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MATERIALS COMPATIBILITY AND LUBRICANTS RESEARCH ON CFC-REFRIGERANT SUBSTITUTES

Quarterly MCLR Program Technical Progress Report

1 October 1992 - 31 December 1992

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MATERIALS COMPATIBILITY AND LUBRICANT RESEARCH ON CFC-REFRIGERANT SUBSTITUTES

ABSTRACT

The Materials Compatibility and Lubricants Research (MCLR) program supports critical research to accelerate the introduction of CFC-refrigerant substitutes. The MCLR program addresses refrigerant and lubricant properties and materials compatibility. The primary elements of the work include data collection and dissemination, materials compatibility testing, and methods development. The work is guided by an Advisory Committee consisting of technical experts from the refrigeration and air-conditioning industry and government agencies. Under the current MCLR program the Air-Conditioning and Refrigeration Technology Institute, Inc., (ARTI) is contracting and managing multiple research projects and a data collection and dissemination effort. Preliminary results from these projects are reported in technical progress reports prepared by each researcher.

SCOPE

The Materials Compatibility and Lubricant Research (MCLR) program is a 36 month research grant administered by the Air-Conditioning and Refrigeration Technology Institute (ARTI), a not-for-profit organization for scientific research in the public interest. The program was implemented on 30 September 1991 and, as currently funded, will run through 30 September 1994. The MCLR program currently consists of a number of research projects grouped in phases. Phase I encompasses seven research projects and a data collection and dissemination project. Phase I projects began in January 1992 and will run through March 1993. Phase II currently consists of eight research projects and a data collection and dissemination project. Phase II projects began in October 1992 and will run through September 1994. This report summarizes the research conducted during the 4th quarter of calendar year 1992.

SIGNIFICANT RESULTS

THERMOPHYSICAL PROPERTIES

Objective:

To provide highly accurate, selected thermophysical properties data for refrigerants HFC-32, HCFC-123, HCFC-124, and HFC-125, and to fit these data to simple, theoretically-based equations of state, as well as complex equations of state and detailed transport property models. The new data will fill the gaps in existing data sets and resolve the problems and uncertainties that exist in and between the data sets. Thermodynamic properties measurements and determinations will include vapor pressure-volume-temperature behavior, liquid pressure-volume-temperature behavior, saturation and critical points, vapor sound speed and ideal gas heat capacity, isochoric heat capacity, Carnahan-Starling-DeSantis (CSD) and the modified Benedict-Webb-Rubin (MBWR) equations of state. Transport properties measurements and correlations will include thermal conductivity and viscosity measurements.

Results:

The Thermophysics Division of the National Institute of Standards and Technology (NIST) is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-8A, *Thermophysical Properties*, Quarterly Report 1 October 1992 - 3 December 1992, by Dr. Richard F. Kayser. Key results are summarized below:

HFC-32: NIST has analyzed the data from 147 gas-phase measurements. Pressure-volume-temperature (PVT) results are presented on Table 1 of the NIST quarterly report. Using the Burnett apparatus in the isochoric mode, NIST completed eleven isochores spanning the temperature range from 268 to 373 K (23 to 212°F) and density range from 7.5 to 500 kg/m^3 (0.47 to 34.3 lb/ft^3). Two Burnett expansions at 373 K (212°F) were used to establish the densities of the isochores.

NIST has also analyzed data from 654 liquid-phase measurements. Results are tabulated in Table 3 of the NIST quarterly report. A vibrating tube densimeter was used to complete twenty-one isotherms spanning the temperatures from 243 to 343 K (-22 to 158°F) and pressures from 2000 to 6500 kPa (290 to 940 psi).

Burnett and ebulliometric vapor-pressure data for HCFC-32 and their deviations from the resulting correlation are shown in Figure 1, along with data from P.F. Malbrunot, et al. [J. Chem. & Eng. Data 13, 16 (1967)]. Uncertainties of the NIST measurements are of the order of 0.05%. Data includes measurements of vapor pressure using the Burnett apparatus at eighteen temperatures ranging from 268 K (23°F) to the critical temperature, 351.36 K (172.78°F). Ebulliometer measurements covered vapor pressures at low temperatures between 208 and 237 K (-85 and -32°F). New vapor-pressure data are presented in Table 3 of the NIST quarterly report.

NIST extrapolated the Burnett vapor-phase and vibrating tube liquid-phase PVT data to the vapor pressure curve to obtain saturated vapor and liquid densities. Results are presented in Tables 4 and 5 of the NIST quarterly report.

NIST used an adiabatic calorimeter expand measurements of molar heat capacity at constant volume (C_v) along five additional isochores. The data now include 79 C_v liquid state measurements and 105 vapor + liquid two-phase region measurements covering the temperature range from 141 to 342 K (-206 to 156°F) and pressures to 35 MPa (5000 psi). Figure 2 depicts the liquid heat capacity data as a function of temperature and Figure 3 shows the saturated liquid heat capacity (C_σ) derived from the two-phase measurements. Tabular data are presented, respectively, in Tables 6-13 and Tables 14-16 of the NIST quarterly report.

Transient hot-wire studies of thermal conductivity were extended to include two supercritical isotherms at 365 and 380 K (197 and 225°F). Measurements now include 1926 data points spanning temperatures from 160 to 380 K (-167 to 225°F) and pressures to 70 MPa (10,000 psi). Figure 4 depicts a plot of the thermal conductivity measurements.

During the thermal conductivity measurements at 400 K (260°F) three of the four tantalum leads to the bottom of the hot wires failed. When NIST personnel disassembled the test cell, they found a reddish-brown deposit coating the platinum hot wires and the stainless steel cell walls. The tantalum leads were extremely corroded and brittle. Researchers at NIST suspect that the failure was the result of fluorine corrosion. They plan to do a chemical analysis on the fluid sample and the reddish-brown deposit. The transient hot-wire cell has been rebuilt using copper leads in place of the tantalum leads.

Shear viscosity measurements of the compressed fluid have been completed at temperatures between 150 and 315 K (-190 to 116°F) and pressures to 30 MPa (4400 psi). Figure 5 contains a plot of fluidity (reciprocal viscosity) as a function of molar volume and an analysis of the measurement deviations.

HCFC-123: Analysis of thermal conductivity data is underway based on the 32-term modified Benedict-Webb-Rubin (MBWR) equation of state model. The data set includes 1618 transient hot-wire data points ranging temperatures from 180 to 480 K (-130 to 405°F) at pressures to 70 MPa (10,000 psi). Figure 6 is a plot of the thermal conductivity surface.

Compressed liquid densities were measured at 105 liquid-state conditions using an isochoric PVT apparatus. The measurements span a range of temperatures from 176 to 380 K (-143 to 224°F) and pressures to 35 MPa (5000 psi). The pressures, temperatures and densities are presented in Table 24 of the NIST quarterly report.

Molar heat capacity at constant volume (C_v) were measured at 79 single-phase-liquid states and 92 saturated-liquid states using an adiabatic calorimeter. The measurements spanned temperatures from 167 to 241 K (-159 to 155°F) and pressures to 35 MPa (5000 psi). Tabulated data for the liquid phase measurements are presented in Tables 25 - 30 of the NIST quarterly report. Data for the two-phase region are presented in Tables 31 and 32 of the NIST quarterly report.

The MBWR equation of state for HCFC-123 has been revised and considerably improved using the liquid-phase PVT and isochoric heat capacity data. Weaknesses in the previous HCFC-123 MBWR fit were noted in some of the derived properties (e.g. speed of sound and heat capacity). The new equation is accurate for all thermodynamic properties from just above the triple point to about 550 K (530°F) and at pressures to 40 MPa (6000 psi).

HCFC-124: NIST analyzed previous liquid-phase PVT measurements and presented results in Table 17 of their quarterly report. The data include vibrating tube densimeter measurements spanning temperatures from 275 to 372 K (-35 to 210°F) and pressures from 396 to 6500 kPa (57 to 922 psi).

Vapor-phase PVT measurements at 44 temperatures between 222 and 286 K (-60 and 55°F) and pressures from 14 to 259 kPa (2 to 37.5 psi) were made using an ebulliometer. The tabulated data are presented in Table 18 of the NIST quarterly report. Figure 7 depicts the vapor-pressure data and the Antoine equation fit of the data.

Gas-phase PVT measurements with the Burnett apparatus are underway. Approximately 150 measurements have been made over temperatures ranging from 278 to 423 K (41 to 302°F).

HFC-125: NIST has analyzed its liquid-phase PVT measurements and published results in Table 20 of their quarterly report. The vibrating tube densimeter measurements cover fifteen isotherms that span temperatures from 275 to 369 K (36 to 205°F) and pressures from 1500 to 6200 kPa (230 to 900 psi).

Compress liquid densities were measured at 87 liquid-state conditions using an isochoric PVT apparatus. Data is presented in Table 21 of the NIST quarterly report. The measurements spanned temperatures from 174 to 398 K (-146 to 257°F) and pressure to 35 MPa (5000 psi).

Vapor pressure measurements were measured at 41 temperatures using an ebulliometer. The measurements spanned temperatures from 219 to 247 K (-65 to -15°F) and pressures from 74 to 262 kPa (10.7 to 38 psi). The new data is presented in Table 22 of the NIST quarterly report. Figure 8 depicts the data with a plot of the Antoine equation fit of the data and a plot of the deviation of the data from the Antoine equation fit.

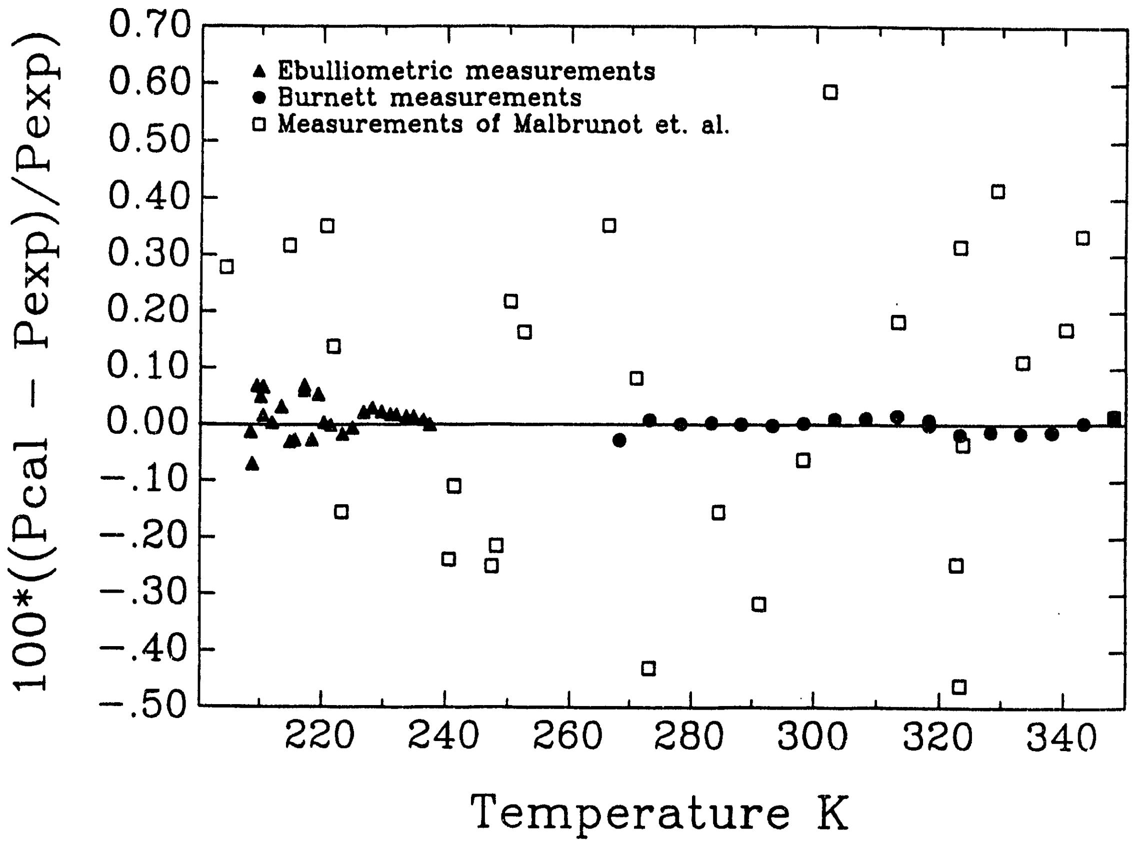


Figure 1. Deviations of HFC-32 vapor pressure data from a correlation of the Burnett and ebulliometric vapor pressure data obtained at NIST. The open squares denote the data from P.F. Malbrunot, et al., J. Chem. & Eng. Data 13, 16 (1968).

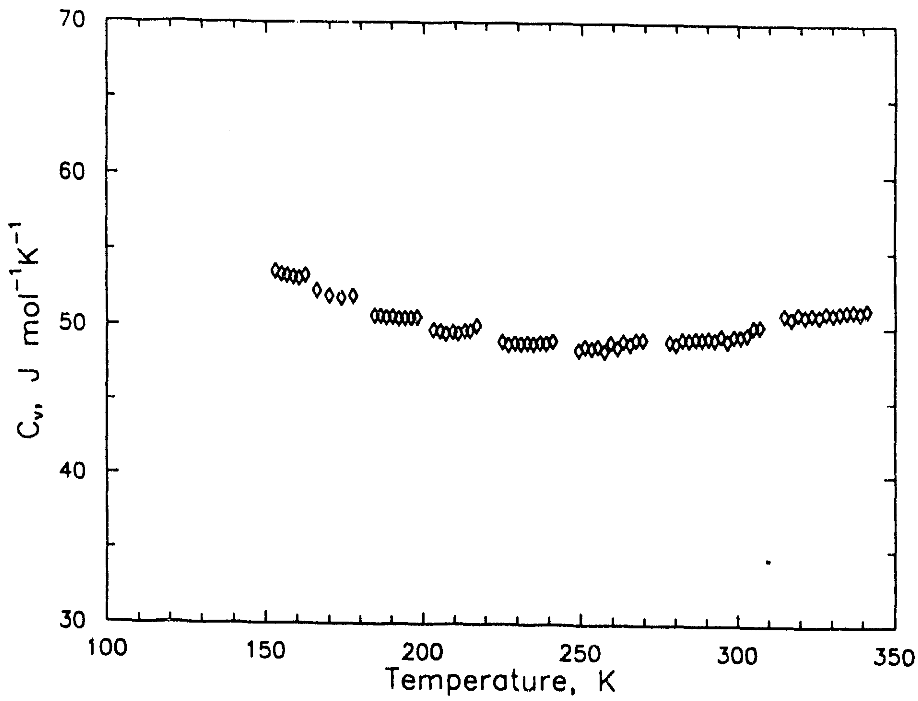


Figure 2. Measurements of heat capacity at constant volume (C_v) for HFC-32.

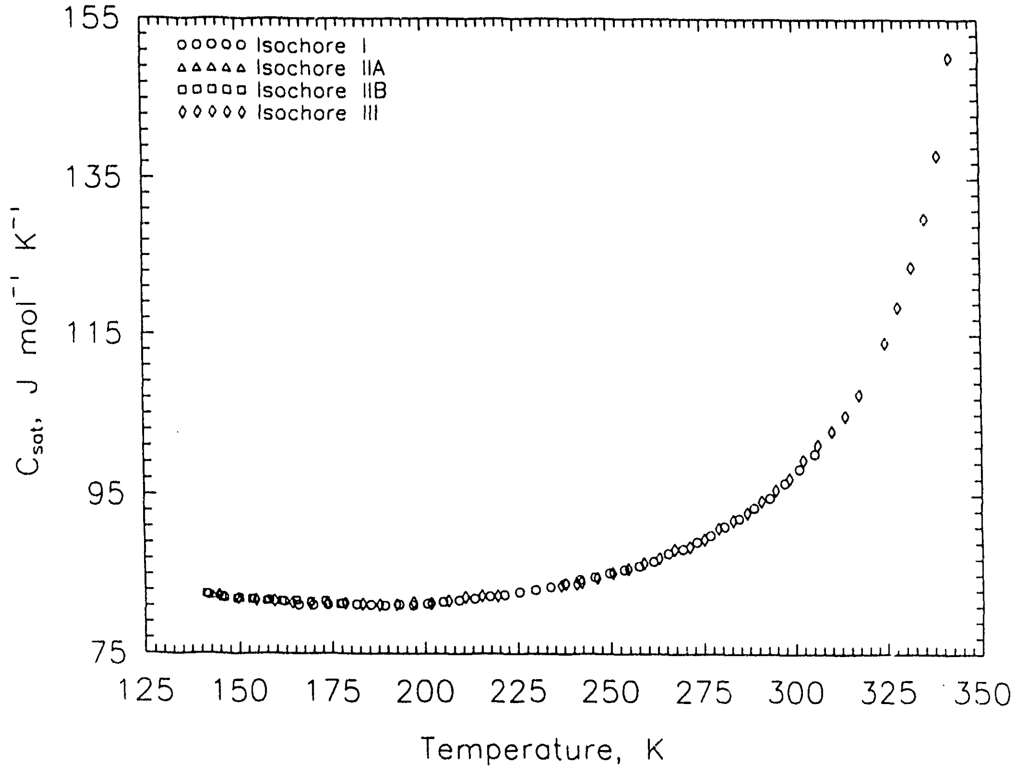


Figure 3. Measurements of saturated liquid heat capacity (C_σ) for HFC-32.

R32 Thermal Conductivity Data

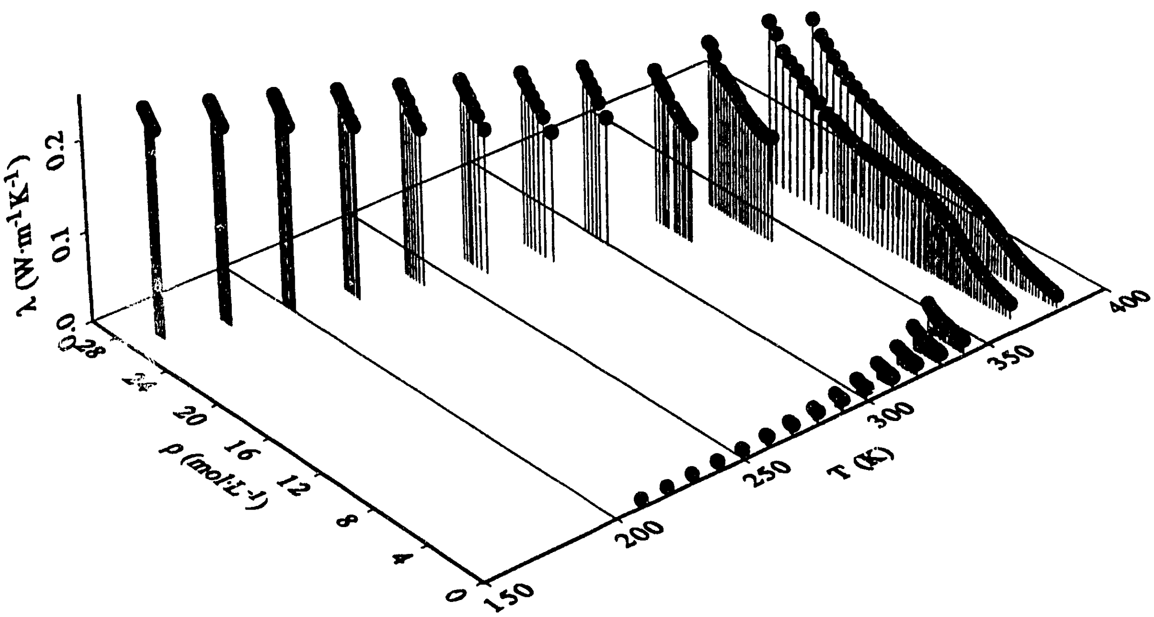
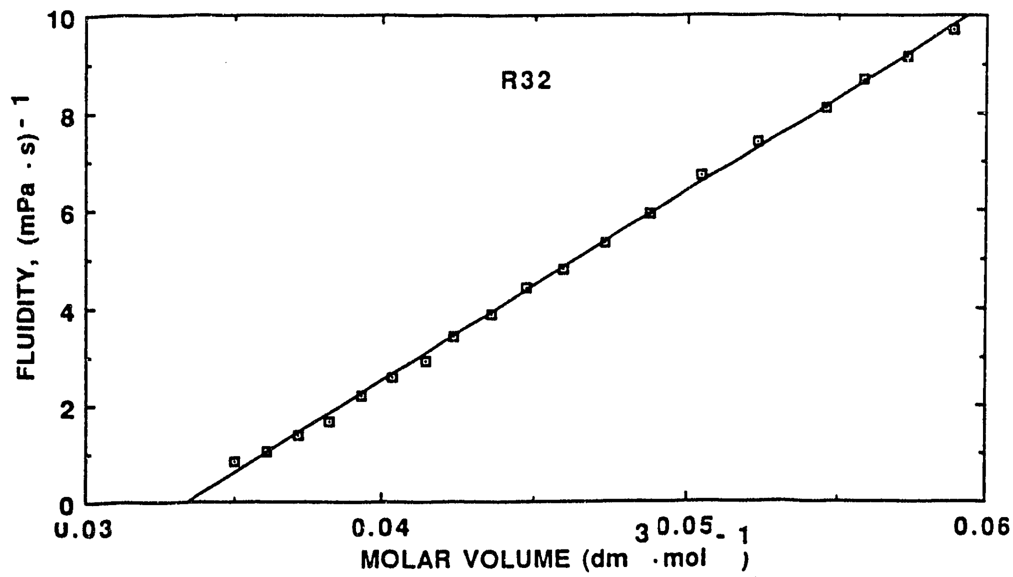


Figure 4. Thermal conductivity measurements for HFC-32.



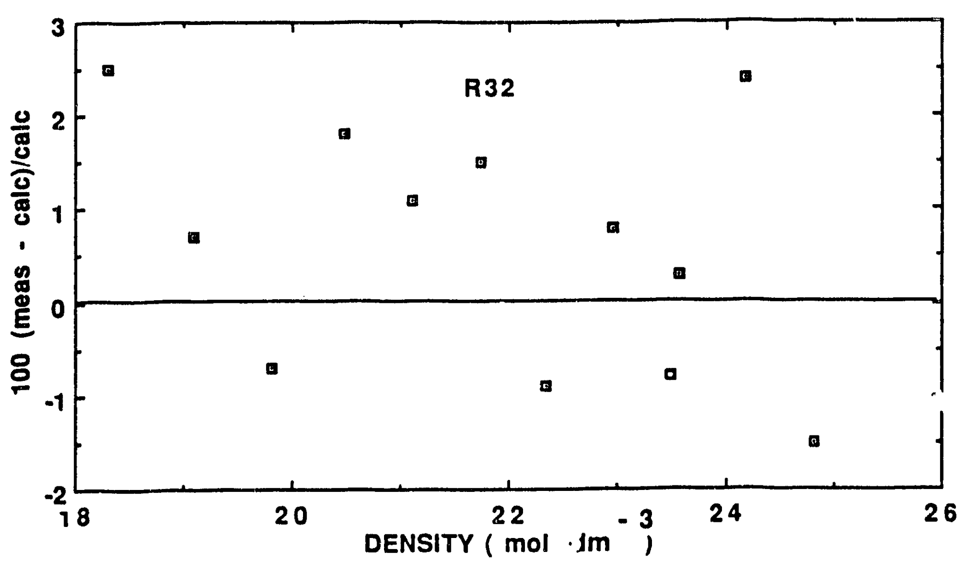


Figure 5. Top: Dependence of HFC-32 fluidity (reciprocal viscosity) data on molar volume. The data has been correlated with the equation, $1/\eta = 406.1\ (V - 0.034)$, where the viscosity, η, is in mPa·s and the molar volume, V, is in dm^3/mol.
Bottom: Comparison of HFC-32 viscosity data with correlating equation. The differences are consist with an imprecision of ± 3 percent.

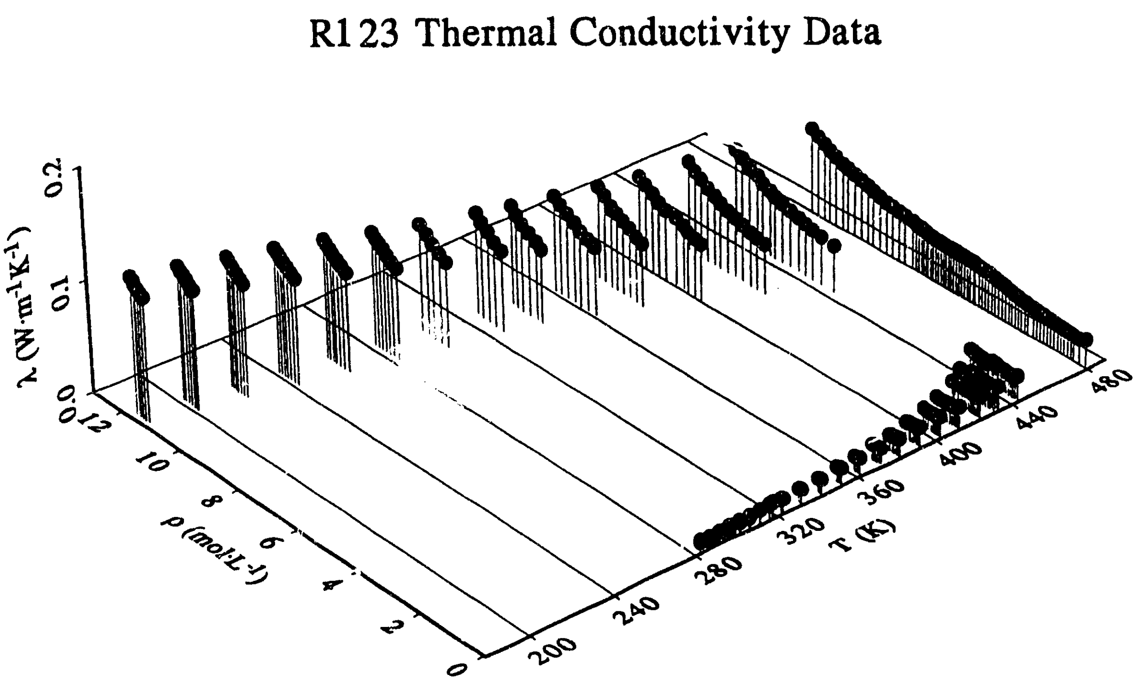


Figure 6. Thermal conductivity measurements for HCFC-123.

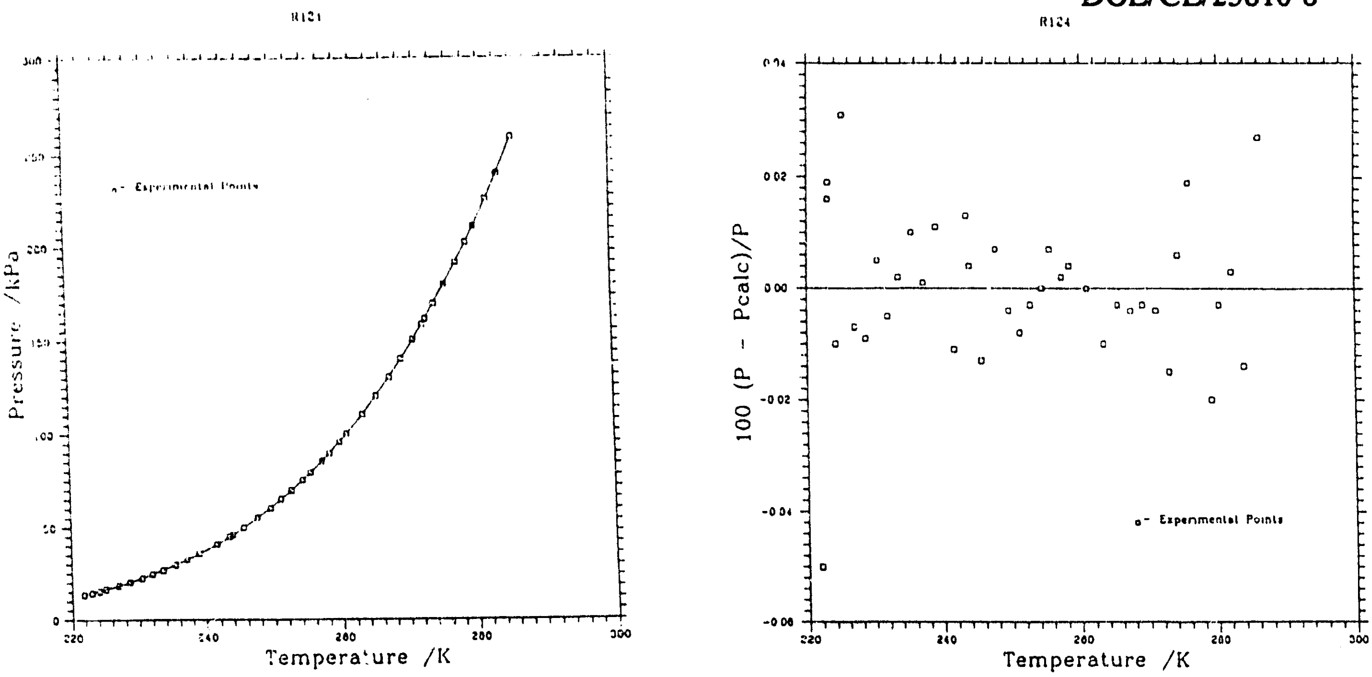


Figure 7. Left: Experimental vapor pressure data for HCFC-124 (open square) and Antoine equation fit (solid line).
Right: Deviations of vapor pressure data from Antoine equation.

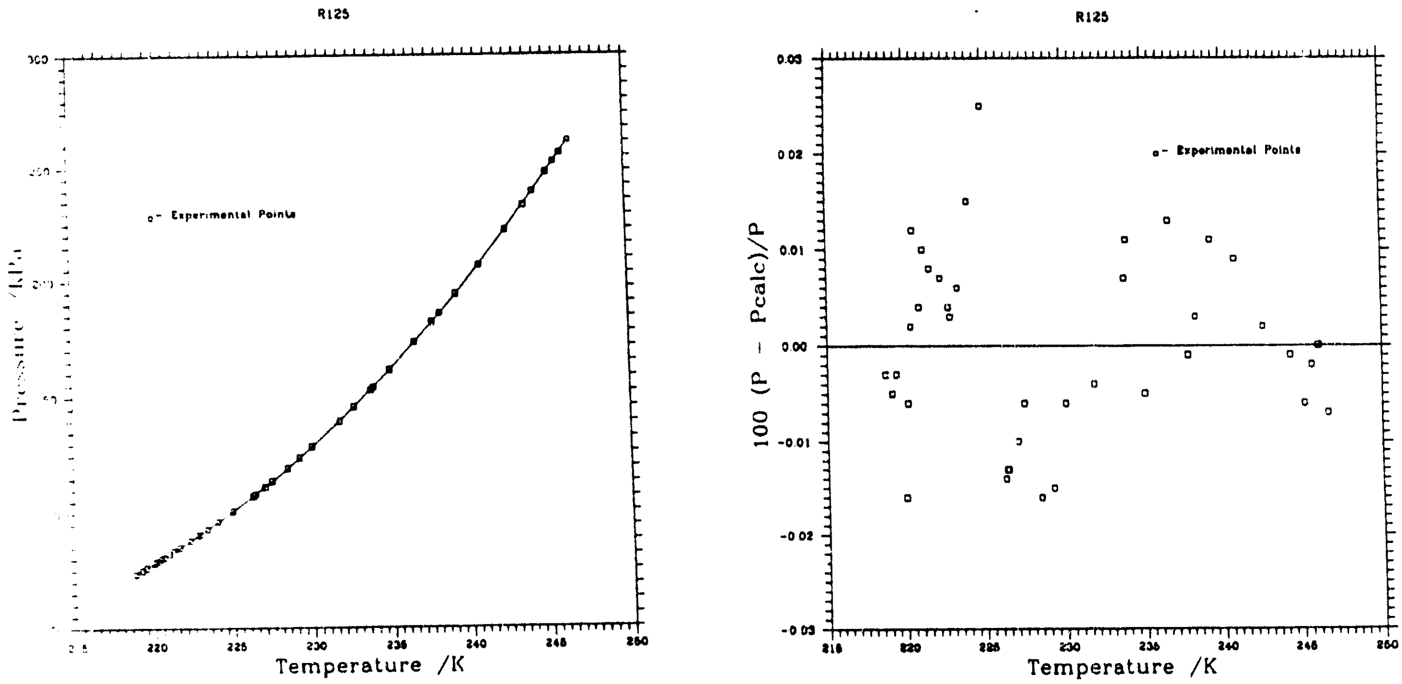


Figure 8. Left: Experimental vapor pressure data for HFC-125 (open squares) and Antoine equation fit (solid line).
Right: Deviations of vapor pressure data from Antoine equation.

THEORETICAL EVALUATIONS OF R-22 ALTERNATIVE FLUIDS:

Objective:

To provide information regarding the Coefficients of Performance (COP), capacities, compressor discharge temperatures, compressor discharge pressures and compressor discharge pressure ratios of the following nine alternative fluids, relative to HCFC-22 and three alternative fluids relative to R-502:

<u>Alternative Refrigerants/Blends (% Weight)</u>

HCFC-22 Alternatives

HFC-32/HFC-123 (60/40)
HFC-32/HFC-134a (30/70)
HFC-125/HFC-134a (45/55)
HFC-32/HFC-125/HFC-134a (10/70/20)
HFC-32/HFC-125/HFC-134a (30/10/60)
HFC-134a
HFC-125/HFC-143a/HFC-134a (40/45/15)
R-290 (Propane)
HFC-32/HFC-125/HFC-134a/R-290 (20/55/20/5)

R-502 Alternatives

HFC-32/HFC-125/HFC-143a (10/45/45)
HFC-125/HFC-143a/HFC-134a (44/52/4)
HFC-125/HFC-143a (45/55)

Results:

The Building Environment Division of the National Institute of Standards and Technology (NIST) completed this research under contract with ARTI. Detailed results of this study are reported in DOE report number DOE/CE/23810-7, *Theoretical Evaluations of R-22 Alternative Fluids*, Final Report, by Dr. Piotr A. Domanski and David A. Didion, January 1993.

CHEMICAL AND THERMAL STABILITY OF REFRIGERANT-LUBRICANT MIXTURES WITH METALS

Objective:

To provide information on the stability of potential substitutes for CFC refrigerants and appropriate lubricants.

Results:

Spauschus Associates, Inc., has completed this research under contract with ARTI. A detailed report of results is presented in DOE report number DOE/CE/23810-5, *Chemical and Thermal Stability of Refrigerant-Lubricant Mixtures with Metals*, Final Report, by Dr. Dietrich F. Huttenlocher. Key results are summarized below:

<u>Alternative Refrigerant-Lubricant Combinations</u>

CFC-11 (baseline) with:
- naphthenic mineral oil ISO 32
- naphthenic mineral oil ISO 46

CFC-12 (baseline) with:
- naphthenic mineral oil ISO 32
- alkylbenzene

HCFC-22 with:
- naphthenic mineral oil ISO 32

HFC-32 with:
- pentaerythritol ester, branched acid
- polypropylene glycol butyl monoether

HCFC-123 with:
- naphthenic mineral oil ISO 32
- naphthenic mineral oil ISO 46

HCFC-124 with:
- alkylbenzene

HFC-125 with:
- pentaerythritol ester, branched acid
- polypropylene glycol butyl monoether
- modified polyglycol

HFC-134 with:
- pentaerythritol ester, branched acid

HFC-134a with:
- pentaerythritol ester, mixed acid
- pentaerythritol ester, branched acid
- pentaerythritol ester, 100 cSt
- polypropylene glycol butyl monoether
- polypropylene glycol diol
- modified polyglycol

HCFC-142b with:
- alkylbenzene

HFC-143a with:
- pentaerythritol ester, branched acid

HFC-152a with:
- alkylbenzene

Based on the results of his research, Dr. Huttenlocher made the following conclusions:

- All HFCs tested, along with HCFC-22, were very stable and did not undergo any measurable chemical reactions or thermal decompositions at temperatures up to 200°C

(392°F).

- HCFC-124 and HCFC-142b were less stable than the HFCs tested but more stable than CFC-12; a long time industry standard.

- While HCFC-123 was the least stable of the "new" refrigerants tested, it was still ten fold more stable than CFC-11; the refrigerant it is intended to replace in low pressure chiller applications.

- The pentaerythritol esters included in the project exhibited acid number increases after aging at 200°C (392°F). The high viscosity (100 cSt) pentaerythritol ester exhibited additional evidence of molecular changes during aging at 200°C. The formation of CO_2 indicated decarboxylation of the high viscosity pentaerythritol ester lubrication at that temperature.

- All of the polyalkylene glycol lubricants indicated signs of molecular change after aging.

MISCIBILITY OF LUBRICANTS WITH REFRIGERANTS

Objective:

To provide information on the miscibility of both current and new lubricants with potential substitutes for CFC refrigerants.

Results:

Iowa State Ur. ersity of Science and Technology is performing this research under contract with ARTI. Part 1 of the project, preliminary miscibility screening, has been completed. These studies examined mixtures at three refrigerant-lubricant concentrations (10, 50, and 95 % refrigerant by weight) and a single viscosity for each lubricant. A detailed report on the results of this research is contained in DOE report number DOE/CE/23810-6, Miscibility of Lubricants with Refrigerants, Final Report (Part 1), by Dr. Michael B. Pate, Mr. Steven C. Zoz, and Mr. Lyle J. Berkenbosch.

Iowa State University is continuing with Part 2 of the project which encompasses more detailed miscibility plots. Five additional refrigerant-lubricant concentrations (20, 35, 65, 80 and 90% refrigerant by weight) will be examined with two viscosity grade of each lubricant.

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH MOTOR MATERIALS

Objective:

To provide information on the compatibility of motor materials with potential substitutes for CFC refrigerants and with suitable lubricants.

Results:

The Trane Company is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-8C, *Compatibility of Refrigerants and Lubricants with Motor Materials*, Quarterly Report 1 October 1992 - 31 December 1992, by Dr. Robert Doerr, Mr. Stephen Kujak, and Todd Waite.

This project investigates the compatibility of 24 samples of commercially available motor materials with ten pure refrigerants and 17 refrigerant-lubricant mixtures. At the end of the reporting period, Trane had completed all of the compatibility tests with pure refrigerants and the 17 refrigerant-lubricant combinations.

The sample motor materials were exposed to refrigerant or refrigerant-lubricant mixtures for 500 hours at temperatures specified for each refrigerant. The effect of heat alone was determined by exposing the samples in nitrogen gas at the same temperatures as the refrigerants exposures.

HCFC Refrigerants		HFC Refrigerants		Baseline Exposures
HCFC-22	@ 90°C*	HFC-152a	@ 90°C	Nitrogen @ 60°C
HCFC-123	@ 90°C	HFC-134a	@ 90°C	Nitrogen @ 90°C
HCFC-124	@ 90°C	HFC-134	@ 90°C	
HCFC-142b	@ 90°C	HFC-125	@ 60°C**	*90°C = 194°F
		HFC-32	@ 60°C	**60°C = 140°F
		HFC-143a	@ 60°C	

The various evaluations listed below were made on the motor materials immediately after the 500 hour exposure, and also after the 500 hour exposure with an additional 24 hour air bake at 150°C (302°F) to out-gas the absorbed refrigerant. The test samples included six different varnishes, three different magnet wires, six different sheet insulation materials, one tie cord, three different spiral wrapped sleeving insulating materials, and three different tapes. For the magnet wire/varnish samples, the three types of magnet wire were overcoated with one of each of the six varnishes, producing eighteen different magnet wire/varnish combinations.

Motor Materials Evaluations

Varnish
weight change

Lead Wire
weight change
dielectric strength

Tie Cord
weight change
break load strength

Magnet Wire/Varnish
bond strength
burnout resistance
dielectric strength

Spiral Wrapped Sleeving
weight change
break loan strength

Sheet Insulation
weight change
tensile strength
elongation
dielectric strength

Tapes
weight change

The Trane quarterly technical progress report contains data tables summarizing the per cent change in material properties after exposure to each of the 17 refrigerant-lubricant combinations and the nitrogen atmosphere thermal base when compared to unexposed samples.

Preliminary observations of the data indicate that the refrigerant-lubricant mixtures affected the motor materials less than the pure refrigerants. Two issues of concern were the delamination of sheet insulation materials when exposed to mixtures with polyalkylene glycol - diol, and the decrease strength of tie tapes. Mineral oil extracted polyester materials. However, the synthetic lubricants did not. The synthetic oils tested present few compatibility problems with current motor materials.

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH ELASTOMERS

Objectives:

- To provide compatibility information for elastomers with potential substitutes for CFC refrigerants and with suitable lubricants.
- To obtain data on changes in the physical and mechanical properties of selected elastomers after thermal aging in refrigerant-lubricant mixtures.

Results:

The University of Akron is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-8D, *Compatibility of Refrigerants and Lubricants with Elastomers*, Quarterly Report 1 October 1992 - 31 December 1992, by Dr. Gary R. Hamed and Mr. Robert H. Seiple.

This research project examines the compatibility of ten refrigerant and seven lubricants with 95 elastomeric materials:

Refrigerants		Lubricants
HCFC-22	HFC-32	naphthenic mineral oil
HCFC-123	HFC-125	alkylbenzene
HCFC-124	HFC-134	polypropylene glycol butyl monoether
HCFC-142b	HFC-134a	polypropylene glycol diol
	HFC-143a	modified polyglycol
	HFC-152a	pentaerythritol ester, mixed-acid
		pentaerythritol ester, branched-acid

Elastomer Families

butyl polypropylene TPE (1 type)
butyl rubbers (7 types)
chlorinated polyethylenes (3 types)
chlorosulfonated polyethylenes (5 types)
epichlorohydrin based rubbers (6 types)
EPM rubbers (3 types)
ethylene acrylic elastomers (2 types)
ethylene propylene diene rubbers (5 types)
fluorinated rubbers (7 types)
nitrile rubbers (10 types)
polychloroprenes (2 types)
polyisoprenes (3 types)
polysulfide rubbers (4 types)
polyurethanes (7 types)
silicones (5 types)
styrene butadiene rubbers (3 types)
thermoplastic elastomers, TPEs (11 types)

plus, ten industry-supplied gaskets of various compositions

Swell behavior of elastomer samples were determined by comparing pre-exposure sample measurements for weight, thickness and diameter with their measurements after exposure. As indicated above, these elastomeric formulations include general purpose and specialty thermoset and thermoplastic elastomers.

Lubricant Immersion Studies: Elastomer samples were completely immersed in the test lubricant, sealed in a glass vessel and then heated at 60°C (140 °F) for 14 days. Sample diameters were measured in situ after 24 hours of exposure. The elastomer samples were also measured for weight, thickness and diameter immediately after the 14 day exposure and then again 24 hours after removal.

Several of the elastomeric compositions, including some of the industry-supplied gaskets, were resistant to swelling in all of the lubricants. These included rubbers from the epichlorohydrin, nitrile, polysulfide rubber, and thermoplastic elastomer families. Refer to Table 9 for a relative comparison of the in situ swelling results.

Refrigerant Immersion Studies: Elastomer samples were completely immersed in the test refrigerant, sealed in a pressure vessel and maintained at room temperature (ambient) for 14 days. In situ diameter changes were determined using a traveling microscope after 24 hour, 72 hour and 14 day exposures. Following the 14 day exposures, the samples were remeasured 2 hours and 24 hours after they were removed from the pressure vessels.

In reviewing the results, the following general statements can be made concerning in situ swelling measurements after the 14 day exposures:

- samples exposed to HCFC-123 had the largest swell
- samples exposed to HCFC-22, HCFC-124, HCFC-142b had moderate swell
- samples exposed to HFC-134, HFC-134a, HFC-125, HFC-143a, and HFC-152a had the least swell

Refer to Table 9 for a relative comparison of in situ swelling results.

Refrigerant-Lubricant Thermal Aging Tests: Based on the results of the separate lubricant and refrigerant studies, 25 elastomeric samples were identified for inclusion in the refrigerant-lubricant thermal aging tests. These 25 elastomers will be fully immersed in 17 individual refrigerant-lubricant mixtures for 14 days at 100 °C (212 °F). Depending on the refrigerant-lubricant combination, the refrigerant weight percent will vary from 32% to 65% concentration to maintain a pressure of 275-300 psia. After the 14 day exposures, the tensile properties of the elastomers will be measured and compared to those of non-aged specimens.

Results from the refrigerant-lubricant thermal aging tests will be presented in the next report.

RELATIVE ELASTOMER SWELLING: REFRIGERANTS

	22	32	123	124	125	134	134a	142b	143a	152a
butyl polypropylene TPE	–	*	S	–	S	S	S	–	S	–
butyl rubbers	S	S	–	S	S	S	S	S	S	S
chlorinated polyethylenes	S	*	–	S	S	S	S	S	S	S
chlorosulfonated polyethylenes	–	*	–	S	S	S	S	S	S	S
epichlorohydrin based rubbers	L	S	L	L	S	–	S	S	S	S
EPM rubbers	S	*	–	S	S	S	S	S	S	S
ethylene acrlic elastomers	L	*	L	L	L	–	–	L	S	–
ethylene propylene diene rubbers	S	*	–	S	S	S	S	S	S	S
fluorinated rubbers	L	–	L	L	–	L	L	L	–	L
nitrile rubbers	L	–	L	L	S	–	S	–	S	–
polychloroprenes	S	S	–	S	S	S	S	S	S	S
polyisoprenes	–	S	L	S	S	S	S	–	S	S
polysulfide rubbers	S	*	L	S	S	S	S	S	S	S
polyurethanes	L	*	L	L	–	–	S	–	S	–
silicones	L	–	L	L	–	–	–	L	–	L
styrene butadiene rubbers	–	S	L	S	S	S	S	S	S	S
thermoplastic elastomers (TPE)	–	*	–	–	S	S	S	S	S	S

RELATIVE ELASTOMER SWELLING: LUBRICANTS

	AB	MO	PEBA	PEMA	PPGBM	PPGD	MPG
butyl polypropylene TPE	–	–	S	S	S	S	S
butyl rubbers	L	L	S	S	S	S	S
chlorinated polyethylenes	S	–	–	–	S	S	S
chlorosulfonated polyethylenes	–	–	–	–	S	S	S
epichlorohydrin based rubbers	S	S	–	–	S	–	S
EPM rubbers	L	L	S	S	S	S	S
ethylene acrlic elastomers	–	–	L	L	L	L	L
ethylene propylene diene rubbers	L	L	S	S	S	S	S
fluorinated rubbers	S	S	L	–	S	S	S
nitrile rubbers	S	S	–	–	S	S	S
polychloroprenes	–	–	–	L	–	S	S
polyisoprenes	L	L	–	–	S	S	S
polysulfide rubbers	S	S	S	S	S	S	S
polyurethanes	–	S	S	–	S	–	–
silicones	–	–	–	S	S	S	S
styrene butadiene rubbers	L	L	–	–	–	S	S
thermoplastic elastomers (TPE)	S	–	S	S	S	S	S

legend:

S – small linear swells; less than 8 %
L – large linear swells; greater than than 35 %
– – mixed swell values and/or 8% < swell < 35%
* – test data not yet available

AB – alkylbenzene
MO – mineral oil
PEBA – Pentaerythritol ester branched acid
PEMA – pentaerythritol ester mixed acid
PPGBM – polypropylene glycol butyl monoether
PPGD – polypropylene glycol diol
MPG – modified polyglycol

TABLE 9. Relative Elastomer Swelling.

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH ENGINEERING PLASTICS:

Objectives:

- To provide compatibility information for engineering plastics with potential substitutes for CFC refrigerants and with suitable lubricants.
- To obtain data on changes in the mechanical properties of selected plastics after thermal aging in refrigerant-lubricant mixtures.

Results:

Imagination Resources, Inc., is performing this research under contract with ARTI. A detailed report of their progress is contained in DOE report number DOE/CE/23810-8E, *Compatibility of Refrigerants and Lubricants with Engineering Plastics*, Quarterly Report 1 October 1992 - 31 December 1992, by Dr. Richard C. Cavestri.

This research project examines the compatibility of ten refrigerants and seven lubricants with 23 engineering plastics:

Refrigerants		Lubricants
HCFC-22	HFC-32	naphthenic mineral oil
HCFC-123	HFC-125	alkylbenzene
HCFC-124	HFC-134	polypropylene glycol butyl monoether
HCFC-142b	HFC-134a	polypropylene glycol diol
	HFC-143a	modified polyglycol
	HFC-152a	pentaerythritol ester, mixed-acid
		pentaerythritol ester, branched-acid

Engineering Plastics Tested

acetal	polyamide-imide (2 types)
polyethylene terephthalate (PET)	acrylonitrile-butadiene-styrene (ABS)
polyaryletheretherketone (PEEK)	polyimide thermoset (2 types)
liquid crystal polymer (LCP)	polyaryletherketone (PEK)
polyphenylene sulfide (PPS)	modified polyetherimide
polyaryl sulfone	polyphthalamide
modified polyphenylene oxide	polybutylene terephthalate (PBT)
polypropylene	nylon 6/6
polycarbonate	polytetrafluoroethylene (PTFE)
phenolic	polyetherimide
polyvinylidene fluoride	

Lubricant Immersion Studies: The plastic specimens were evaluated after 14 day exposures in pure lubricants at 60°C (140°F) and 100°C (212°F). Each plastic was affected to some extent by the lubricants. In general, weight and dimensional changes were in the plus or minus 1-2% range. However, the ABS specimens exhibited relatively larger changes in all the lubricants (in the 5-15% range).

Refrigerant Immersion Studies: The plastics were evaluated at room temperature (ambient) and 60°C (140°F) in pure refrigerant for 14 days at the saturation pressure of the refrigerant. All refrigerants had some effect on the plastics; generally, weight increase and some softening of the plastics. HFCs seem to have the least effect. The ABS plastic failed (e.g., dissolved or deformed) in HCFC-22, HFC-32, HCFC-123, HCFC-124, HFC-134, and HFC-152a. The polycarbonate and the modified polyphenylene oxide plastics failed in HCFC-123.

Stress Crack-Creep Rupture Tests: Linear creep is measured for plastic test bars submerged in a 32 ISO VG branched acid polyolester lubricant with 40% refrigerant concentrations (by weight) at 20°C (68°F) for 14 days. Each plastic is weight loaded at 25% of its ultimate tensile capability to stress the gage area of specimen test bars. The resultant deformation under load information provides the creep modulus arising from the exposure effects of synthetic lubricant with the differing refrigerants.

Stress crack-creep results are reported on plastic test bars immersed in HCFC-22, HFC-134, and HFC-152a. ABS and modified polyphenylene oxide plastic test bars failed (broke) within one hour after individual exposures to HCFC-22, HFC-134, and HFC-152a with the polyolester lubricant. Stress crack-creep information on plastics exposed to other refrigerants will be completed by the next report.

Refrigerant-Lubricant Thermal Aging Tests: Thermal aging tests on the 23 plastic specimens in 17 refrigerant-lubricant combinations were completed. These tests were performed at 150°C (300°F) for 14 days at a 275-300 psia refrigerant pressure exposure. Due to its higher reactivity, HCFC-123 aging tests were performed at 125°C (260°F) and at 105°C (220°F). Physical changes were observed, dimensional changes measured, and specimen tensile properties were compared to the original, unexposed specimens.

After aging, the plastics exhibited minimal dimensional and weight changes (i.e., generally within plus or minus 2%). However, the phenolic, polyvinylidene fluoride, and polypropylene plastic specimens exhibited the largest dimensional and weight changes (generally 5-20%). As compared to the tensile tests performed on non-aged plastic test bars, the aged specimens exhibited large reductions in tensile capabilities (i.e., changes in tensile strengths ranged from a 30% gain to a 50% loss, changes in elongation ranged from a 10% increase to a 85% loss). Hence, as a result of environmental embrittlement, many plastics broke after a much smaller elongation under a much lower tensile load; as compared to the non-aged specimens.

ACCELERATED SCREENING METHODS FOR PREDICTING LUBRICANT PERFORMANCE IN REFRIGERANT COMPRESSORS:

Objective:

To develop methods and procedures to simulate lubricant performance in refrigeration and air-conditioning compressors.

Results:

The University of Illinois at Urbana-Champaign is performing this research under contract with ARTI. This research, divided into problem identification and evaluation components, is just getting underway. A preliminary problem definition report will be available after June 1993. The final report, including evaluations and recommendations, will be available after September 1994.

MEASUREMENT OF VISCOSITY, DENSITY, AND GAS SOLUBILITY OF REFRIGERANT AZEOTROPES AND BLENDS IN SELECTED REFRIGERANT LUBRICANTS:

Objective:

To measure the viscosity, density, and solubility of four refrigerant mixtures that may potentially replace HCFC-22 or R-502.

Results:

Imagination Resources, Inc., is performing this research under contract with ARTI. Following a preliminary miscibility screening test, four of the following refrigerant blends will be evaluated:

Possible HCFC-22 Alternatives	Possible R-502 Alternatives
HFC-32/HFC-125 (60/40%)	HFC-125/HFC-143a (45/55%)
HFC-32/HFC-134a (30/70%)	HFC-125/HFC-143a/HFC-134a (44/52/4%)
HFC-32/HFC-125/HFC-134a (30/10/60%)	
HFC-32/HFC-125/HFC-134a/R-290 (20/55/20/5%)	

Data from this project will be presented in upcoming reports.

ELECTROHYDRODYNAMIC (EHD) ENHANCEMENT OF POOL AND IN-TUBE BOILING OF ALTERNATIVE REFRIGERANTS:

Objectives:

- To construct a test rig that can measure improvements with in-tube boiling and in-tube condensation heat transfer performance when utilizing EHD enhancement technology.

- To ascertain the heat transfer benefits on pool boiling with HCFC-123/lubricant on single and multiple enhanced tubes when utilizing EHD techniques.

Results:

The University of Maryland is performing this research under contract with ARTI. A report detailing the pool boiling test results and the fabrication and qualification of the in-tube apparatus will be available upon the completion of the project at the end of the second quarter 1993.

COMPATIBILITY OF DESICCANTS WITH REFRIGERANTS AND LUBRICANTS:

Objective:

To provide compatibility information for desiccants with alternative refrigerants and lubricants.

Results:

This project will be released by ARTI for competitive bid in April 1993.

VISCOSITY, SOLUBILITY AND DENSITY MEASUREMENTS OF REFRIGERANT-LUBRICANT MIXTURES:

Objective:

To measure the viscosity, solubility, and density of alternative refrigerant-lubricant mixtures

Results:

Spauschus Associates, Inc. is performing this research under contract with ARTI. This research involves complete viscosity, solubility, and density measurements of the following 38 refrigerant-lubricant mixtures at 7 different concentrations (0, 10, 20, 30, 80, 90, and 100 % refrigerant by weight).

Baseline Fluids

- CFC-12/mineral oil (ISO 32)
- CFC-12/mineral oil (ISO 100)
- HCFC-22/mineral oil (ISO 32)

Test Mixtures:

- HFC-134a/polypropylene glycol butyl monoether (ISO 68)
- HFC-134a/penta erythritol-mixed acid (ISO 22)
- HFC-134a/penta erythritol-mixed acid (ISO 32)
- HFC-134a/penta erythritol-mixed acid (ISO 68)
- HFC-134a/penta erythritol-mixed acid (ISO 100)
- HFC-134a/penta erythritol-branched acid (ISO 22)
- HFC-134a/penta erythritol-branched acid (ISO 32)
- HFC-134a/penta erythritol-branched acid (ISO 68)
- HFC-134a/penta erythritol-branched acid (ISO 100)

- HCFC-123/mineral oil (ISO 32)
- HCFC-123/mineral oil (ISO 100)
- HCFC-123/alkylbenzene (ISO 32)
- HCFC-123/alkylbenzene (ISO 68)

- HFC-32/penta erythritol-mixed acid (ISO 22)
- HFC-32/penta erythritol-mixed acid (ISO 68)
- HFC-32/penta erythritol-branched acid (ISO 100)

- HFC-125/penta erythritol-mixed acid (ISO 22)
- HFC-125/penta erythritol-mixed acid (ISO 68)

HFC-125/penta erythritol-branched acid (ISO 32)
HFC-125/penta erythritol-branched acid (ISO 100)

HFC-152a/alkylbenzene (ISO 32)
HFC-152a/alkylbenzene (ISO 68)
HFC-152a/penta erythritol-mixed acid (ISO 22)
HFC-152a/penta erythritol-mixed acid (ISO 68)

HFC-143a/penta erythritol-mixed acid (ISO 22)
HFC-134a/penta erythritol-mixed acid (ISO 68)
HFC-143a/penta erythritol-branched acid (ISO 32)
HFC-143a/penta erythritol-branched acid (ISO 100)

HCFC-124/alkylbenzene (ISO 32)
HCFC-124/alkylbenzene (ISO 68)

HCFC-142b/alkylbenzene (ISO 32)

Spauschus Associates have completed low refrigerant concentration (0, 10, 20, and 30 % refrigerant by weight) for three of the 38 mixtures. Figures 10, 11, and 12 depict the Daniel plots and density plots for CFC-12/mineral oil (ISO 32), HCFC-22/mineral oil (ISO 32), and HFC-134a/penta erythritol ester - mixed acid (ISO 32), respectively.

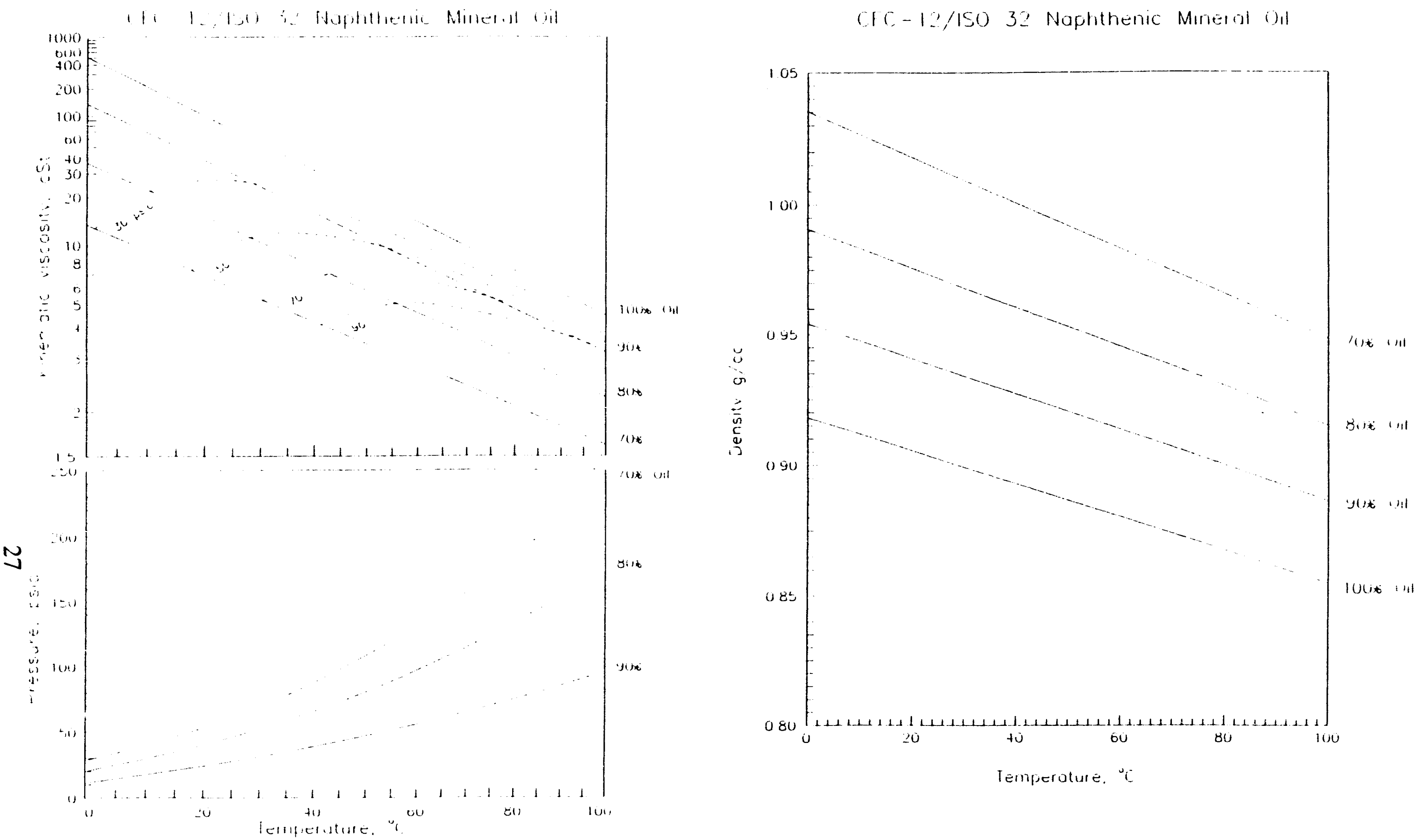


Figure 10. Daniel and density plots for CFC-12/mineral oil (ISO 32).

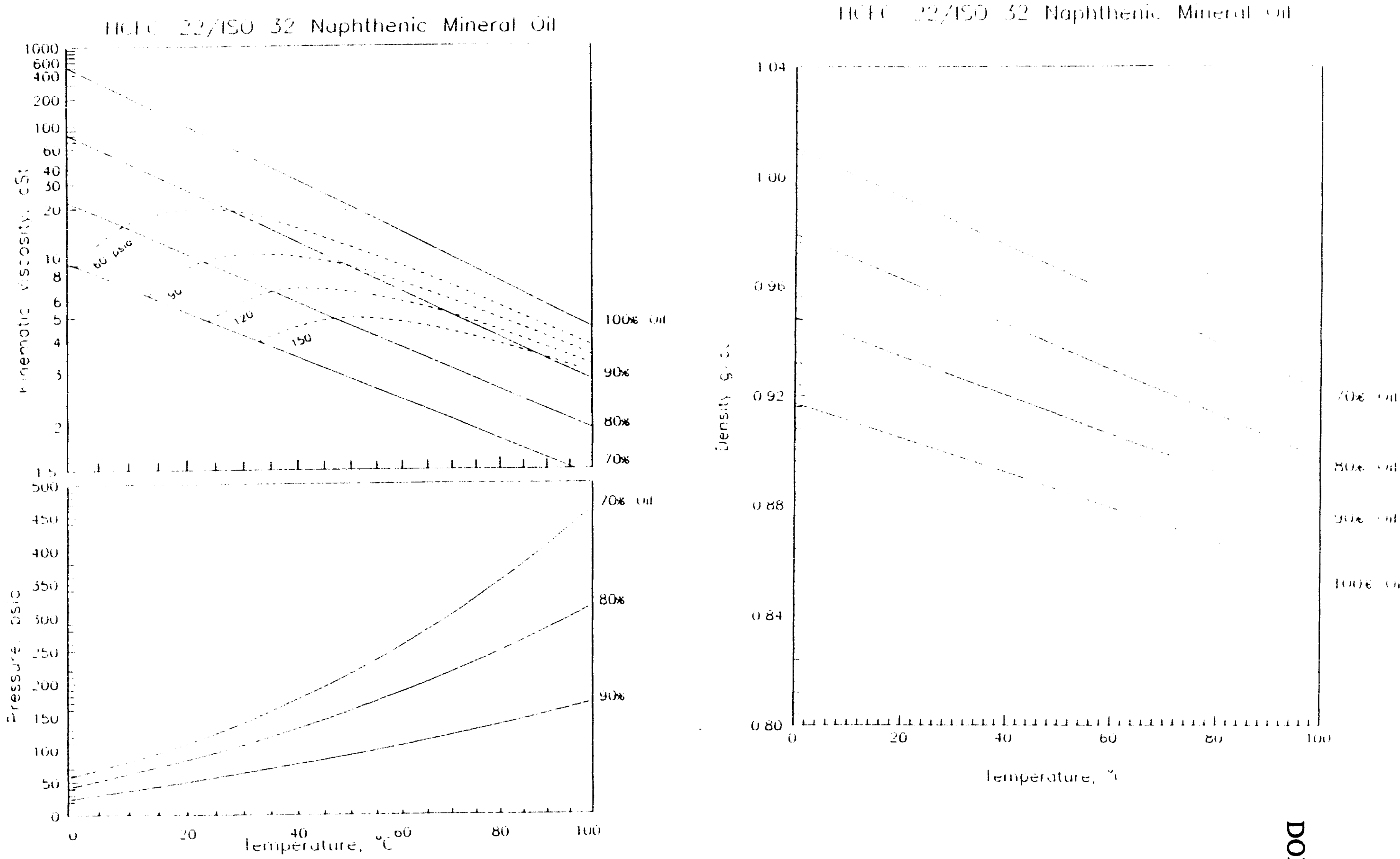


Figure 11. Daniel and density plots for HCFC-22/mineral oil (ISO 32).

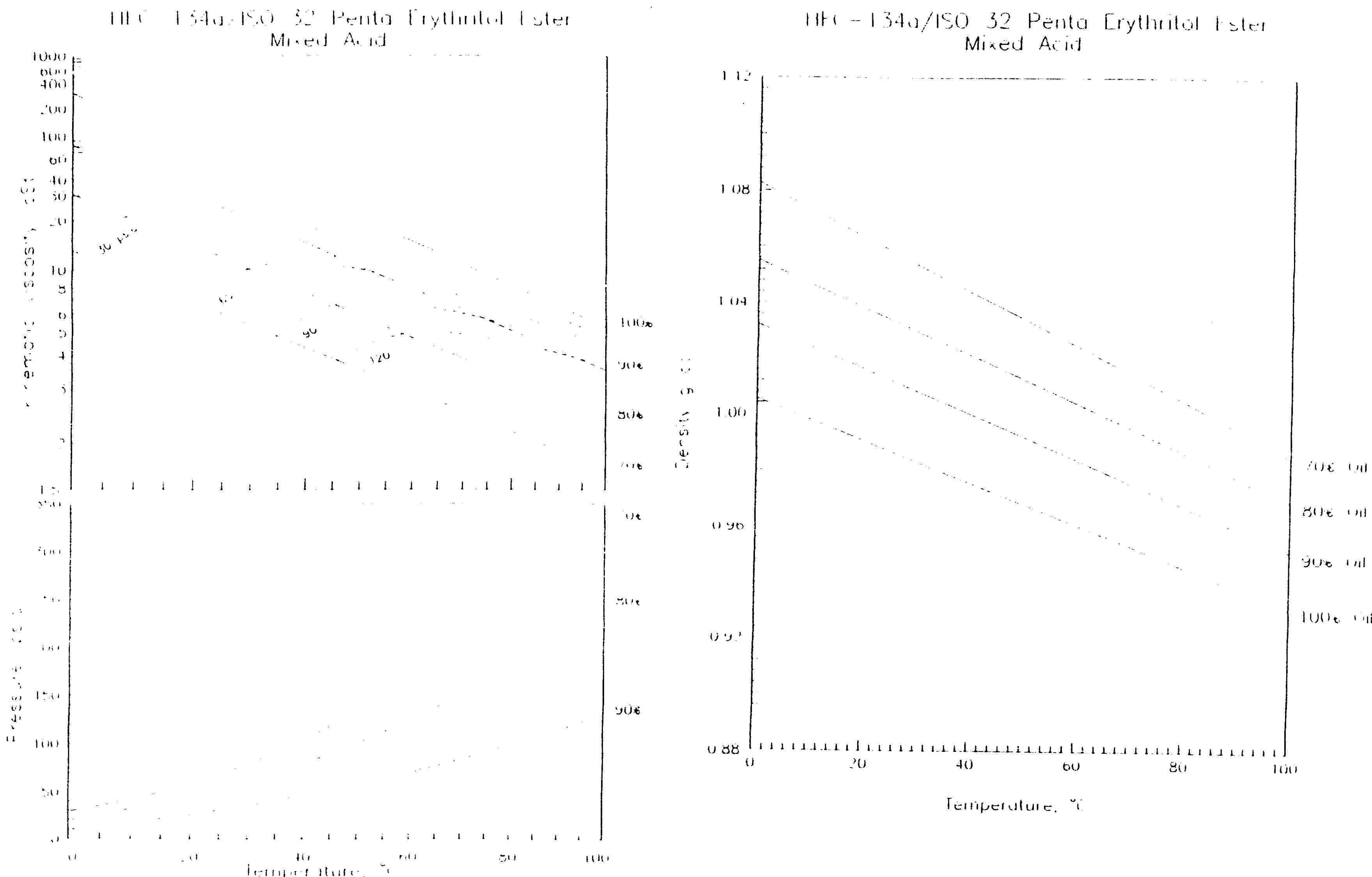


Figure 12. Daniel and density plots for HFC-134a/penta erythritol ester - mixed acid (ISO 32).

ACCELERATED TEST METHODS FOR PREDICTING THE LIFE OF MOTOR MATERIALS EXPOSED TO REFRIGERANT-LUBRICANT MIXTURES:

Objectives:

- To develop test methods and procedures to predict the life of motor insulating materials and varnishes used in hermetic motors

- To validate test method and procedures

Results:

The Radian Corporation is performing this research under contract with ARTI. Radian Corporation is currently conducting a literature search and analysis of current procedures and motor failure mechanism.

ACCELERATED SCREENING METHODS FOR DETERMINING CHEMICAL AND THERMAL STABILITY OF REFRIGERANT-LUBRICANT MIXTURES:

Objectives:

- To develop screening method(s) and procedure(s) to assess the chemical and thermal stability of refrigerants and lubricants, as well as additives, metals, surface treatments, and polymers, used in hermetic systems.

- To validate screening method(s) and procedure(s).

Results:

This research is being performed by the University of Dayton Research Institute under contract to ARTI.

REFRIGERANT DATABASE

Objectives:

- To develop a database for materials compatibility and lubricant research (⁄ICLR) information on substitutes for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants for air-conditioners, heat pumps, refrigeration equipment, and automotive and applied refrigeration cycles.

- To assemble physical properties, materials compatibility, lubricant, and related test data for these refrigerants, along with comparative data for currently-used refrigerants.

- To make the data readily accessible for rapid screening and identification of pertinent source documents based on user-defined search criteria.

Results:

The February 1993 release of the ARTI Refrigerant Database will contain approximately 600 paper citations.

COMPLIANCE WITH AGREEMENT

ARTI has complied with all terms of the grant agreement during the reported period.

PRINCIPAL INVESTIGATOR'S EFFORT

Mr. Mark Menzer is the ARTI principal investigator for the MCLR program. During the fourth quarter of calendar year 1992, Mr. Menzer devoted a total of two-hundred and two labor hours (43.7% of his available work hours) on the MCLR program.

END

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3 / 17 / 93