/134a (30/70)**, Alternative Refrigerants Evaluation Program (AREP) report 151, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, January 1994 (10 pages with 1 figure and 2 tables, available from JMC as RDB4751)

This report summarizes performance tests of R-32/134a (30/70) with an unidentified ester lubricant. They were tested in a 2.4 kW (8300 Btu/hr) room air conditioner (RAC) / heat pump with a 750 W (1 hp) rotary, rolling-piston compressor. The tests included both an unmodified (drop-in) and optimized system, the latter with modified circuiting of the indoor and outdoor heat exchangers. These modifications are shown in a schematic. The results are tabulated with corresponding data for R-22 with an

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unidentified mineral oil. The charge and lubricant quantities and the test conditions are indicated. Operating temperatures and pressures are given for the inlets and outlets of the compressor and evaporator as well as the outlets from the condenser and expansion device. The results show nearly identical capacity and efficiency in the cooling mode except for a 10.4% efficiency loss for the drop-in case. Capacity increases of less than 1%, and efficiency decreases of 5 and 1.2%, were measured for the drop-in and soft-optimized versions, respectively, in the heating mode.

Field Tests

P. Lundqvist and L. Herbe (Kungl Tekniska Högskolan, KTH, Sweden), **Laboratory Evaluation and Field Tests of Replacements for R-22 and R502**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 57-62, July 1996 (6 pages with 2 figures and 1 table, RDB6758)

system performance of R-404A, R-407A, and R-407C; phaseout schedule of common refrigerants in Sweden showing completion by 2000 for chlorofluorocarbon (CFC) refrigerants and curtailment of R-22 use by 2002; presents performance data from a simple field test for R-22 and R-407C in milk coolers; discusses methods and limitations for rigorous field tests with sample data for R-22 and R-407C in a 10 kW (34,000 Btu/hr) water-to-water heat pump; plots performance of R-407C relative to that of R-22 for laboratory drop-in tests and performance data for R-404A and R-407A in a scroll compressor with a liquid injection port, tested in single-stage, with an added suction gas heat exchanger, and with an economizer configurations

Recycling, Reclamation, and Disposal

M. Beatty (National Refrigerants, Incorporated, NRI), **Implementing a Successful Refrigerant Management Program**, paper DE-93-11-1, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 821-824, 1993 (4 pages, RDB3628)

D. Clodic (École des Mines de Paris, France) and F. Sauer (Dehon Services, France), **The Refrigerant Recovery Book**, publication 90371, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1994 (236 pages with 73 figures and 31 tables, available from ASHRAE for $33 to members and $49 for others; RDB4673)

This book describes methods for efficient and economical recovery of refrigerants from a variety of systems. It begins with a review of ozone depletion and global warming with specific focus on the role of chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) refrigerants. It then summarizes the phaseout schedule for ozone-depleting substances under the Montreal Protocol, U.S. regulations for phaseout and emission reduction, and corresponding restrictions in the European Community. The book presents recovery devices and methods, including recovery cylinders, equipment for recovery in the vapor and liquid phases, and procedures. It reviews considerations and quality requirements for recycling, reclaim, and disposal with attention to ISO Standard 11650R and ARI Standard 700. It also outlines accepted destruction methods. The book then presents nine case studies covering domestic refrigerators, a small cold room (refrigerated walk-in box), a supermarket, transport refrigeration systems, an industrial plant, R-11 and R-113 centrifugal chillers, railway car air-conditioning units, and automotive air conditioners. It provides a questionnaire to prepare for recovery operations and reviews fundamental physical principles associated with refrigerant handling and recovery. They include the vapor-pressure law for a pure substance, departures from theory at equilibrium conditions, supercritical states, and the behavior of fluid mixtures. The discussion of the last of these subjects focuses on composition diagrams for zeotropic and azeotropic mixtures and on pressure-composition diagrams for refrigerant-lubricant mixtures. Appendices summarize the purity requirements of ARI Standard 700-88, the results of a bench test of the performance of recovery and recycling equipment, and thermodynamic properties of common CFC, HCFC, and HFC refrigerants. [see RDB4672 for original edition in French]

D. Clodic (École des Mines de Paris, France) and F. Sauer (Dehon Services, France), **Results of a Bench Test of the Performance of Refrigerant Recovery and Recycling Equipment**, paper DE-93-11-5, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 834-840, 1993 (7 pages with 6 tables, RDB3632)

D. Clodic (École des Mines de Paris, France) and F. Sauer (Dehon Services, France), **Vade-Mecum de**

la récupération des CFC [Handbook of CFC Recovery], PYC Édition, Paris, France, 1992 (in French, RDB4672)

[see RDB4673 for abstract of English language edition]

J. P. Doyle (National Refrigerants, Incorporated, NRI), **Refrigerant Management: Conserving a Valuable Resource**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 3, pages 59-62, March 1993 (4 pages with 2 figures and 2 tables, RDB3413)

M. G. Garst (Lennox Industries, Incorporated), **Recovery, Recycling, and Reclamation Guidelines when Servicing Unitary Air-Conditioning and Heat Pump Equipment**, paper DE-93-11-2, *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 825-828, 1993 (4 pages, RDB3629)

D. L. Harmon, W. R. Rhodes (U.S. Environmental Protection Agency, EPA), and L. Weitzman (Acurex Corporation), **Mobile Air Conditioner Refrigerant Evaluation**, report EPA/600/D-89/064 (AEERL-P-527), U.S. Environmental Protection Agency (EPA), Washington, DC, 1989 (RDB3962)

Y. Z. R. Hu, C. H. Chang, C. Y. Yang, and C. C. Chung (Industrial Technology Research Institute, ITRI, Taiwan), **The Development of CFC-Refrigerant, Recovery, Recycling and Reclamation Equipment in ITRI, Taiwan**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 473-481, October 1995 (9 pages with 5 figures and 5 tables, available from JMC as RDB5B16)

R-11 and R-12 recovery, ODS phaseout schedule, R-12 usage in Taiwan

P. G. Johansing, Jr. (Transformation Technologies, Limited), **Chemical and Process Description for Production of High Purity Calcium Halides by Transformation of Halogenated Hydrocarbon Gases**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 500-507, October 1995 (8 pages with 1 figure, available from JMC as RDB5B19)

refrigerant disposal

R. E. Kauffman (University of Dayton Research Institute), **Sealed-Tube Tests of Refrigerants from Field Systems Before and After Recycling**, paper DE-93-11-3 (683-RP), *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 414-424, 1993 (11 pages with 2 figures and 5 tables, RDB3630)

R. E. Kauffman (University of Dayton Research Institute), **Chemical Analysis and Recycling of Used Refrigerant from Field Systems**, paper 3555 (601-RP), *Transactions* (Winter Meeting, Anaheim, CA, January 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 1, pages 128-136, 1992 (9 pages with 4 figures and 1 table, RDB2429)

This paper summarizes research to identify and quantify the typical contaminant levels in used refrigerants. A total of 39 samples were taken from both normally operating and failed air-conditioning and refrigerating systems. These samples included R-11 from centrifugal chillers, R-12 from commercial refrigeration systems, R-22 from unitary heat pumps and air conditioners, and R-502 from low-temperature frozen food cases. Results are summarized for measurement of water content (Karl Fisher technique), acid content (ASTM 664 tests), ion content (ion-specific electrode), high-boiling content (gravimetric technique, gas chromatography, and mass spectrography), particulate content (direct-current plasma emission spectrometer and scanning electron microscope), and volatile impurity content (gas chromatography and mass spectrometry). The contaminant levels found exceeded those of new refrigerants, but the types and concentrations varied by refrigerant, application, and whether a system burnout had occurred. Laboratory tests evaluated a recycling scheme based on oil separation followed by water and acid removal, by an alumina/molecular sieve filter/dryer. The preliminary study showed that this recycling procedure is effective in removing acids, but has insignificant effects on volatile impurities and high-boiling residue. The effects of noncondensable gases were not addressed.

D. Kolar (Navesink Environmental Testing), **Durability of Refrigerant Recovery Equipment**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 222-231, October 1993 (10 pages with 1 figure, RDB6319)

recovery, reclaim

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K. W. Manz (Robinair Division of SPX Corporation), **Removing Restrictions on the Sale of Recycled Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 218-221, October 1993 (4 pages, RDB6318)

recovery, reclaim

W. A. Phillips, **Implementation of a Refrigerant Management Program by the Service Industry**, unpublished paper presented at the International CFC and Halon Alternatives Conference (Washington, DC), York International Corporation, York, PA, October 1993 (8 pages, available from JMC as RDB3A69)

S. Snyder (Robinair Division of SPX Corporation), J. Willis (Asoma Instruments, Incorporated), R. Tobias (Hitek Hardware, Incorporated), and K. W. Manz (Robinair Division of SPX Corporation), **Portable Refrigerant Identification by Near Infrared Spectrophotometry**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 115-120, July 1994 (6 pages with 4 figures and 2 tables, RDB4814)

S. Snyder and K. W. Manz (Robinair Division of SPX Corporation), **Determination of Refrigerant Type Using Vapor Thermal Conductivity Measurements of a Controlled Vapor Sample**, paper DE-93-11-4 (683-RP), *Transactions* (Annual Meeting, Denver, CO, June 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 2, pages 829-833, 1993 (5 pages with 4 figures and 2 tables, RDB3631)

M. Suzuki (Clean Japan Center, Japan), T. Abe, A. Kobayashi, K. Imoto (Nippon Steel Corporation, Japan), T. Amano, H. Komaki (JEOL Limited, Japan), Y. Kawaguchi, (Tokyo Electric Power Company, TEPCO, Japan), C. Ohyama (Ichikawa Kankyou Engineering Company, Limited, Japan), T. Takaichi, (Japan Fluorocarbon Manufactures Association, Japan), and K. Mizuno (National Institute for Resources and Environment, Japan), **Chlorofluorocarbons (CFCs) Destruction Technology by Induction Coupled Plasma**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 490-499, October 1995 (10 pages with 6 figures and 4 tables, available from JMC as RDB5B18)

describes development of a commercial-scale plant to destroy CFC refrigerants using plasma decomposition technology, already used to dispose of more than 15 tonnes of R-12 recovered from old refrigerators

L. Voers (L&E Teknik og Management, Denmark), **A Scheme for Collecting and Registration of CFC, HCFC, HFC, etc.**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 482-489, October 1995 (8 pages with 1 table, available from JMC as RDB5B17)

Danish program for increasing on-site recycling and recovery of refrigerants as well as leak reduction

L. Weitzman (Acurex Corporation), **Evaluation of Refrigerant from Mobile Air Conditioners**, project summary EPA/600/S2-89/009, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, June 1989 (4 pages with 1 table, available from JMC as RDB5444)

refrigerant purity

Code of Practice for the Reduction of Chlorofluorocarbon Emissions from Refrigeration and Air Conditioning Systems (Code de Pratique Visant la Réduction des Émissions de Chlorofluorocarbures des Systèmes de Réfrigération et de Conditionnement d'Air), code of practice EPS 1/RA/1, Environment Canada, Ottawa, Ontario, Canada, March 1991 (76 pages with 2 tables, in English and French, RDB3505)

This code provides guidelines for reduction of atmospheric emissions of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) used in refrigeration and air-conditioning applications. It covers residential, commercial, and industrial refrigeration, heat pumps, and air conditioning, including mobile air conditioning. The code addresses design, manufacture, installation, servicing, use, recovery, handling, storage, disposal, and training. Three standards recommended by the Society of Automotive Engineers (SAE) are appended. They include *Recommended Service Procedure for the Containment of R-12* (J1989), *Extraction and Recycle Equipment for Mobile Automotive Air-Conditioning Systems* (J1990), and *Standard for Purity of Used Refrigerant in Mobile Air-Conditioning Systems* (J1991). A list of widely-used refrigerants, with chemical names, formulae, and ozone depletion potentials (ODPs) also is appended.

Containers for Recovered Fluorocarbon Refrigerants, ARI Guideline K-1990, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1990 (10 pages, available from ARI for $15.00, RDB3102)

This document provides recommendations for voluntary use by those who supply, use, store, or transport containers for recovered fluorocarbon refrigerants. It is intended as a guide of good practice to facilitate recovery, recycling, and reclamation of refrigerants, to in turn reduce environmental impacts. The need for containers designed and identified specifically for these uses stems from practical and safety considerations. The guideline identifies mandatory federal requirements in the United States, but it is neither an exhaustive listing nor does it address local requirements. It covers cylinders and ton tanks for R-12, R-22, R-114, R-500, and R-502 as well as drums for R-11 and R-113.

Handling and Reuse of Refrigerants in the United States, Industry Recycling Guideline IRG-2, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, December 1994 (16 pages with 1 figure and 1 table, available from JMC as RDB5133)

This manual provides procedures and guidelines to maintain the quality of refrigerants used in air-conditioning and refrigeration (ACR) equipment. It defines the terms "recover," "recycle," and "reclaim" and then identifies three options for refrigerant reuse. They include reuse of the refrigerant - without recycling - in the equipment from which it was removed, recycling the refrigerant into the system same or another system from the same owner, or reclaim of the refrigerant. Five considerations are discussed as a basis for selecting the appropriate action. They include the reason the system is being serviced, condition of the refrigerant and system, equipment manufacturers' policies, refrigerant cleaning capability of recycling equipment, and feasibility and owner's preference. A flow chart diagrams the decision process. The document indicates that used refrigerants shall not be sold, or used in a different owner's equipment, unless the refrigerant has been analyzed and found to meet the requirements of ARI Standard 700, "*Specifications for Fluorocarbon and Other Refrigerants*." The document also provides a table of maximum contaminant levels for recycled refrigerants in the same owner's equipment, and notes that the owner's consent should be obtained for such reuse. It provides guidance for identification and avoidance of mixed refrigerants (other than manufactured blends) as well as handling of blends with compositions that were altered by selective leakage. This guideline was developed by a broad base of interests, including refrigerant reclaimers, manufacturers, contractors, engineers, government, building owners and managers, and consumers. It responds to a mandated sunset provision in regulation of reused refrigerants. The underlying goal is indicated as protection of end users, consumers, and ACR products owned by consumers.

Refrigerant Recovery/Recycling Equipment, standard 740-1993, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1993 (20 pages with two figures and 4 tables, available from ARI for $15.00, RDB4944)

This standard establishes uniform methods of testing for rating and evaluating performance of equipment for refrigerant recovery and/or recycling. It addresses contaminant or purity levels, capacity, speed, and purge loss, the last to minimize emission into the atmosphere of refrigerants. The standard is intended for guidance of the industry, including manufacturers, refrigerant reclaimers, repackagers, distributors, installers, servicemen, contractors, and consumers. The refrigerants covered include R-11, R-12, R-13, R-22, R-113, R-114, R-123, R-134a, R-500, R-502, and R-503. It does not apply to zeotropic mixtures of these or other refrigerants. The standard covers general equipment requirements, specifies standard samples for testing, and outlines test apparatus. It prescribes a performance testing procedure, sampling and chemical analysis methods, performance calculations and rating, tolerances, and product labeling. The rating sample characteristics include contents of moisture, particulates, acids, mineral oil, and noncondensable gases. Schematic diagrams show the test apparatus for self-contained equipment and the configuration of a standard air-conditioning or refrigeration system for use as a test apparatus. An appendix specifies the particulate material to be used in standard contaminated refrigerant samples. Conformance with the standard is voluntary, but conformance may not be claimed unless all requirements of the standard are met.

Sealed-Tube Tests of Refrigerants from Field Systems Before and After Recycling, research project 683-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1991 - ongoing (ASH0683)

This project will quantify typical contaminant levels in refrigerants after oil separation, filtering, and drying. It also will determine the effects of contaminants at the concentrations found. The focus is on R-11 from centrifugal chillers, R-12 from commercial refrigeration systems, R-22 from unitary heat pumps, and R-502 from low-temperature commercial refrigeration systems. The work is an extension of ASHRAE research project 601-RP and is being performed by the same contractor, the University of Dayton Research Institute led by R. E. Kaufman. It is sponsored by ASHRAE Technical Committee

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3.3, *Contaminant Control in Refrigerating Systems.*

State of Knowledge Summary of Chlorofluorocarbon Handling Technologies: Destruction, Recycling, and Encapsulation, draft report for U.S. Department of Energy, E. A. Mueller Consulting Engineers, Baltimore, MD, May 1989 (65 pages, RDB1107)

Reducing Emission of Fully Halogenated Chlorofluorocarbon (CFC) Refrigerants in Refrigeration and Air-Conditioning Equipment Applications, ASHRAE Guideline 3-1990 plus addendum ASHRAE Guideline 3a-1992, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990 and 1992 (30 pages with 5 tables, RDB2911)

This guideline covers all refrigeration and air-conditioning equipment and systems that use fully halogenated CFC refrigerants. It recommends practices and procedures to reduce inadvertent release of CFC refrigerants during manufacture, installation, testing, operation, maintenance, and disposal of refrigeration and air-conditioning equipment and systems. It also covers refrigerant recovery, recycling, reclaim, and disposal.

Retrofit and Conversion

R. Brinkmann (York International GmbH, Germany), **Influence on the Transition of Chlorofluorocarbons to Alternative Refrigerants**, *Ki Luft- und Kältetechnik*, volume 31, number 10, pages 472-474, 1995 (3 pages in German, RDB6310)

technical, economic, and safety considerations; refrigerant selection

N. E. Carpenter (ICI Chemicals and Polymers, Limited), **Retrofitting HFC-134a into Existing CFC-12 Systems**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 6, pages 332-339, July 1992 (8 pages, RDB3739)

R-12, R-134a

H. T. Gilkey (Energy Consultant), **Refrigerant Management**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 66, number 1, pages 78-82 and 85-87, February 1993 (8 pages with 2 figures and 1 table, RDB4304)

This article outlines strategies to prolong equipment life through refrigerant conservation and reclamation and through conversion to alternative refrigerants. It cites the phaseout schedules for chlorofluorocarbon (CFC) refrigerants and consequent need to develop a refrigerant management program. The article outlines options to retain, convert, or replace systems and cites considerations in selecting among them. It also cites statistics on the inventory of existing equipment and then reviews steps to develop a management plan. The three key actions are identified as designating a corporate and/or facility refrigerant manager, conducting an inventory of equipment and refrigerants, and developing a plan for refrigerant conservation and utilization. The article explains these steps and refrigerant recovery options, including simple recovery, recycling, and reclaim. It also explains the terminology and designations being introduced for new refrigerants. The author concludes that the opportunity to implement effective refrigerant management is just about gone based on the phaseout schedule for CFCs.

R. L. Hall (Battelle) and M. R. Johnson (U.S. Air Force), **Alternatives to Ozone Depleting Refrigerants in Test Equipment**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 183-189, July 1994 (7 pages with 1 figure and 2 tables, RDB-4825)

This paper describes initial results of equipment retrofits to use hydrofluorocarbon (HFC) refrigerants. The equipment included environmental chambers, ultralow temperature freezers, coolant recirculators, a temperature control unit, a vapor degreaser, and a refrigerant recovery system. The conversions entailed replacement of R-12 and R-500 with R-134a, R-13 and R-503 with R-23, and R-502 with R-404A. The mineral oil lubricants were replaced with polyolesters, including Mobil EAL Arctic(R) 22 CC, ICI Emkarate(TM) RL 32S, and Castrol Icematic(R) SW32 based on recommendations of the compressor manufacturers; CPI Soltest(R) LT-32 was used with R-23. The paper outlines the refrigerants used, considerations in selecting alternatives and associated lubricants, concerns with materials compatibility, and the conversions steps followed. The paper indicates that system capacities and power requirements remained virtually unchanged, but that minimum operating temperatures increased slightly in some conversions, notably by 7 °C (12 °F) when replacing R-503 with R-23.

P. Lundqvist and L. Herbe (Kungl Tekniska Högskolan, KTH, Sweden), **CFC and HCFC Refrigerants Retrofit Experiences and Results**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, August 1995), International Institute of Refrigeration (IIR), Paris, France, 1995 (RDB6763)

Field Conversion/Retrofit of Products to Change to an Alternative Refrigerant - Construction and Operation, standard 2170, First Edition, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 17 September 1993 (20 pages with 2 tables, RDB3B06)

This standard contains requirements for safety engineers to evaluate the construction and operation of air conditioning and refrigeration equipment intended for field conversion/retrofit to an alternative refrigerant. The equipment covered include, but are not limited to, remote commercial refrigerators and freezers, unit coolers, condensing units, split-system central cooling air conditioners and heat pumps, and self-contained equipment. The self-contained group includes commercial refrigerators and freezers, ice makers, ice cream makers, room air conditioners, central cooling air conditioners, heat pumps, and liquid chillers. The standard sets out its scope, supplementary requirements, and general requirements for components. It also provides a glossary of terminology used and clarifies the applicable units of measurement and versions of referenced documents. It then specifies requirements relating to the construction of the refrigerating system, refrigerants, design pressures, parts subject to pressure, remote condensers and evaporators, pressure-limiting devices, and pressure relief devices. It also prescribes operational tests for unitary and self-contained equipment and for other equipment types. It concludes with requirements for identification including marking of retrofit equipment and possible notification of the authority having jurisdiction. A table specifies the minimum design pressures for the low-pressure side at 27 °C (80 °F) and high side at 41 and 52 °C (105 and 125 °F). It covers R-11, R-12, R-13, R-13B1, R-14, R-21, R-22, R-23, R-113, R-114, R-115, R-123, R-124, R-125, R-134a, R-C318, R-401A, R-401B, R-402A, R-402B, R-500, R-502, R-503, R-744 (carbon dioxide), and R-764 (sulfur dioxide). A second table specifies minimum wall thickness for steel tubing and for protected and unprotected copper tubing, from 6-67 mm (1/4 - 2-5/8").

Field Conversion/Retrofit of Products to Change to an Alternative Refrigerant - Insulating Material and Refrigerant Compatibility, standard 2171, First Edition, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 17 September 1993 (16 pages with 1 table, RDB3B07)

This standard contains test procedures to evaluate the compatibility of an alternative refrigerant with hermetic motor insulating materials and lubricants, for air conditioning and refrigeration equipment intended for conversion/retrofit to an alternative refrigerant. The equipment covered include, but are not limited to, remote commercial refrigerators and freezers, unit coolers, condensing units, split-system central cooling air conditioners and heat pumps, and self-contained equipment. The self-contained group includes commercial refrigerators and freezers, ice makers, ice cream makers, room air conditioners, central cooling air conditioners, heat pumps, and liquid chillers. The standard sets out its scope, supplementary requirements, and general requirements for components. It also provides a glossary of terminology used and clarifies the applicable units of measurement and versions of referenced documents. It then specifies three alternative performance requirements to determine the compatibility of an alternative refrigerant with materials used in the refrigerating system. The first entails testing in accordance with UL Standard 984 or CSA Standard C22.2. The second involves tests by compatibility exposures. The third allows investigation by accepted safety test methods judged equivalent to the preceding two options and that contain specific pass/fail criteria. The remainder of the standard prescribes tests for compatibility exposures, with primary attention to motor insulating materials and motorettes. Required tests are tabulated for magnet wire, helical coils, sheet insulation, lead wire, tie cord, sleeving, tapes, and motorettes. The tests include visual inspection, percent elongation, bond strength, dielectric breakdown, burnout strength, tensile properties, and voltage withstood. The number of samples and test (acceptance) criteria are indicated.

Field Conversion/Retrofit of Products to Change to an Alternative Refrigerant - Procedures and Methods, standard 2172, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 17 September 1993 (RDB3B08)

Forane(R) Retrofit Training Guide, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1993 (68 pages with 6 tables, available from JMC as RDB4771)

This manual provides a training guide on key issues and procedures associated with refrigerants that affect the air-conditioning and refrigeration industry. It begins with an update on regulations governing the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. It summarizes phaseout schedules under the Clean Air Act Amendments (CAAA) of 1990 for the United States and under the Montreal Protocol. A table indicates the CFC production reduction steps under the original Protocol, 1992 Copenhagen amendments, and CAAA. The document also summarizes CAAA and Protocol deadlines for related

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actions to reduce emissions of ozone-depleting substances. It then summarizes regulations for refrigerant handling and guidelines and standards associated with refrigerants. Those addressed include Underwriters Laboratories (UL) Guideline 2154 on equipment retrofit, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 15 on safety for mechanical refrigeration, and the Society of Automotive Engineers (SAE) J Standards that give guidelines for automotive applications. The manual then identifies Atochem's refrigerants and presents refrigerant management options. It provides suggestions for promoting retrofits, and discusses factors influencing justifications. The document then discusses lubricants for alternative refrigerants and tabulates the suitability of mineral oil, alkylbenzene, polyalkylene glycol, and polyolester lubricants for common and alternative refrigerants. It describes lubricant flushing procedures and provides a table on residual levels of mineral oil, based on starting concentrations and the number of flushes. The document presents terminology and designations for refrigerants, control and accessory compatibility, and desiccant compatibility. A table shows the suitability of UOP 4A-XH-5, 4A-XH-6, XH-7, and XH-9 molecular sieves with R-11, R-12, R-22, R-32, R-113, R-123, R-124, R-125, R-134a, R-143a, and R-152a. The document then presents general retrofit procedures for hermetic reciprocating-piston and scroll compressors from R-12 to R-409A and R-502 to R-404A, semi-hermetic reciprocating-piston compressors from R-12 to R-134a and R-502 to R-404A, screw compressors from R-12 to R-134a and R-502 to R-404A, centrifugal chillers from R-12 or R-500 to R-134a and R-11 to R-123, and automotive air conditioners from R-12 to R-134a. Eight appendices outline Atochem's refrigerant reclamation program, provide a glossary of terminology and retrofit checklist, outline the previously named guidelines and standards, and provide tabular data on refrigerant-lubricant system replacements and capacity changes for R-123, R-134a, R-404A, and R-409A. Elf Atochem's product names for the refrigerants are Forane(R) 11, 12, 22, 123, 134a, 404A (FX-70), FX-10 (408A), FX-56 (409A), 500, and 502.

Guide for the Field Conversion/Retrofit of Products to Change to an Alternative Refrigerant Using UL2170-2172, Underwriters Laboratories Incorporated, Northbrook, IL, 17 September 1993 (10 pages, available from JMC as RDB3B09)

Moving to Alternative Refrigerants: Ten Case Histories - Comfort Coolers, Industrial Process, and Commercial Refrigeration, report EPA 430-K-93-002, U.S. Environmental Protection Agency (EPA), Washington, DC, November 1993 (40 pages, available from JMC as RDB4141)

Appliances

Air Conditioners and Heat Pumps

B. S. Lunger, K. A. Geiger, T. L. Anglin, and S. Narayaman (DuPont Fluoroproducts), **Heat Pump / Air Conditioner Field Test Data for an HCFC-22 Alternative Containing HFC-32, HFC-125, and HFC-134a**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 25-30, July 1994 (6 pages with 5 tables, RDB4805)

R-407C [R-32/125/134a (23/25/52)], Suva(R) 9000 (formerly AC9000)

Chillers

A. M. Bell (McQuay International, then SnyderGeneral Corporation), **How to Convert CFC-12 Chillers to HFC-134a**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 4, pages 39-42, April 1993 (4 pages with 3 figures, RDB3457)

E. M. Clark, G. G. Anderson, and W. D. Wells (DuPont Chemicals), **Retrofitting Existing Chillers with Alternative Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 33, number 4, pages 38-41, April 1991 (4 pages with 1 table, RDB5549)

R-123, R-134a, conversion, performance, compatibility

E. D. Lawler, **HFC-134a vs R-12 Centrifugal Chiller Performance Comparison**, McQuay International (then SnyderGeneral Corporation), Staunton, VA, 22 August 1990 (1 page with 1 table, available from JMC as RDB0801)

The performance of a 100-ton, single-stage, hermetic centrifugal water chiller is compared for R-12 and R-134a. Both tests were run at standard rating conditions (ARI Standard 550-88) with the chiller operating at its maximum capacity. The compressor gears were changed to increase the impeller speed to accommodate the greater isentropic head rise required with R-134a. The low-pressure cut-out switch and thermostatic expansion valve were adjusted after changing refrigerants, but other hardware and control settings were the same for both tests.

The capacity and efficiency increased with R-134a, by 0.8 and 4%, respectively.

E. D. Lawler, **HFC-134a vs R-500 Centrifugal Chiller Performance Comparison**, McQuay International (then SnyderGeneral Corporation), Staunton, VA, 29 August 1990 (1 page with 1 table, available from JMC as RDB0802)

The performance of a 112-ton, single-stage, hermetic centrifugal water chiller is compared for R-500 and R-134a. Both tests were run at standard rating conditions (ARI Standard 550-88) with the chiller operating at its maximum capacity. The chiller initially was tested with R-500 as a baseline and then recharged with R-134a. The lubricant was changed from a naphthenic mineral oil (Witco Suniso(R) 4GS) to an ester (Mobil XRL 1681-1). The low-pressure cut-out switch and thermostatic expansion valve were adjusted after changing refrigerants, but other hardware and control settings were the same for both tests. A third test was run with the impeller replaced to provide higher flow. The compressor gears were changed for a fourth test to increase the impeller speed. The capacity with R-134a decreased by 9.9, 1.3, and 4.1% for the three tests and the efficiency decreased by 2.8 and 0.5% for the second and fourth tests, but increased by 0.1% for the third.

W. A. Phillips (York International Corporation), **Refrigerant Retrofits: An Overview**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 4, pages 33-37, April 1993 (5 pages with 7 figures, RDB3456)

B. Seibert (The Trane Company), **How to Convert CFC-11 Chillers to HCFC-123**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 4, pages 45-50, April 1993 (6 pages with 5 figures, RDB3458)

S. G. Sundaresan and R. W. Griffith (Copeland Corporation), **Retrofitting CFC-12 and R-502 Commercial Refrigeration Equipment**, unpublished presentation at the International CFC and Halon Alternatives Conference, Washington, DC, 30 September 1992 (4 pages with 1 figure and 2 tables, available from JMC as RDB4306)

This paper outlines an approach for retrofit of commercial equipment from R-12 or R-502 to either a hydrochlorofluorocarbon (HCFC) or HCFC blend or to a hydrofluorocarbon (HFC) or HFC blend alternative. The paper identifies three verification areas before retrofit: 1) performance, leaks, required oil level, refrigerant-lubricant color and acidity, and operation, 2) materials compatibility, and 3) regulatory compliance and safety approvals. It then discusses refrigerant properties to assure suitability. It suggests that manufacturers be consulted to determine the proper refrigerant charge and operating parameters. The paper discusses considerations for lubricant selection and again recommends consultation with the compressor manufacturer, to determine both selections and cleaning procedures. It reviews typical procedures and provides data from five case histories, to illustrate residual mineral oil concentrations for 1-5 flushes. The authors conclude that retrofit can be successful if recommended procedures are followed; that pending further retrofit experience, sampling and analysis of refrigerants and lubricants is recommended; that knowledge of prior service history is a key requirement; and that shortcuts should be avoided. Tables summarize available refrigerants and lubricants for retrofits.

Retrofitting CFC 12 Systems with Klea(TM) 134a and Emkarate RL Synthetic Lubricants, ICI Americas Incorporated, New Castle, DE, undated circa 1992 (6 pages with 2 tables, available from JMC as RDB3907)

This document provides information to assist equipment manufacturers and system owners in the conversion of R-12 systems to R-134a. It is based on a comprehensive program of refrigerant and lubricant compatibility studies. The document reviews reasons why R-134a is an important retrofit candidate. They include extension of equipment life beyond the phase out date of R-12, thermodynamic similarity of these two fluids, economic advantages as R-12 costs rise, and avoidance of replacement or conversion delays when R-12 shortages occur. The document reviews lubrication, system modifications, and system chemistry as considerations in retrofits. It then discusses lubrication reliability, compressor reliability, system cooling performance, and energy efficiency after retrofit. The document briefly summarizes two case studies. The first involved a 300 ton Snyder-General McQuay centrifugal chiller, from R-500 and mineral oil to R-134a and an ester based lubricant, without a gear change. The capacity decreased by 15.4%, but could be increased with a change in impeller speed. The efficiency improved slightly. The second study involved a large heat pump in Hammarby (Stockholm) Sweden, also from R-500 to R-134a. With changes to the centrifugal compressor, the retrofit system is proving to be at least as efficient with R-134a. The document concludes with a tabular comparison of R-12 and R-134a properties.

Suva(R) 123 (Suva Centri-LP, HCFC-123) in Chillers, document ART-2 (H-42443), DuPont

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Chemicals, Wilmington, DE, October 1992 (8 pages with 6 tables, available from JMC as RDB4504)

This bulletin discusses use of R-123 in new and retrofit chillers. It briefly introduces R-123 as one of the alternatives to replace chlorofluorocarbon (CFC) refrigerants. A table compares the boiling point, flammability, exposure limit, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP) for R-11 and R-123. The bulletin identifies general considerations for chiller conversions, indicating that alternative refrigerants cannot simply be "dropped into" systems designed for CFCs. Comparative ranges are provided for capacity, coefficient of performance (COP), evaporator and condenser pressures, and discharge temperature for R-123 relative to R-11. The usual changes in capacity and COP are indicated as -5 to -20% and 0 to -5%, respectively. The bulletin then outlines chemical compatibility considerations, and illustrates differences with a table comparing R-11 and R-123 compatibility with plastics, after exposures at 24 and 54 °C (75 and 130 °F). They include linear polyethylene (DuPont Alathon(R) 7150), polypropylene (Alathon(R) 9140), acetal resin (DuPont Delrin(R)), ABS polymer (USS Chemicals Krylastic(R)), polycarbonate (General Electric Lexan(R)), methyl-methacrylate (DuPont Lucite(R)), polyvinyl chloride (PVC), polystyrene (Dow Chemical Styron(R)), fluoropolymer resin (DuPont Teflon(R) TFE), and nylon (DuPont Zytel(R) 101). A separate table provides compatibility data with elastomers, including urethane (Uniroyal Adiprene(R) C), hydrocarbon rubber (DuPont Nordel(R)), natural rubber, butyl rubber, Buna N and S, neoprene W, fluoroelastomer (DuPont Viton(R) A), polysulfide (Morton Thiokol(R) FA), silicone, and chlorosulfonated polyethylene (DuPont Hypalon(R) 48). The bulletin also discusses lubricants, noting that those currently used with R-11 are fully miscible with R-123 for expected conditions. It cites stability tests with metals, including steel 1010, copper, and aluminum; the tabulated findings show that R-123 is more stable than R-11. The bulletin then reviews recommended handling and operating procedures, specifically addressing storage, charging, maintenance, sampling, leaks, and spills. The bulletin outlines factors for chiller retrofit from R-11 to R-123. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document then describes a retrofit program, with major equipment manufacturers, to convert DuPont's large chillers from CFCs to alternative refrigerants. It reviews field experience with three case histories, the first involving retrofit of a 1670 kW (475 ton), York open-drive chiller converted to R-123 in September 1988. Monitoring and refrigerant and lubricant sampling are described, along with measurements of machine room concentrations. Typical concentrations of 1 ppm - even during refrigerant removal and recharging - are indicated, with spikes of approximately 8 ppm when making or breaking hose connections. Two other machines at the same site were converted in May/June 1990. The second case history involved conversion of a 3517 kW (1000 ton), Carrier chiller in February 1988. Tests showed 18% loss in capacity, restored with replacement of the impellers at a tradeoff of 13% in efficiency. Measured exposure levels of 1-2 ppm are noted, with spikes as high as 20 ppm during maintenance. A 2110 kW (600 ton), Trane hermetic chiller conversion in October 1990 also is summarized. Although field data were not then available, the capacity was predicted to remain unchanged and the efficiency to drop slightly. Normal machine room concentrations of 1-2 ppm were found. DuPont's product names for R-123 in chillers are Suva(R) 123 and Suva(R) Centri-LP.

Suva(R) 134a (Suva Cold MP, HFC-134a) in Chillers, document ART-3 (H-42444-1), DuPont Chemicals, Wilmington, DE, January 1994 (6 pages with 5 tables, available from JMC as RDB4509)

This bulletin discusses use of R-134a in new and retrofit chillers. It briefly introduces R-134a as one of the alternatives to replace chlorofluorocarbon (CFC) refrigerants. A table compares the boiling point, flammability, exposure limit, ozone depletion potential (ODP), and halocarbon global warming potential (HGWP) for R-12 and R-134a. The bulletin identifies general considerations for chiller conversions, indicating that alternative refrigerants cannot simply be "dropped into" systems designed for CFCs. Comparative ranges are provided for capacity, coefficient of performance (COP), evaporator and condenser pressures, and discharge temperature for R-134a relative to R-12. The usual changes in capacity and COP are indicated as -10 to +2% and -8 to +2%, respectively. The bulletin then outlines and tabulates chemical compatibility considerations, and illustrates differences with a table comparing R-12 and R-134a compatibility with elastomers after exposures at 25, 80, and for some 141°C °C (77, 176, and 285 °F). They include urethane (Uniroyal Adiprene(R) C), Buna N and S, butyl rubber, chlorosulfonated polyethylene (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone, polysulfide (Morton Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). The bulletin also discusses lubricants and contrasts polyalkylene

glycol (PAG) and polyolester (POE) synthetics to mineral oils (MO). A table indicates the temperature ranges from -50 to 93 °C (-58 to 200 °F) for solubility of R-134a in naphthenic and paraffinic MO, alkylbenzene and dialkylbenzene, two PAGs, and four POEs. The bulletin outlines factors for chiller retrofit from R-12 and R-500 to R-134a. It notes that requirements may range from a minimum effort, such as lubricant replacement, to significant changes, such as replacing gears, impellers, or materials of construction. The document describes a retrofit program, with major equipment manufacturers, to convert DuPont's large chillers from CFCs to alternative refrigerants. It then reviews field experience with a 3460 kW [probably 2460 kW] (700 ton), York International TurboPak(R) centrifugal chiller, converted to R-134a and an unidentified 300 SUS PAG lubricant in November 1989. Subsequent inspections and a second retrofitting of the drive gear, in the spring of 1990, are described, indicating satisfactory operation with a decrease in efficiency of up to 7% and an increase in capacity of up to 9%. The document also discusses conversion of a Carrier open-drive, R-12 chiller rated at 4224 kW (1200 ton) to R-134a with a PAG in December 1990; the gear set was changed in the spring of 1991. A maintenance problem with the lubricant oil pump and slight wear in the compressor journal bearings were found. While the cause was not ascertained, the lubricant was changed to a POE, indicated as less sensitive to residual chlorides. A third case history involved a 10,560 kW (3000 ton) open drive, York R-500 chiller with naphthenic MO. It was converted to R-134a with a POE in April 1991; preliminary testing confirmed that a gear change was not needed. A fourth was with a 10,560 kW (3000 ton) open drive, Carrier 17DA chiller, for which the external gear set was replaced to increase the speed by 13%. The R-12 and naphthenic MO were replaced with R-134a and a POE in April 1991. The efficiency and capacity were increased, the latter by 7%. A fifth case involved conversion of a 7040 kW (2000 ton) Worthington 52EH chiller, from R-12 and MO to R-134a and POE in July 1992. After overhaul and a speed increase, the capacity and efficiency increased by 2 and 10%, respectively. This case was unique in several respects, since this chiller design is limited in operating pressure and condenser replacement may be required for other machines. Also, the chiller had not been overhauled since its original installation in 1965. The bulletin mentions flushing with R-11 for the first two retrofits and with POE for the remainder. Also, the lubricant viscosity had to be increased in the last two to reduce operating pressures. The bulletin indicates that monitoring is continuing. DuPont's product names for R-134a refrigerant are Suva(R) 134a and Suva(R) Cold MP.

Commercial Refrigeration

D. Arnaud, J. C. Tanguy, P. Weiss (Elf Atochem S.A., France), G. D. Rolotti (Elf Atochem North America), and M. Vauthier (Association pour la Formation Professionnelle des Adultes, AFPA, France), **An Example of R-502 Retrofit with Forane(R) FX 10 in Commercial Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 177-186, October 1993 (10 pages with 6 figures and 3 tables, RDB3A40)

FX10, R-143a/22

M. R. Brubaker, G. D. Rolotti, and P. F. Radice (Elf Atochem North America), **Practical Interim Solutions for Existing R-12 and R-502 Installations: Technical Data and Case Studies on R-409A and R-408A**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 225-233, October 1995 (9 pages with 5 figures and 3 tables, available from JMC as RDB5A63)

R-408A, R-409A, lubricant miscibility, flammability, fractionation, efficiency, retrofit, vending machine, commercial ice maker

J. J. Byrne (Integral Sciences, Incorporated), **Investigation of Flushing and Clean-Out Methods for Refrigeration Equipment to Ensure System Compatibility**, report DOE/CE/23810-51F, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 15 December 1994 (16 pages with 2 tables, available from JMC as RDB5803)

This report addresses a procedure to remove mineral oil from a refrigeration system for conversion to R-134a. It notes that R-134a is immiscible with the oil, leading to impeded oil return and interference with refrigerant flow and heat transfer. The method uses a low-side, oil separator to prevent oil from contaminating the new polyolester (POE) lubricant. It is described as requiring less time and materials compared to the prevailing "triple-flush" approach, without compromising the reliability of the result. The report describes a 12 kW (3 ton) test system, employing a bolted hermetic reciprocating compressor. It also describes the system preparation and oil measurement methods used. It then outlines both the triple-flush and advanced methods. The report notes that the advanced method requires increased effort to install and

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remove additional components, but eliminates two site visits. It notes a second drawback of transfer of most of the oil from high-side separators to the system, a problem circumvented with use of 99.994% efficient separators. The report describes and a table compares the materials and labor for a "triple flush" and three variants of the advanced method. A second table adds comparisons of the waste generated and site visits required. The low-side, oil separator method shows cost savings of 5-15%. The report identifies three planned field tests, two with R-12 to R-134a and a one entailing an R-502 conversion.

S. Corr (ICI Chemicals and Polymers, Limited), T. W. Dekleva, and A. L. Savage (ICI Americas, Incorporated), **Retrofitting Large Refrigeration Systems with HFC-134a**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 34, number 2, pages 29-33, February 1992 (5 pages with 3 figures and 2 tables, RDB3303)

S. Corr, R. D. Gregson, G. Tompsett (ICI Chemicals and Polymers, Limited), A. L. Savage and J. A. Schukraft (ICI Americas, Incorporated), **Retrofitting Large Refrigeration Systems with R-134a**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 221-230, July 1992 (10 pages; expanded reprint available from JMC, 14 pages with 7 figures and 1 table, RDB2724)

J. P. Davey and C. C. Mulliss (Rhône-Poulenc Chemicals Limited, UK), **Field Experience in Retrofitting Isceon 134a and Isceons 69-S and 69-L**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and Institute of Refrigeration, London, UK, 11 November 1992 (13 pages with 1 figure and 7 tables, available from JMC as RDB3331)

R-134a, R-403A, and R-403B

D. H. Walker, **Medium-Temperature Supermarket Refrigeration Conversion from CFC-12 to HCFC-22 (R-12 to R-22)**, report TR-101265, Electric Power Research Institute (EPRI), Palo Alto, CA, December 1992 (78 pages with 8 figures and 24 tables, RDB3616)

Klea(R) 60, Replacement for R-502 in New and Existing Equipment, technical note 620250450, ICI Americas Incorporated, Wilmington, DE, October 1993 (8 pages with 3 tables, available from JMC as RDB3A61)

This document describes R-407A, a ternary, zeotropic blend of R-32, R-125, and R-134a (R-32/125/134a), developed as a replacement for R-502 for commercial and transport refrigeration. The technical note summarizes the phase out of chlorofluorocarbon (CFC) refrigerants, the need for alternatives to R-502, and ICI's search for likely replacements. It then compares the atmospheric lifetimes, ozone depletion potentials (ODPs) and halocarbon global warming potentials (HGWPs) of R-22, R-32, R-125, R-134a, R-502, and the R-32/125/134a blend. It also provides a tabular comparison of the physical properties, at the normal boiling point, and theoretical performance between R-502 and the blend. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite the R-32 content. The bulletin also discusses handling and leakage and states that composition changes are anticipated to be less serious than had been expected. It discusses appropriate lubricants, with focus on the ICI Emkarate(R) family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability and toxicity specifics, blend design information, handing and storage advice, and retrofit case studies. ICI's product name for R-407A is Klea(R) 60.

Klea(R) 61, Replacement for R-502 in New and Existing Equipment, technical note 620250460, ICI Americas Incorporated, Wilmington, DE, October 1993, reprinted April 1994 (8 pages with 3 tables, RDB3A62)

This document describes R-407B, a ternary, zeotropic blend of R-32, R-125, and R-134a (R-32/125/134a), developed as a replacement for R-502 for commercial and transport refrigeration. It is specifically targeted for R-502 retrofit applications operating at high lift, for example -40 °C (-40 °F) evaporating and 40 °C (105 °F) or higher condensing. It may also be suited for use in hermetic compressors where discharge temperature is a critical parameter. The technical note summarizes the phase out of chlorofluorocarbon (CFC) refrigerants, the need for alternatives to R-502, and ICI's search for likely replacements. It then compares the atmospheric lifetimes, ozone depletion potentials (ODPs) and halocarbon global warming potential (HGWPs) of R-22, R-32, R-125, R-134a, R-502, and the R-32/125/134a blend. It also provides a tabular comparison of the physical properties, at the normal boiling point, and theoretical performance between R-502 and the blend. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite the

R-32 content. The bulletin also discusses handling and leakage and states that composition changes are anticipated to be less serious than had been expected. It discusses appropriate lubricants, with focus on the ICI Emkarate(R) family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability and toxicity specifics, blend design information, handing and storage advice, and retrofit case studies. ICI's product name for R-407B is Klea(R) 61.

"Klea(R) 407C ("Klea(R) 66), Replacement for HCFC-22", technical note 620250471, ICI Klea Incorporated, Wilmington, DE, January 1995 (12 pages with 2 figures and 3 tables, limited copies available from JMC as RDB6B35)

This document describes and provides data on R-407C, a ternary, zeotropic blend of R-32, R-125, and R-134a [R-32/125/134a (23/25/52)], developed as a replacement for R-22 in new equipment. The technical note summarizes the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, the need for alternatives to R-22, and ICI's search for likely replacements. It then compares atmospheric lifetime, ozone depletion potentials (ODP) and halocarbon global warming potential (HGWP) data for R-22, R-32, R-125, R-134a, and R-407C. It also provides a comparison of physical properties, at the normal boiling point, and theoretical performance comparison between R-22 and the blend. Two plots compare the coefficient of performance (COP) and cooling capacity, for evaporator temperatures of -20 to 10 °C (-4 to 50 °F) for R-22 and the blend. They show the blend's performance to be equal to, or slightly better than that of R-22. The document then discusses the flammability and toxicity of both the blend and its components, noting that the composition was designed to be nonflammable despite its R-32 content. The bulletin briefly reviews handling and leakage. It advises that the blend always should be liquid charged into systems, and that investigation has shown that degradation of performance will not be significant with anticipated leakage. The document next discusses appropriate lubricants, with focus on the ICI Emkarate(R) RL family of synthetic, neopentyl polyolesters. Several documents are cited as available or under preparation to provide thermophysical properties, flammability specifics, blend design information, handing and storage advice, and retrofit guidance. ICI's product name for R-407C is Klea(R) 407C (formerly Klea(R) 66).

Retrofit Changeover Guidelines - CFC-12 to HFC-134a, form 93-04-R1, Copeland Corporation, Sidney, OH, April 1993 (4 pages with 1 table, available from JMC as RDB3714)

R-12 to R-134a

Retrofit Changeover Guidelines - CFC-12 to MP39, form 93-02-R1, Copeland Corporation, Sidney, OH, April 1993 (8 pages with 2 tables, RDB-3715)

R-12 to R-401A

Retrofit Changeover Guidelines - CFC-12 to MP66, form 93-03-R1, Copeland Corporation, Sidney, OH, April 1993 (8 pages with 2 tables, RDB-3716)

R-12 to R-401B

Retrofit Changeover Guidelines - CFC-12 to Suva(R) HP80, form 93-05, Copeland Corporation, Sidney, OH, June 1993 (8 pages with 2 tables, RDB3717)

R-12 to R-402A

Retrofit Guidelines for Suva(R) HP62, document ART-22 (H-53019), DuPont Chemicals, Wilmington, DE, January 1994 (8 pages with 2 tables, available from JMC as RDB4510)

This bulletin provides guidance on retrofit of R-502 equipment with R-404A - R-125/143a/134a (44/52/4) - in medium and low temperature refrigeration applications. It briefly reviews the properties and safety of the two refrigerants and provides a table comparing their boiling points, vapor pressures and liquid densities at 25 °C (77 °F), vapor densities at -15 °C (5 °F), ozone depletion potentials (ODP), global warming potentials (GWP), capacities, and efficiencies. The bulletin outlines lubricant selection criteria, and notes that polyolester (POE) lubricants are recommended for most hydrofluorocarbon (HFC) systems. It offers guidance on handling POEs and the impacts of residual mineral oil. The bulletin identifies retrofit modifications, including consideration of compatibility with plastics and elastomers, but notes that minimal changes are anticipated. As for lubricants, it recommends that the materials involved be reviewed with the equipment manufacturer before retrofit. The refrigerant is indicated as suited for use in such applications as food service, commercial refrigeration, and transport refrigeration. The bulletin discusses suitability considerations and provides guidance in choosing among selected retrofit alternatives. It provides an overview of the retrofit process and identifies equipment and supplies needed. An inset notes the conditions under which Copeland Corporation approves the use of R-402A and R-404A and that excess pressure, possibly resulting in an explosion,

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could result without a properly installed, appropriate pressure relief valve. The bulletin then presents an eight-step retrofit procedure accompanied by a retrofit checklist and system data sheet to facilitate the process. It also provides a pressure-temperature chart, in metric (SI) and inch-pound (IP) units, covering 25-2900 kPa and -71 to 61 °C (-25 to 400 psig and -107 to 140 °F). DuPont's product name for R-404A is Suva(R) HP62.

Retrofit Guidelines for Suva(R) HP80, document ART-9 (H-45947-2), DuPont Chemicals, Wilmington, DE, December 1993 (10 pages with 2 tables, available from JMC as RDB4506)

R-402A

Retrofit Guidelines for Suva(R) HP81, document ART-15 (H-47763-1), DuPont Chemicals, Wilmington, DE, March 1993 (10 pages with 1 table, available from JMC as RDB4507)

R-402B

Retrofit Guidelines for Suva(R) MP39 and Suva(R) MP66, document ART-5 (H-42446-2), DuPont Chemicals, Wilmington, DE, December 1993 (14 pages with 4 tables, available from JMC as RDB4505)

R-401A and R-401B

Retrofit Guidelines for Suva(R) 134a (Suva(R) Cold MP) in Stationary Equipment, document ART-16 (H-47761-1), DuPont Chemicals, Wilmington, DE, January 1993 (H-47761), revised March 1993 (8 pages with 1 table, available from JMC as RDB3447)

This bulletin provides guidance on retrofit of R-12 equipment with R-134a in commercial refrigeration, air conditioning, medium temperature appliances, and chillers using both positive displacement and dynamic compressors. The bulletin notes that R-134a may be used in lower evaporator temperature applications, but may result in reduced capacity. It cautions that R-134a should not be used in conjunction with other refrigerants, and specifically not added to an R-12 charge, since the mixture can form a high pressure azeotrope that could cause damage. The bulletin outlines lubricant selection criteria, and notes that polyolesters are recommended for most R-134a systems. It offers guidance on handling polyolesters and the impacts of residual mineral oil. The bulletin identifies retrofit modifications, including consideration of compatibility with plastics and elastomers, but notes that minimal changes are anticipated. It provides an overview of the retrofit process and identifies equipment and supplies needed. It then presents a ten-step retrofit procedure accompanied by a retrofit checklist and system data sheet to facilitate the process. It also provides a pressure-temperature chart in metric (SI) and inch-pound (IP) units covering 25-3600 kPa and -53 to 95 °C (-15 to 300 psig and -40 to 160 °F). DuPont's product names for R-134a are Suva(R) 134a and Suva(R) Cold MP.

Heat Pumps for District Heating

K. Berglöf (AKA Kyla AB, Sweden) and A. Bertelsen (Marketing Communications AB, Sweden), **Replacing CFC-12 in the World's Largest Heat Pumps**, *IEA Heat Pump Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 32-34, March 1995 (3 pages with 1 figure, RDB5690)

R-12 to R-134a conversion, Ryaverket, Göteborg, Sweden

T. W. Dekleva (ICI Americas, Incorporated), B. Durr, P. D. Guy (ICI Chemicals and Polymers, Limited, UK), L. Petersson, and T. Widgren (ABB STAL AB, Sweden), **Retrofit of a Swedish District Heat Pump from R-500 to Klea(R) 134a**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 203-210, October 1993 (8 pages with 3 figures and 4 tables, RDB-3A43)

R-500 to R-134a

T. Widgren with preface by L. Petersson, **Conversion to HFC-134a in a 25 MW Heat Pump, Hammarby, Sweden**, report RT-IST-51/92, ABB STAL AB, Finspång, Sweden, September 1992 (28 pages with 13 figures and 2 tables, RDB2B10)

This report summarizes conversion of a large heat pump, for district heating, from R-500 to use of R-134a and the first subsequent year of operating experience. The report reviews both use of large heat pumps in Sweden and corresponding use of refrigerants. It then reviews specific considerations for this conversion, including a description of the heat pump and its two-stage, centrifugal compressor. The thermophysical properties of alternative refrigerants are outlined, with emphasis on projected performance with R-134a. Equipment modifications for the conversion are described, including a summary of compatibility considerations with the new refrigerant and polyalphaoleofin (PAO) lubricant. The conversion, start up, and added refrigerant leak monitors are reviewed. Operational experience for 1991/1992 is discussed, including capacity, efficiency, availability, refrig-

erant and lubricant sampling, sealants, and leakage. The report concludes that the conversion was successful. The heat pump ran for 6,641 hours of operation and 148 GWh (0.5 trillion Btu) of production at output temperatures sometimes exceeding 90 °C (194 °F). There were no unplanned outages. Peak capacity is 2-4% lower with R-134a than with R-500, leading to an annual reduction in output of 1.4%. Efficiency is essentially the same. [This conversion is believed to be the largest single use of R-134a to date.]

Industrial Heat Pumps

B. Hivet and C. Gillet (Électricité de France, ÉDF, France), **HFC-134a and HCFC-22/142b Mixture for Conversion of CFC-12 Heat Pumps**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 159-164, July 1994 (6 pages with 4 figures, RDB-4821)

R-134a, R-22/142b

Industrial Refrigeration

D. Arnaud (Elf Atochem S.A., France) and G. D. Rolotti (Elf Atochem North America, USA), **An Example of Successful CFC-12 Retrofit with HFC-134a in the Industrial Field**, *Stratospheric Ozone Protection for the 90's (*proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 193-202, October 1993 (10 pages with 3 figures and 5 tables, RDB3A42)

Mobile Air Conditioners

M. W. Abel (Integral Sciences Incorporated), **Flushing Solvent Criteria for Mobile A/C Systems**, conference presentation (Mobile Air Conditioning Society (MACS) Annual Meeting, New Orleans, LA, 28 January 1995); published as paper DOE/CE/23810-56, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (21 pages with 2 figures, available from JMC as RDB5342)

A series of presentation charts outlines an investigation of and criteria for selection of a flushing solvent, for retrofit of mobile air-conditioning (MAC) systems. The cleanout is needed when converting from R-12 with mineral oil to R-134a and a suitable lubricant. A chart identifies seven requirements, namely compatibility with system materials, ease of removal, minimal (ideally zero) ozone depletion potential (ODP), low flammability, low toxicity, cost effectiveness, and ease of recycling and ultimate disposal. Further charts describe flushing procedures using liquid R-12 and terpenes. Others outline the Environmental Protection Agency (EPA) Solvent Alternatives Guide (SAGE), a computer program that suggests replacements for chlorinated solvents based on responses to a series of questions. The SAGE process and chemical alternatives are identified. Presentation comments note that SAGE recommendations manifest a high tolerance for aqueous and flammable solvents as well as those requiring complex methods. The presentation then lists solvent requirements and acceptable solvents under the EPA Significant New Alternatives Program (SNAP). It also discusses observations on commercially-available solvents, noting that they are either aqueous, flammable, have high boiling points, or are unacceptable under SNAP. Of the more than 1000 organic compounds screened, all fail one or more of the ideal requirements. Charts summarize complexities of solvent removal, for example from dead spots in the system and evaporation difficulty. Two plots compare the volume of a fixed weight of 14 solvents, to suggest an index of solvent removal difficulty. They include R-12, R-13l1, R-22, R-113, R-123, R-141b, R-290 (propane), R-502, acetone, and hexane. B-pinene, d-limonene, and water also are included, but shown to be much more difficult to remove.

W. Atkinson (Sun Test Engineering), **Mobile Air Conditioning Overview**, *Stratospheric Ozone Protection for the 90's (*proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 269-274, October 1993 (6 pages, RDB3A47)

H. Ax (Sanden International, Incorporated, USA), N. Jingu, and S. Komatu (Sanden Corporation, Japan), **The Development of a Retrofitting Procedure for CFC-12 Automotive A/C Systems to HFC-134a and P.A.G. Lubricant**, paper 932906 (SAE Worldwide Passenger Car Conference and Exposition, Dearborn, MI, 25-27 October 1993), Society of Automotive Engineers (SAE), Warrendale, PA, 1993 (12 pages with 8 figures and 18 tables, RDB5135)

R-134a, mobile air-conditioning (MAC) systems, retrofit conversion

S. H. Colmery, T. W. Dekleva, and C. L. Jarrell (ICI Klea), **Studies on the Condition of Vehicle Air Conditioning Systems - Two Years After Retrofitting HFC-134a**, paper 940599 (SAE International Congress and Exposition, Detroit, MI, 28 February -

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3 March 1994), Society of Automotive Engineers (SAE), Warrendale, PA, pages 67-72, 1994 (6 pages, RDB4A25)

R-134a, mobile air-conditioning (MAC) systems

S. Corr, E. Goodwin, R. D. Gregson, A. Halse, A. Lindley (ICI Chemicals and Polymers, Limited), S. H. Colmery, T. W. Dekleva, and R. Yost (ICI Americas, Incorporated), **Ester Lubricants for Use with HFC-134a Retrofit Applications**, seminar presentation at the Society of Automotive Engineers (SAE) International Congress and Exposition (Detroit, MI), ICI Americas Incorporated, New Castle, DE, 25 February 1992 (22 pages with 23 charts, RDB2619)

This document provides the presentation charts and text for an update on retrofit of mobile air air-conditioning (MAC) systems. The presentation reviews the basis for selection of R-134a including consideration of performance, avoidance of ozone depletion, and safety. The lubricant used is identified as a fundamental issue in retrofitting MAC systems with R-134a. Properties of two candidate esters and sealed-tube test results, including both mineral oil and R-12 as contaminants, are reviewed. One finding is that the lubricants impact the materials examined more than the refrigerants. Volume change (swell) is plotted for R-12 with mineral oil, the same pair followed by R-134a with a polyolester, and R-134a with the ester alone for nine elastomers. They include chlorosulfonated PE, EPDM, EPDM-O, EPDM-S, fluoropolymer, HNBR, natural rubber, neoprene, and nitrile. Compressor tests to examine the suitability of the fluids are summarized; the tests included high contaminant levels to approximate those expected in retrofits. A rating system to gauge wear is outlined. Fleet trials conducted in Australia are summarized, noting anecdotal suggestions that R-134a may provide improved performance. While much more study is needed, the esters tested appear promising for use with R-134a in MAC system retrofit.

P. G. Gott, **Automotive Air-Conditioning Refrigerant Service Guide**, Society of Automotive Engineers (SAE), Warrendale, PA, and Mobile Air Conditioning Society (MACS), East Greenville, PA, September 1992 (RDB3735)

This publication details proper service procedures involving refrigerants for automotive air conditioners for service technicians. It addresses issues such as how to avoid refrigerant contamination. It also contains the complete text of Society of Automotive Engineers (SAE) standards applicable to R-12 and R-134a recycling and service. They include "Recommended Service Procedure for the Containment of R-12" (standard J1989), "Standard of Purity for Use in Mobile Air-Conditioning Systems" (J1991), "Standard of Purity for Recycled HFC-134a for Use in Mobile Air-Conditioning Systems" (J2099), "Service Hoses for Automotive Air Conditioning" (J2196), "HFC-134a Service Hose Fittings for Automotive Air-Conditioning Service Equipment" (J2197), "Recommended Service Procedure for the Containment of HFC-134a" (J2211), and "Safety and Containment of Refrigerants" (J639).

Y. Z. R. Hu, C. H. Chang, W. F. Sung, and C. L. Shyu (Industrial Technology Research Institute, ITRI, Taiwan), **Current Development of Retrofitting Mobile Air Conditioning System in Taiwan**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 516-525, October 1995 (10 pages with 5 tables, available from JMC as RDB5B21)

R-12 to R-134a and R-401C, retrofit of automotive air conditioners

G. Rolotti (Elf Atochem North America, Incorporated), **Issues and Findings Over 2 Years of MAC Retrofits**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 526-535, October 1995 (10 pages with 1 figure and 2 tables, available from JMC as RDB5B22)

R-12 to R-134a retrofit of mobile air-conditioning (MAC) system, refrigerant losses, failures, user perceptions, flushed versus non-flushed results

A. M. Smith, M. C. Beggs, and B. D. Greig (Castrol Limited), **Experience of Retrofitting Automotive Air-Conditioning from CFC-12 to HFC-134a**, paper 930292 (SAE International Congress and Exposition, Detroit, MI, 1-5 March 1993), Society of Automotive Engineers (SAE), Warrendale, PA, March 1993 (8 pages with 1 figure and 4 tables, RDB3504)

This paper describes the development of and presents a procedure for retrofit of mobile air conditioners. The conversion addressed is from R-12 and mineral oil to use of R-134a and a polyolester (POE) based lubricant, Castrol Icematic(R) SW100. The paper reviews requirements for retrofit lubricants for R-134a, covering miscibility, thermal and hydrolytic stability, lubricating properties, and compatibility with elastomers. Miscibility is discussed in terms of matching that for conventional mineral oil systems, including the influences of residual mineral oil. Sealed-tube tests with copper, steel, and aluminium coupons in refrigerant-lubricant systems were performed; no reactions or cop-

per plating were observed. The tests were repeated with added moisture, to provide an indication of hydrolytic stability. Copper plating was observed with both high moisture levels and an additive-free lubricant, but not with the fully-formulated POE and 300 ppm moisture. A Turbine Oxidation Stability Test (TOST, based on DIN 51587) to demonstrate the effectiveness of the hydrolytic stabilizer is summarized. Falex pin and v-block tests with refrigerant gas bubbled through the lubricant are described. Whereas mineral oil alone is indicated to be a poor lubricant, its performance improves with R-12; the reverse is noted for the POE, which is a good lubricant alone and is compromised by inclusion of R-134a. The lower performance is attributed to a combination of factors, including reduction in viscosity and increased cooling. The brief description of compatibility testing notes significant variation within generic elastomer groups, and points to the need to test elastomers from specific suppliers. The paper outlines field trial experience, from January 1990, initially using three different compressor types (Sanden SD 508, Diesel Kiki DKS - York, and Seiko Seiki SS170). Initial results based on use of polyalkylene glycol (PAG) lubricants are briefly outlined, including discussion of one failed o-ring attributed to incompatibility between the fluoroelastomer (DuPont Viton(R)) and R-134a. One of the test systems was lost in an unrelated incident; the other two were refit with the POE and the tests continued. Early retrofit procedures, and their limitations, are discussed. Mention is made of a test of more than 50 vehicles using a procedure that removes less than 75% of the mineral oil. No failures have occurred, though poor performance under idling conditions is noted and attributed to the higher latent heat of R-134a compared to R-12. An attachment details and a figure shows the sequence of a recommended retrofit procedure.

Marine Refrigeration and Air Conditioning Systems

R. L. Mansmann (Ashland Chemical Company), **Retrofitting Marine Refrigeration and Air Conditioning Systems to HFC Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 179-186, October 1995 (8 pages with no figures or tables, RDB5A57)

R-12, R-22, R-134a, lubricants

Valves and Accessories

S. Adachi (Union Showa K.K., Japan), **Development of Molecular Sieve Desiccants for Alternative Refrigerants**, paper 5.6, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 130-134, December 1994 (5 pages with 11 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5424)

R-32; 4A XH-5, 4A NRG, 4A XH-6, XH-9, XH-10c, and developmental molecular sieves; compatibility tests

A. H. Blom (Danfoss A/S, Denmark), **Filter Driers for Alternative and Transitional Refrigerants**, *Ki Luft- und Kältetechnik*, Germany, volume 31, number 10, pages 468-471, 1995 (4 pages in German, RDB6309)

R-134a, requirements and sizing for filter driers to absorb water and acid in refrigeration systems, filtration efficiency, compatibility with hydrofluorocarbon (HFC) refrigerants, polyolester (POE) lubricants and additives

A. P. Cohen and C. S. Blackwell (UOP), **Inorganic Fluoride Uptake as a Measure of Relative Compatibility of Molecular Sieve Desiccants with Fluorocarbon Refrigerants**, paper 3909, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 341-347, 1995 (7 pages with 4 figures and 5 tables, RDB6335)

R-32, molecular sieve desiccants, reaction of refrigerant with desiccant

A. P. Cohen and S. R. Dunne (UOP), **Review of Automotive Air Conditioners Drydown Rate Studies - The Kinetics of Drying Refrigerant 12**, *Transactions* (Annual Meeting, Nashville, TN, 27 June - 1 July 1987), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 93, part 2, pages 725-735, 1987 (11 pages with 7 figures and 4 tables, RDB5552)

R-12, 4Å molecular sieve, silica gel

O. S. Hernandez (Uberlândia Federal University, Brazil) and S. A. Lopes (Ouro Preto Federal University, Brazil), **Performance of a Medium Size, Constant Superheating PC-Controlled Expansion Valve for Chillers**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue Uni-

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versity, West Lafayette, IN, pages 359-364, July 1994 (6 pages with 7 figures, RDB4846)

R. H. Kim (University of North Carolina), **A Numerical Analysis of a Capillary Tube Expansion Valve in a Vapor-Compression Refrigeration System with Alternative Refrigerants**, *Heat Transfer with Alternate Refrigerants* (proceedings of the 29th National Heat Transfer Conference, Atlanta, GA, 8-11 August 1993), edited by H. J. Sauer, Jr., and T. H. Kuehn, publication HTD-Vol. 243, American Society of Mechanical Engineers (ASME), New York, NY, pages 43-51, 1993 (9 pages with 10 figures and 5 tables, RDB3B19)

W. O. Walker (University of Miami), **Latest Ideas in Use of Desiccants and Driers**, *Refrigerating Service and Contracting* (RSC), Business News Publishing, Troy, MI, pages 24-30, August 1963 (7 pages with 4 figures, RDB4B58)

desiccant types; water capacity and moisture equilibria curves for R-12 and R-22; removal of burn-out products

W. O. Walker, J. M. Malcolm, and H. C. Lynn, **Hydrophobic Behavior of Certain Desiccants**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 63, pages 50 ff, April 1955 (RDB4B59)

desiccants

Other

C. Arzano (Électricité de France, ÉDF, France), D. Clodic (École des Mines de Paris, France), B. Hivet and C. Ducruet (ÉDF), **Influence of Thermodynamic Parameters in a Vapour Compression Cycle**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 247-252, July 1996 (6 pages with 9 figures and 2 tables, RDB-6910)

R-12, R-22, R-134a, R-142b, R-152a, R-290, R-C318 (identified in the paper as FC 318), R-600a, and R-717: influence of molar heat capacity on performance; mathematical models for compression, desuperheating, expansion, subcooling, heat transfer, cycle calculations; role of liquid-vapor heat exchanger and determination of when it is advantageous

T. Broccard (Hussmann Corporation), **A Revolutionary New Approach to Supermarket Refrigeration**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, pages 61-69, May 1994; republished in *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 313-321, October 1995 (9 pages with 7 figures, RDB4A26)

This paper presents an approach for reducing the amount of refrigerant used in supermarket systems. It employs decentralized, water-cooled, condensing units located in close proximity to the display cases served. The concept differs from traditional practice, based on centralized equipment rooms. The new system introduces three ways to reduce the required refrigerant charge. First, the reduced line lengths lower the inventory, especially in the liquid line. Second, the internal volume is lowered by using smaller tubing sizes, since large diameters are no longer needed to minimize pressure drops for long runs. Third, use of compact, water-cooled, brazed plate, heat exchangers enables heat rejection to an intermediate water circuit, piped to fluid coolers on the roof or rear of the store. Doing so avoids the need for flooded condensers, to maintain head pressure at low ambient temperatures. The paper outlines and illustrates the concept. It indicates that refrigerant charge was reduced by 50% and joints by 50-75% in demonstration applications. The paper then reviews customer concerns that had to be resolved to make the system viable. They include control of in-store noise and serviceability, avoidance of lost merchandising space, loss of heat reclaim, and potential increases in electrical distribution costs. The paper outlines a solution, predicated on use very compact, multiplexed scroll compressors serving closely-located display cases with similar suction temperatures. The paper also indicates that R-404A, described as "an environmentally-friendly refrigerant," was selected. Heat reclaim is addressed by drawing heat from the heat rejection fluid or from a heat-reclaim condenser coil. The paper concludes that the microprocessor controlled system offers reduced refrigerant charge, reduced opportunities for leaks, lower installed costs, and reliable and simplified systems.

J. Calhoun (Sanden International, Incorporated), **The Impact of HFC-134a on the Manufacture and Service of Automotive Air Conditioning Compressors**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA,

pages 285-293, October 1993 (9 pages with 8 figures, RDB3A49)

T. P. Castle, R. H. Green (EA Technology, UK), and D. Anderson (Lancaster University, UK), **Modelling of an Integrated Supermarket Refrigeration and Heating System Using Natural Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 363-368, July 1996 (6 pages with 5 figures, RDB6936)

simulation model for an integrated supermarket refrigeration and heating system using R-717 (ammonia) and hydrocarbons; secondary loop refrigeration systems

W. D. Cooper and H. Borchardt (E. I. duPont de Nemours and Company, Incorporated), **The Use of Refrigerant Mixtures in Air-to-Air Heat Pumps**, *Proceedings of the XVth International Congress on Refrigeration* (Venice, Italy, 23-29 September 1979), 1979 (RDB6430)

use of zeotropic refrigerant blends

S. Corr, F. T. Murphy (ICI Chemicals and Polymers, Limited, UK), and S. Wilkinson (ICI Engineering, UK), **Composition Shifts of Zeotropic HFC Refrigerants in Service**, paper OR-94-1-2, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 538-546, 1994 (9 pages with 8 figures, RDB4702)

R-32, R-125, R-134a, R-143a, R-32/125 (60/40), R-32/125/134a (24/16/60) and (30/10/60)

M. A. Di Flora (Bristol Compressors, Incorporated), **Alternative Refrigerant Effect on Compressor Design**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 194-199, October 1995 (6 pages with 5 presentation charts, available from JMC as RDB5A59)

R-22 replacements

P. A. Domanski, D. A. Didion (National Institute of Standards and Technology, NIST), and J. P. Doyle (Giant Foods, Incorporated), **Evaluation of Suction Line - Liquid Line Heat Exchange in the Refrigeration Cycle**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 131-139, July 1992; republished in the *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 7, pages 487-493, September 1994 (9/7 pages with 7 figures and 1 tables, RDB54A6)

R-11, R-12, R-13, R-13B1, R-14, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-124, R-125, R-134, R-E134, R-134a, R-141b, R-142b, R-143a, R-152a, R-170, R-216a (sic), R-216b (sic), R-218, R-290, R-C270, R-C318, R-600a

P. A. Domanski and D. A. Didion (National Bureau of Standards, NBS), **Equation-of-State-Based Thermodynamic Charts for Nonazeotropic Refrigerant Mixtures**, paper CH-85-05-2, *Transactions* (Winter Meeting, Chicago, IL, 27-30 January 1985), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 91, part 1, January 1985 (9 pages with 6 figures, RDB6426)

R-13B1/152a, composition management for capacity control

R. C. Downing and V. H. Waldin (E. I. duPont de Nemours and Company), **Phase-Change Heat Transfer in Solar Hot Water Heating Using R-11 and R-114**, *Transactions* (Semiannual Meeting, Los Angeles, CA, 3-7 February 1980), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 86, part 1, pages 848-856, 1980 (9 pages, RDB2731)

R. C. Downing, **Pressure-Enthalpy Charts and Their Use**, *Service Manual*, Refrigeration Service Engineers Society (RSES), Des Plaines, IL, 1962; republished as bulletin RT-40, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1962 (RDB4351)

thermodynamic properties, thermophysical data, service

T. Enkemann and H. Arnemann (Universität Hannover, Germany), **Investigation of CO_2 as a Secondary Refrigerant**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, 1994 (RDB6933)

use of R-744 (carbon dioxide) as a heat transfer fluid in secondary-loop commercial refrigeration

E. D. Fry (Tecumseh Products Company), **Compressor Technology Trends**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 200-205, October 1995 (6 pages, available from JMC as RDB5A60)

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effects of new refrigerants and lubricants on compressors

R. W. Griffith (Copeland Corporation), **Alternate Refrigerants for the Refrigeration Industry**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 19-21, 1994 (3 pages with 4 figures, RDB4516)

This paper reviews the refrigerant aspects, and corresponding implications, that a compressor manufacturer must examine when evaluating a refrigerant for suitability. They include the effects on performance, compression temperature, discharge pressure and compression ratio, and motor design including materials compatibility. A figure compares the saturation pressures of R-402A (DuPont Suva(R) HP80), R-402B (Suva HP81), R-404A (Suva HP62 or Atochem Forane(R) FX-70), and R-507A (AlliedSignal Genetron(R) AZ-50) to that of R-502 for a discharge temperature of 54 °C (130 °C). It similarly compares R-407C (Suva 9000), R-410A (Genetron AZ-20), and two unspecified blends of R-32/134a to R-22. It also compares R-134a, R-401A (Genetron and Suva MP39), and R-401B (Genetron and Suva MP66) to R-12. The paper then discusses issues associated with zeotropic blends including their temperature glides, fractionation, and charging. Turning to performance, the paper notes that the heat transfer characteristics of the new refrigerants are better than the original fluids, leading to comparable or improved capacity and efficiency. The paper then addresses lubricants, with emphasis on polyolesters (POEs). A figure compares the hygroscopicity of an unidentified POE and mineral oil. The author observes that POE may break down to its original acid and alcohol constituents in the presence of excessive moisture, leading to copper plating and rusting. The higher solvency of POE than mineral oil, however, may lead to a cleaner system. A second figure and related discussion indicate that an R-404A/POE mixture may yield a higher maximum cylinder pressure under flooded start conditions. A final figure compares the sound levels of three compressors using R-22 with a POE and a mineral oil. The paper notes that POEs are more quiescent, and that lower foaming with POEs may result in somewhat noisier operation. The author concludes that many new refrigerants are being introduced and that while similar to those they replace, they are not identical. The new refrigerants appear promising from many standpoints, but they will require changes in handling and charging procedures.

U. Hesse (Spauschus Associates, Incorporated), **Secondary Refrigerant Systems for Supermarket Application with Brine or Carbon Dioxide**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 369-376, July 1996 (8 pages with 8 figures and 4 tables, RDB6937)

evaluation of an organic salt and water solution, propylene glycol, ice slurry, and R-744 (carbon dioxide) as heat transfer fluids in secondary-loop commercial refrigeration, supermarket systems; concludes that secondary-loop systems are promising to avoid refrigerant leakage into supermarkets, organic salt solutions are more efficient than propylene glycol in high-temperature systems, and use of R-744 in a phase change or cascaded system is promising; cites defrost problems as a not insurmountable barriers as a heat transfer fluid

U. Hesse (Spauschus Associates, Incorporated), **Secondary Refrigerant System Options for Supermarket Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 322-330, October 1995 (9 pages with 5 figures and 6 tables, RDB5B06)

R-22, R-410A, R-507A, R-717, R-744; propylene glycol and organic salt heat transfer fluids

H. M. Hughes, W. P. Dulaney, and R. L. Broussard (AlliedSignal Incorporated), **A Refrigerant Producer's Experience in Manufacturing Zeotropic Blends**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 101-106, July 1996 (6 pages with 1 table, RDB6818)

R-407C, blending and packaging of refrigerant blends; fractionation; composition tolerances; product specifications: addresses the influences of blending equipment, techniques, quantity of components, blend formulation, temperature, and any residual "heel" (remainder of out-of-tolerance blend from preceding tank draw-down) on maintenance of zeotropes within product specifications during container filling operations

S. W. Inlow and E. A. Groll (Purdue University), **A Performance Comparison of Secondary Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 357-362, July 1996 (6 pages with 6 figures and 1 table, RDB6932)

performance comparison of R-744 (carbon dioxide), ethylene glycol, propylene glycol, undisclosed hydrofluoroether, and an undisclosed synthetic organic fluid as heat transfer fluids in secondary-loop commercial refrigeration, supermarket systems; concludes that a system using R-717 (ammonia) as a refrigerant with R-744 as a heat transfer fluid offers a coefficient of performance equivalent to that for R-22

S. W. Inlow and E. A. Groll (Purdue University), **Analysis of Secondary-Loop Refrigeration Systems Using Carbon Dioxide as a Volatile Secondary Refrigerants**, *HVAC&R Research*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 2, number 2, pages 107-121, 1996 (15 pages, RDB6934)

use of R-744 (carbon dioxide) as a heat transfer fluid in secondary-loop commercial refrigeration

M. Kauffeld, **Neue NH_3-Technologie - NH_3 mit CO_2 als Kaltetrager** [New Ammonia Technology - Ammonia with Carbon Dioxide as a Secondary Refrigerant], *Ki Klima-Kälte-Heizung*, pages 931-932, 1995 (2 pages, in German, RDB6935)

use of R-744 (carbon dioxide) as a heat transfer fluid in secondary-loop commercial refrigeration with R-717 (ammonia) as the primary refrigerant

A. A. Kornhauser, **The Use of an Ejector as a Refrigerant Expander**, *Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 10-13, July 1990 (4 pages, RDB6439)

cycle modifications, minimizing expansion losses

L. J. M. Kuijpers (Phillips Research Laboratories, The Netherlands), **The Influence of Refrigerant Charge on the Functioning of Small Refrigerating Appliances**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, pages 813-828, 1988 (16 pages with 11 figures and 1 table, RDB5553)

optimum charge, capacity, efficiency, void fraction correlation

P. Linnert (The Trane Company), **Rotary Compressor Technology - Meeting the Needs of the Future**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 187-193, October 1995 (7 pages with 4 figures, available from JMC as RDB5A58)

compressor trends, refrigerant selection, R-134a, R-407C, R-410A, efficiency

H. Lorenz, **Die Ausnutzung der Brennstoffe in den Kühlmaschinen** [The Utilization of Combustible Substances in Refrigeration Machines], *Zeitschrift für die gesamte Kälte Industrie* [Journal of the Combined Refrigeration Industry], Germany, volume 1, pages 10-15, 1894 (6 pages, in German, RDB4870)

R. C. Niess, **CFCs and Electric Chillers - Selection of Large-Capacity Water Chillers in the 1990s**, report TR-100537, Electric Power Research Institute (EPRI), Palo Alto, CA, March 1992 (188 pages with 3 figures and 34 tables, RDB2A18)

J. Peters (Bundesfachschule Kälte-Klima-Technik, Germany), **Designing and Building a Hydrocarbon-Based Commercial Refrigeration System to Customer Specifications**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 303-310, October 1995 (8 pages with 3 figures and 2 tables, available from JMC as RDB5B05)

R-290, comparisons to R-22, use, performance, safety

P. Pieczarca and J. Lavelle (Elf Atochem North America, Incorporated), **Storage, Bulk Transfer, and In-Plant Handling of Zeotropic Refrigerant Blends**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 107-112, July 1996 (6 pages with 4 figures and 1 table, RDB6819)

R-407C, delivery truck and bulk tank operations for a refrigerant blend with a high temperature glide, adjustments to maintain blend composition, progressive change in composition

J. H. Robinson (Young Life) and D. L. O'Neal (Texas A&M University), **The Impact of Charge on the Cooling Performance of an Air-to-Air Heat Pump for R-22 and Three Binary Blends of R-32 and R-134a**, paper OR-94-1-1, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 529-537, 1994 (9 pages with 8 figures and 9 tables, RDB4701)

R-32/134a (40/60), (30/70), and (22/78)

E. R. Rodgers (Arlington County), **Obtaining Approval for the Use of Non-CFC Refrigerants in Your Building**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC,

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20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 246-249, October 1993 (4 pages, RDB6321)

building code, mechanical code, alternate methods and materials, waiver

S. M. Sami and M. A. Comeau (University of Moncton, Canada), **Experimental Study of the Dynamic Behavior of Non-Azeotropic Binary Mixtures in Heat Pumps**, *Journal of Heat Recovery Systems and CHP*, Pergamon Press Limited, UK, volume 11, number 6, pages 505-515, 1991 (11 pages with 15 figures and 1 table, RDB6715)

R-22/114 (80/20), (60/40), (40/60), and (20/-80); R-22/152a (90/10), (80/20), and (70/30); undisclosed binary zeotrope identified as *NARM/UM*: experimental study of dynamic behavior in an 11 kW (3 ton) water-to-air heat pump during the heating mode under start-up conditions; found a 35% improvement in efficiency over R-22 for NARM/UM; plots show the pressures and temperatures of the blends at key locations in the refrigerant circuit during transient start-up conditions; concludes that the state of the refrigerant and its composition have a significant effect on performance and that zeotropic mixtures offer potential as refrigerants in heat pump applications

E. L. Smithart (The Trane Company), **Choosing a Building Chiller**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 20-22 October 1993), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 250-258, October 1993 (9 pages, with 13 figures and 9 tables, RDB6322)

R-123, centrifugal chillers, availability, cost, safety, emissions, environmental considerations, transition planning

R. L. Webb, A. S. Wanniarachchi, and T. M. Rudy (Pennsylvania State University), **The Effect of Noncondensible Gases on the Performance of an R11 Centrifugal Water Chiller Condenser**, *Transactions* (Annual Meeting, Denver, CO, 22-26 June 1980), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 86, part 2, pages 19-27, 1980 (9 pages with 6 figures and 2 tables, RDB5263)

R-11, performance, purge requirements

F. J. Wiesner, Jr., and H. E. Caswell, **Effects of Refrigerant Properties on Centrifugal Compressor Impeller Dimensions and Stage Performance**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 65, pages 355-376, 1965 (22 pages, RDB4128)

E. F. Wojtkowski, **System Contamination and Cleanup**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 49-52, June 1964 (4 pages, RDB4747)

CFCs and Electric Chillers - Selecting Large Water Chillers as CFCs are Phased Out, brochure CU.2039R.7.92, Electric Power Research Institute (EPRI), Palo Alto, CA, July 1992 (6 pages with 4 figures, RDB3454)

CFCs and Electric Utilities - Making the Transition to a Safer World, report CU-7027 (project RP2792-12), Electric Power Research Institute (EPRI), Palo Alto, CA, October 1990 (76 pages with 29 figures, RDB3455)

This report provides an illustrated narrative, based on a series of slide presentations, to review the phase out of chlorofluorocarbon (CFC) refrigerants, their use in electric-powered equipment, and estimates of phaseout impacts. The tie between the chemical composition of refrigerants and stability, flammability, and toxicity is illustrated. Data on the ozone-depletion potential (ODP), global warming potential (GWP) and atmospheric lifetime also are indicated. The report reviews data on use of refrigerants by application and resultant electric utility loads and revenues. The report notes that utility income from these sources is more than double that received by other industry participants. Likely alternative refrigerants as well as their impacts on equipment cost, efficiency, resultant energy consumption, and loads are projected.

DuPont HFC-134a: Properties, Uses, Storage and Handling, bulletin P134a (233264C), DuPont Chemicals, Wilmington, DE, November 1994 (32 pages with 10 figures and 20 tables, available from JMC as RDB6739)

This document provides extensive application information for R-134a. It reviews identifiers and potential uses, shows an infrared spectrum for laboratory analyses, compares theoretical performance to R-12, and summarizes physical properties as well as flammability, environmental, and toxicity indices. Plots of solubility in water, pressure-temperature relationships, and vapor thermal conductivity are included. Pressure-enthalpy diagrams, in both inch-pound (IP) and metric (SI) units, are provided. The bulletin reviews chemical and thermal stability data, including thermal decomposition, stability with metals and refrigeration lubricants, stability with foam chemicals, and concerns if mixed with R-12. It then addresses compatibility with plastics, elastomers, desiccants, and refrigeration lubricants. A table summarizes compatibility with plastics including ABS polymer (Kralastic(R)),

acetal (DuPont Delrin(R)), acrylic (Lucite(R)), cellulosic (Ethocel(R)), epoxy, polytetrafluoroethylene (PTFE, DuPont Teflon(R)), ETFE (Tefzel(R)), PVDF, ionomer (Surlyn(R)), nylon 6/6 polyamide (DuPont Zytel(R)), polyarylate (Arylon(R)), polycarbonate (Tuffak(R)), polybutylene terephthalate (PBT, GE Valox(R)), polyethylene terephthalate (PET, DuPont Rynite(R)), polyetherimide (GE Ultem(R)), polyethylene-HD (Alathon(R)), polyphenylene oxide (PPE, GE Noryl(R)), polyphenylene sulfide (Ryton(R)), polypropylene, polystyrene (Styron(R)), polysulfone (Polysufone(R)), and polyvinyl chloride (PVC and CPVC). Tabular summaries also are provided for R-134a compatibility with a urethane rubber (Uniroyal Adiprene(R) L), Buna N, Buna S, butyl rubber, synthetic rubber (DuPont Hypalon(R) 48), natural rubber, neoprene W, hydrocarbon rubber (DuPont Nordel(R)), silicone rubber, polysulfide rubber (Thiokol(R) FA), and fluoroelastomer (DuPont Viton(R) A). These summaries indicate changes in length, weight, Shore A hardness, elasticity, and appearance after exposures at 25 and 80 °C (77 and 176 °F). A table summarizes permeation through elastomeric hoses made of nylon, Hypalon 48, and two nitriles with identified liners, reinforcement, and covers. Solubility data are provided for R-134a in unidentified naphthenic and paraffinic mineral oils, dialkylbenzene, alkylbenzene, polyalkylene glycol (PAG), and ester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, and skin and eye contact. Flammability data and recommended practices for leak testing, bulk delivery, storage, charging, and recovery are reviewed. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal.

DuPont Suva(R) HP Refrigerant Blends: Properties, Uses, Storage, and Handling, bulletin P-HP (H-47122-2), DuPont Chemicals, Wilmington, DE, February 1994 (28 pages with 9 figures and 7 tables, available from JMC as RDB4503)

This document provides extensive application information for R-402A and R-402B, both blends of R-125, R-290, and R-22 - R-125/290/22 (60/2/38) and R-125/290/22 (38/2/60) respectively. It also addresses R-404A, a blend of R-125, R-143a, and R-134a - R-125/143a/134a (44/52/4). It reviews identifiers, the blend compositions, and potential uses. The bulletin then summarizes physical properties as well as flammability, environmental, and toxicity indices. Pressure-enthalpy diagrams are provided in both metric (SI) and inch-pound (IP) units. The bulletin reviews chemical and thermal stability data, including thermal decomposition. A table provides representative data on stability with metals (copper, iron, and aluminum) based on sealed-tube tests of mixtures of R-402B with mineral oil (Witco Suniso(R) 3GS), alkylbenzene (Shrieve Zerol(R) 150 TD), and a branched acids polyolester (Castrol Icematic(R) SW32) lubricants. Results also are provided for R-404A with the same lubricants and a mixed acids ester (Mobil EAL Arctic(R) 22). The report reviews compatibility of the refrigerant blends with R-502, noting chemical compatibility, but potential performance differences and separation difficulty, the latter leading to a need for disposal by incineration. It then addresses compatibility with elastomers; a tabular summary is provided for five polymers with combinations of the cited lubricants and R-502, R-402B, and R-404A. The compounds tested were polytetrafluoroethylene (PTFE, DuPont Teflon(R) in commercial grade sheet from Tex-O-Lon Manufacturing), Buna N nitrile butadiene (NBR, Parker Seal), hydrogenated NBR (HNBR, Parker Seal N1195), chloroprene (CR, Precision Rubber neoprene W), and EPDM (Kirkhill Rubber). Compatibility data also are discussed for polyethylene terephthalate (PET, DuPont Mylar(R) film), polyesterimide motor wire with amide-imide overcoating, and Dacron/Mylar/Dacron(R) lead wire (Belden) as well as for molecular sieve desiccants (UOP 4A-XH-5 and XH-9). Miscibility is summarized for R-502 and the three zeotropes with mineral oil, alkylbenzene, and polyolester lubricants. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, skin and eye contact, and flammability. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal. DuPont's product names for R-402A, R-402B, and R-404A are Suva(R) HP80, Suva(R) HP81, and Suva(R) HP62 respectively.

DuPont Suva(R) MP Refrigerant Blends: Properties, Uses, Storage, and Handling, bulletin P-MP (H-45944), DuPont Chemicals, Wilmington, DE, December 1992 (36 pages with 14 figures and 13 tables, available from JMC as RDB3441)

This document provides extensive application information for R-401A, R-401B, and R-401C - R-22/152a/124 (53/13/34), (61/11/28), and (33/15/52), respectively. It reviews identifiers, the blend compositions, potential uses, compares theoretical performance to R-12, and discusses temperature glides. Using R-401A as an illustration, it presents tabular data on the theoretical effect of leakage on performance. The bulletin then summarizes physical properties as well as

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flammability, environmental, and toxicity indices. Plots of pressure-temperature relationships and pressure-enthalpy diagrams, in both inch-pound (IP) and metric (SI) units, are provided. The bulletin reviews chemical and thermal stability data, including thermal decomposition. A table provides representative data on stability with metals (copper, iron, and aluminum) and refrigeration lubricants; comparative information is given for R-12 with two mineral oils. The lubricants addressed include alkylbenzenes (Shrieve Zerol(R) 150DL, 300, and 500T), branched acids polyolesters (Castrol Icematic(R) SW22, SW32, SW68, and SW100), mixed acids polyolesters (Mobil EAL Arctic(R) 68, Henkel Emery(R) ISO 10 and 100, and Lubrizol ISO 150). It then addresses compatibility with elastomers; a tabular summary is provided for R-22/152a/124 (36/-24/40), Zerol(R) 500, and a 50/50 mixture with 11 polymers including natural rubber (NR), butyl rubber (IIR), EPDM (DuPont Nordel(R)), chloroprene (CR, DuPont Neoprene(R) W), styrene-butadiene copolymer (SBR, Buna-S), Buna N nitrile (NBR, Polysar Krynac(R)), hydrogenated NBR (HNBR, Polysar Tornac(R)), chlorosulfonated polyethylene (CSM, DuPont Hypalon(R) 48), fluoroelastomer (FKM, DuPont Viton(R)), silicone rubber (SI, Dow Silastic(R)), epichlorohydrin homopolymer (CO, Goodrich Hydrin(R) 100), epichlorohydrin copolymer (ECO, Goodrich Hydrin(R) 200), urethane (Uniroyal Adiprene(R)), and polysulfide rubber (T, Thiokol(R) FA). A separate table summarizes the compatibility of R-401C, a mixture of this refrigerant with Zerol(R) 500T and a mineral oil (BVM 100N), and Zerol(R) 500T alone with 5 polymers; they include CR (DuPont Neoprene(R)), NBR nitrile, HNBR, CO, and ECO. Compatibility data also are provided for polyester insulation material for motors and for molecular sieve desiccants (UOP 4A-XH-5 and XH-9). Miscibility data are provided for 30, 60, and 90% weight lubricant mixtures with R-401B and naphthenic mineral oil, paraffinic mineral oil, alkylbenzenes, polyolesters, and the latter two also with mineral oils. Hose permeation rates are presented for nylon-lined and nitrile hoses. Safety data are then presented including a review of inhalation toxicity, cardiac sensitization, responses to spills or leaks, skin and eye contact, and flammability. Monitors and leak detection are discussed as are storage, handling, and shipping. The bulletin concludes with discussion of recovery, reclamation, recycling, and disposal. DuPont's product names for R-401A, R-401B, and R-401C are Suva(R) MP39, Suva(R) MP66, and Suva(R) MP52, respectively.

Forane(R) for Refrigeration and Air Conditioning, bulletin DIREP-1985E, Elf Atochem S.A., Paris - La Défense, France, January 1994 with addendum dated May 1994 (23 pages with 13 tables, RDB-4B16)

This bulletin outlines the replacement offerings of Elf Atochem for chlorofluorocarbon (CFC) refrigerants. It reviews the schedule for CFC phaseout and provides a table showing the applications of R-11, R-12, R-22, R-123, R-134a, R-142b, R-404A, R-409A, R-500, and R-502 as well as R-22/124/142b (65/25/10), R-23/32/134a (4.5/21.5/74), R-32/125/143a (10/45/45), and R-143a/22 (55/45). It briefly discusses lubricants, including the Elf Atochem polyolesters (Planetelf(R)), and filter driers, including CECA's - an Elf Atochem subsidiary - molecular sieves (Siliporite(R)) for alternative refrigerants. The bulletin comments on leak detection methods and then discusses conversion of existing systems, with specific attention to R-123 for R-11; R-134a, R-409A, and R-22/124/142b (65/25/10) for R-12; R-404A, R-32/125/143a (10/45/45), and R-143a/22 (55/45) for R-502; and R-23/-32/134a (4.5/21.5/74) for R-22. Tabular swell data are provided for the cited refrigerants with plastics and elastomers, including polychloroprene (Neoprene), butadiene acrylonitrile (BNR, Buna N), butadiene styrene (Buna S), hexafluoropropylene/vinylidene fluoride (Viton) butyl rubber (IIR), chlorosulfonated polyethylene (Hypalon), polyamide 11 (Rilsan), polystyrene (PS), and polyvinyl chloride (PVC). Summary property data (chemical formula, chemical name, molecular mass, bubble temperature, temperature drop (glide), critical temperature, critical pressure, pressure and density at representative conditions, ozone depletion potential (ODP), global warming potential (GWP), and flammability limits) and safety data (toxicity, recommended exposure limits, and flammability limits) also are tabulated. The bulletin concludes with brief discussion of handling, storage, recovery, recycling, and the company's quality program. Elf Atochem's product names for R-404A and R-409A are Forane(R) FX-70 and FX-56, respectively. Its names for R-22/124/142b (65/25/10), R-23/32/134a (4.5/21.5/74), and R-32/125/-143a (10/45/45) are Forane(R) FX-57, FX-220, and FX-40, respectively. Its name for R-143a/22 (55/45) until 9 May 1994 was FX-10, when it was reformulated as R-125/143a/22 (7/46/47) - R-408A. An addendum explains revision of the formulation to meet the Underwriters Laboratories (UL) requirements for classification as "practically nonflammable," as requested by equipment manufacturers in the United States. The addendum provides two tables with comparative data for the physical characteristics and performance of the initial and revised formulations of FX-10. The conclusions state that the two blends can be mixed, characteristics remain

unchanged, and the materials compatibility and retrofit guidelines are the same.

Isceon 69-L, product bulletin, National Refrigerants, Incorporated, Philadelphia, PA, undated circa 1993 (4 pages containing 4 figures and 2 tables, RDB3A65)

This bulletin provides application information for R-403B, a ternary zeotropic blend of R-22, R-218, and R-290 formulated as R-290/22/218 (5/56/39). The bulletin outlines the development and applications of the blend, and discusses its use as a service fluid for retrofit of R-502 systems. A plot compares the ozone depletion potential (ODP) of the blend with those of R-12, R-22, R-115, and R-502, showing the blend to be the lowest. Two plots and a table compare the capacities and efficiencies of R-502 and the blend for evaporator temperatures of -37 to -21 °C (-35 to -5 °F) and condensing temperatures of 41 and 49 °C (105 and 120 °F); they show higher theoretical capacity and efficiency for the blend. A figure shows how the composition varies as vapor is drawn from a cylinder, leading to the conclusion that charging should be from the vapor phase unless the entire cylinder is to be used in a large system. The document also discusses fractionation under leakage, noting that the propane (R-290) content will not rise above that of the original formulation. Potential liquid and vapor leaks are described as nonflammable, both for the escaping fluid and that remaining in the system. A final table provides physical properties, in inch-pound units. Rhône-Poulenc Chemical's product name for R-403B is Isceon 69-L; National Refrigerants is the exclusive distributor for North America.

SAFETY

L. W. Burgett (The Trane Company), **Revised Standards for Mechanical Refrigeration**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 8, pages 31-35, August 1993 (5 pages with 3 figures and 1 table, RDB-4303)

This article reviews the provisions of ANSI/ASHRAE Standards 34-1992, "*Number Designation and Safety Classification of Refrigerants*," and 15-1992 "*Safety Code for Mechanical Refrigeration*." These revised standards include new alternative refrigerants, a new safety classification matrix for refrigerants, and revised guidance for their application in mechanical refrigeration systems. The article focuses on key provisions and new application requirements. It describes the safety classification matrix, which comprises six groups combining two toxicity and three flammability classes. A table compares the safety groups for common refrigerants under the previous and new classification schemes. The article then reviews the occupancy (institutional, public assembly, residential, commercial, industrial, and mixed) and refrigerating system (high and low probability, referring to risk of occupant exposure in the event of a leak) groupings. These classifications along with that of the refrigerant are used to determine applicable requirements and permissible refrigerant quantities. The article outlines key requirements including those for machinery rooms, ventilation, and sensors. It also discusses efforts to gain recognition of Standards 15 and 34 in model building and fire codes and to further revise and update the two standards. The author concludes that understanding and implementation of the new requirements are essential to promote safe application and use of refrigeration systems. He also notes that all refrigerants present some degree of risk, necessitating care and respect in their use.

W. S. Calcott and R. A. Kehve, **Tests to Show Toxic, Irritant, and Fire Characteristics of Certain Well Known Refrigerants**, Kinetic Chemicals Incorporated, December 1931 (RDB6670)

safety, flammability, toxicity

J. M. Calm (Engineering Consultant), **Refrigerant Safety**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 36, number 7, pages 17-26, July 1994 (10 pages with 3 figures and 2 tables, available from JMC as RDB4766)

This article outlines safety concerns and summarizes safety data for refrigerants, with emphasis on those used in chillers. It briefly reviews the history of refrigeration, noting that nearly all of the early refrigerants were flammable, toxic, or both, and that some also were highly reactive. It describes the discovery of organic fluorides as refrigerants, by Thomas Midgley in 1926, and the first toxicity tests. The article reviews the commercial introduction and growth of fluorocarbon refrigerants. It then describes the attributes of ideal refrigerants, noting that none exist or are likely to be found. The article summarizes toxicity concerns and several reasons for increased attention to them. A table provides a glossary of safety terminology including common indices used to quantify recommended exposure limits and concentrations that pose recognized risks. Among them are

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the Acceptable Exposure Limit (AEL), Immediately Dangerous to Life or Health (IDLH), Industrial Exposure Limit (IEL), Lethal Concentration for 50% of specimens (LC_{50}), No Observed Effect Level (NOEL), Occupational Exposure Limit (OEL), Permissible Exposure Level (PEL), Recommended Exposure Limit (REL), Short-Term Exposure Limit (STEL), Threshold Limit Value (TLV), and Workplace Environmental Exposure Level (WEEL). Flammability limits also are addressed including the lower and upper flammability limits (LFL and UFL, respectively). The article then summarizes toxicity data for R-123 and R-134a, and relates the R-123 data to measured concentrations in machinery rooms. It also explains other hazards, including the potential for irritation, corrosive effects, asphyxiation, narcosis, and other physiological effects. A table compares safety indicators for R-11, R-12, R-22, R-123, R-134a, and R-717 (ammonia) including acute, subchronic, and chronic toxicity, cardiac sensitization response level, mutagenicity, carcinogenicity, and teratogenicity. The paper then summarizes the safety classifications and the recommended installation, handling, and service procedures found in ASHRAE standards 34 and 15, respectively. The article concludes that the new, alternative refrigerants can be used with comparable or higher safety than those they replace. It notes that the alternatives have been subjected to more stringent qualification criteria and testing. The article also indicates that more care is needed with all refrigerants.

D. J. Davis and G. T. Christianson, **Firefighter's Hazardous Materials Reference Book**, Van Nostrand Reinhold Publishers, New York, NY, 1991 (RDB5164)

flammability, toxicity, and other safety data

T. Dierckx and J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Safety Aspects of Working Fluids**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 293-300, 1993 (8 pages with 1 figure and 3 tables, RDB5323)

R-11, R-12, R-22, R-23, R-32, R-125, R-134a, R-142a (possibly intended to be R-143a), R-290 (propane), and R-717 (ammonia) as potential replacements for R-12; R-124 (cited as R-124(a)) and R-227 (probably R-227ea) as potential replacements for R-114; R-21, R-30, R-123, R-132a, and R-133 as potential replacements for R-11; flammability, toxicity

R. E. Dufour and A. J. Perkins, **The Comparative Life, Fire, and Explosion Hazards of Trifluorotrichloroethane ('Freon-113')**, Miscellaneous Hazard Report Number 3072, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 7 April 1941 (22 pages with 6 tables, RDB5174)

R-113, toxicity, flammability, stability

R. E. Dufour and A. J. Perkins, **The Comparative Life, Fire, and Explosion Hazards of Tetrafluoromonochloroethane ('Freon-124')**, Miscellaneous Hazard Report Number 3135, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 23 October 1940 (22 pages with 7 tables, RDB5176)

R-124, toxicity, flammability, stability

R. E. Dufour and A. J. Perkins, **The Comparative Life, Fire, and Explosion Hazards of Difluoromonochloromethane ('Freon-22')**, Miscellaneous Hazard Report Number 3134, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 26 September 1940 (22 pages with 7 tables, RDB5175)

R-22, toxicity, flammability, stability

R. E. Dufour, **The Comparative Life, Fire, and Explosion Hazards of Dichloromonofluoromethane (F21)**, Miscellaneous Hazard Report Number 2630, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 15 January 1935 (22 pages with 7 tables, RDB5173)

R-21, toxicity, flammability, stability

Dutch Institute for the Working Environment and Dutch Chemical Industry Association, **Chemical Safety Sheets**, Kluwer Academic Publishers, Dordrecht, The Netherlands, and Norwell, MA, USA, 1991 (RDB5163)

flammability, toxicity, and other safety data

L. Fluer (Fluer, Incorporated, and HMEx, Incorporated), **Hazardous Materials Classification Guide**, edited by J. M. Shapiro, International Fire Code Institute (IFCI), Whittier, CA, 1993 (818 pages with 1 table, RDB3965)

This book provides guidance for classification of hazards for approximately 3,500 chemicals for use with building and fire safety codes. The volume also explains the fundamentals of hazard classification and provides a cross-reference between more than 7,000 chemical names and Chemical Abstract Service (CAS) registry numbers. A table, forming most of the book, lists the chemicals by CAS number (or pseudo-number for mixtures). It also identifies their chemical and/or trade names as well as common names for verification. Each entry provides the physical state (solid, liquid, or gaseous) at 20 °C (68 °F), concentration, indication of listing

under the U.S. Environmental Protection Agency (EPA) *"List of Extremely Hazardous Substances"* (40 CFR 355 §302 and §304), information for warning placards, and physical and health hazard categories. The placard information follows the National Fire Protection Agency Standard 704-1985 *"Standard System for the Identification of the Fire Hazards of Materials."* It includes recommended hazard identification rating numbers for health, flammability, and reactivity as well as a designator for special hazards. The physical categories identified include aerosols, combustible dusts and fibers, flammable and oxidizing cryogenics, explosives, flammable and combustible liquids, flammable gases, organic peroxides, oxidizers, pyrophorics, unstable reactives, and water reactives. The health hazards addressed are carcinogenic, corrosive, irritant, other health hazard, radioactive, sensitizer, and toxic/highly toxic. An introductory section explains the criteria, data sources, classification approach, and assigned hazard levels for each. The guide covers R-11, R-12, R-12B2, R-13, R-14, R-21, R-22, R-23, R-30, R-113, R-114, R-115, R-116, R-123, R-134a, R-152a, R-290 R-C318, R-500, R-503, R-717 (ammonia), and R-744 (carbon dioxide), R-1132a, and a number of mineral oil lubricants among the other chemicals. [see RDB3966 for software version]

L. Fluer (Fluer, Incorporated, and HMEx, Incorporated), **HMEx Assistant - The Hazardous Materials Expert**, International Fire Code Institute (IFCI), Whittier, CA, version 1.02, 1993 (software package with 72 page user's manual, RDB3966)

This software provides guidance for classification of hazards for approximately 3,500 chemicals for use with building and fire safety codes. The software enables look-up by chemical, commercial, or common names; Chemical Abstract Service (CAS) registry numbers (or pseudo-number for mixtures); or *Registry of Toxic Effects of Chemical Substances* (RTECS(R)) codes. The entries indicate the physical state (solid, liquid, or gaseous) at 20 °C (68 °F), concentration, indication of listing under the U.S. Environmental Protection Agency (EPA) *"List of Extremely Hazardous Substances"* (40 CFR 355 §302 and §304), information for warning placards, and physical and health hazard categories. The placard information follows the National Fire Protection Agency Standard 704-1985 *"Standard System for the Identification of the Fire Hazards of Materials."* It includes recommended hazard identification rating numbers for health, flammability, and reactivity as well as a designator for special hazards. The physical categories identified include aerosols, combustible dusts and fibers, flammable and oxidizing cryogenics, explosives, flammable and combustible liquids, flammable gases, organic peroxides, oxidizers, pyrophorics, unstable reactives, and water reactives. The health hazards addressed are carcinogenic, corrosive, irritant, other health hazard, radioactive, sensitizer, and toxic/highly toxic. The entries also identify the classifier and reviewer for each chemical according to initials or codes. A companion user's manual provides installation instructions and explains the criteria, data sources, classification approach, and assigned hazard levels. The software covers R-11, R-12, R-12B2, R-13, R-14, R-21, R-22, R-23, R-30, R-113, R-114, R-115, R-116, R-123, R-134a, R-152a, R-290 R-C318, R-500, R-503, R-717 (ammonia), and R-744 (carbon dioxide), R-1132a, and a number of mineral oils among the other chemicals. [see RDB3965 for printed version]

D. L. Fenton, A. F. Noeth, and R. L. Gorton (Kansas State University, KSU), **Absorption of Ammonia into Water**, *Transactions* (Winter Meeting, New York, NY, 19-23 January 1991), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 97, part 1, pages 204-211, 1991 (RDB3462)

R-717, venting, emergency releases

International Programme on Chemical Safety (IPCS), **Fully Halogenated Chlorofluorocarbons**, Environmental Health Criteria Report 113, World Health Organization (WHO), Geneva, Switzerland, 1990 (RDB5367)

refrigerant safety

R. E. Lenga, **The Sigma-Aldrich Library of Chemical Safety Data** (Edition II), Sigma-Aldrich Corporation, 1988 (RDB5162)

flammability, toxicity, and other safety data

R. J. Lewis, Sr., **Hazardous Chemicals Desk Reference** (Second Edition), Van Nostrand Reinhold Publishers, New York, NY, 1990 (RDB5165)

flammability, toxicity, and other safety data

W. E. Stewart, R. W. Clark (University of Missouri-Kansas City), L. A. Stickler, and C. K. Saunders (Inter-Mountain Research), **Gaseous Ammonia Dispersion: Comparison of Experimental Data with Two Predictive Models**, paper 3924, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 497-501, 1995 (4 pages with 4 figures and 1 tables, RDB-6362)

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R-717, safety, validation of dispersion models, DEGADIS (DEnse GAs DISpersion model), SLAB

A. H. Nuckolls, **The Comparative Life, Fire, and Explosion Hazards of Common Refrigerants**, Miscellaneous Hazard Report Number 2375, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 13 November 1933 (134 pages with 20 figures and 29 tables, RDB4B64)

This report presents a detailed examination of the comparative safety of then common refrigerants. They included R-11, R-12, R-30, R-40, R-40B1, R-114, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-611 (methyl formate), R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), and R-1130. Data also are provided for R-10 (carbon tetrachloride), R-20 (chloroform), gasoline, and "illuminating gas" for comparison. The report discusses the nature of "life," fire, and explosion hazards and outlines salient concerns for investigation. It then describes the samples tested and documents tests and findings for identification, toxicity before decomposition, toxicity of decomposition products, analytical identification of decomposition products, ignition temperature, limits of flammability, explosion pressure and kinetics, and flame propagation. A summary presents the comparative health hazards, health hazards in the presence of flames, health hazards in the presence of surfaces at high temperatures, and fire and explosion hazards. Interspersed tables and plots illustrate the findings. A summary table recaps the toxicity, fire, explosion, and other hazards of the substances investigated. It includes safety classifications based on a relative scale of toxicity.

P. S. Squair (Air-Conditioning and Refrigeration Institute, ARI), **ARI Code Activity on Refrigerants**, presentation 1.2, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), ARI, Arlington, VA, 1994 (12 pages with 10 presentation charts, available from JMC as RDB-4783)

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Expanded Applications of Ammonia - Coping with Releases to the Atmosphere**, *CFCs: Today's Options - Tomorrow's Solutions* (proceedings of ASHRAE CFC Technology Conference, Gaithersburg, MD, 27-28 September 1989), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 47-55, 1990 (9 pages with 18 figures, RDB-2111)

R-717, venting, dispersion

R. van Gerwen (Netherlands Organization for Applied Scientific Research, TNO, The Netherlands), **Safety Aspects of Natural Working Fluids**, *IEA Heat Pump Center Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 19-21, March 1995 (3 pages with one figure, RDB5684)

R-717, hydrocarbons, accidents, risk assessment

R. van Gerwen and C. M. A. Jansen, **Risk Assessment of the Use of Flammable Refrigerants**, report 8327-24191, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, June 1994 (RDB5686)

safety, flammability, accidents

P. E. J. Vermeulen, **The Use of Ammonia as Refrigerant in the Dutch Food Industry**, report number 92-180, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, May 1991 (in Dutch, RDB5685)

R-717, safety

T. E. Watson (McQuay International), **ASHRAE Standards and Alternative Refrigerants**, paper 7.4, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 187-192, December 1994 (6 pages with 1 figure and 5 tables, available from JMC as RDB5103)

This paper presents an overview of the ASHRAE standards for refrigerant and refrigeration safety. It also discusses potential changes to address alternative refrigerants. The paper describes the role of Standard 34, *Number Designation and Safety Classification of Refrigerants*, in providing an unambiguous numbering system and safety classifications for refrigerants. It outlines this classification system, illustrates the six safety groups in a matrix of increasing toxicity and flammability, and explains the dual classifications - as formulated and worst case of fractionation - for zeotropic blends. The paper then describes Standard 15, noting that the latest revision has been written in code language to accelerate its adoption in building regulations. It notes that the requirements are based on three classifications, namely occupancy, system leak probability into occupied space(s), and refrigerant safety (from Standard 34). A table summarizes application requirements based on these three classifications. A second table indicates the maximum allowed quantities without location of equipment in a specified machinery

room. The paper then discusses future considerations, identifying increased attention to acute toxicity of refrigerants. It also notes a coordinated effort between Standards 15 and 34 to make the latter the definitive source of safety and property data for refrigerants and the former the standard for application requirements. It discusses data needs and issues being addressed, including thermodynamic property data, the definition of "azeotropic," refinement of flammability criteria, and pressure relief valve calculations for blends. Two tables illustrate the data for R-407C and proposed "f factors" for relief valve sizing for R-22, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-407C, R-502, and R-507A.

A Guide to Good Practices for Operation of an Ammonia Refrigeration System, bulletin R1, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 1983 (28 pages with 1 figure and 3 tables, RDB4758)

This guide identifies suggested practices for the operation of an ammonia refrigeration system. It contains general information on the chemical, its production, properties, safety, and uses. A flow diagram shows the components of a typical system. A section on operators' responsibilities covers what operators should know (compressor safety controls, automatic control valves, isolating valves, pressure relief valves, electrical controls, temperature or pressure changes, and pump out), preventative maintenance, and observation of systems to prevent incidents. A section on treatment of ammonia with respect covers effects on the human body, ammonia's self-alarming odor, and effects of exposure to both anhydrous ammonia gas and pure liquid ammonia. The effects of ammonia on unprotected workers are tabulated by concentration level. Three sections cover first aid, protective equipment, and safety programs and training. A final section covers piping and valve identification.

Aard en omvang van het gebruik van ammoniak als koudemiddel in de Nederlandse Voedings- en Genotmiddelenindustrie, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, May 1992 (RDB5495)

accident statistics with use of ammonia (R-717) as a refrigerant in the Netherlands, safety

Addenda to Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34a-o and 34q-x (Addenda to ANSI/ASHRAE 34-1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1996 (20 pages with 3 tables, available from ASHRAE for $8 members and $12 nonmembers plus handling fee, RDB6801)

This cumulative addendum combines addenda a through o, addenda q through x, and errata sheet number 1 to ANSI/ASHRAE Standard 34-1992. The errata correct a conversion error in the metric units for flammability classifications. The addenda provide a designation distinction for zeotropic blends having the same components in different proportions, expand the applicability of dual classifications (as formulated and worst case of fractionation) to azeotropes, and add new definitions. The last address acute toxicity, azeotropic temperature, cardiac sensitization, ceiling (as in exposure limits), chronic toxicity, committee (in the context of the standard), LC_{50} (median lethal concentration), maximum temperature glide, ppm, permissible exposure level (PEL), short-term exposure limit (STEL), and Workplace Environmental Exposure Limit (WEEL). The addenda clarify that concentrations identified as "ppm" for safety classifications are "ppm by volume", expand the purpose, and provide detailed instructions for designation and classification applications. They also modify the designation system for miscellaneous organic compounds as well as inorganic compounds, provide uniform systems to number the carbon atoms in molecules and determine designations for fluoroethers, differentiate among azeotropic blends having the same components, and add a new reference. Composite tables remove the "provisional" notation previously appended to some safety classifications, correct a number of chemical names for consistency with the International Union of Pure and Applied Chemistry (IUPAC) conventions, correct informational (not part of the standard) data on refrigerants, and add safety classifications for R-23, R-32, R-116, R-124, R-125, R-143a, and R-218. The addenda also add designations, tolerances, and safety classifications for R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-507A, R-508A, R-508B, and R-509A. The addenda detail the submission requirements to apply for designations and classifications of additional refrigerants. A foreword and table identify the changes by specific addendum.

Design, Construction, and Safety Investigation on a Liquid-Cooled Heat Exchanger with the Refrigerant NH_3, *DKV-Statusbericht* [Status Report] 7, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1991 (RDB4535)

please see pages 6-8 for ordering information

R-717, ammonia

Equipment, Design, and Installation of Ammonia Mechanical Refrigerating Systems, ANSI/IIAR Standard 2-1992, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, December 1992 (40 pages with 2 figures and 5 tables, RDB-4757)

This voluntary, consensus standard is intended to serve as guide to the design, manufacture, installation, and use of mechanical refrigerating systems employing R-717 (anhydrous ammonia). It applies to closed mechanical refrigerating systems in industrial occupancies. Its provisions represent minimum requirements for the areas addressed, to minimize property damage or loss and risks to persons. The standard comprises a foreword, introduction, definitions, and sections on equipment, machinery room design, and installation. The equipment provisions cover compressors, evaporative condensers, pressure reliefs, shell-and-tube condensers, double-pipe condensers, pressure vessels, evaporators, refrigerant pumps, refrigerant valves, pressure-relief devices, piping, testing, materials, and ultimate strength requirements. Most of these topics identify specific design criteria, nameplate data, and testing. The provisions for machinery rooms cover room layout, open flames, ventilation, architectural features, location, electrical, and piping. The installation topics include materials selection, piping, joints, pipe hangers and supports, pressure-relief protection, foundations and equipment supports, system testing, and ammonia handling and storage. The standard concludes with lists of references and their sources, an appendix on emergency discharge of ammonia refrigerant, and two drawings detailing emergency control stations. This version supersedes ANSI/IIAR Standard 2-1984 and earlier editions.

Forced Dispersion of Ammonia Plumes into the Atmosphere, research project 813-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1994 - October 1995 (ASH0813)

This project encompasses two phases, the first of which will apply one or more selected model(s) to analyze the dispersion of an ammonia plume into the atmosphere. The second entails a series of tests, to measure downwind concentrations to verify the validity of the model(s). One parameter to be explored is the effect of a high velocity discharge. To the extent feasible, the results will be reduced to a family of curves for use to evaluate the concentrations resulting from a discharge. Such curves are intended for use by designers of ammonia refrigeration systems and regulatory bodies. The contractor for the project is Kansas State University (KSU), led by D. L. Fenton; it is sponsored by ASHRAE Technical Committee 10.1, *Custom Engineered Refrigeration Systems*.

Freon(R) Compounds and Safety, bulletin S-16 (A-85178), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1969 and republished February 1978 (16 pages with 7 tables, RDB-5906)

flammability, reactivity, pressure, frostbite, effects on the eyes and skin, acute and chronic toxicity, anesthesia, decomposition, refrigerant safety

International Programme on Chemical Safety (IPCS), **Fully Halogenated Chlorofluorocarbons**, Environmental Health Criteria Report 113, World Health Organization (WHO), Geneva, Switzerland, 1990 (RDB5367)

refrigerant safety

Guidelines for Ammonia Machinery Room Ventilation, IIAR bulletin 111, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, October 1991 (24 pages with 1 figure, RDB4760)

This bulletin provides guidance for ventilation systems for machinery rooms using ammonia in industrial refrigeration facilities. The recommended design scheme and minimum ventilation levels are applicable to systems with large quantities of ammonia, exceeding several thousand pounds, but may not be appropriate for smaller systems or those for other applications. The bulletin identifies reference sources, including major codes and standards, used to prepare the guidelines. It then summarizes ventilation requirements to be classified as a "Non-Hazardous (Unclassified) Location" under the National Fire Protection Association (NFPA) Standard 70, National Electrical Code (NEC). It specifically addresses continuously operated mechanical exhaust, independent emergency ventilation, and minimum volume requirements, A section on recommended design schemes reviews the steps to determine code minimums and outlines the design process. The document also addresses operation and maintenance. A worksheet to facilitate calculations, system illustration, and design example are provided.

Hazardous Chemicals Data, publication 49, National Fire Protection Association (NFPA), Quincy, MA, 1994 (170 pages, RDB6709)

flammability, toxicity, reactivity, safety classifications

History of Accidents in Ammonia Refrigeration Facilities in Japan (1951-1990), High Pressure Gas Safety Institute of Japan, 1991 (RDB5451)

R-717 (ammonia), safety

Kirk-Othmer Encyclopedia of Chemical Technology (Third Edition), John Wiley and Sons, New York, NY, 1978-1984 (RDB5165)

reference for flammability, toxicity, reactivity, and other safety data

Number Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34-1992, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, April 1992 (16 pages with 1 figure and 5 tables, RDB2909)

This voluntary, consensus standard describes a shorthand way of naming refrigerants and classifies them according to potential hazards. It is intended to establish a simple means of referring to common refrigerants, instead of using the chemical name, formula, or trade name. It also establishes a uniform system for assigning unambiguous reference numbers, composition-designating prefixes for refrigerants, and safety classifications based on toxicity and flammability. This standard is widely cited in construction codes and provides the classifications used in ASHRAE Standard 15-1992, *Safety Code for Mechanical Refrigeration*, to specify safety requirements for refrigerant use. This version supersedes ANSI/ASHRAE Standard 34-1989 and earlier editions.

Ongevallen met Ammoniak Koelinstallaties [Accidents with Ammonia Refrigeration Systems], TNO, Apeldoorn, The Netherlands, 28 May 1991 (RDB5496)

R-717 (ammonia), safety

Proctor and Hughes' Chemical Hazards of the Workplace (Third Edition), edited by G. J. Hathaway, N. H. Proctor, J. P. Hughes, and M. L. Fischman, Van Nostrand Reinhold Publishers, New York, NY, 1991 (666 pages, RDB5159)

flammability, toxicity, and other safety data

Refrigerant Safety Data - Recommendations of the Air-Conditioning and Refrigeration Industry, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (32 pages with 6 tables, available from JMC as RDB3A15)

The report provides toxicity and flammability data on refrigerants as well as recommended hazard categories and safety data. This information is needed to meet requirements for refrigerant use under the Uniform Fire Code (UFC) and Uniform Mechanical Code (UMC). The refrigerants addressed include R-11, R-12, R-22, R-113, R-114, R-123, R-134a, R-500, R-502, R-717 (ammonia), and R-744 (carbon dioxide). The information addressed includes Permissible Exposure Level (PEL), Immediately Dangerous to Life or Health (IDLH), and Lower Flammability Limit (LFL) values needed to set alarm and automatic shutdown levels. Where unavailable from sources prescribed by the UFC and/or UMC, surrogate values - established on a consistent basis - are offered. The report also provides hazard categories determined in accordance with the UFC and hazard signals determined in accordance with the UFC, UFC Standard 79-3, and National Fire Protection Association (NFPA) Standard 704-90. The report summarizes data assembled by industry experts, critically examined at a meeting convened solely for this purpose, and subsequently reviewed by the participants and others. The report provides an extensive list of references used to assemble the data. It also identifies the participants, contributors, and reviewers.

Refrigerants (SBQT2), *Supplement to the 1995 Editions of the Recognized Component Directory and Plastics Recognized Component Directory*, Underwriters Laboratories Incorporated (UL), Northbrook, IL, page 222, 1995 (1 page, RDB5C10)

These supplemental listings cover refrigerants intended for use as components of air-conditioning and refrigerating equipment. The refrigerants have been evaluated for flammability and toxicity as specifically indicated for individual products; pressure hazards were not evaluated. The supplemental listings cover product versions of R-123, R-134a, and R-508B. The listings indicate UL flammability group (nonflammable, practically nonflammable, or flammable) at 100 °C (212 °F). They also indicate the chemical constituents, phase as shipped, and container markings.

Refrigerants (SBQT2), *Recognized Component Directory*, Underwriters Laboratories Incorporated (UL), Northbrook, IL, volume 2, pages 1572-1574, 1995 (3 pages, RDB5931)

These listings cover refrigerants intended for use as components of air-conditioning and refrigerating equipment. The refrigerants have been evaluated for flammability and toxicity as specifically indicated for individual products; pressure hazards were not evaluated. The listings cover product versions of R-11, R-12, R-22, R-23, R-113, R-114, R-115, R-123, R-125, R-134a, R-401A, R-401B, R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-410B, R-500, R-502, R-503, R-507A, and R-22/152a/124 (40/17/43). The listings indicate UL flammability group (nonflammable,

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practically nonflammable, or flammable) at 100 °C (212 °F) as well as UL toxicity group (1-6) in the absence of flames or hot objects, which may result in decomposition. They also indicate the chemical constituents, phase as shipped, and container markings.

Safety Code for Mechanical Refrigeration, ANSI/ASHRAE Standard 15-1994, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, August 1994 (RDB4903)

This voluntary, consensus standard specifies safety requirements for design, construction, installation, and operation of refrigerating systems, to establish safeguards for life, limb, health, and property. It applies to mechanical refrigerating systems and heat pumps used in identified occupancies. It also covers components added after adoption, refrigerant conversions, and replacement of parts and components with new ones that are not identical in function. This standard is widely incorporated into construction codes, either by reference or by transcription with amendments. It identifies occupancy, system, and refrigerant safety classifications, the last by reference to ANSI/ASHRAE Standard 34-1992. It then prescribes restrictions on refrigerant use, including the maximum quantities of individual refrigerants that may be used for specific occupancies and systems. It also prescribes safety standards for design and construction of equipment and systems, operation, testing, and general requirements. Minimum safety devices, labeling, and tests also are specified. Appendices address the maximum allowable concentrations for blends, guidelines for emergency discharge of refrigerants, worst case fractionation, and a method for calculating the discharge capacity of pressure-relief devices for positive displacement compressors. A final appendix provides a cross-reference between paragraph numbers in the previous and current versions of this standard. This version supersedes ANSI/ASHRAE Standard 15-1992 and earlier editions.

Safety of Suva Refrigerants, document AS-1 (H-27530-3), DuPont Chemicals, Wilmington, DE, January 1994 (6 pages with 1 table, RDB4C48)

This bulletin reviews considerations for safe use of refrigerants by providing answers to common questions. It outlines the introduction of alternative refrigerants and associated testing. It briefly reviews the collaborative Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and individual programs and findings for specific refrigerants. The document discusses the flammability of R-123, R-124, R-125, and R-134a, noting that they are neither flammable nor explosive, but can become so when mixed with gases that are. The document notes that mixtures of R-134a with more than 60% air (by volume) can become flammable at raised pressures and temperatures. It counsels against use of refrigerant-air mixtures for leak testing. The document then addresses inhalation toxicity and the potential for suffocation. It explains the DuPont Acceptable Exposure Limit (AEL), a time-weighted average (TWA) concentration for an 8 or 12 hour day or 40 hour week, to which nearly all workers may be repeatedly exposed without adverse effects. It also explains Emergency Exposure Limit (EEL) values as airborne concentrations of brief duration which should not result in permanent adverse effects or interfere with escape in the event of a major release or spill. The document discusses symptoms of exposure to high refrigerant concentrations, cardiac sensitization, suffocation, safety measures for enclosed areas, dangers of deliberate inhalation, detection by odor, and guidance when a large spill or leak occurs. It goes on to address special requirements for R-123. The chemical formulae, boiling points, AELs, and EELs are tabulated for R-123, R-124, R-125, and R-134a. The bulletin provides general advice on skin and eye contact with refrigerants, frostbite, pressure hazards, handling and disposal of cylinders, brazing or welding of pipes in air-conditioning and refrigeration systems, and decomposition. It concludes with specific cautions. The document identifies related bulletins that may be helpful and recommends familiarization with the Material Safety Data Sheet (MSDS) provided for the refrigerant to be used. DuPont's product names are Suva(R) Centri-LP and Suva(R) 123 for R-123, Suva(R) 124 for R-124, and Suva(R) 125 for R-125. It identifies R-134a as Suva(R) Cold-MP, Suva(R) Trans A/C, and Suva(R) 134a.

Sax's Dangerous Properties of Industrial Materials (Ninth Edition), edited by R. J. Lewis, Sr. (revision of publication by N. I. Sax), Van Nostrand Reinhold Publishers, New York, NY, 1996 (3 volumes totalling more than 5500 pages, RDB6106)

widely cited reference for flammability, toxicity, and other safety data

Unfallverhütungsvorschrift UVV 20, Kälteanlagen [Accident Prevention Regulations UVV 20, Refrigerating Plants], Federal Republic of Germany, Köln, Germany (RDB4681)

refrigerant safety requirements

Toxicity

J. Adir, D. A. Blake, and G. W. Mergner (University of Maryland), **Kinetics of Uptake and Elimination of Trichlorofluoromethane (F-11) and Dichlorodifluoromethane (F-12) in Beagles and Humans**, abstract 171 (13th Annual Meeting of the Society of Toxicology, Washington, DC, 10-14 March 1974), *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, New York, NY, USA, and London, UK, volume 29, number 1, pages 142-143, July 1974 (2 pages with no figures or tables, RDB59A9)

kinetics of uptake and elimination of R-11 and R-12 based on blood concentration in 6 beagles and 2 humans; concludes that the kinetics of these chemicals are consistent with their blood solubilities, oil-water partition characteristics, and other physiologic considerations

Y. Alarie and J. E. Luo, **Sensory Irritation by Airborne Chemicals: A Basis to Establish Acceptable Levels of Exposures**, *Toxicology of the Nasal Passages* (based on the Seventh Chemical Industry Institute of Toxicology, CIIT, Conference on Toxicology, Raleigh, NC, 22-23 February 1984), edited by C. S. Barrow, Hemisphere Publishing Corporation, Washington, DC, pages 91-100, 1986 (10 pages with 5 figures and 1 table, RDB6285)

acute toxicity, sensory irritation, prediction of acceptable levels, TLV-TWA predictions based on RD_{50}, RD_{50} values for 40 industrial chemicals, among which are 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide)

Y. Alarie (University of Pittsburgh), **Dose-Response Analysis in Animal Studies: Prediction of Human Responses**, *Environmental Health Perspectives*, volume 42, pages 9-13, 1981 (5 pages with 2 figures and 4 tables, RDB6279)

acute toxicity, dependence on exposure durations for irritation and lethal concentration measures, prediction of the levels and types of responses in humans at various multiples of the RD_{50} value found in mice, regression to TLV-TWA, RD_{50} values for 25 airborne, sensory irritants: Among them are 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide). The effects indicated at multiples of the RD_{50} are severe injury and possible mortality at 10, intolerable to humans at 1, some sensory irritation at 0.1, no sensory irritation at 0.01, and no effect of any kind on the respiratory system at 0.001

Y. Alarie (University of Pittsburgh), **Bioassay for Evaluating the Potency of Airborne Sensory Irritants and Predicting Acceptable Levels of Exposure in Man**, *Fundamentals of Cosmet. Toxicology*, Pergamon Press Limited, United Kingdom, volume 19, pages 623-626, 1981 (RDB6557)

health effects, toxicity, RD_{50}, TLV, R-717, R-764

Y. Alarie, L. E. Kane, and C. S. Barrow (University of Pittsburgh), **Sensory Irritation: A Basis to Establish Acceptable Exposure to Airborne Chemical Irritants**, *Principles and Practice of Industrial Toxicology*, edited by A. Reeves, John Wiley and Sons, New York, NY, 1980 (RDB6504)

health effects, toxicity, RD_{50}

Y. Alarie, **Sensory Irritation by Airborne Chemicals**, *Critical Reviews in Toxicology*, Chemical Rubber Company (CRC), Cleveland, OH, volume 2, pages 299-366, 1973 (RDB6503)

acute toxicity, sensory irritation

Y. Alarie, I. Wikisaka, and S. Oka, **Sensory Irritation by Sulfur Dioxide and Chlorobenzylidene Malononitrile**, *Environmental Physiology and Biochemistry*, volume 3, pages 53-74, 1973 (22 pages, RDB6506)

R-764 (sulfur dioxide), acute toxicity, sensory irritation, RD_{50} = 117 ppm [as reported in RDB 6557]

M. W. Anders (University of Rochester Medical Center), **Metabolism and Toxicity of Hydrochlorofluorocarbons: Current Knowledge and Needs for the Future**, *Environmental Health Perspectives*, National Institute of Health, U.S. Department of Health and Human Services, Research Triangle Park, NC, volume 96, pages 185-191, 1991 (7 pages, RDB5935)

R-123, R-125, and others, toxicity, mutagenicity

D. M. Aviado, **Comparative Cardiotoxicity of Fluorocarbons**, *Cardiac Toxicology*, CRC Press, Boca Raton, FL, volume II, pages 213-222, 1981 (10 pages, RDB6477)

R-22, R-152a, and others, toxicity, health effects

D. M. Aviado and M. S. Micozzi, **Fluorine-Containing Organic Compounds**, *Patty's Industrial Hygiene and Toxicology* (Third Revised Edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, New York, NY, volume 2B (Toxicology), chapter 42, pages 3071-3115, 1981 (45 pages, RDB6284)

summary toxicity data and outline of toxicological considerations for fluorocarbons using R-11 as a prototype; also addresses comparative toxicity of R-12, R-21, R-22, R-113, R-114, R-115, R-142b, R-152a, R-C318; animal models for evaluation of fluorocarbon toxicity

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D. M. Aviado, S. Zakheri, and T. Watanabe, **Nonfluorinated Propellants and Solvents for Aerosols**, CRC Press, Cleveland, OH, pages 3182-3183, 1977 (RDB6569)

R-600a (2-hr LC_{50} mouse = 520,000 ppm) and others, toxicity, health effects

D. M. Aviado and J. Drimal (University of Pennsylvania School of Medicine), **Five Fluorocarbons for Administration of Aerosol Bronchodilators**, *Journal of Clinical Pharmacology*, American College of Clinical Pharmacology, Lippincott-Raven Publishers, Philadelphia, PA, volume 15, number 1, part 2, pages 116-128, 1975 (13 pages with 4 figures and 3 tables, RDB6122)

R-11, R-12, R-114, R-115, and R-C318; toxicity

D. M. Aviado and D. G. Smith (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VIII. Respiration and Circulation in Primates**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, pages 241-252, 1975 (12 pages, RDB5735)

R-11, R-23, and others; toxicity, health effects

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, X. Proposed Classification**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, number 3, pages 321-332, 1975 (12 pages with 2 tables, RDB5920)

R-11, R-12, R-21, R-22, R-30, R-113, R-114, R-115, R-140 or R-140a, R-142b, R-152a, R-290, R-C318, R-600a, and R-1140; toxicity: classification scheme based on relative pressure and toxicity, the latter primarily effects on the respiratory and circulatory systems and the levels at which cardiac arrhythmias were produced [referenced in RDB 5143 and 6107]

D. M. Aviado and M. A. Belej (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, V. Ventricular Function in the Dog**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, pages 79-86, 1975 (8 pages with 2 figures and 2 tables, RDB5C80)

R-11, R-113, R-115, R-152a, and R-C318; toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosols with Special Reference to the Role of Propellants in Asthmatic Deaths**, *The Journal of Clinical Pharmacology*, American College of Clinical Pharmacology, Lippincott-Raven Publishers, Philadelphia, PA, volume 15, pages 86-104, 1975 (RDB65F6)

toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Propellants**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], Birkhäuser Verlag, Basel, Switzerland, volume 18, pages 365-397, 1974 (35 pages, RDB6593)

R-11, R-12, R-21, R-22, R-30, R-113, R-114 or R-114a, R-140a, R-142b, R-152a, R-290, R-C318, R-600a, R-1140, and others; health effects; toxicity: review of available information on the toxicity of 15 aerosol propellants (many also used as refrigerants); respiratory and cardiovascular effects on animals;

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Propellants**, *Proceedings of the Fourth Annual Conference on Environmental Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, 16-19 October 1974 (RDB6594)

R-152a, and others, health effects, toxicity

D. M. Aviado and M. A. Belej (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, I. Cardiac Arrhythmia in the Mouse**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 2, number 1, pages 31-42, 1974 (12 pages, RDB5854)

R-113, R-142b, R-152a, R-290, R-600a, and others; toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Cardiopulmonary Effects of Fluorocarbon Compounds**, *Proceedings of the Second Annual Conference on Environmental Toxicology*, report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, pages 31-39, 1971 (9 pages, RDB6736)

R-114 and others, toxicity

A. Azar, H. J. Trochimowicz, J. B. Terrill, and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbon Related to Cardiac Sensitization**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 34, number 3, pages 102-109, 1973 (8 pages, RDB5357)

R-11 and others; toxicity, health effects

A. Azar (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Sensitization of Fluorocarbon Propellants**, presentation at the Conference of Toxic Hazards of Halocarbon Propellants, U.S. Food and Drug Administration (FDA), Washington, DC, 16 July 1971 (23 pages with 3 figures and 7 tables, RDB6596)

R-11, R-12, and R-114; cardiac sensitization, health effects, toxicity

G. N. Bakhishev, **Relation of the Toxicity of Some Halogenated Aliphatic Hydrocarbons to Their Electronic Structure**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 1, pages 39-40, 1980 (2 pages, RDB5820)

R-23 and others, toxicity

R. E. Bales, **Fluorocarbons - An Industrial Hygiene Survey of Worker Exposure in Four Facilities**, publication PB-297772, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1978 (available from NTIS, RDB5824)

R-23 and others; toxicity

S. M. Barlow and F. M. Sullivan, **Fluorocarbons**, *Reproductive Hazards of Industrial Chemistry*, Academic Press, London, UK, pages 326-333, 1982 (8 pages, RDB5171)

R-11, R-12, R-21, R-22, R-31, R-112, R-113, R-114, R-115, toxicity

A. Bartin, H. Bartsch, G. Brun, and A. M. Camus, **Validation and Comparative Studies of 180 Chemicals with Salmonella-Typhimurium Strains and V-79 Chinese Hamster**, *Mutation Research*, Amsterdam, The Netherlands, volume 78, number 1, pages 1-50, 1980 (50 pages, RDB5922)

R-22 and others, toxicity

R. C. Baselt and B. S. Carvey, **A Fatal Case Involving Trichlorofluoromethane and Dichlorodifluoromethane**, *Journal of Forensic Science*, volume 13, pages 407-410, 1968 (4 pages, RDB6721)

R-11, R-12, toxicity, accident involving human exposure

M. A. Belej and D. M. Aviado (University of Pennsylvania School of Medicine), **Cardiopulmonary Toxicity of Propellants for Aerosols**, *The Journal of Clinical Pharmacology*, American College of Clinical Pharmacology, Lippincott-Raven Publishers, Philadelphia, PA, volume 15, number 1, part 2, pages 105-115, January 1975 (11 pages with 3 figures and 3 tables, RDB59A4)

R-11, R-12, R-21, R-114, R-115, R-123B1, R-142b, R-152a, R-C318, and R-600a; toxicity

M. A. Belej, D. G. Smith, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, IV. Cardiotoxicity in the Monkey**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 2, number 4, pages 381-395, 1974 (15 pages, RDB5178)

R-22, R-23, R-600a, and others; toxicity

R. Benigni, M. Cotta-Ramusino, and C. Andreoli, **Relationship Between Chlorofluorocarbon Chemical Structure and Their Salmonella Mutagenicity**, *Journal of Toxicology and Environmental Health*, Taylor and Francis Publishers, volume 34, number 3, pages 397-408, 1991 (12 pages, RDB5778)

R-32, R-124, R-125, R-134a, R-152a, and others, toxicity

M. C. Bindal et al, **Quantitative Correlation of Anesthetic Potencies of Halogenated Hydrocarbons with Boiling Points and Molecular Connectivity**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], Birkhäuser Verlag, Basel, Switzerland, volume 30, number 2, pages 234-236, 1980 (3 pages, RDB6184)

R-124 and others, toxicity

D. A. Blake and G. W. Mergner (University of Maryland), **Are Fluorocarbon Propellants Metabolized? Studies in ^{14}C-Labeled Trichlorofluoromethane (F-11) and Dichlorodifluoromethane (F-12) in Beagles and Humans**, abstract 170 (13th Annual Meeting of the Society of Toxicology, Washington, DC, 14 March 1974), *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, New York, NY, USA, and London, UK, volume 29, number 1, page 142, July 1974 (1 page with no figures or tables, RDB59A7)

investigation of biotransformation of R-11 and R-12 in 5 male and female beagles and 4 humans after a 7-20 minute inhalation; found that essentially all of the chemicals was recovered in unaltered form from exhaled air within one hour and, therefore, that R-11 and R-12 are refractory to biotransformation

W. J. Brock, **Toxicology Summary for CFC's HCFC's and HFC's**, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, undated circa 1996 (RDB6452)

R-11, R-12, R-22, R-23, R-30, R-32, R-113, R-114, R-115, R-123, R-123B1, R-124, R-125, R-134a, R-140a, R-141b, R-143a, R-152a, R-236fa, R-43-10, R-717, R-1110, R-1120: tabular summary of toxicity indicators including ALC/LC_{50}, cardiac sensitization threshold, anesthetic concentration, subchronic NOEL/NOAEL, *in vitro* mutagenicity, in vivo mutagenicity, developmental toxicity, chronic and oncogenicity (carcinogenicity and tumors), AEL/TLV

R. S. Brody, T. Watanabe, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, III. Influence of Bronchopulmonary Lesion on Cardiopulmonary Toxicity in the Mouse**, *Toxicology*, Elsevier/North

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Holland, Amsterdam, The Netherlands, volume 2, pages 173-184, 1974 (12 pages, RDB5C66)

R-11, R-12, R-152a, and others; cardiac sensitization, health effects, toxicity

M. Burgison, W. E. O'Malley, C. K. Heisse, et al, **Anesthesia. XLVI. Fluorinated Ethylenes and Cardiac Arrhythmias Induced by Epinephrine**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 114, pages 470-472, 1955 (3 pages, RDB6568)

R-1111, R-1113, R-1114, R-1122 or R-1122a, R-1130c, R-1130t, R-1132 or R-1132a, and others, cardiac sensitization, toxicity [referenced in RDB 5644]

J. H. Burn, *Proceedings of the Royal Society of Medicine*, United Kingdom, volume 52, pages 95 ff, 1959 (RDB6586)

anesthetic effect in mice: R-112 LOEL 10,000-20,000 ppm with initial excitement and convulsions; R-113 LOEL 50,000-120,000 ppm with initial excitement and convulsions; R-123a 1-hr LOEL 70,000 ppm with no deleterious neurological changes as reported in RDB 5C42

J. H. Burn, H. G. Epstein, and P. J. Goodford, *British Journal of Anaesthesia*, United Kingdom, volume 31, pages 518 ff, 1959 (RDB6587)

anesthetic effect in mice: R-112 LOEL 10,000-20,000 ppm with initial excitement and convulsions; R-113 LOEL 50,000-120,000 ppm with initial excitement and convulsions; R-123a 1-hr LOEL 70,000 ppm with no deleterious neurological changes as reported in RDB 5C42

T. H. S. Burns et al, *Anaesthesia*, volume 37, pages 471-472, 1982 (2 pages, RDB6225)

R-123 and others; anesthetic effect, health effects, toxicity

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), **Fluorine Compounds in Anaesthesia (5): Examination of Six Heavily Halogenated Aliphatic Compounds**, *Anaesthesia*, volume 17, number 3, pages 337-343, 1962 (7 pages with 1 table, RDB5939)

anesthetic effect, toxicity: R-123 10-min anesthetic LOEL mouse = 40,000 ppm v/v, 40-min anesthetic LOEL mouse = 30,000 ppm; R-125 anesthetic NOEL mouse at 930,000 ppm; R-235cb; R-235cbB1; R-1113

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), and D. S. Newland, **An Investigation of New Fluorine Compounds in Anaesthesia (1)**, *Anaesthesia*, volume 16, pages 3 ff, 1961 (RDB65B4)

anesthetic effect, toxicity

J. M. Calm (Engineering Consultant), **The Toxicity of Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 157-162, July 1996; republished as report DOE/CE/-3810-72E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (6 pages with 1 table, available from JMC as RDB-6832)

This paper presents toxicity data and exposure limits for refrigerants. The data address both acute (short-term, single exposure) and chronic (long-term, repeated exposure) effects, with emphasis on the former. The refrigerants covered include those in common use for the last decade, those used as components in alternatives, and selected candidates for future replacements. Specifically addressed are R-11, R-12, R-22, R-23, R-32, R-113, R-114, R-115, R-116, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-290, R-C318, R-600, R-600a, R-717, R-744, and R-1270. The paper also reviews the toxicity indicators used in both safety standards and building, mechanical, and fire codes. Data are tabulated for the LC_{50}, cardiac sensitization NOEL and LOEL, anesthetic/CNS EC_{50}, respiratory RD_{50}, IDLH (both from the Standards Completion Program and from the 1994 revisions), PEL, UL group, and Standard 34 safety classifications. The paper outlines current classification methods for refrigerant safety and relates them to standard and code usage.

D. D. Campbell et al, **Health Effects Among Refrigeration Repair Workers Exposed to Fluorocarbons**, *British Journal of Industrial Medicine*, volume 43, pages 107-111, 1986 (5 pages, RDB-5946)

refrigerants, clinical report of human exposures, safety, toxicity

C. P. Carpenter, H. F. Smyth, Jr., and U. C. Pozzani (Carnegie-Mellon Institute, then the Mellon Institute, University of Pittsburgh), **The Assay of Acute Vapor Toxicity and the Grading and Interpretation of Results on 96 Chemicals**, *Journal of Industrial Hygiene and Occupational Medicine*, volume 31, number 6, pages 343-346, 1949 (4 pages with 2 tables, RDB5643)

R-130, R-140, R-142b, R-150, R-150a, R-152a, R-161, R-717, R-1112a, R-1113, R-1120, R-1130a, R-1132a, and others: LC_{50} (widely referenced)

M. B. Chenoweth, **Ventricular Fibrillation Induced by Hydrocarbons and Epinephrine**, *Journal of Industrial Hygiene and Toxicology*, volume 28, pages 151 ff, 1946 (RDB65A2)

R-602 (hexane), heptane, benzene, xylene, toluene, petroleum ether, and gasoline; cardiac sensitization, health effects, toxicity

D. G. Clark and D. J. Tinston (Imperial Chemical Industries PLC, ICI, UK), **Acute Inhalation Toxicity of Some Halogenated and Nonhalogenated Hydrocarbons**, *Human Toxicology*, Macmillan Press Limited, volume 1, number 3, pages 239-247, 1982 (9 pages with 4 tables, RDB6110)

R-10, R-11, R-12, R-12B1, R-13, R-13B1, R-20, R-22, R-30, R-112, R-113, R-114B2, R-140a, R-290, R-600a, R-1120, and R-1140: acute toxicity, lethality, mortality, LC_{50}, central nervous system effects, EC_{50} CNS, cardiac sensitization, EC_{50} CS

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **Correlation of the Cardiac Sensitizing Potential of Halogenated Hydrocarbons with their Physiochemical Properties**, *British Journal of Pharmacology*, British Pharmacological Society, Stockton Press Limited, Hampshire, UK, volume 49, pages 355-367, 1973 (13 pages, RDB6109)

R-290 and others, cardiac sensitization, toxicity

D. G. Clark and D. J. Tinston (Imperial Chemical Industries PLC, ICI, UK), **Cardiac Effects of Isoproternol, Hypoxia, Hypercapnia and Fluorocarbon Propellants and Their Use in Asthma Inhalers**, *Annals of Allergy*, American College of Allergy, Asthma, and Immunology, Arlington Heights, IL, volume 30, pages 536-541, 1971 or 1972 (6 pages, RDB6724)

R-11, R-12, and others, cardiac sensitization with epinephrine challenge, R-11 LOEL at 12,500 ppm, R-12 LOEL at 70,000-80,000 ppm - as reported in RDB 5143

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **The Influence of Fluorocarbon Propellants on the Arrhythmogenic Activities of Adrenaline and Isoprenaline**, *Proceedings of the XIIIth Meeting of the European Society for the Study of Drug Toxicology*, pages 212-217, 1971 (6 pages, RDB5A68)

refrigerants, toxicity

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity: Past, Present, and Future**, *Journal of the Society of Cosmetic Chemists*, volume 18, pages 333-350, 27 May 1967 (18 pages with 8 tables, RDB5C41)

R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-112a, R-113, R-114, R-115, R-116, R-122, R-123, R-124a, R-125, R-133a, R-133aB1, R-142, R-142B1, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, toxicity, historical evolution of toxicity classification

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity and Biological Action**, *Fluorine Chemistry Reviews*, volume 1, pages 197-252, 1967; republished in Toxicity of Anaesthetics, edited by Fink, Williams and Williams Publishers, 1968 (56 pages with 5 figures and 36 tables, RDB5C42)

R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-112a, R-113, R-114, R-115, R-116, R-122, R-123, R-124a, R-125, R-133a, R-133aB1, R-142, R-142B1, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, toxicity (acute inhalation, biological action, chronic, oral, skin, and eye), historical evolution of toxicity classification; comprehensive summary and outline of attempts to link toxicity to chemical structure

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated) **The Mammalian Toxicology of Organic Compounds Containing Fluorine**, chapter 9, *Handbuch der experimentellen Pharmakologie* [Handbook of Experimental Pharmacology], edited by O. Eichler, A. Farah, H. Herken, and A. D. Welch, Springer-Verlag, Berlin, Germany, volume XX/1, pages 459-500, 1966 (42 pages, RDB6590)

toxicity review of fluorine chemicals [as referenced in RDB 5C42]

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **The Toxicity of Fluorocarbons with Special Reference to Chemical Constitution**, *Journal of Occupational Medicine*, Industrial Medical Association, Harper and Brothers Publishers, volume 4, number 5, pages 262-273, May 1962; republished as bulletin S-22, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, April 1965 (12 pages with 10 figures and 9 tables, RDB5169)

R-10, R-11, R-12, R-13, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-113, R-114, R-115, R-116, R-124a, R-133a, R-133aB1, R-142, R-142B1, R-217ba, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, R-752 (SF_4), R-7146 (SF_6), R-7122 (S_2F_{10}), R-1110, R-1112, R-1113, R-1114, R-1120, R-1130, R-1132a, R-1216, R-1318, fluoroelastomer (Viton A and B), mono-

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fluoroacetic acid, polyfluoroalcohols, polytetrafluoroethylene (PTFE) resin, and others; decomposition, toxicity

M. A. Collins, D. J. Tinston (ICI Chemicals and Polymers Limited, United Kingdom), and C. J. Hardy (Huntingdon Research Centre Limited, HRC, United Kingdom), **Studies on the Acute Toxicity of a Number of Hydrofluorocarbons**, *Proceedings of the Sixth International Congress of Toxicology*, June 1992 (RDB5B43)

R-125 and other HFC refrigerants

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1995: Maximum Concentrations and Biological Tolerance Values at the Workplace**), Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Germany, 1995 (RDB6AA1)

English language version of the *MAK- und BAT-Werte-Liste*; German occupational exposure limits [Maximale Arbeitsplatz Konzentrationen] for chemicals

F. Coulston and T. B. Griffin, *Physiological and Toxicological Aspects of Combustion* (proceedings of international symposium), pages 151-164, 1976 (14 pages, RDB6576)

R-116 and others, inhalation, toxicity

R. Culik and D. P. Kelly, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Dichlorofluoromethane (FREON 21) and 2,2-Dichloro-1,1,1-Trifluoroethane (FC-123)**, report 227-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6156)

R-21 and R-123, toxicity

T. Dalhamn, **Studies on SO_2, NO_2 and NH_3: Effect on Ciliary Activity in Rabbit Trachea of Single in Vitro Exposure and Resorption in Rabbit Nasal Cavity**, *Acta Physiol. Scand.*, volume 58, pages 287-291, 1963 (RDB6A47)

R-717 (ammonia), R-746 (nitrogen dioxide), and R-764 (sulfur dioxide), health effects, toxicity

T. Dalhamn, **Mucous Flow and Ciliary Activity in the Trachea of Healthy Rats and Rats Exposed to Respiratory Irritant Gases (SO_2, H_3N, HCHO). VIII. The Reaction of the Tracheal Ciliary Activity to Single Exposure to Respiratory Irritant Gases and Studies of the pH**, *Acta Physiol. Scand.*, volume 36 (supplement 123), pages 93-105, 1956 (RDB6A46)

R-717, R-764, and others, health effects, toxicity

T. Dalhamn, **Mucous Flow and Ciliary Activity in the Trachea of Healthy Rats and Rats Exposed to Respiratory Irritant Gases (SO_2, H_3N, HCHO). A Functional and Morphologic (Light Microscopic and Electron Microscopic) Study, with Special Reference to Technique**, *Acta Physiol. Scand.*, volume 36 (supplement 123), pages 161 ff, 1956 (RDB6A08)

R-717, R-764, and others, health effects, toxicity

R. H. Davies, R. D. Bagnall, W. Bell, and W. G. M. Jones, **The Hydrogen Bond Proton Donor Properties of Volatile Halogenated Hydrocarbons and Ethers and their Mode of Action in Anesthesia**, *International Journal of Quantum Chemistry: Quantum Biology Symposium*, volume 3, pages 171-185, 1976 (15 pages, RDB6555)

toxicity: R-142b (30-min LC_{50} mouse = 300,000 ppm), and others [as reported in RDB 3721]

R. H. Davies et al, **Quantitative Interpretation of Phase Effects in Anesthesia**, *International Journal of Quantum Chemistry: Quantum Biology Symposium*, volume 1, pages 201-212, 1974 (12 pages, RDB59A6)

toxicity: R-124, R-142b (anesthetic effect, 30-min EC_{50} mouse = 230,000 ppm), and others [s reported in RDB 5869]

W. B. Deichmann and H. W. Gerarde, **Toxicology of Drugs and Chemicals**, Academic Press, New York, NY, 1969 (RDB5266)

general reference on toxicity; cites a 4-hr LC_{50} rat of 2,000 ppm for R-717 (ammonia)

T. DiPaolo et al, **Molecular Connectivity Study of Halocarbon Anesthetics**, *Journal of Pharmaceutical Science*, volume 68, number 1, pages 39-42, 1979 (4 pages, RDB6185)

R-124 and others, fluorocarbon refrigerants, anesthetic effects, toxicity

K. T. Dishart, **The Synthesis and Evaluation of Some New Fluorinated Inhalation Anesthetics**, National Meeting (Chicago), American Chemical Society (ACS), Columbus, OH, September 1961 (RDB5907)

R-226cb, R-226cbB1, R-226daB1, R-244ca, R-244caB1, R-245ca, and others; anesthetic effects, toxicity

E. C. Dittman and E. Etschenberg, **Endoanesthetic and Narcotic Activity in Halogenated Methane Derivatives**, *European Journal of Pharmacology*, volume 24, number 3, pages 389-398, 1973 (10 pages, RDB5821)

R-23 and others

D. E. Dodd, W. T. Brashear, and A. Vinegar, **Metabolism and Pharmacokinetics of Selected Halon Replacement Candidates**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 68, pages 37-47, 1993 (11 pages, RDB6212)

R-123 and others; toxicity

R. E. Doherty and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VI. Influence of Cardiac and Pulmonary Vascular Lesions in the Rat**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, pages 213-224, 1975 (RDB5C81)

R-152a and others; cardiac sensitization, health effects, toxicity

C. T. Dollery, D. S. Davies, G. H. Draffen, F. M. Williams, and M. E. Conolly, **Blood Concentrations in Man of Fluorinated Hydrocarbons After Inhalation of Pressurized Aerosols**, *Lancet*, volume 2, pages 1164-1166, 1970 (6 pages, RDB6725)

effects of inhalation in humans, R-12 and others, no adverse effects from R-12 at aerosol bronchodilator doses in healthy adults or asthmatic patients - as reported in RDB 5143

R. C. Downing (Consultant, formerly DuPont Chemicals), **Refrigerant Toxicology**, *Refrigerating Service and Contracting* (RSC), Business News Publishing, Troy, MI, January 1967 (2 pages with 2 tables, RDB6850)

review of refrigerant inhalation risks for technicians; indicates that fluorocarbon refrigerants are low in toxicity, do not accumulate in the body, and are not metabolized or broken down to any extent; still recommends to avoid breathing them if possible; notes that the decomposition products of fluorocarbons are toxic, but there is no evidence of phosgene ($COCl_2$) formation in decomposition; identifies hydrochloric (HCl) and hydrofluoric acids (HF) as the primary decomposition products, sometimes with small amounts of chlorine gas (Cl_2); these acids have a very acrid, acidic odor at very low concentrations that serves as a warning of decomposition; reviews the historical association of phosgene with fluorocarbon decomposition, noting that other carbonyl halides, notably carbonyl fluoride (COF_2) and carbonyl chlorofluoride (COClF), were misidentified as phosgene in early studies; explains that actual phosgene formation is doubtful based on relative bond strengths of carbon fluorine and carbon-chlorine bonds; explains and presents the ACGIH Threshold Limit Value (TLV) concentrations for HCl, HF, COClF, and phosgene; reviews other studies on the decomposition of refrigerants by lit cigarettes that found miniscule decomposition of R-11 and R-22; concludes that these chemicals do not pose a greater health hazard to smokers than nonsmokers

R. C. Downing and D. Madinabeitia (E. I. duPont de Nemours and Company, Incorporated), **The Toxicity of Fluorinated Hydrocarbon Aerosol Propellants**, *Aerosol Bulletin*, Federation of European Aerosol Associations, February-April 1960; republished in *Aerosol Age*, volume 5, number 9, pages 25 ff, September 1960; republished as bulletin A-52 (A-82784), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, August 1972 (8 pages with 1 figure and 5 tables, RDB5C40)

R-11, R-12, R-22, R-113, decomposition products (phosgene / $COCl_2$, hydrochloric acid / HCl, hydrofluoric acid / HF, chlorine Cl_2, others), refrigerants, toxicity

M. J. Ellenhorn and D. G. Barceloux, **Aerosol Propellants**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, pages 528 ff, 1988 (RDB5947)

refrigerants, toxicity

M. J. Ellenhorn and D. G. Barceloux, **Fluorocarbons**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, pages 884 ff, 1988 (RDB5948)

refrigerants, toxicity

M. J. Ellenhorn and D. G. Barceloux, **Inhalant Abuse**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, pages 841 ff, 1988 (RDB5949)

refrigerants, toxicity

H. B. Elkins and L. Levine (Division of Occupational Hygiene, Massachusetts Department of Labor and Industries), **Decomposition of Halogenated Hydrocarbon Vapors by Smoking**, *Journal of Industrial Hygiene and Toxicology*, volume 21, number 6, pages 221-225, June 1939 (5 pages with 2 tables, RDB6773)

refrigerants, toxicity: reports experiments to determine the extent of decomposition of halocarbons passing through lighted cigarettes and cigars; describes the experimental and analytical methods used; tabulates tested concentrations and measured bromides and chlorides for R-10, R-12, R-160B1, R-1120, R-1130B2, and dichlorobenzene; addresses tolerable phosgene levels and influences of dusts and humidity; notes warning properties of hydrochloric acid, a primary decomposition product representing 80% of decomposition chlorides, at concentra-

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tions of 10 ppm; concludes that the extent of decomposition of the cited compounds in smoking cigarettes or cigars in the presence of their vapors "is of a low order and does not constitute a health hazard"

H. Fabel, R. Wettengel, and W. Hartmann, **Myocardial Ischemia and Arrhythmias Due to the Use of Pressurized Aerosols in Man**, *Deutsch Med. Wochenschrift* [German Medical Weekly], Germany, volume 97, pages 428-431, 1972 (4 pages, RDB6726)

R-12/11 (60/40), acute inhalation effects in humans, no change in EKGs as reported in RDB 5143

V. C. Foltz and R. Fuerst, **Mutation Studies with Drosophila Malanogaster Exposed to Four Fluorinated Hydrocarbon Gases**, *Environmental Research*, volume 7, number 3, pages 275-285, 1974 (11 pages, RDB5139)

R-23, R-152a, and others; toxicity [referenced in RTECS]

A. T. Fidler, E. L. Baker, and R. Letz, **The Neurobehavioral Effects of Occupational Exposure to Organic Solvents Among Construction Painters**, *British Journal of Industrial Medicine*, volume 1, pages 211-228, 1987 (18 pages, RDB5838)

inhalation toxicity

C. E. Finegan and G. M. Rusch (AlliedSignal Incorporated), **Update: Program for Alternative Fluorocarbon Toxicity Testing**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 895-904, October 1993 (10 pages with 12 tables, available from JMC as RDB3A53)

R-32, R-123, R-124, R-125, R-141b, R-134a, R-225ca, R-225cb

N. C. Flowers, R. C. Hand, and L. G. Horan (Helen Dwight Reid Educational Foundation), *Archives of Environmental Health*, American Medical Association (AMA), Helen Dwight Reid Educational Foundation, volume 30, pages 353 ff, 1975 (RDB5C65)

R-11 and others, cardiac sensitization, health effects, toxicity

S. A. Friedman, M. Cammarato, and D. M. Aviado (University of Pennsylvania), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, II. Respiratory and Bronchopulmonary Effects in the Rat**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 1, number 4, pages 345-355, 1973 (11 pages with 2 figures and 4 tables, RDB6191)

R-11, R-12, R-21, R-114, R-115, R-C318, and R-600, cardiac sensitization, anesthesia, health effects, toxicity: exposures to R-12 at 360,000 ppm v/v produced apnea and finally death, but did not cause arrhythmias in rats as reported in RDB 5143 (possible ALC, exposure duration not indicated in RDB 5143)

R. Fuerst and S. Stephens, **Effects of Gases and Gamma Irradiation on Neurospora Crassa**, *Develop. Ind. Microbiology*, volume 11, pages 301-310, 1970 (19 pages, RDB5C83)

R-152a and others; mutagenic potential, toxicity

R. Fuerst and M. M. Landry, *Develop. Ind. Microbiology*, volume 8, pages 305-312, 1966 (8 pages, RDB6130)

mutagenic potential, toxicity

S. C. Gad et al, **Correlation of Ocular and Dermal Irritancy of Industrial Chemicals**, *Journal of Toxicology Cutaneous Ocular Toxicol.*, volume 5, number 3, pages 195-214, 1986 (20 pages, RDB6133)

R-152a and others; toxicity

M. L. Gargas et al, **Modeling the Tissue Solubilities and Metabolic Rate Constant (V_{max}) of Halogenated Methanes, Ethanes, and Ethylenes**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 43, number 1-3, pages 235-256, 1988 (22 pages, RDB5776)

toxicity

M. L. Gargas, H. J. Clewell III, and M. E. Andersen, **Metabolism of Inhaled Dihalomethanes in Vivo: Differentiation of Kinetic Constants for Two Independent Pathways**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 82, number 2, pages 211-223, 1986 (13 pages, RDB5780)

R-32 and others, toxicity

S. Garrett and R. Fuerst, **Sex-Linked Mutations in Drosophila after Exposure to Various Mixtures of Gas Atmospheres**, *Environmental Research*, volume 7, number 3, pages 286-293, 1974 (8 pages, RDB5819)

R-23, R-152a, and others; mutagenicity, inhalation toxicity

E. M. Gause and J. R. Rowlands, **Effects of Fluorocarbon Inhalants upon Alveolar Macrophages**, *Proceedings of the Western Pharmacology Society*, volume 19, pages 373-380, 1976 (8 pages, RDB5822)

R-23 and others, toxicity

T. L. Giguz, **Effect of Low Concentrations of Ammonia and Nitrogen Oxides in Adolescents Undergoing Vocational Training in the Chemical Industry**, *Hyg. Sanitariya*, volume 33, pages 491 ff, 1968 (RDB6A49)

R-717, R-746, and others, health effects, toxicity: study of chronic, occupational exposures of humans; 140 students aged 16-19 exposed to ammonia as well as nitrogen oxides in a fertilizer factory experienced an 11% increase in respiratory tract disorders and a 27% increase in xeroderma (disease of the skin characterized by dryness and roughness) in the first year, compared to 85 students in the same vocational school not exposed to ammonia or nitrogen oxides; diseases of the upper respiratory tract and skin increased by 24 and 36%, respectively, in the second year; groups of 34 students with 3 hour shifts in the factory were then compared to a control group of 26 students; the exposed group showed increases in gamma globulin and decreases in serum albumen together with changes in fat metabolism; author suggested that there is stress on the hepatic functions that could be ascribed to low concentrations of ammonia [as reported in RDB1106]; limitations to the study, including unknown prior health of the subjects and possible causes other than ammonia are discussed in RDB1106

J. H. Glover and H. W. Hodgson, **An Investigation of New Fluorine Compounds in Anaesthesia (3)**, *Anaesthesia*, volume 16, pages 333 ff, 1961 (RDB-65B6)

anesthetic effect, toxicity

J. H. Glover and H. W. Hodgson, **An Investigation of New Fluorine Compounds in Anaesthesia (2)**, *Anaesthesia*, volume 16, pages 19 ff, 1961 (RDB-65B5)

anesthetic effect, toxicity

A. E. Goldsmith et al, *Cancer Detection and Prevention*, volume 4, number 1-4, pages 109-115, 1981 (7 pages, RDB5784)

R-744 (carbon dioxide) and others, toxicity, health effects

R. E. Gosselin, R. P. Smith, and H. C. Hodge, **Fluorocarbon Refrigerants and Propellants**, *Clinical Toxicology of Commercial Products* (Fifth Edition), Williams and Wilkins, Baltimore, MD, pages 11-159, 1984 (148 pages, RDB5177)

reference for toxicity data

W. M. Grant, **Toxicology of the Eye** (Third Edition), Charles C. Thomas Publishers, Springfield, IL, 1986 (RDB5C51)

refrigerants and other chemicals, toxicity [referenced in RDB 5C46]

T. Green, **The Metabolic Activation of Dichloromethane and Chlorofluoromethane in a Bacterial Mutation Assay Using Salmonella-Typhimurium**, *Mutation Research*, Amsterdam, The Netherlands, volume 118, pages 277 ff, 1983 (RDB6480)

R-30, R-31, and others, toxicity, mutagenicity

T. B. Griffin and F. Coulston, **Study of Toxicological Evaluation of Fire Suppressants and Extinguishers**, report CR-147658, National Aeronautics and Space Administration (NASA), Washington, DC, 31 March 1975 (RDB6571)

R-116 and others, toxicity: rabbits exposed to 50,000 ppm atmospheres of R-116 showed low absorption which was quickly eliminated; 4-hr ALC rat >800,000 ppm - as reported in RDB 6687

C. A. Halder et al, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 47, number 3, pages 164-172, 1986 (9 pages, RDB-6189)

R-600, R-600a, R-601, R-601a, toxicity, health effects, inhalation studies in rats

C. A. Halder et al, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 47, number 3, pages 173-175, 1986 (3 pages, RDB-6190)

R-600, R-600a, R-601, R-601a, toxicity, health effects, inhalation studies in rats

P. L. Hanst, J. W. Spence, And F. R. Clay (U.S. Environmental Protection Agency), **Chlorofluoromethanes: Their Thermal Stability in Passing Through Cigarettes**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 39, pages 772-776, September 1978 (5 pages with 4 figures, RDB6775)

refrigerants, toxicity: test for decomposition of R-11 at 2,000 ppm and R-22 at 2,500 ppm on passing through lit cigarettes; no carbonyl chloride (phosgene), carbonyl fluoride, or carbonyl chlorofluoride was found at a sensitivity of 0.1% of the starting material; documents the reactions that might yield the toxic carbonyl halides, experimental methods, and measured infrared spectra; found no measurable decomposition of the chlorofluoromethane compounds with simulated smoking; concludes that chlorofluoromethane pollutants in a room do not pose a greater health hazard for smokers than nonsmokers

C. J. Hardy et al, **Halon 13B1, Freon 23, Mixture of Freon 23 and HFC 125: Assessment of Car-**

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diac Sensitization Potential in Dogs, report DPT 273/921009, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 15 March 1993 (42 pages, RDB6458)

toxicity, tests for cardiac sensitization in beagle dogs with administration of adrenaline by intravenous injection before and during inhalation; R-11 LOEL (100%) at 20,000 ppm v/v; R-13B1 NOEL at 100,000 ppm, LOEL (17%) at 150,000 ppm, EC_{50} at 250,000 ppm; R-23 NOEL at 500,000 ppm with auxiliary oxygen; R-23/125 (36.5/63.5 v/v) LOEL (1/6) at 100,000 ppm

C. J. Hardy, **Assessment of Cardiac Sensitization Potential in Dogs, Comparison of HFC-125 and Halon 13B1**, report ALS 11/920116 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 10 June 1992 (RDB5755)

cardiac sensitization in dogs: R-125 5-min NOEL dog (0/6) at 75,000 ppm v/v, LOEL (1/6) at 100,000 ppm, and EC_{50} at 100,000-150,000 ppm; comparative tests with R-11 indicate an EC_{50} at ≤20,000 ppm, and with R-13B1 a NOEL at 150,000 ppm, LOEL (33%) at 200,000 ppm, and EC_{50} at ≤250,000 ppm as reported in RDB 5C15 and 65E6

J. W. Harris, J. P. Jones, J. L. Martin, A. C. LaRosa, M. J. Olson, L. R. Pohl, and M. W. Anders, **Pentahaloethane-Based Chlorofluorocarbon Substitutes and Halothane: Correlation of In Vivo Hepatic Protein Trifluoroacetylation and Urinary Trifluoroacetic Acid Excretion with Calculated Enthalpies of Activation**, *Chem. Res. Toxicology*, volume 5, number 5, pages 720-725, 1992 (6 pages, RDB5942)

R-125, R-134a, and others; health effects, metabolism, toxicity

J. Healy and O. W. Van Auken, **Comparison of the Effects of Three Fluorocarbons on Certain Bacteria**, *Canadian Journal of Microbiology*, Canada, volume 21, number 2, pages 221-226, 1975 (6 pages, RDB5921)

R-22 and others, toxicity

H. Hermann and J. Vial, **Nouvelles Syncopes Cardiaques par Association Toxique de l'Adrénaline et de Divers Produits Organiques Volatils** [New Cardiac Sensitization by Toxic Effect of Adrenaline and Various Volatile Organic Compounds], *Compte Rendu Société Biol.*, Paris, France, volume 119, pages 1316-1317, 1935 (2 pages, RDB6564)

identifies R-10 as having intermediate potency as a cardiac sensitizer; identifies R-30, R-40, R-40B1, R-40I1, R-150, R-160B1, R-160I1, and other chemicals as weak cardiac-sensitizing agents [as reported in RDB 5644]

G. Hodson-Walker (Life Science Research Limited, LSR, UK), G. M. Rusch (AlliedSignal Incorporated, USA), and F. M. H. Debets, **Mutagenicity Testing of a Number of CFC Replacements: Methodology and Results**, Proceedings of the Sixth International Conference on Environmental Mutagens, Melbourne, Australia, February 1993; republished Proceedings of the 24th Annual Meeting of the Environmental Mutagen Society, Norfolk, VA, April 1993; republished in *Environ. Mol. Mutagen*, volume 21 (suppl. 22), pages 28 ff, 1993 (RDB65D3)

R-123, R-125, and others, mutagenicity, toxicity

B. K. Hoover and R. C. Graham, **A Table of Acute Oral and Dermal LD_{50}'s and Inhalation LC_{50}'s for Fluorocarbon-11, 12, 22, 113, 114, 115, and 152a**, report OTS-052-0424, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 May 1978 (8 pages, RDB6595)

R-11, R-12, R-22, R-113, R-114, R-115, R-152a, toxicity, LD_{50}, LC_{50}

R. M. Hopkins and J. C. Krantz, Jr., **Anesthesia. LXXV. Relative Effects of Haloforms and Epinephrine on Cardiac Automaticity**, *Anesthesia and Analgesia*, volume 47, number 1, pages 56-67, 1968 (12 pages, RDB5136)

R-20B3, R20I3, R-23 (no cardiac sensitization at 800,000 ppm with an inspired, oxygen-enriched, mixture, as reported in RDB 5604), R-50, toxicity, physiological effects

C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, HRC, United Kingdom), **Assessment of Cardiac Sensitization Potential (CSP) of a Range of Halogenated Materials**, poster presentation, Society of Toxicology, 1994 (10 pages with 4 figures and 1 table, RDB-6684)

cardiac sensitization potential (CSP) in beagle dogs; method modification to predetermine appropriate adrenaline challenge for individual animals; presents [widely accepted] test regime for CSP measurement; 10-min EC_{50} dog was 10,000-20,000 ppm for R-11, 120,000 ppm for R-12, 250,000 for R-13B1, >500,000 ppm for R-23, >350,000 ppm for R-32, 170,000 ppm for R-125, 205,000 ppm for R-134a, 20,000 ppm for R-141b, ≈310,000 ppm for R-143a, >400,000 ppm for R-218, >400,000 ppm for R-31-10, >170,000 ppm (maximum attainable vapor concentration) for R-51-14, and >230,000 (maximum attainable vapor concentration) for perfluoro-N-methyl morpholine; examines relation to normal boiling

point and to molecular composition with data from the current and prior studies; concludes that "although cardiac sensitization is likely to be an example of physical toxicity and is related to the physiochemical properties of a material, the [normal] boiling point alone cannot be used as a predictor"; also concludes that "halogenated alkanes in which >75% of the halogens are fluorine are likely to be of low CSP and that halogenated alkanes in which ≥50% of the halogens are chlorine are likely to be of high CSP"; finally concludes that "knowledge of the molecular formula and the boiling point may, together, allow some indication of likely CSP" as a guide for animal studies

C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, HRC, United Kingdom), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFA 134a and A12**, report CTL/C/2521, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 13 September 1991 (RDB5B42)

cardiac sensitization in beagle dogs, toxicity: for R-12 EC_{50} >80,000 and <160,000 ppm; for R-134a LOEL >40,000 and <80,000 ppm as reported in RDB 5A79, EC_{50} >160,000 and <320,000 ppm as reported in RDB 5870

C. J. Hardy, I. J. Sharman, and D. O. Chanter (Huntingdon Research Centre Limited, HRC, United Kingdom), **Assessment of Cardiac Sensitization Potential in Dogs and Monkeys: Comparison of I-141b and F11**, report PWT 86/89437, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA 8 September 1989 (50 pages with 7 figures and 7 tables, RDB5C63)

cardiac sensitization in beagle dogs and cynomolgus monkeys, toxicity: potential to cause cardiac sensitization is similar for R-11 and R-141b; for R-11, NOEL dog at 9,000 ppm v/v and LOEL dog at 13,000 ppm; for R-141b LOEL dog at 9,000 ppm; LOEL monkey is 5,000-10,000 ppm for both

N. F. Izmerov, I. V. Sanotsky, and K. K. Siderov, **Toxicometric Parameters of Industrial Toxic Chemicals Under Single Exposure**, USSR State Committee for Science and Technology, Moscow, USSR, 1982 (in Russian, RDB5C91)

R-141b, R-152a, and others; toxicity [referenced in RTECS and RDB 5868]

R. T. Johnstone and S. E. Miller, **Occupational Diseases and Industrial Medicine**, W. B. Saunders Company, Philadelphia, PA, 1961 (RDB5C43)

fluorocarbon inhalation effects, oxygen deprivation, toxicity

D. A. Keller, **Acute Inhalation Toxicity of HFC-236fa and HFC-236ea in the Rat**, report 761-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 November 1994 (RDB6803)

R-236ea, R-236fa, toxicity: both can cause sleep induction (narcosis); for R-236ea, 4-hr ALC rat is >85,000 ppm v/v and NOEL and LOEL for narcosis are 14,000 and 24,000 ppm, respectively; for R-236fa, 4-hr ALC rat are >189,000 ppm and NOEL and LOEL for narcosis are 134,000 and 189,000 ppm, respectively

D. P. Kelly, R. Culik, H. J. Trochimowicz, and W. E. Fayerweather (E. I. duPont de Nemours and Company, Incorporated), **Inhalation Teratology Studies on Three Fluorocarbons**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, abstract 170 (Seventeenth Annual Meeting of the Society of Toxicology), volume 45, number 1, pages 293 ff, 1978 (RDB5827)

R-123, R-142b, and others; toxicity

D. P. Kelly, **Two-Week Inhalation Toxicity Studies on FC 21 and FC 123**, report 149-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, March 1976 (RDB6158)

R-21, R-123, toxicity

C. J. Kirwin et al, *Journal of the Society of Cosmetic Chemists*, volume 31, number 7, pages 367-370, 1980 (RDB6111)

health effects, mutagenic potential, toxicity; R-600 not mutagenic in the Ames Salmonella/microsome assay [as reported in RDB 6A83]; negative result for R-290

J. C. Krantz, Jr., and F. G. Rudo, **The Fluorinated Anesthetics**, chapter 10, *Handbuch der experimentellen Pharmakologie* [Handbook of Experimental Pharmacology], edited by O. Eichler, A. Farah, H. Herken, and A. D. Welch, Springer-Verlag, Berlin, Germany, volume XX, part 1, pages 501-564, 1966 (64 pages, RDB6589)

R-113a, R-114, and others, toxicity review of fluorine chemicals: R-113a anesthetic concentration at 60,000 ppm) as reported in RDB 5143

J. C. Krantz, Jr., C. G. Carr, and J. F. Vitcha (University of Maryland), **Anesthesia XXXI. A Study of Cyclic and Noncyclic Hydrocarbons on Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 94, pages 315-318, 1948 (4 pages with 1 figure and 1 table, RDB6192)

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cardiac sensitization with epinephrine injection, toxicity: the number of dogs sensitized at concentrations of 100,000-250,000 ppm was 2/4 for R-170, 3/3 for R-290, 2/2 for R-C318, 2/2 for R-600, 2/2 for R-600a, 0/12 for R-1150, and 2/2 for R-1270; the number sensitized at 150,000-900,000 ppm was 2/3 for R-C41-10 and 3/3 for R-601a; data also are provided for cis-trans-butene-2, cyclobutene, and 2,2-dimethylbutane

H. Kubler, **Physiological Properties of Propellants**, *Journal of the Society of Cosmetic Chemists*, volume 14, pages 341-351, 1963 (11 pages, RDB-6737)

R-114 and others, toxicity

M. M. Landry and R. Fuerst, *Develop. Ind. Microbiology*, volume 9, pages 370-388, 1967 (19 pages, RDB6112)

R-116, R-152a, R-290, R-1270, and others; mutagenic potential, toxicity; R-1270 is not mutagenic in Escherichia coli, but protects against mutations [as reported in RDB 6A59]

W. R. Lee, S. Abrahamson, R. Valencia, E. S. von Halle, F. E. Wurgler, and S. Zimmering, **The Sex-Linked Recessive Lethal Test for Mutagenesis in Drosophila Malanogaster Exposed to Four Fluorinated Hydrocarbon Gases** (Report of the U.S. Environmental Protection Agency, EPA, Gene-Tox Program), *Mutation Research*, volume 123, pages 183-279, 1983 (97 pages, RDB6592)

R-152a and others, mutagenicity, toxicity

D. Lester and L. A. Greenberg (Yale University), **Acute and Chronic Toxicity of Some Halogenated Derivatives of Methane and Ethane**, *Archives of Industrial Hygiene and Occupational Medicine*, volume 2, pages 335-344, 1950 (10 pages with 9 tables, RDB5147)

R-11, R-12, R-132bB2, R-142b, R-152a, R-1132a, and R-1141, toxicity: acute exposures of rats, for 30 min, to concentrations of 0-80% by volume, dominant clinical response found to be narcosis evidenced by disappearance of various reflexes at increasing concentrations, death when occurring appeared to be due to respiratory failure, recommends maximum allowable concentrations; chronic exposures of rats for 16 hr/day; provides data for ALC, complete anesthesia, recommended maximum allowable exposures; attempts to correlate toxic effects to boiling points

A. Lincoff and I. Kreissing, *Dev. Ophthalmol.*, volume 2, pages 17-23, 1981 (7 pages, RDB5C78)

R-116, R-218, and others; ophthalmological effects, toxicity

N. Loprieno and A. Abbondandolo, **Comparative Mutagenic Evaluation of Some Industrial Compounds**, *Proceedings of the Symposium on Short-Term Testing for Systematic Detection of Carcinogenicity*, edited by K. H. Norpoth and R. C. Garner, Springer-Verlag, Berlin, Germany, pages 333-356, 1980 (24 pages, RDB5930)

R-22 and others, toxicity, health effects, mutagenicity: findings for R-22 were negative [as reported in RDB 5923]

F. Leuschner, B. W. Neumann, and F. Hübscher, **Report on Subacute Toxicological Studies with Several Fluorocarbons in Rats and Dogs by Inhalation**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], Birkhäuser Verlag, Basel, Switzerland, volume 33(II), number 10, pages 1475-1476, 1983 (2 pages, RDB5607)

R-22, R-23 (subchronic NOAEL rat = 10,000 ppm, subchronic NOAEL dog = 5,000 ppm, as reported in RDB 6404), and others, toxicity

G. T. Linteris (National Institute of Standards and Technology, NIST), **Acid Gas Production in Inhibited Propane-Air Diffusion Flames**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, pages 225-242, 1995 (8 pages, RDB6209)

R-13B1, R-22, R-116, R-124, R-134a, R-218, R-227ea, R-236fa, R-31-10, R-C318, R-410A, decomposition in flames, reaction kinetics, potential formation of corrosive byproducts containing hydrofluoric and hydrochloric acids (HF and HCl)

E. Longstaff, M. Robinson, C. Bradbrook, J. A. Styles, and I. F. H. Purchase (ICI Chemicals and Polymers, United Kingdom), **Genotoxicity and Carcinogenicity of Fluorocarbons: Assessment by Short-Term in Vitro Tests and Chronic Exposure in Rats**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 72, number 1, pages 15-31, 1984 (32 pages, RDB5781)

R-32, R-123, R-124, R-134, R-134a, R-142b, R-143a, R-152a, and others; negative carcinogenic findings, toxicity [referenced in RDB 4B90, 5862, 5870, 5C16, and 6686]

E. Longstaff, M. Robinson, C. Bradbrook, J. A. Styles, and I. F. H. Purchase (ICI Chemicals and Polymers, United Kingdom), **Carcinogenicity of Chlorofluorocarbons. Assessment by Short-Term in Vitro Tests and Chronic Exposure in Rats**, *The Toxicologist*, Society of Toxicology (SOT), volume 2, pages 106 ff, 1982 (RDB6276)

toxicity

R. G. Love et al, *Annals of Occupational Hygiene*, volume 22, number 1, pages 43-54, 1979 (12 pages, RDB5785)

R-744 (carbon dioxide) and others, toxicity, health effects

G. Lu, J. S. L. Ling, and J. C. Krantz, Jr., **The Anaesthetic Properties of Certain Fluorinated Hydrocarbons and Ethers**, *Anesthesiology*, volume 14, pages 471 ff, 1953 (RDB65B7)

anesthetic effect, toxicity

H. R. Ludwig, S. G. Cairelli, and J. J. Whalen, **Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs)**, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, May 1994 (available from NTIS as document PB-94-195047, RDB5340)

This publication documents the criteria and information sources used to determine the National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life or Health (IDLH) concentrations. It addresses approximately 400 substances.

B. T. Luke et al, **Theoretical Investigation of the Anaerobic Reduction of Halogenated Alkanes by Cytochrome P-450. 2. Vertical Electron Affinities of Chlorofluoromethanes as a Measure of Their Activity**, *Journal of the American Chemical Society*, American Chemical Society (ACS), Columbus, OH, volume 110, number 11, pages 3396-3400 (5 pages, RDB5777)

toxicity, fluorocarbons

E. T. McHale, **Habitable Atmospheres Which Do Not Support Combustion**, Atlantic Research Corporation, 15 March 1972 (RDB5C79)

toxicity: R-116 1-hr ALC >800,000 ppm as reported in RDB 5605; R-218, acute and subchronic inhalation toxicity, 4-hr LC_{50} rat >113,000 ppm v/v, 10-min CNS EC_{50} rat >113,000 ppm v/v as reported in RDB 5858

W. D. McNally, **A Case of Phosgene Poisoning**, *Industrial Medicine*, volume 6, pages 539 ff, 1937 (RDB6774)

refrigerants, toxicity: asserts that phosgene is formed when R-1120 (trichloroethylene) passes through burning tobacco in smoking

G. Malinverno and G. Bargigia, **Reproductive Toxicity and Teratogenicity of Alternatives to Current CFCs**, *Proceedings of the Sixth International Congress of Toxicology*, June 1992 (RDB-5B45)

R-125 and other refrigerants

C. Maltoni, G. Lefermine, D. Tivoli, and G. Perino, **Long-Term Carcinogenicity Bioassays of Three Chlorofluorocarbons (Trichlorofluoromethane, FC11; Dichlorodifluoromethane, FC12; and Chlorodifluoromethane, FC22) Administered by Inhalation to Sprague-Dawley Rats and Swiss Mice**, *Annals of the New York Academy of Science (Living Chem. World)*, volume 534, pages 261-282, 1988 (22 pages, RDB6570)

R-11, R-12, R-22, toxicity: 104-week inhalation study in the rat and 78-week inhalation study in the mouse, findings negative

W. J. Meek, H. R. Hathaway, and O. S. Orth, **The Effects of Ether, Chloroform, and Cyclopropane in Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 61, pages 240-252, 1937 (13 pages, RDB6562)

R-20, R-C270, and probably R-610, cardiac sensitization, toxicity

K. W. Miller et al, **Physiochemical Approaches to the Mode of Action of General Anesthetics**, *Anethesiology*, volume 36, number 4, pages 339-351, 1972 (RDB6129)

inhalation toxicity

R-J. Millischer (Elf Atochem S.A., France) and C. H. Farr (Elf Atochem North America, USA), **Genetic Toxicity and Carcinogenicity of Fluorinated CFC Substitutes Studied within the Programme for Alternative Fluorocarbon Toxicity Testing**, *Proceedings of the Sixth International Congress of Toxicology*, June 1992; republished in *Toxicology Letters Supplement*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, pages 87-88, 1992 (RDB5B46)

R-125 and other refrigerants

R. R. Montgomery and C. F. Reinhardt, **Toxicity of Fluorocarbon Propellants**, *Handbook of Aerosol Technology*, edited by P. Saunders, Van Nostrand-Reinhold Publishers, New York, NY, 1979 (RDB-65F7)

toxicity

A. F. Moore, **Safety Assessment of Isobutane, Isopentane, n-Butane, and Propane**, *Journal of the American College of Toxicology*, volume 1, number 4, pages 127-142, 1982 (26 pages, RDB-6113)

R-290, R-600, R-600a, and R-601a, acute inhalation, dermal irritation, toxicity: R-600 causes drowsiness in humans at concentrations of 10,000 ppm for 10 min [as reported in RDB 6A83]

L. E. Morris, M. H. Noltensmeyer, J. M. White Jr., **Epinephrine Induced Cardiac Irregularities in the**

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Dog During Anesthesia with Trichloroethylene, Cyclopropane, Ethyl Chloride, and Chloroform, *Anesthesiology*, volume 14, pages 153-158, 1953 (6 pages, RDB6563)

R-20, R-160, R-C270, and R-1120, cardiac sensitization, toxicity

L. S. Mullin, A. Azar, C. F. Reinhardt, P. E. Smith, Jr., and E. F. Fabryka (E. I. duPont de Nemours and Company, Incorporated), **Halogenated Hydrocarbon-Induced Cardiac Arrhythmias Associated with Release of Endogenous Epinephrine**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 33, number 6, pages 389-396, June 1972 (8 pages with 3 figures and 3 tables, RDB5360)

R-11, R-12, R-114, toxicity: compares cardiac abnormalities produced by endogenous epinephrine with those produced by exogenous epinephrine in beagle dogs; the results show that higher concentrations are needed to sensitize a dog's heart to the action of its own circulating level of epinephrine, raised by exercise, than by experimental injection; the observed responses were fewer and less severe; paper notes that the wide differences cannot be extrapolated directly to humans, but they suggest a sufficient margin of safety based on tests by *epinephrine* injection; paper also notes that humans could develop cardiac arrhythmias under conditions of stress, such as fear, anxiety, or exertion, by exposures to unusually high levels of propellant [fluorocarbon] vapors

National Research Council (NRC) Committee on Toxicology, **Toxicity of Alternatives to Chlorofluorocarbons: HFC-134a and HCFC-123**, National Academy Press, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1996 (RDB6A01)

R-123, R-134a, assessment by the Board on Environmental Studies and Toxicology

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1984 (RDB6289)

Emergency Exposure Guidance Level (EEGL): R-114 and others

T. K. Nikijenko and T. A. Kochetkova, **Effect of Some Hydrochlorofluorocarbons on the Thyroid (Experimental Study)**, *Toksikologiya Novykh Promyshlennykh Khimicheskikh Veshchestva* [Toxicology of New Industrial Chemical Substances], Moscow, Russia (then USSR), volume 9, pages 175-182, 1967 (8 pages in Russian, RDB5853)

R-141b, R-142b, and other HCFCs, toxicity

T. K. Nikijenko and M. S. Tolgskaya, **On the Toxico-Pharmamorphological Changes in Animals Under the Effect of Freon(R) 141, 142, and 143 and the Intermediates Used in Their Production**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 9, number 10, pages 37-44, 1965 (8 pages in Russian, RDB5852)

R-141b, R-142b, and R-143a, toxicity

Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, **Air Contaminants; Rule**, 58 FR 124, *Federal Register*, U.S. Government Printing Office, Washington, DC, pages 35338-35351, 30 June 1993 (14 pages, available from JMC as RDB3904)

This rule revokes the *Final Rule* exposure limits in Table Z-1-A (*Limits for Air Contaminants*) of 29 CFR 1910.1000. It leaves the *Permissible Exposure Limits* (PELs) included in Table Z-1 before 1989, also published as Transitional Limits in table Z-1-A, in effect. Tables Z-2 and Z-3 (*Mineral Dusts*) also remain in effect. The rule reviews the court decision leading to this action and provides the three tables for enforcement of the action. A number of refrigerants are covered. PEL values are provided for R-10, R-11, R-12, R-12B2, R-13B1, R-20B3, R-21, R-30, R-40, R-40B1, R-40I1, R-110, R-112, R-112a, R-113, R-114, R-130, R-140, R-140a, R-160, R-160a, R-160B1, R-290, R-601, R-602, R-610, R-611, R-630, R-717, R-744, R-746, R-748, R-764, R-7146, R-1110, R-1120, and others. This rule is subject to revision and may have been amended or withdrawn.

Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, Code of Federal Regulations, **Air Contaminants**, 29 CFR Part 1910, U.S. Government Printing Office, as published at 54 FR 2920, 19 January 1989 (RDB3905)

Permissible Exposure Limit (PEL) values: This regulation is subject to revision and may have been amended or withdrawn.

H. Oujesky and L. Job, **Effects of Five Gaseous Atmospheres on the Survival Rate of DNA Synthesis in Escherichia Coli**, *Develop. Ind. Microbiology*, volume 18, pages 451-456, 1977 (6 pages, RDB6514)

R-23 and others; mutagenicity, toxicity, biochemical studies

H. Oujesky and R. Fuerst, *Develop. Ind. Microbiology*, volume 15, pages 405-410, 1974 (6 pages, RDB5C82)

R-23, R-152a, and others; mutagenicity, toxicity

H. Oujesky and I. Bhagat, **Response of Staphylococcus Aureus to Atmospheres of Freon(R)s and Genetron(R)s**, *Develop. Ind. Microbiology*, volume 14, pages 229-237, 1973 (9 pages, RDB5823)

R-23, R-152a, and others; mutagenicity, toxicity

J. W. Patterson, M. F. Sudlow, and S. R. Walker, **Blood Levels of Fluorinated Hydrocarbons in Asthmatic Patients After Inhalation of Pressurized Aerosols**, *Lancet*, volume 2, pages 565-568, 1971 (RDB6728)

R-12 and others

G. Paulet, **Les Fluorocarbones en Question** [Fluorocarbons at Issue], *European Journal of Toxicology and Environmental Hygiene*, supplement to volume 9, number 7, pages 385-407, 1976 (23 pages in French, RDB5179)

R-114 and others, toxicity

G. Paulet, **The Fluorocarbons at Issue**, *Aerosol Report*, volume 16, number 2, pages 44-49 and 52, 1977 (7 pages, RDB6126)

R-114 and others, inhalation toxicity

G. Paulet, **The Fluorocarbons at Issue**, *Aerosol Report*, volume 16, number 1, pages 22-30, 1977 (9 pages, RDB6125)

R-114 and others, inhalation toxicity

G. Paulet, G. Roncin, E. Vidal, P. Toulouse, and J. Dassonville, **Fluorocarbon and General Metabolism in the Rat, Rabbit, and Dog**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 34, pages 197-203, 1975 (7 pages, RDB5142)

toxicity

G. Paulet, J. Lanoë, A. Thos, P. Toulouse, and J. Dassonville (Laboratoire de Physiologie Médicale, U.E.R. Médicales et Pharmaceutiques, France), **Fate of Fluorocarbons in the Dog and Rabbit After Inhalation**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, New York, NY, USA, and London, UK, volume 34, number 2, pages 204-213, November 1975 (10 pages with 6 figures and 5 tables, RDB5C71)

R-11 and R-12, toxicity: inhalation of R-11 at 25,000 and 50,000 ppm, R-12 at 200,000 and 500,000 ppm, and R-12/11 (90/10) at 250,000 and 900,000 ppm by anesthetized dogs and rabbits through tracheal cannula with oxygen adjusted to 200,000 ppm; animals were tested for these chemicals in their exhaled air, blood, bile, cerobrospinal fluid, and urine to measure elimination; concluded that the chemicals diffuse quickly in the body fluids, but that elimination is completed in 20-50 minutes, 98% of it through the pulmonary system

G. Paulet, *Aerosol Report*, volume 8, number 12, pages 612-622, 1969 (11 pages, RDB5148)

R-114 and others

G. Paulet, R. Chevrier, J. Paulet, et al, **Retention of Freons by the Lungs and the Pulmonary Arteries**, *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, Paris, France, volume 30, number 3, pages 101-120, 1969 (20 pages, RDB5370)

toxicity, fluorocarbons

J. A. Pendergast, R. A. Jones, L. J. Jenkins, Jr., and J. Siegel (National Naval Medical Center, U.S. Navy), **Effects on Experimental Animals of Long Term Inhalation of Trichloroethylene, Carbon Tetrachloride, 1,1,1-Trichloroethane, Dichlorodifluoromethane, and 1,1-Dichloroethylene**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, New York, NY, USA, and London, UK, volume 10, number 2, pages 270-289, March 1967 (20 pages with 1 figure and 4 tables, RDB5C44)

R-12, R-14, R-140a with 8% inhibitor, R-1120, R-1130a, subchronic inhalation toxicity: effects of long-term inhalation exposure to develop data pertinent to human exposures in submarines; continuous exposures of rats, guinea pigs, monkeys and dogs for 90 days and repeated exposures for 8 hr/day, 5 days/week, for 6 weeks; 2 of 15 rats and 1 guinea pig died during continuous exposures to R-12 at 840 ppm (3,997 mg/m^3); 1 of 15 rats died in the repeated exposures to R-12 at 4,136 mg/m^3; no other signs of toxicity were observed for R-12, suggesting that the mortality was not treatment related

L. Pennington and R. Fuerst (Helen Dwight Reid Educational Foundation), **Biochemical and Morphological Effects of Various Gases on Rabbit Erythrocytes**, *Archives of Environmental Health*, American Medical Association (AMA), volume 22, number 4, pages 476-481, 1971 (6 pages, RDB6131)

R-152a and others; biochemical studies, toxicity

A. Poklis, **Determination of Fluorocarbon 11 and Fluorocarbon 12 in Postmortem Tissues: A Case Report**, *Forensic Science*, volume 5, pages 53-59, 1975 (7 pages, RDB6729)

fatal human exposures involving R-11 and R-12, sudden sniffing death from abusive use of aerosol products

please see pages 6-8 for ordering information

I. F. H. Purchase, E. Longstaff, J. Ashby, J. A. Styles, D. Anderson, P. A. Lefevre, and F. R. Westwood (ICI Chemicals and Polymers, United Kingdom), **An Evaluation of Six Short-Term Tests for Detecting Organic Chemical Carcinogens**, *British Journal of Cancer*, volume 37, pages 873 ff, 1978 (RDB6277)

toxicity, carcinogenicity

A. Quevauviller, **Hygiene and Safety of Propellants in Medicated Aerosols**, *Prod. Probl. Pharm.*, volume 20, pages 14-29, 1965 (RDB5A72)

R-114 and others, toxicity, eye and skin irritation

A. Quevauviller, M. Schrenzel, and V. Ngoc Huyen, **Local Tolerance of Skin, Mucous Membranes, Sores, and Burns of Animals to Chlorofluorohydrocarbons**, *Therapie*, volume 19, pages 247-263, 1964 (17 pages, RDB5368)

R-22, R-114, and others, toxicity, eye and skin irritation, hydrochlorofluorocarbons (HCFC): daily dose of R-12 tolerated by rats for a period of 23-33 days as reported in RDB 65H1

A. Quevauviller, M. Chaigneau, and M. Schrenzel, **Tolerance of the Lungs of Mice to Fluorinated Chlorohydrocarbons**, *Ann. Pharm. Fr.*, volume 21, number 11, pages 727-734, 1963 (8 pages, RDB-6128)

R-22 and others, toxicity, hydrochlorofluorocarbons (HCFC)

J. Raventos and P. G. Lemon, **The Impurities of Fluoroethane: Their Biological Properties**, *British Journal of Anaesthesia*, United Kingdom, volume 37, number 10, pages 716-737, 1965 (22 pages, RDB6165)

R-123 (LC_{50} mouse, 1 hour = 74,080 ppm), R-161, and others; toxicity [referenced in RTECS and RDB 3719 and 5861]

C. F. Reinhardt, L. S. Mullin, and M. E. Maxfield (E. I. duPont de Nemours and Company, Incorporated), **Epinephrine-Induced Cardiac Arrhythmia Potential of Some Common Industrial Solvents**, *Journal of Occupational Medicine*, volume 15, number 12, pages 953-955, December 1973 (3 pages with 1 figure and 1 table, RDB65A0)

cardiac sensitization in beagle dogs for 5-minute exposures with epinephrine challenge provides NOEL, LOEL, and EC_{50} data; R-30 0/12 dogs sensitized at 20,000 ppm v/v; R-113 0/12 at 2,500, 10/29 at 5,000, and 3/4 at 10,000 ppm; R-140a 0/12 at 2,500, 3/18 at 5,000, and 12/12 at 10,000 ppm; R-1110 0/12 at 10,000 ppm; R-1120 1/12 at 5,000 and 7/12 at 10,000 ppm; central nervous system effects above 20,000 ppm with R-30 and 10,000 ppm with R-1110 precluded cardiac sensitization tests at higher concentrations; toxicity

C. F. Reinhardt, L. S. Mullin, and M. E. Maxfield (E. I. duPont de Nemours and Company, Incorporated), **Halocarbon-Epinephrine-Induced Cardiac Arrhythmia Potential of Some Common Industrial Solvents**, abstract 81 (11th Annual Meeting of the Society of Toxicology, Williamsburg, VA, 5-9 March 1972), *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 22, number 2, pages 305, June 1972 (1 page with no figures or tables, RDB-6558)

cardiac sensitization in beagle dogs with epinephrine challenge, toxicity; reports no sensitization at 20,000 ppm with R-30 or at 10,000 ppm with R-1110; response at 5,000-10,000 with R-113 (possibly R-113a), R-140a, and R-1120; central nervous system effects above 20,000 ppm with R-30 and 10,000 ppm with R-1110 precluded cardiac sensitization tests at higher concentrations

C. F. Reinhardt, A. Azar, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Arrhythmias and Aerosol 'Sniffing'**, *Archives of Environmental Health*, American Medical Association (AMA), volume 22, number 2, pages 265-279, February 1971 (15 pages with 4 figures and 7 tables, RDB5644)

R-11, R-22, R-22, R-114, R-115, R-142b, R-152a, R-E170, R-290, R-C318, R-502, R-600a, R-1140, and others; cardiac sensitization, health effects, toxicity [referenced in RDB 4B90, 5141, 5856, 5865, and 6107]

R. W. Reinhold and G. M. Rusch, **Review of the Toxicity of Ten Selected Fluorocarbons**, Department of Toxicology Report MA-127-80-2, AlliedSignal Incorporated, Morristown, NJ, 22 January 1986 (RDB5143)

R-12, R-32, R-113, R-113a, R-114, R-114a, R-123, R-123a, R-134a, R-142b, toxicity

B. R. Rennick, S. D. Malton, G. K. Moe, et al, **1,1,1-Trichloroethane and Epinephrine**, *Federation Proceedings*, volume 8, pages 327 ff, 1949 (RDB-65A3)

R-140a, cardiac sensitization, health effects, toxicity

L. K. Riggs (E. R. Squibb and Sons), **Anesthetic Properties of the Olefine Hydrocarbons, Ethylene, Propylene, Butylene, and Amylene**, Proceedings of the Society of Experimental Biology and Medicine, New York, pages 269-270, 1925; republished in *Journal of the American Pharmaceuti-*

cal Association, volume 14, number 5, pages 380-387, May 1925 (8 pages, RDB65B9)

anesthetic effect in rats, toxicity: R-1150 results in light anesthesia at 900,000 ppm in 18-20 minutes and no other toxic symptoms in 3 hours, deep anesthesia [oxygen deprivation?] at 950,000 ppm within 1 minute; R-1270 produces light anesthesia at 400,000 ppm within 15 minutes and no other toxic symptoms in 6 hours, and deep anesthesia at 550,000 ppm in 3-6 minutes; butylene; amylene

B. H. Robbins, **Preliminary Studies of the Anesthetic Activity of Fluorinated Hydrocarbons**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 86, pages 197-204, 1946 (8 pages, RDB5980)

R-133a, R-133aB1, R-141b (anesthetic effect in mice at 25,000 ppm), R-142, R-142b (anesthetic effect, 10-min EC_{50} mouse = 250,000 ppm), R-142B1, toxicity [referenced in RDB 5169, 5868, and 5869]

R. Rubenstein (U.S. Environmental Protection Agency, EPA), **Human Health and Environmental Toxicity Issues for Evaluation of Halon Replacements**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 68, number 1-2, pages 21-24, 1993 (4 pages, RDB5950)

R-125 and others

G. M. Rusch (AlliedSignal Incorporated), **Results from the Program for Alternative Fluorocarbon Toxicology Testing Activities**, *FCKW - Ausstieg wohin?* [CFC - Phaseout Whereto?] (proceedings of the 8. Dechema-Fachgespräch Umweltschutz [Eighth DECHEMA Colloquium on Environmental Protection], Bonn, Germany, 2-3 May 1990), Deutsche Gesellschaft für Chemisches Apparatewesen (DECHEMA), Chemische Technik und Biotechnologie e.V., Frankfurt am Main, Germany, pages 245-261, 1990 (17 pages with text and 17 presentation charts, RDB65F4)

R-123, R-124, R-125, R-134a, R-141b, toxicity: progress report on the Programme for Alternative Fluorocarbons Toxicity Testing (PAFT) structure, tests, findings, and plans

G. M. Rusch (AlliedSignal Incorporated), **Toxicity Studies with New Refrigerant Gases**, *The Toxicologist*, Society of Toxicology (SOT), volume 11, number 1, pages 102 ff, 1989 (RDB6551)

R-125 and R-134a, health effects, toxicity

E. E. Sandmeyer, **Aliphatic Hydrocarbons**, *Patty's Industrial Hygiene and Toxicology* (Third Revised Edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, New York, NY, volume 2B (Toxicology), pages 3175-3220, 1981 (46 pages with 4 tables, RDB6290)

R-50 (methane), R-170 (ethane), R-290 (propane), R-600 (butane), R-600a (isobutane), R-601 (pentane), R-601a (isopentane), R-601b (neopentane), R-602 (hexane), and others; health effects, toxicity: 10 minute exposure of humans to R-600 at 10,000 ppm results in drowsiness [as reported in RDB 6A83]; 1-hr LC_{50} mouse = 21,944 ppm for R-600a

K. E. Schaefer, *Experientia*, volume 38, number 10, pages 1163-1168, 1982 (6 pages, RDB5786)

R-744 (carbon dioxide) and others, toxicity, health effects

J. Scholz, **New Toxicological Investigations of Certain Types of Freons Used as Propellants for Aerosols and Sprays**, *Fortschritte Biologischen Aerosolforschung 1957-1961* (proceedings of the Aerosol Congress, Berlin, Germany), volume 4, pages 420-429, 1962 (10 pages, RDB5355)

[Frigen(R)] R-11, R-12, R-113, R-114, narcotic effect, toxicity

B. Shugaev, **Concentrations of Hydrocarbons in Tissues as a Measure of Toxicity**, *Archives of Environmental Health*, American Medical Association (AMA), volume 18, pages 878-882, 1969 (5 pages, RDB5363)

R-600 and others, health effects, toxicity: 2-hr LC_{50} mouse = 286,000 ppm; 4-hr LC_{50} rat = 277,000 ppm [as reported in RDB 6A83]; 4-hr LC_{50} rat = 280,000 ppm for R-600 [as reported in RDB 5141]

B. Shugaev, *Farmakol. Toksikol.*, volume 31, number 3, pages 360-363, 1968 (4 pages, RDB-6A89)

R-600, health effects, metabolism, toxicity

B. Shugaev, *Farmakol. Toksikol.*, volume 30, number 1, pages 102-105, 1967 (4 pages, RDB6A90)

R-600, health effects, toxicity: 2-hr LC_{50} mouse = 286,000 ppm; 4-hr LC_{50} rat = 277,000 ppm [as reported in RDB 6A83]

J. A. Simaan and D. M. Aviado (University of Pennsylvania School of Medicine), **Hemodynamic Effects of Aerosol Propellants, I. Cardiac Depression in the Dog**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 5, number 2, pages 127-138, 1975 (12 pages with 1 figure and 4 tables, RDB6123)

R-11, R-12, R-114, R-152a, and R-C318, cardiac sensitization, health effects, toxicity

please see pages 6-8 for ordering information

J. A. Simaan and D. M. Aviado (University of Pennsylvania School of Medicine), **Hemodynamic Effects of Aerosol Propellants, II. Pulmonary Circulation in the Dog**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 5, number 2, pages 139-146, 1975 (RDB6124)

R-12, R-114 and others, cardiac sensitization, health effects, toxicity

S. R. Skaggs and T. A. Moore (New Mexico Engineering Research Institute, NMERI), **Toxicological Properties of Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 10, pages 99-109, 1994 (11 pages with 3 tables, RDB5526)

toxicity: indicates a 15-min LC_{50} rat of 274,000 ppm for R-13I1; 4-hr ALC rat concentrations of 663,000 ppm for R-23, 230,000 ppm for R-124, >800,000 ppm for R-125, and >800,000 ppm for R-31-10 ("PFC-410"); 4-hr LC_{50} rat concentrations of 100,000-130,000 ppm for R-12B1, 32,000 ppm for R-123, >800,000 ppm for R-227ea, and >800,000 ppm for R-51-14; also indicates NOAEL levels for cardiac sensitization of 50,000-100,000 ppm for R-12B1, 70,000 ppm for R-13B1, 2,000 ppm for R-13I1, 300,000 ppm for R-23, 10,000 ppm for R-123, 10,000 ppm for R-124, 75,000 ppm for R-125, 90,000 ppm for R-227ea, 400,000 ppm for R-31-10, and >400,000 ppm for R-51-14; also tabulates developmental toxicity NOAEL and subchronic (13-week) inhalation toxicity NOAEL; data sources are not explicit

F. E. Speizer, D. H. Wegman, and A. Ramirez, **Palpitation Rate Associated with Fluorocarbon Exposure in a Hospital Setting**, *New England Journal of Medicine*, volume 292, pages 624 ff, 1975 (RDB5366)

fluorocarbons, toxicity

F. A. Smith, W. L. Downs, H. C. Hodge, and E. A. Maynard (University of Rochester School of Medicine and Dentistry), **Screening of Fluorine-Containing Compounds for Acute Toxicity**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, New York, NY, USA and London, UK, volume 2, number 1, pages 54-58, January 1960 (RDB5908)

R-51-12 and other fluorine-containing organic and inorganic compounds, health effects, acute toxicity

S. Stephens et al, **Phenotypic and Genetic Effects in Neurospora Crassa Produced by Selected Gases and Gases Mixed with Oxygen**, *Develop. Ind. Microbiology*, volume 12, pages 346-353, 1971 (8 pages, RDB6515)

R-23 and others; mutagenicity, toxicity, biochemical studies

R. D. Stewart, P. E. Newton, E. D. Baretta, A. A. Herrmann, H. V. Forster, and R. J. Soto (Medical College of Wisconsin), **Physiological Response to Aerosol Propellants**, *Environmental Health Perspectives*, volume 26, pages 275-285, October 1978 (11 pages with 10 tables, RDB6115)

R-11, R-12, R-290, and R-600a; subchronic human exposures to 1000 ppm, toxicity: exposures of healthy adult male and female volunteers to R-12 levels of up to 1,000 ppm for 8 hr/day, 5 days/wk, for 4 weeks did not produce any abnormal effects; routine hematology, clinical chemistry, EKG, pulmonary function tests, and neurological measurements were performed - as reported in RDB 5143

R. D. Stewart et al (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Isobutane and Propane**, report PB-279205/LLC, National Technical Information Service (NTIS), Springfield, VA, April 1977 (available from NTIS, RDB6599)

R-290, R-600, health effects, toxicity

R. W. Stoughton (possibly Stroughton) and P. D. Lamson, **The Relative Anesthetic Effect of the Butanes and Pentanes**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 58, pages 74-78, 1936 (RDB6197)

anesthesia, acute inhalation toxicity: light anesthesia produced in mice exposed to R-600 at 130,000 ppm for 25 minutes or 220,000 ppm for 1 minute [as reported in RDB 6290 and 6A83]; anesthesia produced in dogs by R-600 at 220,000 ppm [as reported in RDB 6A83]; light anesthesia induced in mice exposed to R-600a, at 150,000 ppm for 60 minutes or 200,000 ppm for 17 minutes [as reported in RDB 5865]; R-600, and others

M. Stupfel et al, **Comparative Acute Toxicity, in Male and Female Mice, of Several Air Pollutants: Automobile Exhaust Gas, Nitrogen Oxides, Sulfur Dioxide, Ozone, Ammonia, and Carbon Dioxide**, *C. R. Soc. Biol.*, volume 165, number 9, pages 1869-1872, 1971 (4 pages, RDB5817)

R-717, R-744, R-748, R-764, health effects, toxicity

W. F. ten Berge (DSM, The Netherlands), A. Zwart, and L. M. Appelman (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), **Concentration-Time Mortality Response Relationship of Irritant and Systematically Acting Vapours and**

Gases, *Journal of Hazardous Materials*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 13, pages 301-309, 1986 (9 pages with 7 figures and 4 tables, RDB6278)

This article presents an analysis of mortality data, to determine time-dependent relations for lethal acute concentrations in various species for 20 chemicals. The maximum likelihood estimates of regression coefficients, variances, and covariances and chi-square confidence predictor were determined by probit analysis of the raw data from previously published toxicity studies. The results show that the product of exposure and time (c·t) is not always a good parameter for predicting mortality response (Haber's rule). The product of exposure to the power of n and time predicts the response well, where n ranges from 0.8 to 3.5 for 20 studied substances. Among them are n=2.8 for R-10, n=1.6 for R-30B1, n=2.0 for R-717 (ammonia), n=3.5 for R-746 (nitrogen dioxide), n=2.0 for R-1110, and n=0.8 for R-1120. These results estimate the LC_{50} for a specified period from data taken for another exposure duration.

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **Industrial Research on Alternative Fluorocarbons**, *Toxicology Letters*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 68, number 1-2, pages 25-30, 1993 (6 pages wit 5 tables, RDB5170)

R-123, R-124, R-125, R-134a, R-141b, R-142b, R-152a, R-E170 (DME), R-225ca, R-225cb: brief review of candidate alternatives for refrigerants and other chlorofluorocarbons and halons; overview of the Programme for Alternative Fluorocarbons Toxicity Testing (PAFT); brief summaries of findings for R-123, R-124, R-125, and R-134a indicate 4-hr LC_{50} rat concentrations as 32,000, 262,500, >800,000, and >500,000 ppm v/v, respectively, and 5-min cardiac sensitization thresholds in dogs at 20,000, 25,000, 100,000, and 75,000 ppm, respectively

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated) and T. Kawano (Daikin Industries, Limited), **Subchronic Inhalation Toxicity Studies on Seven Alternative Fluorocarbons**, *Proceedings of the Sixth International Congress of Toxicology*, June 1992 (RDB5B44)

R-125 and other refrigerants

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of Certain Gaseous Fluorocarbons**, *Proceedings of the 2nd International Symposium on Gaseous Dielectrics*, edited by L. G. Christophoran, Pergamon Press, Oxford, UK, pages 450 ff, 1980 (RDB6489)

R-22 and others, toxicity, health effects

H. J. Trochimowicz, J. P. Lyon, D. P. Kelly, and T. Chiu (E. I. duPont de Nemours and Company, Incorporated), **Ninety-Day Inhalation Toxicity Studies on Two Fluorocarbons**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 41, pages 200 ff, 1977 (RDB5915)

R-142b and others, toxicity

H. J. Trochimowicz, B. L. Moore, and T. Chiu (E. I. duPont de Nemours and Company, Incorporated), **Subacute Inhalation Toxicity Studies on Eight Fluorocarbons**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, abstract 161, volume 41, pages 198-199, 1977 (RDB5A13)

R-32, R-124, and others, toxicity, health effects

H. J. Trochimowicz, C. F. Reinhardt, L. S. Mullin, A. Azar, and B. W. Karrh (E. I. duPont de Nemours and Company, Incorporated), **The Effect of Myocardial Sensitization Potential of Certain Halocarbons**, *Journal of Occupational Medicine*, Industrial Medical Association, Harper and Brothers Publishers, volume 18, number 1, pages 26-30, January 1976 (5 pages with 3 figures and 3 tables, RDB65E7)

R-11, R-13B1 (halon 1301), R-140a (methyl chloroform), toxicity, cardiac sensitization NOEL and LOEL: summarizes tests on beagle dogs; "results showed no greater potential for cardiac sensitization among dogs having recovered from [induced] myocardial infarction as compared to normal healthy animals"

H. J. Trochimowicz, A. Azar, J. B. Terrill, and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbons Related to Cardiac Sensitization: Part II**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 35, number 10, 632-639, October 1974 (8 pages with 7 figures and 7 tables, RDB5361)

R-11, R-12, R-113, R-114, and R-115; health effects, toxicity

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbon During and After Acute Inhalation**, paper 11, *Proceedings of the Fourth Annual Conference on Environmental Toxicology* (Fairborn, OH, 16-18 October 1973), report AMRL-TR-73-125, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, pages 137-149, 1973 (13 pages with 7 figures and 7 tables including discussion, available from NTIS as document AD-781 031, RDB65H2)

R-11, R-12, R-113, R-114, R-115, toxicity

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S. Tsukamoto et al, *Journal of Toxicol. Science*, volume 10, number 4, pages 323-332, 1985 (10 pages, RDB6116)

R-290, R-600a, and others; metabolism in mice, toxicity

D. S. Young et al, **Journal of the American Chemical Society**, American Chemical Society (ACS), Columbus, OH, volume 62, pages 1171-1173, 1940 (3 pages, RDB5944)

R-125 and others

F. Valic and D. Beritic-Stahuljak, **Are Chlorine-Free Compounds a Solution for Health Problems Caused by Ozone-Depleting Substances?**, *Acta Medica Croatica*, volume 50, number 2, pages 61-63, 1996 (3 pages, RDB6A97)

reviews the environmental consequences of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs); concludes that CFCs and HCFCs are not acceptable based on their potentials for ozone depletion; examines the toxicity of HFC candidates; of those found to be nonflammable, the paper suggests that the toxicity of R-125, R-134a, and R-227ea appear to be low, but have not been fully evaluated

F. Valic and D. Beritic-Stahuljak, **Substitutes for Dangerous Chlorofluorocarbons, A Challenge**, *Croatian Medical Journal*, volume 34, number 2, pages 108-114, 1992 (7 pages, RDB5967)

R-125 and others, toxicity

A. Van Poznak and J. F. Artusio, Jr. (New York Hospital and Cornell University Medical College), **Anesthetic Properties of a Series of Fluorinated Compounds I. Fluorinated Hydrocarbons**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 2, number 4, pages 363-373, July 1960 (11 pages with 1 table, RDB5828)

R-12, R-12B1, R-22, R-23, R-114, R-124, R-124B1, R-125, R-133aB1, R-152a, R-243db and others; health effects, acute toxicity, anesthetic effects in dogs

A. Van Poznak and J. F. Artusio, Jr. (New York Hospital and Cornell University Medical College), **Anesthetic Properties of a Series of Fluorinated Compounds II. Fluorinated Ethers**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 2, number 4, pages 374-378, July 1960 (5 pages with 1 table, RDB5872)

health effects, acute toxicity, anesthetic effects and cardiac sensitization in dogs

W. F. von Oettingen, **The Halogenated Hydrocarbons: Their Toxicity and Potential Dangers**, *Journal of Industrial Hygiene and Toxicology*, volume 19, pages 422 ff, 1937; republished as publication 414, Public Health Service, U.S. Department of Health and Human Services, Washington, DC, 1955 (RDB5933)

refrigerants, health effects, toxicity: asserts that phosgene is formed when R-1120 (trichloroethylene) passes through burning tobacco in smoking

Y. Wang, M. J. Olson, and M. T. Baker, **Interaction of Fluoroethane Chlorofluorocarbon (CFC) Substitutes with Microsomal Cytochrome P450 - Stimulation of P450 Activity and Chlorodifluoroethene Metabolism**, *Biochemical Pharmacology*, Oxford, United Kingdom, volume 46, number 1, pages 87-94, 1993 (6 pages, RDB6545)

R-123, R-123B1, R-133a, R-124, R-134a and R-125 metabolism and toxicity: ability to stimulate cytochrome P450 activities; R-1122a (CDE) defluorination in hepatic microsomes from phenobarbital-treated rabbits; 10,000 ppm v/v R-123 doubled oxygen consumption; R-124, R-134a, and R-125 were successively less effective, increasing oxygen consumption by 50-100%

R. S. Waritz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of Some Commercial Fluorocarbons**, paper 7, *Proceedings of the Second Annual Conference on Environmental Toxicology*, report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, pages 85-99, 1971 (15 pages with 11 tables, RDB65H1)

R-11, R-12, R-22, R-113, R-114, R-115, R-116, R-152a, R-C318: ALC, clinical signs from inhalation, ALD, acute eye toxicity, chronic inhalation toxicity, chronic oral toxicity, chronic skin and eye toxicity, human studies

T. Watanabe and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VII. Influence of Pulmonary Emphysema and Anesthesia in the Rat**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, pages 225-240, 1975 (RDB5C64)

R-11, R-152a, and others; cardiac sensitization, health effects, toxicity

T. Watanabe and D. M. Aviado (University of Pennsylvania School of Medicine), *Pharmacologist*, volume 17, number 2, pages 192 ff, 1975 (RDB5A74)

R-114; reduced pulmonary compliance in rats with 30 minute exposures to 40,000 ppm for 6 days/week for 3 weeks [referenced in RDB 5141 and 5855]

W. Weigand (Farbwerke Hoechst AG, Germany), **Untersuchungen über die Inhalationstoxizität von Fluoroderivaten des Methan, Äthan, und Cyclobutan** [Studies of the Inhalation Toxicity of Fluorinated Derivatives of Methane, Ethane and Cyclobutane], Zentralbl. für Arbeitsmedizin und Arbeitsschutz [Occupational Medicine and Safety], volume 21, number 5, pages 149-156, 1971 (RDB-5365)

R-12B1, R-13, R-21, R-22, R-115, R-C318, and others, fluorocarbons, toxicity [referenced in RDB 5856]

J. H. Wills, P. Bradley, H. Kao, H. Grace, W. Hull, T. B. Griffin, F. Coulston, and E. S. Harris (Albany Medical College and NASA Manned-Spacecraft Center), **Sensitization of the Heart to Catecholamine-Induced Arrhythmia by Haloalkanes**, abstract 82 (11th Annual Meeting of the Society of Toxicology), *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 22, pages 305-306, 1972 (2 pages, RDB6118)

R-11, R13B1, R-114B2 or R-114aB2, R-116, R-C318, cardiac sensitization via tracheal cannulae in anesthetized guinea pigs, cats, and dogs at concentrations of up to 200,000 ppm, all resulted in sensitization with R-11 the most potent followed by R-114B2 or R-114aB2

W. P. Yant (U.S. Bureau of Mines), *American Journal of Public Health*, volume 23, pages 930 ff, 1933 (RDB5A73)

R-114 and others, toxicity

J. A. Zapp, Jr., **Fluorocarbons**, *Encyclopedia of Occupational Health and Safety* (Third Edition, Revised), volume 1, pages 895-897, 1983 (3 pages, RDB5951)

R-125 and others, toxicity

S. Zakhari, **Cardiovascular Toxicology of Halogenated Hydrocarbons and Other Solvents**, *Cardiovascular Toxicology* (Second Edition), Raven Press Limited, New York, NY, 1992 (RDB6685)

addresses possible mechanisms responsible for cardiac sensitization of refrigerants and other chemicals

S. Zakhari and D. M. Aviado, **Cardiovascular Toxicology of Aerosol Propellants, Refrigerants, and Related Solvents, III. Toxicodynamics**, *Target Organ Toxicology Series, Cardiovascular Toxicology*, edited by E. W. Van Stee, Raven Press, New York, NY, pages 281-326, 1982 (46 pages, RDB-6132)

R-10B4, R-12B1, R-31, R-40B2, R-41, R-113a, R-114, R-114a, R-114B2, R-130a, R-150, R-150B2, R-151a, R-152a, R-260da, R-280fa, R-280faB1, R-C318, R-31-10, R-1110, R-1114, R-1130c, R-1130t, R-1140B1, and others; toxicity

C. Zenz, **Fluorides**, *Occupational Medicine, Principles and Practical Applications* (Second Edition), Year Book Medical Publishers, Incorporated, Chicago, IL, chapter 35, pages 540-544, 1987 (5 pages, RDB5945)

R-125 and others, personal protective equipment, skin contact

1996 Threshold Limit Values for Chemical Substances in the Work Environment, *1996 TLVs(R) and BEIs(R): Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1995, pages 1-52 and notes (52 of 148 pages with 5 tables and 4 appendices, available from ACGIH for $14.00, RDB6901)

This book provides data for use as guidelines or recommendations in the control of potential hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document flags TLVs and other data for compounds included in the Notice of Intended Changes (NIC), to flag data for which future revision has been proposed. It also provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others. The carcinogenicity designations are revised for approximately 200 substances in this edition; such designations are added for many of the covered refrigerants.

Documentation of the Threshold Limit Values and Biological Exposure Indices (Sixth Edition), publication 0206, American Conference of Gov-

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ernmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1991 (RDB5141)

This book documents the bases for threshold limit values (TLVs) for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Double-Walled Heat Exchangers for Class 2 Refrigerants, proposed research project 794-WS, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH0794)

This research project is sponsored by ASHRAE Technical Committee 8.3, *Absorption and Heat Operated Machines*.

Encyclopedia of Occupational Health and Safety, International Labour Office, Geneva, Switzerland, 1983 (RDB5140)

toxicity, flammability

Guide to Occupational Exposure Values - 1995, publication 0373, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1995 (132 pages, RDB5902)

This reference document compares the most recent concentrations for widely cited toxicity exposure limits. It includes Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH), Permissible Exposure Limits (PEL) from the Occupational Safety and Health Administration (OSHA), the Recommended Exposure Limits (REL) from the National Institute for Occupational Safety and Health (NIOSH), and the 1989 Maximum Concentration Values in the Workplace (MAK) from the Deutsche Forschungsgemeinschaft (DFG) Commission for the Investigation of Health Hazards of Chemical Compounds in the Workplace. It also identifies carcinogens found in the workplace that are identified by the above organizations, the International Agency for Research on Cancer (IARC), the U.S. National Toxicology Program (NTP), and the U.S. Environmental Protection Agency (EPA). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Kälteanlagen - Sicherheitstechnische Grundsätze für Gestaltung, Ausrüstung, Aufstellung, und Betrieben [Refrigerating Plants - Safety Principles for their Construction, Equipment, Installation, and Operation], DIN Standard 8975, Deutsches Institut für Normung e.V., Berlin, Germany (RDB4680)

Merck Index (Eleventh Edition), edited by S. Budavari, M. J. O'Neil, A. Smith, and P. E. Heckelman, Merck Company, Rahway, NJ, 1989 (RDB6A05)

widely cited reference for toxicity and other safety data

NEHC Recommends Submarine Atmosphere Limits for New Ozone-Friendly Refrigerants, *CFC-Halon News*, Navy CFC & Halon Clearinghouse, Arlington, VA, volume 5, number 3, page 6, September 1995 (1 page with 1 table, copies available from JMC as RDB5A11)

R-134a, R-236fa, Navy Environmental Health Center (NEHC), preliminary atmosphere control limits for submarines based on toxicity and potential decomposition by and/or corrosive effects on catalytic oxygen replenishment systems

NIOSH Pocket Guide to Chemical Hazards, publication 94-116, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1994 (438 pages with 7 tables; available from GPO as document #017-033-00473-1 or NTIS as PB95-100368; limited copies available from JMC as RDB-5204)

This document lists safety information in tabular form for 677 chemicals found in the work environment. Many of them are regulated by the U.S. Occupational Safety and Health Administration (OSHA). Each entry identifies the chemical by name, synonym(s), trade name(s), structural or empirical chemical formula, Chemical Abstract Service (CAS) and Registry of Toxic Effects of Chemical Substances (RTECS) numbers, and assigned U.S. Department of Transportation identification and guide numbers. It then gives the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL), Short Term Exposure Limit (STEL), ceiling REL (REL-C),

carcinogenic identification or cautions, and/or Immediately Dangerous to Life or Health (IDLH) value. It also indicates the OSHA Permissible Exposure Limit (PEL) or PEL ceiling value (PEL-C). The entries also provide physical descriptions and summary chemical and physical properties, as available. They include concentration conversion factors, molecular weight, normal boiling point, solubility in water, flash point, ionization potential, representative vapor pressure, melting or freezing point temperature, flammability limits, minimum explosive concentration, representative specific gravity, and relative density of gases referenced to air. Entries list incompatibilities, reactivities, and measurement methods for the chemicals along with recommendations for personal protection, sanitation, and respirators. The entries conclude with health hazard summaries that identify body entry routes, symptoms, first aid measures, and impacted target organs. An introduction briefly describes these data and the codes used in the listings. Appendices provide recommendations on potential occupation carcinogens, identify 13 regulated carcinogens, discuss supplementary exposure limits, discuss exposure limits for certain substances without established RELs, discuss respirator recommendations for selected chemicals, and provide miscellaneous notes. They also list more protective OSHA PELs that were vacated by a court decision and provide indices by synonym and trade names, by CAS registry numbers, and by DOT identification numbers. A number of historical, current, and candidate refrigerants are covered. They include R-10, R-11, R-12, R-12B2, R-13B1, R-21, R-22, R-30, R-30B1, R-40, R-112, R-113, R-114, R-115, R-290 (propane), R-600 (butane), R-600a (isobutane), R-601 (pentane), R-610, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1120, R-1130, R-7146 (sulfur hexafluoride), and others.

PAFT Update, document H-45950), DuPont Chemicals, Wilmington, DE, November 1992 (4 pages with 2 tables, available from JMC as RDB3909)

This bulletin outlines the Programme for Alternative Fluorocarbons Toxicity Testing (PAFT), a cooperative research effort sponsored by chlorofluorocarbon producers. PAFT is designed to expedite the development of toxicology data for possible substitute fluorocarbons. The programs integrate past and present toxicological information to perform a careful risk assessment. The bulletin outlines the six main types of studies conducted by PAFT. They include acute toxicity primarily by inhalation, genotoxicity, subchronic toxicity by inhalation, developmental toxicity by teratology and inhalation, chronic toxicity and carcinogenicity by inhalation, and environmental toxicity. PAFT has initiated more than 100 individual toxicology studies. A table gives the schedule for testing, broken into phases the longest of which requires four years. Five programs are identified: PAFT I, which began in 1987, covers R-123 and R-134a. PAFT II, initiated in 1988, addresses R-141b. PAFT III, begun in late 1989, is studying R-124 and R-125. PAFT IV, established in May 1990, will examine R-225ca and R-225cb for solvent cleaning. PAFT V, established in early 1992, will examine R-32. A table summarizes key results as of November 1992 for the fluids names as well as for R-11 and R-12 for comparison. The data include ALC/LC_{50}, oral LD_{50}, cardiac sensitization thresholds, Ames assay, in vivo mutagenicity, subchronic no observed effect level (NOEL), teratogenic, chronic inhalation, and flammability data. The completion schedule and recommended exposure limits are included.

Patty's Industrial Hygiene and Toxicology (Fourth Edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, New York, NY, 1993-1995 (11 books totalling more than 9000 pages, RDB5704)

detailed reference for toxicity and other safety data; comprises volumes on "General Principles", "Toxicology", and "The Theory and Rationale of Industrial Hygiene Practice"

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Washington, DC, September 1995 (16 pages, available from JMC as RDB5C39)

Eight data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), sub-chronic toxicity (repeated exposure to determine any overall toxicological effect), reproductive and developmental toxicity (teratology, assessment of the effects on the reproductive system and of the potential for causing birth defects), chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer), and ecotoxicity (assessment of potential to affect living organisms in the environment). Toxicology summaries for R-32, R-123, R-124, R-125, R-134a, and R-141b as well as a combined summary for R-225ca and R-225cb indicate that all have low or very low toxicity. Test results show them not to be genotoxic and, except for the R-225 isomers, also not developmental toxicants. The findings show that R-225ca produced effects on the liver of rodents and a minor effect in a pri-

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mate at 650-1,000 ppm. Exposures to R-225cb in the range of 1,000 to 5,000 ppm resulted in only marginal effects in rodents or a primate. Additionally, R-123 was found to have low acute dermal and inhalation toxicity, but caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposures. R-134a and R-141b also caused an increased incidence of benign - but not life threatening - tumors in animals following long-term exposure to high concentrations. A *Glossary of Terms* is provided.

Registry of Toxic Effects of Chemical Substances (RTECS(R)), computerized database, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, updated quarterly since June 1971 (see synopsis below for availability, RDB4450)

The Registry of Toxic Effects of Chemical Substances, more widely known by the trademarked acronym RTECS(R), is a database of toxicologic information originally identified as the "Toxic Substances List" (TSL). RTECS is compiled, maintained, and updated by NIOSH pursuant to the Occupational Safety and Health Act of 1970. The database is a compendium of data extracted from the open scientific literature on more than 120,000 substances. They include most chemicals previously and currently used as refrigerants. Six types of toxicity data are included, namely primary irritation, mutagenic effects, reproductive effects, tumorigenic effects, acute toxicity, and other multiple-dose toxicity. Specific numeric toxicity values such as LC_{50}, LD_{50}, TC_{Lo}, are noted with the species studied, exposure duration, and route of administration. A coded bibliographic source is included for most data to enable access to the cited studies. The actual data have not been evaluated by NIOSH. RTECS also includes chemical identification data and special reviews, including exposure limits and carcinogenicity assessments. It also includes information on regulatory requirements, NIOSH-generated data, and notations on U.S. Government program data tracking and sources. The database records consist of coded data that can be expanded, by the accessing software, to readable form. Quarterly updates to the database can be leased from the National Technical Information Service (NTIS). RTECS is more commonly accessed through a number of on-line services, among them the National Library of Medicine (NLM) TOXNET System, the Canadian Centre for Occupational Health and Safety (CCOHS) CCINFOLine system, and the European Space Agency (ESA) Informational Retrieval Service (IRS), and commercial sources. They include the Chemical Information Service (CIS), DIALOG, Science and Technology Network (STN, available in North America through the Chemical Abstract Service, CAS), and others. It also is available on the CHEM-BANK(TM) compact disk from SilverPlatter Information Limited (Norwood, MA, USA, and London, UK) and TOMES-PLUS(TM) from Micromedex Incorporated (Denver, CO, USA).

Registry of Toxic Effects of Chemical Substances (RTECS(R)) - Comprehensive Guide to the RTECS(R), publication 93-1330, edited by D. V. Sweet, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, September 1993 (80 pages with 1 figure, 19 tables, and a microfiche with the bibliographic citations, available from GPO, RDB4449)

This guide provides a detailed description of the format of the RTECS(R) database and tabulates the codes used and their meanings. The code tables and text define the measures, abbreviations, and qualitative descriptors contained in RTECS. The guide also summarizes data sources and record formats. It also reviews sources to obtain or access RTECS.

Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals, standard E981-84, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, May 1994, reapproved in 1992 (10 pages with 9 figures, RDB6567)

This standard prescribes a laboratory test method for rapid determination of the sensory irritant potential for a wide range of airborne chemicals, including refrigerants and refrigerant blends. The procedure quantifies the concentration of airborne irritant that produces a 50% decrease in the respiratory rate (RD_{50}) in mice, based on a dose-response curve constructed from tests conducted for a range of concentrations. The RD_{50} may be used to estimate the threshold limit value (TLV) for man, but does not address discomfort from odors. The standard outlines the significance and use of the method; details the required apparatus, reagents, and test animals; and identifies associated hazards and limitations. It outlines and schematically illustrates the procedure, including required steps for sample preparation, calibration, pretest conditioning, and selection of test parameters. It then presents the actual test procedure and methods to interpret the results. It also identifies the minimum information to be recorded and concludes with a nonmandatory list of accepted apparatus and suppliers.

The AIHA 1996 Emergency Response Planning Guidelines and Workplace Environmental Expo-

sure Level Guides Handbook, document 215-EA-96, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1995 (RDB6451)

ERPG: R-10, R-30, R-40, R-40l1, R-630, R-717, R-764, R-1113, R-1114; WEEL: R-32, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-E170, R-1113; definitions, history

unpublished data, report 14-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6A04)

R-11, R-113; toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; LOEL at 5,000 ppm v/v [as reported in RDB 6467]

unpublished data, report 354-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6274)

toxicity, cardiac sensitization in dogs: R-142b NOEL > 25,000 ppm, EC_{50} > 50,000 ppm [as reported in RDB 5869 and 6467]; also R-502 NOEL > 50,000 ppm, EC_{50} > 100,000 ppm [as reported in RDB 5866]

R-10

E. M. Adams, H. C. Spencer, V. K. Rowe, D D. McCollister, and D. D. Irish, **Vapor Toxicity of Carbon Tetrachloride Determined by Experiments on Laboratory Animals**, *Archives of Industrial Hygiene and Occupational Medicine*, American Medical Association (AMA), volume 6, pages 50-66, 1952 (7 pages, RDB6509)

R-10, health effects, toxicity, LC_{50}

Emergency Response Planning Guidelines - Carbon Tetrachloride, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1995 (RDB-4B82)

R-10, tetrachloromethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-11

J. Adir et al, *Journal of Clinical Pharmacology*, American College of Clinical Pharmacology, Lippincott-Raven Publishers, Philadelphia, PA, volume 15, pages 116-128, 1975 (13 pages, RDB6552)

R-11, health effects, toxicity

J. Adir, D. A. Blake, and G. W. Mergner, *The Journal of Clinical Pharmacology*, American College of Clinical Pharmacology, Lippincott-Raven Publishers, Philadelphia, PA, volume 15, pages 760-770, 1975 (11 pages, RDB5C74)

R-11, health effects, inhalation toxicity

J. Adir et al, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 29, number 1, pages 142-143, 1974 (2 pages, RDB6553)

R-11, health effects, toxicity

Y. M. Amin et al, *Journal of Pharmaceutical Science*, volume 68, number 2, pages 160-163, 1979 (4 pages, RDB6554)

R-11, health effects, toxicity

J. Angerer, B. Schroder, and R. Heinrich, **Exposure to Fluorotrichloromethane (R-11)**, *International Archives of Occupational and Environmental Health*, Springer-Verlag, Berlin, Germany, volume 56, pages 67-72, 1985 (6 pages, RDB6493)

R-11, toxicity, health effects

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, IX. Summary of the Most Toxic: Trichlorofluoromethane (FC 11)**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 3, pages 311-319, 1975 (9 pages, RDB5C69)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

C. E. Barras, report 648-74, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, October 1974 (RDB5C53)

R-11, narcotic effects, inhalation, toxicity [referenced in RDB 5141]

D. A. Blake and G. W. Mergner, **Inhalation Studies of the Biotransformation and Elimination of [^{14}C] Trichlorofluoromethane and [^{14}C] Dichlorodifluoromethane in Beagles**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 30, number 3, pages 396-407, 1974 (RDB5C70)

R-11 and R-12, inhalation toxicity [referenced in RDB 5141]

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), *Proceedings of the European Society of Drug Toxicity*, volume 13, pages 212 ff, 1972 (RDB5C62)

R-11, cardiac sensitization, toxicity [referenced in RDB 5141]

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C. W. Eddy, **Eye Irritation in Rabbits**, report 423-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1 October 1970 (RDB-5C54)

R-11, dermal contact toxicity, irritation [referenced in RDB 5141]

D. B. Hood, **Eye Irritation**, report 107-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 September 1964 (RDB5C55)

R-11, dermal contact toxicity, irritation [referenced in RDB 5141]

L. J. Jenkins, Jr., R. A. Jones, R. A. Coon, and J. Siegel, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 16, pages 133 ff, 1970 (RDB5C60)

R-11, inhalation toxicity [referenced in RDB 5141]

A. Koops, **Mutagenicity Activity of Methane, Trichlorofluoro- in the Salmonella/Microsome Assay**, report 568-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 August 1977 (RDB5C58)

R-11, mutagenicity, Ames Assay, toxicity [referenced in RDB 5141]

G. W. Mergner, D. A. Blake, and M. Helrich, **Biotransformation and Elimination of ^{14}C-Trichlorofluoromethane (FC 11) and ^{14}C-Dichlorodifluoromethane (FC 12) in Man**, *Anethesiology*, volume 42, pages 345-351, 1975 (7 pages, RDB5C72)

R-11, R-12, inhalation toxicity

A. Morgan, A. Black, M. Walsh, and D. R. Belcher, *International Journal of Applied Radiat. Isot.*, volume 23, pages 285 ff, 1972 (RDB5C73)

R-11, inhalation toxicity

S. D. Morrison, report 53-61, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1961 (RDB65H3)

R-11, inhalation, acute toxicity: 4-hr ALC rat = 66,000 ppm v/v as reported in RDB 65H1

S. Nick, **Inhalation Toxicity of Freon(R) 11**, report 71-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 June 1964 (RDB5C56)

R-11, inhalation toxicity [referenced in RDB 5141]

J. W. Sarver and D. A. Snee, **Washout Time of Freon(R) 11**, report 349-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 August 1970 (RDB5C59)

R-11, inhalation toxicity [referenced in RDB 5141]

H. Sherman, **90-Day Feeding in Rats and Dogs with Freon(R) 11**, report 63-72, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 February 1972 (RDB5C57)

R-11, ingestion toxicity [referenced in RDB 5141]

T. F. Slater, *Biochemical Pharmacology*, Oxford, United Kingdom, volume 14, pages 178 ff, 1965 (RDB5C52)

R-11, ingestion toxicity [referenced in RDB 5141]

R. D. Stewart et al (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Fluorotrichloromethane** [trichlorofluoromethane], report PB-279203/LLC, National Technical Information Service (NTIS), Springfield, VA, 1 December 1975 (available from NTIS, RDB6598)

R-11, health effects, toxicity

G. J. Taylor and R. T. Drew, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 32, pages 177 ff, 1975 (RDB5C67)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

G. J. Taylor, *Archives of Environmental Health*, American Medical Association (AMA), volume 30, pages 349 ff, 1975 (RDB5C68)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

NCI Carcinogenesis Bioassay Experimental Design Status Report, Contract Number 723278, Agent Number CO4637, National Cancer Institute (NCI), Bethesda, MD, page 53, 22 February 1978 (RDB5C61)

R-11, tumor incidence, toxicity [referenced in RDB 5141]

Toxicity Summary - Genetron(R) 11 (Trichloromonofluoromethane), Acute Toxicity and Cardio-Toxicity, unpublished report, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, March 1978 (RDB5144)

R-11

Trichlorofluoromethane (CFC 11) Health Effects Information, CAS# 75-69-4, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B47)

R-11, summary of toxicological and ecological information

R-12

A. Azar, C. F. Reinhardt, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin, **Experimental Human Exposure to Fluorocarbon 12 (Dichlorodifluoromethane)**, presented at the AIHA Conference (Toronto, Canada, May 1971); republished in *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 33, pages 207-216, 1972 (10 pages, RDB5358)

R-12, toxicity

M. Bass, **Sudden Sniffing Death**, *Journal of the American Medical Association* (JAMA), American Medical Association (AMA), volume 212, pages 2075-2079, 1970 (5 pages, RDB6722)

fatal human exposure involving R-12 from abusive use of aerosol products

R. F. Carlton, **Fluorocarbon Toxicity: Aerosol Deaths and Anesthetic Reactions**, *Annals of Clinical and Laboratory Science*, volume 6, pages 411-414, 1976 (4 pages, RDB6723)

fatal human exposure involving R-12, sudden sniffing death from abusive use of aerosol products

C. W. Eddy and F. D. Griffith (E. I. duPont de Nemours and Company, Incorporated), **Metabolism of Dichlorodifluoromethane C^{14} (Freon(R) 12 C^{14}) by Rats**, presented at the AIHA Conference (Toronto, Canada, May 1971), American Industrial Hygiene Association (AIHA), Fairfax, VA, 1971 (RDB65H9)

R-12, metabolism, toxicity: radio-labeled R-12 study; approximately 2% of oral dose metabolized to carbon dioxide and ½% excreted in urine; R-12 and its matabolites were eliminated within 30 minutes - as reported in RDB 65H1

I. G. Jefferson, **Accidental Death of Child Playing with Deodorant Aerosol**, *Lancet*, volume 1, pages 779 ff, 1978 (RDB6727)

fatal human exposure involving R-12 from abusive use of aerosol products, sudden sniffing death

R. A. Kehoe, **Report on Human Exposure to Dichlorodifluoromethane in Air**, The Kettering Laboratory, University of Cincinnati, OH, June 1943 (RDB5C45)

R-12, toxicity: acute exposures of humans, for 11-80 minutes to concentrations of 40,000-110,000 ppm [summarized in RDB 5906]

T. Midgley, Jr., and A. L. Henne (Ohio State University), **Decomposition of Difluoro-Dichloromethane by Flames**, presentation at the 83rd Meeting (New Orleans, LA, 28 March - 1 April 1932), American Chemical Society (ACS), Columbus, OH; republished in *Industrial and Engineering Chemistry*, ACS, volume 24, pages 641-645, June 1932 (5 pages with 11 figures and 6 tables, RDB2530)

R-12, toxicity resulting from decomposition in open flames; concludes that "even under the worst possible circumstances [of decomposition] life is not endangered"

G. M. Rusch, **An Interpretive Review of the Toxicity and Human Exposure Data on Dichlorodifluoromethane**, Department of Toxicology Report MA-250-82-2, AlliedSignal Incorporated, Morristown, NJ, 11 February 1983 (RDB6138)

R-12, toxicity

R. R. Sayers, W. P. Yant, J. Chomyak, and H. W. Shoaf, **Toxicity of Dichlorodifluoromethane: A New Refrigerant**, Report of Investigations 3013, U.S. Bureau of Mines, Washington, DC, May 1930 (18 pages with 1 figure and 3 tables, available from JMC as RDB5356)

Dogs, monkeys, and guinea pigs were exposed to air containing 200,000 ppm R-12 by volume for 7-8 hr/day, 5 days/week and 4 hr/day, 1 day/week for a 12-week period. No fatalities occurred among the dogs and monkeys; two of 16 treated guinea pigs and one of 16 controls died, from which the report concludes that there was "no effect of exposure on fatality." The document identifies symptoms observed during exposure, which included generalized tremor in dogs and mild to moderate tremor in monkeys. The maximum severity was reached in the first 10-20 minutes, suggesting development of tolerance during and for subsequent exposures. The report documents the test methods and observed responses, including slight to moderate inhibition of weight and growth in the first 2-3 weeks, which were subsequently regained and maintained similar to control animals. Like patterns were identified in red blood cell increases. Autopsies showed no treatment-related gross pathology. No differences were observed in the pregnancies and offspring of the guinea pigs. The report concludes that "the possibility of public health and accident hazards resulting from exposure to [R-12] when used as a refrigerant are remote."

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H. S. Sherman, J. R. Barnes, and E. F. Stula (E. I. duPont de Nemours and Company, Incorporated), **The Oral Toxicology of Dichlorodifluoromethane**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 29, pages 152 ff, 1974 (RDB6711)

R-12, chronic and reproductive toxicity: not teratogenic to rats, did not interfere with reproduction and lactation, did not effect survival or clinical laboratory parameters (hematology, urinalysis, and liver function; no evidence of toxicity in dogs after administered in feed at 10 mg/kg and 3,000 mg/kg for two years - as reported in RDB 5143

H. S. Sherman and J. R. Barnes, report 12-66, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1966 (RDB65H8)

R-12, ingestion toxicity: 90-day feeding study in rats and dogs; no clinical or histopathologic signs of toxicity; urinary fluoride and plasma alkaline phosphatase levels were higher than for controls but within normal ranges; blood and urine analytical results were comparable between treated animals and controls in dogs - as reported in RDB 65H1

R. D. Stewart, A. A. Herrmann, E. D. Baretta, H. V. Forster, J. H. Crespo, P. E. Newton, and R. J. Soto (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Difluorodichloromethane** [dichlorodifluoromethane], report PB-279204/LLC, National Technical Information Service (NTIS), Springfield, VA, April 1976 (available from NTIS, RDB6486)

R-12, health effects, toxicity

Dichlorodifluoromethane (CFC 12) Health Effects Information, CAS# 75-71-8, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B48)

R-12, summary of toxicological and ecological information

Report on Dichlorodifluoromethane, Miscellaneous Hazard Report Number 2256, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 10 October 1931 (RDB6671)

R-12, flammability, toxicity, decomposition

R-12B1

P. S. Beck, D. G. Clark, and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **The Pharmacologic Actions of Bromochlorodifluoromethane (BCF)**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 24, pages 20-29, 1973 (10 pages, RDB5A26)

R-12B1, toxicity

J. A. Styles et al (ICI Chemicals and Polymers, United Kingdom), **Activity of Bromochlorodifluoromethane (BCF) in Three Mutation Tests**, *Mutation Research*, Amsterdam, The Netherlands, volume 142, pages 187-192, 1985 (6 pages, RDB-65G7)

R-12B1, mutagenicity, toxicity: mixed positive and negative results depending on test as reported in RDB 65G1

R-13B1

G. Paulet, *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, Paris, France, volume 23, pages 341 ff, 1962 (RDB-6588)

R-13B1, toxicity

C. F. Reinhardt and R. Reinke (E. I. duPont de Nemours and Company, Incorporated), **Toxicity of Halogenated Fire Extinguishing Agents: Halon 1301 (Bromotrifluoromethane)**, *An Appraisal of Halogenated Fire Extinguishing Agents*, National Academy of Sciences (NAS), Washington, DC, pages 67-78, 1972 (12 pages, RDB5A69)

R-13B1, health effects, toxicity

E. W. Van Stee and K. C. Back (U.S. Air Force Aerospace Medical Research Laboratory, AMRL), **The Hypotensive Response in Dogs Exposed to Bromotrifluoromethane**, abstract 85 (11th Annual Meeting of the Society of Toxicology), *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 22, pages 306-307, 1972 (2 pages, RDB6559)

R-13B1, cardiac sensitization, toxicity

R-13I1

E. R. Kinkead et al (ManTech Environmental Technologies), **90-Day Nose Only Inhalation Toxicity Study of Trifluoroiodomethane (CF_3I) in Male and Female Fischer Rats** report AL/OE-TR-1996-0024, Armstrong Laboratories, March 1996 (RDB-65G8)

R-13I1, subchronic inhalation toxicity: exposures at 20,000, 40,000, and 80,000 ppm for 2 hr/day, 5 days/week, for 90 days: found alteration in thyroid hormone levels indicated as specific to rats; no pre-cancerous cell changes were noted - as reported in RDB 65G1

A. D. Mitchell, **Genetic Toxicity Evaluation of Iodotrifluoromethane (CF_3I), Results of In Vivo Mouse Bone Marrow Erythrocyte Micronucleus Testing** Genesys Research Incorporated, Research Triangle Park, NC, 1995 (RDB65H0)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: no significant changes were seen in the male's premature red blood cells (PRBCs) at 25,000, 50,000, or 75,000 ppm; significant changes were observed in the results were seen in the female's PRBCs exposed to 25,000 ppm and above - as reported in RDB 65G9

A. D. Mitchell, **In Vitro Forward Mutation Assay of Iodotrifluoromethane (CF_3I) Using the L5178Y/tk+/- Mouse Lymphoma Cell Mutagenesis Assay (MLA) With Colony Sizing, With and Without Metabolic Activation** report on project 94036, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G4)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB 65G1

A. D. Mitchell, **In Vivo Bone Marrow Erythrocyte Micronucleus Testing of Iodotrifluoromethane (CF_3I)** report on project 94037, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G5)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB 65G1

A. D. Mitchell, **Mutagenesis Testing of Iodotrifluoromethane (CF_3I) Using the Ames Salmonella Typhimurium Histidine Reversion Assay for Volatile Chemicals, With and Without Metabolic Activation** report on project 94036, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G6)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB 65G1

Acute Inhalation Toxicity Study of Iodotrifluoromethane in Rats report on project 1530-001 study 2, ManTech Environmental Technologies, March 1994 (RDB65G2)

R-13I1, trifluoroiodomethane, toxicity: 15-min LC_{50} rat 274,000 ppm; animals showed drowsiness, drooling, and heavy breathing at concentrations >100,000 ppm - as reported in RDB 6208 and 65G1

Comparing the Toxicology of Triodide(TM) and Halon 1211, HTL/KIN-Tech Division, Pacific Scientific, Duarte, CA, May 1996 (RDB65G9)

R-12B1, R-13I1, toxicity: acute inhalation toxicity, cardiac sensitization, mutagenicity, decomposition product toxicity in fires with comparisons of R-13I1 to R-12B1, R-13B1, R-23, R-227ea, R-31-10, and R-51-14

Toxicology of Triodide(TM), HTL/KIN-Tech Division, Pacific Scientific, Duarte, CA, April 1996 (RDB-65G1)

R-13I1, toxicity: 15-min LC_{50} rat 274,000 ppm; cardiac sensitization NOAEL at 2,000 ppm and LOAEL at 4,000 ppm; mixed positive and negative results for potential for changes in genetic material depending on test; alteration in thyroid hormone levels, but no pre-cancerous cell changes were noted in subchronic inhalations tests

unpublished data, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, July 1994 (RDB65G3)

R-13I1, cardiac sensitization study, toxicity: NOAEL at 2,000 ppm; LOAEL at 4,000 ppm - as reported in RDB 65G1

R-14

R-20

A. G. Levy and T. Lewis, **Heart Irregularities, Resulting from the Inhalation of Low Percentages of Chloroform Vapor, and their Relationship to Ventricular Fibrillation**, *Heart*, volume 4, pages 319-378, 1913 (60 pages, RDB6560)

R-20, historic identification of cardiac sensitization, toxicity

A. G. Levy, **The Exciting Causes of Ventricular Fibrillation in Animals Under Chloroform Anesthesia**, *Heart*, volume 3, pages 99-111 and 1911-1912, 1950 (15 pages, RDB6561)

R-20, cardiac sensitization, toxicity

R-20B3

Occupational Safety and Health Guideline for Bromoform; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC, 1992

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(available from GPO, also available from JMC as RDB5C47)

R-20B3, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, special requirements, respiratory protection, personal protective equipment, references

R-22

D. Anderson and C. R. Richardson, **Arcton 22: A Second Cytogenetic Study in the Rat**, report CTL/P/445, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 3 May 1979 (RDB5924)

R-22, toxicity, health effects

D. Anderson, C. R. Richardson, C. Howard, R. A. Riley, and T. M. Weight, **Arcton 22: Cytogenetic Study in the Rat**, report CTL/R/429, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 6 December 1977 (RDB5925)

R-22, toxicity, health effects

D. Anderson, E. C. M. Hodge, T. M. Weight, and R. A. Riley, **Arcton 22: Dominant Lethal Study in the Mouse**, report CTL/R/430, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 6 December 1977 (RDB5926)

R-22, toxicity, health effects

B. E. Butterworth, **In Vitro Microbiol Mutagenicity Studies of Methane, Chlorodifluoro**, report 398-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6478)

R-22, toxicity, health effects, mutagenicity, positive Ames assay [as reported in RDB 5923]

I. F. Carney, **Arcton 22 (Chlorodifluoromethane). Relationship Between Blood Levels and Inhaled Concentrations in Anesthetized, Artificially-Ventilated Rats**, report CTL/R/422, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1977 (RDB6479)

R-22, toxicity, health effects, uptake and metabolism studies

P. W. Grube and R. C. Graham, untitled toxicity review for chlorodifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 March 1990 (28 pages, RDB5856)

R-22, summary of published and unpublished toxicity literature

E. C. M. Hodge, D. Anderson, I. P. Bennett, and T. M. Weight, **Arcton 22: Second Dominant Lethal Study in the Mouse**, report CTL/R/450 (revised), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 9 November 1979 (RDB5927)

R-22, toxicity, health effects

B. C. Karpov, **The Chronic Toxicity of 'Freon' 22**, *Tr. Leningrad Sanit. Gigien. Med. Inst.*, volume 75, pages 231-240, 1963 (10 pages in Russian, RDB-6166)

R-22, toxicity, health effects

D. F. Krahn, **Mutagenic Activity of Methane, Chlorodifluoro- in the Salmonella Microsome Assay**, report 577-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6481)

R-22, toxicity, health effects, mutagenicity, positive Ames assay [as reported in RDB 5923]

I. P. Lee and K. Suzuki, **Studies on the Male Reproductive Toxicity of Freon 22**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), volume 1, pages 266 ff, 1981 (RDB6482)

R-22, toxicity, health effects

M. H. Litchfield and E. Longstaff (Imperial Chemical Industries (ICI) plc, United Kingdom), **The Toxicological Evaluation of Chlorofluorocarbon 22 (CFC 22)** [sic, HCFC-22], *Fundamentals of Chemical Toxicology*, Pergamon Press, Limited, United Kingdom, volume 22, number 6, pages 465-475, 1984 (11 pages with 1 figure and 7 tables, RDB-5923)

R-22, detailed review of acute, subchronic, and chronic toxicity studies: inhalation, mortality, uptake and metabolism, mutagenicity (R-22 "can be assessed as a bacteria-specific mutagen on the evidence of the Ames test, but it did not exhibit any consistent mutagenic activity in other assay systems"), reproductive toxicity, carcinogenicity

E. Longstaff and D. B. McGregor (Imperial Chemical Industries (ICI) plc, United Kingdom), **Mutagenicity of the Halocarbon Refrigerant Monochlorodifluoromethane (R-22) in Salmonella Typhimurium**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 2, pages 1 ff, 1978 (RDB6275)

R-22, toxicity, health effects, positive Ames assay [as reported in RDB 5923]

K. T. McCooey, **Methane, Chlorodifluoro-, Chinese Hamster Ovary Cell Assay for Mutagenicity**, report 149-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1980 (RDB6483)

R-22, toxicity, health effects, mutagenicity in both the presence and absence of metabolic activation at 330,000, 670,000, and 1,000,000 ppm, no mutagenic activity was found [referenced in RDB 5923]

A. K. Palmer, D. D. Cozens, R. Clark, and G. C. Clark, **Effect of Arcton 22 on Pregnancy of the New Zealand White Rabbit**, report ICI 177/78505, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1 August 1978 (RDB-5928)

R-22, toxicity, health effects

A. K. Palmer, D. D. Cozens, R. Clark, and G. C. Clark, **Effect of Arcton 22 on Pregnant Rats: Relationship to Anophthalmia and Microphthalmia**, report ICI 174/78208, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 12 June 1978 (RDB5929)

R-22, toxicity, health effects

M. Sakata, H. Kazama, A. Miki, A. Yoshida, M. Haga, and M. Morita, **Acute Toxicity of Fluorocarbon-22: Toxic Symptoms, Lethal Concentration, and Its Fate in Rabbit and Mouse**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 59, pages 64-70, 1981 (7 pages, RDB5739)

R-22, inhalation toxicity, uptake and metabolism studies in the rabbit: 30-min MLC (ALC) rabbit = 300,000 ppm, 30-min LC_{50} mouse = 280,000 ppm [as reported in RDB 5923]

A. G. Salmon, S. K. Basu, M. Fitzpatrick, and J. A. Nash, **Arcton 22: Metabolism Study in Vivo in Rats and in Vitro**, report CTL/P/438, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1979 (RDB6484)

R-22, toxicity, health effects

M. Smidt, O. Axelson, and C. Edling, **Kohortstudie av Freonexponerade**, *Acta Soc. Med. Suec. Hung.*, volume 90, pages 77 ff, 1981 (RDB6485)

R-22, toxicity, health effects, epidemiological study of workers exposed to chlorofluorochemicals including R-22 found no increase in mortality due to heart, circulatory, or tumor disorders [as reported in RDB 5923]

D. J. Tinston, I. S. Chart, M. J. Godley, C. W. Gore, B. A. Gaskell, and M. H. Litchfield, **Chlorodifluoromethane (CFC 22): Long-Term Inhalation Study in the Mouse** [HCFC-22], report CTL/P/547, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1981 (RDB6487)

R-22, chronic toxicity, health effects [referenced in RDB 5923]

D. J. Tinston, I. S. Chart, M. J. Godley, C. W. Gore, M. H. Litchfield, and M. Robinson, **Chlorodifluoromethane (CFC 22): Long-Term Inhalation Study in the Rat** [HCFC-22], report CTL/P/548, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1981 (RDB6488)

R-22, chronic toxicity, health effects [referenced in RDB 5923]

D. J. Tinston, unpublished data, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1976 (RDB6127)

R-22, acute toxicity [referenced in RDB 5856 and 5923]

E. W. Van Stee and E. E. McConnell, **Studies of the Effects of Chronic Inhalation Exposure of Rabbits to Chlorodifluoromethane**, *Environmental Health Perspectives*, volume 20, pages 246 ff, 1977 (RDB6490)

R-22, toxicity, health effects

Assistant Manager at Ice Rink Asphyxiated by an Oxygen-Deficient Atmosphere, Alaska, May 20, 1991, Fatal Accident Circumstances and Epidemiology (FACE) Report, 1991 (available from NTIS as PB92-193697, RDB6A95)

This report summarizes an accident from an R-22 leak in which a 24 year old male was killed by asphyxiation. The victim was the assistant manager for a skating rink located in a 170-store shopping mall. The refrigeration system had a long history of leaks, one of which had been plugged in a "makeshift fashion." While performing a routine check, a maintenance worker noticed oil oozing from under the doors of the compressor room. He entered the machinery room with a maintenance supervisor and the victim to stop the leak. The victim was wearing a cartridge type respirator, which was inadequate in an oxygen deficient atmosphere. also, the machinery room had self-closing doors. A coworker saw the maintenance worker and supervisor lying on the floor and called 911, the emergency assistance number in most of the USA, for help. They were rescued by the responding paramedics. The victim was not seen immediately and was not removed from the

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room until later, by which time he had suffocated. Two swimmers in a pool, also located in the mall, and rescue personnel also were affected by the R-22 vapor, which spread into adjacent areas. The accident investigation found that there was no safety policy or program in place and identified a number of safety deficiencies including an absence of leak detectors.

Chlorodifluoromethane (CAS No. 75-45-6), Joint Assessment of Commodity Chemicals (JACC) report 9, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, 19 October 1989 (80 pages with 1 figure and 11 tables, RDB3718)

This assessment reviews the environmental impacts and toxicity of R-22, described as a nonflammable, colorless, and nearly odorless gas under normal conditions. It notes that a large amount is used as a chemical intermediate, and not emitted to the atmosphere, whereas that used for air conditioning and refrigeration will eventually be released under current practices. Most released R-22 is destroyed by reaction with OH- radicals in the troposphere or OH- and excited oxygen atoms in the stratosphere, but not to any major extent by photodecomposition. The calculated ozone depletion potential (ODP) for R-22 is 0.05, described as low compared to fully halogenated chlorofluorocarbons. The report indicates that R-22 has a negligible bioaccumulation potential, based on its moderate water solubility and low octanol-water partition coefficient. Contamination of food or water should not be expected, and has not been reported. R-22 is rapidly equilibrated in tissues after inhalation, and is eliminated from the blood in expired air, with a half life of only a few minutes. Blood concentrations are linearly correlated with inhalation concentrations over a wide range, but metabolism occurs in only minor amounts if at all. The report indicates that R-22 has an extremely low order of acute toxicity, and that concentrations exceeding 200,000 ppm v/v are required to produce a lethal effect. The report reviews cardiovascular studies and cites a cardiac sensitization NOEL (0/12) to adrenaline for male beagles of 24,700 ppm and a LOEL (2/12) of 50,000 ppm with. R-22 showed no adverse effects on fertility in animal studies and was not teratogenic in rabbits at doses up to 50,000 ppm. A low incidence of anophthalmia (congenital absence of eyes) and microphthalmia (abnormally small eyes) combined (10 fetuses in 383 litters) was found when groups of 400 pregnant rats were exposed to 50,000 ppm. Although statistically significant, these findings and those of subsequent studies were deemed to not threaten the health of human beings occupationally exposed at or below recommended exposure limits. Most in vitro tests of R-22 are negative and a positive response in the Ames test is consistent with occurrence of bacteria-specific metabolic pathways. Only minimal or no effects were observed chronic exposures of rats and mice for 4-131 weeks. A slight decrease in body weight gain and a small increase in liver and kidney weight occurred with an exposure level of 50,000 ppm. The only exception was a limited study in rats, mice and rabbits which reported changes in the blood, liver, lung and nervous system in animals exposed to 14,000 ppm over a ten month period; these findings were not confirmed in subsequent studies. R-22 did not produce neoplastic changes in female rats and male and female mice exposed to concentrations as high as 50,000 ppm. In one study in male rats, a concentration of 50,000 ppm was associated with an increase in the number of fibrosarcomas and Zymbal gland tumors; they occurred late in the study and were not considered relevant to humans. Lower concentrations (10,000 ppm and below) did not increase tumor rates in any study. The assessment concludes that R-22 does not constitutes a carcinogenic hazard to man. The toxicological activities described are unlikely to be due to the formation of reactive intermediates. Although not a skin sensitizer, liquid R-22 in contact with skin causes local freezing. Reports on adverse health effects from R-22 are rare and are consistent with findings in experimental animals. Permissible occupational exposure limits vary between 500-1000 ppm (8 hr TWA) by country; the assessment judged these limits to provide adequate health protection.

Occupational Safety and Health Guideline for Chlorodifluoromethane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, 1995 (7 pages, available from JMC as RDB6286)

R-22, Occupational Health Guideline (OHG), Occupational Safety and Health Guideline (OSHG), physical data, reactivity, flammability, exposure limits, health hazard information, toxicity, emergency procedures, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, emergency planning and community right-to-know requirements, hazardous waste management requirements, respiratory protection, personal protective equipment, references

R-23

R. Atkinson, *Chem. Review*, volume 85, pages 69-201, 1985 (133 pages, RDB5B61)

R-23, toxicity

R. Atkinson and W. P. L. Carter, *Chem. Review*, volume 84, pages 437-470, 1984 (34 pages, RDB-5825)

R-23, toxicity

C. A. Branch, D. A. Goldberg, J. R. Ewing, S. C. Fagan, S. S. Butt, and J. Gayner (Henry Ford Hospital), **Evaluation of the Acute Cardiac and Central Nervous System Effects of the Fluorocarbon Trifluoromethane in Baboons**, *Journal of Toxicology and Environmental Health*, Taylor and Francis Publishers, volume 43, number 1, pages 25-35, September 1994 (11 pages, RDB5158)

This study reports tests of R-23 for acute cardiotoxic, anesthetic, and central nervous system effects in primates (papio anubis). A dose-response effect was established for respiratory rate, electroencephalogram, and cardiac sinus rate, which exhibited a stepwise decrease from 10% R-23. No spontaneous arrhythmias were noted, and arterial blood pressure remained unchanged at any inspired level. Intravenous epinephrine infusions (1 μg/kg) induced transient cardiac arrhythmia in one animal with 70% R-23 by volume. R-23 appears to induce mild dose-related physiological changes at inspired levels of 30% or more, indicative of an anesthetic effect. These data suggest that R-23 may be safe to use in humans, without significant adverse acute effects, at an inspired level of 30%.

C. A. Branch et al (Henry Ford Hospital), *Stroke*, volume 21, number 8, pages 1172-1177, 1990 (6 pages, RDB5818)

R-23, toxicity

J. C. Edwards, **Arcton 23 - Documentation for Hygiene Standard**, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 17 June 1985 (1 page, RDB5A75)

R-23, toxicity, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

J. R. Ewing, C. A. Branch, S. C. Fagan, J. A. Helpern, R. T. Simkins, S. M. Butt, and K. M. A. Welch (Henry Ford Hospital), **Fluorocarbon-23 Measure of Cat Cerebral Blood Flow by Nuclear Magnetic Resonance**, *Stroke*, volume 21, pages 100-106, 1990 (7 pages, RDB5736)

R-23, toxicity

S. C. Fagan, A. A. Rahill, G. Balakrishnan, J. R. Ewing, C. A. Branch, and G. G. Brown (Henry Ford Hospital), **Neurobehavioral and Physiological Effects of Trifluoromethane in Humans**, *Journal of Toxicology and Environmental Health*, volume 44, pages 101-109, 1995 (9 pages with 1 table, RDB5737)

R-23, toxicity: investigation of R-23 as a nuclear magnetic resonance indicator in human subjects, discontinued based on slight anesthetic effects, light headedness, tingling and numbness of the extremities, and hyperacusis at 300,000 ppm; heart rate and rhythm as well as blood pressure not affected at concentrations studied

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for trifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1992 (RDB5604)

R-23, summary of published and unpublished toxicity literature

O. Schaumann, *Archiv für Experimentelle Pathologie und Pharmakologie*, volume 181, pages 144-145, 1936 (2 pages, RDB5606)

R-23, narcotic properties, toxicity

Hazardous Substance Fact Sheet - Trifluoromethane, New Jersey Department of Health, Trenton, NJ, August 1988 (RDB5138)

R-23, toxicity

Toxicology Summary for FC 23 (Trifluoromethane), ICI Chemicals and Polymers Limited, Runcorn, UK, 21 September 1994 (1 page, RDB5168)

R-23, toxicity: references a 2-hr ALC rat >200,000 ppm, cardiac sensitization EC_{50} >500,000 ppm, and Ames test (not mutagenic); cites an ICI recommended exposure limit of 1,000 ppm, 8 hr TWA

Trifluoromethane (HFC 23) Health Effects Information, CAS# 75-46-7, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B49)

R-23, summary of toxicological and ecological information

unpublished data, report 23-45, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1945 (RDB6511)

R-23, toxicity

unpublished data, report 25-60, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1945 (RDB6512)

R-23, toxicity

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unpublished data, report 641-80, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1980 (RDB6513)

R-23, health effects, toxicity: 4-hr ALC rat > 663,000 ppm; anesthetic concentration rat = 186,000 ppm [as reported in RDB 5604]

R-30

M. E. Andersen, H. J. Clewell III, M. L. Gargas, F. A. Smith, and R. H. Reitz, **Physiologically Based Pharmacokinetics and the Risk Assessment Process for Methylene Chloride**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 87, pages 185-205, 1987 (21 pages, RDB65E5)

R-30, health effects, toxicity

R-30B1

T. R. Torkelson, F. Oyen, and V. K. Rowe, **The Toxicity of Bromochloromethane as Determined on Laboratory Animals**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 21, pages 275-286, 1960 (12 pages, RDB-6510)

R-30B1, health effects, toxicity, LC_{50}

R-32

M. Asakura (Japan Bioassay Laboratory, JBL, Japan), **Report on a Chromosomal Aberration Test of Difluoromethane on Cultured Mammalian Cells (CHL)**, report 5918 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 1993 (RDB5750)

R-32, toxicity

R. D. Callander, **HFC 32: An Evaluation of Mutagenic Potential Using S. Typhimurium and E. Coli**, report CTL/P/3351 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 10 June 1992 (RDB5745)

R-32, toxicity: negative result for mutagenicity as reported in RDB 6686

M. K. Ellis, R. Trebicock, J. L. Naylor, K. Tseung, et al (Zeneca Central Toxicology Laboratory, UK), **The Inhalation Toxicology, Genetic Toxicology and Metabolism of Difluoromethane in the Rat**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 31, number 2, pages 243-251, 1996 (9 pages, RDB6A98)

R-32: toxicity, developmental toxicity, and genotoxicity; metabolism and disposition; physiologically-based pharmacokinetic (PB-PK) model; approximately 2.1% of inhaled R-32 is absorbed; steady-state blood levels are achieved within 2 hr and are proportional to dose; carbon dioxide is the major metabolite at all exposure levels; carbon monoxide was not detected; approximately 63% (1.4% of the R-32 entering the airways) was metabolized at all doses; inhalation of R-32 (up to 50,000 ppm) caused no organ-specific effects, but resulted in slight maternal toxicity in pregnant rats and rabbits and some fetotoxicity in rats; 50,000 ppm did not sensitize the heart to adrenaline; the overall results indicate that R-32 is of very low toxicity

M. K. Ellis, R. Trebicock, and T. Green, **Hydrofluorocarbon 32: Pharmacokinetics and Metabolism in the Rat**, report CTL/R/1220 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 1994 (RDB5979)

R-32, toxicity

M. K. Ellis, J. L. Naylor, and T. Green, **Hydrofluorocarbon 32: Pharmacokinetics and Metabolism in Male Rats and Mice Following a Single Exposure by Inhalation**, report CTL/R/1137 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 23 December 1992 (RDB5749)

R-32, toxicity

J. Ferguson-Smith, **HFC 32 Hygiene Standard Documentation**, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 3 June 1996 (6 pages, RDB6686)

R-32, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

C. J. Hardy and P. C. Kieran, **Hydrofluorocarbon 32: Assessment of Cardiac Sensitization Potential in Beagle Dogs**, report ISN 276/920493 (also identified as ICI report CTL/C/2723) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 18 September 1992 (RDB5748)

R-32, health effects, toxicity: exposures as high as 350,000 ppm v/v did not produce a cardiac sensitization response in beagle dogs with an intravenous epinephrine challenge as reported in RDB 5C14 and 6686

Jackson Laboratory, unpublished data, report 57-15, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, date unknown (RDB-6169)

R-32, toxicity, subchronic exposure of guinea pigs [referenced in RDB 5862]

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for difluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 July 1992 (RDB5862)

R-32, summary of published and unpublished toxicity literature

J. M. Mackay and C. A. Howard, **HFC 32: An Evaluation in the In Vitro Cytogenetic Assay in Human Lymphocytes**, report CTL/P/3465 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 5 June 1992 (RDB5744)

R-32, toxicity, mutagenicity: no evidence of genotoxicity at 50,000-1,000,000 ppm as reported in RDB 6686

M. E. Moxon, **HFC-32: Developmental Toxicity Study in the Rat**, report CTL/P/3835 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 20 May 1992 (RDB-5747)

R-32, toxicity: not teratogenic to the rat at 5,000-50,000 ppm for 6 hr/day; maternal food consumption was slightly decreased at 50,000 ppm; minimal fetal toxicity at 50,000 ppm - as reported in RDB 6686

M. E. Moxon, **HFC-32: Modified Chernoff-Kavlock Assay in the Rat**, report CTL/P/3695 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 20 May 1992 (RDB5C31)

R-32, toxicity: negative for potential teratological effects as reported in RDB 6686

D. P. Myres, **HFC-32: A Study of the Effect on Pregnancy of the Rabbit**, report ALS 19/942190 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 12 August 1994 (RDB5743)

R-32, toxicity: not teratogenic to the rabbit at concentrations of 5,000-50,000 ppm for 6 hr/day; animals exposed to 50,000 ppm had slight loss of body weight during days 8-10 of pregnancy; no evidence of fetal or embryo toxicity - as reported in RDB 6686

R. Parr-Dobrzanski, **HFC 32: 90-Day Inhalation Toxicity Study in the Rat**, report CTL/P/4064, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 4 October 1993 (RDB5742)

R-32, toxicity

R. Parr-Dobrzanski, **HFC-32: 28-Day Subacute Inhalation Toxicity Study in the Rat**, report CTL/P/-3746, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 24 August 1992 (RDB-5741)

R-32, toxicity: exposures of up to 50,000 ppm for 6 hr/day, 5 day/week, for 28 days; NOEL at 50,000 ppm as reported in RDB 6686

R. Parr-Dobrzanski, **Four-Hour Acute Inhalation Toxicity Study in the Rat**, report CTL/P/3456, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 5 June 1992 (RDB5740)

R-32, toxicity: 4-hr LC50 rat >520,000 ppm v/v, anesthetic effect at 86,000 ppm as reported in RDB 5C13 and 5C14; 10-min CNS EC_{50} rat = 370,000 ppm v/v as reported in RDB 5A76 and 6686

V. M. Randall and J. M. Mackay, **HFC 32: An Evaluation of the Mouse Micronucleus Test**, report CTL/P/3927, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 23 December 1992 (RDB5746)

R-32, toxicity, mutagenicity: no evidence for clastogenicity as reported in RDB 6686

Difluoromethane (HFC-32, CAS No. 75-10-5), Joint Assessment of Commodity Chemicals (JACC) report 32, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1995 (32 pages, RDB5C13)

R-32, difluoromethane, environmental impacts, toxicity

Difluoromethane (HFC 32) Health Effects Information, CAS# 75-10-5, Elf Atochem North Amer-

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ica, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B50)

R-32, summary of toxicological and ecological information

Hydrofluorocarbon 32: Physiologically Based Pharmacokinetic Modelling to Predict Uptake and Metabolism in the Rat, report CTL/R/1137, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 1992 (RDB6689)

R-32, toxicity

Workplace Environmental Exposure Level Guide - Difluoromethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (RDB5C14)

R-32, WEEL, toxicology data, toxicity, safety classification

unpublished data, report 257-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1973 (RDB6170)

R-32, toxicity, cardiac sensitization in dogs: NOEL = 200,000 ppm, LOEL = 250,000 ppm as reported in RDB 5862

unpublished data, report 698-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1975 (RDB6171)

R-32, toxicity, mortality in rats: ALC 4 hour > 760,000 ppm, anesthetic effect at 111,000 ppm as reported in RDB 5862

unpublished data, report 159-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6172)

R-32, toxicity, subchronic exposures in rats as reported in RDB 5862

R-40

Emergency Response Planning Guidelines - Methyl Chloride, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1995 (RDB4B83)

R-40, chloromethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-40I1

Emergency Response Planning Guidelines - Methyl Iodide, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (RDB4B80)

R-40I1, iodomethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-113

R. Carchman and M. M. Greenberg, **Summary Review of Health Effects Associated with 1,1,2-Trichloro-1,2,2-trifluoroethane (Chlorofluorocarbon 113): Health Issue Assessment**, report EPA 600/8-82/0002F, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, January 1983 (available from NTIS as document PB84-118843, RDB6494)

R-113, health effects, toxicity

E. E. Christofano, J. B. Bryant, J. M. Trowell, **Human Exposures to 1,1,2-Trichloro-1,2,2-trifluoroethane**, abstract 91, proceedings of the AIHA conference (Denver, CO, 10-16 May 1969), American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 30, pages 134 ff, 1969 (RDB5C02)

R-113, health effects, toxicity

H. R. Imbus and C. Adkins, **Physical Examinations of Workers Exposed to Trichlorotrifluoroethane**, *Archives of Environmental Health*, American Medical Association (AMA), Helen Dwight Reid Educational Foundation, volume 24, pages 257-261, 1972 (RDB6733)

R-113, human exposures, toxicity

D. C. May and M. J. Blotzer, **A Report of Occupational Deaths Attributed to Fluorocarbon-113**, *Archives of Environmental Health*, American Medical Association (AMA), Helen Dwight Reid Educational Foundation, volume 39, number 5, pages 352-354, 1984 (RDB6734)

R-113, human exposures, toxicity

G. B. Raffi and F. S. Violante, **Is Freon 113 Neurotoxic? A Case Report**, *International Archives of Occupational and Environmental Health*, volume 49, pages 125-127, 1981 (RDB6735)

R-113, human exposures, toxicity

C. F. Reinhardt, M. E. McLaughlin, M. E. Maxfield, L. S. Mullin, and P. E. Smith, **Human Exposures to Fluorocarbon 113**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 32, pages 143-152, March 1971 (10 pages, RDB6496)

R-113, health effects, toxicity

H. Savolainen and P. Pfaffli, **Dose Dependent Neurochemical Effects of 1,1,2-Trichloro-1,2,2-trifluoroethane Inhalation Exposure in Rats**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 6, pages 43-49, 1980 (RDB6497)

R-113, health effects, toxicity

J. W. Server, 1,1,2-Trifluoro-1,2,2-trichloroethane: Four-Hour Inhalation Toxicity, report 104-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 7 April 1971 (2 pages with 1 table, RDB6804)

R-113, toxicity tests by acute inhalation in male, Manor Farm rats at 32,000, 40,500, 45,000, and 53,000 ppm v/v and for 10 repeated, subacute exposures at 1,000 ppm; record of clinical signs shows anesthetic/central nervous system (CNS) effects as well as slight weight loss, followed by normal weight gain, at 32,000 ppm; 4-hr LC_{50} rat = 52,500 ppm; pathologic examination of exposed animals revealed no compound-related changes in the respiratory tract; comparison to prior test results with Charles River rats, which showed the 4-hr LC_{50} to be 56,000 ppm, concludes that "there are basically no differences ... in the two strains of rats" within 95% confidence limits

G. Triebig and K. Burkhardt, **Occupational Medicine Investigations into Occupational Exposure to FC113**, *International Archives of Occupational and Environmental Health*, Springer-Verlag, Berlin, Germany, volume 42, pages 129-135, 1978 (7 pages, RDB6498)

R-113, health effects, toxicity

H. Vainio, J. Nickels, and T. Heinonen, **Dose Related Hepatotoxicity of 1,1,2-Trichloro-1,2,2-trifluoroethane in Short-Term Intermittent Inhalation Exposures in Rats**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, volume 18, pages 17-25, 1980 (RDB6499)

R-113, health effects, toxicity

B. H. Woollen, E. A. Guest, W. Howe, J. R. Marsh (ICI Central Toxicology Laboratory, UK), H. K. Wilson (Occupational Medicine and Hygiene Laboratories, UK), T. R. Auton, and P. G. Blain (ICI Central Toxicology Laboratory, UK), **Human Inhalation Pharmacokinetics of 1,1,2-Trichloro-1,2,2-trifluoroethane (FC113)**, *International Archives of Occupational and Environmental Health*, Springer-Verlag, Berlin, Germany, volume 62, pages 73-78, 1990 (6 pages, RDB6492)

R-113, health effects, toxicity: study of absorption and elimination in experimental human exposures

Report 488-84, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 March 1985 (RDB6730)

R-113, two year inhalation study in rats, as reported in RDB 5143

Report 724-81, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 December 1981 (RDB6731)

R-113, 90-day inhalation study in rats, as reported in RDB 5143

Report CTL/P/731, ICI Central Toxicology Laboratory, Cheshire, United Kingdom, 19 November 1982 (RDB6732)

R-113, teratogenicity study in rats, as reported in RDB 5143

R-114

H. Desoille, L. Truffert, C. Gierard-Wallon, et al, **Experimental Research on the Long-Term Chronic Toxicity of Dichlorotetrafluoroethane**, *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, Paris, France, volume 34, number 3, pages 117-125, 1973 (9 pages, RDB5362)

R-114, toxicity

Z. Durakovic, L. Stilinovic, and I. Bakran, Jr., **Electrocardiographic Changes in Rats After Inhalation in Dichlorotetrafluoroethane, Arcton 114, $C_2Cl_2C_4$**, *Japan Heart Journal*, volume 17, number 6, pages 753-759, 1976 (7 pages, RDB6738)

R-114, toxicity

F. D. Griffith and H. Sherman, unpublished data, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, December 1969 (RDB-5A70)

R-114, toxicity, three-week intubation exposure study with rats, possibility of some metabolism [referenced in RDB 5141]

D. B. Hood, report 110-67, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1967 (RDB65H6)

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R-114, dermal toxicity: no irritation observed when sprayed on shaved backs of guinea pigs as reported in RDB 65H1

D. B. Hood and M. Ward, report on project MR-312-7, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1955 (RDB65H5)

R-114, ingestion toxicity: oral ALD rat >2,250 mg/kg (based on the maximum feasible dose dissolved in corn oil); mild conjunctivitis persisting less than 48 hours resulted from acute eye toxicity tests with a mineral oil solution - as reported in RDB 65H1

R. R. Montgomery, M. A. Lee, R. C. Graham, and P. J. Lardear, untitled toxicity review for 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 June 1992 (RDB5855)

R-114, summary of published and unpublished toxicity literature

G. Paulet and S. Desbrousses, **Dichlorotetrafluoroethane**, *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, Paris, France, volume 30, number 9, pages 477-492, 1969 (16 pages in French, RDB5172)

R-114, toxicity

H. Sherman, unpublished data, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, January 1972 (RDB5A71)

R-114, toxicity, 90-day intubation exposure study with dogs and rats [referenced in RDB 5141]

W. P. Yant, H. H. Schrenk, and F. A. Patty, **The Toxicity of Dichlorotetrafluoroethane**, Report of Investigations 3185, U.S. Bureau of Mines, Washington, DC, October 1932 (12 pages with 1 table, available from JMC as RDB5359)

R-114; 12-week exposures of dogs, guinea pigs, and monkeys to 200,000 ppm v/v, reduced to 150,000 ppm v/v and then 141,600 ppm v/v (equivalent fluorine content on a weight basis to 200,000 ppm v/v R-12) following observation of effects; documents observed symptoms including tremors and convulsions, changes in weight, changes in blood picture, fatality, and pathology; report concludes that "the toxicity of [R-114] on a vapor-volume basis is somewhat greater than [R-12], but on a weight basis is of the same order as the latter, and is an organic vapor of remarkably low toxicity"

1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114) Health Effects Information, CAS# 76-14-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (8 pages, RDB5B51)

R-114, summary of toxicological and ecological information

Occupational Health Guideline for Dichlorotetrafluoroethane (Refrigerant 114), U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, September 1978 (4 pages, available from JMC a RDB6287)

R-114, Occupational Health Guideline (OHG), exposure limits, health hazard information, toxicity, physical data, reactivity, flammability, monitoring and measurement, respirators, personal protective equipment, emergency first aid procedures, spills and leaks, references

unpublished data, report 52-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6121)

R-114, cardiac sensitization, toxicity, LOEL in 1 of 12 dogs at 25,000 ppm as reported in RDB 5855

R-115

J. W. Clayton, Jr., D. B. Hood, M. S. Nick, and R. S. Waritz (E. I. duPont de Nemours and Company, Incorporated), **Inhalation Studies of Chloropentafluoroethane**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 27, May-June 1966 (RDB65H4)

R-115, toxicity: 4-hr ALC rat >800,000 ppm v/v as reported in RDB 65H1

H. S. Sherman, report 146-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1964 (RDB65H7)

R-115, ingestion toxicity: intragastric intubation of R-115 in cottonseed oil to rats on a daily level of 140-172 mg/kg for 10 days produced no clinical or histopathologic changes related to R-115 as reported in RDB 65H1

Chloropentafluoroethane (CFC 115) Health Effects Information, CAS# 76-15-3, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B52)

R-115, summary of toxicological and ecological information

Occupational Safety and Health Guideline for Chloropentafluoroethane, U.S. Department of

Health and Human Services and U.S. Department of Labor, Washington, DC, 1995 (7 pages, available from JMC as RDB6288)

R-115, Occupational Health Guideline (OHG), Occupational Safety and Health Guideline (OSHG), physical data, reactivity, flammability, exposure limits, health hazard information, toxicity, emergency procedures, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, leaks, emergency planning and community right-to-know requirements, hazardous waste management requirements, respiratory protection, personal protective equipment, references

R-116

J. Carson et al, abstract 133, *Veterinary and Human Toxicology*, volume 31, number 4, pages 363 ff, 1989 (RDB6575)

accidents resulting in injection of R-116 into the fingers of workers, treatment and result

J. V. Dilley et al, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 27, number 3, pages 582-590, 1974 (RDB6579)

R-116, metabolism, toxicity

J. Ferguson-Smith, **Hygiene Standard Documentation: Perfluoroethane** document ESC/PFC 116, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 22 January 1996 (5 pages, RDB-6687)

R-116, toxicity, literature review, rationale for recommended hygiene standard (Health Based Standard) of 1,000 ppm, 8-hr TWA

T. B. Griffin et al, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 29, pages 92 ff, 1974 (RDB6577)

R-116, toxicity

T. B. Griffin et al, *Proceedings of the Symposium on Application of Halogenated Fire Extinguishing Agents*, pages 136-147, 1972 (RDB6578)

R-116, toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for hexafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 July 1991 (RDB5605)

R-116, summary of published and unpublished toxicity literature

M. Hughes, unpublished data, Atlantic Research Corporation, 1973 (RDB6119)

R-116, cardiac sensitization, toxicity: indicates a cardiac sensitization NOEL dog at 600,000 ppm, but the test protocol (e.g., whether an epinephrine challenge was used, whether the test mixture was oxygen enriched, and the duration of exposure) is not clear - as reported in RDB 5605

S. D. Morrison, report 41-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1962 (RDB6580)

R-116, inhalation, acute toxicity: 2-hr ALC rat >200,000 ppm, 4-hr ALC rat >800,000 ppm as reported in RDB 5605 and 65H1

Report 150-72, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1972 (RDB6120)

R-116, cardiac sensitization, toxicity [referenced in RDB 5605]

Report CTL/L/6119, ICI Central Toxicology Laboratory, Cheshire, United Kingdom, 22 November 1994 (RDB6691)

R-116, toxicity, mutagenicity: Ames test with and without metabolic activation to *Salmonella typhimurium* and *Escherichia coli*: not mutagenic as reported in RDB 6687

Report CTL/L/6908, ICI Central Toxicology Laboratory, Cheshire, United Kingdom, 31 October 1995 (RDB6690)

R-116, toxicity, mutagenicity: not clastogenic to human lymphocytes with and without metabolic activation as reported in RDB 6687

R-123

F. C. Barsky, **In Vitro Microbial Mutagenicity Studies of 2,2-Dichloro-1,1,1-Trifluoroethane**, report 581-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB-6164)

R-123, toxicity

W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **Teratogenic Study via Inhalation with Genetron 123 in Albino Rats**, report 8562-09344 PO Number 578-31438, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 8 November 1977 (RDB6143)

R-123, teratology, toxicity

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W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **90 Day Subacute Inhalation Toxicity Study with Genetron 123 in Albino Rats**, report 8562-09344, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 2 September 1977 (RDB6144)

R-123, inhalation toxicity

M. R. Brittelli, **Eye Irritation Test in Rabbits**, report 747-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1975 (RDB6160)

R-123, health effects, toxicity

W. J. Brock, **Acute Dermal Toxicity Study of HCFC-123 in Rabbits**, report 578-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6148)

R-123, health effects, toxicity, ALD skin rabbit >2,000 mg/kg [referenced in RDB 5861]

W. J. Brock, **Acute Dermal Toxicity Study of HCFC-123 in Rats**, report 577-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6147)

R-123, health effects, toxicity, ALD skin rat >2,000 mg/kg [referenced in RDB 5861]

W. J. Brock, **Primary Dermal Irritation Study with HCFC-123 in Rabbits**, report 535-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6149)

R-123, health effects, toxicity

D. Brusick (Litton Bionetics Incorporated, LBI), **Mutagenicity Evaluation of Genetron 123**, report on LBI project 2547, AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 30 July 1976 (RDB6135)

R-123, toxicity, health effects

R. D. Callander, **HCFC 123: An Evaluation Using the Salmonella Mutagenicity Assay**, report CTL/P/2421 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT) #88-01, ICI Central Toxicology Laboratory, Cheshire, United Kingdom, 15 December 1989 (RDB6136)

R-123, toxicity, mutagenicity

J. W. Clayton and/or R. S. Waritz, **Acute Inhalation Toxicity on 1,1-Dichloro-2,2,2-trifluoroethane (FC-123, Commercial Grade)**, report 16-66, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, February 1966 (RDB6150)

R-123 (2,2-dichloro-1,1,1-trifluoroethane), toxicity

J. W. Clayton, **Preliminary Studies on the Inhalation Toxicity of Technical (70.9 per cent) 1,1-Dichloro-2,2,2-Trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], report 151-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1966 (RDB6151)

R-123, toxicity

W. B. Coate (Hazleton Laboratories America, Incorporated), **LC_{50} of G123 in Rats**, report M165-162, AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 4 October 1976 (RDB6137)

R-123, acute inhalation toxicity, LC_{50} rat, 6 hr = 52,640 ppm [referenced in RDB 3719 and 5861]

D. W. Coombs, **HCFC-123: 13-Week Inhalation Neurotoxicity Study in the Rat**, report ALS 3/931038 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1994 (RDB6217)

R-123, toxicity

C. A. Dance, **In Vitro Assessment of the Clastogenic Activity of HCFC-123 in Cultured Human Lymphocytes**, report 91/PFE 003/0093 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1991 (RDB6219)

R-123, toxicity, mutagenicity

R. W. Darr, **An Acute Inhalation Toxicity Study of Fluorocarbon 123 in the Chinese Hamster**, Corporate Medical Affairs report MA-25-78-15, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 10 June 1981 (25 pages with 1 figure and 1 table, RDB5149)

R-123, LC_{50}, cytogenic evaluation, inhalation toxicology

W. Dekant, **Metabolism of 1,1-Dichloro-2,2,2-trifluoroethane** [2,2-Dichloro-1,1,1-trifluoroethane], report MA-RR-93-1972a, Universität Würzburg, Germany, 1994 (RDB65C2)

R-123, toxicity

C. Doleba-Crowe, **Ninety-Day Inhalation Exposure of Rats and Dogs to Vapors of FC-123**, report 229-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and

Company, Incorporated, Newark, DE, 19 May 1978 (RDB6155)

R-123, toxicity [referenced in RDB 3719]

C. N. Edwards, **HCFC-123 (Vapour Phase): In Vitro Assessment of Clastogenic Activity in Cultured Human Lymphocytes**, report 91/PFE 002/0125 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1991 (RDB6220)

R-123, toxicity, mutagenicity

J. Ferguson-Smith, **Hygiene Standard Documentation - 1,1-Dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], document HSP/-92/14, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 1992 (14 pages with 3 tables, RDB5A77)

R-123, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 10 ppm, 8-hr TWA, provisional

R. Ferrara, R. Tolando, L. J. King, and M. Manno, **Reductive Activation of 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) by Rat Liver Microsomal Cytochome P-450**, Proceeding of the Fifth International Symposium on Biological Reactive Intermediates, Munich, Germany, 4-8 January 1995 (RDB-65C5)

R-123, toxicity

C. S. Godin, J. M. Drerup, and A. Vinegar, **Conditions Influencing the Rat Liver Microsomal Metabolism of 2,2-Dichloro-1,1,1-Trifluoroethane (HCFC-123)**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 21, pages 551-553, 1993 (3 pages, RDB6213)

R-123, toxicity

N. C. Goodman, **Primary Skin Irritation and Sensitization Tests on Guinea Pigs**, report 678-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 31 December 1975 (RDB6161)

R-123, health effects, toxicity

G. T. Hall and B. L. Moore, **Acute Inhalation Toxicity of Freon 123**, report 426-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 16 July 1975 (RDB6139)

R-123, toxicity, LC_{50} rat, 4 hr = 32,000 ppm as reported in RDB 3719 and 5861

J. W. Harris, L. R. Pohl, J. L. Martin, and M. W. Anders, **Tissue Acylation by the Chlorofluorocarbon Substitute 2,2-Dichloro-1,1,1-Trifluoroethane**, *Proceedings of the National Academy of Science* (NAS), Washington, DC, volume 88, number 4, pages 1407-1410, 1991 (4 pages, RDB6222)

R-123, toxicity

J. E. Henry, **Acute Oral Test on FC-123**, report 638-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 October 1975 (RDB6140)

R-123, toxicity, ALD [referenced in RDB 5861]

E. W. Hughes, **A Study of the Effect on the Reproductive Function of Two Generations in the Rat**, report ALS 5/932336 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1994 (RDB6218)

R-123, toxicity

E. W. Hughes, D. P. Myers, and D. W. Coombs, **Range Finding Study in Mature Male and Female Rats and Their Offspring**, report ALS 4/920200 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1992 (RDB6574)

R-123, reproductive toxicity

J. Huwyler, D. Aeschlimann, U. Christen, and J. Gut, **The Kidney as Novel Target Tissue for Protein Adduct Formation Associated with Metabolism of Halothane and the Candidate Chlorofluorocarbon Replacement 2,2-Dichloro-1,1,1-trifluoroethane**, *European Journal of Biochemistry*, volume 208, pages 229-238, 1992 (10 pages, RDB-65C7)

R-123, R-123B1, health effects, toxicity

J. Huwyler and J. Gut, **Exposure to the Chlorofluorocarbon Substitute 2,2-Dichloro-1,1,1-trifluoroethane and the Anesthetic Agent Halothane is Associated with Transient Protein Adduct Formation in the Heart**, *Biochemical and Biophysical Research Communications*, volume 184, pages 1344-1349, 1992 (6 pages, RDB65C8)

R-123, R-123B1, health effects, toxicity

C. A. Jenkins, **HCFC 123: Acute Toxicity to Daphnia Magna**, report 91/PFE 006/0972 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1992 (RDB65C9)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

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C. A. Jenkins, **HCFC 123: Acute Toxicity to Rainbow Trout**, report 91/PFE 004/0939 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1992 (RDB65D0)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

C. A. Jenkins, **HCFC 123 (liquid): Biotic Degradation Closed Bottle Test**, report 91/PFE 008/-0477 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1992 (RDB65D1)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

C. A. Jenkins, **HCFC 123: Determination of its EC_{50} to Selenastrum Capricornutum**, report 91/-PFE 007/0935 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 1992 (RDB65D2)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

D. P. Kelly, **Four-Week Inhalation Study with HCFC-123 in Rats**, report 229-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB6157)

R-123, toxicity

J. C. Kennelly, **HCFC 123: Assessment for the Induction of Unscheduled DNA Synthesis in Rat Liver after Inhalation Exposure**, report CTL/P/-3807 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 4 October 1993 (RDB6215)

R-123, toxicity

M. A. Lee, R. C. Graham, and S. W. Snyder, untitled toxicity review for ethane, 2,2-dichloro-1,1,1-trifluoro- (HCFC-123), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 August 1991 (16 pages, RDB5861)

R-123, summary of published and unpublished toxicity literature

R. W. Lewis, **HCFC 123: 28-Day Inhalation Study to Assess Changes in Rat Liver and Plasma**, report CTL/T/2706, ICI Central Toxicology Laboratory, Cheshire, United Kingdom, 1990 (RDB6214)

R-123, toxicity

P. H. Lieder, J. C. Cook, and D. A. Keller, **Similarities in Peroxisome Proliferation and Biochemical Effects Between HCFC-123 and Halothane (HCFC-123B1)** [sic HBCFC-123B1] **in Rats**, abstract 1552, *The Toxicologist*, Society of Toxicology (SOT), volume 13, number 1, pages 396 ff, 1993 (RDB6224)

R-123, R-123B1, toxicity, mechanistic studies

G. D. Loizou (University of Rochester), G. Urban, W. Dekant (Universität Würzburg), and M. W. Anders (University of Rochester), **Gas-Uptake Pharmacokinetics of 2,2-Dichloro-1,1,1-Trifluoroethane (HCFC-123)**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 22, number 4, pages 511-517, 1994 (7 pages with 5 figures and 3 tables, RDB6223)

R-123, in vivo metabolic rate constants in rats based on 6-hr inhalation exposures at 500-5,000 ppm, toxicity

J. M. Mackay, **HCFC 123: An Evaluation in the In Vitro Cytogenetic Assay**, report CTL/P/2978 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, January 1992 (RDB6572)

R-123, mutagenicity, toxicity

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. Carakostas (SmithKline Beecham Animal Health), J. F. Hansen (DuPont), G. M. Rusch (AlliedSignal Incorporated), D. P. Kelly (DuPont), and H. J. Trochimowicz (DuPont), **Two-Year Inhalation Toxicity Study in Rats with Hydrochlorofluorocarbon 123**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 25, pages 101-114, 1995 (14 pages with 3 figures and 10 tables, RDB65D4)

R-123, combined chronic toxicity and oncogenicity study

L. A. Malley, **Combined Chronic Toxicity/Oncogenicity Study with HCFC-123: Two-Year Inhalation Toxicity Study in Rats**, report 669-91 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB6152)

R-123, toxicity

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. Carakostas (SmithKline Beecham Animal Health), J. F. Hansen (DuPont), H. J. Trochimowicz (DuPont), and G. M. Rusch

(AlliedSignal Incorporated, **Chronic Toxicity of Hydrochlorofluorocarbon HCFC-123**, *The Toxicologist*, Society of Toxicology (SOT), volume 11, pages 103 ff, 1991 (RDB65F0)

R-123, toxicity

L. A. Malley, **Subchronic Inhalation Toxicity Study: 90-Day Study with HCFC-123 in Rats**, report 594-89 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, January 1990 (RDB6154)

R-123, toxicity

G. B. Marit, D. E. Dodd, M. E. George, and A. Vinegar, **Hepatotoxicity in Guinea Pigs Following Acute Exposure to 1,1-Dichloro-2,2,2-Trifluoroethane**, *Toxicologic Pathology*, volume 22, number 4, pages 404-414, 1994 (11 pages, RDB6216)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, toxicity

R. R. Marshall, **Evaluation of Chromosomal Aberrations Frequencies in Cultured Peripheral Blood Lymphocytes from Rats Treated with HCFC-123**, report 1RLREASU.001 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Hazleton Microtest, Harrogate, North Yorkshire, United Kingdom, 1992 (RDB6221)

R-123, toxicity, health effects

Meridian Research, Incorporated, **Results of Employee Exposure Monitoring for HCFC-123 at Centrifugal Chiller Installations**, U.S. Environmental Protection Agency (EPA), Washington, DC, 26 November 1991 (82 pages, RDB2529)

R-123, toxicity, machine room concentrations, occupational exposures

L. S. Mullin, **Behavioral Toxicity Testing of Fluorocarbon 123 in Rats**, report 941-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6153)

R-123, toxicity

W. Müller and T. Hofmann (Pharma Research Toxicology and Pathology Laboratory), **HCFC 123 - Micronucleus Test in Male and Female NMRI Mice After Inhalation**, report 88.0372 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 1988 (RDB6141)

R-123, mutagenicity, toxicity

T. L. Pravecek and S. R. Channel, **A Volatile Exposure Method for Precision Cut Tissue Slices: HCFC-123 Study**, *In Vitro Toxicology*, volume 8 number 3, pages 283-289, 1995 (7 pages, RDB6A99)

R-123 toxicity; application of precision-cut tissue slice cultures to study the metabolic fate and toxicologic effects; analyses of R-123 metabolism in rat livers suggest significant strain differences and that R-123 may inhibit its own metabolism at higher concentrations

G. M. Rusch (AlliedSignal Incorporated), H. J. Trochimowicz, L. A. Malley, D. P. Kelly (E. I. duPont de Nemours and Company, Incorporated) (DuPont), J. Peckham (Experimental Pathology Laboratory), J. Hansen (DuPont), and J. B. Charm (AlliedSignal), **Subchronic Inhalation Toxicity Studies with Hydrochlorofluorocarbon 123 (HCFC 123)**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 23, pages 169-178, 1994 (10 pages with 11 tables, RDB65D8)

R-123, toxicity

G. M. Rusch, **A Ninety-Day Inhalation Toxicology Study and an Inhalation Teratology Study of Genetron 123 in the Rat**, report MA-127-80-1, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 19 September 1985 (RDB6142)

R-123, toxicity: summary report on the findings of two studies (reports 8562-09344, 2 September 1977, and 8562-09344 PO Number 578-31438, 8 November 1977) conducted by Industrial Bio-Test Laboratories, Incorporated

J. Sandow, W. Rechenberg, and G. Jerabek-Sandow, **HCFC-123: Effect of HCFC-123 and Androgen Biosynthesis and Gonadotropin Secretion in Rats**, report ALS 5 for Hoechst study Exp. 8-210 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1994 (RDB65D9)

R-123, toxicity

R. Schroeder, **An Inhalation Developmental Toxicity Study in Rabbits with HCFC-123**, report 3304-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB6162)

R-123, toxicity

R. Schroeder, **An Inhalation Range-Finding Study to Evaluate the Toxicity of HCFC-123 in the Pregnant Rabbit**, report 3303-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB6163)

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R-123, toxicity

H. W. Sibley, **A Study for Determining Refrigerant Exposure Levels While Servicing an HCFC-123 Centrifugal Chiller**, publication 819-061, Carrier Corporation, Syracuse, NY, April 1992 (8 pages with 4 figures and 1 table, RDB2916)

This report summarizes an investigation to determine the exposure levels encountered while working around or on chillers using R-123. It also addresses whether there are reliable instruments to measure that low, and whether a machine room can be adequately monitored and ventilation controlled to stay below a recommended exposure limit of 10 ppm [subsequently raised by some refrigerant manufacturers]. The single test involved a 700 kW (200 ton) hermetic centrifugal chiller at the manufacturer's plant. The report outlines steps to select and qualify refrigerant sensors, develop a decision model for the test, prepare a team for use of the refrigerant monitors and safety equipment, develop service practices, and execute the plan. It was based on removal of R-123 from the machine and recharge with R-11. Additional steps were scheduled between charge removal and recharging, to determine the effects on components exposed to R-123 in a year of operation. For purposes of this test, the exhaust fans in the machinery room were reset from 10 ppm to operation when concentrations exceeded 500 ppm. A table lists the R-123 monitors used, and a figure outlines the safety decision model developed. A figures shows measured exposure concentrations, with two excursions to approximately 500 ppm, and time-weighted average (TWA) exposures of 2-5 ppm. The report notes that once R-123 was released, "it tended to drop to floor level, hang together, and move as an invisible cloud." One part of the plan included a deliberate spill of 1 litre (¼ gallon), deemed the maximum that would be lost during a typical accident. A plot shows the resulting concentrations. The report concludes that new methods and procedures will have to be employed to minimize exposures. A brief addendum to the report notes concentrations in field restoration of three other chillers from R-123 back to R-11 use.

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of HCFC-123 (2,2-Dichloro-1,1,1-Trifluoroethane)**, *Proceedings of the European Meeting of the Toxicology Forum* (Toulouse, France, 19-22 September 1989), 1989; republished in the *Journal of the American College of Toxicology*, volume 8, number 6, pages 1220 ff, 1989 (RDB6145)

R-123, toxicity: dose-related, anesthetic effects observed in rats at 5,000 ppm during subchronic inhalation exposures, NOEL at 2,500 ppm, as reported in RDB 3719

H. J. Trochimowicz and L. S. Mullin, **Cardiac Sensitization Potential (EC_{50}) of Trifluorodichloroethane**, report 132-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 March 1973 (RDB6146)

R-123, toxicity, cardiac sensitization in dogs with control injection of adrenalin before exposure and a challenge injection after inhalation for five minutes: NOEL 0/3 = 10,300 ppm v/v, LOEL 4/6 = 20,900 ppm; calculated EC_{50} = 19,000 ppm

G. Urban, P. Speerschneider, and W. Dekant (Universität Würzburg), **Metabolism of the Chlorofluorocarbon Substitute 1,1-Dichloro-2,2,2-Trifluoroethane by Rat and Human Liver Microsomes: The Role of Cytochrome P450 2E1**, *Chem. Research Toxicology*, American Chemical Society (ACS), Washington, DC, volume 7, number 2, pages 170-176, 1994 (7 pages with 8 figures and 3 tables, RDB65E1)

R-123, toxicity: showed that trifluoroacetic acid is a major metabolite of R-123 and that chlorodifluoroacetic acid and inorganic fluoride also are products of the enzymatic oxidation of R-123 in rat and human liver microsomes; concludes that cytochrome P450 2E1 plays a major role in metabolism of R-123 and its analog R-123B1 (halothane) in vitro

G. Urban and W. Dekant (Universität Würzburg), **The CFC Substitute 2,2-Dichloro-1,1,1-Trifluoroethane Is Primarily Oxidized by Cytochrome P450 2E1**, abstract 1704, *The Toxicologist*, Society of Toxicology (SOT), volume 13, page 431, 1993 (1 page, RDB65E4)

R-123, toxicity

A. Vinegar, R. J. Williams, J. W. Fischer, and J. N. McDougal, **Dose-Dependent Metabolism of 2,2-Dichloro-1,1,1-trifluoroethane: A Physiologically Based Pharmacokinetic Model in the Male Fischer 344 Rat**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, London, United Kingdom, volume 129, pages 103-113, 1994 (11 pages, RDB65E2)

R-123, toxicity

D. B. Warheit, **Mechanistic Studies with HCFC-123**, report 828-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1993 (RDB6159)

R-123, toxicity

1,1-Dichloro-2,2,2-trifluoromethane (HCFC-123, CAS No. 306-83-2), Joint Assessment of Commodity Chemicals (JACC) report 33, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1996 (68 pages with 2 figures and 11 tables, RDB-65E8)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, environmental impacts, toxicity

1,1-Dichloro-2,2,2-trifluoroethane (HCFC 123) Health Effects Information, CAS# 306-83-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (5 pages, RDB5B53)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, summary of toxicological and ecological information

2,2-Dichlor-1,1,1-trifluorethan Toxikologisch-arbeitsmedizinische Begrundung von MAK-Werten (Maximale Arbeitsplatz Konzentrationen) [Toxicological and Occupational Medical Basis for the 2,2-Dichloro-1,1,1-trifluoroethane MAK Values (Maximum Workplace Concentrations), Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Germany, 1994 (18 pages, RDB-6AA0)

R-123, German occupational exposure limit, listing as a III B compound [substances with systemic effects having an onset longer than 2 hr] in the *List of MAK and BAT Values*

Report on Testing and Analysis of the Concentration of HCFC-123 in Field Installations with General Machinery Rooms Containing Hermetic Centrifugal Chillers, report CFC-1, The Trane Company, La Crosse, WI, October 1991 (34 pages with 14 figures and 15 tables, limited copies available from JMC as RDB2246)

This report provides measured data on R-123 concentrations in equipment rooms housing hermetic centrifugal chillers. Twelve sites, representing a broad range of applications, were tested during normal operation. Additional data were taken at two sites during refrigerant transfers. Measurements were made by gas chromatography, both on site and using activated charcoal tubes (subsequently analyzed in laboratories). All of the sites except one were determined to have concentrations substantially less than 1 ppm, if any. Concentrations above minimum quantifiable levels, 0.33-0.56 ppm, were detected in only two cases. Leakage from empty, but improperly sealed, refrigerant drums was identified as the probable cause for one site. The sources in the other were improperly sealed drums and a leak from the purge vent line. The latter was ascribed to improper field installation and use of incompatible piping materials. A retest of this site, after corrections, found concentrations in line with the others. Reports on the individual sites and summary discussion describe the tests and safety considerations for refrigerants. The findings emphasize the importance of following proper refrigerant handling and storage procedures as well as installation recommendations.

Report of Worker Exposure to HCFC-123 During Servicing of Hermetic Centrifugal Chillers, report CFC-2, The Trane Company, La Crosse, WI, May 1992 (16 pages with 3 figures and 9 tables, limited copies available from JMC as RDB2908)

This report addresses the safety aspects of exposure of service personnel to R-123 during the full range of service procedures for centrifugal chiller applications. Earlier toxicity findings and implications are reviewed as background. The report then documents the measured concentrations during refrigerant transfer, routine maintenance, and major service from three different installations. Chronic (long-term), acute (short-term intermittent), and emergency acute exposure considerations are outlined. The measurement procedures are described; they used activated charcoal tubes subsequently analyzed by gas chromatography in laboratories, and on-site infrared vapor analyzers. Time-weighted average (TWA) exposures are tabulated for the chronic exposures, ranging from less than the limit of quantification (LOQ) to 1.9 ppm. Peak concentrations and durations are tabulated for the intermittent, acute exposures. Test reports are included to describe each site and provide detailed measured data. The report concludes that the long-term concentrations observed were more than five times below the allowable exposure limit (AEL) of 10 ppm [subsequently raised by some refrigerant manufacturers]. The instantaneous concentrations were well within the 30-50 ppm limits based on guidelines developed by the American Conference of Governmental Industrial Hygienists (ACGIH). The findings emphasize the importance of following proper handling and storage procedures for refrigerants and installation recommendations of ASHRAE Standard 15R [now 15-1992].

Workplace Guidelines for Suva Centri-LP (HCFC-123) in Refrigeration and Air Conditioning Applications, document AS-5 (H-53018), DuPont Chemicals, Wilmington, DE, November 1993 (4 pages with 2 tables, RDB4C50)

This bulletin presents recommended workplace guidelines for use of R-123 in air-conditioning and refrigeration applications. It notes that DuPont has concluded that R-123 poses no acute (short-term, single exposure) or chronic (long-term, repeated exposure) hazard when handled in accordance with recommendations and when exposures are maintained at or below

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its recommended Acceptable Exposure Limit (AEL). The bulletin indicates that the AEL for R-123 has been set at 30 ppm for exposures of 8 or 12 hours daily or 40 hours weekly on a time-weighted average (TWA) basis. It also notes that DuPont has set an Emergency Exposure Limit (EEL) of 1000 ppm for up to 1 hour, with a 1 minute ceiling of 2500 ppm. The bulletin recommends that users read and understand the Material Safety Data Sheet (MSDS) and presents guidance for storage, handling, and use of R-123. It notes that ASHRAE Standard 15 requires area monitors to detect refrigerant concentrations and additional guidance on system and machinery room design. A table recommends alarm levels and appropriate actions for increasing detection levels. A second table outlines minimum respirator protection for concentrations exceeding the cited AEL. The bulletin identifies prohibited uses for R-123, personal protective equipment, and storage and handling procedures. It also recommends safety measures for system charging, maintenance, and sampling as well as responses to leaks or spills. DuPont's product names for R-123 are Suva(R) Centri-LP and Suva(R) 123.

Report 88-3304 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Bio/dynamics Incorporated, East Millstone, NJ, September 1989 (RDB6573)

R-123, reproductive toxicity

R-123B1

K. D. Hall and F. H. Norris Jr., **Fluothane Sensitization of Dog Heart to Epinephrine**, *Anesthesiology*, volume 19, pages 632-641, 1958 (10 pages, RDB6565)

identifies R-123B1 as a cardiac sensitizer as reported in RDB 5644

R-124

Bio/dynamics Incorporated, report 89-3513, AlliedSignal Incorporated, Morristown, NJ, 1991 (RDB-6177)

R-124, toxicity, health effects as reported in RDB 5863

Hazleton Laboratories America, Incorporated, **LC_{50} of G124 in Rats**, report on project 165-164, AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 4 October 1976 (RDB5806)

R-124, toxicity, health effects as reported in RDB 4B88

Industrial Bio-Test Laboratories, Incorporated, report 8562-09345, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 1977 (RDB6173)

R-124, toxicity

Industrial Bio-Test Laboratories, Incorporated, report 8562-09345 PO Number 578-31438, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 1977 (RDB6174)

R-124, toxicity

D. M. Krentz, R. C. Graham, and M. A. Lee, untitled toxicity review for 2-chloro-1,1,1,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 June 1992 (RDB5863)

R-124, summary of published and unpublished toxicity literature

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. Carakostas (DuPont), G. S. Elliott, L. Alvarez (DuPont), R. E. Schroeder (PharmacoLSR, Incorporated), S. R. Frame (DuPont), C. Van Pelt (DuPont), H. J. Trochimowicz (DuPont), and G. M. Rusch (AlliedSignal Incorporated), **Subchronic Toxicity and Teratogenicity of 2-Chloro-1,1,1,2-tetrafluoroethane (HCFC-124)**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 33, number 1, pages 11-22, 1996 (12 pages, RDB-65F5)

R-124, toxicity: rat and mouse inhalation exposures for 6 hr/day, 5 days/week, for 13 weeks at 0, 5000, 15,000, and 50,000 ppm v/v; R-124 caused minimal compound-related effects; hepatic beta-oxidation activity was significantly higher at 5000, 15,000, and 50,000 ppm in male mice, but there were no compound related effects on beta-oxidation activity in rats; rats, mice, and rabbits exposed to 50,000 ppm were less responsive to auditory stimuli or less active compared to controls; male rats exposed to 15,000 or 50,000 ppm for 13-weeks had decreased arousal; no compound-related effects on mortality, clinical signs, ocular tissues, hematology parameters, organ weights, and tissue morphology at any concentration in rats or mice; female rats showed a significant decrease in weight gain and food consumption at 50,000 ppm; pregnant rabbits also had lower food consumption at 50,000 ppm; no evidence of fetal toxicity at any concentration

Life Science Research Limited (LSR, United Kingdom), report 91/PAR 001/0925, AlliedSignal Incorporated, Morristown, NJ, 1991 (RDB6175)

R-124, toxicity, health effects, mutagenic potential as reported in RDB 5863

Life Science Research Limited (LSR, United Kingdom), report 91/PAR 002/0885b, AlliedSignal Incorporated, Morristown, NJ, 1991 (RDB6176)

R-124, toxicity, health effects, mutagenic potential, clastogenic (chromosome-damaging) activity [referenced in RDB 5863]

Litton Bionetics Incorporated (LBI), **Mutagenic Evaluation of Genetron 124**, report MA-250-82-31, AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 30 July 1976 (RDB-5807)

R-124, toxicity, health effects as reported in RDB 4B88

L. S. Mullin, **Cardiac Sensitization: Fluorocarbon 124**, report 220-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 March 1976 (RDB5808)

R-124, toxicity, health effects as reported in RDB 4B88 and 5863

M. J. Olson, J. T. Johnson, J. F. O'Gara, and S. E. Surbrook, Jr., **Metabolism In Vivo and In Vitro of the Refrigerant Substitute 1,1,1,2-Tetrafluoro-2-chloroethane**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 19, number 5, pages 1004-1011, 1991 (8 pages, RDB6183)

R-124, 2-chloro-1,1,1,2-tetrafluoroethane, toxicity, metabolism in rats

1-Chloro-1,2,2,2-tetrafluoroethane (HCFC 124, CAS No. 2837-89-0), Joint Assessment of Commodity Chemicals (JACC) report 25, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, July 1994 (34 pages, RDB4C02)

R-124, 2-chloro-1,1,1,2-tetrafluoroethane, environmental impacts, toxicity

2-Chloro-1,1,1,2-Tetrafluoroethane (HCFC 124) Health Effects Information, CAS# 2837-89-0, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (5 pages, RDB5B54)

R-124, summary of toxicological and ecological information

An Inhalation Developmental Toxicity Study in Rabbits with HCFC-124, report 89-3514 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Bio/dynamics Incorporated, East Millstone, NJ, 19 December 1991 (RDB5A12)

R-124, toxicity, health effects [referenced in RDB 4B88]

HCFC-124: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (the Ames Assay), report 91/PAR 001/0842 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 20 December 1991 (RDB5809)

R-124, toxicity, health effects, mutagenic potential [referenced in RDB 4B88]

In Vitro Assessment of the Clastogenic Activity of HCFC-124 in Cultured Chinese Hamster Ovary Cells, report 91/PAR 002/0885a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 20 December 1991 (RDB5A19)

R-124, toxicity, health effects [referenced in RDB 4B88]

In Vitro Evaluation of HCFC-124 for Chromosome Aberrations in Human Lymphocytes, report 367-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB-5A20)

R-124, mutagenicity, toxicity, potential clastogenic (chromosome-damaging) activity [referenced in RDB 4B88 and 5863]

Mouse Bone Marrow Micronucleus Assay of HCFC-124, report 52-90 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 February 1990 (RDB-5A21)

R-124, toxicity, health effects, mutagenic potential [referenced in RDB 4B88]

Subchronic Inhalation Toxicity: 90-Day Study with HCFC-124 in Rats, report 79-91 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 August 1991 (RDB5C06)

R-124, toxicity, health effects [referenced in RDB 4B88]

Subchronic Inhalation Toxicity: Four-Week Study with HCFC-124, report 257-90 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and

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Company, Incorporated, Newark, DE, 24 October 1990 (RDB5A14)

R-124, toxicity, health effects: anesthetic LOEC rat = 50,000 ppm [referenced in RDB 4B88 and 5863]

Teratogenicity Study of HCFC-124 in Rats, report 482-90 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 October 1991 (RDB5A22)

R-124, toxicity, health effects [referenced in RDB 4B88]

Workplace Environmental Exposure Level Guide - 2-chloro-1,1,1,2-tetrafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (RDB4B88)

R-124, WEEL, toxicology data, toxicity, safety classification

unpublished data, report 349-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6178)

R-124, toxicity, health effects, mutagenic potential [referenced in RDB 5863]

unpublished data, report 727-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6179)

R-124, toxicity, health effects, subchronic inhalation study: anesthetic LOEC rat = 100,000 ppm as reported in RDB 5863

unpublished data, report 71-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6180)

R-124, toxicity, health effects, acute inhalation study: 4-hour ALC rat = 230,000-300,000 ppm as reported in RDB 5863

unpublished data, report 108-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6181)

R-124, toxicity, health effects, developmental and reproductive toxicity, teratogenicity [referenced in RDB 5863]

unpublished data, report 191-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6182)

R-124, toxicity, health effects, mutagenic potential [referenced in RDB 5863]

R-125

M. W. Anders, **Pharmacokinetics of HFC-125 (Pentafluoroethane) in Rats**, report for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), University of Rochester Medical Center, Rochester, NY, 16 December 1993 (RDB5751)

R-125, toxicity

R. Atkinson et al, *Advances in Photochemistry*, volume 11, pages 375-488, 1979 (114 pages, RDB-5936)

R-125

R. Atkinson, monograph 1, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, 1979 (RDB5937)

R-125

A. J. Brooker, P. J. Brown, D. M. John, and D. W. Coombs, **A Study of The Effect of HFC-125 on Pregnancy of the Rabbit**, report ALS 10/920856 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Center Limited (HRC), Cambridgeshire, United Kingdom, 24 November 1992 (RDB5752)

R-125, developmental toxicity: neither embryotoxic nor teratogenic in the rabbit at exposures up to 50,000 ppm v/v as reported in 65E6

F. A. Charlesworth, *Food and Cosmetics Toxicology*, Oxford, United Kingdom, volume 13, pages 572-574, 1975 (3 pages, RDB5940)

R-125, toxicity

C. A. Dance and G. Hodson-Walker, **In Vitro Assessment of the Clastogenic Activity of HFC-125 in Cultured Chinese Hamster Ovary (CHO) Cells**, report 91/PAR 006/1015a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 18 May 1992 (RDB5759)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity as reported in RDB 65E6

C. A. Dance, K. E. Beach, and G. Hodson-Walker, **In Vitro Assessment of the Clastogenic Activity of HFC-125 in Cultured Human Lymphocytes**, report 91/PAR 005/1014a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life

Science Research Limited (LSR), Suffolk, United Kingdom, 18 May 1992 (RDB5760)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity as reported in RDB 65E6

C. N. Edwards, G. Hodson-Walker, and S. Cracknell, **HFC-125: In Vitro Assessment of Clastogenic Action on Bone Marrow Erthrocytes in the Micronucleus Test**, report 92/PAR 004/0148 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 7 July 1992 (RDB-5758)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity in the mouse micronucleus assay as reported in RDB 65E6

J. Ferguson-Smith, **Hygiene Standard Documentation - HFC 125**, document HSP/92/20, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 27 January 1993 (4 pages, RDB5A78)

R-125, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA, provisional

T. Kawano (Daikin Industries, Limited, Japan), H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated, USA), G. Malinverno (Ausimont S.p.A., Italy, and G. M. Rusch (AlliedSignal Incorporated, USA), **Toxicological Evaluation of 1,1,1,2,2-Pentafluoroethane (HFC-125)**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 28, pages 223-231, 1995 (9 pages with 7 tables, RDB65E6)

R-125, summary of Program for Alternative Fluorocarbon Toxicity Testing (PAFT) studies: 4-hr ALC and LC_{50} rat is >800,000 ppm v/v; 5-min cardiac sensitization NOEL dog is 75,000 ppm, LOEL is 100,000 ppm, and EC_{50} is 100,000-150,000 ppm; subchronic exposures of rats for 6 hr/day, 5 days/week for 4 and 13 weeks showed no evidence of toxicity at 50,000 ppm, the highest concentration tested; developmental tests found slight, reversible toxicity in the rabbit and rat dams, but no convincing evidence of embryotoxicity or teratogenicity; *in vitro* tests in *Salmonella typhimurium* and *Escherichia coli* bacteria (Ames Assay) found no clear evidence of clastogenic activity in Chinese hamster ovary (CHO) cells or human lymphocytes; *in vivo* tests found R-125 not mutagenic in the mouse micronucleus test, even at concentrations as high as 600,000 ppm for 6 hours; the paper concludes that R-125 is "very low in biological reactivity," "is not acutely toxic, not a cumulative toxin, not a developmental toxin, not a mutagen," and is "low or lower in toxicity than any of the CFCs it will eventually replace."

R. E. Masters, R. J. Brown, D. M. John, and D. W. Coombs, **A Study of the Effect of HFC-125 on Pregnancy of the Rat (Inhalation Exposure)**, report ALS 9/920434 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Center Limited (HRC), Cambridgeshire, United Kingdom, 6 November 1992 (RDB5753)

R-125, developmental toxicity: neither embryotoxic nor teratogenic in the rat at exposures up to 50,000 ppm v/v as reported in 65E6

K. May, D. Watson, and G. Hodson-Walker, **HFC-125 in Gaseous Phase: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (The Ames Test)**, report 91/PAR 003/1152a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, United Kingdom, 28 May 1992 (RDB5757)

R-125, toxicity, mutagenicity, Ames assay: R-125 deemed not mutagenic as reported in RDB 65E6

E. Nakayama, K. Nagano, M. Chrishi, S. Katagin, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Acute Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0184 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 18 March 1992 (RDB5754)

R-125, toxicity: 4-hr ALC rat >800,000 ppm v/v and anesthetic LOEC at 800,000 ppm as reported in RDB 5C15 and 65E6

E. Nakayama, K. Nagano, M. Ohnishi, S. Katagin, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Four-Week Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0182 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 23 October 1992 (RDB5756)

R-125, inhalation toxicity: 13-wk NOAEL rat at 0, 5,000, 15,000, or 50,000 ppm v/v as reported in RDB 65E6

E. Nakayama, K. Nagano, M. Ohnishi, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Thirteen-Week Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0197 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 31 August 1993 (RDB5761)

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R-125, inhalation toxicity: R-125, toxicity: 4-wk NOAEL rat at 0, 5,000, 15,000, or 50,000 ppm v/v as reported in RDB 65E6

A. S. Panepinto, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HFC-125**, report 582-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6457)

R-125, toxicity, health effects, inhalation tests, 4-hr ALC and LC_{50} rat > 709,000 ppm as reported in RDB 5871 and 65E6

R. L. Swann et al, **Research Review**, volume 85, pages 17-28, 1983 (12 pages, RDB5943)

R-125, toxicity

T. Takano and Y. Miyazaki, *Journal of Toxicol. Science*, volume 7, number 2, pages 143-149, 1992 (7 pages, RDB5971)

R-125, toxicity

V. Thompson and R. C. Graham, untitled toxicity review for pentafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 December 1993 (16 pages, RDB5871)

R-125, summary of published and unpublished toxicity literature

Pentafluoroethane (HFC-125, CAS No. 354-33-6), Joint Assessment of Commodity Chemicals (JACC) report 24, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1994 (36 pages with 2 tables, RDB4C01)

R-125, environmental impacts, toxicity

Pentafluoroethane (HFC 125) Health Effects Information, CAS# 354-33-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B55)

R-125, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide - 1,1,1,2,2-pentafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (4 pages, RDB5C15)

R-125, WEEL, toxicology data, toxicity, safety classification

unpublished data, report 54-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1964 (RDB6456)

R-125, toxicity, health effects, inhalation tests, 4-hr ALC and LC_{50} > 100,000 ppm

unpublished data, report 726-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6455)

R-125, toxicity, health effects, mutagenicity

R-134

M. A Collins, **Toxicology Summary for 1,1,2,2-Tetrafluoroethane (HFC 134)**, ICI Chemicals and Polymers Limited, Runcorn, UK, 9 June 1993 (2 pages, RDB6688)

R-134, summary of published and unpublished toxicity literature; ICI Hygiene Standard = 10 ppm Occupational Exposure Band; no metabolism data available, but absorption is expected to be poor; reported to be of low acute inhalation toxicity, but no data are available; no chronic exposure data, but R-134 was administered to rats at 7 ppm for 1 yr, as an impurity in refrigerant 134a, with no effect; mutagenicity tests (Ames test in human lymphocyte in vitro cytogenetics study) negative for genotoxic effects; concludes that R-134 is probably of low overall toxicity

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for 1,1,2,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 October 1992 (RDB5864)

R-134, summary of published and unpublished toxicity literature

HFC 134: Assessment of Cardiac Sensitization Potential in Dogs, report DPT 300/932252, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 21 February 1994 (29 pages, RDB6802)

R-134, cardiac sensitization in beagle dogs for exposures with epinephrine challenge; NOEL at 50,000 and 75,000 ppm v/v, LOEL 33% at 100,000 ppm

unpublished data, report 725-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6186)

R-134, toxicity, health effects, mutagenicity, potential clastogenic (chromosome-damaging) activity [referenced in RDB 5864]

unpublished data, report 729-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I.

duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6187)

R-134, toxicity, health effects, mutagenic potential, Ames Assay negative [referenced in RDB 5864]

unpublished data, report 452-91, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1991 (RDB6188)

R-134, toxicity, health effects, ALC rat 4 hour >460,000 ppm as reported in RDB 5864

R-134a

D. Anderson and C. R. Richardson, **Arcton 134a: A Cytogenetic Study in the Rat**, report CTL/P/444 (SR0002, FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 17 May 1979 (RDB5B33)

R-134a, mutagenicity, toxicity: no chromosomal damage in rat bone marrow cells [as reported in RDB 5870 and 6533]

A. Araki (Japan Bioassay Laboratory, JBL, Japan), **Report on Reverse Mutation Assay in Bacteria on Tetrafluoroethane**, report 5292/5312, Japan Industrial Safety and Health Association, Kanagawa, Japan, 11 October 1990 (RDB6534)

R-134a, health effects, mutagenicity, toxicity

M. Asakura (Japan Bioassay Laboratory, JBL, Japan), **Report on a Chromosomal Aberration Test of 1,1,1,2-Tetrafluoroethane in Cultured Mammalian Cells**, report 5879 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 14 June 1990 (RDB6535)

R-134a, health effects, mutagenicity, toxicity

R. D. Callander and K. P. Priestley, **HFC 134a: An Evaluation Using the Salmonella Mutagenicity Assay**, report CTL/P/2422 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 16 March 1990 (RDB5B37)

R-134a, toxicity

C. A. Coleman and R. S. Thompson, **HFC 134a: Determination of the Acute Toxicity to Pseudomonas Putida**, report CTL/BL3980/B, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1990 (RDB65B0)

R-134a, toxicity [referenced in RDB 6533]

M. A. Collins (ICI Chemicals and Polymers Limited, UK), G. M. Rusch (AlliedSignal Incorporated, USA), F. Sato (Showa Denko K.K., Japan), P. M. Hext (Zeneca Central Toxicology Laboratory, UK), and R-J. Millischer (Elf Atochem S.A., France), **1,1,1,2-Tetrafluoroethane: Repeat Exposure Inhalation Toxicity in the Rat, Developmental Toxicity in the Rabbit, and Genotoxicity in Vitro and in Vivo**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 25, pages 271-280, 1995 (10 pages with 1 figure and 6 tables, RDB5610)

This paper summarizes toxicity studies for animal exposures to R-134a by inhalation. It presents the findings for subchronic and chronic rat exposures to 0, 2,500, 10,000, and 50,000 ppm for 13, 52, and 104 weeks. No statistically significant effects were observed on clinical condition, growth, and survival or on hematological, clinical chemistry, and urinary parameters. The only treatment-related pathological changes seen were increased incidence of Leydig cell hyperplasia (abnormal or unusual increase) and adenoma (benign tumor of glandular structure or origin) in male rats exposed to 50,000 ppm. The tumors, which also were found in control animals, were benign and not life threatening. The survival rates are plotted and key data are tabulated for these chronic inhalation studies. The paper also summarizes a battery of "in vivo" and "in vitro" tests for genotoxic activity. They include mouse micronucleus, unscheduled DNA synthesis assays, Ames assay, cytogenic assay in cultured mammalian cells, and cytogenic assay in human lymphocytes. Pregnant rabbits exposed to R-134a showed minimal maternal toxicity at high concentrations, but there were no effects on fetal development. The paper presents the test methods and conditions, statistical analysis approaches, and results. Data are tabulated for the developmental toxicity and in vivo genotoxicity studies. The paper concludes that R-134a is of very low toxicity.

M. A. Collins, **HFC 134a: Acute Toxicity in Rats to Tetrafluoroethane**, report CTL, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 1984 (RDB-65A9)

R-134a, inhalation toxicity [referenced in RDB 6533]

M. C. Dodge, M. Kilmartin, R. A. Riley, T. M. Weight, and J. Wilson, **Arcton 134a: Teratogenicity Study in the Rat**, report CTL/P/417 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 9 January 1980 (RDB5B31)

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R-134a, developmental and reproductive toxicity

M. C. Dodge, D. Anderson, I. P. Bennett, and T. M. Weight, **Arcton 134a: Dominant Lethal Study in the Mouse**, report CTL/R/437 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 8 January 1979 (RDB5B32)

R-134a, mutagenicity (negative), toxicity [as reported in RDB 5870]

M. K. Ellis, L. A. Gowans, T. Green, and R. J. N. Tanner (Zeneca Central Toxicology Laboratory, then part of ICI Chemicals and Polymers Limited, United Kingdom), **Metabolic Fate and Disposition of 1,1,1,2-Tetrafluoroethane (HFC-134a) in Rat Following a Single Exposure by Inhalation**, *Xenobiotica*, volume 23, number 7, pages 719-729, July 1993 (RDB6531)

R-134a, metabolism, toxicity: tests in rats following single 1-hr inhalation exposures at 10,000 ppm; approximately 1% was recovered in urine, feces, and expired air after exposures, indicating low absorption of R-134a by the lungs; of the 1%, approximately two-thirds were exhaled within 1 hr of the cessation of exposure as unchanged R-134a; remainder was exhaled as carbon dioxide and excreted in urine and feces as trifluoroacetic acid; carbon dioxide was the major metabolite accounting for 0.22 and 0.27% of the inhaled dose in male and female rats, respectively; urinary excretion accounted for 0.09% of the dose and fecal excretion 0.04% of the dose by both sexes; total metabolism in urine, feces and as carbon dioxide amounted to 0.34 and 0.40% of the inhaled dose in males and females, respectively; no evidence for a specific uptake of R-134a or metabolites into any organ or tissue analyzed, including fat

J. Ferguson-Smith, **Hygiene Standard Documentation - HFC 134a**, document HSP/93/02, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 1993 (9 pages with 2 tables, RDB5A79)

R-134a, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

E. L. Frederickson and C. Nielson, *Progr. Anaesthesiology* (proceedings of the 4th World Congress of Anaesthesiology, 1968), pages 723-729, 1970 (7 pages, RDB6532)

R-134a, cardiac study, health effects, toxicity

P. W. Grube, D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for ethane, 1,1,1,2-tetrafluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 14 February 1994 (18 pages, RDB5870)

R-134a, summary of published and unpublished toxicity literature

P. M. Hext and R. Parr-Dobrzanski, **HFC 134a: 2-Year Inhalation Toxicity Study in the Rat**, report CTL/P/3841, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, United Kingdom, 19 March 1993 (RDB6546)

R-134a, health effects, 2-yr inhalation toxicity study in rats exposed to 0, 2,500, 10,000, and 50,000 ppm for 6 hr/day, 5 days/week: no significant differences in survival, body weight, clinical chemistry (except occasional small increases in urinary fluoride levels at 10,000 and 50,000 ppm), hematology, or organ weight (with exception of testes); mean testicular weight was higher at 50,000 ppm; tumor incidence comparable between control and exposed groups except at 50,000 ppm, at which the incidence of Leydig cell hyperplasia and benign Leydig cell tumors was statistically higher; low incidence of generalized large granular lymphocyte leukemia was seen across all groups, and while slightly higher in the control group and at 50,000 ppm; NOEL = 10,000 ppm [referenced in RDB 5870]

P. M. Hext, **HFC 134a: 90-day Inhalation Toxicity Study in the Rat**, report CTL/P/2466 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 15 November 1989 (RDB5B38)

R-134a, toxicity study in rats exposed to 2,000, 10,000, and 50,000 ppm for 6 hr/day, 5 days/week: NOEL = 49,500 ppm [as reported in RDB 5870]

G. L. Kennedy, **Acute Inhalation Toxicity Study of Tetrafluoroethane**, report 422-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1979 (RDB6529)

R-134a, health effects, toxicity: 4-hr ALC rat = 567,000 ppm, anesthetic LOEC rat = 205,000 ppm [as reported in RDB 5870]

G. L. Kennedy, **Subacute Inhalation Toxicity of Tetrafluoroethane (FC 134a)**, report 228-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, August 1979 (RDB6528)

R-134a, toxicity study in rats: no exposure-related hematological, chemical analysis, or pathologic changes were observed; significant increase in fluoride excretion indicates metabolism of R-134a [as reported in RDB 5870]

M. Lu, **1,1,1,2-Tetrafluoroethane (FC 134a): Embryo-Fetal Toxicity and Teratogenicity Study by**

Inhalation in the Rat, report 317-81, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1981 (RDB6530)

R-134a, developmental and reproductive toxicity

J. M. Mackay, **HFA 134a: An Evaluation in the In Vitro Cytogenetic Assay**, report CTL/P/2977 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 10 July 1990 (RDB5B41)

R-134a, mutagenicity, toxicity

R-J. Millischer (Elf Atochem S.A., France), **The Toxicology of HFC 134a**, *Journal of the American College of Toxicol.*, volume 8, number 6, pages 1220 ff, 1989 (RDB6549)

R-134a, health effects, toxicity

L. S. Mullin, **FC 134a: Cardiac Sensitization**, report 42-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1979 (RDB-6527)

R-134a, health effects, toxicity: cardiac sensitization in dogs, LOEL = 75,000 ppm, NOEL = 50,000 ppm as reported in RDB 5870

W. Müller and T. Hofmann (Pharma Research Toxicology and Pathology Laboratory, report 88.1244/-89.0115, **CFC 134a Micronucleus Test in Male and Female NMRI Mice After Inhalation**, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 1989 (RDB6584)

R-134a, toxicity

M. J. Olson, C. A. Reidy, J. T. Johnson, and T. C. Pederson, **Oxidation of 1,1,1,2-Tetrafluoroethane in Rat Liver Microsomes is Catalyzed Primarily by Cytochrome P450IIE1**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 19, number 2, pages 298-303, 1991 (6 pages, RDB6537)

R-134a, health effects, metabolism, toxicity

M. J. Olson and S. E. Surbrook, Jr., **Defluorination of the CFC-Substitute 1,1,1,2-Tetrafluoroethane: Comparison in Human, Rat and Rabbit Hepatic Microsomes**, *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, volume 59, number 1-3, pages 89-99, December 1991 (11 pages, RDB6538)

R-134a, toxicity: compares metabolism by hepatic microsomes in human tissue to that from rats and rabbits; defluorination of R-134a in a cytochrome-P450 catalyzed reaction was similar; maximal rate of R-134a metabolism was very low and showed little interindividual variation; findings indicate that laboratory animals are an adequate surrogate for humans to characterize R-134a toxicity, especially that which may be mediated by products of halocarbon metabolism

M. J. Olson et al, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 18, number 6, pages 992-998, 1990 (7 pages, RDB6539)

R-134a, health effects, metabolism, toxicity

M. J. Olson, C. A. Reidy, and J. T. Johnson, **Defluorination of 1,1,1,2-Tetrafluoroethane (R-134a) by Rat Hepatocytes**, *Biochemical and Biophysical Research Communications*, volume 166, number 3, pages 1390-1397, 1990 (8 pages, RDB6540)

R-134a, health effects, toxicity

M. J. Olson, C. A. Reidy, and J. T. Johnson, **Modulation of Glucose Metabolism in Isolated Rat Hepatocytes by 1,1,1,2-tetrafluoroethane**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 15, number 2, pages 270-280, August 1990 (11 pages, RDB6541)

R-134a, toxicity: effects on cell viability and functional competence at concentrations of ≤750,000 ppm by glucose metabolism measurements in cultures of hepatocytes derived from fed or fasted rats; R-134a did not produce evidence of cytolethality following a 2-hr exposure; by contrast, R-123B1 caused cell death at 1250 ppm; 125,000-750,000 ppm R-134a increased glycolysis (production of lactate and pyruvate) in a concentration-dependent manner in hepatocytes from fed rats; no effect was observed at 50,000 ppm; R-12, R-114, and R-134a were equal in potency to stimulate glycolysis at 250,000 ppm; R-115 depressed glycolysis slightly; R-123B1 markedly increased glycolysis rates at concentrations as low as 300 ppm; glucose production by hepatocytes of fed rats was decreased by R-12, R-114, and R-134a only at concentrations of ≥250,000 ppm; R-123B1 potently decreased glucose production by hepatocytes at ≥300 ppm; R-134a exposure inhibited gluconeogenesis in a concentration-dependent manner in cells isolated from livers of fasted rats, although this effect was not significant until concentrations reached 125,000 ppm; comparative potency studies showed that R-12, R-114, and R-134a inhibited gluconeogenesis about equally at 250,000 ppm while R-123B1 was effective at 300 ppm and R-115 was without effect at 250,000 ppm; paper concludes that toxicologically significant alteration of glucose-linked bioenergetics is unlikely at anticipated

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levels of R-134a exposure in the workplace or environment

M. J. Olson et al, abstract 202, *The Toxicologist*, Society of Toxicology (SOT), volume 10, number 1, pages 51 ff, 1990 (RDB6542)

R-134a, health effects, toxicity

C. A. Reidy, J. T. Johnson, and M. J. Olson, **Metabolism In Vitro of Fluorocarbon R-134a**, abstract 1295, *The Toxicologist*, Society of Toxicology (SOT), volume 10, number 1, pages 324 ff, 1990 (RDB6543)

R-134a, biochemical study, health effects, toxicity

R. A. Riley, I. P. Bennett, I. S. Chart, C. W. Gore, M. Robinson, and T. M. Weight, **Arcton 134a: Subacute Toxicity to the Rat by Inhalation**, report CTL/P/463 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 6 December 1979 (RDB5B34)

R-134a, health effects, 13-week inhalation toxicity study in rats exposed to 1,000, 10,000, and 50,000 ppm for 20 days in a 28-day period: gas was absorbed into the blood; changes were noted in liver, kidney, and gonad weights of males at 50,000 ppm, but there were no pathology changes in these tissues; pathological change was observed in the lungs of several male rats at the 50,000 ppm dose [as reported in RDB 5870]

G. M. Rusch, **Review of the ICI Toxicology Studies on Fluorocarbon 134a**, report MA-141-80-1, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 3 March 1983 (RDB5150)

R-134a, toxicity summary

S. E. Surbrook, Jr., and M. J. Olson, **Dominant Role of Cytochrome P450 2E1 in Human Hepatic Microsomal Oxidation of the CFC-Substitute 1,1,1,2-Tetrafluoroethane**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 20, number 4, pages 518-524, 1992 (7 pages, RDB6544)

R-134a, health effects, metabolism, toxicity

R. W. Trueman, **HFC 134a: Assessment for the Induction of Unscheduled DNA Synthesis in Rat Hepatocytes In Vivo**, report CTL/P/2550 (SR0337) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, June 1990 (RDB5B40)

R-134a, mutagenicity, toxicity

Arcton 134: Excretion, Tissue Distribution and Metabolism in the Rat, report CTL/P/513 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 6 March 1980 (RDB-5B35)

R-134a, biochemical study, toxicity

Fluorocarbon 134a: Embryotoxicity Inhalation Study in the Rabbit, report CTL/P/2380 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 23 November 1989 (RDB5B36)

R-134a, developmental and reproductive toxicity

HFC 134a: 2-year Inhalation Toxicity Study in the Rat. Interim Report after 52 Weeks, report CTL/P/3317 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, circa 1992 (RDB6582)

R-134a, chronic toxicity study

HFC 134a: Teratogenicity Inhalation Study in the Rabbit, report CTL/P/2504 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, 23 November 1989 (RDB5B39)

R-134a, developmental and reproductive toxicity

Hydrofluorocarbon 134a: Pharmacokinetics and Metabolism in Rats Following a Single Exposure by Inhalation, report CTL/R/1090, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, United Kingdom, circa 1985 (RDB6581)

R-134a, biochemical study, toxicity

Mutagenicity Evaluation of Genetron 134a, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, October 1976 (RDB-6583)

R-134a, toxicity

1,1,1,2-Tetrafluoroethane (HFC-134a, CAS No. 811-97-2), Joint Assessment of Commodity Chemicals (JACC) report 31, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1995 (42 pages with 1 figure and 3 tables, RDB6533)

R-134a, environmental impacts, toxicity

1,1,1,2-Tetrafluoroethane (HFC 134a) Health Effects Information, CAS# 811-97-2, Elf Atochem

North America, Incorporated, Philadelphia, PA, undated circa 1995 (6 pages, RDB5B56)

R-134a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide - 1,1,1,2-tetrafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (4 pages, RDB4B86)

R-134a, WEEL, toxicology data, toxicity, safety classification

unpublished data, report 190-67, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1967 (RDB6525)

R-134a, toxicity

unpublished data, report 534-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1978 (RDB6526)

R-134a, Ames assay (negative) health effects, mutagenicity, toxicity [as reported in RDB 5870]

unpublished data, Litton Bionetics Incorporated (LBI), Kensington, MD, 1976 (RDB6536)

R-134a, health effects, extended oral toxicity study in rats administered 300 mg/kg/day, 5 days/week, for 52 weeks: no significant increase in the incidence of neoplasms was observed in any organ [referenced in RDB 5870]

R-E134

R. C. Graham and P. J. Lardear, untitled toxicity review for bis(difluoromethyl) ether, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 April 1994 (5 pages, RDB6206)

R-E134, summary of published and unpublished toxicity literature

unpublished data, report for project MR-9563-1, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, undated, before 1994 (RDB6207)

R-E134, toxicity, health effects, ALC rat 4 hour >95,000 ppm as reported in RDB 6206

R-141b

W. J. Brock, H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), R-J. Millischer (Elf Atochem S.A., France), C. H. Farr (Elf Atochem North America, USA), T. Kawano (Daikin Industries, Japan), and G. M. Rusch (AlliedSignal Incorporated, USA), **Acute and Subchronic Toxicity of 1,1-Dichloro-1-Fluoroethane (HCFC-141b)**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 33, number 6, pages 483-490, 1995 (8 pages with 3 tables, RDB65A4)

This paper summarizes acute and subchronic toxicity test methods and findings for R-141b, to assist in establishing proper handling guides. It describes the sample material used, acute oral toxicity tests in rats administered in corn oil, dermal toxicity tests in rats and rabbits, occular and dermal irritation tests in rabbits, and dermal sensitization studies in guinea pigs. It also outlines acute, two-week, four-week, and 90-day inhalation tests in rats, cardiac sensitization tests in beagle dogs and monkeys, and neurobehavioral toxicity tests in rats. The paper summarizes results including an oral LD_{50} rat of >5,000 mg/kg and oral LD_{50} rat of >2,000 mg/kg, since none of the specimens died in these tests. It also provides inhalation lethality data by sex, concluding that the 4-hr and 6-hr LC_{50} rat is 61,647 and 56,700 ppm, respectively. It notes that reduced motor activity, rapid breathing, and anesthesia were observed at all concentrations above 29,000 ppm. The cardiac sensitization study showed a LOEL at 9,000 and 3,000 ppm in the dog and monkey, respectively, the lowest concentrations tested; reference is made to earlier tests that showed an LOEL of 5,000 ppm in dogs exposed for 5 minutes, also with epinephrine challenges. The NOAEL for subchronic inhalation studies was considered to be 8,000 ppm. No changes were found to indicate neurotoxicity. The data indicate that R-141b has low acute oral and inhalation toxicity potential, but is a mild skin and eye irritant.

CIVO, report V89.214, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, 1989 (RDB5973)

R-141b, toxicity

CIVO, Report No. V88.156/271236, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, 1988 (RDB5974)

R-141b, toxicity

C. H. de Rooij (Solvay S.A., Belgium), **The Toxicology of HFA-141b**, *Proceedings of the European Meeting of the Toxicology Forum* (Toulouse, France, 19-22 September 1989), 1989 (RDB65A7)

please see pages 6-8 for ordering information

R-141b, toxicity

F. J. Dwyer et al, **CFC Alternatives in Thermoset Foam Production**, *Proceedings of the 33rd Annual Polyurethane Technical/Marketing Conference* (20 September - 3 October 1990), pages 400-406, 1990 (7 pages, RDB59A5)

R-141b, toxicity

J. H. Harris and M. W. Anders, **In Vivo Metabolism of the Hydrochlorofluorocarbon 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Biochemical Pharmacology*, Oxford, United Kingdom, volume 41, number 9, pages R13-R16, 1991 (4 pages, RDB-5975)

R-141b, toxicity

W. Howe, **Hygiene Standard Documentation - HCFC 141b**, document MC001, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 14 October 1991 (3 pages, RDB5A80)

R-141b, toxicity, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 500 ppm, 8-hr TWA, and for a short-term exposure limit of 1,250 ppm for 10 minutes

IRCHA, Report B7072 (FYI-OTS-590-0695), Allied-Signal Incorporated, Morristown, NJ, 1989 (RDB-6474)

R-141b, toxicity, aquatic/environmental studies in daphnia magna

IRCHA, Report B7073 (FYI-OTS-590-0695), Allied-Signal Incorporated, Morristown, NJ, 1989 (RDB-6475)

R-141b, toxicity, aquatic/environmental studies in brachydanio rerio (zebra fish)

B. C. Karpov, *Tr. Leningrad Sanit. Gigien. Med. Inst.*, volume 241, pages 128-137, 1963 (10 pages, RDB5976)

R-141b, toxicity

M. A. Lee, D. M. Krentz, and R. C. Graham, untitled toxicity review for ethane, 1,1-dichloro-1-fluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 November 1993 (18 pages, RDB5868)

R-141b, summary of published and unpublished toxicity literature

G. D. Loizou and M. W. Anders (University of Rochester), **Gas-Uptake Pharmacokinetics and Biotransformation of 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Drug Metabolism and Disposition*, American Society for Pharmacology and Experimental Therapeutics, volume 21, pages 634-639, 1993 (6 pages, RDB65E3)

R-141b, biochemistry, metabolism, toxicity

R-J. Millischer (Elf Atochem S.A., France), C. H. de Rooij (Solvay S.A., Belgium), H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), C. H. Farr (Elf Atochem North America, USA), R. Ben-Dyke, C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), D. J. Lewis, and G. Hudson-Walker, **Evaluation of the Genotoxicity and Chronic Inhalation Toxicity of 1,1-Dichloro-1-Fluoroethane (HCFC-141b)**, *Food and Chemical Toxicology*, volume 33, pages 491-500, 1994 (10 pages, RDB65A8)

R-141b, toxicity

L. S. Mullin, **Fluorocarbon 141b (Ethane, 1,1-dichloro-1-fluoro): Cardiac Sensitization**, report 957-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 23 November 1977 (3 pages with 1 table, RDB6467)

R-141b, toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; NOEL at 2,600 ppm v/v; LOEL (1/10) at 5,200 ppm; lethal to 1 of 10 dogs at 10,200 ppm and to 2 of 2 at 21,600 ppm; concludes that R-141b is a strong cardiac sensitizer

T. K. Nikijenko, *Toksikologiya Novykh Promyshlennykh Khimicheskikh Veschestva* [Toxicology of New Industrial Chemical Substances], volume 8, pages 83-97, 1966 (11 pages in Russian, RDB5978)

R-141b, toxicity

1,1-Dichloro-1-fluoroethane (HCFC-141b, CAS No 1717-00-6), Joint Assessment of Commodity Chemicals (JACC) report 29, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, December 1994 (RDB6585)

R-141b, environmental impacts, toxicity

1,1-Dichloro-1-fluoroethane (HCFC 141b) Health Effects Information, CAS# 1717-00-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (6 pages, RDB5B57)

R-141b, summary of toxicological and ecological information

Prehl. Prumysolve Toxikol. Org. Latky, pages 134 ff, 1986 (RDB5981)

R-141b, toxicity

Workplace Environmental Exposure Level Guide - 1,1-dichloro-1-fluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (RDB4B87)

R-141b, WEEL, toxicology data, toxicity, safety classification

Report DR-0006-8553-002, Dow Chemical Company, 1989 (RDB5982)

R-141b, toxicity

Report DR-0006-8553-002B, Dow Chemical Company, 1989 (RDB5983)

R-141b, toxicity

Report 55645/23/88, Duphar B.V., The Netherlands, 1988 (RDB6460)

R-141b, toxicity: LD_{50} dermal rat > 2000 mg/kg [referenced in RDB 5868]

Report 55645/32/88, Duphar B.V., The Netherlands, 1988 (RDB6461)

R-141b, toxicity

Report 55645/60/88, Duphar B.V., The Netherlands, 1988 (RDB6462)

R-141b, toxicity

Report 55645/61/88, Duphar B.V., The Netherlands, 1988 (RDB6463)

R-141b, toxicity

Report 55635/49/90 [possibly 55645/49/90], Duphar B.V., The Netherlands, 1991 (RDB6464)

R-141b, toxicity

Report T-2966, Hita Research Laboratories, 1992 (RDB5984)

R-141b, toxicity

Report PWT 77/88952, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1989 (RDB5985)

R-141b, toxicity

Report PWT 82/89243, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1989 (RDB5986)

R-141b, toxicity

Report PWT/86, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1989 (RDB5987)

R-141b, toxicity

Report PWT 90/8913D/AC, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1989 (RDB5988)

R-141b, toxicity

Report ALS 1/901565, Huntingdon Research Centre (HRC), Cambridgeshire, United Kingdom, 17 December 1990 (RDB6473)

R-141b, toxicity, health effects, neurologic study in rats, no changes indicative of neurotoxic effect [referenced in RDB 5868]

Report ALS 1/921032, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5989)

R-141b, toxicity

Report ALS 2/920766, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5990)

R-141b, toxicity

Report PWT 91/881114D/AC, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5991)

R-141b, toxicity: ALD dermal rat > 2000 mg/kg [referenced in RDB 5868]

Report PWT 92/881066D/SE, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5992)

R-141b, toxicity

Report PWT 93/881067D/SE, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5993)

R-141b, toxicity

Report PWT 94/881236D/SS, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5994)

R-141b, toxicity

Report PWT 95/881676, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1988 (RDB5995)

R-141b, toxicity: 4-hr LC_{50} rat = 61,647 ppm [referenced in 5868]

Report PWT 76/8893, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1987 (RDB5996)

R-141b, toxicity

Report 89/PFG001/0971a (FYI-OTS-0690-0695), Life Science Research Limited, Suffolk, United Kingdom, 1990 (RDB5997)

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R-141b, toxicity

Report 89/PFG002/1029 (FYI-OTS-00690-0695), Life Science Research Limited, Suffolk, United Kingdom, 1989 (RDB5998)

R-141b, toxicity

Report 89/PFG003/0600, Life Science Research Limited, Suffolk, United Kingdom, 1989 (RDB5999)

R-141b, toxicity

Report 88/PSV004/237, Life Science Research Limited, Suffolk, United Kingdom, 1988 (RDB59A0)

R-141b, toxicity

Report 88/PSV005/257, Life Science Research Limited, Suffolk, United Kingdom, 1988 (RDB59A1)

R-141b, toxicity

Report 88/PSV008/258, Life Science Research Limited, Suffolk, United Kingdom, 1988 (RDB59A2)

R-141b, toxicity

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R-141b, toxicity

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R-141b, toxicity, health effect, metabolic and biochemical studies in rats

unpublished data, report 61-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6465)

R-141b, toxicity, health effects, 6-hr ALC rat = 50,200 ppm [referenced in RDB 5868]

unpublished data, report 715-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6466)

R-141b, toxicity, health effects, subchronic inhalation tests [referenced in RDB 5868]

unpublished data, report 988-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6468)

R-141b, toxicity, health effects, Ames Assay, not mutagenic [referenced in RDB 5868]

unpublished data, report 312-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6469)

R-141b, toxicity, health effects, dermal irritation in rabbits, not a skin irritant [referenced in RDB 5868]

unpublished data, report 318-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6470)

R-141b, toxicity, health effects, eye irritation in rabbits [referenced in RDB 5868]

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R-141b, toxicity, health effects, LD_{50} oral rat > 5,000 mg/kg [referenced in RDB 5868]

unpublished data, report 501-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6471)

R-141b, toxicity, health effects, LD_{50} dermal rabbit > 2,000 mg/kg [referenced in RDB 5868]

unpublished data, report 746-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6472)

R-141b, toxicity, health effects, mutagenicity [referenced in RDB 5868]

R-142b

F. C. Barsky and B. E. Butterworth, **In Vitro Microbial Mutagenicity Studies of Ethane, Chlorodifluoro**, report 322-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6517)

R-142b, health effects, toxicity [referenced in RDB 3721 and 5869]

R. Culik and D. P. Kelly, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Chlorodifluoroethane**, report 700-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6520)

R-142b, health effects, developmental and reproductive toxicity [referenced in RDB 3721 and 5869]

D. R. Danske, F. J. Mecler, and R. P. Beliles, **Teratology Study in Rats - Isotron 142b - Monochlorodifluoroethane**, report for project 29890,

Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5914)

R-142b, toxicity

A. P. Filicheva, **Changes in the Nervous System Following the Chronic Action of Fluorinated Aliphatic Carbohydrates**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 10, pages 14-16, 1975 (3 pages in Russian, RDB6523)

R-142b, health effects, toxicity

P. W. Grube, M. A. Lee, G. T. Hall, R. C. Graham, and L. J. Ver Nooy, untitled toxicity review for ethane, 1-chloro-1,1-difluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 January 1990 (12 pages, RDB5869)

R-142b, summary of published and unpublished toxicity literature

D. R. Jagannath and D. J. Brusick, **Mutagenicity Evaluation of Isotron 142b**, report for project 20838, Litton Bionetics Incorporated (LBI), Kensington, MD, 1977 (RDB5912)

R-142b, toxicity

D. P. Kelly and H. J. Trochimowicz, **Ninety Day Inhalation Exposure of Rats and Dogs to Vapors of 1-Chloro-1,1-difluoroethane**, report 469-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6518)

R-142b, health effects, toxicity: no adverse clinical hematological, blood chemical, urine analytical, or histopathologic evidence of effects attributable to exposures at 1,000 or 10,000 ppm v/v [as reported in RDB 3721 and 5869]

A. Koops and D. F. Krahn, **Mutagenic Activity of Ethane, Chlorodifluoro- in the Salmonella/Microsome Assay**, report 578-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6519)

R-142b, health effects, toxicity [referenced in RDB 2721 and 5869]

D. W. Matheson and D. Brusick, **Mutagenicity Evaluation of Isotron 142b in the In Vitro Transformation of BALB/3T3 Cells Assay**, report for project 20840, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5913)

R-142b, toxicity

F. J. Mecler and P. J. Knapinsky, **Acute Inhalation Toxicity Study in Rats. Isotron 142b**, report for project 20888, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB59A8)

R-142b, toxicity

B. L. Moore and H. J. Trochimowicz, **Subacute (Two-Week) Inhalation Toxicity of 1-Chloro-1,1-difluoroethane**, report 145-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6516)

R-142b, health effects, toxicity, inhalation study in the rat: no clinical hematological, blood chemical, urine analytical, or histopathologic evidence of effects attributable to exposures at 20,000 ppm as reported in RDB 3721 and 5869

J. A. Seckar, H. J. Trochimowicz, and G. K. Hogan, **Toxicological Evaluation of Hydrochlorofluorocarbon 142b**, *Fundamentals of Chemical Toxicology*, Pergamon Press, Limited, United Kingdom, volume 24, number 3, pages 237-240, 1986 (RDB5919)

R-142b, toxicity

J. D. Sterling, *Aerosol Age*, volume 12, pages 48-52, 1982 (5 pages, RDB6524)

R-142b, health effects, toxicity

A Dominant-Lethal Inhalation Study with Fluorocarbon 142b in Rats, report 79-7288, Bio/dynamics Incorporated, East Millstone, NJ, 1980 (RDB5916)

R-142b, toxicity

A Study in the Rat of the Cytogenetic Effect of Inhalation of Fluorocarbon 142b for 13 Weeks, report 79-7289, Bio/dynamics Incorporated, East Millstone, NJ, 1980 revised 1983 (RDB5917)

R-142b, toxicity

A Two-Year Inhalation Study of Fluorocarbon 142b in the Rat, report 79-7287, Bio/dynamics Incorporated, East Millstone, NJ, 1983 (RDB5918)

R-142b, health effects, toxicity

Acute Toxicity Study in Rats - Isotron 142b, Monochlorodifluoroethane, report for project 20795, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5911)

R-142b

Chlorodifluoroethane (1-Chloro-1,1-difluoroethane; HFA-142b, CAS: 75-68-3), Joint Assessment of Commodity Chemicals (JACC) report 17, European Chemical Industry Ecology and Toxicology

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Centre (ECETOC), Brussels, Belgium, February 1991 (36 pages with 1 table, RDB3721)

R-142b, environmental impacts, toxicity

Workplace Environmental Exposure Level Guide - 1-chloro-1,1-difluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1994 (RDB4B89)

R-142b, toxicity, safety classification: 4-hr ALC rat = 128,000 ppm, WEEL = 1,000 ppm

unpublished data, report 81-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1970 (RDB6522)

R-142b, health effects, toxicity, effect of frightening noise to stimulate the release of endogenous epinephrine in cardiac sensitization [referenced in RDB 5869]

unpublished data, report 752-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1975 (RDB6521)

R-142b, health effects, toxicity [referenced in RDB 5869]

R-143

L. J. Sibinski, **Two-Year Oral (Diet) Toxicity/Carcinogenicity Study of the Fluorochemical FC 143 in Rats**, Riker Laboratories, Incorporated, 3M Company, Minneapolis, MN, 1987 (RDB65E0)

R-143 (possibly R-143a), toxicity

R-143a

W. J. Brock, H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), C. H. Farr (Elf Atochem North America, USA), R-J. Millischer (Elf Atochem S.A., France) and G. M. Rusch (AlliedSignal Incorporated, USA), article 0092, **Acute, Subchronic, and Developmental Toxicity and Genotoxicity of 1,1,1-Trifluoroethane (HFC-143a)**, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), Academic Press, Incorporated, volume 31, pages 200-209, 1966 (10 pages with 7 tables, RDB6597)

D. P. Kelly, **Four-Hour Acute Inhalation Toxicity Study with FC-143a in Rats**, report 283-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 August 1990 (11 pages with 2 tables, RDB5C17)

R-143a, health effects, toxicity: 4-hr ALC rat >540,000 ppm v/v based on tests of male rats; rats exposed to 97,000 and 540,000 ppm showed slight and moderate to severe, respectively, weight loss on the day following exposure, but returned to normal weight gain in the 14-day recovery period; animals responded normally to a slight tail pinch during exposures, implying that the anesthetic LOEC rat is >540,000 ppm

M. A. Lee, P. J. Lardear, and R. C. Graham, untitled toxicity review for 1,1,1-trifluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 February 1994 (RDB5867)

R-143a, summary of published and unpublished toxicity literature

Pharmaco-LSR Limited (UK), **Forane(R) 143a in Vapour Phase: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (the Ames Test)**, Pharmaco-LSR report 93/ATH008/0209, Elf Atochem S.A., Paris - La Défense, France, 1993 (RDB5C27)

R-143a, toxicity, health effects [referenced in RDB 5C16]

An Inhalation Developmental Toxicity Study of HFC-143a in Rabbits, report WIL-189005, WIL Research Laboratories, Incorporated, 27 August 1993 (RDB5C28)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Bacterial Mutagenicity Testing of HFC-143a in the Salmonella Typhimurium and Escherichia Coli: Plate Incorporation Assay, report 787-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1993 (RDB5C18)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Developmental Toxicity Study of HFC-143a in Rats, report 700-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB5C19)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Four-Week Inhalation Toxicity Study with HFC-143a in Rats, report 6-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de

Nemours and Company, Incorporated, Newark, DE, 1992 (RDB5C20)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Four-Week Inhalation Toxicity Study with HFC-143a in Rats, report 99-91, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1991 (RDB5C21)

R-143a, toxicity, health effects [referenced in RDB 5C16]

HFC-143a: Assessment of Cardiac Sensitization Potential in Dogs, report DPT281/930477, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 1993 (RDB5C26)

R-143a, toxicity, cardiac sensitization: NOEL = 250,000 ppm, sensitization level = 300,000 ppm [referenced in RDB 5C16]

In Vitro Evaluation of HFC-143a for Chromosome Aberrations in Human Lymphocytes, report 788-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB-5C22)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Metabolism of HFC-143a in the Rat, report 3-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (RDB5C23)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Mouse Bone Marrow Micronucleus Assay of HFC-143a by Inhalation, report 770-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB5C24)

R-143a, toxicity, health effects [referenced in RDB 5C16]

Subchronic Inhalation Toxicity: 90-Day Study with HFC-143a in Rats, report 690-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB5C25)

R-143a, toxicity, health effects [referenced in RDB 5C16]

1,1,1-Trifluoroethane (HFC 143a) Health Effects Information, CAS# 420-46-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B58)

R-143a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide - 1,1,1-trifluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (2 pages, RDB5C16)

R-143a, WEEL, toxicology data, toxicity, safety classification

unpublished data, report 540-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB5C92)

R-143a, toxicity, aquatic effects, 96-hr LC_{50} rainbow trout [referenced in RDB 5867]

unpublished data, report 541-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB5C93)

R-143a, toxicity, aquatic effects, 96-hr EC_{50} daphnia magna [referenced in RDB 5867]

R-152a

R. H. Bruner (Pathology Associates, Incorporated), **Pathology Peer Review of a Two-Year Inhalation Study of FC-152a in CD Rats**, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 May 1992 (RDB5C90)

R-152a, inhalation toxicity [referenced in RDB 4B90]

R. Culik and D. P. Kelly, **Embryotoxicity and Teratogenicity Studies in Rats with 1,1-Difluoroethane (FC-152a)**, report 437-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 March 1980 (RDB5C88)

R-152a, chronic inhalation toxicity [referenced in RDB 4B90]

J. C. Edwards, **Arcton 152a - Documentation for Hygiene Standard**, ICI Chemicals and Polymers Limited, Cheshire, United Kingdom, 17 June 1985 (2 pages, RDB5A81)

R-152a, toxicity, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

A. Koop, **Mutagenic Activity of Ethane, 1,1-Difluoro in the Salmonella/Microsome Assay**, report 731-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and

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Company, Incorporated, Newark, DE, 16 September 1977 (RDB5C86)

R-152a, mutagenicity, toxicity [referenced in RDB 4B90]

M. A. Lee, P. W. Grube, and R. C. Graham, untitled toxicity review for 1,1-difluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 May 1990 (10 pages, RDB5857)

R-152a, summary of published and unpublished toxicity literature

D. E. Malek, **Approximate Lethal Dose (ALD) of HFC-152a in Rats**, report 524-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 September 1990 (RDB5C84)

R-152a, ingestion toxicity [referenced in RDB 4B90]

J. W. McAlack and P. W. Schneider, **Two-Year Inhalation Study with Ethane, 1,1-Difluoro (FC-152a) in Rats**, report 8-82 (OTS-052-0320), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 November 1982 (RDB5C87)

R-152a, chronic inhalation toxicity [referenced in RDB 4B90]

B. L. Moore, **Acute Inhalation Toxicity (Rats)**, report 699-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 November 1975 (RDB5C85)

R-152a, inhalation toxicity [referenced in RDB 4B90]

B. L. Moore, **Subacute Two-Week Inhalation Toxicity**, report 158-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 2 March 1976 (RDB5C89)

R-152a, inhalation toxicity [referenced in RDB 4B90]

1,1-Difluoroethane (HFC 152a) Health Effects Information, CAS# 75-37-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B59)

R-152a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide - 1,1-difluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1994 (4 pages, RDB4B90)

R-152a, WEEL, toxicology data, toxicity, safety classification

R-160

H. Hermann and J. Vial, **Syncopes Adrénalino-Monochloroéthanique** [Sensitization by Adrenaline and Chloroethane], *Compte Rendu Société Biol.*, Paris, France, volume 117, pages 439-440, 1934 (2 pages, RDB6566)

R-160, cardiac sensitization, toxicity

R-217I1

Acute Inhalation Toxicity Study of Iodoheptafluoropropane in Rats report on project 1530-001 study 3, ManTech Environmental Technologies, 1994 (RDB6693)

R-217I1 (either R-217bal1 or R-217cal1), heptafluoroiodopropane, toxicity: 15-min LC_{50} rat 62,000 ppm (also see RTECS) as reported in RDB 6208

R-218

Huntingdon Research Centre Limited (HRC, United Kingdom), **Perfluoropropane: Mouse Micronucleus Test**, Rhône-Poulenc Chemicals, Bristol, UK, 1992 (RDB6556)

R-218, health effects, mutagenicity for 6 hr exposure of mice (negative at necropsy), toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for 1,1,1,2,2,3,3,3-octafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 January 1986 (5 pages, RDB5858)

R-218, summary of published and unpublished toxicity literature

Product Toxicity Summary Sheet: PF-5030 3M Brand Performance Fluid, summary 25937, 3M, St. Paul, MN, 22 October 1993 (2 pages, RDB5703)

R-218, toxicity: 4-hr LC_{50} rat >110,000 ppm; cardiac sensitization NOEL 0/6 dogs at 300,000 ppm and LOEL 2/8 at 400,000 ppm; not mutagenic by in vitro assay in Salmonella typhimurium bacteria at 800,000 ppm v/v

Report MIN 68/930457, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, May 1993 (RDB65F8)

R-218 (3M PF-5030), acute inhalation (whole body exposure) toxicity study in rats: 4-hr LC_{50}

rat >110,000 ppm; no deaths or clinical signs; body weight gain of female rats was slightly less than in the control group; macroscopic pathological examination after a 15-day observation period following exposures revealed some lung congestion in 1 of 10 exposed rats - as reported in RDB 5703

Report MIN 101/930623, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 23 June 1993 (RDB65F9)

R-218 (3M PF-5030), cardiac sensitization study in dogs, toxicity: tests at 50,000, 100,000, 200,000, 300,000, and 400,000 ppm in air (oxygen enriched above 100,000 ppm to maintain oxygen concentration at approximately 22%; sensitization NOEL 0/6 at 300,000 ppm, LOEL 2/8 (one of them a questionable response) at 400,000 ppm - as reported in RDB 5703

Report MIN 67/920961, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 24 August 1992 (RDB65G0)

R-218 (3M PF-5030), mutagenicity, toxicity: in vitro assay in Salmonella typhimurium bacteria at 800,000 ppm v/v; concluded not mutagenic - as reported in RDB 5703

R-225ca and R-225cb

Four-Week Repeated Inhalation Study of HCFC-225ca and HCFC-225cb in the Common Marmoset, report 3L029, Mitsubishi-Kasei Institute of Toxicological and Environmental Sciences (MITES), Japan, 1993 (RDB65D6)

R-225ca, R-225cb, toxicity

R-227ea

C. P. Chengelis (WIL Research Laboratories, Incorporated), **Toxicological Evaluation of HFC-227ea (FM-200(TM)) - Background Document**, Great Lakes Chemical Corporation, West Lafayette, IN, 20 June 1994 (RDB65F1)

R-227ea, toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for 1,1,1,2,3,3,3-heptafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 January 1986 (5 pages, RDB5860)

R-227ea, summary of published and unpublished toxicity literature

FM-200(TM) Toxicological Study Summaries, Great Lakes Chemical Corporation, West Lafayette, IN, circa 1995 (RDB65F2)

R-227ea, toxicity: 4-hr LC_{50} rat = >788,698 ppm, anesthetic LOEL rat = 800,000 ppm, not mutagenic by reverse mutation assay with *Salmonella typhimurium* or *Escherichia coli*, no induction of chromosomal aberrations in cultured Chinese hamster lung, NOAEL = 100,000 ppm in both a 10-day range-finding inhalation study in the rabbit and in a 14-day inhalation screening study in the rat, NOEL rat = 105,000 ppm in a 90-day inhalation study, NOAEL rat = 105,000 ppm in a developmental toxicity study, 30-min cardiac sensitization in beagle dogs showed NOAEL (effects described as minimal or mild in nature) = 90,000 ppm, LOAEL = 105,000 ppm, and EC_{50} = 140,000 ppm

R-236fa

C. J. Hardy, P. C. Kieran, and I. J. Sharman, **HFC 236fa: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 293/931308, Huntingdon Research Centre Limited (HRC), Cambridgeshire, United Kingdom, 3 February 1994 (RDB65A5)

R-236fa, cardiac sensitization in beagle dogs for 10-minute exposures with epinephrine challenge; provides NOEL, LOEL, and EC_{50} data; 0/6 dogs sensitized at 50,000 or 100,000 ppm v/v, 2/6 at 150,000, and 3/6 at 200,000 ppm; tests at higher concentrations were not completed due to animal struggling at 250,000 ppm and observed anesthesia at 300,000 ppm; toxicity

R. J. Hilarski (International Research and Development Corporation, IR&D), **Nose Only Acute Inhalation Toxicity Evaluation on T-6195 in Rats**, report 137-178, 3M Company, St. Paul, MN, 27 September 1995 (RDB6692)

R-236fa, acute toxicity by nose-only, 4 hr inhalation in 5 male and 5 female albino rats; exposures at mean vapor concentrations of 1,960 and 148,600 ppm v/v; no mortalities at either concentration [4-hr ALC rat >148,600 ppm]; post exposure weight gain was normal, at 7 and 14 days, and no significant macroscopic abnormalities were noted at necropsy; no significant pharmacotoxic signs were observed at 1,960 ppm; animals exposed to 148,600 ppm exhibited rapid respiration; no anesthetic effect indicated at either concentration

N. D. Smith, **Summary of HFC-236fa Toxicity Studies**, fax to D. Minday (3M Company), U.S. Environmental Protection Agency (EPA), Research

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Triangle Park, NC, 22 February 1996 (5 pages, RDB65A6)

R-236fa, toxicity: mutagenicity tests in the Salmonella typhimurium and Escherichia coli (negative); clastogenic (chromosome damaging) test in human lymphocytes (negative); mouse bone-marrow micronucleus test (negative); two-week inhalation study in the rat at 0, 5,000, 20,000, and 50,000 ppm (NOAEL at 5,000 ppm and anesthetic effect at 20,000 ppm); 90-day inhalation study in the rat for 6 hr/day, 5 day/week, for 14 weeks (NOAEL at 20,000 ppm); inhalation developmental study in the rat at 0, 5,000, 20,000, and 50,000 ppm (maternal NOAEL at 5,000 ppm, developmental NOAEL at 50,000, anesthetic effect at 20,000 ppm); 5-day extended inhalation study in the rat at 50,000 ppm (slight respiratory tract irritation, concluded that R-236fa has low acute inhalation toxicity at 50,000 ppm)

R. Valentine, D. A. Keller, J. C. Cook, L. B. Biegel, G. S. Elliott, T. W. Slone, S. M. Munley, K. S. Bentley, W. J. Brock (E. I. duPont de Nemours and Company, Incorporated), and G. B. Briggs (GeoCenters, Incorporated), **Toxicologic Profile of the Alternative Refrigerant HFC-236FA**, abstract 1489 (35th Annual Meeting, 1996), *The Toxicologist*, Society of Toxicology (SOT); *Fundamental and Applied Toxicology*, SOT, Academic Press, Incorporated, volume 30, number 1, part 2, page 291, March 1996 (1 page, RDB6A96)

R-236fa, HFC-236fa: acute, subchronic, developmental, and genetic toxicity; cardiac sensitization; 4-hr ALC rat >195,000 ppm; narcosis was the predominant clinical sign observed during exposure; cardiac sensitization LOEL in beagle dogs was ≥150,000 ppm with a NOEL of 100,000 ppm; no evidence of mutagenic or genotoxic activity was found in vitro in Ames or human lymphocyte assays or in vivo in the mouse micronucleus assay; subchronic inhalation studies with exposures of rats for 6 hr/day, 5 days/week, for 2 and 13 weeks at 5,000, 20,000 and 50,000 ppm yielded no evidence of body or organ weight effects, clinical pathology, organ pathology, or induction of hepatic peroxisomes; rats exposed to 20,000 or 50,000 ppm had a transiently diminished acoustic startle response during exposures; rats exposed to 5,000 ppm were unaffected and some adaptation to narcosis was noted as the study progressed for the higher concentrations; maternal weight gain was evident at ≥20,000 ppm in a rat developmental toxicity study; fetal toxicity was found at ≥5,000 ppm; the overall NOEL was 5,000 ppm, based on narcosis noted at concentrations of ≥20,000 ppm

R. Valentine, **Two-Week Inhalation Toxicity Study with HFC-236fa in Rats**, report 596-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 June 1995 (211 pages, RDB-6A93)

R-236fa, health effects, toxicity: four groups of 5 female and 5 male rats were exposed by inhalation to 0, 5,020, 20,000, or 50,000 ppm v/v for 6 hr/day, 5 days/week, for two weeks; no body weight effects or abnormal clinical observations to exposed rats; NOAEL rat = 5,000 ppm; anesthetic NOEL at 5,000 ppm and LOEC rat at 20,000 ppm; slight decrease in hepatic ß-oxidation activity at 50,000 ppm in rats killed after the tenth exposure, but this effect was deemed not biologically adverse since the change was not accompanied by relevant clinical, pathologic, organ weight, or liver histopathologic changes

Acute Inhalation Toxicity Study of HFC-236fa in Albino Rats, report WIL-189022, WIL Research Laboratories, Incorporated, circa 1996 (RDB6A94)

R-236fa, health effects, toxicity; 4-hr ALC rat by whole-body exposure of 5 female and 5 male rats is >457,000 ppm; hyperactivity and then prostration was noted during the exposure (at 457,000 ppm) for all animals, but recovery occurred in 1 day; 2 females exhibited slight body weight loss, but appeared normal by the end of the 14-day observation period; 4 animals had dark red lungs at necropsy; 2 females had cysts on the kidneys and 1 female had an enlarged pituitary gland

R-245ca

R. D. Bagnall et al, *Journal of Fluorine Chemistry*, volume 13, number 3, pages 209-223, 1979 (RDB-5C76)

toxicity

P. W. Grube, untitled toxicity review for 1,1,2,2,3-pentafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 July 1991 (5 pages, RDB5859)

R-245ca, summary of published and unpublished toxicity literature

unpublished data, report 33-60, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, date 1960 (RDB5C77)

R-245ca, toxicity, health effects [referenced in RDB 5859]

R-C270

J. W. Stutzman, Q. Murphy, C. R. Allen, and W. J. Meek, *Anesthesiology*, volume 8, pages 579 ff, 1947 (RDB65B8)

R-C270, cardiac sensitization, toxicity

R-290

L. L. Anderson and R. C. Graham, untitled toxicity review for propane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 March 1990 (RDB6107)

R-290, summary of published and unpublished toxicity literature

W. E. Brown and V. E. Henderson, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 27, number 1, pages 1-8, 1926 (8 pages, RDB6108)

R-290, toxicity

F. A. Patty and W. P. Yant, **The Toxicity of Propane**, Report of Investigations 2979, U.S. Bureau of Mines, Washington, DC, 1929 (RDB6114)

R-290; human exposures

S. Tsukamoto et al, *Nippon Hoijaku Zasshi*, Japan, volume 39, number 2, pages 124-130, 1985 (7 pages, RDB6117)

R-290, metabolism, toxicity

Occupational Health Guideline for Propane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, September 1978 (4 pages with 1 table, RDB5608)

R-290, safety, toxicity, flammability, OHG, occupational exposure guidance

Propane, chemical infogram 87, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, October 1990 (1 page, RDB5609)

R-290, safety, toxicity, flammability, occupational exposure guidance

R-C318

J. W. Clayton, Jr., M. A. Delaplane, and D. B. Hood (E. I. duPont de Nemours and Company, Incorporated), **Toxicity Studies with Octafluorocyclobutane**, *American Conference of Governmental Industrial Hygienists Quarterly*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, volume 21, pages 382-388, 1960 (7 pages, RDB5A25)

R-C318, health effects, toxicity

R-401A, R-401B, R-401C

Safety of Suva MP Refrigerants, document AS-3 (H-35814-1), DuPont Chemicals, Wilmington, DE, May 1994 (4 pages with 1 table, RDB4C49)

This bulletin reviews considerations for safe use of R-401A, R-401B, and R-401C - ternary blends of R-22, R-152a, and R-124 - by providing answers to common questions. It outlines the uses of these as replacements for R-12 in medium-temperature stationary refrigeration, stationary refrigeration with evaporator temperatures below -23 °C (-10 °F) and some transport refrigeration, and retrofit of mobile air-conditioning systems, respectively. It briefly reviews the collaborative Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and partial findings for R-124. The document discusses the flammability of R-22/152a/124 blends, noting that they are neither flammable nor will become so with leakage, but can become flammable when mixed with gases that are. The document notes that mixtures of R-134a with more than 60% air (by volume) can become flammable at raised pressures and temperatures. It counsels that R-22/152a/124 blends may behave similarly and counsels against use of refrigerant-air mixtures for leak testing. The document then addresses inhalation toxicity. It explains the DuPont Acceptable Exposure Limit (AEL), a time-weighted average (TWA) concentration for an 8 or 12 hour day or 40 hour week, to which nearly all workers may be repeatedly exposed without adverse effects. The compositions, average boiling points, and AELs are tabulated for R-401A, R-401B, and R-401C. The document discusses symptoms of exposure to high refrigerant concentrations, cardiac sensitization, and special charging procedures these near-azeotropic blends. It also discusses suffocation, safety measures for enclosed areas, guidance when a large spill or leak occurs, dangers of deliberate inhalation, and detection by odor. The bulletin provides general advice on skin and eye contact with refrigerants, frostbite, pressure hazards, handling and disposal of cylinders, brazing or welding of pipes in air-conditioning and refrigeration systems, and decomposition. It concludes with specific cautions. The document recommends familiarization with the Material Safety Data Sheet (MSDS) available for these refrigerants. DuPont's product names R-401A, R-401B, and R-401C are Suva(R) MP39, Suva(R) MP66, and Suva(R) MP52, respectively.

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R-502

M. A. Lee, untitled toxicity review for isobutane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 May 1992 (RDB5866)

R-502, summary of published and unpublished toxicity literature

unpublished data, report 91-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1962 (RDB6272)

R-502, toxicity: ALC rat 2 hr > 200,000 ppm as reported in RDB 5866

unpublished data, report 156-63, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. *duPont* de Nemours and Company, Incorporated, Newark, DE, 1963 (RDB6273)

R-502, toxicity [referenced in RDB 5866]

other blends

C. Aranyi et al, *Toxicology Ind. Health*, volume 2, number 1, pages 85-98, 1986 (14 pages, RDB6194)

R-600a/601a, subchronic inhalation toxicity in rats, health effects

S. Wason et al, *Journal of the American Medical Association* (JAMA), American Medical Association (AMA), volume 256, number 1, pages 78-80, 1986 (3 pages, RDB6198)

R-290, R-600, and R-600a; case history of human exposure incident, health effects, toxicity

R-600

A. C. Evans and D. Ralstrick, *British Journal of Psychiatry*, United Kingdom, volume 150, pages 769-773, June 1987 (5 pages, RDB6A84)

R-600, health effects, toxicity; study of the effects of misuse by direct inhalation; compared effects for 12 youths to 31 inhaling toluene and resultant marked changes of mental state; most users reported elevation of mood and hallucinations; nearly one-fourth believed they were able to fly or swim [as reported in RDB 6A83]

R. Fytizas-Danielidou, *Ann. Inst. Phytopathol. Benaki*, volume 10, number 4, pages 327-332, 1973 (6 pages, RDB6A85)

R-600, health effects, toxicity; liquified butane causes burns or frostbite to the eyes upon direct contact [as reported in RDB 6A83]

T. J. Hughes (possibly Huges) et al, report EPA 600/S1-84-005, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, 1984 (RDB6A86)

R-600, health effects, mutagenicity, toxicity: not mutagenic in Salmonella typhimurium or Escherichia coli in the absence and presence of rat microsomal activation [as reported in RDB 6A83]

M. A. Lee and R. C. Graham, untitled toxicity review for butane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 29 January 1990 (RDB6A83)

R-600, summary of published and unpublished toxicity literature

B. Mathew et al, **Commercial Butane Abuse: A Disturbing Case**, *British Journal of Addiction*, volume 84, number 5, pages 563-564, 1989 (2 pages, RDB6A91)

R-600, health effects, toxicity: "sniffing"

H. J. Oettel, *Arch. Exp. Pathol. Pharmakol.*, volume 83, pages 641-696, 1936 (RDB6A87)

R-600, health effects, toxicity: contact with the skin may result in frostbite

H. Shimizu et al, *Sangyo Igaku*, volume 27, number 6, pages 400-419, 1985 (20 pages, RDB6A88)

R-600, health effects, toxicity; not mutagenic in Salmonella typhimurium or in Escherichia coli in the absence or presence of rat microsomal activation [as reported RDB 6A83]

M. Vr'cevi'c and R. Stani'c, **Butane Gas Poisoning - Current Problems in Emergency Internal Medicine**, *Med. Pregl.*, volume 26, number 5, pages 173-179, 1973 (7 pages, RDB6A92)

R-600, health effects, toxicity

Occupational Safety and Health Guideline for n-Butane; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; 1992 (available from GPO, also available from JMC as RDB-5C48)

R-600, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, leaks, special requirements, respiratory protection, personal protective equipment, references

R-600a

M. A. Lee and R. C. Graham, untitled toxicity review for isobutane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 February 1990 (RDB5865)

R-600a, summary of published and unpublished toxicity literature

T. Litovitz, *Occupational Medicine - State of the Art Review*, volume 3, number 3, pages 567-568, 1988 (2 pages, RDB6193)

R-600, R-600a, cardiac sensitization, health effects, toxicity

H. J. Oettel, *Archiv für Experimentelle Pathologie und Pharmakologie*, volume 183, pages 641 ff, 1936 (2 pages, RDB6195)

R-600a, contact effects, frostbite, health effects, toxicity

R. D. Stewart, A. A. Herrmann, E. D. Baretta, et al (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Isobutane**, *Scandinavian Journal of Work Environment and Health*, volume 3, pages 234-243, 1977 (10 pages, RDB5364)

R-600a, toxicity

Industrial Hygiene and Toxicology Bulletin, Phillips Petroleum Company, November 1976 (RDB6196)

R-600a, health effects, toxicity

R-630

Emergency Response Planning Guidelines - Monomethylamine, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1990 (RDB4B77)

R-630, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-717

I. M. Alpatov, **A Study of Gaseous Ammonia Toxicity**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 2, pages 14-18, 1964 (5 pages in Russian, RDB6232)

R-717, toxicity

I. M. Alpatov and V. I. Mikhailov, **Inquiries into Gaseous Ammonia Toxicity**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 12, pages 51-53, 1963 (3 pages in Russian, RDB6233)

R-717, toxicity

J. Andanson, J. Berenger, R. Castela, J. Catoir, P. Delmon, M. Graille, B. Guidoni, J. P. d'Ortoli, H. Raulot-Lapointe, and J. J. Vigneau, **L'Intoxication Chronique par l'Ammoniaque: Est-Elle Observable en Service Médical Interentreprises?** [Chronic Ammonia Poisoning: Is it Detectable in Joint Plant Medical Services?], *Reveu de Médecine du Travail*, volume 4, number 4, pages 293-300, 1976 (in French, RDB6A36)

R-717, health effects, toxicity: workers exposed to low levels of ammonia for prolonged periods have reported symptoms of headache, drowsiness, asthma, laryngitis, and skin irritation [as reported in RDB 6270]

L. M. Appelman (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), W. F. ten Berge (DSM, The Netherlands), and P. G. J. Reuzel (TNO-CIVO), **Acute Inhalation Toxicology Study of Ammonia in Rats with Variable Exposure Periods**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 43, number 9, pages 662-665, September 1982 (4 pages with 4 tables, RDB5152)

R-717, toxicity: LC_{50} male rat, 1 hr = 14,071 ppm; LC_{50} female rat, 1 hr = 19,671 ppm [referenced in RDB 1106 and 5151]

R. Arwood, J. Hammond, and G. G. Ward, **Ammonia Inhalation**, *Journal of Trauma*, volume 25, pages 444-447, 1985 (4 pages, RDB6257)

R-717, health effects, toxicity

C. S. Barrow and W. H. Steinhagen (University of Pittsburgh), **NH_3 Concentrations in the Expired Air of the Rat: Importance to Inhalation Toxicology**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 53, pages 116-121, 1980 (6 pages, RDB-6A45)

R-717, health effects, toxicity

C. S. Barrow, Y. Alarie, and M. F. Stock (University of Pittsburgh), **Sensory Irritation and Incapacitation Evoked by Thermal Decomposition Products of Polymers and Comparisons with Known Sensory Irritants**, *Archives of Environmental Health*, American Medical Association (AMA), volume 33, pages 79-88, March-April 1978 (10 pages with 6 figures and 1 table, RDB6231)

R-717 (ammonia), health effects, toxicity, source-study for widely cited RD_{50} mouse of 303 ppm; the maximal response was achieved

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within the first two minutes of exposure for tested concentrations of R-717

S. P. Bessman and N. Pal, **Ammonia Intoxication: Energy Metabolism and Brain Protein Synthesis**, *Israeli Journal of Medical Science*, volume 18, number 1, pages 171-175, 1982 (5 pages, RDB-5762)

R-717, health effects, toxicity

G. A. Birken, P. J. Fabri, and L. C. Carey, **Acute Ammonia Intoxication Complicating Multiple Trauma**, *Journal of Trauma*, volume 21, number 9, pages 820-822, 1981 (3 pages, RDB6258)

R-717, health effects, toxicity

G. Bittersohl and H. Heberer, **Toxicity of Aliphatic Amines**, *Zeitschrift für die gesamte Hygiene und Ihre Grenzgebiete*, volume 24, number 7, pages 529-534, 1978 (6 pages, RDB6A39)

R-717 and others, health effects, toxicity

G. Bittersohl, presentation at the XVIth International Congress of Occupational Health (Tokyo, Japan, 1969), Japanese Industrial Health Association, pages 250-251, 1971 (RDB6A57)

R-717, carcinogenic potential, health effects, toxicity: evaluation of neoplasms (new benign or malignant growths resembling the tissues from which they arise, but serving no physiologic functions) in East German manufacturing facilities; workers in ammonia plants exhibited a 500-600% higher rate of tumors than others; 80% of the workers were exposed for more than 10 years to exposures of 60-100 ppm [as reported in RDB 1106]

G. Bittersohl, **Epidemiologic Study on Cancer of Workers in a Chemical Plant**, *Archiv für Gesh.*, volume 38, pages 198-201, 1971 (4 pages in German, RDB6A58)

R-717, carcinogenic potential, health effects, toxicity: expands on study in RDB6A57, noting that known carcinogens were present; reports a 200% increase in cancers for workers exposed to ammonia and asbestos compared to asbestos alone [as reported in RDB1106]; RDB-1106 discusses limitations to the study and concludes that the influencing effect of ammonia on the formation of tumors by other agents, such as asbestos, cannot be determined

E. M. Boyd, M. L. McLachlan, and W. F. Perry, **Experimental Ammonia Gas Poisoning in Rabbits and Cats**, *Journal of Industrial Hygiene and Toxicology*, volume 26, pages 29-34, 1944 (6 pages, RDB6245)

R-717, toxicity: LC_{50} [summarized in RDB 5151]

L. A. Buckley, X. Z. Jiang, R. A. James, K. T. Morgan, and C. S. Barrow (Chemical Industry Institute of Toxicology, CIIT), **Respiratory Tract Lesions Induced by Sensory Irritants at the RD_{50} Concentration**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 74, number 3, pages 417-429, 1984 (13 pages with 8 figures and 2 tables, RDB6227)

toxicity; health effects; study to determine if pathologic changes occur in the respiratory tracts of mice after inhalation exposure at their RD_{50} concentration for 10 sensory irritants including R-717 (ammonia, RD_{50} mouse = 303 ppm) and R-764 (sulfur dioxide, RD_{50} mouse = 117 ppm); found no or slight changes of doubtful significance in the squamous epithelium for all 10; found slight to minimal changes but moderate inflammation to the respiratory epithelium and no change to the olfactory epithelium or lungs for R-717; found moderate to severe changes and moderate inflammation to the respiratory epithelium and minimal to severe changes to the olfactory epithelium for R-764; comments that ionization of R-717 in water is comparatively limited resulting in less damage than for hydrogen chloride, for which the RD_{50} and water solubility are similar; concludes that "the value of the mouse sensory irritant model for setting occupational guidelines to sensory irritants is strengthened in that these studies demonstrate the RD_{50} concentration is associated with respiratory tract damage and is not an acceptable concentration for occupational exposures"; safe levels are predicted at 0.01-0.1 times the RD_{50} concentration

T. R. Burns, M. L. Mace, S. D. Greenberg, et al, **Ultrastructure of Acute Ammonia Toxicity in the Human Lung**, *American Journal of Forensic Medical Pathologists*, volume 6, pages 204-210, 1985 (RDB6A41)

R-717, health effects, toxicity

T. R. Burns, S. D. Greenberg, M. L. Mace, and J. A. Jachimczyk, **Pulmonary Ultrastructure in Acute Ammonia Toxicity in Humans**, *Environmental and Occupational Health*, volume 127, pages 180 ff, 1983 (RDB6259)

R-717, health effects, toxicity

M. Caplin, **Ammonia Gas Poisoning - Forty-Seven Cases in a London Shelter**, *Lancet*, volume 2, pages 95-96, 1941 (6 pages, RDB6A06)

R-717, accident involving human exposure, health effects, toxicity: 13 of 47 people exposed to ammonia in an air raid shelter died within 48 hr of initial exposure; paper documents affects including symptoms similar to pulmonary edema and bronchopneumonia

B. L. Carson, C. M. Beall, H. V. Ellis III, and L. H. Baker, **Ammonia Health Effects**, report EPA 460/3-81/027, Office of Mobile Source Air Pollution Control, U.S. Environmental Protection Agency (EPA), Ann Arbor, MI, 1981 (available from NTIS as document PB82-116047, RDB6260)

R-717, health effects, toxicity

E. Chico et al, **Ammonia Overloading in Hepatocytes Isolated from Liver of Fetal and Adult Rats**, *Biochim. Biophys. Acta.*, volume 586, number 3, pages 481-491, 1979 (RDB6A40)

R-717, health effects, toxicity

Clement Associates, Incorporated, **Health Effects Assessment for Ammonia**, The Fertilizer Institute, Washington, DC, February 1990 (148 pages, RDB-1106)

This document reviews data relevant to assessing the health effects of inhalation exposure to ammonia. The focus is on chronic exposures; information on subchronic and acute exposures also is reviewed to acquire a complete picture of the toxicity of ammonia. Physical and chemical properties, sources, environmental fate, environmental effects, and other related topics are discussed to provide context and perspective.

L. G. Close, F. I. Catlin, and A. M. Cohn, **Acute and Chronic Effects of Ammonia Burns of the Respiratory Tract**, *Archives of Otolaryngology*, volume 106, number 3, pages 151-158, 1980 (8 pages, RDB5763)

R-717, health effects, toxicity

T. J. Cole, J. E. Cotes, G. R. Johnson, et al, **Ventilation, Cardiac Frequency and Pattern of Breathing During Exercise in Men Exposed to o-Chlorobenzylidene Malonitrile and (CS) and Ammonia Gas in Low Concentrations**, *Quarterly Journal of Experimental Physiol. Cogn. Medical Science*, volume 62, pages 341-351, 1977 (11 pages, RDB6A07)

R-717, health effects, toxicity

R. A. Coon, R. A. Jones, L. J. Jenkins, Jr., and J. Siegel, **Animal Inhalation Studies on Ammonia, Ethylene Glycol, Formaldehyde, Dimethylamine, and Ethanol**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 16, pages 646-655, 1970 (10 pages, RDB6234)

R-717 (ammonia) and five other gases, health effects, toxicity [summarized in RDB 5151]

L. V. Cralley, **The Effect of Irritant Gases Upon the Rate of Ciliary Activity**, *Journal of Industrial Hygiene and Toxicology*, volume 24, pages 193-198, 1942 (6 pages, RDB6235)

R-717, toxicity

T. Dalhamn, **Effect of Ammonia Alone and Combined with Carbon Particles on Ciliary Activity in the Rabbit Trachea in Vivo with Studies of the Absorption Capacity of the Nasal Cavity**, *International Journal of Air and Water Pollution*, volume 7, pages 531-539, 1963 (RDB6A42)

R-717, health effects, toxicity

M. L. Dalton, Jr., and D. L. Bricker, **Anhydrous Ammonia Burn of the Respiratory Tract**, *Tex. Med.*, volume 74, number 9, pages 51-54, 1978 (4 pages, RDB5764)

R-717, toxicity, corrosivity

K. T. Dodd and D. R. Gross, **Ammonia Inhalation Toxicity in Cats: A Study of Acute and Chronic Respiratory Dysfunction**, *Archives of Environmental Health*, American Medical Association (AMA), volume 35, pages 6-14, 1980 (RDB6236)

R-717, toxicity

J. A. Duke, **Phytotoxin Tables**, *Critical Reviews in Toxicology*, Chemical Rubber Company (CRC), Cleveland, OH, volume 5, pages 191 ff, 1977 (RDB-5153)

R-717, toxicity

J. L. Egle, Jr., **Retention of Inhaled Acetone and Ammonia in the Dog**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 34, pages 533-539, 1974 (7 pages, RDB-6A09)

R-717, health effects, toxicity

W. S. Ferguson, W. C. Koch, L. B. Webster, and J. R. Gould, **Human Physiological Response and Adaptation to Ammonia**, *Journal of Occupational Medicine* (JOM), Industrial Medical Association, Harper and Brothers Publishers, volume 19, pages 319-326, 1977 (RDB6237)

R-717, health effects, toxicity: people regularly exposed to ammonia may develop tolerance to its effects, as demonstrated in exposures of 6 male and female volunteers exposed to 25, 50, and 100 ppm for 6 weeks; acclimatized subjects experienced eye tearing and some discomfort at 150-200 ppm, but no lasting health effects were observed [as reported in RDB 6270]

A. J. Finkel, **Ammonia**, *Hamilton and Hardy's Industrial Toxicology of Commercial Products* (Fourth Edition), John Wright PSG Incorporated, pages 150-152, 1983 (3 pages, RDB6A35)

R-717, health effects, toxicity: anecdotal report of long-term exposure effect on humans; man working in a walk-in refrigerator developed a

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persistent cough and dyspnea (breathing difficulty); test showed lung damage even 3 yr later [as reported in RDB 6270 and 6A37]

K. E. Flury, D. E. Dines, J. R. Rodarte, and R. Rogers, **Airway Obstruction Due to Inhalation of Ammonia**, *Mayo Clinic Proceedings*, Mayo Clinic, Rochester, MN, volume 58, pages 389-393, 1983 (RDB6238)

R-717, health effects, toxicity

M. J. Gerald And M. D. Slot, **Ammonia Gas Burns (An Account of Six Cases)**, *Lancet*, pages 1356-1357, 1938 (2 pages, RDB6A48)

R-717, health effects, toxicity, accident involving human exposure

R. E. Gosselin, R. P. Smith, and H. C. Hodge, **Ammonia**, *Clinical Toxicology of Commercial Products* (Fifth Edition), Williams and Wilkins, Baltimore, MD, pages III-21 - III-26, 1984 (6 pages, RDB6A34)

R-717, health effects, toxicity

R. F. Griffiths and L. C. Megson, **The Effect of Uncertainties in Human Toxic Response on Hazard Range Estimation of Ammonia and Chlorine**, *Atmospheric Environment*, Pergamon Press Limited, UK, volume 18, number 6, pages 1195-1206, 1984 (12 pages, RDB6261)

R-717, health effects, toxicity

D. V. Hatton and C. S. Leach, **Collagen Breakdown and Ammonia Inhalation**, *Archives of Environmental Health*, American Medical Association (AMA), volume 34, pages 83-87, 1979 (RDB6A10)

R-717, health effects, toxicity

R. A. Hawkins, A. L. Miller, R. C. Nielson, and R. L. Veech, **The Acute Action of Ammonia on Rat Brain Metabolism In Vivo**, *Biochemical Journal*, volume 134, number 4, pages 1001-1008, 1973 (8 pages, RDB5765)

R-717, health effects, toxicity

C. Heymans and J. J. Es, **Blood Changes Due to Ammonia Inhalation**, *Science*, American Association for the Advancement of Science (AAAS), Washington, DC, volume 109, pages 121-122, 1949 (RDB6A50)

R-717, health effects, toxicity

C. J. Hilado, H. G. Cumming, A. M. Machado, C. J. Casey, and A. Furst, **Effect of Individual Gaseous Toxicants on Mice**, *Proceedings of the Western Pharmacology Society*, volume 21, pages 159-160, 1978 (2 pages, RDB6A11)

R-717, health effects, toxicity

C. J. Hilado, C. J. Casey, and A. Furst, **Effect of Ammonia on Swiss Albino Mice**, *Journal of Combustion Toxicology*, volume 41, pages 385-388, 1977 (4 pages, RDB6251)

R-717, health effects, toxicity: 30-min LC_{50} mouse = 21,000 ppm [summarized in RDB 5151]

H. B. Hoeffler, H. I. Schweppe, and S. D. Greenberg, **Bronchiectasis Following Pulmonary Ammonia Burn**, *Archives of Pathology and Laboratory Medicine*, volume 106, number 13, pages 686-687, 1982 (2 pages, RDB5766)

R-717, health effects, toxicity; accident in Houston involving a tanker truck, carrying 17.2 tonnes (38,000 lb) of anhydrous ammonia, resulted in dispersion 1500 m (5000') downwind and 550 m (1800') wide; resulted in 5 deaths and 178 injuries; the fatalities and most disabling injuries occurred within approximately 70 m (230') of the accident; bronchiectasis is a a late-stage from of chronic bronchitis in which permanent dilation of bronchi due to destruction of the elastic and muscular components of the airway walls

H. Hofer, E. Reindle, and E. Hruby, **Acute Inhalation Toxicity of Ammonia - Evaluation of an Apparatus**, publication unknown, Austria, 1981 (RDB-6246)

R-717, toxicity: LC_{50} mouse, 30 min = 9,085 ppm [summarized in RDB 5151]

D. L. Holness, J. T. Purdham, and J. R. Nethercott, **Acute and Chronic Respiratory Effects of Occupational Exposure to Ammonia**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 50, number 12, pages 646-650, December 1989 (4 pages with 7 tables, RDB3238)

R-717, toxicity, health effects

International Programme on Chemical Safety (IPCS), **Ammonia**, Environmental Health Criteria Report 54, World Health Organization (WHO), Geneva, Switzerland, 1986 (RDB6241)

R-717, health effects, toxicity

N. I. Jarudi and B. Golden, **Ammonia Eye Injuries**, *Journal of the Iowa Medical Society*, volume 63, number 6, pages 260-263, 1973 (4 pages, RDB-5767)

R-717, health effects

J. Johnston, L. Legters, and R. Dailey (Enviro Control, Incorporated), **Biological Effects of Short, High-Level Exposure to Gases: Ammonia**, draft final report under contract DMD 17-79-C-9086, U.S.

Army Medical Research and Development Command, Fort Detrick, MD, 1979 (RDB6262)

R-717, health effects, toxicity: This draft report is widely cited in the literature, though no reference has been found to the final version.

S. R. Jones, **Ammonia and the Nervous System**, *Journal of the American Medical Association* (JAMA), American Medical Association (AMA), pages 620 ff, 1945 (RDB6A51)

R-717, health effects, toxicity

L. E. Kane, C. S. Barrow, and Y. Alarie (University of Pittsburgh), **A Short-Term Test to Predict Acceptable Levels of Exposure to Airborne Sensory Irritants**, *AIHA Journal*, American Industrial Hygiene Association (AIHA), Fairfax, VA, volume 40, pages 207-229, March 1979 (23 pages with 2 figures and 16 tables, RDB6249)

presents a model to predict human sensory irritation responses based on sensory irritation data from animal tests; provides RD_{50} data and TLV comparisons for 11 chemicals including 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide); compares predicted responses to published effects; proposes use of the RD_{50} measure to set guidelines for exposure limits; concludes that the threshold limit value (TLV) should be set at 1-10% of the RD_{50}, the short-term exposure limit (STEL) at 20% of the RD_{50}, and the emergency exposure limit (EEL) at 30% of the RD_{50}

J. C. Kapeghian, A. B. Jones, and I. W. Waters (Mississippi University), **Effects of Ammonia on Selected Hepatic Microsomal Enzyme Activity in Mice**, *Bulletin of Environmental Contamination and Toxicology*, volume 35, pages 15-22, 1985 (8 pages, RDB6A14)

R-717, toxicity, health effects

J. C. Kapeghian, H. H. Mincer, A. B. Jones, A. J. Verlangieri, and I. W. Waters (Mississippi University), **Acute Inhalation Toxicity of Ammonia in Mice**, *Bulletin of Environmental Contamination and Toxicology*, volume 29, number 3, pages 371-378, 1982 (8 pages, RDB5768)

R-717, toxicity: 30-min LC_{50} mouse = 4,230 and 60-min LC_{50} mouse = 5,981 ppm, depending on calculation method [referenced in RDB (with summary) 5151 and 5155]

I. Kass, N. Zamel, C. A. Bobry, and M. Holzer, **Bronchiectasis Following Ammonia Burns of the Respiratory Tract**, *Chest*, volume 62, pages 282-285, 1972 (4 pages, RDB6A13)

R-717, toxicity, health effects: high concentrations of ammonia dissolve in moisture on the skin, leading to skin corrosion [as reported in RDB 6270]

A. Kimmerle, *JFF/Combustion Technology*, volume 1, pages 4-51, 1974 (48 pages, RDB6250)

R-717 (ammonia), health effects, toxicity: review of toxicity parameters and data, from other sources, on inhalation toxicity of ammonia in animals; characterizes concentrations of 480-570 ppm and 800-1070 ppm as "irritation" for 4 hour exposures and "strong irritation" for 7 hour exposures, respectively; the latter overlaps with dyspnea and traechitis from 820-1430 ppm; indicates an ALC 4 hr of 4,000 ppm and LC_{50} 2 hr of 10,930 ppm, both for rats [summarized in RDB 5151]

V. Kirhov, **Neuroautonomic Response of Workers in the Ammonia Industry**, *Suvrem Med*, Bulgaria, volume 28, number 10, pages 10-13, 1977 (in Bulgarian, RDB6A55)

R-717, health effects, toxicity: anecdotal study of extended occupational exposures; compares beginning and end-of-day symptoms for 45 male and 28 female workers, exposed to 13-51 ppm, for 5-10 years in an ammonia production plant; subjects reported increases in headaches, vertigo, staggering, and tremors to interviewers; findings were dismissed by others as "not meaningful due to major methodological flaws" [as reported in RDB 1106]

V. Kondrasuov, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 2, pages 34-38, 1978 (5 pages in Russian, RDB6252)

R-717, toxicity: LC_{50} rat comparison between inhalation and skin absorption [summarized in RDB 5151]

Kujawska, **Analysis of Lung Function in Workers Exposed to Irritating Dusts and Gases**, *Med. Pr.*, Poland, volume 28, number 5, pages 419-426, 1977 (in Polish, RDB6A56)

R-717, health effects, toxicity: anecdotal study of extended occupational exposures; 143 workers exposed to 7-41 ppm of ammonia, as well as other irritants, had lowered forced expiratory volume than workers form the same facility not exposed to ammonia; critiqued for methodological flaws and other confounding factors [as reported in RDB 1106]

D. Leduc, P. Gris, P. Lheureux, et al, **Acute and Long Term Respiratory Damage Following Inhalation of Ammonia**, *Thorax*, volume 47, pages 755-757, 1992 (3 pages, RDB6A15)

R-717, toxicity, health effects

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K. B. Lehmann (Universität Würzburg), **Experimental Studies on the Acquisition of Tolerance to Technically and Hygienically Important Gases and Vapors: Ammonia**, *Archiv für Hygiene*, volume 6, 1889 (126 pages in German, RDB6247)

R-717, toxicity: early toxicity testing with cats, dogs, guinea pigs, rabbits, and rats; distinctions among species [summarized in RDB 5151]

K. B. Lehmann (Universität Würzburg), **Experimental Studies on the Effect of Technically and Hygienically Important Gases and Vapors on the Organism (Part I, Ammonia)**, *Archiv für Hygiene*, volume 5, pages 1-126, 1886 (126 pages in German, RDB6248)

R-717, toxicity: early toxicity testing with cats, dogs, guinea pigs, rabbits, and rats; distinctions among species [summarized in RDB 5151]

D. M. Levy, M. B. Divertie, T. J. Litzow, and J. W. Henderson, **Ammonia Burns of the Face and Respiratory Tract**, *Journal of the American Medical Association* (JAMA), American Medical Association (AMA), volume 190, pages 95-98, 1964 (4 pages, RDB6243)

R-717, health effects, toxicity: accidental exposure to high concentrations may cause severe eye injury, including fluid accumulation in the eyelids, scarring of the cornea, and even loss of vision [as reported in RDB 6270]

H. Lonsdale, **Ammonia Tank Failure - South Africa**, *Ammonia Plant Safety*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 17, pages 126-131, 1975 (6 pages, RDB6A16)

R-717, health effects, toxicity, accident involving human exposure: failure of a pressurized ammonia tank in Potchefstroom, South Africa, released 38 tonnes (42 tons) of anhydrous ammonia resulting in 18 deaths and multiple injuries

J. D. MacEwen and E. H. Vernot (University of California, Irvine), **Annual Technical Report**, report NTIS AD 3555 358, Toxic Hazards Research Unit Technical, National Technical Information Service (NTIS), Springfield, VA, 1972 (RDB6230)

R-717, toxicity, LC_{50} rat, 1 hr = 7,338 ppm [referenced in RDB 1106 and (with summary) 5151]

A. Manninen, S. Antilla, and H. Savolainen, **Rat Metabolic Adaptation to Ammonia Inhalation**, *Proceedings of the Society of Experimental Biol. Medicine*, volume 187, pages 278-281, 1988 (4 pages, RDB6263)

R-717, health effects, toxicity

R. S. Marknam, **A Review of Damage from Ammonia Spills**, *Proceedings of the Ammonia Symposium* (Boston, MA, August 1986), American Institute of Chemical Engineers (AIChE), New York, NY, 1986 (RDB6A17)

R-717, health effects, toxicity, accident involving human exposure

J. L. Martin, **Review of Literature on the Toxicity of Ammonia**, The Fertilizer Institute, Washington, DC, 1979 (RDB6A54)

R-717, health effects, toxicity; anecdotal report of the potential effects of long-term, human occupational exposure to ammonia; physician reviewed the results of physical examinations of employees of a fertilizer manufacturer prior to employment and every two years thereafter for up to 15 years; concludes that there is no long-term toxicity due to ammonia exposure [as reported in RDB 1106]

M. H. Mayan and C. P. Merilan, **Effects of Ammonia Inhalation on Young Cattle**, *New Zealand Veterinary Journal*, volume 24, pages 221-224, 1976 (RDB6A18)

R-717, health effects, toxicity

M. H. Mayan and C. P. Merilan, **Effects of Ammonia Inhalation on Respiration Rate of Rabbits**, *Journal of Animal Science*, volume 34, pages 448-452, 1972 (RDB6A19)

R-717, health effects, toxicity

R. A. Michaels, **Acute Inhalation Risk Potentially Posed by Anhydrous Ammonia**, RAM TRAC Corporation, Schenectady, NY, 1996 (99 pages, RDB6A25)

R-717, health effects, toxicity

W. Moeller, **Zur chronischen Ammoniak-Exposition aus Opthalmologischer Sicht** [Chronic Ammonia Exposure from an Ophthalmologic Point of View], *Zeitschrift für die gesamte Hygiene und Ihre Grenzgebiete*, volume 20, number 9, pages 579-581, 1974 (3 pages, RDB5769)

R-717, health effects

T. J. Montague and A. R. Macneil, **Mass Ammonia Inhalation**, *Chest*, volume 77, number 4, pages 496-498, 1980 (3 pages, RDB5770)

R-717, toxicity, health effects

K. Mudan and K. Mitchell, **Report on the Potchefsroom, South Africa Ammonia Incident**, Four Elements, Incorporated, Columbus, OH, 1996 (14 pages, RDB6A20)

R-717, health effects, toxicity, accident involving human exposure

J. S. Mulder and H. O. Van der Zalm, **A Fatal Case of Ammonia Poisoning**, Tijdsch Soc Geneeskd, The Netherlands, volume 45, pages 458-460, 1967 (in Dutch, RDB6A21)

R-717, health effects, toxicity, accident involving human exposure: worker exposed to a very high, but unknown concentration of ammonia vapor immediately experienced coughing, dyspnea, and vomiting; developed conjunctivitis 3 hr after exposure, and died of cardiac arrest 6 hr after exposure; autopsy revealed marked respiratory irritation, denudation of the tracheal epithelium, and pulmonary edema

National Research Council (NRC) Committee on Medical and Biological Effects of Environmental Pollutants, **Ammonia**, University Park Press, Baltimore, MD, 1979 (RDB5771)

R-717, toxicity, health effects

National Research Council (NRC) Committee on Toxicology, **Guideline for Short Term Exposures of the Public to Air Pollutants, IV, Guide for Ammonia**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1987 (RDB5154)

R-717, toxicity, health effects

A. Niden, **Effect of Ammonia Inhalation on the Terminal Airways**, *Proceedings of the 11th Aspen Emphysema Conference*, volume II, pages 41-44, 1968 (4 pages, RDB6253)

R-717, health effects, toxicity: histological changes of the lung after acute exposure to ammonia, dose-dependent effects in mice [summarized in RDB 5151]

G. J. O'Kane, **Inhalation of Ammonia Vapour: A Report of Eight Patients During the Acute Stages**, Anesthesia, volume 38, pages 1208-1213, 1983 (6 pages, RDB6A22)

R-717, health effects, toxicity, accident involving human exposure

F. Pedersen and R. S. Selig, **Predicting the Consequences of Short-Term Exposure to High Concentrations of Gaseous Ammonia**, *Journal of Hazardous Materials*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 21, pages 143-159, 1989 (17 pages, RDB6A23)

R-717, health effects, toxicity

J. O. Pierce, **Ammonia**, *Patty's Industrial Hygiene and Toxicology* (Fourth Edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, New York, NY, volume IIA, pages 756-782, 1994 (27 pages, RDB6A24)

R-717, health effects, toxicity

A. S. Propkop'eva and G. C. Yushkov, **Toxicology of Ammonia in Animals Repeatedly Exposed for Short Lengths of Time**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 9, pages 54-55, 1975 (2 pages in Russian, RDB6228)

R-717, health effects, toxicity: subchronic exposures of rats [summarized in RDB 5151]

A. S. Propkop'eva, G. C. Yushkov, and I. O. Ubasheev, **Materials for a Toxicological Characteristic of the Long-Term Effect of Ammonia on the Organisms of Animals After Brief Exposure**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), volume 6, pages 56-57, 1973 (2 pages in Russian, RDB6229)

R-717, toxicity, LC_{50} rat = 26,704 ppm for 5 min, 17,371 ppm for 15 min, 10,050 ppm for 30 min, and 11,341 ppm for 60 min [as reported in RDB 1106, 5106, and (with summary) 5151]

P. K. Raj, J. H. Hagopian, A. S. Kalelkar, and J. Cece, **Predicting Health Hazards from Ammonia Spills**, *Ammonia Plant Safety*, volume 17, pages 102-108, 1975 (7 pages, RDB6A52)

R-717, health effects, toxicity

D. Richard, J. Jouany, and C. L. Bondène, **Acute Toxicity of Ammonia in Rabbits by Inhalation**, *Compte Rendu de l'Académie de Science* [Proceedings of the Academy of Science], Paris, France, series D, volume 287, number 4, pages 375-378, 1978 (4 pages, RDB5772)

R-717, health effects, toxicity: acute exposures of rabbits at 1000-2000 ppm [summarized in RDB 5151]

D. Richard, G. Bouley, and C. L. Bondène, **Effets de l'Inhalation Continué d'Ammoniac Chez le Rat et la Souris** [Effect of Continuous Inhalation of Ammonia in the Rat and Mouse], *Bulletin of the European Physiopathol. Respir.*, volume 14, number 5, pages 573-582, 1978 (10 pages in French, RDB6244)

R-717, health effects, toxicity: chronic exposures of rats at 250-300 ppm, without general toxic effect, and 500 ppm [summarized in RDB 5151]

K. J. Schadeberg, J. W. Goode, M. L. Keplinger, and J. C. Calandra (Industrial Bio-Test Laboratories, Incorporated), **Irritation Threshold Evaluation Study with Ammonia**, report IBT 663-03161, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 23 March 1973 (RDB6A12)

R-717, health effects, toxicity: effects generally are greater as exposure increases, with no eye

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irritation at 50 ppm or less for 5 minutes, irritation in some individuals at 72 ppm, tearing and eye irritation at 134 ppm [as reported in RDB 6270]

M. M. Saifutdinov, **Maximum Permissible Concentration of Ammonia in the Atmosphere**, *Hyg. Sanitariya*, volume 31, pages 171-176, 1966 (6 pages in Russian, RDB6A53)

R-717, health effects, exposure limit, toxicity

A. D. Schaerdel, W. J. White, C. M. Lang, et al, **Localized and Systemic Effects of Environmental Ammonia in Rats**, *Laboratory Animal Science*, volume 33, pages 40-45, 1983 (16 pages, RDB-6A26)

R-717, toxicity, health effects

M. B. Shimkin, A. A. de Lorimier, J. R. Mitchell, and T. P. Burroughs, **Appearance of Carcinoma Following Single Exposure to a Refrigeration Ammonia-Oil Mixture: Report of a Case and Discussion of the Role of Co-Carcinoginesis**, *Archives of Industrial Hygiene and Occupational Medicine*, volume 9, pages 186-193, 1954 (8 pages, RDB6264)

R-717, carcinogenic potential, health effects, toxicity: technician splattered with R-717 and lubricant on his nose and lip developed a small blister, which became a persistent, chronically inflamed lump; biopsy confirmed presence of epidermoid carcinoma 6 months later [as reported in RDB1106]; RDB1106 discusses confounding factors and concludes that it is impossible to draw conclusions concerning the role of R-717 in the observed response

S. D. Silver and F. P. McGrath, **A Comparison of Acute Toxicities of Ethylene Amine and Ammonia to Mice**, *Journal of Industrial Hygiene and Toxicology*, volume 30, pages 7-9, 1948 (3 pages, RDB6254)

R-717, health effects, toxicity: acute exposures of mice at high concentrations, LC_{50} mouse, 10 min = 10,152 ppm [summarized in RDB 5151]

L. Silverman, J. L. Whittenberger, and J. Muller, **Physiological Response of Man to Ammonia in Low Concentrations**, *Journal of Industrial Hygiene and Toxicology*, volume 31, pages 74-78, 1949 (5 pages, RDB6226)

R-717, toxicity: controlled human exposures at 500 ppm for 30 min resulted in hyperpnea (abnormally rapid or deep breathing), increased blood pressure, increase pulse rate, lacrimation (abnormal or excessive secretion of tears), and complaints of respiratory irritation with some effects persisting for 24 hours after exposures

H. F. Smyth, Jr., J. Seaton, and L. Fischer (Carnegie-Mellon Institute, then the Mellon Institute), **The Single Dose Toxicity of Some Glycols and Derivatives**, *Journal of Industrial Hygiene and Occupational Medicine*, volume 23, number 6, pages 259-268, June 1941 (10 pages with 3 tables, RDB-6267)

R-717 and others, health effects, toxicity: widely referenced LD_{50} oral, rat = 350 mg/kg based on tests using ammonium hydroxide (ammonia-water solution, NH_4OH) with calculated result for ammonia

R. Sobonya, **Fatal Anhydrous Ammonia Inhalation**, *Human Pathology*, volume 8, number 3, pages 293-299, 1977 (7 pages, RDB5773)

R-717, health effects, toxicity, accident involving human exposure: 4 fatalities following exposure to ammonia in a farming accident; 3 workers died immediately; the fourth, a 25-yr old man, died from secondary effects 60 days later

S. Stroud, **Ammonia Inhalation - A Case Report**, *Critical Care Nurse*, volume 1, number 2, pages 23-26, 1981 (4 pages, RDB5774)

R-717, toxicity, health effects

M. Stupfel et al, *Compte Rendu Société Biol.*, Paris, France, volume 165, pages 1869-1872, 1971 (4 pages, RDB6255)

R-717, health effects, toxicity: acute exposures of mice at 12,000 ppm for 20 min and at 11,000 ppm for 40 min; males mortality found to be higher [summarized in RDB 5151]

R. B. Swotinsky and K. H. Chase, **Health effects of Exposure to Ammonia: Scant Information**, *American Journal of Industrial Medicine*, volume 17, pages 515-521, 1990 (7 pages, RDB6A27)

R-717, toxicity, health effects

Syracuse Research Corporation, **Toxicological Profile for Ammonia**, report TP-90-03, Agency for Toxic Substances and Disease Registry (ATSDR), Public Health Service, U.S. Department of Health and Human Services, Washington, DC, December 1990 (available from NTIS as document PB91-180315, RDB5156)

R-717, health effects, toxicity

S. P. Targowski W. Klucinski, S. Babiker, et al, **Effect of Ammonia on in Vivo and in Vitro Immune Responses**, *Infect. Immunology*, volume 43, pages 289-293, 1984 (5 pages, RDB6A43)

R-717, health effects, toxicity

J. S. Tepper, B. Weiss, and R. W. Wood, **Alterations in Behavior Produced by Inhaled Ozone or**

Ammonia, *Fundamental and Applied Toxicology*, Society of Toxicology (SOT), volume 5, pages 1110-1118, 1985 (7 pages, RDB6A28)

R-717, health effects, toxicity

Y. C. Ting, **The Toxicity of Ammonia**, *Science*, American Association for the Advancement of Science (AAAS), Washington, DC, volume 112, pages 91 ff, 1950 (RDB6265)

R-717, health effects, toxicity

M. M. Verberk, **Effect of Ammonia on Volunteers**, *International Archives of Occupational and Environmental Health*, Springer-Verlag, Berlin, Germany, volume 39, pages 73-81, 1977 (9 pages, RDB6A29)

R-717, toxicity, health effects

E. H. Vernot, J. D. MacEwen, C. C. Haun, and E. R. Kinkead (University of California, Irvine), **Acute Toxicity and Skin Corrosion Data for Some Organic and Inorganic Compounds and Aqueous Solutions**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 42, pages 417-423, 1977; republished in report AMRL-TR-77-9, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1977 (7 pages with 1 table, RDB5157)

R-717 (ammonia), health effects, toxicity: LC_{50} rat, 1 hr = 7338 ppm; LC_{50} and/or LD_{50} data for 110 organic compounds and aqueous solutions thereof (except for ammonia, the others are not commonly used as refrigerants)

K. Verschueren, **Handbook of Environmental Data on Organic Chemicals** (Second Edition), Van Nostrand Reinhold Company, New York, NY, pages 194-196, 1983 (3 pages, RDB6211)

R-717, toxicity, cites RD_{50} mouse = 303 ppm

M. Walton, **Industrial Ammonia Gassing**, *British Journal of Industrial Medicine*, volume 30, pages 78-86, 1973 (9 pages, RDB6A30)

R-717, toxicity, health effects: 1 of 7 workers exposed to ammonia in an industrial accident died; autopsy showed marked laryngeal edema, acute congestion, pulmonary edema (evidence of damage to alveolar region), and denudation of the bronchial epithelium

R. C. Wands, **Alkaline Materials**, *Patty's Industrial Hygiene and Toxicology* (Third Revised Edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, New York, NY, volume 2B (Toxicology), chapter 42, pages 3045-3052, 1981 (8 pages, RDB6A38)

R-717 and others, health effects, toxicity

K. Ward, B. Murray, and G. P. Costello, **Acute and Long Term Pulmonary Sequelae of Acute Ammonia Inhalation**, *Irish Medical Journal*, volume 76, pages 279-281, 1983 (3 pages, RDB6A44)

R-717, health effects, toxicity

J. H. Weatherby, **Chronic Toxicity of Ammonia Fumes by Inhalation**, *Proceedings of the Society of Experimental Biol. Medicine*, volume 81, pages 300-301, 1952 (2 pages, RDB6239)

R-717, health effects, toxicity

F. R. Weedon, A. Hartzell, and C. Setterstrom, **Toxicity of Ammonia, Chlorine, Hydrogen Cyanide, Hydrogen Sulfide, and Sulfur Dioxide**, *V. Animals Contrib. Boyce Thompson Institute*, volume 11, pages 475-482, 1940 (8 pages, RDB6256)

R-717, health effects, toxicity: acute exposures of rats, mice, and flies at 1,000 ppm for 16 hr [summarized in RDB 5151]

J. Withers, W. F. ten Berge, J. Gordon, et al, **The Lethal Toxicity of Ammonia. A Report to the Major Hazards Advisory Panel**, Institution of Chemical Engineers, number 1, 1986 (RDB6A31)

R-717, health effects, toxicity

K. L. Wong, **Ammonia**, *Maximum Allowable Concentrations for Selected Airborne Contaminants in Spacecraft*, National Research Council (NRC), Committee on Toxicology, pages 39-59, 1995 (RDB6A32)

R-717, toxicity, health effects

R. W. Wood, **Determinants of Irritant Termination Behavior**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 61, pages 260-268, 1981 (RDB6266)

R-717 (ammonia), health effects, toxicity

R. W. Wood, **Behavioral Evaluation of Sensory Irritation Evoked by Ammonia**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 50, pages 157-162, 1979 (RDB6240)

R-717 (ammonia), health effects: tolerance and respiratory depression (5% and 500 ppm) [summarized in RDB 5151]

D. Zissu (Institut National de Recherche et de Sécurité, France), **Histopathological Changes in the Respiratory Tract of Mice Exposed to Ten Families of Airborne Chemicals**, *Journal of Applied Toxicology*, volume 15, number 3, pages 207-213, 1995 (7 pages with 3 figures and 3 tables, RDB6A33)

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study to identify and compare the histopathological changes induced in the respiratory tract of mice by repeated exposures at targets of 0.3, 1.0, and 3.0 times the RD_{50} concentrations of airborne chemicals, among them R-717 (ammonia); toxicity; health effects: only 11 of the 15 tested irritants induced lesions, among them R-717 which injured the respiratory epithelium; no pathological changes were observed from R-717 at 257 ppm (RD_{50} x 0.85), but lesions were found following exposures at 711 ppm (RD_{50} x 2.35); injuries from R-717 progressed from moderate for 4 days to severe for 9 days to very severe for 14 days based on exposures of 6 hr/day for 5 days/week; the authors suggest that a repair mechanism may moderate further injury for the majority of tested chemicals, for which the most severe injuries occurred within the first 4 days, but the intensity of lesions induced by R-717 became more severe with further exposures

Ammonia, chemical infogram 73, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, October 1990 (1 page, RDB6269)

R-717, safety, toxicity, flammability, occupational exposure guidance

Ammonia, *Industrial Exposure and Control Technologies for OSHA Regulated Hazardous Substances*, Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC, pages 104-111, March 1989 (available from GPO, RDB6A37)

R-717, health effects, toxicity, exposure and use statistics, controls and protective equipment

Ammonia (CAS 7664-41-7), chemical hazard summary 37, report C88-1E, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, 1988 (18 pages with 1 table, RDB6270)

R-717, safety, toxicity, flammability, occupational exposure guidance

Ammonia: Environmental and Technical Information for Problem Spills, Environment Canada, Ottawa, Ontario, Canada, 1984 (RDB6271)

R-717, safety, toxicity, flammability, environmental impact

Ammonia Health Effects Information, CAS# 7664-41-7, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (2 pages, RDB5B60)

R-717, summary of toxicological and ecological information

Ammonia Toxicity Monograph, The Institution of Chemical Engineers, Warwickshire, UK, 1988 (RDB-5151)

R-717, health effects: review and statistical analysis of LC_{50} studies, regression for LC_{50} for the rat by time (30 min = 11,502 ppm, 1 hr = 8,133 ppm, 4 hr = 4,067 ppm)

Criteria for a Recommended Standard - Occupational Exposure to Ammonia, publication 74-136, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1974 (RDB5369)

R-717, toxicity

Critical Reviews in Toxicology, Chemical Rubber Company (CRC), Cleveland, OHvolume 5, pages 189 ff, 1977 (RDB6591)

R-717, toxicity

Emergency First Aid Treatment Guide for Ammonia (7664-41-7), U.S. Environmental Protection Agency (EPA), Washington, DC, undated circa 1990 (RDB6268)

R-717, health effects, toxicity

Emergency Response Planning Guidelines - Ammonia, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1988 (4 pages, RDB4B76)

R-717, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

Hygienic Guide Series - Anhydrous Ammonia, American Industrial Hygiene Association (AIHA), Fairfax, VA, June 1978 (RDB5775)

R-717, toxicity, health effects

Occupational Safety and Health Guideline for Ammonia; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; 1992 (available from GPO, also available from JMC as RDB5C46)

R-717, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, special requirements, personal protective equipment, references

Summary Review of Health Effects Associated with Ammonia: Health Issue Assessment, report EPA 600/8-89/052F, Office of Health and Environ

mental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, June 1989 (RDB-5155)

R-717, health effects, toxicity

R-744

M. R. Banerjee, *International Journal of Biometeorology*, volume 16, number 3, pages 259-267, 1972 (RDB6454)

R-744, toxicity, effects on rats of acute exposure to increased carbon dioxide in the air

P. Brighten, **A Case of Industrial Carbon Dioxide Poisoning**, *Anaesthesia*, volume 31, number 3, pages 406-407, 1976 (2 pages, RDB5788)

R-744, toxicity

E. S. Cooper et al, **The Relation Between Cardiac Function and Cerebral Blood Flow in Stroke Patients 1: Effect of CO_2 Inhalation**, *Stroke*, volume 1, number 5, pages 330-347, 1970 (18 pages, RDB-5789)

R-744 (carbon dioxide), toxicity

D. J. Cullen and E. L. Eger, **Cardiovascular Effects of Carbon Dioxide in Man**, *Anesthesiology*, volume 41, pages 345-349, 1974 (RDB5790)

R-744, health effects, toxicity

P. M. Gramenitskii et al, **Long Term Exposure of Rats to High Concentration of Carbon Dioxide**, *Biull. Eksp. Biol. Med.*, volume 86, number 9, pages 285-287, 1978 (3 pages, RDB5791)

R-744, health effects, toxicity

A. Hendrik and F. Muller, **Hyperglycemic Effect of Acute Carbon Dioxide Intoxication**, *Zeitschrift für die gesamte Innre Medizin*, Germany, volume 28, number 7, pages 209-211, 1973 (3 pages, RDB-5792)

R-744, health effects, toxicity

F. Herles et al, **Influence of Acute Respiratory Acidosis, Induced by Carbon Dioxide Inhalation, on Pulmonary Circulation**, Vnitr. Lek., volume 13, number 7, pages 692-699, 1967 (8 pages, RDB-5793)

R-744, health effects, toxicity

I. Juzwiak and K. Brodziak-Krzesiek, **Clinical Studies on Persons Subjected to the Effect of Carbon Dioxide in Comparison to the Environmental Studies in Cellulose and Plastic Industry**, *Postepy Hig. Med. Dosw.*, volume 22, number 2, pages 353-356 (4 pages, RDB5794)

R-744, health effects, toxicity

S. Kwiatowski et al, **Permanent Sequelae of Acute Carbon Dioxide Poisoning**, *Pol. Tyg Lek.*, volume 36, number 31, pages 1165-1168 (4 pages, RDB-5795)

R-744, health effects, toxicity

A. A. LaVerne et al, **Occupational, Accidental, Explorational Carbon Dioxide Inhalation Poisonings and Prevention**, *Behavioral Neuropsychiatry*, volume 4, number 12, pages 33-48 (16 pages, RDB-5796)

R-744, health effects, toxicity

H. Mitsuda et al, **Effects of Carbon Dioxide on Serum Biochemical Patterns and on Histopathological Changes of Organ in Rats**, *Journal of Nutritional Science and Vitaminology*, volume 28, number 2, pages 105-115 (11 pages, RDB5797)

R-744, health effects, toxicity based on studies of male rats anesthetized with a 40/60 mixture of carbon dioxide and oxygen for 3 hours

R. R. Montgomery, untitled toxicity review for carbon dioxide, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 9 August 1983 (RDB6453)

R-744, summary of published and unpublished toxicity literature

D. Sevel and A. Freedman, **Cerebro-Retinal Degeneration Due to Carbon Dioxide Poisoning**, *British Journal of Opthalmology*, London, UK, volume 51, number 7, pages 475-482, 1967 (8 pages, RDB5798)

R-744, health effects, toxicity

J. M. Stinson and J. L. Mattsson, **Cardiac Depression in the Detection of the High Environmental CO_2: A Comparative Study in Rhesus Monkeys and Chimpanzees**, *Aerospace Medicine*, volume 42, number 1, pages 78-80, 1971 (3 pages, RDB-5815)

R-744, health effects, toxicity

J. M. Stinson and J. L. Mattsson, **Tolerance of Rhesus Monkeys to Graded Increase in Environmental CO_2: Serial Changes in Heart Rate and Cardiac Rhythm**, *Aerospace Medicine*, volume 41, number 4, pages 415-418, 1970 (4 pages, RDB5816)

R-744, health effects, toxicity

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N. L. Vandemark et al, **Alterations in Testes of Rats Exposed to Elevated Atmospheric Carbon Dioxide**, *Journal of Reproduction and Fertility*, volume 28, number 3, pages 457-459, 1972 (3 pages, RDB5826)

R-744, toxicity

H. I. Williams, **Carbon Dioxide Poisoning - Report of Eight Cases, with Two Deaths**, *British Medical Journal*, volume 2, pages 1012-1014, 1958 (3 pages, RDB6281)

R-744, toxicity

J. Winter, *Arbeitsschutz* [Occupational Safety], pages 104-105, 1937 (RDB6282)

R-744, toxicity, fatalities

Tabulae Biologicae, volume 3, pages 231 ff, 1933 (RDB6283)

R-744, toxicity: 5-min LCLo human = 90,000 ppm as reported in RTECS

Criteria for a Recommended Standard - Occupational Exposure to Carbon Dioxide, publication 76-194, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1976 (available from GPO as publication 017-033-00199-5, RDB5787)

R-744, toxicity

Hygienic Guide Series - Carbon Dioxide, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1964 (RDB5783)

R-744, toxicity

Occupational Health Guideline for Carbon Dioxide; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; September 1978 (available from GPO as part of publication PB83-154609, also available from JMC as RDB-6280)

R-744, toxicity; identification, exposure limits, health hazard information, chemical and physical properties, monitoring and measuring procedures, respirators and respiratory protection, personal protective equipment, common operations and controls, emergency first aid procedures, leak procedures, references

R-744a

B. D. Greenberg, R. Moore, R. Letz, and E. L. Baker, **Computerized Assessment of Human Neurotoxicity: Sensitivity to Nitrous Oxide Exposure**, *Clinical Pharmacology and Therapeutics*, American Society for Pharmacology and Experimental Therapeutics, Mosby - Year Book, Incorporated, Saint Louis, MO, volume 38, pages 656-660, 1985 (6 pages, RDB5738)

R-744a

R-764

Emergency Response Planning Guidelines - Sulfur Dioxide, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1990 (RDB4B78)

R-764, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-7146

D. Lester and L. A. Greenberg, **The Toxicity of Sulfur Hexafluoride**, *Archives of Industrial Hygiene and Occupational Medicine*, volume 2, pages 348-349, 1950 (2 pages, RDB5A39)

R-7146, toxicity

R-1110

E. Guberan and J. Fernandez, **Control of Exposure to Tetrachloroethylene by Measuring Alveolar Concentrations: Theoretical Approach Using a Mathematical Model**, *British Journal of Industrial Medicine*, volume 31, pages 159-167, 1974 (9 pages, RDB6495)

R-1110, health effects, toxicity

V. K. Rowe, D D. McCollister, H. C. Spencer, E. M. Adams, and D. D. Irish, **Vapor Toxicity of Tetrachloroethylene for Laboratory Animals and Human Subjects**, *Archives of Industrial Hygiene and Occupational Medicine*, American Medical Association (AMA), volume 5, pages 566-579, 1952 (14 pages, RDB6507)

R-1110, health effects, toxicity, LC_{50}

R-1113

Emergency Response Planning Guidelines - Chlorotrifluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (RDB-4B81)

R-1113, 1-chloro-1,2,2-trifluoroethene, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

Workplace Environmental Exposure Level Guide - Chlorotrifluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1986 (RDB-4B85)

R-1113, 1-chloro-1,2,2-trifluoroethene, WEEL, toxicology data, toxicity, safety classification

R-1114

Emergency Response Planning Guidelines - Tetrafluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (RDB4B79)

R-1114, tetrafluoroethene, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-1120

E. M. Adams, H. C. Spencer, V. K. Rowe, D D. McCollister, and D. D. Irish, **Vapor Toxicity of Trichloroethylene Determined by Experiments on Laboratory Animals**, *Archives of Industrial Hygiene and Occupational Medicine*, American Medical Association (AMA), volume 4, pages 469-481, 1951 (13 pages, RDB6508)

R-1120, health effects, toxicity, LC_{50}

C. R. Elcombe, **Species Differences in Carcinogenicity and Peroxisome Proliferation Due to Trichloroethylene: A Biochemical Human Hazard Assessment. Receptors and Other Targets for Toxic Substances**, *Archives of Toxicology Supplement*, volume 8, pages 6-17, 1985 (12 pages, RDB65C4)

R-1120, health effects, toxicity

C. Maltoni, G. Lefermine, and G. Cotti, **Experimental Research on Trichloroethylene Carcinogenesis**, *Archives of Research on Industrial Carcinogenesis*, edited by C. Maltoni and M. A. Mohlman, Princeton Scientific Publishing Company, Princeton, NJ, volume 5, pages 1-393, 1986 (393 pages, RDB65C0)

R-1120, health effects, toxicity

J. H. Mennear, **Toxicology and Carcinogenensis Studies of Trichloroethylene in Four Strains of Rats**, report 273 for the U.S. National Toxicology Program (NTP), National Institute of Health (NIH), Bethesda, MD, 1988 (available from NIH as publication 88-2529, RDB65D5)

R-1120, carcinogenicity, health effects, toxicity

R. M. Waters, O. S. Orth, and N. A. Gillespie, **Trichloroethylene Anesthesia and Cardiac Rhythym**, *Anesthesiology*, volume 4, pages 1 ff, 1943 (RDB65A1)

R-1120, cardiac sensitization, health effects, toxicity

R-1140

Occupational Safety and Health Guideline for Vinyl Chloride - Potential Human Carcinogen, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1988 (available from GPO as document 1993-750-004/80503, also available from JMC as RDB4A73)

R-1140, toxicity; properties, exposure limits, health hazard information, recommended medical practices, monitoring and measurement procedures, personal protective equipment, sanitation, common operations and controls, emergency first aid procedures, spills and leaks, waste removal and disposal, respiratory protection, references

R-1270

A. P. Altshuller et al, *Preprints*, American Chemical Society (ACS), Washington, DC, volume 5, number 1, pages 183-184, 1965 (2 pages, RDB6A60)

R-1270, health effects, toxicity: irradiated (to induce decomposition) mixture of 1 ppm R-1270 and nitric oxide produced slight eye irritation, increased to moderate with 2-3 ppm R-1270 [as reported in RDB 6A59]

W. E. Brown, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 23, pages 485-496, 1924 (8 pages, RDB6A61)

R-1270, health effects, toxicity: anesthetic effect in cats at 370,000-500,000 ppm v/v sustainable with 200,000-310,000 ppm; some toxic effects above 400,000 ppm; 500,000 ppm produced anesthesia in humans in 2 minutes; recovery was complete [as reported in RDB 6A59 and 6A65]

M. Combaz, *Staub-Reinhalt. Luft.*, volume 36, number 1, pages 15-19, 1976 (5 pages, RDB6A62)

R-1270, health effects, toxicity, accident involving human exposure: poisoning in a petroleum refinery involving propylene and other work pollutants; recommends use of respiratory masks

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E. F. Darley, *Journal of Agriculture and Food Chemistry*, volume 8, number 6, pages 483-485, 1960 (3 pages, RDB6A63)

R-1270, eye irritation, health effects, toxicity: no appreciable effect with propylene-ozone reaction mixtures [as reported in RDB 6A59]

B. M. Davidson, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 26, pages 33-36, 1925 (4 pages, RDB6A64)

R-1270, anesthetic and central nervous system (CNS) effects, health effects, toxicity: 64,000 ppm v/v yields mild intoxication, parasthesia, and inability to concentrate in 2¼ minute in humans; the same symptoms are accentuated at 128,000 ppm in 1 minute; unconsciousness results at 240,000 ppm in 3 minutes [as reported in RDB 6A59]

J. T. Halsey, C. Reynolds, and W. A. Prout (Tulane University of Louisiana), **A Study of the Narcotic Action of Propylene**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 26, pages 479-490, 1926 (12 pages with 3 tables, RDB-6A65)

R-1270, anesthetic and central nervous system (CNS) effects, health effects, toxicity: anesthetic LOEL mouse = 400,000 ppm v/v; ALC mouse >600,000 and ≤650,000 ppm v/v; anesthetic LOEL dog = 400,000 ppm; ALC dog = 750,000-800,000 ppm; effects are similar in cats and dogs; anesthetic effect in humans at 350,000-400,000 ppm; effects may be intensified by manufacturing contaminants; anesthetic LOEC mouse for R-1150 is 850,000-900,000 ppm

J. T. Halsey (Tulane University of Louisiana), **Anesthetic Properties of Propylene**, *Anesthesia and Analgesia*, volume 4, pages 195-198, 1925 (4 pages, RDB6A78)

R-1270, anesthetic and central nervous system (CNS) effects, health effects, toxicity

J. T. Halsey, C. Reynolds, and H. B. Cook (Tulane University of Louisiana), **New Anesthetic Gases**, *New Orleans Medical and Surgical Journal*, volume 77, pages 29-30, 26 May 1924 (2 pages, RDB-6A79)

R-1270 and others, anesthetic and central nervous system (CNS) effects, health effects, toxicity

J. K. Haseman, **Results From 86 Two-Year Carcinogenicity Studies Conducted by the National Toxicology Program**, *Journal of Toxicology and Environmental Health*, Taylor and Francis Publishers, volume 14, numbers 5-6, pages 621-640, 1984 (20 pages, RDB6A80)

R-1270 and others, carcinogenicity, health effects, toxicity

T. J. Hughes, *Environ. Mutagen.*, volume 6, pages 411-412, 1984 (2 pages, RDB6A66)

R-1270, mutagenic potential, health effects, toxicity: not mutagenic in Salmonella typhimurium [as reported in RDB 6A59]

M. H. Kahn And L. K. Riggs, *Annals of Internal Medicine*, volume 5, pages 651-658, 1931 (2 pages, RDB6A67)

R-1270, health effects, toxicity: human exposures at 400,000-750,000 ppm v/v caused reddening of the eyelids, flushing of the face, lacrimation, coughing, and sometimes flexing of the legs in a few minutes [as reported in RDB 6A59]

M. A. Lee, R. C. Graham, R. R. Montgomery, G. T. Hall, and L. J. Ver Nooy, untitled toxicity review for propylene, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 January August 1993 (RDB6A59)

R-1270, summary of published and unpublished toxicity literature

D. B. McGregor et al, *Environmental and Molecular Mutagenicity*, volume 17, number 2, pages 122-129, 1991 (RDB6A69)

R-1270, health effects, mutagenicity, toxicity

K. H. Meyer and H. Hopff, *Zeitschrift für Physiol. Chem.*, Berlin and Leipzip, Germany, volume 126, pages 280-298, 1923 (RDB6A70)

R-1270, health effects, toxicity: R-1270, white mice narcotized by 500,000 ppm v/v [as reported in RDB 6A65]

K. Pernov, *Suvrem Med*, Bulgaria, volume 30, number 1, pages 27-31, 1979 (in Bulgarian, RDB6A71)

R-1270, health effects, toxicity: irritation as a component of smog

J. A. Quest et al, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 76, number 2, pages 288-295, 1984 (RDB6A72)

R-1270, carcinogicity, health effects, toxicity

C. Reynolds, *Anesthesia and Analgesia*, volume 6, pages 121-124, 1927 (4 pages, RDB6A73)

R-1270, health effects, inhalation toxicity: anesthetic LOEL white mouse = 400,000 ppm v/v; ALC = 650,000 ppm; cardiac effects in dogs above 250,000 ppm (not clear whether test

involved epinephrine injections) [as reported in RDB 6A59]

C. Reynolds, *Journal of Pharmacology and Experimental Therapeutics* (JPET), volume 27, pages 93-99, 1926 (7 pages, RDB6A74)

R-1270, health effects, toxicity: subchronic inhalation study in mice at 350,000 ppm v/v for 90 min/day for 1-10 days; pathological examination found very slight to moderate liver degeneration in 3 of 13 animals with no degenerative signs in the others [as reported in RDB 6A59]

L. K. Riggs and H. D. Goulden (E. R. Squibb and Sons), *Anesthesia and Analgesia*, volume 4, pages 299-307, 1925 (9 pages, RDB6A75)

R-1270, health effects, inhalation toxicity in humans

L. K. Riggs (E. R. Squibb and Sons), **Further Studies on the Physiologic Action of Propylene**, *Journal of the American Pharmaceutical Association*, volume 16, pages 380-388 or 635-639, 1925 (RDB6A81)

R-1270 and others, anesthetic and central nervous system (CNS) effects, health effects, toxicity: anesthetic effect in white rats at 40,000 ppm v/v and 2-hr LC_{65} rat = 650,000 ppm [as reported in RDB 6A59]

F. E. Shipway, **Acetylene, Ethylene, and Propylene**, *Lancet*, volume 1, pages 1126-1130, 1925 (5 pages, RDB6A82)

acetylene, R-1150, and R-1270, health effects, toxicity

L. I. Sof'ina, *Tr. Ufim. Nauch.-Issled. Inst. Gigiena i Professional'nye Zabolevaniya*, volume 5, pages 64-68, 1969 (5 pages, RDB6A76)

R-1270, health effects, chronic inhalation toxicity in rats

T. S. Sunargulov and E. T. Akhmetova, *Vopr. Reakt. Org. Norme Patol. Mater. Nauchn. Konf.*, pages 118-120, 1974 (3 pages, RDB6A77)

R-1270, health effects, inhalation toxicity in humans

Properties and Essential Information for Safe Handling and Use of Propylene Chemical Safety Data Sheet SD-59, Manufacturing Chemists Association, Washington, DC, 1974 (RDB6A68)

R-1270

R-E170

Workplace Environmental Exposure Level Guide - Dimethyl Ether, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1980 (RDB4B84)

R-E170, E-170, DME, WEEL, toxicology data, toxicity, safety classification

Lubricants

D. A. Kalman, K. J. Voorhees, D. Osborne, and I. N. Einhorn, **Production of Bicyclophosphate Neurotoxic Agent During Pyrolysis of Synthetic Lubricant Oil**, *Journal of Fire Sciences*, volume 3, pages 322 ff, 1985 (RDB6381)

lubricants, safety, toxicity

G. D. Nielsen (Danish National Institute of Occupational Health, Denmark) and Y. Alarie (University of Pittsburgh), **Sensory Irritation, Pulmonary Irritation, and Respiratory Stimulation by Airborne Benzene and Alkylbenzenes: Prediction of Safe Industrial Exposure Levels and Correlation with Their Thermodynamic Properties**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, United Kingdom, volume 65, pages 459-477, 1982 (19 pages with 10 figures and 4 tables, RDB6505)

lubricants, safety, toxicity, sensory irritation, RD_{50}

J. D. Smith et al, **Health Aspects of Lubricants**, report 5/87, CONCAWE, The Hague, The Netherlands, 1987 (RDB6383)

safety, toxicity

Flammability

F. J. Benz, C. V. Bishop, and M. D. Pedley, **Ignition and Thermal Hazards of Selected Aerospace Fluids**, report RD-WSTF-0001, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, White Sands Test Facility, New Mexico, 1988 (RDB4B61)

R-717 (ammonia), flammability

J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Working Fluid Safety**, report HPC-AN20-1, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, October 1994 (RDB6B04)

flammability

J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Effects of Accidents with Flammable Re-**

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frigerants and the European Attitude Towards Their Use, presentation 5.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (12 pages with 10 presentation charts, available from JMC as RDB-4795)

flammability

K. Bier et al, (Universität Karlsruhe, Germany), **Stoffpaares R134a/R152a als ozonunschädliche Alternative zum Kältemittel R12** [Working Pair R-134a/152a as an Ozone-Safe Alternative to Refrigerant R-12], *Verbundvorhaben Minderung von FCKW-Emissionen in der Kälte- und Klimatechnik* [Program for Reduction of CFC Emissions in Refrigeration and Air Conditioning], DKV-Statusbericht [Status Report], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 8, pages 13-21, 1991 (in German, RDB6548)

R-134a, R-152a, R-134a/152a

K. Bier, L. Oellrich, M. Türk, J. Zhai, M. Dressner, M. Christill, G. Geidel, and W. Leuckel (Universität Karlsruhe, Germany), **Untersuchungen des Stoffpaares R134a/R152a als ozonunschädliche Alternative zum Kältemittel R12** [Investigation of the Working Pair R-134a/152a as an Ozone-Safe Alternative to Refrigerant R-12], *Verbundvorhaben Minderung von FCKW-Emissionen in der Kälte- und Klimatechnik* [Program for Reduction of CFC Emissions in Refrigeration and Air Conditioning], DKV-Statusbericht [Status Report], Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 7, pages 39-51, 1991 (in German, RDB4529)

R-134a, R-152a, R-134a/152a, thermal stability, flammability, performance

K. Bier, M. Crone, M. Türk, W. Leuckel, M. Christill, and B. Leisenheimer (Universität Karlsruhe, Germany), **Untersuchungen zur thermischen Stabilität sowie zum Zünd- und Brennverhalten der Kältemittel R152a und R134a** [Investigation of the Thermal Stability, Ignition, and Combustion Behavior of Refrigerants R-152a and R-134a], *DKV-Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein [DKV, German Association of Refrigeration and Air-Conditioning Engineers], Germany, volume 17, number 2, pages 169-191, 1990 (22 pages, in German, RDB3C14)

This paper presents experimental studies on the stability and safety of R-134a, R-152a, and their mixtures. The studies examined the possibility of suppressing the relatively high flammability of R-152a by mixing it with R-134a, without substantial loss of the benefits of its low global warming potential.

H. J. Borchardt and R. C. Gilbaugh, **Hazard of FC22/142b Flammability**, report KSS-8274, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1979 (RDB4A02)

R-22/142b

J. Bond, **Sources of Ignition. Flammability Characteristics of Chemical Products**, Butterworth-Heinemann, Limited, UK, 1991 (RDB4B91)

LFL, UFL, combustibility

W. L. Bunkley and H. W. Husa, **Combustion Properties of Ammonia**, *Chemical Engineering Progress*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 58, number 2, pages 81-84, 1962 (4 pages, RDB4B63)

R-717 (ammonia), LFL, UFL

L. W. Burgett (The Trane Company), **Flammable Refrigerants: Equipment Manufacturer Concerns**, presentation 3.3, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (22 pages with 19 presentation charts, available from JMC as RDB-4792)

R. C. Cavestri and E. Falconi (Imagination Resources, Incorporated, IRI), **An Objective Method for Determining Refrigerant Flammability**, presentation 2.3, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (10 pages with 29 presentation charts, available from JMC as RDB4786)

These presentation charts outline a study of the use of imaging spectroscopy and reduced-pressure combustion methods to evaluate refrigerant flammability. These techniques are suggested to be more objective than the standard ASTM E681 method, which depends on visual identification of flame propagation. The introductory chart notes that observers perceive flame quality and colors differently. It also describes characteristics of true flame initiation, which begins with ultraviolet (UV) emission and is always associated with a visible continuum with known emission energy and wavelengths. Two charts show a schematic of the combustion chamber used for tests and the spectral spark response of dry nitrogen, as a reference for a nonflammable gas. A series of spectral plots show the responses R-143a in dry nitrogen, helium, and air for varied concentrations and for a series of repeated spark initiations. Some of the

plots illustrate the spectral response at reduced cell pressures, to show transient pressure and temperature rises. The sensitivity of the temperature and pressure rises to the degree of pressure reduction are plotted. Spectra of spark responses also are shown for R-134a in dry helium and ambient air and for R-125 in ambient air. A concluding chart indicates that imaging spectroscopy is an effective analytical tool for differentiating between chemical ionization and flames as well as for studying the flame propagation of marginally flammable materials. The conclusions note that bright emissions in nitrogen and helium are due to reactions among hydrofluorocarbon (HFC) fragments rather than oxidative combustion.

D. Clodic, **Diffusion of Flammables in Rooms Due to Leaks from Portable Air-Conditioners or Refrigerators Working with Propane or Isobutane**, unpublished presentation (International Conference on Ozone Protection Technologies, Washington, DC 21-23 October 1996), École des Mines de Paris, France, October 1996 (12 pages with 26 figures and 3 tables, available from JMC as RDB-6B03)

This paper presents tests of the spread of simulated leaks of R-290 and R-600a in an instrumented room. It examines localized concentrations for flammable gases that are denser than air, with specific attention to the leakage amount, flow rate, and air circulation. The study measured both the time and distance to ignition points as well as the possibility of secondary ignition of other materials. Tests were conducted with leaks from window air conditioners, inside and outside domestic freezers, and from a refrigerant container. The paper concludes that the lower flammability limit (LFL) of a dense gas can be locally exceeded with pooling effect near the floor, even when the quantity limits specified in safety standards (European EN-378 and ASHRAE Standard 15) are satisfied. It recommends that safety limits for flammable gases should consider absolute quantities and heats of combustion, rather than concentrations based on the full room volume.

H. F. Coward and G. W. Jones, **Limits of Flammability of Gases and Vapors**, bulletin 503, Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1952 (RDB4908)

LFL, UFL

W. J. De Coursey, N. Zubryckyj, and N. Yoshida, **Effects of Water Vapor Content on the Inflammable Limits of Ammonia-Oxygen-Nitrogen Mixtures**, *Canadian Journal of Chemical Engineering*, Canadian Society for Chemical Engineering, Ottawa, ON, Canada, volume 40, pages 203-209, 1962 (7 pages, RDB4B75)

R-717, LFL, UFL, flammability

T. W. Dekleva (ICI Klea), **Flammability Testing: Observations Related to HFC Systems**, presentation 2.5, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (12 pages with 31 presentation charts, available from JMC as RDB4788)

These charts outline a presentation on flammability testing of hydrofluorocarbon (HFC) refrigerants. The introductory chart notes that ASTM E681 tests at 100 °C (212 °F) are globally the most conservative, but that reported results have differed and may not reflect real-world conditions. A chart summarizes sensitivity tests to test conditions and criteria, including vessel size, ignition sources, and test temperatures and pressures. Current practice and concerns are identified for visual determinations of flammability; definitions are given for "combustibility," "flammability," and "propagate." A chart itemizes factors affecting flammability, including stoichiometry changes with humidity and inerting agents, ignition energies, temperature, pressure, and vessel size. Stoichiometric effects are described and illustrated when the hydrogen to fluorine ration in an HFC are greater than or equal to 1, are less than one, or there is insufficient oxidant present. A series of charts examines the effects of assumptions and variables on heat of combustion calculations. shows the combustion reaction of R-134a, noting that the formation of molecular fluorine is unlikely even though prescribed for heat of combustion calculations by ANSI/ASHRAE Standard 34-1992

T. W. Dekleva, A. A. Lindley (ICI Klea), and P. Powell (ICI Chemicals and Polymers, Limited), **Flammability and Reactivity of Select HFCs and Mixtures**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 12, pages 40, 42, and 44-47, December 1993 (6 pages with 2 figures and 3 tables, available from JMC as RDB4302)

This article provides information on the reactivity and flammability of fluorocarbon refrigerants. A table presents the temperatures at which reactivity begins, *T-onset*, and at which 50% of the flowing refrigerant is decomposed, *T-50%*. Data are presented for a nitrogen atmosphere with glass as a catalyst for R-11, R-12, R-32, R-113, R-123, R-124, R-125, R-134, and R-134a and with iron gauze, aluminum, and copper as catalysts for R-12 and R-134a. Data also are presented for reactivity in air (with oxygen) with

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glass and iron gauze as catalysts for R-12 and R-134a. The reactivities of R-12 and R-134a opposite aluminum are compared, based on the potential for exothermic reactions in chillers when impellers become unbalanced. The authors indicate that there appears to be little or no potential for a spontaneous exothermic halogenation reaction for R-134a with molten aluminum; no reactions are anticipated for R-134a with 2% magnesium alloys or for R-32. The article then addresses the test methods for flammability and provides definitions for combustibility, flammability, a critical flammability ratio (CFR). "Combustibility" describes the chemical process in which an oxidant is reacted rapidly with a fuel to decompose and liberate stored energy. "Flammability" describes a more specific situation in which the reaction is self sustaining and the flame propagates away from the ignition source. The article discusses flammability test methods, including ASTM E681-85 and the ignition-source modification of ANSI/ASHRAE Standard 34-1992. It discusses the influences and test vessel size, ignition source, pressure, and temperature. Flammability results are reported for R-32, R-125, and R-134a. A table compares flame limits of R-32 based on vessel size and ignition source using published and new data. Four figures map the flammable concentrations of R-134a with oxygen and nitrogen at 100 and 170 °C (212 and 338 °F) at atmospheric pressure, and for 170 °C (38 °F) at 345 and 690 kPa (50 and 100 psia. Ignition conditions are discussed for R-134a in air and compared to those for R-22. The article then addresses the flammability of R-32 blends. It defines the CFR as the percentage of nonflammable refrigerant required to just render a mixture nonflammable at specified temperature and pressure on dilution with air. Values are tabulated for binary blends or R-32/125 and R-32/134a for different vessel sizes. A methodology is illustrated for use in analyzing fractionation scenarios for blends. The study confirms the low reactivity of the hydrofluorocarbons (HFCs) addressed.

P. E. DiNenno, **SFPE Handbook of Fire Protection Engineering**, National Fire Protection Association (NFPA), Quincy, MA, 1988 (RDB4C54)

flammability, flame limits, LFL, UFL, combustibility, ignition

D. E. Douglas and F. J. Benz, **Lower and Upper Flammability Properties of Ammonia in Air at Reduced Pressures**, report TR-205-002, National Aeronautics and Space Administration (NASA), White Sands Test Facility, New Mexico, 1978 (RDB-4B62)

R-717 (ammonia), LFL, UFL

D. L. Fenton, K. S. Chapman, R. D. Kelley, and A. S. Khan (Kansas State University, KSU), **Operating Characteristics of a Flare/Oxidizer for the Disposal of Ammonia from An Industrial Refrigeration Facility**, paper 3921 (682-RP), *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 463-475, 1995 (13 pages with 12 figures, RDB6351)

flame limits of R-717 combusted with methane, influences of naphthenic and paraffinic mineral oils as well as polyolester (POE) lubricants, effects of injection of liquid ammonia, measurements of ammonia, carbon dioxide, carbon monoxide, hydrocarbons, oxygen, and nitrous oxides in discharge

D. L. Fenton, A. S. Khan, R. D. Kelley, and K. S. Chapman (Kansas State University, KSU), **Combustion Characteristics Review of Ammonia-Air Mixtures**, paper 3922, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 476-485, 1995 (10 pages with 6 figures and 3 tables, RDB6352)

R-717; kinetics of reaction with air; survey of published flame limits (LFL and UFL); effects of pressure, temperature, diluents, ignition energy, and burning velocity; mists, droplets, and sprays; autoignition, thermal and explosion hazards

D. L. Fenton and K. S. Chapman (Kansas State University, KSU), **Combustion of Ammonia With and Without Oil Vapor**, final report for 682-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 20 May 1994 (RDB4B60)

This report presents a detailed study of the combustibility of ammonia refrigerant, R-717. The first part presents a literature review covering flammability limits, test methods, and the effects of pressure, temperature, inert gas diluents, ignition energy, and form (mists, droplets, or sprays). It also discusses the chemical kinetics of ammonia combustion. The second documents flammability determinations using the ASTM E681-85 standard test method, with attention to relative humidity and other test conditions. The third part describes the equipment, procedures, and findings for examination of ammonia flaring (oxidizing) for emergency releases. The last part addresses the influence of lubricating oil and ammonia liquid on the flammability limits. The study reports lower and upper flammability limits (LFL and UFL), based on published studies, of 14.8 and 33.5%, respectively. The flammability range based on

tests was found to be 15.15-27.35% for dry air and for air at 50% relative humidity; the limits narrowed to 15.95-26.55 at 100% relative humidity. Lower pressures tended to narrow the flammability range, and the LFL decreases as temperature rises. The report outlines tests and problems encountered with use of "flow-through" system to simplify flammability testing. Data are provided on ammonia flammability in air mixtures with unidentified naphthenic and paraffinic mineral oils, a polyolester (POE) lubricant, an experimental lubricant, and natural gas (methane). A 10% lubricant to ammonia weight ratio of naphthenic oil reduces the LFL to below 12% and 30% mixtures with paraffinic oil or POE reduce the LFL to approximately 8%. Oil concentrations exceeding 20% slightly reduce the UFL, while 30% POE reduces the UFL by nearly 5%. Injection of liquid ammonia into a near stoichiometric air-natural gas pilot flame at ammonia-to-natural mass ratios of less than 0.5 yielded ammonia exhaust concentrations less than 5 ppm. As the mass ratio increases, the ammonia concentration in the exhaust stream increases to over 6000 ppm before the flame extinguishes under stable flame conditions.

F. Fedorko, L. G. Frederick, and J. G. Hansel, **Flammability Characteristics of Chlorodifluoromethane (R-22)-Oxygen-Nitrogen Mixtures**, paper 3097, *Transactions* (Annual Meeting, Nashville, TN, 27 June - 1 July 1987), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 93, part 2, pages 716-724, 1987 (9 pages with 4 figures and 1 table, RDB3A13)

flammability, LFL, UFL, heat of reaction

G. H. Goble (Purdue University), C. James Dahn (Safety Consulting Engineers, Incorporated), B. Hardaway (Bill's Heating and Air Conditioning), and R. H. Miller (Peoples Welding Supply, Incorporated), **Some Safety Studies of a Ternary Refrigerant**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 165-169, July 1994 (5 pages with 2 figures and 2 tables, available from JMC as RDB4822)

R-406A [R-22/600a/142b (55/4/41)], fractionation, flammability

W. Goetzler and L. Bendixen (Arthur D. Little, Incorporated, ADL), **Risk Assessment of HFC-32/-HFC-134a (30/70) in Mini-Split Residential Air Conditioners**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 27-32, July 1996 (6 pages with 3 figures, RDB6753)

concludes that the risks due to fires resulting from use of R-32/134a (30/70) in mini-split air conditioners in Japanese residences would be extremely low; risks from servicing and other handling are higher but can be controlled

W. Goetzler and H. Ozog (Arthur D. Little, Incorporated, ADL), **Risk Assessments for Flammable Refrigerants**, paper 7.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 181-186, December 1994 (6 pages with 2 figures, RDB5433)

R-32, R-152a, flammability, zeotropic blends, fractionation, safety, refrigerator, air conditioning

W. Goetzler (Arthur D. Little, Incorporated, ADL), **Development of a Risk Assessment for Flammable Refrigerants**, presentation 4.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (18 pages with 28 presentation charts, available from JMC as RDB4794)

D. P. Grob (Underwriters Laboratories, Incorporated), **Current Status for UL 2182, Flammability Testing of Refrigerant Blends for Flammability Rating**, paper 7.2-1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 168-173, December 1994 (6 pages, RDB-5431)

flammability, blends, fractionation, safety

D. P. Grob (Underwriters Laboratories, Incorporated), **Safety Requirements for a Refrigerator That May Use a Flammable Refrigerant**, paper 7.2-2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 174-180, December 1994 (7 pages with 1 table, RDB5432)

flammability, blends, fractionation, safety

D. P. Grob (Underwriters Laboratories, Incorporated), **Barriers in the U.S.A. to Using Propane as a Refrigerant**, *R-22 and R-502 Alternatives* (Pro-

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ceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 109-114, 1994 (6 pages, RDB4526)

D. P. Grob (Underwriters Laboratories, Incorporated), **Summary of Flammability Characteristics of R-152a, R-141b, R-142b, and Analysis of Effects of Potential Applications**, *Proceedings of the 42nd Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, May 1991), IATC, Batavia, IL, May 1991 (RDB4925)

D. P. Grob (Underwriters Laboratories, Incorporated), **Flammability Characteristics of R-32 and R-32 Mixtures**, proceedings (Symposium to Evaluate R-32 and R-32 Mixtures in Refrigeration Applications, Washington, DC, 19-20 March 1991), U.S. Environmental Protection Agency (EPA), Washington, DC, 1991 (RDB4A04)

flammability, LFL, UFL

W. L. Grosshandler (National Institute of Standards and Technology, NIST), **Lean Flammability Limit as a Fundamental Material Property**, presentation 3.4, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (24 pages with 21 presentation charts, available from JMC as RDB4793)

G. F. P. Harris and P. E. MacDermott, **Flammability and Explosibility of Ammonia**, *Institute of Chemical Engineering Symposium*, University of Manchester Institute of Science Technology, United Kingdom, number 49, pages 31-39, 1977 (9 pages, RDB6358)

R-717, flammability limits, explosivity, LFL, UFL

E. W. Heinonen and R. E. Tapscott (New Mexico Engineering Research Institute, NMERI), **Methods Development for Measuring and Classifying Flammability/Combustibility of Refrigerants**, presentation (ARI Alternative Refrigerants Evaluation Program, AREP, Meeting, Chicago, IL, 27 January 1995), report DOE/CE/23810-52A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, January 1995 (20 pages with 3 figures and 1 table, available from JMC as RDB-5254; photograph reproductions are of poor quality)

These document comprises presentation charts summarizing research to develop procedures and equipment to measure refrigerant flammability. A second objective is to characterize parameters affecting flammability. The charts outline three tasks, to gather and review available data, establish a test plan, and perform laboratory testing; each task is described. The first includes performance of a structured literature search, development of an information storage system named REFLIBRY, and preparation of an annotated bibliography and summary. REFLIBRY is described as a database with more than 100 entries covering flammability, ignition, and refrigerants. The second task used the information found, to identify data shortfalls and to design experiments and methods to address them. Nine parameters affecting flammability are noted, including apparatus size and construction, composition of the refrigerant, humidity, pressure, temperature, ignition type and strength, turbulence, component mixing, and altitude. The summary of the testing task addresses the data acquisition system (DAS); ASTM E681 flask and enclosure; ignition system; blends of R-32, R-125, R-134a; data analysis; and development of recommendations. The DAS is described and both the E681 apparatus and NMERI explosion sphere are shown. The ignition source investigation and tests are outlined, and a plot illustrates the flammability sensitivity of R-32/125 to concentration, humidity, and temperature. The presentation concludes that starting pressure, and therefore altitude, has a significant effect, illustrated with tabular data for R-32/134a, and that flammability can be measured by a pressure increase. The charts outline recommendations to improve E681 tests and for further research.

E. W. Heinonen, R. E. Tapscott, and F. R. Crawford (New Mexico Engineering Research Institute, NMERI), **Methods Development for Measuring and Classifying Flammability/Combustibility of Refrigerants: Task 3 - Laboratory Test Results**, report DOE/CE/23810-50 also identified as NMERI 1994/44, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, December 1994 (96 pages with 30 figures and 17 tables, available from JMC as RDB5A18)

This report summarizes an investigation of the flammability characteristics of selected blends of refrigerants R-32, R-125, and R-134a using both a novel and conventional measurement methods. A detailed introduction reviews definitions of flammability and the lower and upper flammability limits (LFL and UFL). It also identifies indications of flammability beyond visual and presents the parameters that affect flammability. They include the ignition source, temperature and pressure of the mixture, humidity of the air, size and shape of the test vessel, test vessel materials, turbulence, concentration of the test gas, reactivity and mixing of the components, and altitude and resulting barometric pressure. The report then discusses and schematically illustrates the NMERI explo-

sion sphere and an ASTM E681 test flask. It outlines the data reduction methodology and presents test results for R-32, R-125, R-134a, and blends of them. An analysis of the data examines the sensitivity to the cited parameters. The report presents conclusions regarding the effects of these influences. It recommends procedures for use of both the explosion and E681 apparatus as well as for future study of the effects of humidity and altitude and improvement of the explosion sphere method. It concludes that the method of determining flammability using ASTM E681 is marginally adequate, but can be improved, and that both it and use of the explosion sphere have their own niches for testing. Appendices present the data acquisition instructions, apparatus operating instructions, and tabular test results.

N. Kalkert and H. G. Schecker, **Determination of Explosion Limits of Ammonia in Mixtures with Simple Hydrocarbons and Air**, German Chemical Engineering, volume 3, pages 53-56, 1980 (4 pages, RDB6354)

R-717, flame limits

O. Kataoka, M. Yoshizawa, H. Ohnishi, and S. Ishida (Daikin Industries, Limited, Japan), **Flammability Evaluation of HFC-32 and HFC-32/134a Under Practical Operating Conditions**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 33-38, July 1996 (6 pages with 9 figures and 2 tables, RDB6754)

R-32, R-32/134a (35/65), (40/60), and (60/40): flammability, diffusion analysis, combustion under practical conditions; concludes that the combustion behavior of refrigerants is very different under practical conditions than in small-scale (e.g., ASTM E-681) tests

F. J. Keller, L. Sullivan, and H. Liang (Carrier Corporation), **Assessment of Propane in North American Residential Air Conditioning**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 39-44, July 1996 (6 pages with 6 figures and 2 table, RDB6755)

comparison of R-290 with R-22 and R-410A in systems using safety measures, in a blend of R-290/227ea (70/30), and with a secondary heat transfer circuit; system considerations; simulated performance; direct and indirect global warming impacts (TEWI); flammability in manufacturing; concludes that the system with safety features to address flammability offers the best performance and lowest TEWI, but requires a 30% increase in cost; the same cost premium can lower TEWI if spent to increase the efficiency of an R-410A system

A. S. Khan, R. D. Kelley, K. S. Chapman, and D. L. Fenton (Kansas State University, KSU), **Flammability Limits of Ammonia-Air Mixtures**, paper 3920 (682-RP), *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 454-462, 1995 (9 pages with 6 figures, RDB-6350)

R-717, flame limits: measured LFL-UFL = 15.15-27.35% in dry air and 15.95-26.55% at 100% relative humidity

R. A. Kingsbury (Underwriters Laboratories Incorporated, UL), **ASTM E681: A Sound Basis for Flammability Testing of Alternative Refrigerants**, presentation 2.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (10 pages with 7 presentation charts, available from JMC as RDB4784)

These charts recap a presentation of the flammability test procedure prescribed in ASTM E681-85. A schematic diagram illustrates the apparatus used for tests. The charts outline discussion of applicability for gases, liquids, and solids - including those that are volatile under test conditions for the latter two - and the ignition sources used. They may include an electrical spark, exploding copper wire, or (as required by ANSI/ASHRAE Standard 34-1992 for halocarbon refrigerants) an electrically-activated kitchen match head. A chart indicates as advantages that the tests are reproducible, temperature is easily controlled, and humidity or inerting gases can be added. Another cites as disadvantages that it is a "small" test, flame propagation is sometimes difficult to see, and tests may not reflect real-world conditions. A final chart indicates that the prescribed method is a controlled laboratory test, but not a risk assessment.

V. N. Krivulin, L. A. Lovachev, E. Z. Kudryavtsev, and A. N. Baratov, **Study of Flammability Limits I, Ammonia-Air Mixtures**, *Fiz. Goreniya Vzryva*, volume 11, number 6, pages 890-897, 1975 (8 pages, RDB6359)

R-717, flammability limits, LFL, UFL

W. Leuckel, B. Leisenheimer, and K. Bier (Universität Karlsruhe, Germany), **Verbrennungstechnische Eigenschaften des Kältemittels R152a und seiner Mischungen mit R134a beziehungsweise R32** [Flammability of Refrigerants R-152a and its Mixtures with R-134a or R-32], *Ki Klima-Kälte-Hei-*

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zung, Germany, volume 20, pages 113-117, April 1992 (5 pages, in German, RDB4528)

R-134a/152a, R-32/152a, combustibility

A. A. Lindley, **Klea(R) 134a Flammability Characteristics at High Temperatures and Pressures**, ICI Chemicals and Polymers, Wilmington, DE, undated circa 1993 (9 pages with 4 figures, RDB4A01)

This document summarizes tests of R-134a to gauge the effects of temperature and pressure on its flammability. The document defines the terminology used, including flammability, upper and lower flammability limits, and combustion. It describes an autoclave used for the tests and comments on the effects of vessel size and the ignition source used. Flammability diagrams are provided for R-134a with nitrogen and oxygen at 100 °C (212 °F) and 103 kPa (15 psia) and at 170 °C (338 °F, reported as 388 °F) and 103, 345, and 689 kPa (15, 50, and 100 psia). The document concludes that R-134a is not flammable at atmospheric pressure at temperatures up to at least 170 °C (338 °F). It estimates that a minimum pressure of 483-517 kPa (70-75 psia) would be required to achieve flammability at 170 °C (338 °F, reported as 388 °F), with a narrow range of flame limits (8-12% R-134a by volume), in air for the vessel size used. It cautions that mixtures of R-134a with air should not be used for pressure leak testing and that the decomposition products of R-134a are irritating and highly toxic. It also recommends use of breathing apparatus if R-134a is exposed to fire conditions.

J. F. Missenden, R. W. James, and A. K. H. Wong, **Propane for Systems with Small Refrigerant Charge**, *Proceedings of the Franco, Swedish Conference of AICVF*, France, March 1990 (RDB-5556)

R-290, safety, flammability

H. Onishi (Daikin Industries, Limited, Japan), **The Current Status and Remain**[ing] **Issues for Evaluation of Refrigerant Safety**, paper 7.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 163-167, December 1994 (5 pages with 2 figures and 3 tables; in Japanese with abstract and figures in English; RDB5430)

R-22, R-32, R-125, R-134a, R-143a, R-152a, R-32/134a (30/70), ozone depletion potential (ODP), global warming potential (GWP), flammability

H. Onishi (Daikin Industries, Limited, Japan), **Flammability Evaluation Method for High LFL Substances**, presentation 2.6, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (8 pages with 6 presentation charts, available from JMC as RDB-4789)

H. Ohnishi, N. Izutani, S. Inagaki, K. Karasawa, S. Ishida, and O. Kataoka (Daikin Industries, Limited, Japan), **Relationship Between Flammability and Composition Ratio of HFC-32/HFC-134a Blend**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 115-125, 1994 (11 pages with 15 figures and 6 tables, RDB4527)

R-32/134a, R-32/125/134a

P. R. Reed and J. J. Rizzo (E. I. duPont de Nemours and Company), **Combustibility and Stability Studies of CFC Substitutes with Simulated Motor Failure in Hermetic Refrigeration Equipment**, paper 152, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 888-891, August 1991 (4 pages with 1 figure and 2 tables, RDB-3A11)

The paper summarizes a study to determine if alternative refrigerants become combustible when sufficient air is present, the mixture is heated and/or pressurized, and a suitable ignition source is provided. It cites prior studies (see RDB3A12 and RDB3A13) that document similar effects for R-22 and other refrigerants containing hydrogen. The paper illustrates and explains the experimental apparatus used and describes the test procedures. A table summarizes a matrix of tests for different ratios of air, temperatures, and pressures. The refrigerants tested included R-11, R-12, R-123, R-134a, R-22/152a/114 (36/24/40) (DuPont MP30), and R-22/152a/124 (36/24/124) (DuPont MP33). A second table provides lower and upper vapor combustibility limits for R-134a in air at temperatures of 16-177 °C (61-351 °F) and absolute pressures of 40-2122 (6-308 psi). The document indicates that all of the tested refrigerants were noncombustible with 0-2% air by volume and 82-177 °C (180-351 °F). The authors conclude that all fluorocarbons containing hydrogen will result in combustible mixtures with sufficient air at some temperatures and pressures. R-134a exhibited combustion at elevated pressures when air exceeded 80% and the blends did likewise when air exceeded 80% at elevated

temperatures at any pressure. The paper notes the combustion products pose no undue hazard and that most equipment would stop working with the high air ratios required.

W. R. Rolingson, J. MacPherson, P. D. Montgomery, and B. L. Williams, **Effect of Temperature on the Upper Flammable Limit of Methane, Ammonia, and Air Mixtures**, *Journal of Chemical and Engineering Data*, number 5, pages 349-351, 1960 (3 pages, RDB6203)

R-50, R-717, flammability limits, LFL, UFL

I. R. Shankland (AlliedSignal Incorporated), **Some Issues Related to Flammability Classification of Refrigerants, or When is a Refrigerant Flammable? How Flammable is Flammable?**, publication unknown, 1993 (RDB4A05)

J. J. Shepherd, **Ammonia Flares: Costs, Codes, Installation and Design Considerations**, *Technical Papers of the 12th Annual Meeting* (Memphis, TN, 4-7 March 1990), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 111-125, March 1990 (RDB6360)

R-717

H. N. Sherbo, A. Y. Korolchenko, O. Y. Eremenko, S. G. Tsarickenko, and V. Navtshenya, **Concentration Limits of Flammability in Vapor-Gas Mixtures Based on Halohydrocarbons**, *Zhurnal Fizicheskoi Khimiii* [Journal of Physical Chemistry], Moscow, Russia, volume 64, number 5, pages 1327-1331, 1991 (5 pages probably in Russian, RDB4C55)

R. G. Richard and I. R. Shankland (AlliedSignal Incorporated), **Flammability of Alternative Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 34, number 4, pages 20 and 22-24, April 1992 (4 pages with 1 figure and 5 tables, RDB2525)

This article reports data for refrigerant flammability measurements using the ASTM E681 test procedure. Lower and upper flame limits (LFL and UFL) are tabulated for R-11, R-22, R-30 (methylene chloride), R-32, R-50 (methane), R-113, R-123, R-123a, R-124, R-125, R-134, R-134a, R-140a, R-141b, R-142b, R-143, R-143a, R-152, R-152a, R-161, E-170 (dimethyl ether), R-218, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-611 (methyl formate), R-717 (ammonia), and R-7146 (sulfur hexafluoride). The flammability test procedure and apparatus are discussed, including attention to the ignition source, based on recommendations of ASHRAE Standard 34-1992. Flammability limits are compared for R-32, R-141b, and R-142b, to illustrate the influence of alternative ignition sources and conditions. Critical flammability ratios are presented for selected mixtures.

W. V. Richards (William V. Richards Incorporated), **Design and Installation of Large Ammonia Systems**, presentation 5.2, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (10 pages with 3 presentation charts, available from JMC as RDB4796)

R-717

J. J. Rizzo (DuPont Fluoroproducts), **Flammability Testing and Vapor Fractionation Issues in Blends**, presentation 3.2, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (8 pages with 6 presentation charts, available from JMC as RDB-4791)

W. A. Rosser, H. Wise, and J. Miller, **Mechanism of Combustion Inhibition by Compounds Containing Halogens**, *Proceedings of the Seventh International Symposium on Combustion*, Butterworth-Heinemann, Limited, London, UK, pages 175-182, 1959 (RDB4B66)

J. R. Sand and D. L. Andrjeski (The Trane Company), **Combustibility of Chlorodifluoromethane**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 24, number 5, pages 38-40, May 1982 (3 pages with 1 figure and 4 tables, RDB3A12)

This article summarizes laboratory tests of the combustibility of pressurized mixtures containing R-22 and air or oxygen, prompted by a fatal industrial explosion. The article reviews prior flammability testing of R-22 and presents thermochemical calculations, using heats of formation, heat capacities, and postulated products. These calculations show that an exothermic reaction between R-22 and air is theoretically possible. The experimental apparatus and procedures used are described followed by discussion of the results. The article notes inconsistencies in the data, which are summarized in a table, and attributes them to vessel geometry, volume-to-surface ratio, ignition influences. Combustion test data for oxygen/R-22 mixtures are tabulated and plotted. The highest heats of combustion appear for mixtures containing 25-40 mole % R-22. These results are compared to predicted stoichiometric values and testing observations. Comparative heats of combustion (HOC) are presented for R-22, R-50 (methane), R-20 (chloroform), and R-20I3 (iodoform). The HOC values given are ~419, 844, 373, and 678 MJ/kg·mol (180,000, 380,000, 160,000, and

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291,000 Btu/lb-mol), respectively, for the four gases. Combustion products also are listed for air/R-22 and oxygen/R-22 mixtures, though the article notes that identification was distorted by contaminants from reactions between resultant acids and the sample bags used. The authors conclude that pressurized mixtures of R-22 and air containing at least 50% air are combustible. The heat generated by this reaction is capable of increasing the pressure in a closed container by 6-8 times, but large activation energies are necessary for initiation. Tests of R-11 and R-12 mixtures with oxygen found them not combustible under similar conditions.

I. R. Shankland (AlliedSignal Incorporated), **Flammability, Fractionation, and Test Conditions**, presentation 3.1, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (20 pages with 17 presentation charts, available from JMC as RDB4790)

H. Shaoqiang, L. Xiaoping, and X. Chunfei (Wanbao Refrigerator Industrial Corporation, China), **Refrigerant HFC-152a Flammability Test Results**, publication unknown, undated circa 1991 (4 pages with 1 table, available from JMC as RDB2512)

This paper assesses the flammability risk of R-152a, which is reported as flammable in concentrations of 4.7-16.8% by volume in air. The authors hypothesized that the highest probability of fires and explosions will occur when enough refrigerant leaked from the freezer evaporator into the fresh-food compartment, with ignition caused by an arc or spark from the thermostat. Concentrations of 5, 10, 15, and 20% R-152a were tested using an electric pulse spark. Ignition was found to be unlikely in the model tested (BCD-158), because of incomplete mixing and the location of the thermostat. The risk would be high in a frost-free refrigerator, requiring an explosion-proof thermostat. The paper concludes that the most likely scenario for a fire is when the concentration reaches 12% and is exposed to an open flame. A person standing near the refrigerator could be injured by a blow from the door opened by fire or explosion, by flames, or both. No deformation or damage to the refrigerator cabinet was observed from test fires.

H. W. Sibley (Carrier Corporation), untitled keynote address (presentation 1.1), *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (7 pages, available from JMC as RDB4782)

N. D. Smith (U.S. Environmental Protection Agency, EPA) and M. W. Tufts (Acurex Environmental Corporation), **Flammable Properties of HFC Refrigerants - Some Fundamental Considerations**, presentation 2.2, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (24 pages with 22 presentation charts, available from JMC as RDB-4785)

These presentation charts review fundamental considerations for flammability of hydrofluorocarbon (HFC) refrigerants and offer recommendations on test and ranking methods. The first illustrates the effect of moisture on the flammability of R-245ca and R-245fa, indicating increasing flammability rank with increasing relative humidity, up to approximately 60%. A table lists the combustion reactions and changes in Gibbs free energy and enthalpy (heat) of combustion (HOC) for R-32, R-50, R-143, R-143a, R-152, R-152a, R-170, and R-290. Two more give the same data, reactions with moisture present, and moisture dependence for R-134a, R-227ea, R-236ea, R-245ca, R-245fa. Tables then show the stoichiometric compositions, ranges between lower and upper flammability limits (LFL and UFL), weighted free energy, HOC, and LFL for the cited refrigerants. A plot shows the HOC dependence of refrigerant concentrations in oxygen for R-32, R-134a, R-152a, and R-245fa. A chart outlines the role of an oxidizing free radical in combustion kinetics. A table and plot show the reaction rate constants at 25 °C (-4 °F), resultant LFL, and relative rate of combustion versus refrigerant concentration. A table and plot suggest and illustrate a flammability ranking dependent on the free energy, reaction rate, and stoichiometric ratio. Another table shows that this ranking is inversely related to the extent of fluorination for hydrofluorocarbon (HFC) refrigerants. The flammability ranges for R-32, R-152a, R-245ca, and R-245fa are plotted as functions of their concentrations in air and the concentration of R-134a as a suppressant. A chart summarizes the chemistry of suppression, listing bromine, chlorine, iodine, and the CF_3 radicals as free radical (OH) scavengers A table gives the ideal gas heat capacities by mole and by weight for the HFCs addressed plus R-125, R-134, R-143, and R-227ca. Another table outlines selection of optimum HFC flammability suppressants. The presentation charts then summarize experimental ranking factors as the lowest concentration in air which results in flame propagation (LFL), range of LFL to UFL, amount of energy released, ease of ignition, and rate of pressure rise or maximum pressure. The conclusions note that all HFCs are potentially combustible, those having fewer hydrogen than fluorine atoms may involve water as a reactant, and that insufficient water is available in air for com-

plete combustion. Further, stoichiometric fuel/air compositions yield the highest HOC, but not necessarily the highest reaction rate. Relative flammabilities can be calculated for screening purposes, molecular criteria for decreasing flammability can predict when refrigerants are nonflammable at normal conditions, and refinement of the ASTM E681 test method should be considered. The presentation provides recommendations for experimental determinations of flammabilities of refrigerants, fire hazard risk determinations, and clarification of flammability limits via the ASTM E681 method.

E. S. Starkman and G. S. Samuelson, **Flame-Propagation Rates in Ammonia-Air Combustion at High Pressure**, *Proceedings of the Eleventh International Symposium on Combustion*, Butterworth-Heineman, Limited, London, UK, pages 1037-1045, 1967 (8 pages, RDB6356)

R-717

D. W. Treadwell (Lennox Industries Incorporated), **Packaged Air-Conditioning Equipment Employing Propane**, presentation 5.3, *ARI Flammability Workshop - Summary and Proceedings* (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (42 pages with 39 presentation charts, available from JMC as RDB-4797)

R-290

Y. Urano, S. Horiguchi, K. Tokuhashi, M. Iwasaka, and S. Kondo, **Flammability Limits of Alternative Refrigerants**, *Koatsu Gasu* [High Pressure Gases], Tokyo, Japan, volume 27, number 6, pages 22-28, April 1990 (7 pages, in Japanese, RDB5648)

LFL, UFL

K. S. Willson and W. O. Walker (Ansul Chemical Company), **Flammability Limits in Air ... Methyl Chloride and Mixtures of Methyl Chloride with Dichlorodifluoromethane**, *Industrial and Engineering Chemistry*, American Chemical Society (ACS), Columbus, OH, volume 36, number 5, pages 466-468, May 1944 (3 pages with 2 figures and 1 table, RDB6633)

R-40, LFL-UFL (8.0-18.9% v/v), comparisons with different ignition sources (spark, cigar, cigarette, hot wire, match); R-12/40 (of interest due to R-12 shortages) found to be not flammable when the R-12 fraction is 10% or greater

C. Womeldorf, M. King, and W. L. Grosshandler (National Institute of Standards and Technology, NIST), **Lean Flammability Limit as a Fundamental Refrigerant Property (Interim Technical Report - Phase I)**, report DOE/CE/23810-58, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 31 March 1995 (34 pages with 17 figures and 2 tables, available from JMC as RDB5601)

The report presents an investigation of a fundamental flammability limit that is independent of the ignition source. It defines the limit as the fuel-air mixture that extinguishes an adiabatic flame when the strain rate (i.e., the normal gradient of velocity) is zero. The report explains that no method currently exists to measure this fundamental limit directly, but that measurements with a counterflow burner provide a quantifiable basis for extrapolating to the zero value. Preliminary results of the lean flammability limit of R-32 and of the critical flammability ratio of R-125 in R-32 are reported. The report reviews the background, describes the experimental apparatus and procedures, discusses the fundamental flammability limit, and summarizes the equilibrium chemistry involved. It summarizes measurements for R-50 (methane), R-32, R-125, and R-32/125. Figures illustrate the counterflow burner, burner flow control system, extinction curve for methane as a function of the local strain rate, and the definition of the global strain rate. Plots show the equilibrium composition and temperature of R-32, R-125, and R-290 (propane) in air as well as the adiabatic equilibrium temperature of R-32 and R-32/125 (90/10) in air. Further plots show the determination of peak equilibrium temperatures, global and local strain rates at extinction for methane, range of lean flammability limits for R-32, a comparison of flammability limits (LFL and UFL) for R-32 using various methods at ambient temperatures. Two final plots show the extinction points for R-32 and R-125 and extrapolation of the global strain rate, to determine the critical flammability ratio of R-125 in R-32.

A. K. H. Wong, **Some Implications of the Application of Propane in Domestic Refrigerators**, research memorandum 123, Institute of Environmental Engineering, South Bank University, London, United Kingdom, June 1989 (RDB5560)

R-290, safety, flammability

ARI Flammability Workshop - Summary and Proceedings (Chicago, 8-9 March 1994), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1994 (290 pages with summary and 16 sets of presentation charts, available from ARI; RDB4781)

Flammability Characteristics of Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page, available from JMC as RDB0521)

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Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-141b based on ASTM E681 tests. The limits cited are 7.4-15.5% at 21 °C (70 °F) and 5.8-16.5% at 120 °C (250 °F). The maximum explosion pressure and maximum rate of pressure rise are tabulated for the same temperatures. Flammability characteristics of ethyl alcohol and R-290 (propane) are presented for comparison. A higher concentration of R-141b is required for flammability. Additionally, R-141b exhibits significantly lower rates of pressure rise and lower heats of combustion.

Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, publication 325, National Fire Protection Association (NFPA), Quincy, MA, 1994 (RDB6710)

flammability data

Report on Alternatives to Currently-Used Chlorofluorocarbon (CFC) Refrigerants, report USNC181 Project 89NK14414, Underwriters Laboratories, Incorporated, Northbrook, IL, 1989 (RDB-4A06)

flammability

Results of Testing: Limits of Flammability for Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (4 pages with 5 figures and 1 table, available from JMC as RDB0522, picture missing)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-141b based on ASTM E681-85 tests. The limits cited are 7.4-15.5% at 21 °C (70 °F) and 5.8-16.5% at 120 °C (250 °F). Comparative data are presented for R-600a (isobutane) and ethanol, 1.86-8.5% and 3.46-18.4% respectively. A modified test procedure and the method of determining flammability limits are presented. Additionally, the effects of humidity, temperature, and ignition source on flammability testing are discussed.

Results of Testing: Flashpoint of Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page, available from JMC as RDB0523, picture missing)

The procedure and results of measuring the flash point of R-141b are summarized based on ASTM D1310 tests using a Fisher/Tag open cup apparatus. No flash point was observed for this fluid even though it has lower and upper flammability limits. The nature of the liquid is such that it does not produce a vapor layer that will flash according to the standard test method. The document notes that similar behavior has been observed for chlorinated solvents such as R-30 (methylene chloride) and R-140a (methyl chloroform).

Results of Testing: Maximum Rate of Pressure Rise - Maximum Explosion Pressure of Isotron 141b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (2 pages with 1 table, available from JMC as RDB0524, picture missing)

The procedure and results of measuring the maximum rate of pressure rise and maximum explosion pressure of R-141b are summarized. The rate of pressure rise is reported as 262 and 220 kPa/s (38 and 32 psi/s) at 21 °C (70 °F) and 120 °C (250 °F), respectively, in a 0.37 m^3 (13.1 cf) vessel. The maximum pressure is reported as 78 and 57 psig at corresponding conditions. A comparison of normalized rates of pressure rise (the Kg) shows R-141b to be approximately 230 times less severe than R-290 (propane) and 50 times less severe than ethanol.

Flammability Characteristics of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page, available from JMC as RDB0525)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-142b based on ASTM E681 tests. The LFL cited is 7.8% at 21 °C (70 °F) using a fuse wire as the ignition source. The cited LFL and UFL, using a match as the ignition source, are 6.9-17.0% at 21 °C (70 °F) and 6.1-17.8% at 120 °C (250 °F). The maximum explosion pressure and maximum rate of pressure rise are tabulated for the same temperatures. Flammability characteristics of ethyl alcohol and R-290 (propane) are presented for comparison. A higher concentration of R-142b is required for flammability. Additionally, R-142b exhibits significantly lower rates of pressure rise and lower heats of combustion.

Results of Testing: Limits of Flammability for Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (4 pages, available from JMC as RDB0526, picture missing)

Lower and upper flammability limits (LFL and UFL), as a volume percentage of refrigerant in humid air, are given for R-142b based on ASTM E681 tests. The LFL cited is 7.8% at 21 °C (70 °F) using a fuse wire as the ignition source. The cited LFL and UFL, using a match as the ignition source, are 6.9-17.0% at 21 °C (70 °F) and 6.1-

17.8% at 120 °C (250 °F). Comparative data are presented for R-600a (isobutane) and ethanol, 1.86-8.5% and 3.46-18.4% respectively. A modified test procedure and the method of determining flammability limits are presented. Additionally, the effects of humidity, temperature, and ignition source on flammability testing are discussed.

Results of Testing: Flashpoint of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (1 page with 1 figure, available from JMC as RDB0527, picture missing)

The procedure and results of measuring the flash point of R-142b are summarized based on ASTM D1310 tests using a Fisher/Tag open cup apparatus. No flash point was observed for this fluid. An upward extension of a test flame was observed when passed over a sample of the refrigerant. The extension grew with increasing temperature of the refrigerant, but the vapor space above the liquid neither flashed nor burned away from the test flame.

Results of Testing: Maximum Rate of Pressure Rise - Maximum Explosion Pressure of Isotron 142b, preliminary information bulletin, Elf Atochem North America, Incorporated (provided by the former Pennwalt Corporation), King of Prussia, PA, May 1989 (2 pages with 1 table, available from JMC as RDB0528, picture missing)

The procedure and results of measuring the maximum rate of pressure rise and maximum explosion pressure of R-142b are summarized. The rate of pressure rise is reported as 606 and 634 kPa/s (88 and 92 psi/s) at 21 °C (70 °F) and 120 °C (250 °F), respectively, in a 0.37 m^3 (13.1 cf) vessel. The maximum pressure is reported as 88 and 68 psig at corresponding conditions. A comparison of normalized rates of pressure rise (Kg) shows R-142b to be approximately 100 times less severe than R-290 (propane) and 23 times less severe than ethanol.

Standard for Refrigerants, standard 2182, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 30 December 1994 (18 pages with no figures or tables, RDB5216)

This standard contains test procedures and methods to evaluate and categorize refrigerants according to their extent of flammability. The refrigerants covered are intended for use in air-conditioning and refrigeration equipment. The standard comprises a scope defining applicability and exclusions (e.g., efficiency, physiological effects, and toxicity), units of measure, definitions, and sections on flammability rating, storage containers, fractionation analysis, flammability testing, and autoignition temperature tests. Refrigerants that exhibit no flame limits (i.e., do not propagate a flame at 100 °C, 212 °F) and additionally do not have an autoignition temperature less than 750 °C (1382 °F) are categorized as "nonflammable." Those with no flame limits but having an autoignition temperature less than 750 °C (1382 °F) are categorized as "practically nonflammable." Refrigerants that propagate a flame are classed as "flammable." The standard prescribes test procedures and conditions to determine the flame limits, measure the autoignition temperature, and categorize blends considering both their as-blended and worst-case fractionated conditions. It also details a procedure to simulate leakage as well as charge and recharge cycles for testing azeotropic and zeotropic blends. A final section specifies requirements for container markings, including manufacturer and refrigerant identities, fire-hazard ratings, and orientation or liquid-phase charging warnings.

Standard Test Method of Autoignition Temperature of Chemicals, standard E659-78, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, 1978, reapproved in 1989 (RDB2920)

Standard Test Method for Concentration Limits of Flammability of Chemicals, standard E681-94, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, 1994 (RDB5810)

flammability limits, LFL, UFL

Standard Test Method for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure, standard E918-83, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, 1983, reapproved in 1988 (RDB2922)

flammability limits, LFL, UFL

Standard Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures, standard E582-76, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, 1976, reapproved in 1981 (RDB2921)

Reactivity

Aerodyne Research, Incorporated, **Heterogeneous Chemistry of Alternate CFC Oxidation Intermediates with HCFC-21 and Other Chemicals**, report EPA 86-920001060 (OTS0544334), Alternative

please see pages 6-8 for ordering information

Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, 31 July 1992 (RDB5968)

R-21, R-125 and others, reactivity, environmental impacts

C. Chiorboli et al, **Application of Chemometrics to the Screening of Hazardous Substances: Part II. Advances in the Multivariate Characterization and Reactivity Modelling of Haloalkanes**, *Chemometrics Intelligent Laboratory Systems*, volume 19, number 3, pages 331-336, 1993 (4 pages, RDB5969)

R-125 and others, reactivity

P. V. Mitin, V. G. Barabanov, and G. V. Volkov, **Kinetics of the Thermal Decomposition of 1-1-Difluoro-1-chloroethane and 1,1,1-trifluoroethane**, *Kinet. Katal.*, volume 29, number 6, pages 1468-1470, 1988; translation by Cytech Languages, Incorporated, 11 October 1989 (6 pages with 2 figures and 1 table, RDB6A03)

R-142b, R-143a: studies of the thermal kinetics for decomposition in continuous flow systems reveal significant discrepancies based on methods and effects of reactor walls; compares the kinetic reaction parameters with those measured by other investigators

J. Sehested et al, **A Kinetic Study of the Reaction of Fluorine Atoms with Fluoromethane, Chloromethane, Bromomethane, Difluoromethane, Carbon Monoxide, Trifluoromethane, 2,2-dichloro-1,1,1-trifluoromethane, 1,1,1,3- and 1,1,2,2-tetrafluoropropane, 1-chloro-1,1-difluoroethane, 1,1-difluoroethane, and Pentafluoroethane at 295 ±2 K**, *International Journal of Chemical Kinetics*, volume 25, number 8, pages 651-665, 1993 (14 pages, RDB5963)

R-23, R-40B1, R-41, R-32, R-141b, R-123, R-125, R-254cb, R-254fb, R-152a

TEST AND ANALYSIS METHODS

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate - Part I: Venturi and Void Fraction Meters**, paper 3926, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 511-522, 1995 (12 pages with 11 figures, RDB6364)

refrigerant mass-flow rate, instrumentation

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate - Part II: Turbine and Void Fraction Meters**, paper 3927, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 523-531, 1995 (9 pages with 10 figures and 1 table, RDB6365)

refrigerant mass-flow rate, instrumentation

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate - Part III: Combined Turbine and Venturi Meters and Comparison with Other Methods**, paper 3928, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 532-538, 1995 (7 pages with 7 figures, RDB6366)

refrigerant mass-flow rate, instrumentation

A. Abdul-Razzak, M. Shoukri, and J-S. Chang (McMaster University, Canada), **Measurement of Two-Phase Refrigerant Liquid-Vapor Mass Flow Rate**, final report for 722-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1995 (RDB6367)

refrigerant mass-flow rate, instrumentation

G. Angelino and C. Invernizzi, **General Method for the Thermodynamic Evaluation of Heat Pump Working Fluids**, *International Journal of Refrigeration* (IJR), Paris, France, volume 11, pages 16-25, 1988 (RDB3338)

T. D. Armstrong, **Chloride Analyses as a Measure for the Evaluation of Sealed Tube Tests**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 150 ff, 1965 (RDB2325)

M. Arnemann, **Methoden zur Bestimmung Thermophysikalischer Eigenschaften von Öl-Kältemittel-Gemischen** [Methods to Determine Thermophysical Properties of Oil-Refrigerant Mixtures], dissertation, Universität Hannover, Hannover, Germany (in German, RDB4532)

M. J. Assael, C. M. B. P. Oliveira, M. Papadaki, and W. A. Wakeham, **Vibrating-Wire Viscometers for Liquids at High Pressures**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 13, number 4, pages 593-615, 1992 (13 pages, RDB4883)

P. B. Ayscough, **The Analysis of Fluorocarbons: Use of Infrared Spectrophotometry for the Analysis of Small Samples**, *Canadian Journal of Chemistry*, National Research Council of Canada (NRCC), Ottawa, ON, Canada, volume 33, pages 1566-1571, 1955 (6 pages, RDB5352)

R-14, R-23, R-116, analytical chemistry, spectrographic analysis, laboratory techniques

J. P. Balaresque and S. Grabeuil (Dehon Services, France), **A User-Friendly Software for Computations of Vapor Compression Cycles with Pure Fluids and Zeotropic Mixtures**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 223-228, July 1996 (6 pages with no figures or tables, RDB6906)

basic equations and computation methods to calculate thermodynamic and transport properties for single-compound, azeotropic, and zeotropic refrigerants; analysis model for one- and two-stage cycles; description of microcomputer program

C. Baroncini, S. Berti, G. Lucarini, and F. Polonara (Università degli Studi di Ancona, Italy), **Un apparato per la determinazione sperimentale del comportamento P-v-T dei fluidi frigorigeni** [An Apparatus to Experimentally Determine the PVT Properties of Refrigerant Fluids], *Il Freddo* [Refrigeration], Italy, number 2, pages 189-200, 1989 (12 pages, RDB4B46)

thermodynamic properties, thermophysical data

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with a Bypass Viscometer**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, 1988 (RDB2406)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with a Vibrating U-Tube Densimeter**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, pages 571-587, 1988 (17 pages with 12 figures and 1 table, RDB2407)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture with an Acoustic Velocity Sensor**, *Transactions* (Annual Meeting, Ottawa, Ontario, Canada, 25-29 June 1988), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 2, pages 602-615, 1988 (14 pages with 10 figures, RDB2408)

R-12 and R-22 with naphthenic mineral oil, R-502 with an alkylbenzene lubricant

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Measuring the Concentration of a Flowing Oil-Refrigerant Mixture: Instrument Test Facility and Initial Results**, paper 3122 (356-RP), *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 94, part 1, pages 167-177, 1988 (11 pages with 6 figures, RDB2247)

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Properties of Oil-Refrigerant Liquid Mixtures with Applications to Oil Concentration Measurement: Part I - Thermophysical and Transport Properties**, *Transactions* (Winter Meeting, San Francisco, CA, 19-22 January 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 92, part 1A, pages 55-73, 1986 (RDB3B59)

J. J. Baustian, M. B. Pate, and A. E. Bergles, **Properties of Oil-Refrigerant Liquid Mixtures with Applications to Oil Concentration Measurement: Part II - Electrical and Optical Properties**, *Transactions* (Winter Meeting, San Francisco, CA, 19-22 January 1986), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 92, part 1A, pages 74-92, 1986 (19 pages with 16 figures and 3 tables, RDB4924)

This paper presents an investigation of electrical and optical properties of liquid oil-refrigerant mixtures as possible bases for real-time measurement of lubricant concentrations. It recommends measurement of capacitance and refractive index as two options, but also addresses light absorption and dielectric constant.

A. F. Benning, A. A. Ebert, and C. F. Irwin, **Water Determination in Freon-12 by Infrared Spectrophotometry**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 56, February 1948 (RDB6620)

R-12, water content

please see pages 6-8 for ordering information

D. E. Briggs and E. H. Young, **Modified Wilson Plot Techniques for Obtaining Heat Transfer Correlations for Shell-and-Tube Heat Exchangers**, *Chemical Engineering Progress Symposium Series*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 65, pages 35-45, 1987 (RDB4657)

T. J. Bruno, **Accelerated Identification of Alternative Refrigerant Products with Standard Chromatographic Retention Parameters**, unpublished seminar presentation charts (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), National Institute of Standards and Technology (NIST), Boulder, CO, 1995 (26 pages with 12 figures and 1 table, available from JMC as RDB5343)

A set of charts address methods to provide fast, reliable identification of alternative refrigerant products and contaminants with low cost, simple techniques. The method provides for optimization of more sophisticated quantitative analyses. Charts summarize and illustrate a database of information of fluorocarbon spectrography, chromatography, physical properties, and safety. A table compares the information content and costs for identification techniques, including mass spectrometry, infrared spectrophotometry, ultraviolet spectrophotometry, nuclear magnetic resonance, refractive index, and gas chromatography. Further charts outline the limitations of and illustrate resolution measures for gas chromatography. Sample data are presented for R-13, R-14, R-21, R-22, R-23, R-32, R-40, R-41, R-114, R-114a, R-114B1, R-115, R-116, R-123, R-124, R-125, R-133a, R-134, R-134a, R-141b, R-142b, R-143, R-143a, R-152a, R-160, R-161, R-215aa, R-215ba, R-216ba, R-217ba, R-217caB1, R-225ca, R-225cb, R-227ca, R-227ea, R-236ea, R-243db, R-245ca, R-245cb, R-245fa, R-236fa, R-253fb, R-262da, R-263fb, R-270aa, R-270da, R-270fa, R-243db, R-270fb, R-280da, R-1112a, R-1112c, R-1112t, R-1113, R-1122, R-1122B1, R-1123, R-1131a, R-1132a, R-1140B1, R-1141, and R-1243. The report identifies a database in preparation for field use to facilitate analyses.

T. J. Bruno (National Institute of Standards and Technology, NIST), **Chemical Analysis Protocol for Alternative Refrigerants - Part 1: Spectroscopic Methods**, paper 3618, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 204-209, 1992 (6 pages with 2 figures and 1 table, RDB2603)

T. J. Bruno (National Institute of Standards and Technology, NIST), **Chemical Analysis Protocol for Alternative Refrigerants - Part 2: Separation Methods**, paper 3619, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 210-215, 1992 (6 pages with 7 figures, RDB2604)

T. J. Bruno, **Spectroscopic Library for Alternative Refrigerant Analysis**, report NIST Special Publication 794, National Institute of Standards and Technology, Boulder, CO, August 1990 (192 pages, available from GPO as stock number 003-003-03036-8 for $12.00 prepaid, RDB2250)

This report assembles infrared and mass spectra on a range of ethane and ethylene compounds relevant to research of alternative refrigerants. Limited physical property and safety data also are included. Some compounds addressed are not suited for refrigerant use, but could be found as impurities or as reaction/decomposition products in refrigerant tests. This publication provides an information source to aid in identification of such compounds. The ethane compounds addressed include R-112, R-112a, R-113, R-113B2, R-113a, R-114, R-114a, R-114B2, R-115, R-116, R-121, R-122, R-123, R-123B1, R-123B2, R-123aB1, R-124, R-125, R-131, R-131a, R-132b, R-132bB2, R-133a, R-133aB1, R-134, R-134a, R-141, R-141b, R-142B1, R-142b, R-143, R-143a, R-151B1, R-152a, and R-161. Ethylene compounds covered include R-1110, R-1111, R-1112a, R-1112aB2, R-1113, R-1114, R-1120, R-1121, R-1122B1, R-1123, R-1130, R-1130, R-1130a, R-1131a, R-1132a, and R-1141.

T. J. Clancey and S. R. Dunne, **Methods of Testing Desiccants for Refrigerant Drying**, *Transactions* (Winter Meeting, Atlanta, GA, 29 January - 1 February 1984), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 90, part 1, pages 164-178, 1984 (RDB2431)

A. P. Cohen (UOP), **Test Methods for the Compatibility of Desiccants with Alternative Refrigerants**, paper 3662, *Transactions* (Winter Meeting, Chicago, IL, 23-27 January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 408-412, 1993 (5 pages with 8 figures and 1 table, RDB4669)

This paper presents a method for testing the compatibility of desiccants with alternative refrigerants and associated lubricants. The paper notes that the standard sealed-tube test, following ASHRAE Standard 97-1989, does not hold a sufficient sample to properly characterize

desiccants. The new method involves exposure of the materials in a stainless steel cylinder, shown in a photograph. The paper discusses the methods of testing the properties of the exposed desiccants for water content, water capacity, halogen content, crush strength, and attrition resistance. A table summarizes the specific methods along with the required sample mass, precision, and representative ranges of values. The paper shows schematics of the apparatus for each test.

H. A. Connon (E. I. duPont de Nemours and Company), **A Generalized Computer Program for Analysis of Mixture Refrigeration Cycles**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 89, part 2A, pages 628-639, 1983 (12 pages); republished in the *International Journal of Refrigeration* (IJR), Paris, France, volume 7, number 4, pages 167-172, May 1984 (6 pages with 2 figures and 1 table, RDB3214)

zeotropic blends, Cycle Program, properties

H. A. Connon and D. W. Drew (E. I. duPont de Nemours and Company), **Estimation and Application of Thermodynamic Properties for a Non-azeotropic Refrigerant Mixture**, paper presented at the meeting of IIR Commissions B1, B2, E1, and E2 (Essen, Germany, September 1981), International Institute of Refrigeration (IIR), Paris, France, 1981; republished in the *International Journal of Refrigeration* (IJR), Paris, France, volume 6, pages 203-208, 1983 (6 pages, RDB4205)

C. Cusano, H. Yoon, and C. Poppe (University of Illinois at Urbana-Champaign), **Accelerated Screening Methods for Predicting Lubricant Performance in Refrigerant Compressors - Final Report**, report DOE/CE/23810-45, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1994 (160 pages with 84 figures and 80 tables, available from JMC as RDB-5109)

This report summarizes research to improve screening methods for lubricants for air-conditioning and refrigeration compressors. It compares data obtained with a high pressure tribometer (HPT) and those by other methods. The report reviews the general requirements for simulative, specimen testing. It also discusses problems encountered in scaling and test acceleration, the latter by increasing the load or speed to obtain measurable wear in a short period of time. The report notes drawbacks in popular methods, such as Falex(TM) testing and compressor bench tests. The bulk of the report is divided into two parts, the first of which compares HPT data to those obtained by three compressor manufacturers using Falex machines. The specimen data, test parameters, and refrigerant-lubricant combinations are tabulated. Tests were performed using grey cast iron (GCI) with SAE 333 die cast aluminum, SAE 356 die cast aluminum with hardened drill rod, and SAE 380 die cast aluminum and grey cast iron with carburized 1018 steel. The friction and wear data are plotted, typical wear scars shown, and resulting rankings of lubricants are compared to those for three combinations of load and speed with the HPT. The tests employed R-134a and R-32/125/134a (30/10/60) with unidentified polyolester (POE) lubricants as well as R-12 and R-22 with mineral oils. Part II compares accelerated wear data for specific components, supplied by five manufacturers, to data obtained with the HPT and with a Four Ball tester using chrome-alloy steel (AISI E-52100) balls. The HPT tests used SAE 380 die cast aluminum, carburized 1018 steel, ductile cast iron, and sintered ferrous pins and plates paired and tested to approximate the manufacturer tests. The wear data and lubricant rankings are again tabulated and typical wear scars shown. The tests used R-12 and R-22 with mineral oils, R-22 with two alkylbenzenes, and R-134a with 12 different ester lubricants. Additional tests were performed with the HPT and Four Ball devices in lubricant-air environments, to examine the effects on friction and wear. The report concludes that the lubricant rankings for the conventional and HPT tests are not very good except when a lubricant resulted in relatively large wear. Moreover, the HPT tests conducted in lubricant-air environments yielded results unlike those conducted in pressurized refrigerant environments. While the authors note that the data obtained do not give a clear vision about the development of a new bench test method, they suggest that the HPT is likely to be an improvement based on use of the refrigerant environment. An appendix describes and schematically illustrates the HPT, Falex, and Four Ball testers. The HPT is characterized as representing the temperature and pressure environment found in specific contact points in compressors. Further appendices outline the experimental procedures, measurements, and calculations and summarize the raw data in tables. A final appendix provides references on refrigerant compressor lubrication.

D. J. David, **Use of Thermal Analysis to Reduce Magnet Wire Evaluation Time**, *Insulation*, pages 38 ff, November 1967 (RDB6658)

compatibility, motor materials, test methods

J. D. De Groot, J. Kestin, and H. Sookiazian, **Instrument to Measure the Thermal Conductivity of Gases**, *Physica A*, Elsevier Science B.V., Am-

please see pages 6-8 for ordering information

sterdam, The Netherlands, volume 75, pages 454-482, 1974 (29 pages, RDB5636)

measurement, instrumentation, thermophysical properties

J. F. Dexter (Dow Corning Corporation), **Simple Test Uses One Criterion, Few Samples to Evaluate Impregnating Varnishes**, *Insulation*, pages 12-19, September 1955 (8 pages with 6 figures and 6 tables, RDB6666)

compatibility with motor materials, aluminum and copper magnet wire, bond strength with two enamels (Dow Corning 997 and Sylkyd 1400) on bare and varnished wire, film thickness, cure time and temperature, test methods

A. W. Diniak, E. E. Hughes, and M. Fujii (NIST, then the National Bureau of Standards, NBS), **Determination of Water Content in Freon-12 Circulating in a Refrigeration System**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 62, pages 56-59 and 94 ff, February 1954 (RDB6607)

R-12, water content

J. L. Ditzler (Westinghouse Electric Corporation), **Better Methods for Evaluating Hermetic Motor Insulation**, *Air Conditioning, Heating, and Ventilating*, volume 57, pages 64-68, April 1960 (5 pages with 2 figures and 3 tables, RDB6651)

R-22, compatibility, motor materials, evaluation of insulation systems for hermetic compressors, test results for tested wire-twist samples in R-22 and mineral oil: stressing of insulation systems under starting conditions contributes to motor failures; R-22 may reduce the strength of insulated conductors; simulated starting conditions by frequent motor reversals correlate with actual experience; short-time locked-rotor tests under controlled conditions indicate the quality of motor winding systems

G. C. Doderer and H. O. Spauschus (General Electric Company), **A Sealed Tube Gas Chromatograph Method for Measuring Reaction of Refrigerant 12 with Oil**, paper 2003, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 72, part II, pages IV.4.1-IV.4.5, 1966 (RDB-2326)

R-12

E. S. Domalski And E. D. Hearing, **Estimation of Thermodynamic Properties of C-H-N-O-S-Halogen Compounds at 298.15 K**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 22, number 4, pages 805-1159, 1989 (RDB5727)

CFC, HCFC, HFC, FC, thermodynamic properties

P. A. Domanski and M. O. McLinden (National Institute of Standards and Technology, NIST), **A Simplified Cycle Simulation Model for the Performance Rating of Refrigerants and Refrigerant Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 2, pages 81-88, February 1992 (8 pages with 6 figures and 1 table, RDB3448)

P. F. Ellis II, A. F. Ferguson, and K. T. Fuentes (Radian International LLC), **Accelerated Test Methods for Life Prediction of Hermetic Motor Insulation Systems Exposed to Alternative Refrigerant-Lubricant Mixtures, Phase 3: Reproducibility and Discrimination Testing**, final report DOE/CE/23810-69 (DCN 96-660-030-04), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 6 May 1996 (52 pages with 16 figures and 4 tables, available from JMC as RDB-6806)

This report presents tests of a simulated stator unit (SSU) to predict the life of motor insulation materials in hermetic motors for air-conditioning and refrigeration equipment. The SSU consists of a laminated electrical steel core simulating the stator stack of a motor. The report recaps development of the SSU and test method as well as earlier proof-of-concept testing (see RDB3A17 and RDB5649). The report describes and illustrates the SSU, its control and data acquisition system, and test procedures. It then summarizes the objectives and preparatory activities for the subject tests, discusses changes in interpretation of capacitance and power dissipation factor results, and outlines the test environment. It details the charging procedures for both a baseline case with R-22 and mineral oil and a test case with deliberately added contaminants. The latter, identified as an "aggressive refrigerant trial," comprises an R-22-oil mixture with five times the refrigerant contaminants allowed under ARI Standard 700-93. The report then presents the test results and explains rejection of 6 of the 14 tests performed, based on apparatus and/or instrumentation failures. It then outlines an analysis of events-to-failure data, post failure conditions, and insulation property measurement (IPM) data. A series of plots shows the IPM results. The report concludes that these tests show a life difference, based on median surges-to-failure measurements, between the baseline R-22/oil mixture

and the aggressive refrigerant/lubricant. It discusses changes in the test method and recommendations for future relocation of the winding core temperature thermocouple.

P. F. Ellis II, A. F. Ferguson, and K. T. Fuentes (Radian Corporation), **An Improved Accelerated Hermetic Motor Insulation Life Test**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 181-185, July 1996 (5 pages with 3 figures and 1 table, RDB6837)

describes development and validation of a test method, identified as the Simulated Stator Unit (SSU) test, for motor insulation systems that combines the IEEE motorette and standardized plug-reversal tests; provides data from tests with R-22 and mineral oil, both with and without added air, moisture, and hydrochloric acid

P. F. Ellis II and A. F. Ferguson (Radian Corporation), **Accelerated Test Methods for Predicting the Life of Motor Materials Exposed to Refrigerant-Lubricant Mixtures, Phase 2: Proof of Concept Demonstration**, final report DOE/CE/23810-57 (DCN 94-660-030-02), Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 19 April 1995 (68 pages with 13 figures and 5 tables, available from JMC as RDB5649)

This report reviews development and proof-of-concept tests of a simulated stator unit (SSU) to predict the life of motor insulation materials in hermetic motors for air-conditioning and refrigeration equipment. The report recaps a survey of failure modes in hermetic motor insulation and implications for an accelerated life test. It outlines three current test methods and compares them in a table. The report reviews the conceptual design (see RDB3A17) of the SSU and advantages over the IEEE 117 Motorette test. It then describes a prototype test unit, a control and data acquisition system, and test procedures. A detailed table compares the conceptual and as-built prototype designs. It describes the tests and illustrates sample measurements. A table presents the test results for three prototypes. One was tested without thermal stress loads, to demonstrate that the insulation property measurements themselves do not degrade the SSU. The other two were subjected to 20,600 simulated locked-rotor events per day. Both showed progressive deterioration and one suffered a coil-to-coil failure, one of the anticipated failure modes. The report describes a future phase of the study, to answer specific engineering/design questions, incorporate refinements, and examine repeatability and viability of the SSU test concept.

P. F. Ellis II and A. F. Ferguson (Radian Corporation), **Accelerated Test Methods for Predicting the Life of Motor Materials Exposed to Refrigerant-Lubricant Mixtures**, final report DOE/CE/-23810-21, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, August 1993 (68 pages with 13 figures and 4 tables, available from JMC as RDB3A17)

P. F. Ellis II (Radian Corporation), **Accelerated Test Methods for Predicting the Life of Motor Materials Exposed to Refrigerant-Lubricant Mixtures, Phase I: Conceptual Design**, seminar presentation (ASHRAE Winter Meeting, New Orleans, LA, January 1994); report DOE/CE/23810-32, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 24 January 1994 (26 pages with 22 charts, available from JMC as RDB-4212)

This report comprises presentation charts summarizing a study to develop an accelerated test method, to predict the life of motor materials exposed to refrigerant-lubricant mixtures. The charts outline the objectives, namely to conduct a literature search and surveys to identify causes of hermetic motor failures and test methods for insulation for hermetic compressor motors. A further objective is to propose a conceptual test design. Several charts identify failure causes, 76.6% of which were electrical and 89.9% of them involved stator windings. The charts outline the mechanisms of failure and tests currently used in motor development. They include the IEEE Standard 117 and UL Standard 984 motorette tests and a plug-reversal test. The charts outline each of them along with identified advantages and weaknesses. The charts then summarize a simulated stator unit (SSU) device and test method; the SSU is shown in a figure. The anticipated results and advantages of the new approach are listed. The charts conclude with a status summary, indicating completion of the conceptual design and consideration of a prototype as a proof-of-concept demonstration.

H. M. Elsey, **Small Sealed Tube Procedure for Quality Control of Refrigeration Oils**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 143 ff, 1965 (RDB2328)

H. M. Elsey, L. C. Flowers, and J. B. Kelley, **A Method of Evaluating Refrigeration Oils**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA,

please see pages 6-8 for ordering information

volume 60, number 7, pages 737 ff, July 1952 (RDB2321)

R-12, lubricants: factors that influence R12-oil reactions

H. L. Emmons (A. O. Smith Corporation), **Motorette-Autoclave Method for Evaluating Hermetic Motor Insulation Systems**, *Insulation*, volume 10, number 3, pages 30-32, March 1964 (RDB6629)

compatibility, motor materials

J. Enomoto, S. Shiono, T. Imamura, K. Shimamura, and Y. Tokida, **A Chemical Method for Evaluating Refrigerants and Refrigerant Oils During the Refrigerating Cycle**, *Mitsubishi Denki Giho*, Japan, volume 52, number 6, pages 151-154, 1978 (4 pages, RDB4339)

M. M. Feiger (General Electric Company), **The Determination of Varnish Bond Strength in Refrigerant Atmospheres**, *Insulation/Circuits*, pages 30-33, December 1971 (4 pages with 5 figures and 3 tables, RDB6667)

compatibility, motor materials, test method: describes method and equipment to determine bond strength of varnish to magnet wire in refrigerants at elevated temperatures and pressures; illustrative data for epoxy- and acrylic-type varnishes on urethane-modified, polyvinyl formal enameled magnet wire splints and helical coils in R-22 environments

J. E. Field, **Method for Determining Refrigerant and Lubricant Decomposition for HFCs and POEs Using Ion Chromatography**, unpublished seminar presentation charts (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), Spauschus Associates, Incorporated, Stockbridge, GA, 1995 (16 pages with 7 figures and 1 table, available from JMC as RDB5347)

11 presentation charts and notes; hydrofluorocarbon refrigerants, polyolester lubricants, refrigerant and lubricant decomposition after aging in sealed tubes

D. G. Gehring (National Refrigerants), **How to Determine Concentration of Water in System Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 37, number 9, pages 52-53 and 55, September 1995 (3 pages with 2 figures, limited copies available from JMC as RDB5934)

This article discusses the relevance of moisture presence in air-conditioning and refrigeration systems, noting that "water is the single most deleterious contaminant" in a system. It identifies recommended concentration limits both in new refrigerants and lubricants. It then discusses sampling and analysis sensitivity to the phase of the sample. A representative calculation shows that higher accuracy can be obtained using liquid-phase samples. The article discusses other parameters and suggests that sampling temperature is virtually insignificant. Two figures correlate the liquid phase fraction to total water in the vapor phase and to water increase in the liquid phase. As shown, the water content from a sample taken from the liquid phase gives nearly the correct concentration of water, provided the container from which the sample is drawn is at least 75% filled with the liquid. The paper also discusses the influence of other parameters, including wall adsorption of moisture, surface coatings that lead to hydrate formation, and hydrolysis reactions with impurities or lubricant additives. The paper explains why water is sometimes visible when an analysis does not reflect it. This discrepancy is attributed to the slow rate at which water dissolves in refrigerant. The paper stresses the importance of using clean sampling and measuring devices to avoid analyses that show higher than actual water content.

D. G. Gehring, D. J. Barsotti, and H. E. Gibbon (DuPont Chemicals), **Chlorofluorocarbons Alternatives Analysis, Part I: The Determination of HFC-134a Purity by Gas Chromatography**, *Journal of Chromatographic Science*, volume 30, pages 280-284, July 1992 (5 pages with 3 figures and 2 tables, RDB3A56)

R-134a

D. G. Gehring, D. J. Barsotti, and H. E. Gibbon (DuPont Chemicals), **Chlorofluorocarbons Alternatives Analysis, Part II: The Determination of HCFC-141b Purity by Gas Chromatography**, *Journal of Chromatographic Science*, volume 30, pages 301-305, August 1992 (5 pages with 2 figures and 2 tables, limited copies available from JMC as RDB3A57)

R-141b

V. Z. Geller and M. E. Paulaitis (University of Delaware), **The Calculation and Prediction of Transport Properties for New Refrigerants and Blends in Refrigeration Application**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 115-124, September 1992 (10 pages with 6 figures and 3 tables, RDB2A07)

J. L. Glajch and W. G. Schindel, **Column Packing for On-Line GC Analysis of Fluorocarbons in the**

Presence of Reactive Gases, *LC-GC*, volume 4, number 6, 1986 (RDB3512)

R-12, R-22, R-134a, separation of refrigerant mixtures

J. J. Healey, J. D. De Groot, and J. Kestin, **The Theory of the Transient Hot-Wire Method for Measuring Thermal Conductivity**, *Physica* A, Elsevier Science B.V., Amsterdam, The Netherlands, volume 82C, pages 392-408, 1976 (17 pages, RDB-5638)

measurement, instrumentation, thermophysical properties

R. Heide, **Pressure-Resistant Viscometer to Measure the Viscosity of Low Viscosity Liquids**, *Exp. Tech. Phys.*, volume 28, number 5, pages 477-483, 1980 (7 pages, in German, RDB4612)

measurement, instrumentation, thermophysical properties

H. Kelker, **Determination of Inert Gas Components in Refrigerants by Means of Gas Chromatography**, *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 11, pages 101-103, 1959 (3 pages, RDB4746)

D. F. Huttenlocher (General Electric Company), **A Bench Scale Test Procedure for Hermetic Compressor Lubricants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 11, number 6, pages 85-89, June 1969 (5 pages, RDB2421)

D. F. Huttenlocher (General Electric Company), **Accelerated Sealed-Tube Test Procedure for Refrigerant 22 Reactions**, *Proceedings of the 1972 Purdue Compressor Conference*, Purdue University, West Lafayette, IN, July 1972 (RDB4927)

R-22

E. Jones, **Determining Pressure Drop and Refrigerant Flow Capacities of Liquid Line Driers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 6, number 2, pages 70 ff, February 1964 (RDB4A34)

filter-driers, test method

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**, volume I of report DOE/CE/23810-41, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, September 1995 (134 pages with 70 figures and 18 tables, available from JMC as RDB6201)

This report summarizes an investigation of analytical techniques for development of an accelerated method of compatibility testing. The resulting method was designed to be safe and to produce chemical and thermal stability rankings that are consistent with those from conventional thermal-aging tests, independent of refrigerant-lubricant compositions, and suited for a wide variety of materials. The work expands on earlier screening of techniques [see RDB3501] that found in situ measurement of electrical conductivity to be the most suitable. The present report presents data from sealed-tube tests, performed in accordance with ANSI/ASHRAE Standard 97-1989, for R-12, R-22, R-134a, and R-32/134a (30/70) with lubricants and valve-steel catalysts. The specimens were aged at 175 °C (347 °F) for four weeks; the R-12 samples were aged only for two weeks. Comparative data using the conductivity screening method, for up to one-week at the same temperature, also are presented. Additional data are provided for ramped temperatures from 175-205 °C (347-401 °F) for R-12, R-22, and R-134a and lubricants, with and without steel catalysts, and for R-22 with additized polyolester lubricants. The report concludes that there is some agreement between the methods and that the new method may be more sensitive to degradation. It cautions that the new approach should be viewed as a supplement rather than a replacement for conventional methods, pending further testing and evaluation. An appendix shows the gas chromatograms for the pretest and aged refrigerant-lubricant mixtures. A second provides plots of in situ conductivity measurements for the refrigerant-lubricant mixtures. A third appendix describes determination of the volatile degradation product fraction. A final appendix identifies the lubricant samples, which included a naphthenic mineral oil (Witco Suniso(R) 3GS), two paraffinic mineral oils (Penreco Sontex 160LT and 200LT), an alkylbenzene (Shrieve Zerol(R) 150), two polyglycols (Dow P-425 and ICI Emkarox(R) RL 118D), and four polyolesters (POEs). The POEs include two pentaerythritol ester mixed acids (ICI Emkarate(TM) RL 22H and Mobil EAL Arctic(R) 22A) and two pentaerythritol ester branched acids (Henkel Emery(R) 2928 and Castrol Icematic(R) SW32). The refrigerant specimens were obtained from PCR Incorporated.

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part II: Experimental Comparison and Verification of Methods**,

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volume II of report DOE/CE/23810-41, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, September 1995 (1 3½" computer disk accompanied by an 8 page report with 1 table, available from JMC - use 28 pages to determine cost - as RDB6202)

This report provides supporting data from an investigation of analytical techniques to develop an accelerated method of compatibility testing. The resulting method was designed to be safe and to produce chemical and thermal stability rankings that are consistent with those from conventional thermal-aging tests, independent of refrigerant-lubricant compositions, and suited for a wide variety of materials. The work expands on earlier screening of techniques that found in situ measurement of electrical conductivity to be the most suitable. This volume comprises a disk with measured data and a description of the data format.

R. E. Kauffman (University of Dayton Research Institute), **Accelerated Screening Methods for Determining Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures, Part I: Method Assessment**, report DOE/CE/23810-10, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1993 (42 pages with 2 figures and 1 table, available from JMC as RDB-3501)

This report presents the results of a literature search. It addresses analytical techniques suitable for development into accelerated screening tests, to evaluate the chemical and thermal stabilities of refrigerant-lubricant combinations. The search focused on chemical stability data for R-12, R-22, R-134a, and other refrigerant candidates as well as thermal analytical techniques. The computerized search sources and approaches are summarized. Identified literature and prepared abstracts are categorized as analyses of chlorine-free refrigerants, analyses of chlorinated refrigerants, and accelerated thermal analytical techniques. Other documents are listed in an appendix. Evaluation criteria for candidate compatibility tests are indicated. Identified methods are discussed, and two differential thermal analytical (DTA) techniques are outlined for further development. Initial results are presented for one method for separate combinations of R-12 and R-22 with mineral oil. The candidate techniques will be evaluated in a second phase of the project.

K. Kutsuna, Y. Inoue, and T. Mizutani, **Real Time Oil Concentration Measurements in Automotive Air Conditioning by Ultraviolet Light Absorption**, paper 910222, Society of Automotive Engineers (SAE), Warrendale, PA, 1991 (RDB4C25)

D. E. Kvalnes, **The Sealed Tube Test for Refrigeration Oils**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 138-142, 1965 (RDB2324)

R-12, metal catalysts

B. I. Lee and M. G. Kesler (Mobil Research and Development Corporation), **A Generalized Thermodynamic Correlation Based on Three-Parameter Corresponding States**, *AIChE Journal*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 21, number 3, pages 510-527, May 1975 (18 pages, RDB3341)

J-Y. Lin and M. B. Pate (Iowa State University of Science and Technology), **A Methodology for Simultaneously Measuring Thermal Conductivity and Viscosity of Refrigerant Mixtures**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 43-48, July 1994 (6 pages with 2 tables, RDB4808)

J-Y. Lin and M. B. Pate (Iowa State University of Science and Technology), **A Thermal Conductivity Prediction Method for Refrigerant Mixtures in the Liquid Phase**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 365-374, July 1992 (10 pages with 8 figures and 1 table, RDB2819)

R. Masui, W. M. Haynes, R. F. Chang, H. A. Davis, and J. M. H. Levelt Sengers (National Bureau of Standards, NBS, now the National Institute of Standards and Technology, NIST), **Density in Compressed Fluids by Combining Hydrostatic Weighing and Magnetic Levitation**, *Review of Scientific Instruments*, American Institute of Physics (AIP, Woodbury, NY), volume 55, pages 1132-1142, 1984 (11 pages, RDB4311)

M. O. McLinden (National Institute of Standards and Technology, NIST), **Thermodynamic Evaluation of Refrigerants in the Vapor Compression Cycle Using Reduced Properties**, *International Journal of Refrigeration* (IJR), Paris, France, volume 11, pages 134-143, 1988 (RDB3212)

L. Z. Meltser, T. S. Dremluh, L. B. Silina, and Y. P. Ram'yalg (Odessa Technological Institute, USSR), **Uses of IR-Spectroscopic and Gas-Liquid Chromatographic Methods for Evaluating the Stability of Lubricating Oils**, *Kolloidnyi Tekhnika*, volume 16, pages 93-98, 1973 (6 pages, in Russian, RDB4A24)

J. J. Meyer and J. M. Saiz Jabardo (University of Illinois at Urbana-Champaign), **An Ultrasonic Device for Measuring the Oil Concentration in Flowing Liquid Refrigerant**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 7, pages 481-486, September 1994 (6 pages with 11 figures, RDB4B72)

This article describes a pulse-echo technique and ultrasonic transducer developed for real-time, in place measurement of the acoustic velocity of flowing liquid refrigerant. Combined with temperature measurement, the results enable monitoring of oil concentrations in liquid refrigerants. The article reviews the principles, theory of operation, experimental set-up, and procedures used for verification. It also discusses transit-time measurements, pressure effects, and comparisons to prior research findings. Data were taken for R-12 with 0.0-10.64% by mass naphthenic mineral oils (Witco Suniso(R) 3GS and 5GS) and for R-134a with 0.0-9.11% unidentified, ester-based lubricant. The tests covered -22 to 40 °C (-8 to 104 °F). The predicted concentrations based on velocity and temperature measurements and deviations are plotted for water, R-12/mineral oil, and R-134a/ester-based lubricant. Analyses showed that the predicted oil concentration depends linearly on both speed of sound and temperature. Measured data are compared for the new method and the standard technique for determining oil concentration, using ASHRAE Standard 41.4-1984. Uncertainties were of the order of ¼% by weight at typical system concentrations. A slight dependence of acoustic velocity on pressure was found. The article notes that the technique addressed is limited to liquid-line measurements.

J. J. Meyer and J. M. Saiz Jabardo, **An Ultrasonic Device for Measuring the Oil Concentration in Flowing Liquid Refrigerant**, report TR-24, Air-Conditioning and Refrigeration Center (ACRC), University of Illinois at Urbana-Champaign, Urbana, IL, September 1992 (10 pages, RDB5443)

F. T. Murphy (ICI Klea, UK), R. E. Low (ICI Klea, USA), S. Corr (ICI Klea, UK), and B. E. Gilbert (ICI Klea, USA), **Scaling Factors for Compressor Ratings Tables**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 96-106, October 1995 (11 pages with 6 figures and 3 tables, available from JMC as RDB5A50)

R-404A, R-407A, R-407B, R-507A: compressor performance, calorimetry rating tables, capacity correction, subcooling, extension to other suction gas temperatures and pressures

N. S. Nathoo and W. G. Gottenberg, **A New Look at Performance Analysis of Centrifugal Compressors Operating with Mixed Hydrocarbon Gases**, *Journal of Engineering for Power*, American Society of Mechanical Engineers (ASME), New York, NY, volume 105, number 4, pages 920-926, 1983 (7 pages, RDB4630)

C. A. Nieto de Castro (Universidade de Lisboa, Portugal), J. C. G. Calado, W. A. Wakeham, and M. Dix, **An Apparatus to Measure the Thermal Conductivity of Liquids**, *J. Phys. E. Sci. Instr.*, volume 9, pages 1073-1079, 1976 (7 pages, RDB5637)

thermodynamic properties, thermophysical data

D. A. Nissen and D. C. Macmillan (Sandia National Laboratories), **Apparatus for the Precise Measurement of the Physical Properties of Liquids at Elevated Temperature and Pressure**, *Review of Scientific Instruments*, American Institute of Physics (AIP, Woodbury, NY), volume 54, number 7, pages 861-867, July 1983 (7 pages with 7 figures and 4 tables, RDB2818)

This paper describes an instrument designed for measuring the viscosity, surface tension, and density of liquids at temperatures up to 900 °C (1650 °F) and pressures up to 10 atm (147 psia). The theoretical principles, details of construction and operation, and response of the instrument are discussed in detail. The thermodynamic properties of a molten salt mixture was measured for 250-450 °C (482-842 °F) in argon to test its accuracy. The results are shown to be in excellent agreement with published data from prior studies.

D. A. Nissen, **A Single Apparatus for the Precise Measurement of the Physical Properties of Liquids at Elevated Temperature and Pressure**, report SAN080-8034, Sandia National Laboratories, Albuquerque, NM (then Livermore, CA), 1980 (30 pages with 9 figures and 7 tables, available from JMC or NTIS, RDB2248)

This report describes an instrument designed for measuring the viscosity, surface tension, and density of liquids at temperatures up to 900 °C (1650 °F) and pressures up to 10 atm (147 psia). The theoretical principles, details of construction and operation, and response of the instrument are discussed in detail. The thermodynamic properties of a molten salt mixture was measured for 250-450 °C (482-842 °F) to test its accuracy. The results are shown to be in excellent agreement with published data from prior studies.

R. S. Olsen (General Electric Company), **Sealed-Tube Techniques for Hermetic Enamel Evaluation**, paper 71C38EI-38, *Proceedings of the Tenth Electrical Insulation Conference* (EIC, Chicago, IL,

please see pages 6-8 for ordering information

20-23 September 1971), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 119 ff, 1971 (RDB6626)

compatibility with motor materials, magnet wire, varnish

W. A. Pennington (Carrier Corporation), **Refrigerant Sampling**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 58, pages 261-265, March 1950 (5 pages with 3 figures and 5 tables, RDB6604)

techniques for obtaining a representative sample of refrigerant for analysis

W. A. Pennington (Carrier Corporation), **Determination of Water in Freon-12**, *Analytical Chemistry*, volume 21, page 766 ff, 1949 (RDB6606)

R-12, water content

W. C. Percival (E. I. duPont de Nemours and Company), **Quantitative Determination of Fluorinated Hydrocarbons by Gas Chromatography**, paper 203 (Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, February-March 1956); republished Delaware Chemical Symposium (Newark, DE, 18 February 1956); republished in *Analytical Chemistry*, volume 29, number 1, page 20-24, January 1957 (5 pages with 5 figures and 5 tables, RDB6615)

R-12/11, R-12/114, composition and contaminant determination in refrigerant mixtures

U. Plöcker, H. Knapp, and J. Prausnitz, **Calculation of High-Pressure Vapor-Liquid Equilibria from a Corresponding-States Correlation with Emphasis on Asymmetric Mixtures**, *Industrial Engineering Chemical Process Design Development*, volume 17, number 3, pages 324-332, 1978 (9 pages, RDB2337)

U. Plöcker (Technische Universität Berlin, Germany), **Berechnung von Hochdruck-Phasengleichgewichten mit einer Korrespondenzmethode unter besonderer Berücksichtigung asymmetrischer Gemische** [Calculation of High-Pressure Phase Equilibria by Means of a Correspondence Method Under Special Consideration of Asymmetric Mixtures], translation of doctoral dissertation, Oak Ridge National Laboratory, Oak Ridge, TN, undated circa 1992 (RDB3343)

see RDB3342 for original language version

U. Plöcker, **Berechnung von Hochdruck-Phasengleichgewichten mit einer Korrespondenzmethode unter besonderer Berücksichtigung asymmetrischer Gemische** [Calculation of High-Pressure Phase Equilibria by Means of a Correspondence Method Under Special Consideration of Asymmetric Mixtures], doctoral dissertation, Technische Universität Berlin, Berlin, Germany, 1977 (181 pages, in German, RDB3342)

see RDB3343 for translation

P. Popovic and H. N. Shapiro (Iowa State University of Science and Technology), **A Semi-Empirical Method for Modeling a Reciprocating Compressor in Refrigeration Systems**, paper 3912, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 367-382, 1995 (25 pages with 17 figures and 5 tables, RDB6336)

R-12, R-22, R-134a, R-401A (tested with R-22/-152a/124 (52/15/33)], R-401C, R-32/134a (25/-75), and R-32/125/134a (30/10/60) and (23/-20/57), simplified compressor model, prediction of mass flow rates and input power

F. T. Reed, **Moisture Determination in Refrigerant-Oil Solutions by the Karl Fischer Method**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 62, July 1954 (RDB6619)

refrigerant-lubricant mixtures, water content

R. G. Richard and I. R. Shankland (AlliedSignal Incorporated), **A Transient Hot-Wire Method for Measuring the Thermal Conductivity of Gases and Liquids**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, number 3, pages 673-686, 1989 (11 pages with 1 figure and 1 table, RDB5620)

thermodynamic properties, thermophysical data

H. M. Roder, **A Transient Hot Wire Thermal Conductivity Apparatus for Fluids**, *Journal of Research of the NBS*, National Institute of Standards and Technology (NIST, then the National Bureau of Standards, NBS), Gaithersburg, MD, volume 86, pages 457-493, 1981 (RDB5639)

measurement, instrumentation, thermophysical properties

N. D. T. Rohatgi and H. O. Spauschus (Spauschus Associates, Incorporated), **Method for Determining Flexural Property Changes of Polymeric Materials upon Accelerated Aging in Refrigerant-Lubricant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette,

IN, volume 2, pages 395-403, July 1992 (9 pages with 6 figures and 6 tables, available from JMC as RDB2822)

This paper describes a test method to determine changes in flexural properties of small samples of polymeric materials after aging in refrigerants and/or lubricants. The method uses linear stress versus strain curves and calculated flexural modulus of materials. Changes after thermal aging are used to indicate whether a material becomes more flexible (due to absorption of liquid lubricant or refrigerant-lubricant mixture) or less flexible (due to possible extraction of material from the polymeric matrix by the liquid phase). The effects of aging time and temperature also are addressed. The procedure provides quantitative measurements which, along with visual observations, linear swelling and changes in hardness, are necessary to interpret compatibility results from sealed-tube tests. Results are reported for glass-reinforced nylon 6/6, flexible nylon alloy, plasticized nylon copolymers, and polyamide 1212 in R-12 with mineral oil and in R-134a with an unidentified polyalkylene glycol (PAG) lubricant. Density, Shore durometer D hardness, flexural modulus, visual observations, and dimensional changes are tabulated. Stress versus strain curves are plotted both before and after aging.

N. Rosahl and W. Ecknig, **A Gas Chromatographic Method for Determining Oil Remaining in a Compressor**, *Chem. Tech.*, Leipzig, Germany, volume 32, number 11, pages 589-593, 1980 (5 pages, in German, RDB4644)

S. Rosen, A. A. Sakhnovsky (University of Miami), R. B. Tilney (Alco Valve Company), and W. O. Walker (University of Miami), **A Method of Evaluating Filtration and Flow Characteristics of Liquid Line Refrigeration Driers**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, 1965 (6 pages with 6 figures and 5 tables, RDB4A33)

This paper describes a test method for evaluating the filtration capabilities of a liquid-line, filter-driers. The method is based on measurement of the flow and pressure drop of R-113 with added grit through test filters. The grit used is a silicon carbide abrasive grain, selected because it is inexpensive, inert, nonporous, readily available, and easy to see in the refrigerant. The paper discusses the need for a test method, the rationale for use of R-113, the test loop, refrigerant circulation pump, and venturi flow meter. It describes the flow and pressure drop calibration, correlation of R-113 and R-22 flow data, selection of the grit, and the test procedure. A simplified schematic is provided for the apparatus. The paper then presents results for six different types of driers. Measured pressure drops are tabulated for the driers with varied flow rates and grit quantities for three grit sizes. The conclusions indicate a need for a standard rating method.

A. Saitoh, H. Sato, and K. Watanabe (Keio University, Japan), **A New Apparatus for the Measurements of the Isobaric Heat Capacity of Liquid Refrigerants**, *International Journal of Thermophysics*, Plenum Publishing Corporation, Brugge, Belgium, volume 10, pages 649-660, 1989 (12 pages with 1 figure and 1 table, RDB5336)

property measurement, thermophysical data

K. S. Sanvordenker and W. J. Gram (Tecumseh Products Company), **Laboratory Testing Under Controlled Environment Using a Falex Machine**, *Proceedings of the 1974 Purdue Compressor Technology Conference*, Purdue University, West Lafayette, IN, pages 67-75, July 1974 (RDB2527)

K. S. Sanvordenker and M. W. Larime (Tecumseh Products Company), **Screening Tests for Hermetic Magnet Wire Insulation**, paper 71C38EI-39, *Proceedings of the Tenth Electrical Insulation Conference* (EIC), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 122-126, September 1971 (5 pages with 3 figures and 5 tables, RDB2424)

This paper examines both the test methods and results of testing, for magnet wire insulation for hermetic compressors using R-22. Abrasion results (average cycles to failure) are tabulated and plotted as received and following exposures for 7-10 days, one month, and three months. The insulations examined included two batches of urethane modified polyvinyl formal (FU), two batches of polyester-imide (PEI), dual coat amide-imide topcoat on a polyester base (AI/PE), dual coat polyester (PE/PE), and polyimide (PI). The temperature and elapsed time for burnout are tabulated, for these five types of insulations, and compared between environments of R-22 and air. Data on retained dielectric strength are presented for FU, PEI, AI/PE, PE/PE, and for Formvar urethane and polyesteramide imide (PEAI); blister, resistance is tabulated for all but PE/PE. Because the interactions of enamels and R-22, the paper suggests that the rate of R-22 absorption be determined and exposures adjusted for complete saturation. Tests after saturation provide a common basis for comparisons and suitable screening approach for structurally-different enamels.

please see pages 6-8 for ordering information

K. S. Sanvordenker (Tecumseh Products Company), **A Rapid Plant Scale Quality Control Test for Refrigeration Oils**, *Transactions* (Annual Meeting, Lake Placid, NY, 22-24 June 1968), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 74, number 2, 1968; republished in **Today's Compressor Lubrication and its Environmental Chemistry in Hermetic Lubrication**, ASHRAE, pages 7-20, 1968 (14 pages with 3 and 5 tables, RDB6713)

presents a simplified, factory test method for preliminary evaluation and acceptance of refrigeration lubricants; the procedure involves aging an oil sample with copper and steel catalysts and R-10 (carbon tetrachloride) in a screw-cap test tube for 16 hours at 107 °C (225 °F); results are gauged by the acid number following titration; summarizes tests and nominal properties and refining methods of 11 commercial oils; provides plots and tables of measured results and dependence of acid number on the aging time and temperature; discusses repeatability and influences of each test parameter; shows the fraction of R-22 formed, measured by gas chromatography, in sealed-tube tests of the same lubricants and metals with R-12 at 175 °C (347 °F); discusses the roles of contaminants; includes discussion of the paper by C. M. Bosworth (Carrier Corporation), L. C. Flowers, and H. M. Elsey that notes the stabilizing influence of copper, versus steel alone, in decomposition reactions

R. R. Singh, H. T. Pham, and I. R. Shankland (AlliedSignal Incorporated), **Some Issues in the Use Of Refrigerant Mixtures**, presented at the 1992 International Refrigeration Conference (Purdue University, West Lafayette, IN, July 1992), published in *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 455-463, July 1994 (9 pages with 11 figures, RDB4861)

This paper summarizes an investigation of segregation of R-32/134a (30/70), proposed as an alternative for R-22, into its components. The paper briefly cites the benefits of zeotropic refrigerant blends and introduces preferential fractionation based on differences in vapor pressure. It notes that the vapor phase composition is enriched in the more volatile component, compared to the liquid phase, so the more volatile component is lost faster in a vapor leak. The paper discusses the implications for performance, flammability, and recharging. Leakage was simulated with a variable vapor leak. Plots illustrate the dependence of measured capacity, efficiency, and temperature glide on composition. A second series contrasts the vapor and liquid compositions to the flame limit to the fraction of lost charge at -20 and 40.2 °C (-4 and 104 °F). Three final plots show the capacity and corrected capacity for 10 and 20% leak rates at -20 °C (-4 °F) with one to five recharges. The paper reports that fractionation depends on the temperature, can result in potentially flammable vapors, and that continual loss in capacity will occur with recharging if the losses exceed 10%.

Y. W. Song, J. L. Yu, and S. Y. Fu, **KDR-1 Thermal Conductivity Instrument for Liquid and Solid by Transient Hot-Wire Method**, *Chinese Journal of Scientific Instrumentation*, China, volume 6, pages 369-381, 1985 (13 pages, RDB5640)

measurement, instrumentation, thermophysical properties

H. O. Spauschus (Spauschus Associates, Incorporated), G. Freeman, and T. L. Starr (Georgia Tech Research Institute, GTRI), **Surface Analysis of Glass from Sealed Tubes After Aging with HFC-134a**, presentation charts (ASHRAE Annual Meeting, Baltimore, MD, June 1992), Spauschus Associates, Incorporated, Atlanta, GA, USA, June 1992 (21 pages with 7 figures and 2 tables, available from JMC as RDB2729)

This presentation reported findings of an investigation of the sealed-tube test procedure. The study examined whether fluoride decomposition products, formed in aging hydrofluorocarbons (HFCs) at high-temperature, react with the glass surface. The underlying concerns are that such reactions might destroy evidence of other chemical reactions and might also weaken the tubes, posing a safety risk. These concerns challenge the suitability of the ANSI/ASHRAE Standard 97-1989 test procedure for HFCs, and other refrigerants. The charts outline prior studies for and against fluoride attack of glass and an experiment to investigate the issue. Glass shards from sealed tubes, used in thermal aging tests, were examined by photoelectron spectrometer. No fluoride was detected from any tube except one treated with hydrofluoric acid (HF). The study concluded that R-134a undergoes neither thermal decomposition nor reactions with lubricants, metals, or glass at temperatures as high as 200 °C (392 °F). No evidence was found of fluoride formation in the absence of catalysts, such as molecular sieves. The study also concluded that boroslilicate glass tubes are suited as reaction vessels for sealed-tube tests. (See RDB2217, RDB2326, RDB2327, RDB2329, and RDB2526 for related papers)

H. O. Spauschus and D. R. Henderson (Spauschus Associates, Incorporated), **New Methods of Determining Viscosity and Pressure of Refrigerant-Lubricant Mixtures**, *Proceedings of the 1990*

USNC/IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 173-176, July 1990 (4 pages with 7 figures, 6 page preprint available from JMC as RDB2249)

This paper describes new methods for measuring viscosity and vapor pressure of refrigerant-lubricant mixtures for compositions of 0-100% and temperatures from -40 to 150 °C (-40 to 300 °F). The equipment and methods also can be applied to fluids for absorption systems. Automatic data acquisition, data reduction, and computer generated graphics are utilized. Typical viscosity-pressure-temperature-composition data are presented to illustrate engineering applicability. The method uses a new viscometer, based on electromagnetic forces and the time required for a metallic piston to traverse a known distance through the fluid.

H. O. Spauschus and D. R. Hurst, **New Stability Test Methods for Alternative Refrigerants and Mixtures**, presentation slides and abstract (seminar on *Ozone/CFC - Alternative Studies Update*), ASHRAE 1989 Annual Meeting (Vancouver, BC, Canada, 24-28 June 1989) Spauschus Associates, Atlanta, GA, June 1989 (15 pages, available from JMC as RDB0544)

H. O. Spauschus and R. A. Sellers (General Electric Company), **Apparatus and Procedures for Evaluating Dielectric Properties of Wire Enamels in Controlled Environments**, paper 32C79-66, *Proceedings of the Seventh Electrical Insulation Conference* (EIC, October 1967), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 191-193, 1967; republished in, *Journal of Electrical Insulation*, IEEE, volume EI-3, number 3, pages 82-87, August 1968 (6 pages with 7 figures and 1 table, RDB6650)

R-12, R-22, compatibility, dielectric properties, motor materials, varnishes

H. O. Spauschus and R. S. Olsen (General Electric Company), **Gas Analysis - A New Tool for Determining the Chemical Stability of Hermetic Systems**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 67, pages 25 ff, February 1959 (RDB4A31)

H. Steinle (Robert Bosch GmbH, Germany), **Kältemachinenöle, Mindestanforderungen, Neufassung Juli 1963** [Refrigeration Machine Oils, Minimum Requirements, July 1963 Revision], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 15, number 7, pages 204 ff, 1963; republished in *Erdöl und Kohle* [Petroleum and Coal], Germany, volume 16, number 8, pages 867 or 1867 ff, 1963 (in German, RDB6679)

test methods, refrigeration lubricants

H. Steinle (Robert Bosch GmbH, Germany), **Bestimmung der Kältemittel-Beständigkeit von Kältemachinenölen (Philipp Test), Entwurf DIN 51 593** [Determination of Refrigerant Stability with Refrigeration Machine Oils (Philipp Test), Preliminary German Institute for Normalization Standard 51 593], *Kältetechnik*, Verlag C. F. Müller, Karlsruhe, Germany, volume 6, number 12, pages 342 ff, 1954 (in German, RDB6677)

test methods, refrigerant-lubricant stability

H. Steinle (Robert Bosch GmbH, Germany), **Entwurf DIN 6553, Kältemachinenölen** [Preliminary German Institute for Normalization Standard 6553, Refrigeration Machine Oils], *Erdöl und Kohle* [Petroleum and Coal], Germany, volume 3, pages 334 ff, 1950 (in German, RDB6678)

test methods, refrigeration lubricants

G. H. Wagner, G. C. Bailey, and W. G. Eversole, **Determining Liquid and Vapor Densities in Closed Systems**, *Industrial and Engineering Chemistry*, American Chemical Society (ACS), Columbus, OH, volume 14, number 2, pages 129-131, 1942 (3 pages, RDB4288)

W. O. Walker (University of Miami), **Sealed-Tube Tests: A Comparison of Methods**, *Transactions* (Semiannual Meeting, Chicago, IL, 25-28 January 1965), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 71, part I, pages 134-137, 1965 (RDB-6712)

catalytic effects, refrigerant lubricant reactions, compatibility

W. W. Wareham, **New Standards and Tests for Hermetic Motor Wire**, *Proceedings of the Ninth Electrical Insulation Conference* (EIC, Boston, MA, 8-11 September 1969), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, pages 250-253, 1969 (RDB6648)

compatibility, motor materials

W. W. Wareham, **Screening Tests for Hermetic Wire**, *Proceedings of the First Electrical Insulation Conference* (EIC, September 1958), Institute of Electrical and Electronic Engineers (IEEE), New York, NY, 1958 (RDB6662)

compatibility, motor materials

L. A. Weber and A. M. Silva (National Institute of Standards and Technology, NIST), **Report on the Design and Testing of a New High Pressure**

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Ebulliometer for Studying the Thermodynamics of Refrigerant Mixtures, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 31-36, July 1994 (6 pages with 4 figures, RDB4806)

H. Wijaya and H. M. Hughes (AlliedSignal Incorporated), **A Proposed Procedure for Qualifying Halogen Leak Detectors**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD), Alliance for Responsible CFC Policy, Arlington, VA, November 1990 (9 pages with 10 figures and 3 tables, RDB2316)

X. Xu and D. Clodic (École des Mines de Paris, France), **Exergy Analysis on a Vapor-Compression Refrigerating System Using R12, R134a, and R290 as Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 231-240, July 1992 (10 pages with 3 figures and 8 tables, RDB2725)

R-12, R-134a, and R-290

H. K. Yoon, C. H. Poppe, and C. Cusano (University of Illinois at Urbana-Champaign), **Screening Lubricants for Refrigerant Compressors: A Comparison Between a Pin and Block Tester and the High-Pressure Tribometer**, paper 3907, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 322-334, 1995 (13 pages with 10 figures and 12 tables, RDB6330)

This paper summarizes research to improve screening methods for lubricants for air-conditioning and refrigeration compressors. It compares data obtained with a high pressure tribometer (HPT) and those by other methods. The paper notes drawbacks in popular methods, such as Falex(TM) testing and compressor bench tests. The specimen data, test parameters, and refrigerant-lubricant combinations are tabulated. The friction and wear data are plotted and resulting rankings of lubricants are compared to those for three combinations of load and speed with the HPT. The tests employed R-134a and R-32/125/134a (30/10/60) with unidentified polyolester (POE) lubricants as well as R-12 and R-22 with mineral oils.

H. L. Yu, R. Y Li (Shanghai Institute of Mechanical Engineering, China), and D. K. Chen (Concordia University, Canada), **Experimental Comparison on Performance of Rotary Compressors with Different HFC-134a Compatible Lubricants**, paper 3908, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 335-340, 1995 (6 pages with 5 figures and 3 tables, RDB6331)

R-134a with five unidentified lubricants compared to R-12 with mineral oil

Analytical Procedures for ARI Standard 700-93, Appendix 93 to ARI Standard 700, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1993 (176 pages with 40 figures and 40 tables, available from ARI for $75.00, RDB4943)

This document identifies definitive test procedures to determine the quality of new, reclaimed, and/or repackaged refrigerants for use in new and existing refrigeration equipment. These procedures are identified as referee methods; users must be able to demonstrate that the results of alternative test procedures employed are equivalent. Information is provided on the sensitivity, precision, and accuracy of each method. The tests covered are for determination of acidity, water (moisture) by Karl Fischer coulometric titration, high boiling residue by volumetric and/or gravimetric measurement, visual particulate residue, chloride content by silver chloride precipitation, and noncondensable gas content by gas chromatography (GC). The document also identifies GC procedures to determine the purity of R-11, R-12, R-13, R-22, R-23, R-32, R-113, R-114, R-123, R-124, R-125, R-134a, R-143a, R-401 series blends (R-22/152a/124), R-402 series blends (R-125/290/22), R-500, R-502, and R-503.

A Standard Calorimeter Test Method for Flow Measurement of a Volatile Refrigerant, ANSI/-ASHRAE Standard 41.9-1988, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1988 (20 pages with 7 figures, available from ASHRAE for $12 to members and $18 to nonmembers, RDB5218)

This standard outlines recommended practices to measure the rate of flow of volatile refrigerants using a calorimeter. It is intended for use where the entire flow stream enters the calorimeter as a subcooled liquid and leaves as a superheated vapor or the reverse, identified as evaporator- and condenser-types, respectively. The standard defines the terminology used and calorimeter classifications. It also outlines requirements for values to be determined, standard and confirming test methods, test conditions, and safety. It then details the types and precisions of instruments and measurements, describes the apparatus, and test methods and procedures. Schematics show the instrumentation points. The standard identifies the data to be recorded and calculations to reduce the

measured data to final values. An appendix illustrates how to calculate the uncertainty in mass flow rate for representative test conditions.

Lubricity Determination Apparatus for Lubricating Oils Used in Refrigerators, report JP55-55255, Tokyo Shikaura Electric Company, Limited, Japan, 23 April 1980 (in Japanese, RDB4667)

Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), standard test method D445-85, American Society for Testing and Materials, West Conshoshocken, PA, 1985 (RDB4353)

Methods of Testing Discharge Line Refrigerant-Oil Separators, ANSI/ASHRAE Standard 69-1990, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1990 (20 pages with 13 figures, available from ASHRAE for $13 to members and $19 to nonmembers, RDB5217)

This standard provides a uniform test method to determine the capability of a discharge-line oil separator to remove oil from refrigerant. It defines the terminology used, specifies the data required, specifies the calculations involved, and describes the equipment required for the test. A secondary purpose of the standard is to facilitate and encourage necessary research in this area, by providing two procedures for measurement of oil carryover. The first can be used for high concentrations (≥2500 ppm) with low oil-flow rates (≤7.5 l/min, ≤2 gpm), as in reciprocating compressors, and does not require a chemical analysis. The second can be used for low concentrations and high oil-flow rates, as in oil-injected screw compressors, but requires an infrared spectrophotometer. Both methods are detailed and schematically illustrated. The standard describes the test methods, reviews equipment provisions, specifies the instrumentation requirements, identifies the data to be recorded, and provides calibrations procedures and methods to calculate the results.

Methods of Testing the Floc Point of Refrigerant Grade Oils, standard ANSI/ASHRAE 86-1983, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1989 (RDB3A07)

This standard outlines a uniform method for measuring the waxing tendency of oils in refrigeration systems. The floc point test is based on evaluation of the wax precipitation, at low temperatures, in a mixture containing 90% R-12 and 10% oil by volume. The results are intended for comparisons of different oils.

Refrigerant Extraction Test, Copeland Corporation, Sidney, OH, undated circa 1989 (4 pages with 1 table, available from JMC as RDB0005)

This procedure outlines a test to determine the amount of extractable residue in materials that are used in hermetic refrigerant system when exposed to refrigerant environments. Extractables are determined as the fraction of weight loss after exposure to evaporating refrigerant at elevated temperature and pressure. Charging data are provided for R-12, R-22, and R-502.

Refrigerant-Lubricant Soak Test, Copeland Corporation, Sidney, OH, undated circa 1989 (3 pages, available from JMC as RDB0007)

This procedure outlines a test to determine the effect of materials exposed to a refrigerant-lubricant mixture at operating conditions. The parameters determined are dimensional, including swell, and weight change; visual observations of decomposition also are addressed. The procedure described is based on thermal-aging in a pressure vessel, preceded and followed by measurements.

Sealed Glass Tube Method for Determining the Stability of Materials Used within Refrigeration Systems, product engineering specification ES23-138, Copeland Corporation, Sidney, OH, 11 May 1987 (10 pages with 1 figure and 2 tables, available from JMC as RDB0006)

This procedure outlines a sealed-tube test to rate the quality of lubricants with R-12. It is based on visual inspection of the oil and metal (steel and copper) test strips and the amount of reactivity, determined by gas chromatography, after thermal aging at 175 °C (347 °F) for 3- and 14-day periods.

Sealed Tube Method to Test the Chemical Stability of Material for Use within Refrigeration Systems, ANSI/ASHRAE Standard 97-1989, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1989 (RDB2251)

compatibility test procedure

Standard Method for Measurement of Proportion of Oil in Liquid Refrigerant, ANSI/ASHRAE Standard 41.4-1984, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1984 (8 pages with 2 figures and 1 table, available from ASHRAE for $13 to members and $19 to nonmembers, RDB2924)

This standard outlines a uniform experimental method to determine the concentration of oil, by weight, in single-phase solutions in liquid refrigerant. The standard defines the terminology used and describes the equipment required.

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Schematics show the sampling vessel and bleeder assembly used. The test procedure entails evacuation, weighing, sampling, and separation of the refrigerant from the oil for a minimum of three samples. The document identifies the data to be recorded and provides equations to calculate the results.

Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four Ball Method), standard D4172-82, American Society of Testing and Materials (ASTM), West Conshohocken, PA, 1982 (RDB2923)

lubricant screening procedure

Test Method for Inorganic Acid Removal Capacity of Desiccants Used in Liquid Line Filter Driers, proposed research project 793-TRP, American Society of Heating, Refrigerating, Air-Conditioning Engineers (ASHRAE), Atlanta, GA, September 1994 - February 1996 (ASH0793)

This research will develop a method of testing desiccants, at liquid-line conditions, for inorganic acid removal capacity from circulating refrigerant. It then will demonstrate the consistency of the method with different desiccants and refrigerants. UOP molecular sieve 4AX-H6 (8x12), Rhône-Poulenc activated alumina grade A (3-5 mm), and Davison Chemical silica gel grade 407 (8-20 mesh) will be tested. It also will determine the solubility of hydrochloric acid (HCl) in R-12 and R-22 at specified temperatures. The work is needed to assist component manufacturers in design of filter driers with maximum performance. The need is heightened by increased refrigerant recycling and recovery. The contractor for the project is Imagination Resources, Incorporated (IRI), led by R. C. Cavestri; it is sponsored by Technical Committee 3.3, *Contaminant Control in Refrigeration Systems*.

IMPACTS

Costs and Operation

M. H. Blatt (Electric Power Research Institute, EPRI), **Electric Chillers: Cost-Effective Choice for the Future**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 3, pages 75-82, March 1993 (6 pages with 4 figures and 2 tables, RDB3412)

D. A. Didion (National Institute of Standards and Technology, NIST), **The Impact of Ozone-Safe Refrigerants on Refrigeration Machinery Performance and Operation**, paper 10, *Transactions* (Annual Meeting, New Orleans, LA, 17-18 November 1994), The Society of Naval Architects and Marine Engineers, Jersey City, NJ, 1994 (15 pages with 11 figures and 5 tables, RDB4B07)

The paper summarizes requirements for a refrigerant to sustain an efficient, reliable system. It briefly outlines both the development of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, to fill these needs, and the concerns with ozone depletion and global warming that have arisen since. It then summarizes criteria and tradeoffs for identification of alternatives, noting that a screening of 800 industrial chemicals produced essentially no exceptions to the conclusions reached by T. Midgley in 1928. The paper outlines recent steps to commercialize equipment using alternative refrigerants, with attention to R-123 for R-11 and R-134a for R-12. The paper cites technology advances introduced to improve product efficiency, despite the lower theoretical performance of these alternatives. It notes that attention has focused on refrigerant mixtures to replace R-22 and R-502, since no single-compound refrigerants have been identified to match their thermodynamic performance. Two tables summarize the designations, compositions, maximum temperature glide at atmospheric pressure, and trade names for candidate blends containing HCFCs and those that are chlorine free. These tables list R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-411A, R-411B, R-507A, R-32/125/143a (10/45/45), R-32/134a (30/70), and R-290/600a (50/50). The paper identifies advantages, concerns (e.g., composition shifting with leakage and recharging), and some circumventions for use of blends. It then addresses safety and outlines the classifications for flammability and toxicity introduced in ANSI/ASHRAE Standard 34. The paper illustrates composition shifts, with a phase diagram of R-32/134a, and the flammability shifts associated with leakage after vapor and liquid charging, for R-32/125/134a (30/10/60) and (23/25/52). The two ternary blends are developmental and commercialized versions, respectively, of R-407C. The paper outlines materials compatibility considerations, starting with stability, solubility, and lubricity of refrigerants with mineral oils. It discusses the shift from mineral oils to alkylbenzenes, polyalkylene glycols (PAGs), and polyolesters to achieve miscibility with hydrofluorocarbon (HFC) refrigerants. The paper addresses and illustrates moisture absorbance for different generic lubricant types. It

then draws generalized conclusions on the compatibility of new refrigerants and lubricants with motor materials, elastomers, and engineering plastics as well as refrigerant-lubricant compatibility. It outlines efforts to identify alternatives for R-114, especially for naval uses, and discusses the prospects for R-124, R-236ea, and R-236fa. Two appendices summarize the numbering system used to identify refrigerants and the status, advantages, and limitations of R-717 (ammonia).

J. D. Douglas, **A Cost-Based Method for Comparing Alternative Refrigerants Applied to R-22 Systems**, MS thesis, Purdue University, West Lafayette, IN, December 1995 (RDB6750)

R-290, R-290/227ea, cost-based evaluation of propane and propane-blends as replacements for R-22

R. El-Bourini, K. Hayashi, and T. Adachi (Calsonic Corporation), **Automotive Air Conditioning System Performance with HFC-134a Refrigerant**, paper 900214 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (12 pages with 14 figures and 3 tables, RDB2252)

R-134a

P. E. Hansen (Danfoss-Flensburg GmbH, Germany) and L. Finsen (Danfoss A/S, Denmark), **Lifetime and Reliability of Small Hermetic Compressors Using a Ternary Blend HCFC-22/HFC-152a/HCFC-124**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 641-649, July 1992 (9 pages with 6 figures and 2 tables, RDB2839)

R-22/152a/124, R-401 series

E. Heinzelmann and M. S. Ussyk (Empresa Brasileira de Compressores S/A, Embraco), **Hermetic Refrigerating Compressors and CFC Substitution**, *International Journal of Refrigeration* (IJR), Paris, France, volume 14, number 1, pages 10-15, January 1991 (6 pages with 11 figures, RDB1201)

This paper presents a basic methodology for screening substitutes for R-12 in refrigerating compressors. Simple analysis of refrigerant thermodynamic properties are presented within the ranges of evaporating and condensing temperatures in which small refrigerating systems operate. Comparisons of vapor pressure, coefficients of performance (COPs), compression ratio, final isentropic compression temperature, and volumetric refrigerant effect are presented for R-12, R-22, R-134a, and R-152a. Additionally, a procedure for developing compressors for use with alternative refrigerants is presented. Material compatibility, performance, reliability, and means of production are considered. The differences between developed and developing countries are noted, using Brazil as an example.

M. O. McLinden (National Institute of Standards and Technology, NIST) and R. K. Radermacher (University of Maryland), **Methods for Comparing the Performance of Pure and Mixed Refrigerants in the Vapor Compression Cycle**, *International Journal of Refrigeration* (IJR), Paris, France, volume 10, number 8, pages 318-325, November 1987 (8 pages with 8 figures and 2 tables, RDB2508)

M. O. McLinden (National Institute of Standards and Technology, NIST), **Optimum Refrigerants for Nonideal Cycles - An Analysis Employing Corresponding States**, *Proceedings of the 1990 USNC-IIR-Purdue Refrigeration Conference and ASHRAE-Purdue CFC Conference*, edited by D. R. Tree, Purdue University, West Lafayette, IN, pages 69-79, July 1990 (11 pages with 7 figures, RDB0920)

The principle of corresponding states is used to evaluate the effects of the thermodynamic characteristics of working fluid performance in refrigeration cycles. Desired characteristics, expressed in terms of the critical temperature and ideal gas heat capacity using propane as the reference fluid, are examined for various departures from the theoretical (ideal) vapor-compression cycle. The baseline cycle for the comparisons include compressor efficiency and heat transfer limitations in the condenser and evaporator. The paper addresses the modified Benedict-Webb-Rubin (MBWR) equation of state chosen for property calculations, the cycle analysis simulation model, and the application of the model to the selection of alternative refrigerants. The results indicate that modifications to the basic vapor-compression cycle should be considered for refrigerants with two or more carbon atoms to achieve maximum energy efficiency.

J. Pannock and D. A. Didion (National Institute of Standards and Technology, NIST), **Performance Evaluation of Refrigerant Mixtures in Heat Pumps**, report TR-102167, Electric Power Research Institute (EPRI), Palo Alto, CA, March 1993 (250 pages with 116 figures and 4 tables, RDB-3B10)

J. Pannock, D. A. Didion (National Institute of Standards and Technology, NIST), and R. K. Radermacher (University of Maryland), **Performance Evaluation of Chlorine-Free Zeotropic Refrigerant Mixtures in Heat Pumps - Computer Study and Tests**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and*

please see pages 6-8 for ordering information

New Refrigerants, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 25-34, July 1992 (10 pages with 8 figures and 2 tables, RDB2710)

J. Pannock, **Performance of Refrigerant Mixtures in Heat Pumps**, doctoral dissertation, Department of Mechanical Engineering, University of Maryland, College Park, MD, 1992 (RDB4879)

J. Pannock and D. A. Didion (National Institute of Standards and Technology, NIST), **The Performance of Chlorine-Free Binary Zeotropic Refrigerant Mixtures in a Heat Pump**, report NISTIR 4748, National Institute of Standards and Technology, Gaithersburg, MD, December 1991 (78 pages with 50 figures and 2 tables, available from NTIS at price code A05, RDB2507)

This report examines zeotropic mixtures to replace R-22. 15 binary blends of R-23, R-32, R-125, R-134a, R-143a, and R-152a (all hydrofluorocarbons, HFCs) were evaluated using the CYCLE11 simulation program. The rationale for selecting these component fluids is outlined. Efficiency, volumetric capacity, suction pressures, discharge temperatures, and discharge pressures are analyzed and compared. The most promising candidates, R-32/134a and R-32/152a, were tested in a breadboard heat pump. A series of tests to evaluate use of a liquid-line heat exchanger also was performed. The findings indicate that these two zeotropes may be suitable as replacements for R-22, but that multiple tradeoffs exist in performance for different compressor speeds and mixture compositions. Performance improvements of 2 and 14% were found for R-32/152a for the low-temperature heating and high temperature cooling modes, respectively. The ozone depletion potential of this mixture is zero and the global warming potential is approximately one-fourth that of R-22, but the mixture is flammable in the entire composition range. R-32/134a mixtures, containing more than 35% R-32 by mass, yielded slightly improved performance for cooling and slightly lower for heating. Gains of 5% for cooling and 2% for low-temperature heating were measured and compared to R-22 for the equivalent speed and capacities. These results were achieved using the same test apparatus, without optimization for each fluid. Comparative efficiencies and capacities are plotted for the full range of mass fractions at selected operating conditions. An uncertainty analysis is presented in an appendix, but the test results confirm the validity of the modelling approach used.

R. Schmitz (Tecumseh Products Company), **New High Efficiency R-134a Compressor**, *Proceedings of the 45th Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, 9-11 May 1994), IATC, Batavia, IL, pages 227-237, May 1994 (11 pages with 4 figures and 1 table, RDB4A27)

This paper outlines a new design for a hermetic compressor using R-134a and a polyolester (POE) lubricant. A figure shows a cutaway view of the compressor. A plot compares its efficiency with those for conventional R-12 designs in capacities of 2.4-3.4 kW (700-1000 Btu/hr), showing efficiency gains of 20-60%. The paper notes anticipation of further evolutionary improvement, to exceed a COP of 1.76 (6.0 Btu/Wh). The paper discusses the crankcase, crankshaft, bearing, and motor designs as well as changes to minimize suction and discharge plenum heat exchange, clearance volume, and re-expansion volume. Tabular data compare the operating conditions at inlet, intermediate points, and discharge for R-12 and R-134a. The paper also discusses suspension and housing design to reduce sound levels; a plot summarizes the results. The paper briefly cites early tests with polyalkylene glycol (PAG) lubricants and identified concerns with its hygroscopicity, partial miscibility with mineral oil used in manufacture, inadequate thermal stability, and offensive decomposition products. It mentions use of production driers and improved handling and processing to overcome the even higher hygroscopicity of POEs. Approved lubricants are identified, namely Castrol Icematic(R) SW-32, Henkel Emery(R) 2927-A, ICI Emkarate(TM) RL 32S, Mobil EAL Arctic(R) 15 and 22A, Penreco Sontex SEZ-22 and SEZ-32, and Witco Sunisо(R) SL22 and SL32. The paper notes that viscosity and stability issues remain with POEs, but that the effects of decomposition products can be controlled with a metal passivator developed to circumvent problems, specifically blocking the function of the necessary iron catalyst. The paper briefly cites other compatibility issues, and mentions potential capillary tube plugging related to unapproved compounds in drawing condenser tubing and use of an unwanted retardant by a plastic molder. The paper notes that known technical barriers have been resolved, and that resolution of remaining lubricant and additive package issues are underway.

M. W. Spatz (AlliedSignal Incorporated), **Performance of Alternative Refrigerants from a System's Perspective**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 352-361, 1991 (10 pages with 5 figures and 3 tables, RDB2253)

The modeled coefficients of performance (COPs), capacities, and discharge temperatures

for a representative 11 kW (3 ton) air-to-air heat pump are presented for R-22, R-32/125 (60/40), R-134a, and R-152a - all HFCs. The analyses were made with a modified version of the Oak Ridge National Laboratory (ORNL) Mark III Heat Pump System Design Model. Calculated COPs are tabulated both with simple replacement of R-22 and with reoptimization of the expansion device, heat exchangers, and tubing sizes. Calculations based on a simple (saturated) thermodynamic cycle indicate 8% lower, 1% lower, and 4% higher efficiency for R-32/125, R-134a, and R-152a, respectively, compared to R-22. The magnitude of these differences shrink when subcooling and superheating are introduced. With reoptimization, the differences range from -0.3 to 3.2% for a system optimized for both the heating and cooling modes and -0.9 to 0.6% for cooling only, depending on the refrigerant. The paper, therefore, concludes that while these three alternative refrigerants could be used without significant energy penalty, other factors need to be addressed. The approximately 50% higher condensing pressure of R-32/125 could increase costs. Changes in compressor displacement, increased for R-134a and decreased for R-32/125, also effect system costs. The flammability of R-152a would either eliminate it from consideration or impact costs by requiring additional safety controls.

T. G. Statt (U.S. Department of Energy, DOE), **Energy Implications of Global Climate Change**, presentation charts, 1989 ASHRAE Annual Meeting (Vancouver, BC, 24-28 June 1989), U.S. Department of Energy, Washington, DC, June 1989 (16 pages, RDB1109)

Impact of a CFC Ban on the Cost and Performance of Household Refrigerators, Centrifugal Chillers, and Commercial/Industrial Systems, technical memorandum to U.S. Department of Energy, Arthur D. Little, Incorporated, Cambridge, MA, August 1989 (82 pages, RDB1110)

This report assesses the potential response of and impacts on the refrigeration industry to a regulatory ban on the production of CFC working fluids by the year 2000. The primary focus is on the most likely alternatives, in each application category, and their impact on the design and performance of new equipment.

Environmental

A. P. Altshuller, **Comments on the Lifetimes of Organic Molecules in Air**, *Proceedings of the Conference on Methyl Chloroform and Other Halocarbon Pollutants* (1-10 January 1980), report EPA-600/9-80-003, U.S. Environmental Protection Agency (EPA), Washington, DC, 1980 (RDB5841)

fluorocarbon refrigerants, environmental reactions

J. G. Anderson, D. W. Toohey, and W. H. Brune, **Free Radicals Within the Antarctic Vortex: The Role of CFCs in Antarctic Ozone Loss**, *Science*, American Association for the Advancement of Science (AAAS), volume 251, pages 39-46, 4 January 1991 (8 pages with 6 figures, RDB1202)

This article describes experiments and observations linking chlorine and bromine concentrations with ozone depletion in the antarctic vortex. It briefly reports the findings of the National Science Foundation Ozone Experiment (NOZE I) expedition in the austral spring of 1986. It describes in greater detail the high-altitude mission and in situ measurements of the subsequent Airborne Antarctic Ozone Experiment. Mathematical equations defining the mechanisms of ozone depletion are presented for chlorine and bromine. What sets Antarctic ozone depletion apart in the context of global change is both the severity of the phenomenon and the unusual decoupling of physical and chemical time constraints that control transformation rates in a specific region of the atmosphere. The article concludes that the dramatic reduction in ozone over the antarctic continent would not have occurred had CFCs not been released to the atmosphere.

L. G. Anderson, **Atmospheric Chemistry of 1,1,1,2-Tetrafluoroethane**, *Atmospheric Environment*, Pergamon Press Limited, UK, volume 15, number 9, pages 1579-1582, 1981 (4 pages, RDB-6547)

R-134a

Atmospheric and Environmental Research, Incorporated (AER), **Estimates of the Global Warming Potential of C_3F_8**, Rhône-Poulenc Chemicals, Bristol, UK, October 1994 (14 pages with 3 figures and 5 tables, RDB5C04)

R-218, atmospheric lifetimes, radiative forcing factors, global warming potential (GWP)

J. C. Ball and T. J. Wallington, **Formation of Trifluoroacetic Acid from the Atmospheric Degradation of Hydrofluorocarbon 134a: A Human Health Concern?**, *Journal of the Air and Waste Management Association*, volume 43, number 9, pages 1260-1262, September 1993 (RDB65F3)

R-134a, atmospheric reactions, environmental impacts

please see pages 6-8 for ordering information

L. Batt, **The Role of Freons in the Chemistry of the Upper Atmosphere,** report Eur 9436, *Communications of the European Communities*, pages 293-295, 1984 (3 pages, RDB5843)

fluorocarbon refrigerants, environmental reactions, physical and chemical behavior of atmospheric pollutants

A. G. bin-Ujang, N. C. Srivastava, M. S. Ismail, and M. H. bin Saleh (MARA Institute of Technology, Malaysia), **Global Warming Impact Due to CFCs in Refrigerators in Malaysia,** *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 301-306, 1993 (6 pages with 1 figure and 2 tables, RDB5264)

global warming, TEWI

A. C. Brown et al, *Atmospheric Environment*, Pergamon Press Limited, UK, part A, volume 9, pages 2499-2511, 1990 (13 pages, RDB5938)

R-125 and others

J. M. Calm (Engineering Consultant), **Comparative Global Warming Impacts of Electric Vapor-Compression and Direct-Fired Absorption Equipment**, report TR-103297, Electric Power Research Institute (EPRI), Palo Alto, CA, August 1993 (82 pages with 26 figures and 10 tables, RDB4440)

This report compares the global warming impacts of electric vapor-compression and gas-fired absorption-cycle equipment for air-conditioning systems. It outlines alternatives to replace chlorofluorocarbon, and eventually also hydrochlorofluorocarbon, refrigerants. The report notes that absorption chillers do not use ozone-depleting refrigerants, but substitution of alternative refrigerants in vapor-compression equipment also offers radically-reduced or eliminated potential for stratospheric ozone depletion. Net global warming impact (or "total equivalent warming impact", TEWI), therefore, provides a better indication of environmental preferability. Examination requires consideration of both direct and indirect effects. The direct component relates to release of refrigerants that are greenhouse gases, and the indirect to carbon dioxide production in powering the equipment. The report compares the global warming potential (GWP) of common and alternative refrigerants, reviews prior studies, and presents the methodology and data used. The analyses address energy use both for chillers, at multiple efficiency levels, and associated heat rejection by cooling towers. The report then reviews historical trends and regional variations in carbon dioxide emissions for generation of electricity - the "carbon dioxide factor" (CDF). Tabular data are provided on a regional basis for the generation fuel mix, average CDF, and CDF corresponding to typical load profiles to cool commercial buildings. The generation data cover Canada, Mexico, and the United States; the regional data cover only the USA. The report presents chiller performance data, refrigerant loss data, and values used to define two scenario's used for the study. It then summarizes national and regional comparisons, reflecting generation differences. The results show that electric vapor-compression chillers consistently result in lower net warming impact than direct-fired absorption chillers. The analyses also indicate that improved performance, available at lower cost premiums than those associated with absorption chillers, offers further potential for warming reduction. Integration of thermal storage, for peak-demand reduction, offers an advantage over alternative use of gas-fired absorption-cycle chillers. Parametric analyses are presented to test the sensitivity of this finding to varied use assumptions. The report concludes with a discussion of means to reduce net warming impacts and a perspective on the occurrence of global climate change.

J. M. Calm (Engineering Consultant), **Global Warming Impacts of Chillers**, *Heating/Piping/Air Conditioning*, Penton Publishing, Chicago, IL, volume 65, number 2, pages 28-39, February 1993 (9 pages with 9 figures and 1 table, available from JMC as RDB3304)

This paper summarizes a study of comparative impacts of chillers on global warming, including both direct (chemical) and indirect (energy-related) effects. It summarizes refrigerant options for chillers and uses of alternative refrigerants to replace chlorofluorocarbons (CFCs). It then reviews the greenhouse gas impacts of refrigerant emissions, and compares them to other warming sources. It discusses both global warming potential (GWP) values and their variation with the integration time horizon (ITH) selected for analysis. GWPs are plotted for CFC and alternative refrigerants and as a function of ITH. The paper then summarizes prior analyses of chiller warming impacts, and introduces a recent study performed for EPRI. It summarizes information used to calculate historical and projected carbon dioxide factor (CDF) values, ratios of carbon dioxide amount produced per unit of energy used. The paper outlines regional variations in fuels used to generate electricity as well as generation and load profiles. It presents calculated warming findings on both a national and regional bases, noting that the regional data can be extrapolated to impacts for other locations or countries with similar generation mixes. The paper concludes that once high-GWP CFCs are eliminated, global warming will be more readily

influenced through efficiency improvement and emission reduction than by refrigerant substitutions. It reaffirms the findings of prior studies that indirect effect dominates over direct, including the combined impacts leakage, service, and ultimate disposal losses. It also notes that direct effect is equivalent to less than a 0.1 to 1.1% change in efficiency, depending on the refrigerant used, once service and disposal losses are reduced and CFCs eliminated. Three figures show comparative warming on a national and regional basis for chillers using R-11, R-12, R-22, R-123, and R-134a as well as direct-fired, absorption chillers (double-effect, water/lithium-bromide). A final plot shows the progressive reduction in total equivalent warming impact (TEWI) for R-11 and R-123 for 1985-1995 based on emission reductions and efficiency improvements.

W. K. Chang and C. S. Criddle, **Biotransformation of HCFC-22, HCFC-142b, HCFC-123, and HFC-134a by Methanotrophic Mixed Culture MM1**, *Biodegradation*, volume 6, pages 1-9, 1995 (9 pages, RDB65C1)

R-22, R-123, R-134a, R-142b, environmental fate

M. Chwalowski, **Climate Change Update**, unpublished seminar presentation charts (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), Edison Electric Institute, Washington, DC, 1995 (4 pages with 4 figures, available from JMC as RDB5349)

This series of 20 presentation charts summarizes a discussion of basic trends, climate modelling, observed differences, and conclusions. It presents extremes of suggested long-term cooling trends and predictions of dire climate changes. It then critically reviews the basis for and projections of warming, and contrasts temperature records and predictions. The presentation concludes that disagreement exists among scientists, measured and predicted data differ, less is known than not known about the atmosphere, and the politics of climate change have overtaken the science.

C. M. Cisson, G. A. Rausina and P. M. Stonebraker, **Human Health and Environmental Hazard Characterization of Lubricating Oil Additives**, paper 11.7, Ecological and Economical Aspects of Tribology (proceedings of the Ninth International Colloquium), Technische Academie Esslingen, Germany, 1994 (RDB6377)

lubricants, safety, environmental impacts

M. A. A. Clyne and P. M. Holt, **Reaction Kinetics Involving Ground and Excited Hydroxyl Radicals, Part 2. Rate Constants for Reactions of OH with Halogenomethanes and Halogenoethanes**, *Journal of the Chem. Society Faraday Transactions*, volume 2, number 75, pages 582 ff, 1979 (RDB5846)

methane and ethane series halocarbons, alternative refrigerants, atmospheric reactions

J. R. Cooke and R. F. Haycock, **Lubricant Additives and the Environment**, *The Petroleum Industry Faces the Environmental Problems* (international congress), Brussels, Belgium, 1993 (RDB-6378)

lubricants, safety, environmental impacts

D. L. Cooper et al, **Tropospheric Lifetimes of Potential CFC Replacements: Rate Coefficients for Reaction with the Hydroxyl Radical**, *Atmospheric Environment*, Pergamon Press Limited, UK, part A, volume 26, number 7, pages 1331-1334, 1992 (4 pages, RDB5829)

alternative refrigerants, lifetime, atmospheric reactions

D. L. Cooper et al, **Reactions of Hydrofluorocarbons and Hydrochlorofluorocarbons with the Hydroxyl Radical**, *Atmospheric Environment*, Pergamon Press Limited, UK, part A, volume 24, number 9, pages 2417-2419, 1990 (3 pages, RDB-5836)

alternative refrigerants, HFCs, HCFCs, lifetime, reactions

M. F. De Flaun, B. D. Ensley, and R. J. Steffan, **Biological Oxidation of Hydrochlorofluorocarbons (HCFCs) by a Methanotrophic Bacterium**, *Bio/-Technology*, volume 10, number 12, pages 1576-1578, 1992 (RDB65B1)

refrigerant decomposition, destruction, disposal

W. B. DeMore (California Institute of Technology), **Rate Constants for the Reactions of OH with HFC-134a (CF_3CH_2F) and HFC-134 (CHF_2CHF_2)**, *Kinetics and Mechanisms for the Reactions of Halogenated Organic Compounds in the Troposphere* (STEP-HALOCSIDE/AFEAS Workshop, Dublin, Ireland, 23-25 March, 1993), University of Dublin, Ireland, pages 1-6, 1993 (6 pages with 6 tables, RDB5844)

R-134, R-134a, environmental reactions

W. B. DeMore (California Institute of Technology), **Rates of Hydroxyl Reactions with Some HFCs**, *Optical Methods in Atmospheric Chemistry* (proceedings of the SPIE), publication 1715, International Society of Optical Engineering, pages 72-77, 1992 (6 pages, RDB5845)

please see pages 6-8 for ordering information

R-125, R-134, R-134a, and others; environmental reactions

F. de Rossi, R. Mastrullo, and M. Sasso (Università di Napoli "Frederico II", Italy), **R502 Substitution: A Global Evaluation of the Environmental Impact**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 335-341, 1993 (7 pages with 5 figures and 3 tables, RDB5325)

R-22, R-32, R-125, R-32/125 (60/40), R-403A, global warming, TEWI

R. G. Derwent and A. R. Curtis, **Stratospheric Ozone Depletion Estimates for Global Halocarbon Usage Estimated by the Linear Superposition of Contributions from Individual Halocarbons**, report AERE-R 10168, AERE, Harwell, United Kingdom, 1981 (available from Her Majesty's Stationary Office (HMSO), London, UK, RDB6491)

refrigerants, greenhouse effect

R. E. Dickinson and R. J. Cicerone (University of California at Irvine), *Nature*, volume 319, pages 109 ff, 1986 (RDB3C43)

role of chlorofluorocarbons (CFCs) in stratospheric ozone depletion

E. O. Edney and D. J. Driscoll, **Laboratory Investigations of the Deposition of Oxidation Products of Hydrochlorofluorocarbons (HCFCs) and Hydrofluorocarbons (HFCs) to Aqueous Solutions**, *Water, Air, Soil Pollution*, volume 66, number 1-2, pages 97-110, 1993 (14 pages, RDB5952)

R-125 and others, environmental fate of refrigerants

E. O. Edney and D. J. Driscoll, **Chlorine Initiated Photo-oxidation Studies of Hydrochlorofluorocarbons (HCFCs) and Hydrofluorocarbons (HFCs): Results for HCFC-22 ($CHClF_2$), HFC-41 (CH_3F), HCFC-124 ($CClFHCF_3$), HCF-125 (CF_3CHF_2), HFC-134a (CF_3CH_2F), HCFC-142b ($CClF_2CH_3$), and HFC-152a (CHF_2CH_3)**, *International Journal of Chemical Kinetics*, volume 24, number 12, pages 1067-1081, 1992 (15 pages, RDB5953)

R-22 ($CHClF_2$), R-41 (CH_3F), R-124 ($CHClFCF_3$), R-125 (CHF_2CF_3), R-134a (CH_2FCF_3), R-142b (CH_3CClF_2), R-152a (CH_3CHF_2), environmental fate of refrigerants

E. O. Edney, B. W. Gay, and D. J. Driscoll, **Chlorine Initiated Oxidation Studies of Hydrochlorofluorocarbons (HCFCs): Results for HCFC-123 (CF_3CHCl_2) and HCFC-141b ($CFCl_2CH_3$)**, *Journal of Atmospheric Chemistry*, volume 12, pages 105-120, 1991 (16 pages, RDB65C3)

R-123 ($CHCl_2F_3$), R-141b (CH_3CFCl_2), environmental fate of refrigerants

R. T. Ellington and M. Meo, **Development of a Greenhouse Gas Emissions Index**, *Chemical Engineering Progress*, American Institute of Chemical Engineers (AIChE), New York, NY, volume 86, number 7, pages 58-63, 1990 (6 pages, RDB5830)

global warming

G. J. Epstein and S. P. Manwell (Xenergy Incorporated), **Environmental Tradeoffs Between CFCs and Alternative Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 1, pages 38-44, January 1993 (7 pages with 1 figure and 5 tables, RDB3225)

S. J. Feldman and M. W. Spatz (Center for Fluorocarbon Research), **Energy Consumption and TEWI Comparison of R-410A and HCFC-22 in a Residential Heat Pump**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 359-368, October 1995 (10 pages with 4 figures and 4 tables, available from JMC as RDB5B08)

R-22, R-410A comparison

S. K. Fischer (Oak Ridge National Laboratory, ORNL), **Comparison of Global Warming Impacts of Automobile Air-Conditioning Concepts**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 508-515, October 1995 (8 pages, available from JMC as RDB5B20)

direct and indirect global warming, TEWI, comparison of vapor-compression using R-134a, transcritical cycle using R-744 (carbon dioxide), Stirling cycle, and thermoelectric air conditioners for mobile air conditioners (MACs)

S. K. Fischer, J. J. Tomlinson, and P. J. Hughes (Oak Ridge National Laboratory, ORNL), **Energy and Global Warming Impacts of Not-In-Kind and Next Generation CFC and HCFC Alternatives**, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and U.S. Department of Energy (DOE), Washington, DC, 1994 (216 pages with 44 figures and 18 tables, limited copies available from JMC as RDB5509)

S. K. Fischer, P. J. Hughes, P. D. Fairchild (Oak Ridge National Laboratory, ORNL), C. L. Kusik, J. T.

Dieckmann, E. M. McMahon, and N. Hobday (Arthur D. Little, Incorporated, ADL), **Energy and Global Warming Impacts of CFC Alternative Technologies**, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and U.S. Department of Energy (DOE), Washington, DC, December 1991 (602 pages with 98 figures and 40 tables plus supporting figures and tables in appendices, RDB2432)

This report documents detailed analyses of global warming for options to replace chlorofluorocarbons (CFCs) in energy-related applications. The study addressed both direct and indirect effects, namely greenhouse gas impacts of chemical emissions and carbon dioxide emissions from associated energy use. The report compares impacts, for alternative technologies, on the basis of total equivalent warming impact (TEWI). Domestic refrigerator-freezers, commercial refrigeration, commercial chillers, residential and commercial unitary heating and cooling equipment, automobile air conditioning, building insulation, and solvents for metal and electronic cleaning were examined on an international basis. The refrigerants addressed for household refrigeration included R-12, R-134a, R-22/152a/124, R-22/142b; absorption and Stirling cycles also were assessed. R-12, R-22, R-134a, R-502, and R-717 (ammonia) were examined for commercial refrigeration. R-11, R-12, R-22, R-123, R-134a, and R-717 were addressed for commercial air conditioning along with water-lithium bromide absorption cycles. R-22, R-134a, and ammonia-water absorption were analyzed for unitary air conditioners. R-12, R-134a, R-152a, R-290 (propane), and R-22/152a/124 were evaluated for automotive air conditioning along with Brayton and Stirling cycles.

D. A. Fisher (E. I. duPont de Nemours and Company, USA) and P. M. Midgley (M&D Consulting, Germany), **Uncertainties in the Calculation of Atmospheric Releases of Chlorofluorocarbons**, *Journal of Geophysical Research* (JGR), American Geophysical Union, Washington, DC, volume 99, number D8, pages 16,643-16,659, 20 August 1994 (7 pages with 5 figures and 1 table, RDB5502)

R-11, R-12, R-22, R-113, R-114, R-115, production and emission data

D. A. Fisher (E. I. duPont de Nemours and Company, USA) and P. M. Midgley (M&D Consulting, Germany), **The Production and Release to the Atmosphere of CFCs 113, 114, and 115**, *Atmospheric Environment*, Pergamon Press Limited, UK, volume 27A, number 2, pages 271-276, 1993 (6 pages, RDB5503)

R-113, R-114, R-115, production and emission data

D. A. Fisher, C. H. Hales, D. L. Filkin (E. I. duPont de Nemours and Company, USA), M. K. Ko, N. D. Sze (Atmospheric and Environmental Research, Incorporated, AER, USA), P. S. Connell, D. J. Wuebbles (Lawrence Livermore National Laboratory, LLNL, USA), I. S. A. Isaksen, and F. Stordal (Institute of Geophysics, Norway), **Model Calculations of the Relative Effects of CFCs and Their Replacements on Stratospheric Ozone**, *Nature*, Macmillan Magazines Limited, volume 344, number 6266, pages 508-512, 5 April 1990 (5 pages with 3 figures and 4 tables, RDB5851)

alternative refrigerants, reactions and effects of hydrohalocarbons and specifically hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) chemicals, ozone depletion potential (ODP): calculated responses, depicted as ground-level mixing ratios and ozone column change, for single releases of R-11, R-22, and R-123; chemical rate data and ODP values (calculated by four atmospheric modelling groups) for R-10, R-11, R-12, R-22, R-113, R-114, R-115, R-123, R-124, R-125, R-134a, R-140a, R-141b, R-142b, R-143a, and R-152a; uncertainties

D. A. Fisher (E. I. duPont de Nemours and Company), C. H. Hales, W-C. Wang, M. K. W. Ko, and N. D. Sze (Atmospheric and Environmental Research, Incorporated, AER), **Model Calculations of the Relative Effects of CFCs and Their Replacements on Global Warming**, *Nature*, volume 344, number 6266, pages 513-516, 5 April 1990 (4 pages, RDB3328)

alternative refrigerants, global warming potential (GWP)

J. Franklin, **The Atmospheric Degradation and Impact of 1,1,1,2-Tetrafluoroethane (Hydrofluorocarbon 134a)**, *Chemosphere*, volume 27, number 8, pages 1565-1601, 1993 (37 pages, RDB-65B2)

refrigerant decomposition, atmospheric reactions

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R-32, environmental impacts, groundwater and soil

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A set of charts address methods and consequences of reducing R-23 emissions in the manufacture of R-22. The introduction outlines the chemical processes to produce R-21, R-22, and R-23, by reacting R-20 (chloroform) with hydrogen fluoride (HF) in the presence of an antimony catalyst. Hydrogen chloride (HCl) is shown to be a byproduct in all three cases. The charts identify a goal of reducing greenhouse gas emissions, and R-23 in specific, as part of the October 1993 Climate Change Action Plan (CCAP). Further charts outline optimization of the reaction kinetics and identify factors to do so. An alternative option, noted as high cost, is to destroy the R-23 that results as a byproduct. The presentation notes that R-23 emissions will decrease, as R-22 production decreases and with production facility rationalization. It concludes that industry is hopeful of reducing R-23 emissions by 50% of the 1990 level by the year 2000, but that chloroform and HF availability and R-22 pricing will drive the R-22 market, rather than R-23 reduction initiatives.

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A. McCulloch (ICI Chemicals and Polymers Limited, UK), P. M. Midgley (M&D Consulting, Germany), and D. A. Fisher (E. I. duPont de Nemours and Company, USA), **Distribution of Emissions of Chlorofluorocarbons (CFCs) 11, 12, 113, 114 and 115 Among Reporting and Non-Reporting Countries in 1986**, *Atmospheric Environment*, Elsevier Science Limited, UK, volume 28, number 16, pages 2567-2582, 1994 (16 pages with 4 figures and 6 tables, RDB5506)

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M. S. Menzer and G. C. Hourahan (Air-Conditioning and Refrigeration Institute, ARI), **Air-Conditioning and Refrigeration's Contribution to Global Warming Gases**, *Stratospheric Ozone Protection for the 90's (*proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 123-130, October 1995 (8 pages with 5 figures and 3 tables, corrected copy available from JMC as RDB5A01)

This paper compares the total equivalent warming impacts (TEWI) of current and older air-conditioning and refrigeration equipment. The introduction reviews the two components of TEWI, namely direct (release of refrigerant) and indirect (energy related) effects. The paper then presents the methods used to calculate TEWI by converting the direct effect to equivalent emissions of carbon dioxide. A note addresses selection of the integration time horizon (ITH) to determine the global warming potential (GWP) for this calculation. The paper discusses the dependence of TEWI on application factors, including service life, operation, refrigerant choice and associated GWP, system efficiency, and refrigerant charge and make-up rates. Typical values are tabulated for centrifugal chillers, low-temperature supermarket refrigeration systems, residential air conditioners, and domestic refrigerators. The table compares these data for equipment manufactured in 1970 and 1995. The paper briefly reviews the influences of regional generation mixes and changes on emissions; representative data are cited. Four plots then compare the direct, indirect, and total (TEWI) effects for the cited examples. A second table illustrates the sensitivity to changes in GWP and efficiency for an air conditioner. The influences are shown graphically in a plot of constant TEWI as functions of the GWP and efficiency. The paper concludes that small variations in performance have greater impact on TEWI than large variations in GWP. It cautions against dismissal of working fluids based on an arbitrary GWP threshold.

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V. L. Orkin, V. G. Khamaganov, A. G. Guschin, E. E. Kasimovskaya, and I. K. Larin (Institute of Energy Problems of Chemical Physics of the Russian Academy of Sciences, Russia), **Development of Atmospheric Characteristics of Chlorine-Free Alternative Fluorocarbons**, report ORNL/Sub/86-SL103, Oak Ridge National Laboratory, Oak Ridge, TN, April 1993 (28 pages with 8 figures and 7 tables, available from JMC as RDB4890)

This report presents experimental measurements and calculations to determine global warming potential (GWP) values for R-134a and E-143a (CH_3OCF_3). It reviews their reactions with hydroxyl radicals (OH) and outlines the experimental procedure used to measure rate constants for OH reactions. It then presents the experimental data including spectral measurements in the ultraviolet and infrared ranges. The apparatus and spectra are shown. The report concludes with discussion and tabulation of global warming potentials for integration time horizons (ITHs) of 20, 50, 100, 200, and 500 years. The data for R-134a are compared to GWP values published by others. The results for R-134a show lower GWPs than published in the *Scientific Assessment of Ozone Depletion* by the World Meteorological Organization.

M. J. Prather and R. T. Watson (National Aeronautics and Space Administration, NASA), **Stratospheric Ozone Depletion and Future Levels of Atmospheric Chlorine and Bromine**, *Nature*, volume 344, pages 729-734, 19 April 1990 (6 pages with 6 figures and 2 tables, RDB5524)

This paper presents the influences on stratospheric chlorine concentrations of eight scenarios of regulated halocarbon emissions. It notes that atmospheric chlorine concentrations have increased from 0.6 ppb, a century ago, to 2 ppb in the late 1970s, when the ozone hole was recognized to have first occurred. It rose to more than 3 ppb by 1990, predominantly from industrial halocarbons and their photochemical byproducts. The paper suggests that predicted ozone depletion from concentrations of 3-5 ppb are modest, approximately 1-2% in the tropics and 4-6% at high latitudes. Chemical models are unable to predict the extent of changes when chlorine exceeds 5 ppb. The paper reviews the known sources of chlorine, indicating that natural sources make up only 20% and those listed in the 1987 Montreal Protocol another 50%. A table summarizes a numerical model used to calculate the atmospheric abundances of individual halocarbons. They include R-11, R-12, R-113, R-114, and R-115 as well as other compounds and hypothetical substitutes. The paper discusses uncertainties such as the timing of atmospheric response, due to the lag for air to travel from the upper troposphere to the middle stratosphere, and delays between halocarbon production and emission. It then describes and plots the impacts for eight regulatory options. They include changes in the timing, extent, substitutes, compliance, and uncertainties for phaseout of halocarbons. The paper concludes that stratospheric chlorine and bromine levels may return to those prevalent before the onset of the ozone hole, but only if more stringent regulations are applied to halocarbon production.

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S. Solomon, J. B. Burkholder, A. R. Ravishankara, and R. R. Garcia, **Ozone Depletion and Global Warming Potentials of CF_3I**, *Journal of Geophysical Research* (JGR), American Geophysical Union, Washington, DC, volume 99, number D10, pages 20,929-20,935, October 1994 (RDB5A23)

please see pages 6-8 for ordering information

R-13I1, ODP, GWP

S. Solomon and D. L. Albritton (National Oceanic and Atmospheric Administration), **Time-Dependent Ozone Depletion Potentials for Short- and Long-Term Forecasts**, *Nature*, volume 357, pages 33-37, 7 May 1992 (5 pages with 3 figures and 2 tables, RDB2A15)

ODP

S. Solomon, M. Mills (National Oceanic and Atmospheric Administration), L. E. Heidt, W. H. Pollock (National Center for Atmospheric Research), and A. F. Tuck (National Oceanic and Atmospheric Administration), **On the Evaluation of Ozone Depletion Potentials**, *Journal of Geophysical Research* (JGR), American Geophysical Union, Washington, DC, volume 97, number D1, pages 825-842, 20 January 1992 (18 pages with 12 figures and 5 tables, RDB2A16)

ODP

R. S. Stolarski and R. J. Cicerone (University of California at Irvine), **Stratospheric Chlorine: A Possible Sink for Ozone**, *Canadian Journal of Chemistry*, National Research Council of Canada (NRCC), Ottawa, ON, Canada, volume 52, pages 1610-1615, 1974 (6 pages, RDB3240)

first postulated the role of chlorine in depleting stratospheric ozone

Y. Takizawa and H. Muto, **Determination of Fluorocarbons Obtained by the Photochlorination**, *Fluoride*, volume 21, number 4, pages 201-209, 1988 (9 pages, RDB5C03)

environmental effects

Y. Takizawa and H. Muto, **Formation of Fluorocarbons by Ultraviolet Rays**, *Chemosphere*, volume 13, number 7, pages 739-749, 1984 (11 pages, RDB5842)

environmental effects

R. Talukdar, A. Mellouki, T. Gierczak, J. B. Burkholder, S. A. McKeen, and A. R. Ravishankara, **Atmospheric Fate of Difluoromethane, 1,1,1-trifluoroethane, Pentafluoroethane, and 1,1-dichloro-1-fluoroethane: Rate Coefficients for Reactions with Hydroxyl and UV Absorption Cross Sections of 1,1-dichloro-1-fluoroethane**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 95, number 15, pages 5815-5821, 1991 (7 pages, RDB5835)

R-32, R-125, R-141b, R-143a, atmospheric reactions

Y. Tobeta, **Test on Biodegradability of HFC-32 by Microorganisms (Closed-Bottle Method)**, report 12121, Kurume Research Laboratories, Fukuoka, Japan, 1992 (RDB5C33)

R-32, environmental impacts, groundwater and soil

M. L. Tosato et al, **Multivariate Modeling of the Rate Constant of the Gas-Phase Reaction of Haloalkanes with the Hydroxyl Radical**, *Science of the Total Environment*, volume 109-110, pages 307-325, 1991 (19 pages, RDB5840)

atmospheric reactions

E. C. Tuazon and R. Atkinson (University of California at Riverside), **Tropospheric Degradation Products of Hydrochlorofluorocarbons and Hydrofluorocarbons. Potential Replacements for the Chlorofluorocarbons and Halons**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, pages 41-49, 1995 (9 pages, RDB6308)

R-141b, R-142b, and others, environmental impacts, atmospheric reactions

E. C. Tuazon and R. Atkinson (University of California at Riverside), **Tropospheric Transformation Products of a Series of Hydrofluorocarbons and Hydrochlorofluorocarbons**, *Journal of Atmospheric Chemistry*, volume 17, number 2, pages 179-199, 1993 (21 pages, RDB5965)

R-123, R-125, and others, atmospheric reactions

E. C. Tuazon et al, **Rate Constants for the Gas-Phase Reactions of Chlorine Atoms with a Series of Hydrofluorocarbons and Hydrochlorofluorocarbons at 298 ±2 K** [25 °C, 77 °F], *International Journal of Chemical Kinetics*, volume 24, number 10, page 917 ff, 1992 (RDB5966)

R-125 and others, atmospheric reactions, lifetime

E. C. Tuazon et al, **Rate Constants for the Gas-Phase Reactions of Chlorine Atoms with a Series of Hydrofluorocarbons and Hydrochlorofluorocarbons at 298 ±2 K** [25 °C, 77 °F], *International Journal of Chemical Kinetics*, volume 24, number 7, page 639-648, 1992 (RDB6459)

R-125 and others, atmospheric reactions, lifetime

F. A. Vogelsberg, **Stratospheric Ozone Depletion and Linkage to Climate Change**, unpublished seminar presentation charts (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), DuPont Chemicals,

Wilmington, DE, February 1995 (20 pages with 3 figures, available from JMC as RDB5348)

This series of 19 presentation charts provides an update on the understanding of stratospheric ozone depletion, global warming, and their linkage. The summary of ozone depletion draws on the *"Scientific Assessment of Ozone Depletion: 1994"* by NOAA, NASA, UNEP, and WMO [see RDB5301 and RDB5302]. It addresses confirmation of ozone loss, the current and projected extents of that phenomenon, relationship to man-made emissions, consequences of hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) use, and implications for policy making. A plots shows the cumulative equivalent chlorine loading of natural and anthropogenic chemicals for 1979-2054. Another depicts thee global consumption of chlorofluorocarbons (CFCs) for 1986-1992. It reveals that consumption outside the developed countries is projected to exceed that in developed countries in 1994. A third figure shows global consumption of CFC refrigerants by major countries or groups of countries. The charts then outline key issues anticipated to surface in the next meeting of Parties to the Montreal Protocol. The update on global warming capsulizes the *"1994 Report of the Scientific Assessment Working Group"* of the IPCC [see RDB4B13]. A series of charts indicates the levels of scientific confidence in climate change and resultant impacts. Two final charts introduce and summarize an investigation by Oak Ridge National Laboratory (ORNL) of total equivalent warming impacts [see RDB5509].

T. J. Wallington, W. F. Schneider (Ford Research Laboratory, USA), O. J. Nielsen, J. Sehested (Risø National Laboratory, Denmark), D. R. Wornsop (Aerodyne Research, Incorporated, USA), W. J. DeBruyn, and J. A. Shorter (Boston College, USA), **Atmospheric Chemistry and Environmental Impact of Hydrofluorocarbons and Hydrochlorofluorocarbons**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 3, pages 16-30, 1995 (15 pages with 2 figures and 3 tables, RDB6307)

atmospheric chemistry and environmental impacts of HCFCs and HFCs including R-22, R-23, R-32, R-123, R-124, R-125, R-134a, R-141b, R-142b, and R-143a with comparisons to R-11, R-12, and R-744 (carbon dioxide); atmospheric lifetimes, ozone depletion potential (ODP), halocarbon global warming potential (HGWP), gas- and aqueous-phase atmospheric degradation products, heterogeneous and aqueous phase chemistry, formation of toxic or noxious products including trifluoroacetic acid (TFA, CF_3CO_2H) in rainwater

T. J. Wallington, W. F. Schneider (Ford Research Laboratory), D. R. Worsnop (Aerodyne Research, Incorporated, USA), O. J. Nielsen, J. Sehested (Risø National Laboratory, Denmark), W. J. DeBruyn, and J. A. Shorter (Boston College, USA), **The Environmental Impact of CFC Replacements - HFCs and HCFCs**, *Environmental Science and Technology*, volume 28, number 7, pages 320A-326A, 1994 (7 pages, RDB5C34)

environmental impacts

R. P. Wayne, C. E. Canosa-Mas, A. C. Heard, and A. D. Parr, **On Discrepancies Between Different Laboratory Measurements of Kinetic Parameters for the Reaction of Hydroxyl Radical with Halocarbons**, *Atmospheric Environment*, volume 26a, pages 2371-2379, 1992 (9 pages, RDB5848)

alternative refrigerants, lifetime, atmospheric reactions

M. A. Wright, **Biodegradation of ICI Synthetic Lubricants**, PhD thesis, Cranfield Institute of Technology, United Kingdom, 1993 (RDB6384)

lubricants, environmental impacts

D. J. Wuebbles (Lawrence Livermore National Laboratory, LLNL), **Chlorofluorocarbon Emission Scenarios: Potential Impact on Stratospheric Ozone**, paper 2C1676, *Journal of Geophysical Research* (JGR), American Geophysical Union, Washington, DC, volume 88, number C2, pages 1433-1443, 1983 (11 pages with 13 figures and 5 tables, RDB5523)

This paper summarizes theoretical analyses of the influence of chlorocarbon emissions on the atmosphere and to stratospheric ozone depletion in particular. Prior analyses focused on R-11 and R-12. The new results indicate that R-10 (carbon tetrachloride), R-113, and R-140a (methyl chloroform) also could contribute significantly. The paper briefly reviews the scientific understanding of ozone depletion and the evolution of model calculations. It then outlines 15 scenarios developed by the Organization for Economic Cooperation and Development (OECD), and three added cases, to assess potential growth and decline in chlorocarbon releases. The calculated changes in total column ozone are tabulated for 1950-2100 for the 18 scenarios. Steady state projections are included for scenarios reflecting constant emissions following 1980 and the same with increased R-10 emissions. Plots summarize the changes in total ozone with time for the 18 scenarios. A table summarizes the relative efficiencies of halocarbons for the no-growth scenario,

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noting that R-11 and R-12 account for approximately 70% of the ozone loss at steady state conditions. A figure shows the changes in local ozone concentrations by altitude, at selected times, for the no-growth scenario. Two others depict variants with increases and decreases of 7% per year in chlorocarbon emissions after January 2000. The paper concludes with discussion of changes in surface temperature from increased concentrations of R-11 and R-12, by their actions as greenhouse gases. An appendix describes the LLNL Transport-Kinetics Model used.

D. J. Wuebbles, F. M. Luther, and J. E. Penner (Lawrence Livermore National Laboratory, LLNL), **Effect of Coupled Anthropogenic Perturbations on Stratospheric Ozone**, paper 2C1675, *Journal of Geophysical Research* (JGR), American Geophysical Union, Washington, DC, volume 88, number C2, pages 1444-1456, 1983 (13 pages, RDB5510)

This paper discusses the interactions of anthropogenic influences on stratospheric ozone. Chlorocarbon, carbon dioxide, nitrous oxide, and NO_x emissions are identified as coupled perturbations. The paper summarizes calculations of changes due to chlorocarbon emissions, how the other perturbations may have influenced the actual change in ozone, and how both may influence future changes in ozone. It concludes that increasing CO_2 concentrations will have a large offsetting influence to ozone losses from chlorocarbons by altering the atmospheric temperature, and thereby the air density and chemical reaction rates. It postulates that increases in CO_2 and NO_x concentrations may lead to an increase in total ozone. This finding points to the complexity of modelling global-scale chemical and climatic effects.

Z. Zhang, S. Padmaja, R. D. Saine, R. E. Huie, and M. J. Kurylo (National Institute of Standards and Technology, NIST), **Reactions of Hydroxyl Radicals with Several Hydrofluorocarbons: The Temperature Dependencies of the Rate Constants for $CHF_2CF_2CH_2F$ (HFC-245ca), $CF_3CHFCHF_2$ (HFC-236ea), CF_3CHFCF_3 (HFC-227ea), and $CF_3CH_2CH_2CF_3$ (HFC-356ffa)**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and NIST, Gaithersburg, MD, volume 98, number 16, pages 4312-4315, 21 April 1994 (4 pages with 3 figures and 2 tables, RDB5804)

R-227ea, R-236ea (CHF_2CHFCF_3), R-245ca ($CH_2FCF_2CHF_2$), and R-356mff ($CF_3CH_2CH_2CF_3$)

Z. Zhang, R. D. Saine, M. J. Kurylo, and R. E. Huie (National Institute of Standards and Technology, NIST), **Rate Constants for the Reactions of the Hydroxyl Radical with Several Partially Fluorinated Ethers**, *Journal of Physical Chemistry*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and NIST, Gaithersburg, MD, volume 96, pages 9301-9304, 1992 (4 pages, RDB5551)

R-E125, R-E134, R-E143a

Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Summaries, AFEAS, Washington, DC, September 1995 (28 pages with 6 figures and 3 tables, available from JMC as RDB-5C37)

This series of eleven leaflets presents key AFEAS objectives and findings. A summary of the *Montreal Protocol on Substances that Deplete the Ozone Layer* reviews the history of this international accord to phase out production of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants among other chemicals. It also recaps the schedules under the Protocol as well as the U.S. Clean Air Act and European regulations. A sheet on *Production and Sales of Fluorocarbons* reviews and provides a plot of the worldwide production of R-11, R-12, R-22, R-113, R-114, R-115, R-134a, R-141b, and R-142b for 1980-1994. It highlights key changes for CFCs relative to 1986, the base year in the Montreal Protocol, and for CFCs and HCFCs to 1993 production. A summary on *Atmospheric Chlorine: CFCs and Alternative Fluorocarbons* reviews the mechanisms of stratospheric ozone depletion and provides values for ozone-depletion potentials (ODPs). It also illustrates how substitution of HCFCs for CFCs reduces chlorine in the atmosphere. The illustration further shows that use of HCFCs for a limited time will not delay return of atmospheric chlorine to pre-1970s levels. A synopsis of the *Contributions of Greenhouse Gas Emissions to Climate Forcing Relative to CO_2* discusses radiative forcing, a parameter used to perturb the heat balance in modelling of the earth-atmosphere system. It outlines understanding and uncertainties associated with GWP values, atmospheric persistence of greenhouse gas emissions, and the quantitative influence of *integration time horizon* (ITH) on analyses of impacts. A table provides estimates for the atmospheric lifetimes and GWP values for 20, 100, and 500 yr ITH. A sheet on *Total Global Warming Impact* compares the Total Equivalent Warming Impacts (TEWIs) explains the significance of direct (emission related) and indirect (energy related) effects of alternative technologies and fluids. A plot shows the radiative forcing associated with the direct (refrigerant and insulation blowing agent) and indirect compo-

nents of use of a refrigerator freezer. The discussion notes that the direct effect is much smaller and eliminated within 100 years, whereas significant carbon dioxide from the associated energy production persists more than 500 years later. The summary discusses the outlook for "not-in-kind" alternative technologies, suggesting that efficiency improvement for conventional technologies is more promising to mitigate future climate change. A review of the *Breakdown Products of Alternatives* outlines the mechanisms and consequences of CFC, HCFC, and hydrofluorocarbon (HFC) breakdown. It notes that they readily decompose into simple inorganic species in the lower atmosphere, that the ultimate breakdown products are acidic compounds that are washed out in rain, that the acidic concentrations are so low as to have no appreciable effect, and that the alternatives do not contribute to photochemical smog formation in urban areas. A further summary of the *Environmental Fate of Trifluoroacetyl Halides* addresses the atmospheric breakdown of R-123, R-124, and R-134a, producing trace quantities of trifluoroacetyl halides. These halides hydrolyze, in cloud water droplets or surface waters, to form trifluoroacetic (TFA) acid and hydrofluoric or hydrochloric acid. The fate of TFA ions is discussed. While not expected to have an impact on humans, plants, animals, or microorganisms, further study of the ultimate physiochemical and biological fate is underway. A summary on *TFA and Seasonal Wetlands* responds to a published analysis that suggests TFA buildup in transient wetlands. The summary outlines factors that may enhance local TFA concentrations in rain and in wetlands. It also discusses the assumptions used in the analyses and interprets the findings. A sheet on *UV-B Radiation Measurements* discusses the importance of the ozone layer in shielding ultraviolet-B (UV-B) radiation in sunlight as well as efforts to monitor and observed trends of incoming UV-B intensity. A *Glossary of Terms* defines terminology for discussion of the atmospheric effects of alternative fluorocarbons. The last sheet briefly outlines the history and activities of both AFEAS and the companion Programme for Alternative Fluorocarbon Toxicity Testing (PAFT).

Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling, report JPL92-20, Jet Propulsion Laboratory, California Institute of Technology, 1992 (RDB5847)

alternative refrigerants, lifetime, atmospheric reactions

Emissions of Greenhouse Gases in the United States, 1987-1992, report DOE/EIA-0573, Energy Information Administration, U.S. Department of Energy, Washington, DC, November 1994 (146 pages with 10 figures and 57 tables, available from GPO as document 1994-386-802/00033, limited copies available from JMC as RDB4B69)

Handbook of Environmental Fate and Exposure Data for Organic Chemicals, edited by P. H. Howard, 1989-1993 (4 volumes totalling more than 2400 pages, RDB6105)

release, transport, and degradation of organic compounds

Heat Pumps, An Opportunity for Reducing the Greenhouse Effect, report HPC-BR1, International Energy Agency (IEA) Heat Pump Centre (HPC), Sittard, The Netherlands, October 1992 (12 pages, available from the HPC, RDB3724)

Possible Environmental Effects of Chlorofluorocarbons, position statement and paper, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 2 February 1989 (12 pages, RDB1115)

Production, Sales and Atmospheric Release of Fluorocarbons Through 1993, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, March 1995 (84 pages with 29 tables, limited copies available from JMC as RDB5501)

R-11, R-12, R-22, R-113, R-114, R-115, R-142b, production and emission data

Scientific Assessment of Ozone Depletion: 1994, chaired by D. L. Albritton (National Oceanic and Atmospheric Administration, NOAA, USA), R. T. Watson (National Aeronautics and Space Administration, NASA, USA), and P. J. Aucamp (Department of National Health, South Africa), report 37, World Meteorological Organization (WMO), Global Ozone Research and Monitoring Project, Geneva, Switzerland, 1994 (582 pages with 146 figures and 76 tables, available from WMO, RDB5301)

This definitive work, the seventh in a series, updates the assessment used in governmental and international decision-making for protection of the stratospheric ozone layer. The volume addresses common questions about ozone depletion, observed changes in ozone and source gases, atmospheric processes responsible for these changes, simulations of global ozone, consequences of ozone change, and scientific information for future decisions. It was prepared by 13 international panels, consisting of 230 of the world's leading experts in the atmospheric sciences, and subjected to an intensive peer review by 147 scientists. The product summarizes understanding of the stratospheric ozone layer and its relation to humankind. The

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assessment was initiated in November 1992 by the 4th meeting of the parties to the Montreal Protocol in Copenhagen. The results are scheduled for consideration by the parties to the Protocol, for potential revision of the Protocol in 1995 at the 5th meeting in Vienna. The report provides internationally recognized values for atmospheric lifetimes, response times, chlorine and bromine loading, ozone depletion potential (ODP), and global warming potential (GWP) for natural and anthropogenic chemicals impacting the global environment.

Scientific Assessment of Ozone Depletion: 1994 - Executive Summary, chaired by D. L. Albritton (National Oceanic and Atmospheric Administration, NOAA, USA), R. T. Watson (National Aeronautics and Space Administration, NASA, USA), and P. J. Aucamp (Department of National Health, South Africa), report 37 Executive Summary, World Meteorological Organization (WMO), Global Ozone Research and Monitoring Project, Geneva, Switzerland, 1994 (40 pages with 9 figures, available from WMO, also available from JMC as RDB5302)

This report summarizes the definitive assessment used in governmental and international decision-making for protection of the stratospheric ozone layer. The volume addresses the major scientific findings and observations, supporting evidence, related issues, and implications. The second portion responds to common questions about ozone depletion. It discusses how chlorofluorocarbons get to the stratosphere, evidence of stratospheric ozone destruction by chlorine and bromine, and that the majority of the chlorine in the stratosphere comes from human-made (anthropogenic) sources. It also examines whether changes in the sun's output could be responsible, the first appearance of the antarctic ozone hole, and why it occurred there rather than over the northern hemisphere. The summary concludes with discussion of the increase in ground-level ultraviolet radiation, the severity of the ozone depletion, and whether it will get worse. The executive summary and underlying report summarize understanding of the stratospheric ozone layer and its relation to humankind.

The Impact of Heat Pumps on the Greenhouse Effect, report HPC-ASR1, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, June 1992 (64 pages, RDB2C08)

This report summarizes analyses to determine how different types of heat pumps can contribute to reduction of global warming. It focuses on heating-only heat pumps for space and service-water heating. Some discussion is included of dual-mode (heating and cooling) and cooling-only devices. The report reviews the international status of heat pump use, the environmental concerns with stratospheric ozone depletion and global warming, and activities in selected countries to address these issues. The analyses were based on separate studies conducted in member countries of the IEA and by various international organizations. Of the 41 national studies, 32 examine heat pump roles in reducing emissions of greenhouse gases. Eight address heat pumps relative to reductions in electricity or fossil-fuel use. One examines the effects of alternative technologies on heat pump energy use and greenhouse gas emissions. The report reviews the efficiency levels of different types of heat pumps, opportunities to reduce carbon dioxide emissions, and direct warming effects resulting from emissions of working fluids or methane fuel. The report concludes that the greatest reduction in warming impact can be achieved by changing to working fluids with a lower global warming potential. Additional reductions can be achieved by reducing losses during equipment operation, through use of hermetic designs and recycling of fluids upon retirement. The report notes that sealing is essential for reliability and because working fluids are frequently flammable and/or toxic. Addressing the future of heat pumps, the report notes the need to optimize the full energy system including improvement of power plant efficiency and use of cogeneration-based power production.

The Impact of Ozone-Layer Depletion, document 7, Global Environment Monitoring System (GEMS), United Nations Environment Programme (UNEP), Nairobi, Kenya, 1992 (40 pages with 17 figures and 1 table, available from JMC as RDB2704)

This report is one in a series that summarize scientific and engineering assessments for those without technical qualifications. It deals with the effects of ozone depletion on human health and the environment, and outlines ways of reducing damage to the ozone layer. This publication reviews the scientific background for ozone depletion, including observations of the Antarctic ozone hole, mid-latitude ozone-layer depletion, and Arctic ozone-layer depletion. It then addresses the effects of ultraviolet radiation - specifically the UV-B wavelengths - on immune systems, skin cancer, and increasing eye damage. It also discusses impacts on the oceans and aquatic ecosystems, land plants, air pollution, and damage to materials. The document then discusses ozone-friendly technologies for refrigeration, air conditioning, and other uses. It stresses the importance of global cooperation and the need for recycling and destruction of chlorofluorocarbons (CFCs) and halons. The

report discusses future policy options and lists several information sources.

The Ozone Layer, document 2, Environment Monitoring System (GEMS), United Nations Environment Programme (UNEP), Nairobi, Kenya, 1987 (RDB2703)

REGULATORY ACTIONS

W. J. Clinton and A. Gore, **The Climate Change Action Plan**, The White House, Washington, DC, October 1993 (134 pages with 2 figures and 2 tables, available from GPO, limited copies available from JMC as RDB4208)

CCAP

T. W. Dekleva and R. W. Yost (ICI Americas Incorporated), **Responding to the CFC Challenge**, *Proceedings: Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference* (EEIC/ICWA), Rosemont, IL, pages 495-500, October 1993 (6 pages with 3 figures and 5 tables, RDB4138)

This paper briefly reviews the environmental basis for phase out of chlorofluorocarbons (CFCs) and describes responding regulatory changes. It notes a program of research started in 1972 by the Chemical Manufacturers Association (CMA), the Fluorocarbon Program Panel, to support scientific studies of the environmental fate of CFCs. It also cites the published hypothesis by Rowland and Molina, in 1974, connecting CFCs and ozone depletion. The paper traces early regulatory responses, including a ban on CFC uses as aerosol propellants in the United States and a cap on CFC production and uses by the European Community in 1978. It outlines subsequent Montreal Protocol, U.S., and European regulatory responses. It then outlines chemical industry research, beginning in the mid-1970s, to find alternatives. It explains the need to identify suitable lubricants for hydrofluorocarbons (HFCs). It also cites cooperative industry research efforts, including the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) as well as programs by industry associations. The paper outlines challenges and materials compatibility concerns in specific. The paper concludes that scientific information about ozone depletion is increasing and that new findings may lead to further regulatory changes, sometimes rapidly. It suggests that phaseout dates may move forward, but that industry has cooperated to speed the transition to alternatives. Figures and tables summarize the controlled chemicals, atmospheric chlorine loading, and phase out schedules. Further tables summarize basic properties for alternative refrigerants and lubricants and outline representative materials compatibility tests for motor materials and sheet insulation.

The Climate Change Action Plan: Technical Supplement, report DOE/PO-0011, U.S. Department of Energy (DOE), Washington, DC, March 1994 (164 pages with 18 figures and 37 tables, available from NTIS, limited copies available from JMC as RDB4671)

CCAP

International

Handbook for the International Treaties for the Protection of the Ozone Layer, United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, fourth edition, 1996 (326 pages, RDB6904)

This document contains the complete texts of the Vienna Convention and the Montreal Protocol as amended. These international treaties are formally titled the *Vienna Convention for the Protection of the Ozone Layer* and the *Montreal Protocol on Substances that Deplete the Ozone Layer*. They are administered under the auspices of the United Nations Environment Programme (UNEP). The handbook summarizes the resulting control measures, the signature and ratification status by treaty and amendment for the 159 Parties (countries) that have adopted them, and the rules of procedure for meetings of the Parties. The decisions of the Parties and annexes to the Montreal Protocol, that relate to its interpretation, at meetings in Helsinki in (April-May 1989), London (June 1990), Nairobi (June 1991), Geneva (July 1992), Copenhagen (November 1992), Bangkok (November 1993), Nairobi (October 1994), and Vienna (December 1995) are presented and indexed to the Articles to which they pertain. The handbook lists approved destruction procedures and essential use exemptions, composition and procedures (terms of reference) for scientific and economic assessment panels, remedies for noncompliance, procedures for and details of the Interim Multilateral Fund and Multilateral Fund to assist Article 5 (developing) countries, finance of and procedures for the Trust Fund for administration of the treaties, and declarations adopted from 1989 through 1995. They include the *Helsinki*

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Declaration on Protection of the Ozone Layer (1989); declarations by Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Liechtenstein, Netherlands, New Zealand, Norway, Sweden, and Switzerland on advancing the phase out of chlorofluorocarbons (CFCs) to not later than 1997 (1990); a resolution on more stringent measures for ozone depleting substances (1990); statements by Austria, Denmark, Germany, Finland, Norway, Sweden, and Switzerland on more control measures (1991); a resolution on methyl bromide (1992); statements on representation of Yugoslavia (1992); a memorandum on hydrochlorofluorocarbons (HCFCs) (1993); and declarations on methyl bromide (1993), by countries with economies in transition (1993), on the Multilateral Fund (1994), on HCFCs (1995), and methyl bromide (1995). The handbook then lists sources, contacts, and publications for further information, primarily from United Nations and international organizations. A concluding section presents the evolution of the Montreal Protocol from its original text through successive amendments. The Vienna Convention was adopted on 22 March 1985 and entered into force on 22 September 1988. The Montreal Protocol was adopted on 16 September 1987 and entered into force on 1 January 1989, the London Amendment 29 June 1990 and 10 August 1992, the Copenhagen Amendment on 23 November 1992 and 14 June 1994. Entry into force follows ratification, accession, acceptance, or approval by prescribed numbers of Parties.

National

Code of Practice for the Reduction of Chlorofluorocarbon Emissions from Refrigeration and Air Conditioning Systems, document EPS-1/RA/1, Environment Canada, Ottawa, Ontario, Canada, March 1991 (27 pages, RDB3218)

Refrigeration Equipment and Heat Pumps Using CFCs/HCFCs: The Refrigerants Order and Comments, Swedish National Environmental Protection Agency, Stockholm, Sweden, 1988 (71 pages, RDB1130)

Refrigeration Safety Regulation, translated by the Japan Refrigeration and Air Conditioning Industry Association, Tokyo, Japan (36 pages, RDB1132)

SUBSTITUTE REFRIGERANTS

T. Atwood and J. Zheng (AlliedSignal Incorporated), **Cascade Refrigeration Systems: The HFC-23 Solution**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 442-450, 1991 (9 pages with 3 figures and 2 tables, RDB4561)

R-13, R-23, R-503

J. C. Bare (Environmental Protection Agency, EPA), **Identifying and Evaluating Alternatives to CFC-114 for Navy Shipboard Chillers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 38, number 1, pages 44-46, January 1996 (3 pages with 2 tables, RDB6103)

R-114, R-236ea, R-236fa

E. Baskin and R. B. Berry (U.S. Environmental Protection Agency), **The Performance of Hydrocarbons in a Household Refrigerator/Freezer**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 237-244, July 1994 (8 pages with 2 figures and 7 tables, RDB4829)

R-290/600a, propane/isobutane

A. Bensafi and G. G. Haselden (University of Leeds, UK), **Wide-Boiling Refrigerant Mixtures for Energy Savings**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 7, pages 469-474, September 1994; republished in *Proceedings of the Institute of Refrigeration*, London, UK, November 1994 (6 pages with 5 figures and 2 tables, RDB4A08)

R-22/142b (50/50), R-23/134a (18/82), R-23/-125/134a (15/5/80) and (15/25/60), R-23/32/-125/134a (10/15/15/60) and (20/10/10/60), R-32/134a (35/65)

K. Berglöf (AKA Kyla AB, Sweden) and J. Morley (DuPont Fluoroproducts, UK), **Practical Experience in the Use of R-407C in Small Chillers and Heat Pumps in Sweden**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 7-12, July 1996 (6 pages with 2 figures and 1 table, RDB6747)

results from developmental, laboratory testing of R-407C in low-charge chiller systems; concludes that R-407C is a viable substitute for R-22 in direct expansion systems including ground-source heat pumps; notes that approximately

1500 heat pumps using R-407C are in operation in Sweden

S. C. Bhaduri (Indian Institute of Technology, India), **Assessment of HFC-143a as an Alternative of HCFC-22 and R-502**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 87-95, October 1995 (8 pages with 6 figures and 2 tables, available from JMC as RDB5A49)

R-22, R-143a, R-502

D. B. Bivens, M. B. Shiflett, W. D. Wells, G. S. Shealy, A. Yokozeki, D. M. Patron, K. A. Kolliopoulos, C. C. Allgood, and T. E. C. Chisolm (DuPont Chemicals), **HCFC-22 Alternatives for Air Conditioners and Heat Pumps**, paper SD-95-12-2, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 101, part 2, pages 1065-1071, 1995 (7 pages with 5 figures and 1 table, RDB-6394)

R-22 alternatives, R-134a, 407C [R-32/125/134a (23/25/52)], and R-410B [R-32/125 (45/55)], capacity, efficiency, performance, discharge temperature and pressure

P. G. Blacklock (Calor Gas Refrigeration, UK), **HC Refrigeration and Air Conditioning - A Developing Technology**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 404-411, October 1995 (10 pages with 9 figures and 7 tables, available from JMC as RDB5B12)

R-290 (CARE 40), R-170/290 (CARE 50), R-600a (CARE 10), R-290/600a (CARE 30): product development, performance comparison of R-22 and R-170/290, safety, training, technology transfer

B. Boldrin, G. Minotto, G. Panozzo, L. Rebellato, B. Toniolo, G. Varotto (Instituto per la Tecnica del Freddo del CNR, Italy), and A. Bertocco (Truck Frigo, Italy), **Propane as an Alternative Refrigerant in Foodstuffs Transport**, paper 426, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume IV, pages 2062-2067, 1991 (6 pages with 11 figures and 5 tables, RDB5346)

screening of hydrocarbons and hydrofluorocarbons including R-218, R-227ca, R-227ea, R-236fa, R-245cb, R-263fb, R-272ca, R-281ea, R-281fa, and R-290 for transport refrigeration; tabulates their normal boiling points (NBP) and plots their acute toxicity (expressed as 10-min LC_{50} mouse concentrations) against NBP; examines the biological and environmental characteristics as well as costs for R-290 relative to those of older refrigerants; plots the capacities and efficiencies of R-12, R-22, and R-290 and shows comparative test results for these three refrigerants in a transport refrigeration unit (Truck Frigo F10-10); concludes that R-290 offers higher efficiency than R-12; notes that system optimization is needed and that costs could be reduced with substitution of liquified petroleum gas (LPG, approximately 95% propane) for R-290

C. E. Bullock (Carrier Corporation), **Assessment of Carbon Dioxide as a Refrigerant**, *Tech Update*, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, volume 5, number 5, pages 1-2, September 1996 (2 pages with 2 figures, available from JMC as RDB6A02)

R-744, carbon dioxide, possibilities and limitations for use in unitary air conditioners and heat pumps; cycle efficiency; plots compare the coefficient of performance and operating pressure ratio against evaporating temperature, based on isentropic compression, for R-22, R-134a, R-744, and the Carnot cycle; expansion options including expanders; concludes that R-744 offers the advantages of low toxicity and cost, nonflammability, and wide availability, but its inherently low efficiency and high operating pressures will remain serious challenges in the near term

R. Camporese, S. Bobbo (Consiglio Nazionale della Ricerche, CNR, Italy), and F. Rozza (Necchi Compressori, Italy), **Hydrocarbons as Substitutes for Halogenated Refrigerants in Refrigerating Systems**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 231-236, July 1994 (6 pages with 8 figures and 2 tables, RDB4828)

R-290/600a (50/50), propane/isobutane, R-600a

R. Camporese, B. Boldrin, M. Scattolini (Consiglio Nazionale della Ricerche, CNR, Italy), and G. Cortella (Università di Udine, Italy), **Improvement of R-134a Performance by Addition of R-290**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 45-52, July 1992 (8 pages with 9 figures and 3 tables, RDB2712)

R-290/134a

please see pages 6-8 for ordering information

G. Cortella (Università di Udine, Italy), G. Bigolaro, M. Scattolini (Consiglio Nazionale delle Ricerche, CNR, Italy), G. Basile, and E. Musso (Ausimont S.p.A., Italy), **Drop-In Substitutes for R502: The Role of HCFC-22 and HC-290**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 171-176, July 1994 (6 pages with 9 figures and 1 table, RDB-4823)

R-22, R-290, propane, R-502

N. J. Cox (Morris & Young Refrigeration and Air Conditioning Limited, United Kingdom), **The Practical Use of Hydrocarbons in Air Conditioning and Refrigeration**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 412-416, October 1995 (5 pages with 1 table, available from JMC as RDB5B13)

R-170/290 (CARE 50) in a split-system heat pump and in chillers, R-290 in a split-system heat pump

S. Devotta (National Chemical Laboratory, India), **An Assessment of Hydrocarbon Based Green Refrigerators for India**, Swiss Development Corporation, New Delhi, India, October 1993 (22 pages with 5 tables, available from JMC as RDB4906)

This report examines use of hydrocarbons as refrigerants and insulation blowing agents for refrigerators in developing countries and, specifically, in India. It recaps the motivations for phaseout of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. It then compares the paths and considerations to identify alternatives in developed and undeveloped countries. It contrasts countries such as China and India that are self reliant, with substantial domestic markets, to those that are dependent of developed countries either by imports or production for export. The report describes the Indian market for refrigerators, noting that approximately ten million are in use and that the inventory is expected to reach 130 million by 2010. Desired characteristics of refrigerants are outlined. The report discusses the suitability of R-134a, R-152a, R-290 (propane), R-290/600a (propane/isobutane), R-600a (isobutane), R-600 (n-butane) and R-600a blends, and R-E134. The discussion addresses performance, compatibility, flammability and other safety issues, and environmental acceptability. It also covers insulation alternatives, including foams blown with pentane or cyclopentane and vacuum panels. The report concludes that Indian industries usually follow the leads of industrialized counties, which are dominantly switching to R-134a. Whereas financial support for conversion will be available for only one option, the report notes that further evaluation of hydrocarbon options should be undertaken with other funding so both the R-134a and hydrocarbon options can be kept open.

S. Devotta, S. Gopichand, and V. R. Pendyala (National Chemical Laboratory, India), **Assessment of HFCs, Fluorinated Ethers and Amines as Alternatives to CFC-12**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 2, pages 84-90, February 1993 (7 pages, RDB4126)

S. Devotta and S. Gopichand (National Chemical Laboratory, India), **Comparative Assessment of Some Flammable Refrigerants as Alternatives to CFC-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 249-257, July 1992 (9 pages with 4 figures and 1 table, available from JMC as RDB-2727)

This paper reviews the need for assessment of flammable refrigerants and the implications of using such fluids as alternatives to R-12. Because of the complexities and potential adverse findings in qualifying alternative refrigerants, there may not be adequate time for developed countries to fully evaluate new fluids. Developing countries such as India and China, which are self-reliant in the manufacture of refrigerants and equipment, are short of funds and cannot afford to introduce transition fluids, such as HCFCs and possibly HFCs, and then change again. Global environmental concern requires that flammable fluids also be considered, some of which were used in the past even in home refrigerators. Flammability is considered to pose a lower risk than toxicity. The paper reviews the theoretical performance and flammability of R-142b, R-152a, R-C270 (cyclopropane), R-290 (propane), R-600 (butane), R-600a (isobutane). The pressure ratios, specific compressor displacements, theoretical efficiency, and specific shaft power are plotted for these refrigerants as functions of the evaporating temperature for a range of -35 to 5 °C (-31 to 41 °F) for a 50 °C (122 °F) condensing temperature. The performance, flammability and environmental data, and fundamental properties are tabulated and compared to those of R-12. Means to reduce leaks and charge quantities are discussed as ways to reduce the risks. R-C270 would require smaller compressors and may offer superior performance. R-152a may be preferred based on its lower flammability and experience with it.

W. E. Dietrich (McQuay International, then Snyder-General Corporation), **A Positive Outlook for the Future**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 64-65, May 1993 (2 pages, RDB3605)

This article discusses the benefits of R-134a as a long-term refrigerant, noting that R-22, R-123, and R-134a are no longer alternatives, but the norm in chillers offered today. It notes that hydrochlorofluorocarbon (HCFC) refrigerants, including R-22 and R-123, will be phased out under the Montreal Protocol and the Clean Air Act. It then discusses other advantages of R-134a by operation at positive pressure, such as avoidance of purge requirements, backups to rupture disks, and vacuum prevention systems. The article notes testing that found R-134a to be "essentially nontoxic" and that selection of R-134a by the automotive and appliance industries assures a large market for it, with ample supplies and competitive pricing. The article reviews differences in venting requirements for chlorine-free refrigerants. It briefly outlines safety classifications and requirements, and discusses implications for use of zeotropic blends. The article then reviews retrofit procedures and considerations to convert R-12 and R-500 chillers to R-134a, noting that costs generally will be less expensive than conversion of R-11 equipment to R-123.

P. Dinnage (Rhône-Poulenc Chemicals Limited, UK), **R.22 Drop-In Launched**, *Refrigeration and Air Conditioning*, London, UK, June 1996 (1 page with 3 figures, RDB6708)

R-403A, R-413A, Isceon 59 and 89 (replacements for R-22 and R-13B1, respectively); development and performance trials

M. Döhlinger (Greenpeace Germany, e.V., Germany), **The Success of Hydrocarbons in Domestic Refrigeration: Energy Efficient and Environmentally Friendly**, *Refrigeration and Air-Conditioning Technology Workshop* (proceedings of the 1993 Non-Fluorocarbon Refrigeration and Air-Conditioning Technology Workshop, Breckenridge, CO, 23-25 June 1993), edited by P. J. Lewis and D. M. Counce, report ORNL/6797, Oak Ridge National Laboratory, Oak Ridge, TN, pages C1-C20, 1994 (20 pages with 9 figures and 9 tables, available from JMC as RDB3633)

R-290, R-600, R-600a, R-290/600a

J. D. Douglas (AIL Research, Incorporated), E. A. Groll, J. E. Braun, and D. R. Tree (Purdue University), **Evaluation of Propane as an Alternative to HCFC-22 in Residential Applications**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 13-20, July 1996 (8 pages with 5 figures, RDB6748)

R-290, R-290/227ea, cost-based evaluation of propane and propane-blends in comparison to R-134a, R-407C, R-410A, R-32/134a, R-32/125/-134a, and R-32/125a as replacements for R-22

J. D. Douglas, J. E. Braun, E. A. Groll, and D. R. Tree (Purdue University), **Trade-Off Between Flammability and Performance of Hydrocarbon/Flame Suppressant Mixtures as Refrigerants**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, August 1995), International Institute of Refrigeration (IIR), Paris, France, volume IVa, pages 155-162, 1995 (8 pages, RDB6749)

R-290, R-290/227ea, cost-based evaluation of propane and propane-blends in comparison to R-134a, R-407C, R-410A, R-32/134a, R-32/125/-134a, and R-32/125a as replacements for R-22

S. Engelking and H. Kruse (Forschungszentrum für Kältetechnik und Wärmepumpen GmbH, FKW, Germany), **Development of Air Cycle Technology for Transport Refrigeration**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 349-356, July 1996 (8 pages with 7 figures and 2 tables, RDB6929)

R-729 (air), air-cycle refrigeration, turbine-compressor/turbine-expander and pressure-wave prototypes; performance comparison to R-22 vapor-compression cycle equipment; concludes that the pressure-wave machine (PWM) is preferable to the turbo expander and compressor approach for efficiency and cost

R. E. Ertinger (Carrier Corporation), **HCFC-22: Requirements for Unitary Products**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 340-347, 1991 (8 pages with 3 figures, RDB-2257)

This paper estimates the annual quantity of R-22 required internationally for unitary equipment through the year 2000. Based on its properties, including efficiency, low cost, and safety, R-22 is the most widely used refrigerant. The paper estimates its 1990 use as 160 million kg (352 million lbs), of which 14% was used for equipment other than unitary (e.g., existing and new chillers). For the unitary portion, 24% was used in new products and 76% to service existing equipment. Two parametric scenarios are presented: (1) 3, 5, and 7% growth in demand for unitary products with no change in service

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practices, and (2) recovery increasing to 40, 60, or 80 %/yr by 2000. Based on assumptions for usage in room air-conditioners, duct-free split systems, ducted systems, and commercial unitary systems, the paper projects a range of 77-149 million kg (169-327 million lbs), depending on recovery levels, to be required in 2000 at the 5% annual new-product growth rate.

B. Frehn, **Propan als alternatives Kältemittel für Wärmepumpen - Erste Betriebserfahrungen** [Propane as an Alternative Refrigerant for Heat Pumps - Experience with the First Installation], *DKV-Tagungsberichte* (Heidelberg, Germany, November 1990), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 20, pages 51-63, 1993; republished in *Warmepumpe 3* [Heat Pumps 3], Rheinische-Westfälisches Elektrizitätswerk Energie AG (RHE-NAG), Essen, Germany, 1993 (RDB4345)

R-290

G. H. Goble (Peoples Welding Supply, Incorporated), **A Drop-In CFC-12 Replacement for Automotive Air Conditioning**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 607-609, July 1992 (3 pages, available from JMC as RDB2835)

This paper presents a ternary zeotropic blend, proposed as a transition fluid, to replace R-12 in automotive air conditioners. The blend is R-22/600a/142b (55/8/37), which offers an ozone depletion potential of 0.05 and compatibility with mineral oils. It has been tested in approximately 150 vehicles, two since August 1990. Only one failure has resulted, but it was not attributed to the refrigerant change. Colder air delivery than for R-12 was found; the condensing temperature is higher, though still low enough to prevent refrigerant-oil breakdown. The isobutane content makes the blend miscible in standard mineral oils, including Witco Suniso(R) 3GS and 5GS naphthenic oils and Virginia KMP 150 paraffinic oil. The flammability, both as compounded and after fractionation from leakage, is reviewed. Testing of a silane-based, desiccant and sealant additive are described to reduce refrigerant leaks. The paper notes that the blend composition can be customized for hot climates. [The blend addressed is a developmental version of GHG, later reformulated to R-22/600a/142b (55/4/41), R-406A.]

J. C. Goosman, **The Progressive Development of Carbon Dioxide Refrigerating Methods**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 14, number 6, pages 188-189, 1927 (RDB6925)

R-744

E. A. Groll and R. K. Radermacher (University of Maryland), **Vapor-Compression Refrigeration Cycle with Solution Circuit and Desorber-Absorber Heat Exchange**, paper 3743, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 1, pages 73-83, 1994 (11 pages with 10 figures and 2 tables, RDB4414)

This paper discusses a modified vapor-compression cycle incorporating a solution circuit (VCCSC) and a further enhancement incorporating a desorber/absorber heat exchanger (DAHX). The modifications enable internal heat exchange between the desorption and absorption processes, resulting in extremely low pressure ratios compared to those of conventional cycles with pure refrigerants. Figures show the modifications schematically and on a pressure-temperature plot. A simulation program is outlined, and calculated performance is presented for five concentrations of an ammonia/water mixture. Parametric analyses of concentrations and impacts on pressure ratio, capacity, and efficiency are presented. A table compares the condensing and evaporating temperatures, pressure ratios, and cooling coefficients of performance (COPs) for ammonia/water DAHX and VCCSC cycles to those for ammonia and R-22 in a simple vapor-compression cycle. The paper concludes that the DAHX COP is up to 10 or 26% higher than with ammonia or R-22, respectively, in conventional cycles while the pressure ratio is up to 70 and 62% lower, respectively. The result allows use of low cost, low lift compressors, but requires significantly greater - 50-100% - heat exchange surface and introduction of a circulation pump.

E. A. Groll and H. Kruse (Universität Hannover, Germany), **Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel** [Vapor-Compression Refrigeration Machine with a Solution Circuit for Environmentally Friendly Refrigerants], *DKV-Forschungsberichte* [Research Report] 35, Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, May 1992 (in German, RDB5725)

E. A. Groll and H. Kruse (Universität Hannover, Germany), **Kompressionskältemaschine mit Lösungskreislauf für umweltverträgliche Kältemittel - R23/DEGDME und CO_2/Aceton** [Vapor-Com-

pression Refrigeration Machine with a Solution Circuit for Environmentally Friendly Refrigerants - R-23/DEGDME and R-744/Acetone], *Kältetechnik-Klimatisierung*, Gentner Verlag, Stuttgart, Germany, volume 45, pages 206-218, April 1992 (13 pages, in German, RDB4534)

E. Günther (Foron Hausgeräte GmbH, Germany), **Hydrocarbons as Refrigerants in Domestic Refrigerators**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 37-48, 1994 (12 pages, RDB5331)

R-290/600a, R-600/600a (50/50), R-600a

T. Hackenseller and C. Jurisch, **Die Untersuchung von Hochtemperatur-Kompressions-Wärmepumpen mit dem Arbeitsmedium Wasser** [Examination of High-Temperature Vapor-Compression Heat Pumps Using Water as the Working Fluid], *Fortschritt-Berichte VDI*, VDI-Verlag, Düsseldorf, Germany, volume 19, number 71, 1993 (RDB5A15)

R-718

H. Halozan and T. Ebner (Technische Universität Graz, Graz, Austria), **Propane - A Realistic Alternative**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 331-338, 1994 (8 pages, RDB6751)

R-290

G. Hammarberg and H. Nyman, **R407C Zeotrope as an Alternative to R22**, MS thesis, Kungl Tekniska Högskolan (KTH), Stockholm, Sweden, 1994 (RDB6863)

R-22, R-407C

G. G. Haselden (University of Leeds, UK), **Wide-Boiling Refrigerant Mixtures - Technical and Commercial Challenges**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 193-198, July 1996 (6 pages with 1 figure and 2 tables, RDB6839)

energy saving by use of blends with high temperature glide; flow circuit incorporating a liquid injection system coupled with a modulating float valve; evaluations by analytical methods and confirming tests for R-407C, R-32/125/134a (31/32/37), R-125/152a/600a (50/25/25), R-32/227 (probably R-32/227ea) (35/65)

G. G. Haselden and J. Chen (University of Leeds, UK), **A Computer Simulation Program for Mixed-Refrigerant Air-Conditioning**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 5, pages 343-350, June 1994 (8 pages with 11 figures, RDB5813)

zeotropic blends, performance

G. G. Haselden and L. Klimek (University of Leeds, UK), **An Experimental Study of the Use of Mixed Refrigerants for Nonisothermal Refrigeration**, *Proceedings of the Institute of Refrigeration*, volume 54, pages 129-148, 1957 (20 pages with 10 figures and 1 table, RDB2C02)

This paper reviews the history of zeotrope application, beginning with efforts by R. Pictet to use a blend of R-744 (carbon dioxide) and R-764 and (sulfur dioxide) in 1888. Subsequent efforts by A. Stradelli with the same blend in 1933, G. Maiuri with R-50 (methane) and R-1150 (ethene) in 1939, M. Ruhemann in 1947, and finally F. Carr using a ternary blend in 1949 also are noted. The paper reports a partially successful experiment to demonstrate the previously predicted performance benefits. It notes, however, that the power savings claimed may also be partially achieved with multistage operation with a pure refrigerant. The paper discusses the phase behavior of mixtures, concluding that concurrent condensation and evaporation of the components - with complete mixing - is necessary to achieve the low power consumption. It then describes experiments using R-290/600 (propane/butane), first with tubular and then plate heat exchangers. A power savings of 7% was achieved, less than predicted due to deterioration in heat transfer and to separation and remixing of the components during phase change. The paper postulates that improved performance might result with correct selection and sizing of the heat exchangers and use of herring-bone packing to promote phase mixing. The paper also compares the benefits and costs of use of mixtures to conventional cycles using R-12 or R-717 (ammonia).. Figures illustrate the modes of binary-mixture condensation, cycle modifications to utilize zeotrope benefits, cycle diagrams, and the plate heat exchanger. Additional figures depict the change in pressure ratio resulting from addition of R-600 to R-290, temperature profiles of the blend in condensation and evaporation, and boiling and condensing heat transfer coefficients for compositions ranging from 0-30% propane.

U. Hesse and H. Arnemann (Universität Hannover, Germany), **Carbon Dioxide - Hydrocarbon Mixtures as Alternative Fluids in Refrigeration Systems**, *New Applications of Natural Working Fluids*

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in Refrigeration and Air Conditioning (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 711-719, 1994 (9 pages with 5 figures and 2 tables, RDB-4A65)

carbon dioxide/hydrocarbon blends, R-744/600a (carbon dioxide/isobutane), lubricant solubility, flammability, properties

U. Hesse and H. Kruse (Forschungszentrum für Kältetechnik und Wärmepumpen GmbH, FKW, Germany), **Alternatives for CFCs and HCFC-22 Based on CO_2**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 317-325, 1993 (9 pages with 7 figures and 3 tables, RDB4333)

R-744 (carbon dioxide), R-744/acetone, R-23/DEGDME

N. J. Hewitt, J. T. McMullan, and B. Mongey (University of Ulster, UK), **Some Aspects of Using Hydrocarbons as Components in Refrigerant Mixtures**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 143-152, 1994 (10 pages with 10 figures and 2 tables, RDB-4A64)

R-218, R-290 (propane), R-C270 (cyclopropane), R-227ea, R-236ea, R-245cb, R-C318, R-600 (n-butane), R-600a (isobutane), R-32/290/-134a (30/10/60), R-125/290/134a (10/30/60), R-125/290/134a (44/52/4), hydrocarbon blends

K. E. Hickman (York International Corporation), **Redesigning Equipment for R-22 and R-502 Alternatives**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 36, number 1, pages 42-44 and 46-47, January 1994 (5 pages with 1 table, RDB4215)

This insightful article reviews candidates being tested to replace R-22 and R-502, in the Alternative Refrigerants Evaluation Program (AREP). The introduction explains that AREP was organized by the Air-Conditioning and Refrigeration Institute (ARI), to identify the most promising replacements. It notes participation by government and university laboratories and support by the U.S. Department of Energy (DOE), Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) in addition to the primary testing by manufacturers. A table summarizes the alternatives, their characteristics, and commercial examples. The article traces blend reformulations to resolve identified concerns. It describes considerations for three application categories, starting with packaged equipment for residential and commercial air conditioning and heat pump systems. Testing is focusing on an azeotrope, R-32/125 (50/50), and three zeotropes, R-32/-134a (25/75) and (30/70), and R-32/125/134a (30/10/60). The article outlines their advantages and disadvantages, comments on test results, and summarizes comparative findings by evaluations in Japan. The article concludes that the zeotropes are close to R-22 in behavior and would require only minor changes in design, but would not be easy to use in systems with multiple evaporators. R-32/125 shows the best promise to increase efficiency, and its lower volumetric flow rate may allow reductions in equipment size. However, its use would require substantial compressor and heat exchanger redesign. R-134a also is a candidate, but compressors would need approximately 50% larger volumetric displacement. The replacements addressed for R-22 engineered systems - water chillers for centralized plants - include R-32/125 (50/50), R-32/134a (25/75) and (30/70), R-125/143a/134a (44/52/4) [R-404A], R-134a, and R-717 (ammonia). R-32/125 again offers potential performance advantages, but its high condensing pressure may limit its application unless compressors and heat exchangers are redesigned. R-134a already is used in centrifugal chillers, for which the higher flow volumes do not substantially increase costs, but is limited for positive displacement machines (with screw and reciprocating piston compressors) by the larger displacement requirement. Ammonia offers a viable technical alternative, but its consideration is primarily for industrial applications due to safety issues and building code requirements. The article addresses three alternatives to replace R-502 in commercial refrigeration systems, namely R-125/143a (50/50) [R-507A], R-125/143a/134a (44/52/4) [R-404A], R-32/125/-134a (20/40/40), and R-32/125/143a (10/45/-45). The author notes greatest interest and testing for R-32/125/134a, despite earlier announcements of other replacements spurred by impending phase out of R-115, a component of R-502. The article concludes that considerable testing remains to be done for product development to prove system reliability and durability. It also notes that better property data are needed for manufacturers to predict and certify performance with the accuracy that is now standard. Most of the alternatives either do not improve efficiencies or require substantial changes and testing. The author suggests that the alternatives will offer neither performance or cost advantages to customers for systems now

designed for R-22. While manufacturers believe that the refrigerants under test will be viable, testing is still at an early stage and a service infrastructure must be put in place. R-290 (propane) also is listed as a candidate, but is not discussed. [This article is an edited version of RDB4524.]

M. Högberg, L. Vamlingh, and T. Berntsson (Chalmers University, Sweden), **Possible New Working Fluids in High Temperature Heat Pumps**, *Proceedings of the Workshop on High Temperature Heat Pumps* (Hannover, 1989), IEA Heat Pump Center, Sittard, The Netherlands, 1989 (RDB5A16)

alternative refrigerants

Z. P. Hong, **An Overview Concerning Replacement and Treatment of Chlorofluorocarbons (CFCs)**, *Chinese Journal of Environmental Science*, volume 12, number 3, pages 62-66, 1991 (5 pages, RDB5954)

alternative refrigerants

G. C. Hourahan (Air-Conditioning and Refrigeration Institute, ARI), **Planning for the Use of Alternative Refrigerants in Air Conditioning and Refrigeration**, presented at the Seventh Annual Conference (Washington, DC), Defense Fire Protection Association, Alexandria, VA, 29 April 1993 (6 pages with 7 figures and 2 tables, available from JMC as RDB-3502)

This paper illustrates options for equipment planners to alleviate confusion for use of alternative refrigerants in air conditioning and refrigeration. It briefly outlines the phase out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants as well as the tradeoffs between ozone depletion and global warming among alternatives. It summarizes a study by the Congressional Research Service, which predicts a state of chaos and shortages in late 1995 and subsequent several years. A figure indicates the number of CFC chillers that manufacturers expect to convert or replace before 1993 and in 1993-1995. It addresses new alternatives, concluding that there are "no magic compounds around the corner" and new candidates will require 8-12 years to enter full-scale production. Two figures summarize criteria for selection of alternative refrigerants and chiller options by type and refrigerant. Refrigerant containment, equipment conversion, and equipment replacement options are outlined. Recommendations are noted, including designation of a refrigerant manager and development of a management plan. Two tables summarize estimated refrigerant inventories and service needs by equipment category and alternative refrigerants by applications.

H. M. Hughes (AlliedSignal Incorporated), **Azeotrope of HFC-125 and HFC-134a as an Alternative for R-502**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 377-382, July 1994 (6 pages with 5 figures, RDB4849)

R-507A, AZ-50, R-125/143a (50/50)

H. M. Hughes (AlliedSignal Incorporated), **Non-Ozone Depleting Refrigerants for Centrifugal Compressors**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 41-46, September 1992 (6 pages with 4 figures, RDB2A01)

This paper reviews the characteristics sought in a replacement for R-11 and R-123, as well as reasons for their widespread use and the long-term need for a replacement. R-245ca, with a boiling point of 25.5 °C (79.9 °F) and a molecular mass of 134.0, is identified as a candidate. It is reported to be nonflammable and have a global warming potential (GWP) comparable to that of R-134a. The paper presents the results of cycle comparisons based on modelling. These results include figures comparing the capacity and coefficient of performance (COP) for R-11, R-123, and R-245ca. An investigation of multi-stage systems is outlined. The results, excluding interstage losses, indicate that R-245ca matches R-11's efficiency with three stages and becomes more efficient with four or more. Moreover, anticipation of better heat transfer characteristics is noted, based on the higher molecular weight of R-245ca. Little is known of the toxicity of this fluid, though most HFCs tend to have low toxicity. Potential obstacles such as lubricant identification and materials compatibility are discussed.

H. M. Hunter and A. J. Pitt (APV Baker Limited, UK), **The Use of Ammonia and Secondary Refrigerants in Commercial Refrigeration**, *Refrigerants Beyond the Crisis: Practical Solutions* (London, UK, 4 November 1993), Institute of Refrigeration, Surrey, UK; republished in *Engineered Systems*, Business News Publishing, Troy, MI, volume 11, number 3, pages 41-42 and 44, March 1994 (3 pages with 5 figures, RDB4439)

This paper explores the potential for use of R-717 (ammonia) for supermarket refrigeration. It characterizes ammonia refrigeration, secondary coolant systems, and even the combination as established. It suggests, however, that adoption of such systems in retail marketing would be both new and dramatic. The paper indicates that environmental concerns with chlorofluorocarbons, hydrochlorofluorocarbons, and hydrofluorocarbons coupled with the efficiency of

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ammonia would make it the refrigerant of choice, were it not for its toxicity and flammability. The paper suggests that these risks can be reduced by use of a secondary coolant, enabling containment of the ammonia in a restricted access, machinery room. It describes primary and secondary systems, connected by plate-and-shell heat exchangers. This type is described as providing the benefits of plate heat exchangers with the high integrity of shell-and-tube designs. Schematics illustrate the machinery room components and secondary distribution circuits for both two- and four-pipe systems. A plot compares projected maintenance costs of the ammonia-based secondary system to an R-22, direct expansion system. The paper concludes that the ammonia-based secondary system offers environmental and cost benefits, reduced refrigerant charge, lower costs of ownership, and flexibility in store layout. It notes that development work is still required.

M. Jacobs, J. Kaschemekat, V. Simmons, and J. Wijmans (Membrane Technology and Research, Incorporated), **Membrane Systems for Improved Recovery of Refrigerant Vapor**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 232-242, October 1993 (11 pages with 7 figures and 2 tables, RDB-3A45)

R. W. James and J. S. Missenden, **The Use of Propane in Domestic Refrigerators**, *International Journal of Refrigeration* (IJR), Paris, France, volume 15, number 2, pages 95-100, February 1992 (6 pages, RDB4240)

R-290

H. Jürgensen (AEG Hausgeräte AG, Germany), **Messungen an Haushaltskühlgeräten mit brennbaren Kältemitteln** [Measurements of Residential Refrigerators with Flammable Refrigerants], *DKV Jahrestagung* [Proceedings of the DKV Annual Meeting] (Bremen, Germany, 17 November 1992), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 19, number II/2, pages 177-192, 1992; republished in *Die Kälte- und Klimatechnik*, Germany, volume 46, number 2, pages 84-94, February 1993 (16 pages with 5 figures and 5 tables, in German, RDB3108)

R-290, propane, R-600, butane, R-601, isobutane, hydrocarbon blends

H. Jürgensen (AEG Hausgeräte AG, Germany), **Messungen an Haushaltskühlgeräten mit brennbaren Kältemitteln** [Measurements of Residential Refrigerators with Flammable Refrigerants], presentation charts, *DKV Jahrestagung* [DKV Annual Meeting] (Bremen, Germany, 17 November 1992), Deutscher Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, 1992 (18 pages, in German, RDB3109)

R-290, propane, R-600, butane, R-601, isobutane, hydrocarbon blends

M. Kauffeld, H. König, and H. Kruse (Universität Hannover, Germany), **Theoretical and Experimental Evaluation of Air Cycle Refrigeration and Air Conditioning**, paper 219, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume III, pages 1124-1129, August 1991 (6 pages with 14 figures, RDB6931)

R-729 (air), air-cycle refrigeration; open Joule Cycle, also identified as the reversed Brayton Cycle, and variants; reviews cycle performance and examines the consequences of internal heat exchange for direct and indirect systems; discusses problems and potential solutions for use of air cycles; concludes that an air-cycle machine could be developed that would match the performance of current vapor-compression cycle equipment for mobile air conditioning systems and other applications with source and sink temperature glides, but that air cycle equipment cannot be used in all air-conditioning and refrigeration systems because of poor performance in applications with constant temperatures of the heat source and sink fluids

M. Kauffeld, H. König, and H. Kruse (Universität Hannover, Germany), **Luft als Kältemittel** [Air as a Refrigerant], *Kältetechnik-Klimatisierung*, Gentner Verlag, Stuttgart, Germany, volume 44, number 11, pages 846-857, 1991 (12 pages, in German, RDB-4346)

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection Agency, EPA), **Thermodynamic Evaluation and Compressor Characteristics of HFC-236ea and HFC-245ca as CFC-114 and CFC-11 Replacements in Chillers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 167-176, October 1993 (10 pages with 4 figures and 3 tables, available from JMC as RDB3A39)

R-236ea, R-245ca

G. S. Kazachki (Acurex Environmental Corporation) and C. L. Gage (U.S. Environmental Protection

Agency, EPA), **Thermodynamic Evaluation of Predicted Fluorinated Ether, Ethane, and Propane Azeotropes**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 595-605, July 1992 (11 pages with 10 figures and 4 tables, RDB2834)

This paper summarizes thermodynamic analyses of seven predicted azeotropes of fluorinated ethers, ethanes, and propanes. They include E-125/C270, E-125/134a, E-143a/134, R-134a/E-143a, E-143a/152a, R-134/245cb, and R-245cb/227ea. Their performance was evaluated using basic thermophysical property data and the results used to rank the azeotropes among other refrigerants.

K. Kim, U. C. Spindler (University of Maryland), D. Jung (Inha University, Korea), and R. K. Radermacher (University of Maryland), **R-22/152a Mixtures and Cyclopropane (R-C270) as Substitutes for R-12 in Single-Evaporator Refrigerators: Simulation and Experiments**, paper CH-93-20-2, *Transactions* (Winter Meeting, Chicago, IL, January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, 1993, pages 1439-1446 (8 pages with 4 figures and 3 tables, RDB3114)

M. S. Kim, G. Morrison, W. J. Mulroy, and D. A. Didion, **A Study to Determine the Existence of an Azeotropic R-22 'Drop-In' Substitute**, report NISTIR 5784, National Institute of Standards and Technology (NIST), Gaithersburg, MD, March 1996 (available from NTIS, RDB6432)

R-22 alternatives, R-C270/134a, R-134a/600a, R-290/134a

T. S. Kim, J. Y. Shin, S-D. Chang, M. S. Kim, and S. T. Ro (Seoul National University, Korea), **Cycle Performance and Heat Transfer Characteristics of a Heat Pump Using R-22/142b Refrigerant Mixtures**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 53-62, July 1992 (10 pages with 14 figures, RDB2713)

L. Kinne, **Luft als Kältemittel** [Air as a Refrigerant], *Ki Luft- und Kältetechnik*, Germany, volume 5, pages 220-222, 1994 (3 pages, in German, RDB-4A63)

R-729

J. Köhler, M. Sonnekalb, H. Kaiser, and W. Köcher, **Carbon Dioxide as a Refrigerant for Vehicle Air-Conditioning with Application to Bus Air-Conditioning**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 376-385, October 1995 (10 pages with 8 figures, available from JMC as RDB5B09)

R-744, mobile air-conditioning (MAC) systems

K. Koike (Ebara Corporation, Japan), **HCFC-123 Centrifugal Refrigeration Machine**, paper 4.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 67-76, February 1993 (10 pages with 7 figures and 3 tables, RDB3315)

R-123

E. Korfitsen and A. Christensen, **New Ammonia Technology for Heat Pumps**, *Proceedings of the International Symposium on Refrigeration, Energy, and the Environment* (Trondheim, Norway, 22-24 June 1992), Norgest Tekniska Högskole (NTH), Trondheim, Norway), pages 165-177, 1992 (13 pages, RDB4344)

R-717

H. Kruse and F. Rinne (Universität Hannover, Germany), **Performance and Leakage Investigations of Refrigeration and Air-Conditioning Systems Using Refrigerant Mixtures as Working Fluids**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 621-630, July 1992 (10 pages with 10 figures, available from JMC as RDB2837)

H. Kruse (Universität Hannover, Germany), **Energy Savings When Using Hydrocarbons as Refrigerant**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 386-395, October 1995 (10 pages with 9 figures and 7 tables, available from JMC as RDB5B10)

R-C270; R-290; R-600; R-600a; R-601 (n-C5 or pentane); R-601b (2,2-dimethylpropane); R-1250 (propadiene); R-1270; R-290/600; R-290/600/-601; R-290/600a (28/72), (40/60), (50/50), and (72/28); R-290/601 (R-290/n-C5); butene, 2-methyl-1,3-butadiene, 2-methylbutane, 1,2-pentadiene, 1,4-pentadiene, pentene

H. Kruse (Universität Hannover, Germany), **Development Trends of Future Replacement s**

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for Refrigerants R-502 and R-22 for Food Refrigeration at Low Temperatures, *DKV-Statusbericht* [Status Report], Deutsche Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 11, pages 1-45, 1992 (45 pages, RDB5B31)

R-22 and R-502 alternatives

H. Kruse (Universität Hannover, Germany), **Trends to the Substitution of Refrigerant R22**, *DKV-Statusbericht* [Status Report], Deutsche Kälte- und Klimatechnischer Verein (DKV, German Association of Refrigeration and Air-Conditioning Engineers), Germany, volume 10, pages 1-4, 1992 (4 pages, RDB5959)

R-22 alternatives

H. Kruse and E. A. Groll (Universität Hannover, Germany), **Untersuchung alternativer Anlagenschaltungen und Arbeitsstoffe zur Lösung des FCKW-Ozon-Problems** [Examination of Alternative Cycles and Working Materials to Solve the CFC/Ozone-Depletion Problem], final report 01ZH89C1, Bundesminister für Forschung und Technolgie (BMFT) [Federal Ministry of Research and Technology], Bonn, Germany, May 1992 (in German, RDB5499)

alternative cycles and refrigerants, environmental protection

H. Kruse and M. Kauffeld (Universität Hannover, Germany), **Kaltluftkältemaschinen nach dem Joule-Prozess** [Air-Cycle Refrigeration Equipment Based on the Joule Process], *Ki Klima-Kälte-Heizung*, volume 18, number 5, pages 206-211, 1990 (6 pages, in German, RDB6930)

R-729 (air), air-cycle refrigeration

S. L. Kwon, J. Berge, and L. Naley (Thermo King Corporation), **Evaluation and Implementation of R-502 Alternatives for Transport Refrigeration**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 63-70, July 1996 (8 pages with 5 figures and 1 table, RDB6761)

reviews the performance requirements for transport refrigeration, outlines a test program for R-404A, R-407A, R-407B, and R-507A; tabulates the composition, molecular weight, critical properties, ozone depletion potentials (ODPs), halocarbon global warming potentials (HGWPs), and flammability for them; describes component modifications; provides plots of the discharge temperatures and pressures and of the comparative fuel consumptions and capacities for R-404A, R-407A, R-407B, and R-507A

S. L. Kwon, J. Berge, and L. Naley (Thermo King Corporation), **Evaluations of Alternatives for Transport Refrigeration**, paper 3.6, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 72-77, December 1994 (6 pages with 1 figure and 3 tables, RDB5415)

This paper reviews the requirements for R-22 and R-502 alternatives for transport refrigeration, describes a test program to evaluate 12 candidates, and presents a tabular summary of the findings. Four lists, in outline format, describe the methods of refrigerating commodities during transport, application requirements for general purpose transport equipment, performance criteria for alternative refrigerants, and a process for screening refrigerants for transport refrigeration. Notes differentiate between transport (e.g., highway, intermodal, marine, or straight truck) and stationary (e.g., storage or supermarket) refrigeration. A table contrasts the differences between supermarket and transport factors. The paper then discusses refrigerant selection criteria with attention to safety and thermodynamic requirements, discharge vapor temperature, discharge pressure, and compatibility - in terms of capacity, service, and reliability - with existing equipment. The paper briefly describes a test program and schematically shows the system used for laboratory tests of alternative refrigerants. The results are tabulated for transitional and long-term replacements, namely those containing hydrochlorofluorocarbons (HCFCs) and those based on hydrofluorocarbons (HFCs). The former include R-402A, R-402B, R-290/22/218 (6/85/9) and (6/74/20), R-290/22/218 (6/55/39), and R-408A. The tested long-term replacements include R-404A, R-407A, R-407B, R-125/143a (45/55), R-507A, and R-32/125/143a (10/45/-45). The tables identify the discharge pressure and temperature, energy rate, and capacity normalized to data for R-502 with an alkylbenzene lubricant. Data are presented for R-502 with a polyolester lubricant and for R-22 with liquid injection and an alkylbenzene lubricant for comparison. The ambient and box temperatures, based on tests following ARI Standard 1110-92, are indicated. The conclusions note that some of the alternatives that may be acceptable for supermarket use are unacceptable for transport refrigeration, due to their higher discharge temperatures. With redesign, the higher discharge pressures may be accommodated and modifications can improve the efficiency in most systems. The paper also concludes that R-404A is the leading alternative from the standpoint of

performance, as confirmed by extended field trials. [The blend identified as R-290/22/218 (6/74/20) also is identified as R-403A in the paper; R-403A is R-290/22/218 (5/75/20). The blend identified as R-290/22/218 (6/55/39 also is identified as R-403B in the paper; R-403B is R-290/22/218 (5/56/39).]

L. Lankford (J. J. Research Labs) and J. Nimitz (Environmental Technology and Education Center), **A New Class of High-Performance, Environmentally Sound Refrigerants**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 141-149, October 1993 (9 pages with 3 figures and 4 tables, RDB-3A36)

fluoroiodocarbons, FICs; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217I1, R-217cal1

J. W. Linton and W. K. Snelson (National Research Council, Canada, NRCC), **A New Environmentally Acceptable High-Temperature Heat Pump**, *Proceedings: Meeting Customer Needs with Heat Pumps - 1991* (Dallas, TX, October 1991), report TR-101944, Electric Power Research Institute (EPRI), Palo Alto, CA, pages 55-1 - 55-15, December 1992 (14 pages with 9 figures, RDB3B05)

R-123

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **The Use of Natural Refrigerants - A Complete Solution to the CFC/HCFC Predicament**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 21-36, 1994 (7 pages with 8 figures and 1 table, RDB5328)

R-290, R-717, R-718, R-744

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Use of CO_2 in Commercial Refrigeration; An Energy Efficient Solution**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 703-709, 1994 (7 pages with 3 figures, RDB4A62)

R-744, carbon dioxide, transcritical cycle

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Application of 'Natural' Refrigerants**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 55-64, 1993 (10 pages with 3 figures and 1 table, RDB5305)

R-290 (propane), R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), transcritical cycle

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Large Heat Pumps Using CO_2 Refrigerant**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 191-197, 1993 (7 pages with 6, RDB5316)

R-744 (carbon dioxide), transcritical cycle

G. Lorentzen (Norgest Tekniska Högskole, NTH, Norway), **Revival of Carbon Dioxide as a Refrigerant**, *Refrigeration Beyond the Crisis* (London, UK, 4 November 1993), Institute of Refrigeration and the Society of Environmental Engineers, London, UK, 1993; republished in *H&V Engineer*, volume 66, number 721, pages 9-14, 1994; republished in *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 5, pages 292-301, 1994 (6 pages, RDB5330)

R-744, carbon dioxide, transcritical cycle

G. Lorentzen and J. Pettersen (Norgest Tekniska Högskole, NTH, Norway), **A New, Efficient and Environmentally Benign System for Car Air Conditioning**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 1, pages 4-12, January 1993 (RDB5452)

R-744 (carbon dioxide), transcritical cycle

H. Lotz (Bosch-Siemens Hausgeräte GmbH, Germany), **Light Hydrocarbons as Refrigerants and Blowing Agents for Insulation in Household Appliances**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 49-64, 1994 (16 pages with 11 figures and 2 tables, RDB5332)

R-290/600a, R-600a

C. Madan (Continental Products Incorporated), **R-134a: The Best Alternative for Chillers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 58-60, May 1993 (2 pages with 1 figure, RDB3603)

This article briefly reviews efforts by manufacturers to adopt or develop new equipment to use alternative refrigerants. It focuses on use of R-134a, particularly in scroll, screw, and reciprocating-piston compressors. Advantages of

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the R-134a choice are cited, including its being chlorine free, assured availability because of selection by the automobile industry, reasonable pricing resulting from increased production, and worldwide acceptance. The article discusses advantages and disadvantages of R-134a, noting the suitability of existing chiller components but higher prices than for R-22 due to the larger compressor required. The article describes the cost increment as the right choice, to avoid replacement when hydrochlorofluorocarbon (HCFC) refrigerants become obsolete "in just a few years." The article argues for recommended system changes such as inclusion of a pump-down receiver, built-in refrigerant recovery system, and a pressure relief valve and rupture-disk assembly. The article discusses other considerations noting similarities for R-134a and R-22 in assembly, testing, and installation. It cautions that retrofit of R-22 systems should not be attempted without qualified assistance, and that the conversion may require replacement of compressors, controls, and other components.

S. Madigan (Danfoss), **Compressor Manufacturer's Experiences with R-134a Applications**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 153-155, September 1992 (3 pages with 4 figures and 1 table, available from JMC as RDB2A14)

This paper outlines factors requiring attention when substituting R-134a for R-12 in systems with capillary tubes and Danfoss LBP compressors. Pressure-enthalpy diagrams show that the latent heat of vaporization is significantly higher for R-134a than for R-12, requiring lower mass flow for the same capacity. A table compares the enthalpy and design parameters for the two fluids. The paper notes that capillary tubes must be reselected with the refrigerant change to adapt for the differences in pressure and mass and volume flow. Compatibility is noted as good with substitution of polyolester lubricants, to account for miscibility; valve coking is not anticipated. The dependence on a filter drier, with Union Carbide XH7 recommended as the desiccant, is outlined based on the moisture content of the lubricant and the difficulty of drying it. A set of housekeeping rules is outlined.

H. Madsbøll and G. Mindsen (Dansk Teknologisk Institut, DTI, Denmark), **Energy Saving in Process Cooling by Use of Water as Refrigerant**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 75-85, 1993 (11 pages with 7 figures and 1 table, RDB5307)

R-718 (water)

K. Marumoto and N. Nakagawa (Matsushita Refrigeration Company, Japan), **Composition Shift of R32/125/134a in Multiple Air-Conditioning System**, paper 4.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 88-93, December 1994 (6 pages with 14 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5418)

R-407C, R-32/125/134a, capacity modulation by composition management, composition change, simulation, zeotropic blend, multisplit (multicoil) air conditioner

K. Maruo (Daikin Industries, Limited, Japan), **The Development of CFC and HCFC Alternatives for Refrigerant**, paper 1.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 1-6, December 1994 (6 pages with 5 figures and 6 tables; in Japanese with abstract, figures, and tables in English; RDB5401)

CFC, HCFC, HFC, alternatives, refrigerant, ODP, GWP, TEWI, PAFT, AFEAS

S. Massien and R. Demke (Dunham-Bush, Incorporated), **Current and Future Refrigerants for Chillers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 62-63, May 1993 (2 pages, RDB3604)

This article outlines a rationale for use of R-22 in chillers, noting its low ozone depletion potential (ODP), expected availability for the life of equipment being installed today, and energy efficiency. The article cites studies that show the total global warming of chillers using R-22, R-123, and R-134a to be similar. It discusses both the importance of indirect (energy-related) warming and the fallacy of theoretical efficiencies without regard to other variables. The article notes the long history of R-22 use and reliability of the materials compatibility and safety record garnered. The article then addresses future solutions, including candidate replacements such as R-32, R-125, R-134a, and R-152a among the pure fluids. It also refers to

azeotropic blends, noting R-32/125 in particular. It mentions zeotrope consideration. The importance of refrigerant management, including reclaim, is reviewed and the article concludes by noting that the future holds many possibilities, for both refrigerants and the equipment that uses them.

J. A. McGovern and B. Duignan (University of Dublin, Ireland), **An Air Cycle Design Concept for Domestic or Small Commercial Refrigerators**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 261-266, July 1994 (6 pages with 6 figures, RDB4832)

R-729

M. O. McLinden and D. A. Didion (National Institute of Standards and Technology, NIST), **Quest for Alternatives** (561-RP), *ASHRAE Journal*, volume 29, number 12, pages 32-36, 38, 40, and 42, December 1987; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 69-78, 1989 (8/10 pages with 9 figures and 1 table, RDB2259)

This article reviews the criteria required of refrigerants and the reasons chlorofluorocarbons (CFCs) were originally investigated. A systematic examination, based on molecular structure, reveals a range of compounds that should be environmentally acceptable and still retain desired attributes. 860 compounds were screened, resulting in 51 fluids warranting further examination. The article notes that the number of compounds from which to choose alternatives is limited; the chlorofluorocarbon family - including fluorocarbons and hydrocarbons - remains the clear choice by virtue of stability, thermodynamic properties, health and safety characteristics, and familiarity. Some compromise with traditional criteria (e.g., capacity, flammability, and efficiency) will be needed. Present refrigerants resulted from more than 30 years of research and development. Careful scientific and technological planning are required to effect a significant change, and to avoid a new solution that introduces more problems than it solves.

M. O. McLinden and D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), **The Search for Alternative Refrigerants - A Molecular Approach**, proceedings of the meetings of IIR Commissions B1, B2, E1, and E2 (Purdue University, West Lafayette, IN), International Institute of Refrigeration (IIR), Paris, France, volume 2, pages 91-99, July 1988 (9 pages with 5 figures, RDB2442)

M. O. McLinden, D. A. Didion (National Institute of Standards and Technology, NIST, then the National Bureau of Standards, NBS), and C. D. MacCracken (Calmac Manufacturing Company), **Refrigerant Mixture of Trichlorofluoromethane and Dichlorohexafluoropropane**, U.S. patent 4,687,588, 18 August 1987 (3 pages, RDB6814)

use of R-11/216aa, R-11/216ba, R-11/216ca, or R-11/216cb to improve the pressure lift capabilities and operating range of centrifugal compressors; R-11 and the four R-216 isomers form an azeotrope in a 74/11 blend

A. Meyer (DKK Scharfenstein GmbH, Germany), **The Success of Hydrocarbons in Domestic Refrigeration**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 281-291, 1993; republished in *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 2, pages 343-363, February 1993 (11 pages with 4 figures and 1 table, preprint available from JMC as RDB3226)

R-290, R-600a, R-290/600a (50/50), refrigerators, refrigerator/freezers

A. Meyer (DKK Scharfenstein GmbH, Germany), **Der FCKW-frei Kühlschrank der FORON Hausgeräte GmbH - ein Beitrag für eine bessere Umwelt** [The CFC-Free Refrigerator from FORON Hausgeräte GmbH - A Contribution for a Better Environment], *Luft- und Kältetechnik*, Germany, pages 3-4, January 1993 (2 pages, in German, RDB5715)

R-290, R-600a, R-290/600a (50/50), refrigerators, refrigerator/freezers

Y. Mianmian, D. Changwei, Y. Zida, L. Zhikun, H. Chuanqiao, and W. Donning (Haier Group, China), **Latest Developments on CFC Substitution in China**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 331-340, October 1995 (10 pages with 3 figures and 6 tables, available from JMC as RDB5B07)

use of R-600a (isobutane) as a refrigerant and cyclopentane as an insulation blowing agent in a domestic refrigerator

S. M. Miner (Engineering Consultant), **Ammonia as a Refrigerant of Choice**, *ASHRAE Journal*, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 32, number 12, pages 43-44, December, 1990 (3 pages, RDB6355)

R-717

please see pages 6-8 for ordering information

S. M. Miner (Engineering Consultant), **An Appraisal of Ammonia as an Alternative Refrigerant in Light of the CFC and GWP Situation**, *Technical Papers of the 14th Annual Meeting* (22-25 March 1992, Miami, FL), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 231-250, March 1992 (20 pages with 4 figures and 5 tables, RDB2912)

This paper reviews the history of R-717 (ammonia) refrigeration and the impediments - real and perceived - to its broader use. Safety issues and environmental benefits associated with ammonia are identified. Current developments and research efforts related to ammonia use are summarized. The paper then outlines several applications of ammonia as examples and concludes with sources of further information.

S. M. Miner (Engineering Consultant), **An Appraisal of Ammonia as an Alternative Refrigerant** paper 220, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume III, pages 1130-1134, August 1991 (5 pages with 3 figures and 4 tables, RDB2844)

R-717; brief review of history and market status; contrasts accident concerns with those for other refrigerants; reviews performance and other technical aspects of use; describes research activities and tabulates recent R-717 installations; cites sources of training and support

S. Morikawa (Asahi Glass Company, Limited, Japan), **Recent Development of CFC Alternatives**, Catalysis Society of Japan, volume 34, number 7, pages 458-463, 1992 (6 pages, RDB-3325)

D. Mosemann (Kühlautomat Berlin GmbH KAB, Germany), **Ammonia Chillers for Air Conditioning**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 71-96, 1994 (26 pages with 20 figures and 1 table, RDB-5334)

R-717

G. Mozzon and P. Sansalvadore (Aspera-Whirlpool SpA, Italy), **Reliability of Hermetic Compressors for R-134a Appliances**, paper 4.4, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 77-82, February 1993 (6 pages with 2 figures and 6 tables, RDB3316)

E. B. Muir (Copeland Corporation), **HFC Replacements for R-22**, *CFCs: The Day After* (proceedings of the IIR meeting, Padova, Italy, 1994), International Institute of Refrigeration (IIR), Paris, France, pages 249-258, 1994 (10 pages, RDB6862)

R-407C, R-410A, and others

W. Mulroy, M. Kauffeld, M. O. McLinden, and D. A. Didion (National Institute of Standards and Technology, NIST), **An Evaluation of Two Refrigerant Mixtures in a Breadboard Air Conditioner**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, pages 27-34, July 1988 (8 pages with 21 figures and 1 table, RDB4401)

R-22/114, R-13/12

C. S. Munday, B. Yudin, and R. Stephenson, **FRIGC(TM) FR-12 Refrigerant, A Replacement for CFC-12 in Mobile Air Conditioning Systems**, unpublished presentation (International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Intermagnetics General Corporation, Latham, NY, 1994 (6 pages with 5 figures and 4 tables, RDB4C58)

R-134a/124/600, thermodynamic properties, environmental considerations, toxicology, flammability, compatibility, hose permeation, lubricants, performance, commercialization plan

M. Nakayama, H. Iijima, and Y. Tanimura (Mitsubishi Electric Corporation, Japan), **R32/125/134a Cycle Composition Change and its Effect on the System Performance**, paper 4.1, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 79-83, December 1994 (5 pages with 10 figures and 1 tables; in Japanese with abstract, figures, and tables in English; RDB5416)

This paper examines the performance changes in an inverter-driven heat pump using R-407C. The nominal 23% mass fraction was found to increase to 27.8% as surplus refrigerant was retained in the accumulator, resulting in a 6% increase in heating capacity. The test facility is shown schematically and test conditions are tabulated. Plots show the composition shifts of the components with refrigerant accumulation. Further plots show the changes in suction and discharge pressure as well as the capacity at both low and high speed heating operation, 30 and 90 Hz respectively, with accumulation. Capacity and coefficient of performance (COP) ratios are plotted for increasing surplus refrigerant

ratios for both the heating and cooling modes. Two final plots compare measured and predicted heating capacity and COP with changes in the circulating R-32 fraction.

H. Namiki (Mayekawa Manufacturing Company, Limited, Japan), **The Trends in Ammonia for Industrial Refrigeration Plants**, paper 3.3, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 57-62, December 1994 (6 pages with 4 figures and 12 tables; in Japanese with abstract, figures, and tables in English; RDB5412)

This paper describes the development of a new industrial refrigeration system using R-717 (ammonia) as the refrigerant. The development objectives are noted as a system that is entirely leak proof, uses a minimum amount of refrigerant, and can be operated automatically. Key features of the new system are use of a polyalkylene glycol (PAG) lubricant, a direct-expansion evaporator, and a compressor with a "canned motor." Environmental and performance advantages as well as safety concerns are cited for ammonia. A table summarizes the common refrigerants and alternatives used in selected, large-scale industrial refrigeration systems along with the applicable temperature ranges and cooling media. Two further tables list the merits and concerns for ammonia and compare its properties with those of R-22. Plots compare the capacity and coefficients of performance (COPs) for the two refrigerants as functions of evaporating temperatures. A table outlines the challenges of reducing the refrigerant charge, minimizing leakage, and achieving operational safety and high efficiency. Three tables give the characteristics of the PAG, compare its solubility and fluidity to a naphthenic mineral oil, and similarly compare effects on heat transfer. Schematics show the canned-motor drive integration with a reciprocating-piston compressor as well as the system. Tables describe the key component specifications and summarize key parameters for use in cold storage, food processing, marine refrigeration, and air conditioning. The paper describes the resulting system as safe, environmentally friendly, and efficient.

P. Nekså (Norgest Tekniska Högskole, NTH, Norway), **The Transcritical Vapor Compression Cycle - Its Potential in Heat Pump Processes**, *Proceedings of the International Symposium on Refrigeration, Energy, and the Environment* (Trondheim, Norway, 22-24 June 1992), Norgest Tekniska Högskole (NTH), Trondheim, Norway, 1992 (RDB-5497)

R-744 (carbon dioxide), transcritical cycle

O. Nesje (Norgest Tekniska Högskole, NTH, Norway), **Ammonia in Small and Medium Sized Heat Pumps for Energy Efficiency and Environmental Progress**, Proceedings of the Fourth International Energy Agency (IEA) Heat Pump Conference (Maastricht, The Netherlands, 26-29 April 1993), Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1993 (RDB4536)

R-717

A. D. Nickens, G. F. Brunner, and D. L. Hamilton (U.S. Navy), **Navy Investigations of HFC-134a as a Replacement for CFC-12 in Shipboard Applications**, *Naval Engineers Journal*, pages 98-103, May 1992 (6 pages with 4 figures and 4 tables, available from JMC as RDB2706)

This article reviews research and development efforts by the U.S. Navy to qualify R-134a as the retrofit replacement refrigerant for R-12 and for future air-conditioning applications on ships and submarines. The article recaps fleet use of R-12 for air-conditioning and refrigeration, compares the properties of R-134a to those of R-12, and outlines the Navy's review of toxicity data and risk affects. Unique considerations for submarine use are summarized, including potential interactions with life-support and contaminant removal systems, in the event of refrigerant leaks. These systems include burners to oxidize carbon monoxide and hydrogen as well as carbon dioxide scrubbers. The article reviews tests of R-134a in 25 and 80 ton shipboard air-conditioning plants. Initial retrofit tests using R-134a with a polyalkylene glycol (PAG) lubricant resulted in 5% improvements in both capacity and efficiency. Inspection after 5100 hours of operation, however, revealed extensive copper plating and severe damage to one piston, wrist pin, and connecting rod. Damage to other parts, including a chipped oil ring, worn piston rings, and broken or collapsed suction valve springs also were noted. These findings led to a judgement that PAG lubricants are unsatisfactory for shipboard reciprocating compressors for air conditioning. While a molecular-sieve drier had been used for a portion of the cited tests, initial operation was without a drier. The paper reviews a subsequent test of an 80 ton plant with R-134a and a proprietary polyolester (POE) lubricant, provided by the Carrier Corporation. A lubricant analysis after two hours of operation revealed approximately 15% residual mineral oil, which was reduced to approximately 3% after a second oil change. Cooling capacity increased by 1% and efficiency dropped by 2% using R-

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134a. Although minor copper plating was evident after 2000 hours of operation, particularly on the suction valves, no measurable decomposition was detected in the R-134a. No wear was found on any component to date, and the extended operation test is continuing. Onboard demonstration and fleet retrofit plans are summarized.

J. Nimitz and L. Lankford (Ikon Corporation), **Refrigerants Containing Fluoroiodocarbons (FICs)**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 255-260, July 1994 (6 pages with 2 figures and 2 tables, RDB4831)

J. Nimitz (Environmental Technology and Education Center) and L. Lankford (J. J. Research Labs), **Fluoroiodocarbons as Halon Replacements**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 810-819, October 1993 (10 pages with 4 tables, RDB-3A52)

fluoroiodocarbon (FIC) properties; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217I1, R-217caI1

H. Nomura (Daikin Industries, Limited, Japan), **Application of Nonazeotropic Refrigerant Mixtures in Multi-Zone Heat Pump Room Air Conditioner with Hot Water System**, Proceedings of the Meeting of IIR Commissions B1, B2, E1, and E2 (Purdue University West Lafayette, IN), International Institute of Refrigeration, Paris, France, pages 61-69, 1986 (9 pages with 8 figures and 2 tables, RDB5513)

R-13B1/12, R-22/114, zeotropic blends, performance

S. Nowotny and M. D. Mayer, **Alternative Refrigerants for Use in Domestic Refrigeration - A Case Study**, *Refrigeration Beyond the Crisis* (London, UK, 4 November 1993), Institute of Refrigeration and the Society of Environmental Engineers, London, UK, 1993 (RDB5330)

J. Nyvad and F. Elefsen (Dansk Teknologisk Institut, DTI, Denmark), **Energy Efficient Cooling by Use of Cycloid Water Vapor Compressor**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 67-74, 1993 (8 pages with 5 figures and 1 table, RDB5306)

R-718 (water), cycloidal compressor principles and construction

K. Oguni, K. Urata, and H. Matsushima (Hitachi Limited, Japan), **Characteristics of Refrigeration System Utilizing Refrigerant Mixture R32/125/-134a**, paper 4.2, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 84-87, December 1994 (4 pages with 7 figures and 3 tables; in Japanese with abstract, figures, and tables in English; RDB5417)

This paper outlines a capacity modulation method by composition control using R-32/-125/134a - a zeotropic blend to replace R-22 - in an air-to-air heat pump. The concept is based on alternate storing of excess liquid refrigerant in the low and high pressure sides of the refrigeration circuit. By holding refrigerant on the low side, in the accumulator, the circulating refrigerant becomes richer in R-32. When stored in a receiver on the high side, the R-32 fraction is decreased. Schematics show the refrigerant mixture phase equilibria with composition change, the basic cycle on a pressure-enthalpy chart, and the experimental equipment tested. The equipment specifications and test conditions are tabulated. Plots show the component changes in circulating refrigerant with accumulation and changes in refrigerant phase quality. Predicted and measured fractions are tabulated and the capacity, coefficient of performance (COP) and discharge pressure shifts are plotted. The results show a 10% increase in COP for both heating and cooling with composition management.

R. S. Ohling, **Ammonia: The New/Old Refrigerant**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 32, number 12, pages 36-42, December 1994 (7 pages, RDB4B65)

R-717

G. J. O'Neill, **Development of a New Alternative: E-134**, unpublished presentation (*The Global Business Outlook for CFC Alternatives*, Boston, MA, 15-16 June 1993), Hampshire Chemicals Corporation, Nashua, NH, June 1993 (32 pages with 5 figures and 7 tables, RDB5550)

This paper summarizes available data and potential uses for R-E134. It outlines consideration of this chemical and related fluoroethers (including R-E116, R-E125, R-E143, and R-E245) as candidate anesthetics, aerosol propellants, and - with new environmental issues - refrigerants. Two tables summarize key physical properties and compare those of R-E134 and R-114, for which the ether is a potential replacement. The

data suggest that R-E134 may offer 40% higher capacity and 5% greater efficiency. A third table compares the characteristics of R-11, R-12, R-22, R-123, R-124, R-134a, R-141b, R-142b, R-E125, R-E134, and R-E143. The paper then reviews toxicity test data for R-E134, with limited comparisons to R-11, R-12, R-21, and R-22. The information includes acute and subchronic inhalation tests as well as Ames assay results for mutagenicity. Limited data are presented for R-E125. The paper then addresses the stability of R-E134, noting that some of the findings reported by others may have been influenced by impurities or conduct of the tests in glass tubes. It points out several fluoroethers that are known to be unstable with glass at elevated temperatures. They include R-E143, an R-E152 isomer [probably R-E152a], R-E161a, and R-E245 [probably R-E245fa1]. The findings of stability tests in steel and Pyrex(R) glass are tabulated. Four figures show the miscibility limits of R-E134 with polyolester lubricants (CPI Engineering Services developmental lubricants) and a mixture with 5% naphthenic mineral oil. A table summarizes stability tests by York International Corporation of R-E134 and metal catalysts (aluminum, copper, and steel wires) with a mineral oil (unidentified), alkylbenzene (Shrieve Zerol(R) 300), a polyalkylene glycol (PAG, Union Carbide UCON LB-525), and mixtures of them. The tests showed no changes for exposures at 135 °C (275 °F) for 48 hours and at 149 °C (300 °F). Discoloration, some copper plating, sludge formation, and in two cases tube shattering occurred at 182 °C (360 °F) for 24 or 74 hours. The paper then addresses preparation of R-E134 and outlines the potential markets for it. It also recaps development work by W. R. Grace and Company and its transfer to the Hampshire Chemical Corporation.

G. J. O'Neill and R. S. Holdsworth (W. R. Grace and Company), **Bis (Difluoromethyl) Ether Refrigerant**, U.S. patent 4,961,321, 9 October 1990 (4 pages, RDB1133)

This patent describes the use of E-134 as a refrigerant, either as a single component or in a blend. The refrigerant is described as environmentally safe, nontoxic, and nonflammable and as having the desired physical, chemical, and thermodynamic properties necessary for a refrigerant.

A. Ophir (I.D.E. Technologies, Israel) and J. Paul (Integral Technologie GmbH, Germany), **The Ecochiller - A Mechanical Vapour Compression Cycle Using Water as Refrigerant**, paper 67, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, pages 573-577, August 1991 (5 pages with 5 figures and 1 table, RDB5437)

R-718; discusses use of water as a refrigerant; plots required compression ratio as a function of leaving source temperature and temperature lift; compares cycles for use of water and describes the components; proposes a system for use of water as a refrigerant and ice slurry as a heat transfer fluid

P. J. Ostman (York International Corporation), **Environmental Solutions for Today's Refrigerant Challenges**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 70-72, May 1993 (3 pages with 1 figure, RDB3607)

M. A. Palmer (W. S. Atkins Limited, UK), **Better Ways of Using Ammonia**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and Institute of Refrigeration, London, UK, 11 November 1992 (4 pages with 4 figures, RDB3335)

J. Pannock, R. K. Radermacher, Z. Liu, and K. Yu (University of Maryland), **Evaluation of HFC-134a and HFC-152a as Working Fluids in a Domestic Refrigerator/Freezer**, paper NO-94-20-2, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 1, pages 1344-1350, 1994 (7 pages with 6 figures and 4 tables, RDB4411)

R-134a, R-152a

J. R. Parsnow (Carrier Corporation), **The Long-Term Alternative: R-134a in Positive Pressure Chillers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 54-56, May 1993 (2 pages with 1 figure, RDB3602)

This article outlines advantages of positive-pressure chillers, with emphasis on transitional use of R-22 and long-term use of R-134a. It reviews purge and pressure relief implications for other alternatives, opportunities for integral storage tanks, requirements for code compliance for pressure vessels, and equipment size considerations. The article discusses refrigerant containment procedures for existing chillers and discusses the transitional nature of hydrochlorofluorocarbons (HCFCs), including both R-22 and R-123. It then outlines considerations for conversion and replacement decisions. The article suggests typical retrofit costs from R-12 or R-500 to R-134a of 26% of replacement costs. The conversion typically results in 8-10% loss in

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capacity and 1-2% in efficiency for R-12 and minimal capacity and 0.5% efficiency losses for R-500. Modification to impellers and gear sets are mentioned to avoid these losses at an additional 17% or replacement cost. The article concludes that owners and engineers should plan for the refrigerant transition today.

J. Paul (Integral Technologie GmbH, Germany), **Water as Alternative Refrigerant**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 97-108, 1994 (12 pages with 3 figures and 2 tables, RDB5335)

R-718

J. Paul (Integral Technologie GmbH, Germany), **Binary Ice - An Alternative Cooling Method**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, pages 87-96, 1993 (10 pages with 4 figures and 7 tables, RDB5308)

This paper summarizes a cooling method that use an ice slurry, composed of small ice crystals suspended in water, as a coolant in place of chilled water. The slurry may be generated using an indirect process with conventional refrigeration methods. It also may be generated with a direct process, using water under subatmospheric conditions as the refrigerant, identified as "vacuum ice." The paper briefly reviews the German federal Umweltbundesamt (UBA, Authority for the Environment) categorization of refrigerants based on "safe" and "unsafe" environmental properties. Those deemed safe include (R-717) ammonia, R-718 (water), R-729 (air), R-764 (carbon dioxide), and hydrocarbons. A figure shows the conceptual options to provide cooling by combining direct and indirect methods, with and without secondary coolants. The unique properties of the ice slurry are described as combining the advantages of direct-expansion (DX) cooling and the simplicity of a brine, secondary coolant system. Moreover, the slurry offers high energetic density due to the latent heat of the ice crystals, but still flows like water. The slurry is described as a Bingham rather than a Newtonian fluid, and the flow as plug flow not exhibiting laminar and turbulent behavior. The means to generate the slurry are described and shown schematically. For the process using water as the refrigerant, ice is formed at the triple point using flash evaporation in an empty shell, used as the evaporator. The paper describes concepts that use both direct and indirect condensation, the former again using an empty shell for the heat exchanger along with a vacuum pump to remove noncondensable gases. The paper compares and tabulates the pipe and storage sizes with the ice slurry, for different ice fractions, against chilled water. It then describes and tabulates key performance parameters for installations for mine cooling, air conditioning, and beverage refrigeration. Integral Technologie GmbH's trade name for the ice slurry system is Binary Ice; Solmecs Flo-Ice Systems offers a similar product that may use different eutectics under the name Flo-Ice.

S. F. Pearson (Star Refrigeration Limited), **Development of Improved Secondary Refrigerants**, Institute of Refrigeration, London, UK, 3 April 1993 (RDB5726)

heat transfer fluids

S. F. Pearson (Star Refrigeration Limited), **The Development of a Drop-In Replacement for R-502**, paper 92.4, *Proceedings of the Institute of Refrigeration*, London, UK, January 1992 (9 pages with 15 figures and 1 table, RDB2306)

This paper describes the development, performance testing, flammability considerations, charging, and separation of two ternary zeotropes, R-403A and R-403B, developed as replacements for R-502. Both are blends of R-22, R-218 (octafluoropropane), and R-290 (propane). R-403B, which contains 39% R-218, results in marginally lower discharge temperatures; R-403A, which contains 20% R-218, offers discharge temperatures between those of R-502 and R-22. These R-290/22/218 mixtures are nonflammable and of low toxicity. They exhibit ozone depletion potentials (ODPs) of 0.037 and 0.028 and nearly the same refrigerating effect as R-502. Measured coefficients of performance (COPs) with these blends were higher than for R-502 under comparable conditions. The paper describes the choice of components, including initial consideration of blends containing R-125 and R-1270. The test rig, results, and effects of diffusion and replacement of lost refrigerants also are discussed. Extensive international field testing is mentioned, but not described.

S. F. Pearson and J. Brown (Star Refrigeration Limited, Scotland), **Development of a Substitute for R502**, paper 162, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume II, pages 903-909, August 1991 (7 pages with 8 figures and 2 tables, RDB2425)

discusses development of a replacement for R-502 including R-403A and R-403B

J. Pettersen (Norgest Tekniska Högskole, NTH, Norway), **A New and Efficient Vehicle Air-Conditioning System Based on CO_2 Vapor Compression**, paper OR-94-5-3, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 657-665, 1994 (9 page with 7 figures and 1 table, RDB4709) .

R-744, carbon dioxide

J. W. Pillis (Frick Company), **Expanding Ammonia Usage in Air Conditioning**, *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 103-107, 1994 (5 pages with 3 figures and 1 table, RDB4525)

This paper presents tradeoffs for R-717 (ammonia) use in systems of different sizes. The author identifies good efficiency, high heat transfer coefficients, zero ozone depletion and global warming potentials (ODP and GWP), and low cost as positive aspects. He also cites favorable piping sizes, tolerance to water contamination, near insolubility in mineral oils, and ammonia's self-alarming smell to warn of leaks. Toxicity, flammability in the range of 16-27% concentration in air, and incompatibility with copper are cited as negative aspects. A figure shows the efficiencies of R-12, R-22, R-134a, and R-502 relative to that of ammonia for -40 to 4 °C (-40 to 40 °F) assuming isentropic compression. The paper indicates that ammonia probably is not competitive in small refrigeration and air-conditioning systems based on incompatibility with copper, use of which results in systems that are simple to fabricate, are virtually leak free, and offer simple methods for field repairs. The paper discusses design changes required for oil return, need to develop low-cost motors that are compatible with ammonia, and consequences of high discharge temperatures with air-cooled condensing. Two plots show the discharge temperatures of R-22, R-134a, and ammonia at 55 °C and 130 °F as functions of evaporating temperature. The paper notes that ammonia is widely used in large refrigeration systems, notably in industrial applications, based on favorable thermodynamic characteristics and low costs. It also notes that the zeotropic alternatives to R-22 would be a major concern in these applications due to their size, opportunities for leaks, potential for fractionation, and consequent servicing complexity. R-134a is not a good choice due to poor low-temperature efficiency, and the pressures associated with R-32 would necessitate new compressor designs. With R-22 phaseout, ammonia is suggested as the best choice. The paper discusses its advantages for these systems and notes that typical use of open drives, steel pipe for strength and durability, and evaporative condensers overcome the concerns cited for small systems. With zeotropes excluded for chillers in large air-conditioning systems, due to wide use of flooded evaporators and service considerations, ammonia and azeotropes are suggested as alternatives. The paper describes requirements for greater ammonia use including development of cost-competitive, enhanced heat exchangers fabricated with steel, aluminum, or other materials. Based on part-load efficiency, screw or reciprocating compressors would be favored over multistage centrifugal compressors, needed for the high pressure differentials. Two installations of large ammonia chillers are described. Medium-sized chillers as cited as a market segment where ammonia use could increase. Several new packaged chillers, using ammonia, are cited as examples. The paper then discusses impediments to broader use of ammonia, among them toxicity and flammability. Several building code requirements are discussed and contrasted with a table showing the effects of exposure to increasing concentrations of ammonia. Some of the code requirements are suggested to be arbitrarily stringent. The author concludes that ammonia is not the answer for all or even a majority of air-conditioning systems, but that it is a good solution in many installations. He suggests caution to avoid over-regulation of ammonia use and a need to develop codes and standards that provide safe systems, without unnecessary restrictions and cost requirements.

S. Pourreza-Djoushari and R. K. Radermacher (University of Maryland), **Calculation of the Performance of Vapor-Compression Heat Pumps with Solution Circuits Using the Mixture R22/DEDGDME**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 4, May 1993 (RDB4444)

R-22/DEDGDME

R. L. Powell (ICI Chemicals and Polymers, Limited), **Long Term Replacements for R-22 and R-502: The Next Challenge**, unpublished presentation (International CFC and Halon Alternatives Conference, Baltimore, MD, 3-5 December 1991), ICI Americas Incorporated, New Castle, DE, USA, December 1991 (16 pages with 4 figures and 3 tables, RDB2519)

This paper identifies a number of candidates to replace R-22 and R-502, and describes the advantages and disadvantages of each. Options addressed include R-32, R-125, R-134a, R-143a, R-152a, as well as nine binary and ten ternary

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blends of them. Candidate selection was limited to fluorocarbons because they offer the low boiling points needed for refrigeration, including the temperatures needed for frozen-food storage. Chlorinated compounds are excluded because of their potential for ozone depletion. Perfluorocarbons, such as R-218, were deemed unlikely since their high-fluorine content, and resultant long atmospheric lifetimes, are expected to lead to high direct global warming potentials (GWPs). Property similarity to the fluids being replaced, to minimize equipment development requirements, and avoidance of subatmospheric operation were further goals. Flammability and toxicity limited some choices, such as R-290 (propane) and R-717 (ammonia). The paper describes avoidance of high GWPs, flammable ranges, discharge superheat, and fractionation potential in leakage. It also cites the goal of maintaining, or improving, efficiency to further narrow the list of candidates. The paper recommends mixtures of R-32 and R-134a as the preferred solutions; it notes that their blends may be modified by addition of R-125, to suppress the flammability of R-32 and reduce discharge temperatures.

E. Preisegger, **Refrigeration/Refrigerants**, *Ki Klima-Kälte-Heizung*, Germany, volume 11, pages 456-460, 1991; translated by Quest Technology, Incorporated (file QU01043), Arlington Heights, IL (16 pages with 8 figures and 2 tables, RDB3A21)

R-227ea, miscibility, materials compatibility, toxicity, thermodynamic properties, performance

R. K. Radermacher and D. Jung (University of Maryland), **Theoretical Analysis of Replacement Refrigerants for R22 for Residential Uses**, paper 3654, *Transactions* (Winter Meeting, Chicago, IL, 23-27 January 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 99, part 1, pages 333-343, 1993 (11 pages with 7 figures and 1 table, RDB4413)

This paper examines the need for and candidate replacements for R-22. The simulation programs and data used for the study are summarized. Hydrofluorocarbon (HFC) refrigerants R-32, R-125, R-134, R-134a, R-143a, and R-152a and hydrochlorofluorocarbon (HCFC) R-124 were selected for analyses. Results are presented for R-32/124 (30/70), R-32/134 (30/70), R-32/134a (30/70), R-32/152a (40/60), R-125/-152a (20/80), R-143a/124 (30/70), and R-143a/152a (10/90). Results also are provided for three ternary blends, investigated to reduce flammability, namely R-32/152a/124 (20/20/-60), R-32/152a/134 (30/40/30), and R-32/-134a/152a (40/10/50). Coefficients of performance (COPs) are tabulated and both the COPs and seasonal performance factors (SPFs) are plotted. Three figures illustrate the cooling COPs and volumetric capacities of binary mixtures of R-32/124, R-32/134, R-32/134a, R-32/-152a, R-125/124, R-125/134a, R-125/152a, R-143a/124, R-143a/134a, and R-143a/152a as functions of composition. The paper also reviews the design modifications considered, with emphasis on concentration management, by a short distillation column, and use of counterflow heat exchangers. The direct (refrigerant emission) and indirect (energy related) global warming impacts of selected blends are contrasted to those with R-22 in a plot. The paper concludes that refrigerant mixtures can replace R-22 without loss in efficiency, and that gains are possible with use of counterflow heat exchangers and capacity modification by composition shifting. Both the ozone depletion and global warming impacts can be reduced by the blends examined.

R. K. Radermacher and D. Jung (University of Maryland), **Theoretical Analysis of Replacement Refrigerants for R-22 for Residential Uses**, report EPA/400/1-91/041, U.S. Environmental Protection Agency (EPA), Washington, DC, December 1991 (77 pages with 10 figures and 10 tables, available from JMC as RDB2509)

This report examines the need and candidate replacements for R-22. The simulation programs (HAC1 for single fluids and binary mixtures and HACT1 for ternary mixtures) and data used for the study are summarized. Hydrofluorocarbon (HFC) refrigerants R-32, R-125, R-134, R-134a, R-143a, and R-152a and hydrochlorofluorocarbon (HCFC) R-124 were selected for analyses. Results are presented for R-32/124, R-32/134, R-32/134a, R-32/152a, R-125/124, R-125/134a, R-125/152a, R-143a/124, R-143a/134a, and R-143a/152a. Results also are provided for three ternary blends, investigated to reduce flammability, namely R-32/152a/124, R-32/152a/134, and R-32/134a/152a. Coefficients of performance (COPs) and seasonal performance factors (SPFs) were calculated. The report also reviews the design modifications considered and discusses requirements for future research. No single-component refrigerant was found acceptable as a substitute, but binary and ternary blends appear promising. The ternary mixture of R-32/152a/124 showed the best performance, with a COP increase of 13.7% over R-22. Chlorine-free R-32/152a/134 yielded a 12.6% increase, but no manufacturer has indicated intent to produce R-134. R-32/134a shows an improvement of 6% and may not be flammable since it contains 70% R-134a. The report notes that significant design

changes, such as use of counter-flow heat exchangers, will be necessary to achieve these gains. A caveat indicates that the ranking of substitutes may change, due to the influence of transport properties and other variables not considered. (This report replaces the published draft, see RDB1134.)

R. K. Radermacher (University of Maryland) and J. Lavelle (Elf Atochem North America, Incorporated), **Comparison of R-12 with the Blend of R-22/-142b**, *Proceedings of the ASME Winter Annual Meeting* (Chicago, IL), American Society of Mechanical Engineers (ASME), New York, NY, pages 22-30, 1988 (RDB2339)

R. K. Radermacher (University of Maryland), **Vapor-Compression Heat Pump Cycle with Desorber-Absorber Heat Exchange**, *Development in Refrigeration, Refrigeration for Development* (proceedings of the XVIIth International Congress on Refrigeration (Vienna, Austria, 24-29 August 1987), International Institute of Refrigeration (IIR), Paris, France, August, 1987 (RDB6414)

M. V. Rane and R. K. Radermacher (University of Maryland), **Feasibility Study of a Two-Stage Vapor-Compression Heat Pump with Ammonia/Water Solution Circuits: Experimental Results**, *International Journal of Refrigeration* (IJR), Paris, France, volume 16, number 4, pages 258-264, May 1993 (7 pages with 5 figures and 2 tables, RDB4415)

R-717, R-717/718

M. V. Rane, **Experimental Investigation of Two Stage Vapor-Compression Heat Pump with Solution Circuits**, doctoral dissertation, University of Maryland, College Park, MD, 1991 (RDB4416)

A. Reinhart, **Ammonia in Liquid Chillers and Heat Pumps**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 65-70, 1994 (6 pages with 4 figures and 3 tables, RDB5333)

R-717, ammonia

S. H. Rice, Y. Iikubo, M. L. Robin (Great Lakes Chemical Corporation), V. W. Goldschmidt, and D. R. Tree (Purdue University), **Refrigerant Alternative to R-12: Preliminary Testing in a Domestic Refrigerator**, *Proceedings of the 42nd Annual International Appliance Technical Conference* (University of Wisconsin, Madison, WI, May 1991), IATC, Batavia, IL, pages 367-378, 1991; republished in *Proceedings of the International Appliance Technical Conference - China*, pages 141-149, November 1991 (12 pages, RDB4A36)

R-227ea blends

O. K. Riegger and K. S. Sanvordenker (Tecumseh Products Company), **Mixtures as Candidate Replacements for R-22 - Is There a Choice?**, *R-22 and R-502 Alternatives* (Proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 23-29, 1994 (7 pages with 5 figures and 3 tables, RDB4517)

This paper reviews the requirements for alternatives to replace R-22 and discusses evaluations of candidates, both pure components and blends. The paper divides the requirements into three categories: "*must absolutely have*," "*need to have*," and "*like to have*." It discusses the ozone depletion potential (ODP), global warming potential (GWP) and related total equivalent warming potential (TEWI), toxicity, flammability, functionality, compressor operating parameters (pressures, volumetric capacities, and discharge temperatures), and system parameters for candidates. It then discusses six hydrofluorocarbons (HFCs) including R-23, R-32, R-125, R-134a, R-143a, and R-152a. The paper lists concerns with each, concluding that all fall short in one or more requirements. A table presents their boiling and critical point temperatures, atmospheric lifetimes, GWP, flammability, relative capacity and efficiency, and pressure at 7 °C (45 °F). The paper briefly discusses other candidates including fluoroethers, R-290 (propane), and R-717 (ammonia). It concludes that none of the pure compounds could replace R-22 in air conditioners and heat pumps, necessitating consideration of blends. Based on boiling points, flammability, and environmental aspects, the paper suggests combinations that can be eliminated from consideration or relegated to low priority. It discusses the first choice, R-32/-134a and discusses compositions and considerations for capacity matching, heat transfer, evaporating and condensing temperatures, use of glide, and fractionation. It then presents the findings of experimental evaluations of R-32/-134a (30/70) and R-32/125/134a (30/10/60) [a developmental formulation, since modified, of both DuPont Suva(R) AC9000 and ICI Klea(R) 66]. Four figures show the energy efficiency ratios (EERs) and capacity ratios for the two zeotropic blends compared to R-22 at evaporator temperatures from -18 to 15 °C (0-60 °F) and condensing temperatures of 38-60 °C (100-140 °F). The paper discusses chemical reactivity and other compatibility issues, including miscibility with lubricants as well as effects on mo-

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tor insulation and desiccants, for the pure compounds. It also discusses resultant flammability test conditions and limits when blended with R-125. The authors conclude that refrigerant mixtures with capacities matching that of R-22 also suffer disadvantages. They note that the R-32/-125/134a blend is a more desirable match for R-22, but that a spot check in an air conditioner showed significant deterioration in performance associated with pressure drops and heat transfer coefficients.

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Dual Cycle Isobutane Refrigerator/Freezer**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 258-267, October 1995 (10 pages with 5 figures and 10 tables, available from JMC as RDB5A67)

R-600a, consideration, outlook, theoretical performance (R-12, R-134a, R-600a), efficiency, capacity, compressor calorimeter tests, dual cycle, compressor options

D. R. Riffe (Americold / White Consolidated Industries, Incorporated), **Isobutane as a Refrigerator Freezer Refrigerant**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 245-254, July 1994 (10 pages with 4 figures and 4 tables, RDB-4830)

R-12, R-134a, R-600a

F. Rinne and H. Kruse (Universität Hannover, Germany), **Anlagentechnische Untersuchungen mit dem Kältemittelgemisch R23/R152a** [Equipment Test of the R-23/152a Refrigerant Mixture], *Ki Klima-Kälte-Heizung*, volume 19, number 12, pages 505-509, December 1991 (5 pages, in German, RDB4530)

M. L. Robin, Y. Iikubo (Great Lakes Chemical Corporation), G. de Souza Damasceno, J. N. Dubrouillet, V. W. Goldschmidt, and D. R. Tree (Purdue University), **Performance of Alternative Refrigerants: Refrigerator-Freezer Energy Testing with HFC-152a / HFC-227ea Mixtures**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 99-104, September 1992 (6 pages with 2 tables, RDB2A05)

This paper presents measured performance data for blends of R-152a and R-227ea tested in an unmodified home refrigerator. Physical and thermodynamic properties as well as flammability data and ozone depletion potentials (ODPs) are tabulated for R-12, R-152a, and R-227ea for comparison. The energy measurements were based on ANSI/AHAM Standard HRF-1-1988, with an increased number of thermocouples. An unidentified polyolester (POE) was used as the lubricant for the R-152a/227ea mixtures. R-152a/227ea (80/20) offered slightly reduced energy consumption and 50/50 and 20/80 mixtures increased energy consumption by 4.3%. The paper concludes that the R-152a/-227ea blends may offer significantly improved performance compared to R-12 in an optimized system. Recommendations are provided for further work.

D. M. Robinson and E. A. Groll (Purdue University), **Using Carbon Dioxide in a Transcritical Vapor Compression Cycle**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 329-336, July 1996 (8 pages with 6 figures, RDB6923)

literature review of R-744 in refrigeration, suitable applications, and research needs; thermodynamic modeling

R. J. Rose (University of Maryland), D. Jung (Inha University, Korea) and R. K. Radermacher (University of Maryland), **Testing of Domestic Two-Evaporator Refrigerators with Zeotropic Refrigerant Mixtures**, paper 3620, *Transactions* (Annual Meeting, Baltimore, MD, June 1992), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 98, part 2, pages 216-226, 1992 (10 pages with 7 figures and 3 tables, RDB2605)

S. M. Sami and P. J. Tulej (University of Moncton, Canada), **A New Design for an Air-Source Heat Pump Using a Ternary Mixture for Cold Climates**, *Journal of Heat Recovery Systems and CHP*, Pergamon Press Limited / Elsevier Sciences Limited, UK, volume 15, number 6, pages 521-529, 1995 (9 pages with 17 figures, RDB6743)

performance analysis of an air-to-air heat pump using R-23/22/152a (>20/50/<30), identified as NARM/UM, proposed for use in cold regions; paper presents experimental set up and reports field tests of 6 units; plots show calculated coefficients of performance (COPs) and operating parameters; reports an average heating-mode COP of 1.57

S. M. Sami, J. Schnotale (University of Moncton, Canada), and J. G. Smale (DuPont Canada, Incorporated), **An Experimental Investigation of Ternary Blends Performance Proposed as Substitutes for CFC-12**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette,

IN, volume 2, pages 651-660, July 1992 (10 pages with 9 figures, RDB2840)

J. R. Sand and S. K. Fischer (Oak Ridge National Laboratory, ORNL), **Modelled Performance of Nonchlorinated Substitutes for CFC-11 and CFC-12 in Centrifugal Chillers**, *International Journal of Refrigeration* (IJR), Paris, France, volume 17, number 1, pages 40-48, January 1994 (9 pages with 5 figures and 3 tables, RDB2411)

This article presents data on candidate refrigerants to replace R-11 and R-12 in chillers with centrifugal compressors. The partially fluorinated alkanes and ethers examined were identified from earlier studies. The article outlines the sources for and methods used to estimate missing thermophysical property data, to enable analyses. It then discusses the benefits and limitations of various equation of state models considered, leading to selection and fitting of the data to the Carnahan-Starling-DeSantis (CSD) and Lee-Kesler-Plöcker (LKP) equations of state. The article describes a simple chiller model, based on a single-stage compressor, used to simulate performance. The modelled results are tabulated including ideal-cycle isentropic coefficients of performance (COPs), kW electricity input per thermal kW of cooling, and calculated compression superheat for candidates with efficiencies equal to or exceeding that of R-134a. They include - in ascending order of normal boiling point - R-E254cb (CHF_2-O-CF_2CH_3), R-E245cb (CF_3-O-CF_2CH_3), R-152, R-E143, R-123, R-245ca, R-11, R-245fa, R-236ea, R-E134, R-236ca, R-143, R-114, R-236fa, R-236cb, R-134, R-152a, R-134a, and R-12. Indications are given on the flammability (or anticipated flammability) of these refrigerants. Modelled results also are tabulated for eight binary blends of flammable and nonflammable components expected to exhibit near-azeotropic performance. They include R-E143/245ca (21/79) and (45/55), R-143/236ea (11/89) and (48/52), R-143/E134, R-143/R-236ca (11/89) and (48/52), and R-152a/134 (19/81). The paper concludes that while there are potential alternatives for R-11 and R-123, with efficiencies higher than with R-12 or R-134a, several candidates with the best performance are likely to be flammable. Near-azeotropic blends of flammable and nonflammable components with similar vapor pressures may afford solutions, but further studies are needed particularly for the fluorinated ethers and flammability characterization. The article notes that cycle modifications, such as adding subcooling or suction-to-liquid heat exchangers, will preferentially benefit the performance of refrigerants with more complex molecular structures and larger molecular heat capacities. Also, multistage designs with interstage flash cooling (economizer cycles) need verification.

J. R. Sand, S. K. Fischer (Oak Ridge National Laboratory, ORNL), and P. A. Joyner (Electric Power Research Institute, EPRI), **Modeled Performance of Nonchlorinated Substitutes for CFC-11 and CFC-12 in Centrifugal Chillers**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 406-415, 1991 (10 pages with 2 tables, RDB-2260)

J. R. Sand and E. A. Vineyard, **Report of Foreign Travel: 2-5 May 1989** [Zeotropic Blends in Refrigerators], ORNL/FTR-3251, Oak Ridge National Laboratory, Oak Ridge, TN, 18 May 1989 (14 pages, available from JMC as RDB1135)

This informal report summarizes meetings on refrigerator/freezer testing with zeotropic blends of refrigerants (*nonazeotropic mixtures of refrigerants* or *NARMs*) at the Universität Hannover (Hannover, FRG). The research investigated a freezer, modified with a polystyrene block to form separate freezer and fresh-food compartments, operating with an R-22/142b refrigerant blend. The simulation program, testing protocol, instrumentation, and plans for testing other blends were reviewed. Also addressed is a visit to AEG GmbH (Kassel, FRG), a major manufacturer of domestic appliances, to discuss research on alternative refrigerants. Compressor components were reviewed after 1000 hours accelerated life testing in R-134a and in R-22/142b. Parts from the R-134a compressor looked very good, whereas parts from the R-22/142b test unit showed much more thermal breakdown. Some AEG engineers favor R-152a, or blends of R-152a with R-22 or R-134a, as an alternative to R-12.

K. S. Sanvordenker (Tecumseh Products Company), **Compressor Manufacturer's R-134a Applications**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 157-164, September 1992 (8 pages with 3 figures and 3 tables containing corrections to the copy in the proceedings, available from JMC as RDB2901)

This paper highlights the efforts of a compressor manufacturer to implement research data into R-134a applications for hermetic units. Comparative capacity and performance data, based on calorimeter tests, are tabulated for compressors representative of those used in refrigerator/freezer applications. The capacity is approximately 10% lower with R-134a at rating conditions, but the efficiency stays the same.

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Further data show that the relative capacities and efficiencies of R-12 and R-134a may be lower or higher depending on the application conditions. Sound levels are plotted for traditional R-12 and redesigned, high-efficiency R-134a compressors; the overall sound level is lower for the latter. Materials compatibility issues are reviewed, noting the advantages and acceptance of polyolester (POE) lubricants as the consensus selection for R-134a. The paper discusses lubricant stability, chemical reactivity, miscibility, solubility, and lubricity. A plot compares the solubility of R-12 and R-134a in two POEs to R-12 in mineral oil. The discussion suggests that a bigger motor, with a small potential penalty in efficiency, may be required for R-134a due to the impact on equalization pressure and the required starting torque. A need is noted for new test methods for lubricity. The impacts on motor insulation and uncertainties regarding contaminants are covered briefly. The paper concludes that there are no technical barriers to conversion from R-12 to R-134a, but that information dissemination and the cost of the refrigerant and lubricant remain factors in the rate of conversion.

K. S. Sanvordenker (Tecumseh Products Company), **R-152a versus R-134a in Domestic Refrigerator-Freezer - Energy Advantage or Energy Penalty!**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 1, pages 259-263, July 1992 (5 pages with 4 tables, RDB2728)

This paper presents new laboratory data for R-12, R-134a, and R-152a in domestic refrigerator-freezer applications. It responds to assertions and reported findings that R-152a would offer higher efficiency, noting an error in the published thermodynamic data used. The paper reviews reports of R-152a advantages and implications. It also provides capacity and efficiency data, based on calorimeter tests, for six compressors for R-12, R-134a, and R-152a with a polyolester lubricant. These tests were run at -23 °C (-10 °F) evaporator temperature and both 43 and 54°C (110 and 130 °F) condenser temperatures. The test method, ASHRAE Standard 23, and associated peculiarities are reviewed. R-152a consistently yielded a 10% lower capacity than R-134a, which in turn showed a 10% drop compared to R-12. The energy efficiencies were nearly the same at the higher condensing temperature, but R-152a suffered a 6.5% penalty at the more representative lower condensing temperature. The data are briefly related to analyses by other investigators, which corroborate the findings. The paper concludes that use of R-152a instead of R-134a may yield a significant energy penalty rather than advantage.

S. R. Skaggs, D. S. Dierdorf, and R. E. Tapscott (New Mexico Engineering Research Institute, NMERI), **Update on Iodides as Fire Extinguishing Agents**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 800-809, October 1993 (10 pages with 2 tables, RDB3A51)

fluoroiodocarbon (FIC) properties, toxicity; CF_3I, R-13I1; CF_3CF_2I, R-115I1; $CF_3CF_2CF_2I$, R-217caI1

N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, M. W. Tufts, and A. S. Ng (Acurex Environmental Corporation), **HFC-236ea: A Potential Alternative for CFC-114**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 150-157, October 1993 (8 pages with 4 tables, RDB-3A37)

E. L. Smithart and J. G. Crawford (The Trane Company), **R-123: A Balanced Selection for Low-Pressure Systems**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 66-69, May 1993 (3 pages with 1 figure, RDB3606)

L. Snitkjær and F. K. Eggert (Danfoss-Flensburg GmbH, Germany), **Use of a Ternary Blend in Existing Domestic CFC-12 Appliances**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 631-640, July 1992 (10 pages with 5 figures and 4 tables, RDB2838)

M. W. Spatz (AlliedSignal Incorporated), **Alternative Refrigerants for R-22 Chillers**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 35, number 5, pages 50-52, May 1993 (3 pages with 1 figure, RDB3601)

This article focuses on predicted performance of replacements for R-22 in chillers with reciprocating-piston compressors. It quotes statistics indicating that such chillers account for one-third of the installed capacity of chillers and two thirds of annual shipments. The article reviews potential alternatives, noting that the primary replacement candidates are R-134a, R-32/125 (40/60) (marketed as Genetron(R) AZ-20), and

R-32/125/134a (30/10/60). Cycle analyses, using the Genesys(TM) program, are described, leading to a finding that R-134a would offer the best coefficient of performance (COP) based on thermodynamic characteristics alone. A sample comparison between R-12 and R-22 is outlined, to show that the former appears favorable based on thermodynamic COP, but the latter is preferred due to superior transport properties and suitability for more compact designs. The article notes that instrumented testing of fully optimized systems is required to accurately determine performance for a given refrigerant. One requirement is to adjust the compressor displacement. The article indicates that such tests have not yet been performed with alternative refrigerants in reciprocating chillers. A figure compares the thermodynamic and system performance of the three alternatives to those of R-22 in unitary air conditioners, based on measured and modelled data. Although the thermodynamic efficiency of R-32/125 (40/60) is shown to be the lowest, its system efficiency is the highest. The article discusses the difference, attributing the improvement to better heat transfer, lower pressure drop, and smaller change in saturation temperature for a given pressure drop, all contributing to a lower temperature lift. The article then discusses issues that must be resolved to use the alternatives, including considerations for composition management and potential exploitation of temperature glides with zeotropes. The article concludes that the R-32/125 azeotrope may be the best candidate, offering an 8-10% increase in efficiency without the benefit of system optimization.

H. O. Spauschus (Georgia Institute of Technology), **Refrigerant Mixtures - Challenges and Opportunities**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 31, number 11, pages 38-41, November 1989 (RDB4234)

W. F. Stoecker (University of Illinois at Urbana-Champaign), **Growing Opportunities for Ammonia Refrigeration**, *Technical Papers of the 11th Annual Meeting* (12-15 March 1989, Austin, TX), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, March 1989; republished in *CFCs: Time of Transition*, ASHRAE, pages 128-139, 1989 (12 pages with 3 figures and 7 tables, RDB4236)

R-717

R. A. Struss, J. P. Henkes, and L. W. Gabbey (Modine Manufacturing Company), **Performance Comparison of HFC-134a and CFC-12 with Various Heat Exchangers in Automotive Air-Conditioning Systems**, paper 900598 (SAE International Congress and Exposition, Detroit, MI, 26 February - 2 March 1990), Society of Automotive Engineers (SAE), Warrendale, PA, February 1990 (12 pages with 13 figures and 7 tables, RDB2A17)

This paper reviews vehicular wind tunnel tests that were carried out on two automotive air-conditioning systems. The test data compare performance of R-12 and R-134a with various heat exchangers. The vehicles, heat exchangers, test facilities, approach, and findings are reviewed. R-12 was tested with a 525 SUS viscosity mineral oil. R-134a was tested with a proprietary polyalkylene glycol, supplied by DuPont Chemicals. The heat exchangers included both a serpentine and a parallel flow designs. Refrigerant charge requirements were determined by comparative tests. R-134a resulted in higher head pressures, but the same compartment temperatures as with R-12. Heat exchanger selection was found to influence charge levels, indicated as important with use of the more expensive R-134a. An appendix describes the wind tunnel used.

B. Stuij, **CFC and HCFC Replacement**, *IEA Heat Pump Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 13-18, March 1995 (6 pages with 4 figures, RDB5683)

environmental concerns, international regulations, economics, safety issues

S. G. Sundaresan (Copeland Corporation), **Commercial Refrigeration: The Challenge and the Issues Regarding the Retrofit and New Equipment**, paper 4.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 57-66, February 1993 (6 pages with 1 figure and 6 tables, available from JMC as RDB3314)

service history, control and system components, cleanout procedures, refrigerant selection, lubricant selection, moisture control, composition control, comparison of R-12 and R-502 alternatives

S. G. Sundaresan (Copeland Corporation), **Aspects of Lubrication, Fractionation, and Reliability of Compressors with New Refrigerants for Commercial Refrigeration**, *CFC Alternatives: User Experience and Update*, Institution of Mechanical Engineers and Institute of Refrigeration, London, UK, 11 November 1992 (12 pages with 1 figure and 7 tables, available from JMC as RDB-3330)

please see pages 6-8 for ordering information

This paper presents findings of an evaluation of candidate refrigerants to replace R-12 and R-502 in commercial refrigeration. The R-12 alternatives discussed include R-134a, R-22/152a/-124 (52/15/33) (a developmental version of DuPont Suva(R) MP39), and R-22/152a/124 (60/-13/27) (a developmental version of Suva MP66). The R-502 alternatives include R-143a/22 (composition unspecified, a developmental version Atochem Forane(R) FX10), R-32/125/143a (10/-45/45) (a developmental version of Forane FX-40), R-404A [R-125/143a/134a (44/52/4) marketed as Forane FX70 and as Suva HP62], R-402A [R-125/290/22 (60/2/38) marketed as Suva HP80], R-290/22/218 (6/55/39) (a developmental version of Rhône-Poulenc Isceon 69L), R-32/125/134a (30/40/30) (a developmental version of ICI Klea(R) 60), and R-125/143a (45/-55) (a developmental version of AlliedSignal Genetron(R) AZ-50). The lubricants addressed include formulated alkylbenzene and polyolesters, though only the latter was considered for the chlorine-free refrigerants. The paper discusses and tabulates environmental and performance data for the refrigerant candidates. It then discusses selection criteria for lubricants, both for new equipment and retrofit; two tables summarize the lubricants selected. The paper then addresses fractionation. A figure illustrates the change in composition and a table lists the effects on pressure, capacity, efficiency, and discharge temperature with HP62, as a vapor leak progresses. Another table gives the composition changes, capacity and efficiency ratios, and discharge temperature differences at compressor inlet for a near azeotrope. A final table, indicates the change in composition for four blends for liquid removal from a tank from 90 to 10% full.

R. E. Tapscott, S. R. Skaggs (University of New Mexico), and D. Dierdorf (Pacific Scientific), **Perfluoroalkyl Iodides and Other New-Generation Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 14, pages 151-160, 1995 (10 pages with 3 tables, RDB6208)

screening of potential halon replacements with emphasis on fluoroiodocarbons (FICs) R-13I1, R-217bal1, and R-217cal1; carbonyl compounds, alcohols, alkenes, ethers, aromatics, amines, phosphonitriles, and silicon derivates; ozone depletion and global warming potential; toxicity, cardiac sensitization; use as fire suppressants

N. Tengblad, **Resultat från prov med liten luft-luft värmepump med propan/gasol som köldmedium** [Results from Tests on a Small Air-to-Air Heat Pump with Propane/Gasol as Working Medium], report REFR/R-93/12-Se, Kungl Tekniska Högskolan [Royal Institute of Technology] (KTH), Stockholm, Sweden, 1993 (in Swedish, RDB5722)

R-290

R. Thiele and T. Hackensellner, **Industriewärmepumpen mit Kältemittel und Wasser als Arbeitsmedium** [Industrial Heat Pumps Using Refrigerants and Water as the Working Fluid], *Rationelle Energietechnik in der Lebensmittelindustrie* [Efficient Energy Technologies in the Food Processing Industry], report 675, Verein Deutscher Ingenieure (VDI) [Association of German Engineers] (München, Germany), VDI-Verlag, Düsseldorf, Germany, pages 261-275, 1988 (15 pages, RDB5A17)

R-718

T. Tiedemann and H. Kruse (Universität Hannover, Germany), **Evaluation of Zeotropic Hydrocarbon Mixtures in a Lorenz-Meutzner Refrigerator-Freezer**, *New Applications of Natural Working Fluids in Refrigeration and Air Conditioning* (proceedings of the meeting of IIR Commission B2, Hannover, Germany, 10-13 May 1994), International Institute of Refrigeration (IIR), Paris, France, pages 607-620, 1994 (14 pages with 6 figures and 6 tables, RDB5B29)

R-134a, R-C270; R-290; R-600; R-600a; R-601 (n-C5 or pentane); R-601b (2,2-dimethylpropane); R-1250 (propadiene); R-1270; R-290/600; R-290/600/601; R-290/600a (28/72), (40/60), (50/50), and (72/28); R-290/601 (R-290/n-C5); butene, 2-methyl-1,3-butadiene, 2-methylbutane, 1,2-pentadiene, 1,4-pentadiene, pentene, R-E170

T. Tiedemann, M. Kauffeld, K. Beermann, and H. Kruse (Universität Hannover, Germany), **Evaluation of Ozone-Safe, Low Greenhouse Warming Potential Zeotropic Refrigerant Mixtures in Household Refrigerators-Freezers**, paper 271, *New Challenges in Refrigeration* (proceedings of the XVIIIth International Congress of Refrigeration, Montreal, Québec, Canada, 10-17 August 1991), International Institute of Refrigeration, Paris, France, volume III, pages 1166-1170, 1991 (RDB-5B30)

performance evaluation of R-22/123, R-22/124, R-22/142b, R-22/152a, R-22/152a/123, R-23/-152a, R-32/142b, R-32/152a, R-143a/142b, R-143a/152a, R-152a/123, R-290/123, R-290/-152a in refrigerators with dual evaporators (Lorenz-Meutzner cycle); energy savings of 12% were found in a German refrigerator for R-22/-142b, but no improvement was found over R-12 for an American design, the differences in which are detailed; tabulates simulation results for each of the refrigerants and experimental results

for R-22/142b; concludes that the energy improvements reported for R-22/11 in the 1970s by Lorenz and Meutzner could not be reached; difference is attributed to on-off cycling versus steady-state operation, in the earlier studies, and to the way the coefficient of performance (COP) is calculated

D. W. Treadwell (Lennox Industries Incorporated), **Performance Cost and Safety Requirements of Employing R290 (Propane) in Unitary Air Conditioning Equipment**, paper 2.6, *Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants '94 - Performance Evaluations and Commercialization Issues for Air Conditioning and Refrigeration Equipment* (Kobe, Japan, 8-9 December 1994), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, pages 42-45, December 1994 (4 pages with 1 table, RDB5409)

This paper discusses the performance, cost, and safety implications for use of R-290 (propane) in an 8.8 kW (2½ ton) single-package, air-cooled, unitary air conditioner. Test results are tabulated for R-22 and propane, the latter after replacement of the compressor with one having an 18% larger displacement. The table compares the capacity, input power, resultant energy efficiency ratio (EER), refrigerant charge amount, suction and discharge temperatures and pressures, and liquid temperatures at standard rating conditions. The paper notes that the capacity and efficiency are higher with propane and the larger compressor, while the discharge temperature and pressure are favorably lower. It notes that propane is more compatible than R-22 with most materials used, is readily available, is approximately 1/6th the cost of R-22, is nontoxic, has no ozone depletion potential (ODP), and near zero global warming potential (GWP) - approximately 0.2% that of R-22. Also, the charge size would be less than half. The paper then summarizes the findings of a risk assessment for propane use in a 12.3 kW (3½ ton) air conditioner, based on an independent analysis and a product evaluation by an independent test laboratory. They were performed by Arthur D. Little (ADL) and Underwriters Laboratory (UL), respectively. Modifications to isolate the refrigerant in the evaluation unit are outlined, as are further requirements identified by the independent evaluation. A subsequent cost estimate by the manufacturer found that these safety requirements would increase the product cost by 30% over one with R-22. The increment was estimated to be even higher for a unitary, split-system air conditioner. The paper concludes that while propane was deemed to be an excellent refrigerant, the cost to use it would far exceed that to switch to a nonflammable, hydrofluorocarbon (HFC) blend.

D. W. Treadwell (Lennox Industries Incorporated), **Application of Propane (R-290) to a Single Packaged Unitary Air-Conditioning Product**, *Proceedings of the International CFC and Halon Alternatives Conference* (Baltimore, MD, 3-5 December 1991), Alliance for Responsible CFC Policy, Arlington, VA, pages 348-351, 1991 (4 pages with 1 table, available from JMC as RDB2261)

This paper discusses the safety considerations and two tests of propane (R-290) as a refrigerant in a single-package, unitary air conditioner. Advantages cited include lower discharge temperature and pressure compared to R-22, both favorable to compressor life, as well as higher efficiency (by 1-2%) and materials compatibility. The low cost, availability, and favorable environmental attributes (no ozone-depletion potential and near zero global warming potential) are contrasted to its flammability. The paper estimates the charge quantity required to be less than half that of R-22, and concludes that the probability of reaching the lower flammability limit in a house - under identified leak assumptions - is remote. The paper indicates that the potential risks should be evaluated in light of the environmental and other advantages.

S. Uemura, S. Inagaki, N. Kobayashi, T. Teraoka, and M. Noguchi (Daikin Industries, Limited), **Characteristics of HFC Refrigerants**, *Proceedings of the 1992 International Refrigeration Conference - Energy Efficiency and New Refrigerants*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, volume 2, pages 385-394, July 1992 (10 pages with 13 figures and 5 tables, available from JMC as RDB2821)

H. Vakil (General Electric Company), **New Concepts in Capacity Modulation Using Nonazeotropic Mixtures**, *Le Froid au Service de l'Homme* [Refrigeration for Service of Man] (proceedings of the XVIth International Congress of Refrigeration, Paris, France, 1983), International Institute of Refrigeration (IIR), Paris, France, 1983 (RDB6427)

use of zeotropic blends

H. Vakil (General Electric Company), **Thermodynamics of Heat Exchange in Refrigeration Cycles with Mixtures, Part I**, *Le Froid au Service de l'Homme* [Refrigeration for Service of Man] (proceedings of the XVIth International Congress of Refrigeration, Paris, 1983), International Institute of Refrigeration (IIR), Paris, France, 1983 (RDB6428)

use of zeotropic blends

H. Vakil (General Electric Company), **Thermodynamics of Heat Exchange in Refrigeration Cy-**

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cles with Mixtures, Part II, *Le Froid au Service de l'Homme* [Refrigeration for Service of Man] (proceedings of the XVIth International Congress of Refrigeration, Paris, 1983), International Institute of Refrigeration (IIR), Paris, France, 1983 (RDB6429)

use of zeotropic blends

R. P. Vallort, J. Sanchez, and W. V. Richards, **Ammonia and Air Conditioning**, *Technical Papers of the Ninth Annual Meeting*, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, pages 89-98, March 1987 (10 pages, RDB4238)

R-717

E. A. Vineyard (Oak Ridge National Laboratory, ORNL), **The Alternative Refrigerant Dilemma for Refrigerator-Freezers: Truth or Consequences**, *Transactions*, American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Atlanta, GA, volume 97, part 2, 1991 (RDB6311)

alternative refrigerants, performance

C. von Eynatten (Solvay Fluor und Derivate GmbH, Germany), R. Döring (Fachhochschule Münster, Germany), and H. Buchwald (Solvay Fluor und Derivate GmbH, Germany), **HFC-134a/HFC-23: A Very Promising Alternative to HCFC-22**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 119-128, October 1993 (11 pages with 10 figures, RDB-3A34)

R-23/134a

U. G. Wenning (Bosch-Siemens Hausgeräte GmbH, Germany), **No-Frost Refrigeration: A Retrospect After Conversion**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 396-411, October 1995 (6 pages with 1 figure and 4 tables, available from JMC as RDB5B11)

R-12, R-134a, R-C270, R-290, R-600, R-600a, refrigerators, refrigerator/freezers

P. Weiss, M. Barreau, and P. Fauvarque (Elf Atochem S.A., France), **Long Term Issues in Selection of Refrigerants for the Future**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 268-277, October 1995 (10 pages with 4 tables, available from JMC as RDB5B01)

R-134a, R-404A, R-407C, R-408A, R-409A, R-600a, R-717; comparative safety, environmental impact, and performance

M. C. Bogdan, D. J. Williams, P. B. Logsdon, and R. C. Parker (AlliedSignal Incorporated), **Status Report on the Development of HFC-245fa as a Blowing Agent**, *Polyurethanes Expo '96* (proceedings of the 39th Annual Technical and Marketing Conference, September 1996), Society of the Plastics Industry (SPI), Washington, DC, 1996 (10 pages with 13 figures and 17 tables, RDB6B40)

R-245fa, physical properties, flammability, environmental data, toxicity (4-hr LC_{50} rat >200,000 ppm, LC_{50} mouse >101,300 ppm, LD_{50} >2,000 mg/kg, cardiac sensitization >20,000 ppm, weak activity in human lymphocyte at 300,000 ppm v/v, not active in mouse micronucleus study at 100,000 ppm, Ames assay negative), thermal and hydrolytic stability, compatibility (compatible with Buna-N, EPDM, neoprene, polyethylene, polypropylene, polytetrafluoroethylene (PTFE); not compatible with epichlorohydrin, HNBR, nitrile (marginal), Viton; based on shrinkage <5% and swelling <20% after 2-week immersion at room temperature), foaming characteristics, foam aging effects

Y. Yoshida, S. Suzuki, Y. Mukai, K. Nakatani, and K. Fujiwara (Matsushita Electric Industrial Company, Limited, Japan), **Development of Rectifying Circuit with Mixed Refrigerants**, *Status of CFCs - Refrigeration Systems and Refrigerant Properties* (proceedings of the meetings of IIR Commissions B1, B2, E1, and E2, Purdue University, West Lafayette, IN), International Institute of Refrigeration, Paris, France, pages 45-52, July 1988 (8 pages with 10 figures, RDB4404)

R. W. Yost, **Impact of Alternative Refrigerants on Equipment Design**, unpublished seminar presentation (Winter Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE, Chicago, 28 January - 1 February 1995), ICI Klea, New Castle, DE, January 1995 (22 pages with 21 charts, available from JMC as RDB-5341)

These charts summarize a presentation on the equipment changes needed for alternative refrigerants and associated lubricants. The introduction outlines the objectives of charge reduction, leak reduction, and efficiency improvement, to manage utility loads and address global warming concerns. Four charts identify the selection requirements for alternative refrigerants and new lubricants. The presentation then summarizes the implications of polyolesters and polyalkylene glycols on equipment design. A series of charts review the design changes needed for reciprocating pistons com-

pressors, centrifugal, rotary rolling piston, scroll, and screw compressors to address alternative refrigerants and lubricants. Further charts address considerations for driers, sight glasses, expansion devices, heat exchangers, and use of zeotropic blends. The presentation concludes that the transition has given industry opportunities for advancement, and that the transition has gone "remarkably well."

Y. You (Yangzhou Industrial Institute, China), Y. T. Ma, and C. R. Lu (Tianjin University, China), **A New Heat Pump System of Continuous Capacity Control with Nonazeotropic Mixtures**, paper 899420, proceedings of the 24th Intersociety Energy Conversion Engineering Conference (IECEC, Washington, DC, 6-11 August 1989), publication CH2781-3, Institute of Electrical and Electronic Engineers (IEEE), New York, NY, volume 6, pages 2117-2119, 1989 (3 pages with 2 figures, RDB3C18)

This paper presents a conceptual approach to continuously modulate the capacity of a heat pump, without performance loss, by controlling the composition of the zeotropic mixture used as its refrigerant. The concept is compared to systems proposed by others. The authors conclude that the new scheme is comparatively simple in structure, convenient to operate, and has a wide range of modulation. The new system can automatically control the composition based on changes in the indoor-air or return water temperature. No specific zeotropes are cited, but a schematic of the heat pump and a generic temperature-composition diagram, showing dew-point and bubble-point curves, are given.

X. Zeng, G. Peterson, L. Ye, and W. Harvey (Smart Power Systems), **A Performance Analysis of Low Pressure HFC Refrigerants in Vapor-Compression Refrigeration Cycles**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 337-342, July 1996 (6 pages with 8 figures and 1 table, RDB6924)

evaluation of two undisclosed, low-pressure refrigerants identified as HFC-LVP and HFOC-LVP (the latter probably a hydrofluoroether, HFE); comparison to R-134a for air conditioning using a small centrifugal compressor; efficiency comparisons to R-113, R-123, and R-134a; concludes that a performance increase of 5-15% over R-134a is possible

C. Zhang (B-JAC International, Incorporated), **A Chemically-Assisted Mechanical Refrigeration System**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 281-285, July 1994 (5 pages with 2 figures and 1 table, RDB4834)

ammonia/water, CAM, hybrid absorption-vapor-compression

X-Y. Zhao, L. Shi, M-S. Zhu, and L-Z. Han (Tsinghua University, China), **A New Generation of Long-Term Refrigerants as CFC-12 Alternatives**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 286-293, October 1995 (8 pages with 6 figures and 3 tables, available from JMC as RDB5B03)

THR02 blend, R-131 mixtures

Q. Zhou, J. Pannock, and R. K. Radermacher (University of Maryland), **Development and Testing of a High Efficiency Refrigerator**, paper NO-94-20-3, *Transactions* (Winter Meeting, New Orleans, LA, January 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 1, pages 1351-1358 (8 pages with 2 figures and 5 tables, RDB4421)

refrigerant mixture used not identified pending patent application review

M-S. Zhu, L-Z. Han, X-Y. Zhao (Tsinghua University, China) and B. Lu (Beijing Snow Flake Electrical Appliance Group Corporation, China), **Dismantling Inspection and Retrofit of Domestic Refrigerator with HFC-134a**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 81-85, October 1993 (5 pages with 5 tables, RDB3A29)

A Comprehensive Evaluation of Alternative CFC Refrigerants from the Molecular Structure, research project 561-RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA (ASH0561)

The contractor for the project is the National Bureau of Standards (NBS, now the National Institute of Standards and Technology, NIST), led by D. A. Didion and M. O. McLinden; it was sponsored by ASHRAE Technical Committee 3.1, *Refrigerants and Brines*.

Alternatives to Chlorofluorocarbons, bulletin AG-1 (document H-16411-2), DuPont Chemicals, Wilmington, DE, January 1992 (8 pages with 3 figures and 3 tables, available from JMC as RDB4511)

This bulletin discusses nine alternative refrigerants including five hydrochlorofluorocarbons

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(HCFCs) - R-22, R-123, R-124, R-141b, and R-142b - and six hydrofluorocarbons (HFCs) - R-23, R-32, R-125, R-134a, R-143a, and R-152a. It briefly outlines testing for safety and performance and provides a figure contrasting the ozone depletion (ODP) and halocarbon global warming potentials (HGWP) of these refrigerants. A second figure shows their relative photochemical reactivity, or relative contribution to ground-level smog. Tables summarize the range of applications - including as refrigerants, blowing agents, and for other uses - of these fluids and their physical properties. The tabulated data include chemical name and formula, molecular weight, boiling and freezing points, critical parameters (temperature, pressure, specific volume, and density), heat of vaporization, flammability limits in air, ODP, halocarbon GWP (HGWP), Toxic Substances Control Act (TSCA) inventory status, and recommended chronic exposure limit for toxicity. The density, specific heat, vapor pressure, thermal conductivity, viscosity, and solubility in water are given for 25 °C (77 °F). A plot shows the vapor pressure relations to temperature; R-11, R-12, R-113, and R-114, R-500, R-502 also are shown for reference.

Development of an Advanced Refrigerant for Compression Heat Pump, Research Institute of Innovative Technology for the Earth (RITE), Japan, December 1991 (RDB3326)

Greenfreeze, the World's First CFC- and HFC-Free Refrigerators, Greenpeace Germany, e.V., Hamburg, Germany, undated circa 1992 (12 pages with 1 table, RDB3634)

Oil-Flooded Propylene Refrigeration Screw Compressor, *Kobelco Technology*, Japan, volume 2, number 2, pages 63 ff, 1987 (RDB4C18)

R-1270, propene

Report of the ARI Delegation to Japan on Alternative Refrigerants, report DOE/CE/23810-12, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, February 1993 (20 pages including 2 appendices, available from JMC as RDB3401)

This document reports on a trip, by an ARI delegation, to exchange information on alternative refrigerants and to review methods to screen alternatives to chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Five representatives travelled to Japan to participate in the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility. They subsequently visited seven manufacturers and the Ministry of International Trade and Industry (MITI). Techniques for materials compatibility screening, lubricant testing, and flammability studies were of specific interest. This report provides an overview of Japanese phase-out strategies, identifies research into alternative refrigerants and lubricants for them, and reviews the screening methods used. It discusses the status of retrofits and system design. The conference agenda and lists of both the ARI delegates and companies visited are provided in appendices. The report notes that the leading replacement refrigerant is R-134a. Efforts with hydrochlorofluorocarbon (HCFC) alternatives are limited since companies expect to move away from such fluids by the year 2000. R-32/134a (30/70) is considered a candidate to replace R-22, though the Japanese view this zeotrope as not flammable, unlike in the U.S., based on testing under different conditions. More than 50 compounds have been synthesized and are under investigation as alternatives for R-502. Polyolester (POE) lubricants are the prime focus for hydrofluorocarbons (HFCs), except in automotive air conditioning where polyalkylene glycols (PAGs) are used. The report discusses specific fluids, lubricants, test procedures, and regulatory actions and expectations for several application areas. Observations regarding use of absorption chillers as alternatives, government incentives, CFC taxes, safety standards, and a CFC destruction technology also are mentioned.

Status Report on the Development of HFC-245fa, A Non-Flammable Liquid Blowing Agent, AlliedSignal Incorporated, Morristown, NJ, 1995 (29 charts, RDB5C94)

R-245fa, physical properties, environmental data, toxicity (4-hr LC_{50} >200,000 ppm, cardiac sensitization >20,000 ppm, no toxicity at 100,000 ppm), compatibility, foaming characteristics, trial as a foam blowing agent, foam aging effects

The Hydrocarbon Forum, proceedings of a seminar (London Heathrow, UK), Calor Gas Limited, Slough, UK, 15 September 1995 (164 pages, RDB6707)

This documents consolidates lecture texts, presentation charts, and product literature on the introduction and use of hydrocarbon refrigerants in the UK. It includes a review of the 1995 revision to the British safety standard for refrigeration appliances and systems, BS4434, with emphasis on provisions for hydrocarbon use. A series of presentations address use of hydrocarbons in supermarket refrigeration, 1-50 kW (0.3-14 ton) air conditioners, 46 kW (13 ton) chillers with scroll compressors, packaged terminal air conditioners, dehumidifiers, and refrigerator cabinets (display cases and boxes). One presentation outlines implications of using hy-

drocarbon refrigerants in appliance manufacture, the choice and supply of hydrocarbons, charging equipment, and risk assessment studies. Another covers the need for technician training. The hydrocarbons addressed in these proceedings are R-290 (Calor Gas Refrigeration CARE 40), R-600a (CARE 10), R-170/290 (CARE 50), and R-290/600a (CARE 30).

IDENTIFICATION

T. Atwood (AlliedSignal Incorporated), **The Need for Standardized Nomenclature for Refrigerants**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 31, number 11, pages 44-47, November 1989 (3 pages with 1 table, RDB-0545)

Center for Global Environmental Technologies (CGET), **Halocarb(C) Computer Program** and **Halocarbon Nomenclature**, Technical Update Series CGET3, New Mexico Engineering Research Institute (NMERI), Albuquerque, NM, 22 March 1994 (computer disk with software and 8 page documentation with 3 tables, limited copies available from JMC as RDB4674)

This software determines the International Union of Pure and Applied Chemistry (IUPAC) name, halon number, and molecular weight for halocarbons from the structural chemical formula. It does not handle unsaturated, cyclic, or branched-chain compounds. The program runs on DOS-based computers. The documentation reviews the IUPAC nomenclature rules, ASHRAE Standard 34 numbering system, composition-designating prefixes, and halon numbering system. Tables summarize the composition-designating prefixes and conventions for isomer suffixes. Some of the numbering and prefix conventions presented are extensions to those adopted in Standard 34.

International Union of Pure and Applied Chemistry (IUPAC), **Nomenclature of Organic Chemistry, Sections A, B, C, D, E, F, and H**, prepared by J. Rigaudy and S. P. Klesney, Pergamon Press Incorporated, New York, NY, 1979 (RDB4202)

This document presents a system of uniform nomenclature to identify organic chemicals, including most common refrigerants. The rules were formulated and adopted by the IUPAC Commission on the Nomenclature of Organic Chemistry. The sections (A-F and H) incorporated in this publication cover hydrocarbons; fundamental heterocyclic systems; characteristic groups containing carbon, hydrogen, oxygen, nitrogen, halogens, sulfur, selenium, and/or tellurium; organic compounds containing elements that are not exclusively carbon, hydrogen, oxygen, nitrogen, halogens, sulfur, selenium, and tellurium; stereochemistry; general principles for the naming of natural products and related compounds; and isotopically modified compounds. The rules respond to a stated belief "that differences in nomenclature frequently hinder the accurate and intelligible conveyance of information from one chemist to another, so tending to hamper understanding and progress." [An attempt is being made to conform to the definitive IUPAC rules in citing chemical names in the Refrigerant Database, though application of these rules is sometimes challenging.]

Assignment of Refrigerant Container Colors, ARI Guideline N-1995, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1995 (12 pages, with 1 table, available from ARI for $10.00 for members and $20.00 for nonmembers, RDB6601)

This guideline sets color standards for containers for existing, new, and reclaimed refrigerants. It further provides a means by which ARI can assign colors as new refrigerants are introduced, and maintains a record of those assigned and available. The guideline also recommends a container color (light green grey) for refrigerants that are not produced in sufficient quantities to qualify for individual colors. While color coding is not intended as a substitute for reading cylinder labels and markings, the guideline facilitates distinction among refrigerant containers by content. Four groups are identified, namely those for liquids at 20 °C (68 °F) normally packaged in drums, low-pressure fluids, high pressure fluids, and flammable (red band) refrigerants or mixtures. A table summarizes color assignments and corresponding color matching data. Refrigerants with assigned colors include R-11 (orange), R-12 (white), R-13 (light blue, sky), R-13B1 (pinkish-red, coral), R-14 (yellow-brown, mustard), R-22 (light green), R-23 (light blue grey), R-113 (dark purple, violet), R-114 (dark blue, navy), R-116 (dark grey, battleship), R-123 (light blue grey), R-124 (dep green, DOT green), R-125 (medium brown, tan), R-134a (light blue, sky), R-401A (pinkish red, coral), R-401B (yellow-brown, mustard), R-401C (blue-green, aqua), R-402A (light brown, sand), R-402B (green-brown, olive), R-404A (orange), R-407A (lime green), R-407B (cream), R-407C (medium brown, brown), R-408A (medium purple, purple), R-409A (medium brown, tan), R-410A (rose), R-410B (maroon), R-500 (yellow),

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R-502 (light purple, lavender), R-503 (blue-green, aqua), and R-507A (blue-green, teal).

ABSORPTION AND ADSORPTION

M. R. Ally, **Computer Simulation of Absorption Heat Pump Using Aqueous Lithium Bromide and Ternary Nitrate Mixtures**, report ORNL/TM-10392, Oak Ridge National Laboratory, Oak Ridge, TN, June 1988 (52 pages, available from NTIS, RDB-1143)

This report presents the results of a computer simulation study aimed at comparing the potential performance of lithium bromide (LiBr) and ternary nitrate aqueous mixtures in a heat pump. The falling-film heat transfer coefficient for the ternary nitrate mixture is estimated to be lower than that for LiBr by about one-third. Due to a lack of measured thermophysical properties, the estimates relied on extrapolations. The results show that the ternary nitrate mixture may be operated up to 260 °C (500 °F) boost temperature, which is approximately 80 °C (176 °F) higher than what has been demonstrated with LiBr. In higher temperature regimes, the nitrates show the potential for 10% higher COPs and a marginally greater absorber capacity than LiBr. Experimental measurements of the falling film heat transfer coefficient, subcooling, and thermophysical properties are required to make a more definitive investigation.

K. Badrinarayana, S. S. Murthy, and M. V. Krishnamurthy, **Thermodynamic Analysis of R21-DMF Vapour Absorption Refrigeration System for Solar Energy Application**, *International Journal of Refrigeration* (IJR), Paris, France, volume 5, pages 115 ff, 1982 (RDB6312)

R-21/DMF

S. C. Bhaduri (Indian Institute of Technology, India), **Performance of HCFC-22 Based Refrigerant-Absorbent Mixtures**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 129-140, October 1993 (12 pages with 11 figures and 3 tables, RDB3A35)

S. C. Bhaduri (Indian Institute of Technology, India), **Thermodynamic Criterion for Selection of Refrigerant-Absorbent Pairs for Vapor Absorption Refrigeration System**, *Proceedings of the International CFC and Halon Alternatives Conference* (Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, pages 83-98, September 1992 (16 pages with 5 figures and 1 table, RDB-2A04)

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **Liquid Heat Capacity of R22 Based Binary Mixtures**, *Proceedings of the 6th International Symposium on Heat and Mass Transfer* (Miami, FL, 10-12 December 1990), 1990 (RDB6316)

R-22/absorbent, properties

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **Heat of Mixing of R22 - Absorbent Mixtures**, *International Journal of Refrigeration* (IJR), Paris, France, volume 11, pages 92 ff, 1988 (RDB6314)

R-22/absorbent, properties

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **Thermodynamic Properties of R22 - Cyclohexanone Combination for Vapour Absorption Refrigeration System**, *Proceedings of the VIIIth National Symposium on Refrigeration and Air-Conditioning* (Indian Institute of Technology, Kanpur, India, 26-27 February 1988), pages 129 ff 1988 (RDB6315)

R-22/absorbent, properties

S. C. Bhaduri (Indian Institute of Technology, India) and H. K. Varma, **P-T-X Behavior of R22 with Five Different Absorbents**, *International Journal of Refrigeration* (IJR), Paris, France, volume 9, pages 362 ff, 1986 (RDB6313)

R-22/absorbent, thermodynamic properties

I. Borde, M. Jelinek, and N. C. Daltrophe (Ben-Gurion University of the Negev, Israel), **Research on Thermophysical Properties of Absorption Working Fluids at the Energy Laboratory of Ben-Gurion University**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 37-46, 1990 (10 pages with 9 figures, RDB5527)

R-630 (methylamine, monomethylamine, MMA), dimethylamine (DMA), ethylene glycol (EG), MMA/EG, DMA/EG, R-22/N-methylpyrolidone (R-22/NMP), thermodynamic data, cycle analysis, absorption cycles

I. Borde and M. Jelinek (Ben-Gurion University of the Negev, Israel), **Thermodynamic Properties of Binary Fluid Mixtures for Absorption Refrigeration Systems**, paper 86-WA/HT-60, American Society of Mechanical Engineers (ASME), New York, NY, 1986 (RDB5528)

R-22/N-methylpyrolidone (R-22/NMP), thermophysical data, absorption cycles

D. Clodic and C. Ciucasu (École des Mines de Paris, France), **An Optimized Configuration for the Triple-Effect Absorption Cycle**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, pages 343-248, July 1996 (6 pages with 4 figures, RDB6926)

R-717/718 (ammonia/water), performance calculation, cycle optimization

R. L. Cox, **Improvements and Enhancements of the ABSORB Computer Program for Modeling Chemical Absorption Heat Pump Systems**, report ORNL/TM-9957, Oak Ridge National Laboratory, Oak Ridge, TN, July 1986 (56 pages, available from NTIS, RDB1144)

This report provides documentation for updates to ABSORB, a simulation program for modeling chemical absorption heat pump systems of varying configuration. A number of improvements and enhancements have been incorporated to improve the robustness, flexibility, and applicability of this code; these modifications include: 1) a revised strategy of solving the system equations, 2) increased modularization of the program, and 3) the first efforts to employ the code to determine an optimum economic design of a heat pump system. A listing of the Fortran source code for ABSORB is included as an appendix. The listing excludes the optimizing package NPSOL, which is proprietary and must be separately obtained. User documentation to run ABSORB is published separately in report ORNL/Sub/43337/2.

R. C. DeVault, **Advanced Absorption Cycles: System Development and Supporting Research**, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, March 1990 (48 pages, RDB1145)

G. Grossman (Technion, Israel), M. Wilk, and R. C. DeVault (Oak Ridge National Laboratory, ORNL, USA), **Simulation and Performance Analysis of Triple-Effect Absorption Cycles**, *Transactions*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, 1994 (RDB6927)

performance calculation, cycle optimization

G. Grossman and E. Michelson, **Absorption Heat Pump Simulation and Studies, Part I: A Modular Computer Simulation of Absorption Systems**, report ORNL/Sub/43337/2, Oak Ridge National Laboratory, Oak Ridge, TN, circa 1985 (available from NTIS, RDB0926)

G. Grossman and K. W. Childs, **Computer Simulation of a Lithium Bromide-Water Absorption Heat Pump for Temperature Boosting**, *Transactions* (Winter Meeting, Atlantic City, NJ, 23-26 January 1983), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 89, part 1, 1983 (RDB4443)

B. H. Jennings and F. P. Shannon, **The Thermodynamics of Absorption Refrigeration**, *Refrigerating Engineering*, American Society of Refrigerating Engineers (ASRE, now merged into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE), Atlanta, GA, volume 35, pages 333 ff, 1938 (RDB3230)

R. A. Macriss and T. S. Zawacki, **Absorption Fluids Data Survey 1989 Update**, report ORNL/Sub/84-47989/4, Oak Ridge National Laboratory, Oak Ridge, TN, 1989 (52 pages with 21 tables, available from NTIS, RDB1146)

This document updates the series of reports on absorption fluids and data, ORNL/Sub/84-47989/1,2,3, with data developed and published primarily between 1985-1988, and by citation of 44 additional references. Seventy-four worldwide publications containing data relating to properties of binary, ternary, and multicomponent absorption fluids are identified. The fluids discussed include combinations of 9 different refrigerant compounds, as well as 30 single, 7 binary, and 1 ternary absorbent compounds.

T. Ohuchi, M. Aizawa (Hitachi Limited, Japan), R. Kawakami (Osaka Gas Company, Limited, Japan), A. Nishiguchi, T. Hatada, and Y. Kunugi (Hitachi Limited, Japan), **A Study on a Hot-Water Driven Air-Cooled Absorption Refrigerating Machine**, *Proceedings of the 1994 International Refrigeration Conference at Purdue*, edited by D. R. Tree and J. E. Braun, Purdue University, West Lafayette, IN, pages 275-280, July 1994 (6 pages with 13 figures and 5 tables, RDB4833)

V. Patnaik (Phillips Engineering Company), W. A. Miller (Oak Ridge National Laboratory, ORNL), and H. Perez-Blanco (Pennsylvania State University), **An Empirical Methodology for the Design of Vertical Tube Absorbers**, paper 3801, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 185-196, 1994 (12 pages with 18 figures and 1 table, RDB4714)

lithium bromide water, enhanced surface tubes, heat transfer

J. S. Seewald (The Trane Company), **A Simple Model for Calculating the Performance of a Lithium Bromide / Water Coil Absorber**, paper

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3814, *Transactions* (Annual Meeting, Orlando, FL, 25-29 June 1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, volume 100, part 2, pages 318-328, 1994 (11 pages with 12 figures and 2 tables, RDB4723)

Develop Improved Design Techniques for Aqueous LiBr Falling Film Absorption Through Application of an Innovative and Nonintrusive Temperature Measurement Technique, proposed research project 798-URP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, in planning (ASH-0798)

The project is being evaluated by ASHRAE Technical Committee 8.3, *Absorption and Heat-Operated Machines*. Further information is available from the ASHRAE Manager of Research (+1-404/636-8500).

Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps, report HPTC-30-2, edited by T. Saito, Heat Pump Technology Center of Japan, Tokyo, Japan, volume II, March 1990 (362 pages, RDB1148)

This report summarizes the findings of the International Energy Agency (IEA) research project on *Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps* (Annex XIV).

RESEARCH PROGRAMS

G. C. Hourahan and M. S. Menzer (Air-Conditioning and Refrigeration Institute, ARI), **Research Needs in Air-Conditioning and Refrigeration**, *Heat Transfer with Alternate Refrigerants* (proceedings of the 29th National Heat Transfer Conference, Atlanta, GA, 8-11 August 1993), edited by H. J. Sauer, Jr., and T. H. Kuehn, publication HTD-Vol. 243, American Society of Mechanical Engineers (ASME), New York, NY, pages 1-8, 1993 (8 pages with 5 figures and 1 table, available from JMC as RDB3421)

This paper outlines research needs stemming from introduction of alternative refrigerants and the concurrent desire to maintain or increase equipment efficiency. Its purpose is to seed interest in and identify sponsorship opportunities for necessary research. The paper briefly reviews potential impacts of refrigerants on ozone depletion and global warming. It then discusses vapor-compression and absorption cycles and equipment. Starting with their components, it identifies research needs to utilize alternative refrigerants. Research of heat exchanger enhancement, fundamental boiling heat transfer, considerations for glide utilization for zeotropes, and influences of lubricants are among the topics addressed. Design issues for compressors, both positive displacement and centrifugal, are surveyed with emphasis on discharge valve requirements, impeller improvement, oil-free possibilities, and seal refinement. Research needs are cited for materials compatibility and lubricants, composition management for zeotropic blends, and leak sensor requirements. The paper then discusses opportunities for not-in-kind technologies including absorption, adsorption (or desiccant), Stirling, and other cycles. It also mentions needs relating to distribution systems, training of service personnel, and conversions to alternative fluids. The paper mentions ongoing research by the Air-Conditioning and Refrigeration Technology Institute (ARTI) and provides a tabular summary of agencies funding research of air conditioning and refrigeration. They include the ARTI, American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), Electric Power Research Institute (EPRI), Gas Research Institute (GRI), U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA).

H. Kruse (Universität Hannover, Germany), **European Research and Development Concerning CFC and HCFC Substitution**, *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 41-57, 1994 (17 pages with 13 figures and 7 tables, RDB4519)

M. O. McLinden (National Institute of Standards and Technology, NIST, USA) and L. Vamling (Chalmers University of Technology, Sweden), **The Need for, and Availability of, Fluid Property Data: Results from Annexes XIII and 78XVIII**, proceedings of the 4th International Energy Agency (IEA) Heat Pump Conference (Maastrict, The Netherlands, 26-29 April 1993), IEA Heat Pump Centre, Sittard, The Netherlands, April 1993 (12 pages, available from JMC as RDB3703)

G. Morrison (National Institute of Standards and Technology, NIST), **Alternative Refrigerant Properties Measurement and Correlation Program at NIST**, *Proceedings of the XIth Conference on Chemical Thermodynamics* (Como, Italy), International Union of Pure and Applied Chemistry (IUPAC), volume 63, pages 1465-1472, 1991 (18 pages, RDB6437)

thermodynamic properties, thermophysical data, research.

A Research Needs Assessment: Energy Efficient Alternatives to Chlorofluorocarbons, report DOE/ER/30115-H1, U.S. Department of Energy (DOE), Washington, DC, June 1993 (288 pages with 22 figures and 56 table, available from NTIS, RDB3A71)

AFEAS

1992 Annual Report, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, 1993 (12 pages, RDB3609)

Alternative Fluorocarbons Environmental Acceptability Study, program description, AFEAS, Washington, DC, September 1995 (4 pages with 1 figure and 1 table, available from JMC RDB5C36)

This leaflet introduces the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), initiated in December 1988. The program was formed to assess the potential impacts of chlorofluorocarbon (CFC) refrigerant alternatives on the environment. AFEAS is a cooperative research effort sponsored by 11 leading chemical producers. Results were incorporated as an appendix to the *Scientific Assessment* under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Further findings were reported in workshops and as inputs to the 1991 and 1994 assessment updates. The leaflet outlines the overall goals. The first was to identify and help resolve uncertainties regarding potential environmental effects of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). The second objective was to stimulate prompt dissemination of scientific information to the research community, government decision makers, affected industries, and the general public. A table lists alternatives to CFCs, including HCFCs R-22, R-123, R-124, R-141b, R-142b, R-225ca, and R-225cb, as transitional substances, and HFCs R-32, R-125, R-134a, R-143a, and R-152a. The summary notes that scientific studies show that use of HCFCs and HFCs to replace CFCs will reduce the amount of atmospheric chlorine, and thus decrease the risk of ozone depletion. Unlike CFCs, these alternatives will break down readily in the lower atmosphere, forming products with negligible contribution to either acid deposition or ozone pollution. Some of the HCFCs and HFCs can be expected to form trifluoroacetyl halides that will dissolve in water to form trifluoroacetic acid. While the concentrations are so low that adverse effects are unlikely, this issue is being investigated further. A figure shows the potential future contributions from all greenhouse gases. A cited AFEAS study of global warming, co-funded with the U.S. Department of Energy, indicates that HCFCs and HFCs often provide substantial improvements in energy efficiency over CFCs in many applications. Moreover, they do not accumulate in the atmosphere to the same extent as CFCs, and have smaller potential to contribute to the greenhouse effect. The leaflet notes that AFEAS-funded research has been completed, but the organization will be continued for three years to stay abreast of scientific developments.

Research Summary, Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Washington, DC, January 1993 (76 pages, RDB3610)

ARI

AREP Technical Committee, **R-22 Alternative Refrigerants Evaluation Program (AREP) Program Status Report**, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 16 September 1994 (10 pages with 1 table, available from JMC as RDB-5250)

This report summarizes the progress and accomplishments of the Alternative Refrigerants Evaluation Program (AREP). AREP is described as a cooperative program to provide data on the performance of R-22 and R-502 equipment with alternative, non-ozone-depleting refrigerants in a quick and efficient manner. The report reviews the history of the program and cooperation by more than 30 manufacturers in Canada, Europe, and Japan in addition to those in the United States. It outlines the objectives, namely to identify alternatives, establish testing protocols, conduct tests, and publish the results. Test were conducted with 26 refrigerants, which are tabulated. They included R-134a; R-290 (propane); R-717 (ammonia); R-23/32/134a (1.5/-20/78.5), (1.5/27/71.5), and (2/29.4/68.6); R-32/125 (50/50) [R-410A] and (60/40); R-32/-125/134a (10/70/20) [R-407B], (23/25/52) [R-407C], (24/16/60), (25/20/55), and (30/10/60); R-32/125/290/134a (20/55/5/20); R-32/134a (20/80), (25/75), (30/70), and (40/60); and R-125/143a (45/55) as potential replacements for R-22. They also included R-23/32/125 (5/25/-70), R-32/125/134a (10/70/20) [R-407B] and (20/40/40) [R-407A], R-32/125/143a (10/45/-45), R-125/143a (45/55) and (50/50) [R-507A], and R-125/143a/134a (44/52/4) [R-404A] as potential replacements for R-502, an azeotrope of R-22 and R-115. The evaluations comprised compressor calorimeter, system drop-in, soft-

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optimized compressor, and soft-optimized system tests. They were complimented by performance simulations by the National Institute of Standards and Technology (NIST), heat transfer tests by three universities under contract to the Electric Power Research Institute (EPRI), and heat transfer tests by one manufacturer. The resulting reports are available through the ARTI Refrigerant Database; similar future studies will be accepted and also distributed through the database. The report notes that performance was generally inferior with drop-in tests, but close to or better than with R-22 or R-502 with optimized systems. Final evaluation of the data and refrigerant selections are left to individual manufacturers. The report concludes that the program was an unqualified success and proposes continued international cooperation through both discussion forums and cooperative testing.

AREP Technical Committee, **R-22 Alternative Refrigerants Evaluation Program (AREP) Report List**, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 13 September 1994 (6 pages with 1 table, available from JMC as RDB5251)

This document lists reports under review or available from the Alternative Refrigerants Evaluation Program (AREP) [see RDB5250]. It lists the company performing the tests, refrigerants evaluated, type of test, ARTI Refrigerant Database number, length, and approval status for each report. This list is still being revised as final reports are approved.

ARI Research Plan, Air-Conditioning and Refrigeration Institute, Arlington, VA, 10 March 1992 (58 pages, available from JMC as RDB0C01)

This plan documents research needs for air-conditioning and refrigeration, with primary focus on refrigerants, energy conservation, and building environment. It provides industry guidance for public-sector research organizations and sponsors. It also may be useful to individual companies in planning proprietary research and development or cooperative programs. A specific plan for materials compatibility and lubricant research, the basis for the Air-Conditioning and Refrigeration Technology Institute (ARTI) Materials Compatibility and Lubricant Research (MCLR) Program, is included as an appendix. A second appendix provides a series of charts, to show the status of alternative refrigerants and projections for their commercialization. The charts also list announced production plants. Charts are included for R-32, R-123, R-124, R-125, R-134a, R-142b, R-143a, R-152a, and E-134. A third appendix provides elaborations for selected research recommendations including objectives, rationale, suggested approaches, and estimated or recommended budgets and time requirements. This version updates and replaces those published on 6 November 1989, 30 April 1990, 19 December 1990, and 25 September 1991.

Participants' Handbook: R-22 Alternative Refrigerants Evaluation Program (AREP), Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 7 June 1993 (54 pages with 1 figure and 5 tables, available from JMC as RDB3613)

This document outlines an ARI program to identify and evaluate promising alternatives for R-22 for unitary air conditioners, heat pumps, chillers, and refrigeration equipment. This cooperative program seeks to accelerate introduction of alternatives by focusing research efforts and avoiding duplicative work. The document outlines the AREP organization, including its Task Force (chaired by C. J. Tambornino), Technical Committee (chaired by E. B. Muir), and Heat Transfer Project Subcommittee. It identifies cooperating organizations, including the European Committee of Manufacturers of Refrigeration Equipment (CECOMAF), Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), National Research Council of Canada (NRCC), and the Electric Power Research Institute (EPRI). EPRI is funding, coordinating, and managing the heat transfer segment, an integral part of the program. The document identifies the nomination process and resultant candidate refrigerants. They include R-32/125 (60/40), R-32/134a (30/70), R-407B [R-32/125/134a (10/70/20)], R-290 (propane), R-134a, R-717 (ammonia), R-32/125/290/134a (20/55/5/20), R-32/-125/134a (30/10/60), R-32/134a (25/75), R-32/227ea (35/65), R-125/143a (45/55), R-404A [R-125/143a/134a (44/52/4)], and R-32/-125/143a (10/45/45). The last three are of primary interest as potential replacements for R-502, an azeotrope of R-22 and R-115. Procedures and conditions for compressor calorimeter and heat transfer, system simulations, and soft-optimized tests are specified for participants. Related research on toxicity and environmental assessments of the candidate fluids and components will be coordinated and shared. Appendices to this program handbook identify committee members, participating companies, combinations of refrigerants and heat exchanger types to be investigated and equipment categories targeted for soft-optimized testing. This handbook prescribes common terminology, definitions, and report formats and contents to be used. Results of the work will be disseminated via the ARTI Refrigerant Database; an order form is included.

ARTI

R. H. Ernst (The Trane Company), **Materials Compatibility and Lubricants Research with Alternative Refrigerants**, *R-22 and R-502 Alternatives* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 19-20 August 1993), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 91-96, 1994 (6 pages with 4 figures and 2 tables, RDB4523)

This paper summarizes research completed in Phase I of the Materials Compatibility and Lubricant Research (MCLR) Program, reviews progress on Phase II, and discusses the studies planned for Phase III. It emphasizes those projects examining alternatives for R-22 and R-502. It notes the focus of the initial phase as compatibility with motor materials, elastomers, and plastics; chemical and thermal stability; miscibility of lubricants and refrigerants; and thermophysical properties for ten alternative refrigerants and four types of lubricants. They include four hydrochlorofluorocarbons (HCFCs), namely R-22, R-123, R-124, and R-142b, and six hydrofluorocarbons (HFCs), namely R-32, R-125, R-134, R-134a, R-143a, and R-152a. The lubricant classes included mineral oil (MO), alkylbenzene (AB), polyolester (POE), and polyglycol (PAG). A table summarizes the results of compatibility studies of motor materials with R-22/MO and R-32, R-125, R-134a, and R-143a with a POE for magnet wires; varnishes; sheet, sleeving, and lead wire insulations; tapes, and tie cords. The paper indicates that projects for the second phase address compatibility with desiccant materials; viscosity, density, and gas solubility of refrigerant-lubricant mixtures; and development of accelerated test methods for chemical and thermal stability and for the life of motor materials. An illustrative table indicates the miscibility of a POE lubricant at 5, 25, and 60% concentrations in R-32/125 (60/40), R-32/-125/134a (30/10/60), R-32/134a (30/70), R-125/143a (45/55), and R-404A - R-125/143a/-134a (44/52/4). Two figures show the modified sealed tube used for electrical conductivity and stability measurements and the measured conductivity of R-11, R-12, and R-22 with MO at 175 °C (348 °F). Two further figures illustrate a simulated motor stator test specimen and a high pressure tribometer for development of test methods. The paper identifies six projects being investigated for the third phase. They include compatibility of process fluids from manufacturing with HFCs, compatibility of additives to POEs with HFCs, development of low-cost, environmentally acceptable flushing and clean out methods, investigation of motor burnout products, fractionation of zeotropes, and development of an improved flammability test method. The paper also notes an ongoing project to facilitate location of refrigerant and lubricant information, the ARTI Refrigerant Database. The paper identifies the members of the MCLR Advisory committee and acknowledges major sponsorship of the MCLR Program by the U.S. Department of Energy.

ARTI MCLR Program, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, continuous since January 1996 (available from the Internet at http://www.ari.org/rt/mc_sum.html, RDB6905)

Summaries of technical progress are posted for current and completed projects, as well as those open for bids, in the Materials Compatibility and Lubricant Research (MCLR) Program. The program supports critical research to accelerate introduction of substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. It addresses refrigerant and lubricant properties, materials compatibility, and test methods development. This work is jointly funded under a grant from the U.S. Department of Energy and cost sharing by the air-conditioning and refrigeration industry. Summaries identify the title, objective, contractor, principal investigator, and project status for each project. They also indicate report availability and briefly summarize the work, materials tested, and findings. [These reports are available through the ARTI Refrigerant Database along with other MCLR reports and conference papers.]

ASHRAE

1996-1997 Research Plan, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1 January 1996 (26 pages with 7 tables, RDB6301)

This list of prospective research subjects identifies 334 proposed projects, 56 designated as *priority* status. The projects are grouped into eight project classifications, based on approved funding guidelines. Projects relating to refrigerants fall in several of these categories, primarily including the third and sixth highest areas, *Environmentally-Safe Materials* and *Refrigeration Systems*. The research areas were proposed by ASHRAE Technical Committees, Task Groups, and other committees; they were prioritized by ASHRAE's Research and Technical Committee. The highest priority group (*three stars*) includes research of "*HFC Refrigerant-Lubricant Modelling for Gas Solubility and Lubricant Viscosity*," identified as a *high-risk* project. The next

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classification includes "*Thermophysical Properties of R-23*," "*Comprehensive Thermodynamic Property Data for Refrigerant Blends*," and "*Develop Solubility and Viscosity Data for Various Oil-Refrigerant Mixtures at High Discharge Temperatures and Pressures*." The *one-star* priority group includes "*Transport Property Data for Refrigerant Blends*," "*Flammability Properties of Alternative Refrigerants*," "*A Uniform Equation of State for Alternatives to the CFC Refrigerants*," and "*Chloride, Fluoride, and Acidity Measurements of CFC, HCFC, and HFC Refrigerants*." It also includes "*Evaporation of Ammonia Outside Smooth and Enhanced Tubes with Miscible and Immiscible Oils*" and "*Measurement of Solubility, Viscosity, and Density of R-32/125 (R-410 Series) Refrigerant-Lubricant Mixtures*." Among nonpriority projects are: "*Investigation of Major Sources of Refrigerant Emissions and Feasible Methods for Reducing These Emissions*," "*Assessment of Vibration Insulation Material Compatibility with R-22, Alternative Refrigerants, and Ethylene Glycol Mixtures*" "*The Effects of Inundation and Miscible Oil Upon Enhanced Condensation Heat Transfer of Alternative Refrigerants for HVAC Applications*," "*Performance of a Suction-Line Capillary-Tube Heat Exchanger*," "*Performance of an Adiabatic Capillary Tube with Zeotropic Mixtures*," "*Thermophysical Properties of R-245ca*," "*Measurement of R-22 and Alternative Refrigerant Leakage Rates from Open-Shaft Compressors*," "*Double-Walled Heat Exchangers for Class 2 Refrigerants*," "*Heat and Mass Transfer Additives in Aqua-Ammonia Systems*," "*Boiling and Two-Phase Flow of Ammonia and Ammonia-Oil Mixtures in a Corrugated Passage Simulating a Plate Heat Exchanger*," "*Performance Comparison of Different Refrigerants in Flat-Plate, Microchannel Evaporators*," "*Effect of Motion of an Ammonia-Air Mixture in an Enclosed Space on Explosivity*," "*Separating Velocities for Ammonia in Horizontal and Vertical Vessels*," "*Laboratory Verification of Modelling Transients in Refrigerant Lines*," "*Refrigerant Piping Pressure Drop Computer Program*," and "*Optimizing Refrigeration for High T_c Superconducting Applications and Systems*." This plan summarizes anticipated funding and procedures for implementing the research identified; it replaces versions published for preceding years [see RDB5134].

DOE

Refrigeration Systems Program Summary, report DOE/CH10093-120, U.S. Department of Energy (DOE), Washington, DC, December 1991 (24 pages, available from NTIS as GPO #573-122/40020 at price code A03, RDB2263)

This document summarizes results, current activities, and objectives of the U.S. Department of Energy (DOE) for research of refrigerators, air conditioners, heat pumps, chillers, and supermarket systems. Key activities include investigation of alternative refrigerants and refrigeration cycles, developing advanced technologies for future air-conditioning and refrigeration equipment designs, and developing advanced insulation for appliances. The program structure and opportunities for collaboration with industry are outlined.

EPA

W. R. Rhodes (U.S. Environmental Protection Agency, EPA), **Stratospheric Ozone Protection: An EPA Engineering Perspective**, *Journal of the Air and Waste Management Association*, volume 41, number 12, pages 1579-1584, December 1991 (6 pages with 2 tables, available from JMC as RDB-2707)

JRAIA

S. Uemura (Daikin Industries, Limited, Japan), **Basic Requirements and Future Solutions of Air-Conditioning Units with Alternative Refrigerants - 1**, paper 5.2, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 89-94, February 1993 (6 pages with 9 figures and 6 tables, RDB3317)

H. Wakabayashi (Matsushita Electric Industrial Company, Limited, Japan), **Basic Requirements and Future Solutions of Air-Conditioning Units with Alternative Refrigerants - 2**, paper 5.3, *Proceedings of the International Seminar on New Technology of Alternative Refrigerants - Lubricants and Materials Compatibility* (Tokyo, February 1993), Nippon Reito Kyokai [Japanese Association of Refrigeration, JAR], Tokyo, Japan, pages 95-100, February 1993 (6 pages with 6 figures and 4 tables, RDB3318)

PAFT

Programme for Alternative Fluorocarbon Toxicity Testing, program description, PAFT, Washington, DC, September 1995 (4 pages with 1 table, available from JMC as RDB5C38)

This leaflet outlines the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), which was initiated in December 1987. The program was designed to expedite the development of toxicology data for possible substitute fluorocarbons, to replace chlorine-containing compounds such as chlorofluorocarbons (CFCs). PAFT is a cooperative research effort sponsored by 16 of the leading CFC producers from eight countries. Five PAFT program sectors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, PAFT IV for R-225ca and R-225cb, and PAFT V for R-32. The leaflet summarizes objectives, schedules, and results of each of these programs. It notes that the eight cited compounds have been exhaustively tested though more than 200 individual toxicology studies performed in testing laboratories in Europe, Japan, and North America. All of these investigations have been completed except general studies of mechanistic, metabolic, and pharmacokinetic aspects of the toxicology of fluorocarbons, which are not compound specific. The program has cost 21 million dollars in addition to in-house studies, by the sponsoring companies, suggested as costing a similar amount. The results have been reported to regulatory bodies, presented at scientific conferences, used in international assessments, and will be published in peer-reviewed journals. The program assessed acute, subchronic, developmental, and chronic toxicity, carcinogenicity, genotoxicity, and environmental toxicology studies.

Testing to Extremes - Industry's Cooperative Effort to Test the Health and Safety of Selected Fluorocarbon Alternatives to CFCs, Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), Washington, DC, circa 1996 (12 pages with 1 figure and 2 tables, RDB65E9)

This leaflet describes the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), outlines its history, and reviews the hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) compounds addressed. Cited goals were to determine potential health and environmental effects of chlorofluorocarbon (CFC) alternatives in accordance with international guidelines; to derive toxicity information through a rapid, cost-effective program that pooled the resources of member companies and shared the results; and to ensure rapid publication of the results. Five program sectors are identified including PAFT I to address R-123 and R-134a, PAFT II for R-141b, PAFT III for R-124 and R-125, PAFT IV for R-225ca and R-225cb, and PAFT V for R-32. The leaflet summarizes a basic test schedule consisting of studies of acute toxicity, cardiac sensitization, genotoxicity, subchronic toxicity, developmental toxicity, and chronic toxicity and carcinogicity. It notes that further tests were added according to the physical properties, intended application, or expected exposure regime of the chemical. Among them were dermal toxicology, reproductive toxicology, neurotoxicity, ecotoxicology, and metabolism studies. These studies have been completed except for a general study of the mechanistic, metabolic, and pharmacokinetic aspects of fluorocarbon toxicology. The leaflet documents inputs from PAFT to the international and national processes addressing CFC phaseout and to the scientific community. It identifies the member companies and testing laboratories that participated, the latter from Europe, North America, and Japan. It also provides brief summaries of findings for R-32, R-123, R-124, R-125, R-134a, R-141b, R-225ca, and R-225cb. The document concludes with a description of the operation of PAFT and list of presentations and publications.

NEDO

S. Misaki (Research Institute of Innovative Technology for the Earth, RITE, Japan) and A. Sekiya (National Institute of Materials and Chemical Research, NIMC, Japan), **Development of a New Refrigerant**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 278-285, October 1995 (8 pages with 1 figure and 10 tables, available from JMC as RDB5B02)

R-E245cb1, E347 [$CH_3OCF(CF_3)_2$], R-E347scc1; physical properties, synthesis, stability with lubricants and metals (aluminum, copper, and steel), flash point, toxicity, atmospheric lifetime, GWP, HGWP

T. Ohira and K. Yamagishi (New Energy and Industrial Technology Development Organization, NEDO, Japan), **Introducing the R&D Programs Concerning CFC-Related Technologies Implemented by MITI/NEDO**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA,

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pages 294-302, October 1995 (9 pages, available from JMC as RDB5B04)

refrigerant development, reclaim, and destruction

MISCELLANEOUS DOCUMENTS

V. D. Baxter, **Report of Foreign Travel: 9-11 May 1990** [Application of Zeotropic Mixture Refrigerants in Refrigerators and Use of the Lee-Kesler-Plöcker Equation of State], ORNL/FTR-3611, Oak Ridge National Laboratory, Oak Ridge, TN, 14 May 1990 (20 pages, RDB1153)

This informal report summarizes the final working meeting of the International Energy Agency (IEA) research project on *State and Transport Properties of High-Temperature Working Fluids and Nonazeotropic Mixtures* (Annex XIII). It also addresses research at the Universität Hannover, funded by the U.S. Environmental Protection Agency (EPA), on application of refrigerant blends in refrigerators and separate work to use the Lee-Kesler-Plöcker (LKP) equation of state to predict refrigerant properties.

J. M. Calm (Engineering Consultant), **Refrigerant Database**, report DOE/CE/23810-79A, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, November 1996 (432 pages with 1 table, available from JMC as RDB6B41)

This document provides bibliographic citations for more than 3200 publications that may be useful in research, design, and application of air-conditioning and refrigeration equipment. Synopses of the content, materials addressed, and key conclusions are provided for approximately 40% of these documents. The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-600 (butane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene), ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available, even though standard designations may not have been assigned yet. It also addresses mineral oil, alkylbenzene, polyalkylene glycol (PAG), polyolester (POE), and other lubricants. It references documents on compatibility of refrigerants and lubricants with desiccants, elastomers, metals, plastics, motor insulation, and other materials used in refrigerant circuits. The database is available in both a computerized version and as a listing in report form. The computerized version includes more than 4200 citations, including those in the report version, others from a supplement on copper in air conditioning and refrigeration, and an archival group covering historical and superseded documents. The computerized version also includes 474 specially prepared data summaries, including refrigerant (single compound and blend) profiles, tabular compatibility summaries for plastics and elastomers, and toxicity reviews for refrigerants. More than 5,000 pages of reference material can be searched and selectively printed using accompanying retrieval software, which enables very fast searches for user-selected terms or combinations of terms. The search program offers several automated features to simplify searches including optional prompting by search category, an automated *thesaurus* of synonyms and related terms, chain searches to broaden or narrow prior searches, a *wildcard* capability to allow entry of word segments, and a configuration capability to customize a number of options. Both the report and computerized versions include instructions to obtain cited documents or subscriptions for database updates.

J. M. Calm (Engineering Consultant), **Alternative Refrigerants and Lubricants - Data for Screening and Evaluation**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 169-178, October 1995 (10 pages with 2 tables, available from JMC as RDB5A02)

This paper describes the ARTI Refrigerant Database and provides a tabular summary for 86 common and candidate refrigerants. The key elements identified include a collection of documents, a computerized search system, a set of refrigerant summaries, and an information dissemination operation. The document collection, which includes both published and unpublished works, grew from an informal sharing of information on thermophysical properties, materials compatibility, and lubricants for alternative refrigerants. The current set also includes reports from the Air-Conditioning and Refrigeration Technology Institute's (ARTI's) Materials Compatibility and Lubricant Research (MCLR)

Program, the Air-Conditioning and Refrigeration Institute's (ARI's) Alternative Refrigerants Evaluation Program (AREP), contributed works, and other sources. The search and retrieval system is based on a set of bibliographic citations and extended abstracts on refrigerant and lubricants, their properties, compatibility with other materials found in refrigeration systems, effects on heat transfer, system capacity and efficiency, computational and test methods to estimate or determine the preceding data, research, application data, and regulatory information. Two tables present refrigerant identifications, safety classifications, environmental data, and physical property data from the database for 109 of the most common refrigerants. The tabular data include the ANSI/ASHRAE Standard 34 designation, chemical name and formula, flammability limits, safety group, ozone depletion potential (ODP), global warming potential (GWP), molecular mass, freezing point, normal boiling point, and critical parameters (temperature, pressure, and density). The focus of the database and its sponsorship by ARTI, under a grant from the U.S. Department of Energy (DOE), are outlined.

J. M. Calm (Engineering Consultant), **Copper in Air Conditioning and Refrigeration - Supplement to the ARTI Refrigerant Database**, report JMC/-ARTI/CDA-9607D, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, and the Copper Development Association (CDA), New York, NY, July 1996 (60 pages, available from JMC as RDB6720)

This document provides bibliographic citations for 316 publications that may be useful in research, design, and application of air-conditioning and refrigeration (ACR) equipment. Synopses or brief descriptors of the content, materials addressed, and key conclusions are provided for the majority. This supplement to the ARTI Refrigerant Database increases the information provided, by focusing on the suitability of and application data for copper and copper alloys with refrigerants. The key concentration areas are application data, compatibility, and heat transfer (including surface enhancement). An introduction outlines the reasons copper is the preferred fabrication material in many ACR components. It cites the metal's superior heat transfer properties, corrosion resistance, ease of fabrication and joining, strength, and machinability. It also notes the latitude afforded by copper, brass, bronze, and other alloys in manufacturing processes such as casting, forging, machining, drawing, sintering, and forming. A concluding section provides descriptions of both the Refrigerant Database and the Copper Data Center (CDC) database.

P. H. Howard, J. L. Tunkel (Syracuse Research Corporation, SRC), and R. V. Hendriks (U.S. Environmental Protection Agency, EPA), **Identification of CFC and HCFC Substitutes for Blowing Polyurethane Foam Insulation Products**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 417-426, October 1995 (10 pages with 1 figure and 1 table, RDB5B14)

screening of candidates for use as foam blowing agents, tabulates the global warming potential (GWP), molecular mass (MW), and thermal conductivity, and normal boiling point (NP) of the 105 candidates (mostly hydrocarbons and hydrofluorocarbons) ranked highest in potential

K. E. Hummel, T. P. Nelson, and P. A. Thompson (Radian Corporation), **Survey of the Use and Emissions of Chlorofluorocarbons from Large Chillers**, *Transactions*, American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Atlanta, GA, volume 97, part 2, 1991 (RDB6320)

CFC, refrigerant emissions, leak rates, loss rates

International Union of Pure and Applied Chemistry (IUPAC) Commission on Atomic Weights and Isotopic Abundances, **Atomic Weights of the Elements 1993**, *Journal of Physical and Chemical Reference Data*, American Chemical Society (ACS), Columbus, OH, American Institute of Physics (AIP), Woodbury, NY, and National Institute of Standards and Technology (NIST), Gaithersburg, MD, volume 24, number 4, pages 1561-1575, 1995 (15 pages with 2 tables, RDB6303)

definitive atomic weights used to calculated the molecular mass of refrigerants

E. Johnson and J. Noble, **A Survey of Alternatives to Ozone-Destroying Technologies**, Greenpeace International, Washington, DC, June 1990 (35 pages, RDB1154)

This report is a survey of innovations old and new that could provide the goods and services currently dependent on ozone-destroying chemicals. It is represented as an attempt to show the range of technologies that could be used as replacements without adverse impact on the ozone layer. The survey notes that the HCFC and HFC alternatives have not been proven to be harmless to the ozone layer, but are greenhouse gases and have serious toxicity problems.

R. W. Pokelwaldt (York International Corporation), **Challenges and Opportunities in the HVAC&R Business Today**, unpublished keynote address to the Twelfth International Compressor and Fifth International Refrigeration Conferences (Purdue Uni-

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versity, West Lafayette, IN), 19 July 1994 (6 pages, limited copies available from JMC as RDB4864)

H. O. Spauschus (Spauschus Associates, Incorporated), **Status of Transition to Alternative Refrigerants and Lubricants (1994), Recent Developments, and Some Predictions**, unpublished plenary presentation to the Twelfth International Compressor and Fifth International Refrigeration Conferences (Purdue University, West Lafayette, IN), 20 July 1994 (27 pages with presentation charts, limited copies available from JMC as RDB4865)

P. I. Rothfleisch and D. A. Didion (National Institute of Standards and Technology, NIST), **A Performance Evaluation of a Variable Speed, Mixed Refrigerant Heat Pump**, report NISTIR 4597, National Institute of Standards and Technology, Gaithersburg, MD, June 1991 (64 pages with 10 figures and 7 tables, available from NTIS at price code A04, RDB3337)

This report evaluates the performance of an innovative heat pump, equipped with a distillation column to shift the composition of a zeotropic refrigerant mixture. This product was commercialized in Japan on a limited basis, but has since been withdrawn. The report contrasts loads to equipment capacity and shows the composition shifting strategy schematically. It outlines equilibrium (or flash) and continuous rectification approaches for distillation. It reviews prior work in the area and describes the test model, which uses a blend of 20% R-13B1 and 80% R-22 by weight. Measured performance at standard rating conditions and seasonal energy calculations are summarized for both the heating and cooling modes. No composition shifting was observed in the tests. Simulations using an ideal-cycle model are described to demonstrate the potential value of composition control. While heating seasonal performance gains were found to be small, avoidance of auxiliary heat requirements were substantial. Cooling performance is indicated to be approximately 2% lower with R-13B1/22 (20/80) blend than with R-22 alone.

J. D. Roux, A. Albouy (Elf Atochem SA, France), J. Murphy, and J. Costa (Elf Atochem North America, Incorporated, USA), **Recent Developments in Zero ODP Blowing Agents for Rigid Polyurethane Foams**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 23-25 October 1995), Alliance for Responsible Atmospheric Policy, Arlington, VA, pages 448-452, October 1995 (5 pages with 4 tables, RDB5B15)

R-141b, R-245ca, R-245eb, R-245fa, R-365scf ("R-365mcf")

M. Sakamoto (Tokyo Metropolitan University, Japan), **New Refrigerants for Japan's Heat Pump and Refrigeration Markets**, *IEA Heat Pump Center Newsletter - CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, volume 13, number 1, pages 22-24, March 1995 (3 pages with 3 figures, RDB5687)

status of alternative refrigerant use in Japan

K. Stephan and R. Krauss (Universität Stuttgart, Germany), **A Database System for Thermophysical Properties of Pure Fluids and Fluid Mixtures**, *Thermophysical Properties of Pure Substances and Mixtures for Refrigeration* (proceedings of the meeting of IIR Commission B1, Herzlia, Israel, March 1990), International Institute of Refrigeration (IIR), Paris, France, pages 49-55, 1990 (6 pages with 2 figures and 4 tables, RDB5529)

thermodynamic properties, thermophysical data

S. G. Sundaresan (Copeland Corporation), **Standards for Acceptable Levels of Contaminants in Refrigerants**, *International Journal of Refrigeration* (IJR), Paris, France, volume 11, number 4, July 1988; republished in ASHRAE Special Publication, *CFCs: Time of Transition*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, pages 220-223, January 1989 (4 pages with 1 table, RDB5554)

ARI Standard 700P, refrigerant purity, moisture, mineral acids, total organics, organic acids, solids, boiling point and range, high boiling residue, other refrigerants, noncondensables

JICOP Guide, Japan Industrial Conference for Ozone Layer Protection, Tokyo, Japan, January 1991 (8 pages, available from JMC as RDB1204)

JICOP was formed in 1988 as the *Promotion Conference for Rational Use of Specified CFCs* and renamed in June 1990. It is an organization of industrial producers and consumers addressing ozone-layer protection in Japan. Its main activities include publicity, information sharing, surveys of actions by other countries, preparation of guides, and training. This leaflet introduces the organization and lists the 55 current members. Included are the Japan Association of Refrigeration, Japan Association of Refrigeration and Air-Conditioning Contractors, Japan Flon Gas Association, and Japan Refrigeration and Air-Conditioning Industry Association.

Manual for Reductions in the Use of Ozone Depleting Substances, Japan Industrial Conference for Ozone Layer Protection, Tokyo, Japan, second edition, February 1992 (140 pages, available from JMC as RDB2705)

This manual outlines technologies for reduction and substitution of chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODSs). It is intended to assist ODS users to develop the most effective measures for each application. Section III.4 addresses leak prevention and use reduction for refrigerants as well as research and development of substitute refrigerants and technologies to use them. It briefly summarizes reduction measures for centrifugal chillers, automobile air conditioners, commercial refrigeration, transport refrigeration, and refrigerators. Other sections of this document review regulatory measures for refrigerants, toxicity and safety evaluation of alternatives, and the physical properties of ODSs and their alternatives.

Refrigeration and Air-Conditioning Technology Workshop, proceedings of the 1993 Non-Fluorocarbon Refrigeration and Air-Conditioning Technology Workshop (Breckenridge, CO, 23-25 June 1993), edited by P. J. Lewis and D. M. Counce, report ORNL/6797, Oak Ridge National Laboratory, Oak Ridge, TN, 1994 (308 pages with summary and 18 papers, available from JMC as RDB4891)

These proceedings provide an assessment and background papers on alternatives to, and anticipated advances in, air-conditioning and refrigeration systems using fluorocarbon refrigerants. They address a number of vapor compression areas, including use of hydrocarbons and ammonia as refrigerants; free-piston, oil-free compressor developments; Stirling cycle refrigeration; compression-absorption hybrid cycles; sonic and thermoacoustic compression; hydraulic and Malone cycle hydraulic refrigeration; and advanced fluorocarbon systems. They also address absorption, adsorption, sorption, metal hydride, evaporative, desiccant, magnetic refrigeration, and thermoelectric cooling technologies. The introduction outlines the process followed and invitation of expert speakers, to outline the not-in-kind (NIK) and advanced technologies. It also identifies a panel assembled to conduct the sessions and compile technology summaries. These summaries are included along with the workshop agenda, list of participants, presented papers or presentation charts, questions addressed to speakers, and for those received responses. This workshop was one of two, the second held in Germany, on the subject.

Specifications for Fluorocarbon and Other Refrigerants, standard 700-93, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, 1993 (12 pages with 1 table, available from ARI for $15.00, RDB4942)

This standard specifies acceptable levels of contaminants for fluorocarbon and other refrigerants, regardless of source (new, reclaimed, and/or repackaged). It is intended for the guidance of manufacturers, refrigerant reclaimers, repackagers, distributors, installers, servicemen, contractors, and consumers. It identifies purity requirements and determination procedures for acceptance or rejection of refrigerants, for both new and existing refrigeration and air-conditioning products. These refrigerants include R-11, R-12, R-13, R-22, R-23, R-32, R-113, R-114, R-123, R-124, R-125, R-134a, R-143a, R-22/-152a/124 (53/13/34) [R-401A], R-22/152a/124 (61/11/28) [R-401B], R-125/290/22 (60/2/38) [R-402A], R-125/290/22 (38/2/60) [R-402B], R-500, R-502, and R-503. It provides for characterization of refrigerants by gas chromatography and boiling point or boiling point range. It also addresses water (moisture), chloride, acidity, high boiling residue, particulates and solids, noncondensables, and impurities including other refrigerants. The standard outlines procedures of sampling, purity determination, and reporting. A table lists the physical properties and maximum contaminant levels for covered refrigerants. It addresses the boiling point, typical isomer content (including R-113a in R-113, R-114a in R-114, R-123a in R-123, R-124a in R-124, R-134 in R-134a, and R-143 in R-143a), and the cited impurities. An appendix, published separately, describes the test procedures to be used.

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The Refrigerant Database is supported, in part, by U.S. Department of Energy (Office of Building Technology) grant number DE-FG02-91CE23810, *Materials Compatibility and Lubricant Research (MCLR) on CFC-Refrigerant Substitutes*. Federal funding supporting the MCLR program constitutes 93.57% of allowable costs. Additional funding and in-kind support is provided by the air-conditioning and refrigeration industry, through the Air-Conditioning and Refrigeration Institute (ARI), and - for the Refrigerant Database - by copper producers and fabricators, through the Copper Development Association (CDA), and in-kind cost sharing by James M. Calm, Engineering Consultant. Development of the database is part of the MCLR Program, managed by the Air-Conditioning and Refrigeration Technology Institute (ARTI). Support by the cited parties does not constitute an endorsement of the views expressed in the database.