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ANALYSIS OF ADVANCED CONCEPTUAL DESIGNS FOR SINGLE-FAMILY-SIZE ABSORPTION CHILLERS

Project 9101 Quarterly Technical Status Report

For the Period September 1 Through December 31, 1977

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I. CONTRACT OBJECTIVE

The objective of this research study is the development of radically new fluid systems, specifically tailored to the needs and requirements of solar-absorption cooling for single-family-size residences.

II. PROGRESS SUMMARY

To achieve the objectives of this program the work has been divided into three tasks, Exploratory Research, Data Development for System Evaluation, and Systems Evaluation and Recommendations. To date, we have concentrated our efforts towards completion of the subtasks of Task 1. This technical status report summarizes the activities on this project from the start of the contract to the end of calendar year 1977. During this period, we completed a literature search for refrigerants and absorbents of potential utility to this program; we have identified 27 refrigerant-absorbent pairs which display positive deviations from Raoult's Law; screening tests for absorbent crystallization temperature and heat of mixing have been initiated to aid in determination of candidate pairs; and two broad qualitative criteria have been established for synthesizing new refrigerant-absorbent pairs.

A. Literature Search

During the report period, we began and completed a literature search (Subtask I-B) to provide the data and information necessary for the preselection of radically new, but potentially useful, refrigerants, absorbents, and their mixtures for solar-absorption cooling. The data and information sought related to:

- Physical and thermodynamic properties with emphasis on: heat of vaporization, normal boiling point and saturation pressure, specific heat, endothermic heat of solution (for the mixtures), density or specific gravity, critical temperature and pressure, solubility data (for mixtures), crystallization temperatures (especially for mixtures), etc.
- Toxicity, flammability, thermal and chemical stability, corrosivity, cost, etc.

1. Refrigerants

As a guiding tool for the search and selection of useful refrigerants, we have established the following bench marks and criteria:

- Organic and inorganic compounds to be considered as candidate refrigerants must have a normal boiling point in the range of –50°C and +70°C.

- The range of toxicity to be considered in the evaluation of refrigerant compounds is illustrated by examples of toxic compounds in Table II-1.

Table II-1. OSHA MAXIMUM ALLOWABLE EXPOSURE
(8-Hour Weighted Average)

Compound	Formula	ppm	mg/m^3
Ammonia	NH_3	50	35
Carbon monoxide	CO	50	55
Hydrogen sulfide	H_2S	20	28
Methyl mercaptan	CH_3SH	10	20
Hydrogen cyanide	HCN	10	11
Sulfur dioxide	SO_2	5	13
Hydrochloric acid	HCl	5	7
Chlorine	Cl_2	1	3
Phosgene	$COCl_2$	0.1	0.4
Arsine	AsH_3	0.05	0.2

These values purport to represent the greatest amount of a substance to which persons may be exposed for 8 hours a day for a period of months or years without danger to health. Such values cannot be recommended as the sole criterion of use. For example, sulfur dioxide is probably less hazardous than less toxic compounds, such as carbon monoxide, that give no warning of their presence. However, substances having threshold limit values of 20 ppm or less, or the equivalent in mg/m^3, are very undesirable and have been rejected in this screening.

With the toxicity criteria established for refrigerants (and absorbents), we have rejected several classes of compounds, on a group basis, as being highly toxic. In these considerations, we have employed threshold limit values (TLV) and OSHA maximum allowable exposure (MAE), where available. The groups include compounds of arsenic, selenium, tellurium ("probably toxic"), and fluorides (TLV 2.5 mg/cu m). Boron hydrides are highly toxic; boron triethyl and boron trimethyl are "probably very toxic." Thus, boron alkyl hydrides such as $(CH_3BH)_2$, and boron alkoxyl hydrides such as $(CH_3O)_2BH$ are likely to be highly toxic and have been rejected. Phosphine, PH_3, is extremely toxic (TLV 0.05 ppm). No information is readily available on alkyl phosphorus hydrides, such as CH_3PH_2, but it appears very likely that they also are very toxic; they have been rejected on this basis.

Compounds that yield HCl (TLV 5 ppm), HF (TLV 3 ppm), or HBr (TLV 3 ppm) by reaction with moisture have also been rejected. Among these are silicon chlorides, boron chloride, boron dimethyl bromide, methoxy boron chloride (CH_3OBCl_2), cyanogen bromide (BrCN) and chloride (ClCN), thionyl fluoride (SOF_2), thionyl fluorochloride (SOClF), sulfur chloride (SCl_2), sulfur monooxytetrachloride (S_2OCl_4), chlorine trifluoride (ClF_3), bromine pentafluoride (BrF_5), carbonyl bromide $(COBr_2)$, acetyl fluoride (CH_3COF) and chloride (CH_3COCl), sulfuryl chloride fluoride (SO_2ClF), sulfuryl chloride (SO_2Cl_2), and oxalyl chloride $(COCl_2)$. Nitryl chloride (NO_2Cl), nitrosyl chloride (NOCl), and nitrosyl bromide (NOBr) form nitrogen oxides (TLV 5 ppm) as well as HCl or HBr.

Table VI-1 (in Section VI of this report — Supporting Data) summarizes six groups of refrigerants that passed the preliminary screening and are potential candidates to meet the objectives of this program.

2. Absorbents

The toxicity criteria established for the prescreening of refrigerants were also used to select potential absorbents. Two additional criteria were selected in order to ensure selection of potential absorbents with low volatility, at usual cooling cycle temperatures. These criteria relate to the normal boiling and melting points of the substances.

In general, we found that normal boiling points above 150° to 175°C satisfy the low volatility requirements. The upper limit usually is set by considerations of melting point temperature, which is related to the normal boiling point in most instances. Criteria for maximum melting point temperatures, however, are more difficult to specify because they are only partially responsible for refrigerant-absorbent solution crystallization. The other factor is formation of eutectic solution, which usually extends the limit of solubility even below the melting point of the refrigerant. Another criterion of the suitability of the selected absorbents for a practical absorption system is their chemical stability and reactivity in the presence of the refrigerant and other conditions in the cycle. At present, only indications of instability can be factored in (arrived at by considerations of chemical structure and general literature information), with hard data to be considered later under conditions simulating an actual absorption system. Examples of such preliminary evidence and information are the following:

Acridine has a very stable ring system but forms additional compounds with a number of types of compounds. Among these are alkyl halides. These halides form quarternary salts that undergo rearrangement in which the alkyl group migrates to an adjoining carbon atom. Thus an unstable system would be anticipated if this compound were used with a halogenated hydrocarbon.

Anthranil is a colorless liquid that is easily volatile in steam. It converts to anthranilic acid with alkali, but is stable to acids.

Chromone behaves like an α, β-unsaturated ketone. Thus the C=C double bond is very reactive, and numerous reagents, such as ammonia, hydrogen cyanide, and sodium bisulfite, can add to it. Also it appears very likely that it will polymerize.

Methylpurines are highly stable to acids, bases, and oxidizing agents. The melting points of only a few isomers have been reported.

Napthyridine. Six isomers of this compound are possible but only 1,5-napthyridine (previously called 1,5-pyridopyridine) and 1,8-naphthyridine have been studied. Methyl and hydroderivatives of the latter are liquids or low-melting solids and are readily prepared from 2,6-diaminopyridine. A mixture of several of these derivatives would probably be liquid at room temperture. However, the pyridine group can be alkylated by heating with an alkyl halide at 290° to 300°C, and thus may not be stable when heated with halogenated hydrocarbon refrigerants over an extended period.

Urea decomposes into carbonic acid and ammonia on heating with acids or bases. Heating to 150°C to 160°C eliminates ammonia, and biuret ($NH_2 \cdot CO \cdot NH \cdot CO \cdot NH_2$) is formed. At somewhat higher temperatures, cyanic acid (NCOH) is formed.

A list of potential absorbents for each category of refrigerants selected (Table VI-1) is summarized in Table VI-2.

3. Refrigerant-Absorbent Pairs with Positive Deviation from Raoult's Law

One of the objectives of Task 1 (Exploratory Research) of this program was to extend the literature search and analysis to binary and, possibly, multicomponent refrigerant-absorbent systems to identify those exhibiting positive deviation from Raoult's Law (ideal behavior). The basic characteristic, and the criterion for the identification and selection of such systems, is that they exhibit endothermic heats of mixing, in contrast to the conventional absorption pairs (NH_3-H_2O, H_2O-LiBr, etc.), which exhibit exothermic heats of mixing.

Our literature search and analysis to date has uncovered only very few systems for which actual data on heats of mixing are available. However, we have identified a significant number of systems for which data and measurements exist on refrigerant solubility in absorbents. In order to take advantage of the information available, we have assumed, though not necessarily proven, that the refrigerant-absorbent pairs showing a decrease in solubility over the ideal solubility, will exhibit endothermic heats of mixing. We have used this criterion to select 27 potential candidate pairs useful to this program. These systems are listed in Table VI-3.

B. Preliminary Screening Tests

To aid in the selection and evaluation of candidate pairs we have initiated at least two types of screening tests. A crystallization temperature test is designed to screen from the potential list of refrigerant-absorbent systems (listed in Table VI-3) those that may solidify at typical absorption cycle temperatures or form immiscible phases. A heat of mixing test is designed to ascertain how each candidate refrigerant-absorbent pair might deviate from the ideal behavior.

1. Crystallization Temperature Tests

During the report period we completed tests with several pure components and refrigerant-absorbent tests. The pure component tests were used for comparison with literature values in order to prove the technique.

Apparatus

The apparatus consists of: a Kartes double-wall flask, a calibrated chromel-alumel (Type K) thermocouple referenced to an ice bath, a Sargent-Welch model SRG single pen recorder, and a Peninscular Thermo-Stir magnetic stirer. The solution is placed in the double wall flask and is cooled by circulating chilled acetone in the outer chamber of the flask. The rate of cooling is controlled by varying the chilled fluid flow rate and the depth of immersion of the stainless steel coil in the dry ice-acetone or ice-water mixture. In some of the tests the acetone cooling solution was replaced by water directly from the tap.

Test Procedure

Prior to the start of each series of test runs, the recorder is calibrated using a Leeds and Northrup precision portable volt potentiometer. At the start of each run, the test solution is heated in the flask to 30°F to 40°F above the anticipated crystallization temperature. Uniform temperature throughout the solution is maintained by continuously mixing the solution using the magnetic stirer. After a steady temperature is reached in the solution, the cooling solution is pumped in the outer chamber of the flask. As the test solution is cooled the change in temperature is continuously recorded. During cooling, the rate of rotation of the magnetic stirer is observed so that any changes in viscosity can be noted.

Initially, there is a rapid decrease in the solution temperature. However, once crystals begin to form, heat of fusion is released into the solution. Meanwhile, the solution is also losing heat to the coolant in the jacket of the flask. Hence, during solidification the rate of temperature change is markedly different than the initial cooling rate and a point is reached where the temperature remains constant, an indication that crystallization is taking place. This temperature is then the crystallization temperature. Many times the solution is super-cooled, or is cooled below the crystallization temperature before crystals begin to form. Once formation of crystals occur, the temperature rapidly rises to the crystallization and remains constant for some time. The data obtained for 6 solutions and 3 pure compounds are summarized on Table II-2, which also contains a metastable temperature of subcooling without crystallization characteristic of several of the test samples.

Table II-2. MEASURED CRYSTALLIZATION TEMPERATURES

Pairs	Stabilized Crystallization Temperature, °C	Subcooling Prior to Stabilization, °C
BENZENE	5.0	--
80% benzene, 20% butanol	0.5	--
60% benzene, 40% butanol	− 3.9	− 1.6
TERT BUTANOL	2.5	--
80% tert butanol, 20% benzene	3.4	3.3
60% tert butanol, 40% benzene	7.9	− 7.9
ACETIC ACID	16.6	7.2
80% acetic acid, 20% benzene	4.4	− 4.1
60% acetic acid, 40% benzene	2.7	− 8.9
RESORCINOL		
10% resorcinol, 90% ethanol	Crystallization not observed; viscosity change − 36°C to −49°C	
20% resorcinol, 80% ethanol	Crystallization not observed; viscosity change − 22°C	
NAPHTHOL		
10% naphthol, 90% methanol	Crystallization not observed; no viscosity change	
20% naphthol, 80% methanol	Crystallization not observed; no viscosity change	
100% GLYCEROL	Crystallization not observed; slow viscosity change	
80% glycerol, 20% methanol	Crystallization not observed; slow viscosity change	
60% glycerol, 40% methanol	Crystallization not observed; slow viscosity change	

2. Heat of Mixing Tests

During the report period we also completed several heat of mixing tests designed to identify refrigerant-absorbent solutions potentially useful to this program. In the laboratory, such measurements were conducted simply by mixing nearly equal metal quantities of refrigerant and absorbent (properly thermostated) and recording the temperature rise or drop upon mixing. The results from 6 different solutions are summarized in Table II-3, below. Four of the six mixtures tested showed evidence of positive deviation from Raoult's Law ideal behavior and are candidates for further investigation for the usefulness to this program.

Table II-3. HEAT OF MIXING TESTS

Compound	Qty.	Compound Added to	Qty.	Temperature Change, °C	Ambient Temp, °C
N-Butanol	20 ml	Benzene	20 ml	− 5.4	22.3
Naphthol/Methanol	10.2g/34.7g	Methanol	44.9g	+ 0.9	23.9
Resorcinol/Ethanol	10.0g/30.0g	Ethanol	40.0g	+ 1.6	24.2
Benzene	20 ml	Acetic Acid	20 ml	− 2.8	24.1
Benzene	20 ml	Tert-Butanol	20 ml	−10.2	24.7
Methanol	20 ml	Glycerol	20 ml	− 2.2	24.1

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III. CHANGES

Nothing to report.

IV. PROBLEM AREAS

An approximate 1-month delay in the contract completion date will be required because of the late start. This has been verbally agreed to by the Technical Manager.

V. OPEN ITEMS

Issue an amendment to the contract regarding the requested extension of completion date.

VI. SUPPORTING DATA

This section presents tabulations of potential refrigerants, absorbents and refrigerant-absorbent pairs (Tables VI-1 through VI-3) selected as a result of the exploratory research (Task 1) completed to date. For the compounds and systems listed in Tables VI-1 through VI-3, there are, also, available additional tabulations of data and information useful to the program. The type of data and information available for all or part of the compounds and systems shown in these tables are listed below:

- Name
- Formula
- Molecular weight
- Melting point
- Boiling point
- Density
- Solubility
- Heat of vaporization
- Entropy
- Specific gravity
- Vapor pressure
- Viscosity
- Surface tension
- Specific heat
- Heat of mixing (calculated)
- Flammability
- Toxicity
- Thermal and chemical stability.

Table VI-1. REFRIGERANT COMPOUNDS

Refrigerants	Formula	Molecular Weight	Boiling Point, °C	Heat of Vaporization,* Cal/Mole	References‡
Water and Alcohols					
Water	H_2O	18.0	100	10699	7
Methanol	CH_3OH	32.0	64.9	9058	7
Ethanol	CH_3CH_2OH	46.0	78.5	10646	7
Butanol	$CH_3CH_2CH_2CH_2OH$	74.1	117.25		
Ammonia	NH_3	17.0	−33.5	5059	19
Amines					
Methylamine	CH_3NH_2	31.1	−7.2	6058	19
Ethylamine	$C_2H_5NH_2$	45.1	16.6	6683	19
Dimethylamine	$(CH_3)_2NH$	45.1	7.4	6508	19
Trimethylamine	$(CH_3)_3N$	59.1	3.5	5412	19
Halogenated Hydrocarbons					
R-11	CCl_3F	137.38	23.8	6140	19
R-12	CCl_2F_2	120.91	−29.8	4306	19
R-21	$CHCl_2F$	102.93	8	5919	19
R-22	$CHClF_2$	86.48	−40.8	4162	19
R-31	CH_2ClF	68.5	−9	†	19
R-113	$Cl_2FCCClF_2$ $(C_2Cl_3F_3)$	187.38	47.7	7011	19
R-114	Cl_2CFCF_3 $(C_2Cl_2F_4)$	170.92	3.8	5543	19
R-124a	CHF_2CClF_2 (C_2HClF_4)	136.5	−10	5521 calc. at B.P.	2
R-133a	CH_2ClCF_3 $(C_2H_2ClF_3)$	118.5	6	†	
R-134	CHF_2CHF_2 $(C_2H_2F_4)$	102.0	−23	5250 calc. at B.P.	2
Silanes					
Difluoromethylsilane	CH_3SiHF_2	82.1	−35.5	5308	7
Chlorodifluorosilane	$SiHClF_2$	102.5	--	2810	7
Disiloxane	SiH_3OSiH_3	78.1	15	5418	7

*At 40°C unless otherwise indicated.

†To be reported later.

‡See Bibliography to Section II.

Table VI-2, Part 1. ABSORBENTS REPORTED FOR REFRIGERANTS OF TABLE VI-1.

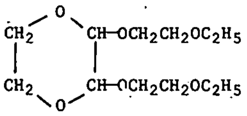
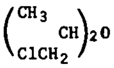
Refrigerant	Absorbent	Formula	Molecular Weight	Melting Point	Boiling Point
				°C	
Water and Alcohols	Lithium Chloride	$LiCl$	42.4	614	1325-60
	Lithium Thiocyanate	$LiSCN$	65.0	--	--
	Lithium Iodide	LiI	133.8	450	1180 ± 10
	Cesium Bromide	$CsBr$	212.8	636	1300
	Cesium Fluoride	CsF	151.9	682	1251
	Rubidium Fluoride	RbF	104.5	775	1410
	Zinc Bromide	$ZnBr_2$	225.2	394	650
	Ethylene Glycol	$C_2H_6O_2$	62.1	−11.5	198
	Butyrolactone	$C_4H_6O_2$	86.1	−42	206
Ammonia or Methylamine	Ammonium Thiocyanate	NH_4SCN	76.12	149.6	170[b]
	Benzoic acid	C_6H_5COOH	122.12	122[a]	249
	p-Chlorophenol	ClC_6H_4OH	128.56	43	217
	Diphenylamine	$(C_6H_5)_2NH$	169.22	53	302
	Ethylene glycol	$HOCH_2CH_2OH$	62.07	−17.4(−12)	197.2
	o-Nitroaniline	$NO_2C_6H_4NH_2$	138.12	71.5	284.11[c]
	Phenol	C_6H_5OH	94.11	41	182
	Phenylacetic acid	$C_6H_5CH_2COOH$	136.14	76.7	265.5
	Succinic acid	$COOHCH_2CH_2COOH$	118.09	185	235[c]
	2,4-Diaminotoluene	$CH_3C_6H_3(NH_2)_2$	122.17	99	280
	Urea	NH_2CONH_2	60.06	132.7	d
	Nitrobenzene	$C_6H_5NO_2$	123.11	5.7	210.8
	Octylamine	$C_8H_{17}NH_2$	129.25	0	179
	Tetraethylene Glycol Dimethyl Ether	$CH_3O\ (C_2H_4O)_4CH_3$	222.28	−27	275.3
	1,4-Butanediol	$HO(CH_2)_4OH$	90.12	16	230
	Tetraethylene Glycol	$H(OCH_2CH_2)_4OH$	194.23	−6.2	328
	Triethylene Glycol Dimethyl Ether	$CH_3(OC_2H_4)_3OCH_3$	178.22	−45	216
	Dimethyl Acetamide	$CH_3CON(CH_3)_2$	87.12	−20	165
	Aniline	$C_6H_5NH_2$	93.13	−6.3	184.13
	2,3-Butanediol	$CH_3CHOHCHOHCH_3$	90.12	--	184
R-11 and R-12	Carbitol Acetate	$C_2H_5O(CH_2CH_2O)_2COCH_3$	176.22	−25	218
	Tetraethylene glycol Diethyl Ether	$C_2H_5O(CH_2CH_2O)_4C_2H_5$	249	e.	e.
R-12	Carbitol Ethyl Ether	$C_2H_5O(CH_2CH_2O)_2C_2H_5$	162.23	--	189
	Carbitol Methoxyacetate	$C_2H_5O(CH_2CH_2O)_2COCH_2OCH_3$	206.24	--	245-46
	4-Methyl, 2-Pentanol Acetate	$(CH_3)_2CHCH_2CH(OCOCH_3)CH_3$	144.22	--	147-48
	2,3-Di-β' Ethoxy-β-Ethoxydioxane		264	e.	e.
	γ,γ' - Dichloro-n-Propyl Ether	$(ClCH_2CH_2CH_2)_2O$	171.01	—	215-45
	Dichloroisopropyl Ether	 $\left(\begin{matrix}CH_3 & \\ & CH \\ ClCH_2 & \end{matrix}\right)_2O$	171.07	--	187

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Table VI-2, Part 2. ABSORBENTS REPORTED FOR REFRIGERANTS OF TABLE VI-1.

Refrigerant	Absorbent	Formula	Molecular Weight	Melting Point °C	Boiling Point °C
	α-Fluoronaphthalene	$C_{10}H_7F$	146.17	− 9	215
	Trichlorobenzene	$C_6H_3Cl_3$	181.45	63-64	208
	Tetraethylene Glycol Dimethyl Ether	$CH_3O(CH_2CH_2O)_4CH_3$	222.28	−27	275.3
	Dimethyl Acetamide	$CH_3CON(CH_3)_2$	87.12	−20	165
	Tetraethylene Glycol Dimethyl Ether-Benzyl Alcohol	$CH_3O(CH_2CH_2O)_4CH_3$ - $C_6H_5CH_2OH$	222.28 108.15	−27 −15.3	275.3 205.35
R-21	Di-β-chloroethyl ether	$ClCH_2CH_2OCH_2CH_2Cl$	143.02	−24.5	178
	Diethylene glycol Dimethyl ether	$CH_3O(CH_2CH_2O)_2CH_3$	134.02	−64	162
	Diethylene glycol Diethyl ether	$C_2H_5O(CH_2CH_2O)_2C_2H_5$	162.23	--	189
	Diethylene glycol Methyl ether chloride	$CH_3(OCH_2CH_2)_2Cl$	138.6	e.	e.
	Triethylene glycol Dimethyl ether	$CH_3O(CH_2CH_2O)_3CH_3$	178.2	−45	216
	Triethylene glycol Methyl Ether Chloride	$CH_3O(CH_2CH_2)_3Cl$	182.45	e.	116-17/12mm
	Tetraethylene glycol Dimethyl ether	$CH_3O(CH_2CH_2O)_4CH_3$	222.28	−27	275.3
	Hexaethylene glycol Dimethyl ether	$CH_3O(CH_2CH_2O)_6CH_3$	310	e.	195-99/15 mm
	γ,γ′-Dichloro-dipropyl ether	$(ClCH_2CH_2CH_2)_2O$	171.07	--	187
	Dichloro-diisopropyl ether	$[ClCH_2(CH_3)CH]_2O$	171.07	--	187
	p-Fluoroanisole	$p\text{-}FC_6H_4OCH_3$	126.13	−45	154
	Resorcinol diethyl ether	$m\text{-}C_6H_4(OC_2H_5)_2$	166.22	12.4	235
	n-Butyl cellosolve Tetrahydrofurfuryl ether	$(C_4H_7O)CH_2O(CH_2)_2OC_4H_9$	202.30	e.	e.
	Diethylene glycol Ditetrahydrofurfuryl ether	$[C_4H_7O)CH_2OCH_2CH_2]_2O$	274	--	199-203/14 mm
	Diphenyl sulfide	$C_6H_6SC_4H_5$	186.26	−25.9	296
	Bis-(β-methylthiol-ethyl) sulfide	$CH_3SCH_2CH_2SCH_2CH_2SCH_3{}^{\alpha}$	182.18	e.	e.
	n-Butyl butyrate	$CH_3(CH_2)_2COO(CH_2)_3CH_3$	144.22	−91.5	166.6
	Ethyl laurate	$CH_3(CH_2)_{10}COOC_2H$	228.38	− 1.8	273
	Diethyl phthalate	$o\text{-}C_6H_4(COOC_2H_5)_2$	222.24	--	298
	Diethyl oxalate	$C_2H_5OCOCOOC_2H_5$	146.14	−38.5	185.7
	Diethyl malonate	$C_2H_5OCOCH_2COOC_2H_5$	160.17	−61.9	181.4
	Triacetin	$(CH_3COOCH_2)_2CHOCOCH_3$	218.21	4.1	258-60
	Tripropionin	$(CH_3CH_2COOCH_2)_2CHOCOCH_2CH_3$	260.29	--	175-6/20 mm
	Tributyrin	$[CH_3(CH_2)_2COOCH_2]_2CHOCO(CH_2)_2CH_3$	302.32	−75	305-10
	Tricaproin	$[CH_3(CH_2)_4COOCH_2]_2CHOCO(CH_2)_4CH_3$	386.54	−60	>200
	Trimethylene glycol diacetate	$(CH_3COOCH_2)_2CH_2$	160.17	−42.5	214
	α,γ-Glycerol dichlorohydrin acetate	$(ClCH_2)_2CHOCOCH_3$	171.03	--	202-08
	4-Methyl-2-pentanol acetate	$(CH_3)_2CHCH_2CH(OCOCH_3)CH_3$	144.22	--	147.8

Table VI-2, Part 3. ABSORBENTS REPORTED FOR REFRIGERANTS OF TABLE VI-1.

Refrigerant	Absorbent	Formula	Molecular Weight	Melting Point °C	Boiling Point °C
	Cellosolve acetate	$C_2H_5O(CH_2)_2OCOCH_3$	132.16	−61.7	156.4
	Cellosolve succinate	$[C_2H_5O(CH_2)_2OCOCH_2]_2$	262.31	e.	159-62/5mm
	Cellosolve adipate	$[C_2H_5O(CH_2)_2OCO(CH_2)_2]_2$	290.36	e.	e.
	Benzyl cellosolve acetate	$C_4H_5CH_2O(CH_2)_2OCOCH_3$	194.23	--	122-25/5mm
	Methyl cellosolve phthalate	$o-C_6H_4(COOCH_2CH_2OCH_3)_2$	298.30	e.	e.
	n-Butyl cellosolve phthalate	$o-C_6H_4(COOCH_2CH_2OC_4H_9)_2$	366	e.	e.
	Ethylene glycol diethoxy acetate	$(C_2H_5OCH_2COOCH_2)_2$	234.25	e.	e.
	Diethylene glycol diethoxyacetate	$(C_2H_5OCH_2COOCH_2CH_2)_2O$	278.31	e.	210-15/5mm
	Diethylene glycol dimethoxy acetate	$(CH_3OCH_2COOCH_2CH_2)_2O$	250.35	e.	204-18/17mm
	Tetrahydrofurfuryl cellosolve acetate	$(C_4H_7O)CH_2OCH_2CH_2OCOCH_3$	188.23	e.	112/6mm
	Triethylene glycol dimethoxy acetate	$(CH_3OCH_2COOCH_2CH_2OCH_2)_2$	294	e.	180-84/20mm
	Methoxyacetate of triethylene glycol acetate	$CH_3OCH_2COO(CH_2CH_2O)_3COCH_3$	264	e.	230-34/15mm
	Triethylene glycol diacetate	$[CH_3COOCH_2CH_2OCH_2]_2$	234	e.	e.
	Carbitol methoxy acetate	$C_2H_5O(CH_2CH_2O)_2COCH_2OCH_3$	206.24	e.	245-46
	n-Butyl carbitol acetate	$C_4H_9O(CH_2CH_2O)_2COCH_3$	204	e.	e.
	Diethylene glycol diacetate	$(CH_3COOCH_2CH_2)_2O$	190	e.	e.
	n-Butyl cellosolve -butyrate	$C_4H_6O(CH_2)_2OCOC_3H_7$	185	e.	220
	n-Butyl cellosolve acetate	$C_4H_6O(CH_2)_2OCOCH_2$	160	e.	192
	n- Butyl cellosolve laurate	$C_4H_9O(CH_2)_2OCO(CH_2)_{10}CH_3$	300	e.	188/8mm
R-22, R-124a R-134, and Chlorodifluorosilane	Acridine		179.21	108 $^{\text{f.}}$	346
	Anthranil		119.12	<−18	215
	Chromone		146.14	59	Sublimes
	m-Dimethoxybenzene	$C_6H_4(OCH_3)_2$	138.16	−52	216.5-217.7
	p-Dimethoxybenzene	$C_6H_4(OCH_3)_2$	138.16	56	212.6:
	N,N-Dimethyl-p-phenylene diamine	$NH_2C_6H_4N(CH_3)_2$	136.19	53	262
	Methylpurine (many isomers)		135.14		
	1-Methyl-IH-purine			234-235	--
	6-Methylpurine			235-236	--
	8-Methylpurine			271-273	--
	1,5-Naphthpyridine (pyridopyridine)		130.14	75	112/12mm
	1,8-Napthyridine		130.14	98.99	147-148/0.05mm
	Tetraethylene glycol dimethyl ether	$CH_3O(CH_2CH_2O)_4CH_3$	222.28	−27	275.3
	Tetramethylurea	$(CH_3)_2N-CO-N(CH_3)_2$	116.16	<25	177
	1,3,5-Trimethoxybenzene	$C_6H_3(OCH_3)_3$	168.19	54-55	255.5

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Table VI-2, Part 4. ABSORBENTS REPORTED FOR REFRIGERANTS OF TABLE VI-1.

Refrigerant	Absorbent	Formula	Molecular Weight	Melting Point °C	Boiling Point °C
R-114	Diethylene glycol Monoethyl Ether Acetate	$CH_3CH_2O(CH_2CH_2O)_2CCH_3$	176.22	25	218
	Tetraethylene Glycol Dimethyl Ether	$CH_3O(CH_2CH_2O)_4CH_3$	222.28	–27	275.3
Disiloxane	Benzoic Acid	C_6H_5COOH	122.12	122[a]	249
	Succinic Acid	$COOHCH_2CH_2COOH$	118.09	185	235[c]
	Phenol	C_6H_5OH	94.11	41	182

a. Ammonium benzoate sublimes at 160°C, melts at 198°C.
b. Decomposes at the boiling point.
c. Decomposes at 270°C.
d. Decomposes at 150°C.
e. To be reported later.
f. Sublimes.

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Table VI-3. REFRIGERANT-ABSORBENT PAIRS FROM TABLE 2 DISPLAYING POSITIVE DEVIATION FROM RAOULT'S LAW

Refrigerant	Absorbent	Heat of Mixing Btu/lb (Ref. 18)	x_p/i_p*	Solubility g/g	Solubility mole fraction (Ref. 16)	Reason for Rejection (Ref. 17)
Ammonia	Tetraethylene Glycol Dimethyl Ether	3.2				
	Triethylene Glycol Dimethyl Ether	4.2				
	Octylamine	3.5				
	Dimethyl Acetamide	0				
Sulfur Dioxide	Heptyl Alcohol	3.4				SO_2 toxicity
Methanol	2-Hydroxytoluene		0.71			
	Phenol		0.67			
	α-Naphthol		0.72			
	Glycerol			Vapor Pressure vs Mole Fraction Curves (Ref. 3)		
	n-Propanol					
Ethanol	Resorcinol		0.25			
Butanol	Benzene			Vapor Pressure vs Mole Fraction Curves (Ref. 3)		Benzene toxicity
Benzene	Acetic Acid					Benzene & Acetic Acid toxicity
Benzene	Tert-Butanol					Benzene toxicity
R-21				Ideal Solution	.381	
	Diphenyl Sulfide			.288	.306	
	Furfural			.621	.367	Furfural toxicity
	Ethylene Glycol			.10	.055	
	Trimethylene Glycol			.106	.073	
	Diethylene Glycol			.285	.288	
	Triethylene Glycol			.358	.330	
	Tetrahydrofurfuryl Alcohol			.588	.368	
	Benzyl Cellosolve			.392	.368	
	Aniline			.385	.258	Aniline toxicity
	Nitrobenzene			.471	.360	
	Decalin			.272	.267	
	Benzotrifluoride			.366	.323	
	α-Monofluoronaphthalene			.327	.317	
R-11				Ideal Solution	.356	
	Diethylene Glycol Monoethyl Ether Acetate (DEG MEEA)			.338	.303	
	Tetraethylene Glycol Dimethyl Ether (Tetra EGDME)			.302	.329	
	Diethylene Glycol Diethyl Ether (DEG DEE)			.495	.370	
R-12				Ideal Solution	.453	
	DEG MEEA			.267	.280	
	Tetra EGDME			.215	.282	
	DEG DEE			.458	.380	
R-113				Ideal Solution	.330	
	DEG MEEA			.330	.248	
	Tetra EGDME			.275	.212	
	DEG DEE			.465	.288	
R-114				Ideal Solution	.390	
	DEG MEEA			.155	.137	
	Tetra EGDME			.120	.135	
	DEG DEE			.300	.222	

* x_p = Vapor Pressure of Refrigerant

i_p = Pressure of Refrigerant Above that of Ideal Solution

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VII. PROGRAM PLAN STATUS AND SCHEDULE

Figure VII-1 shows the progress to date on Tasks I through III.

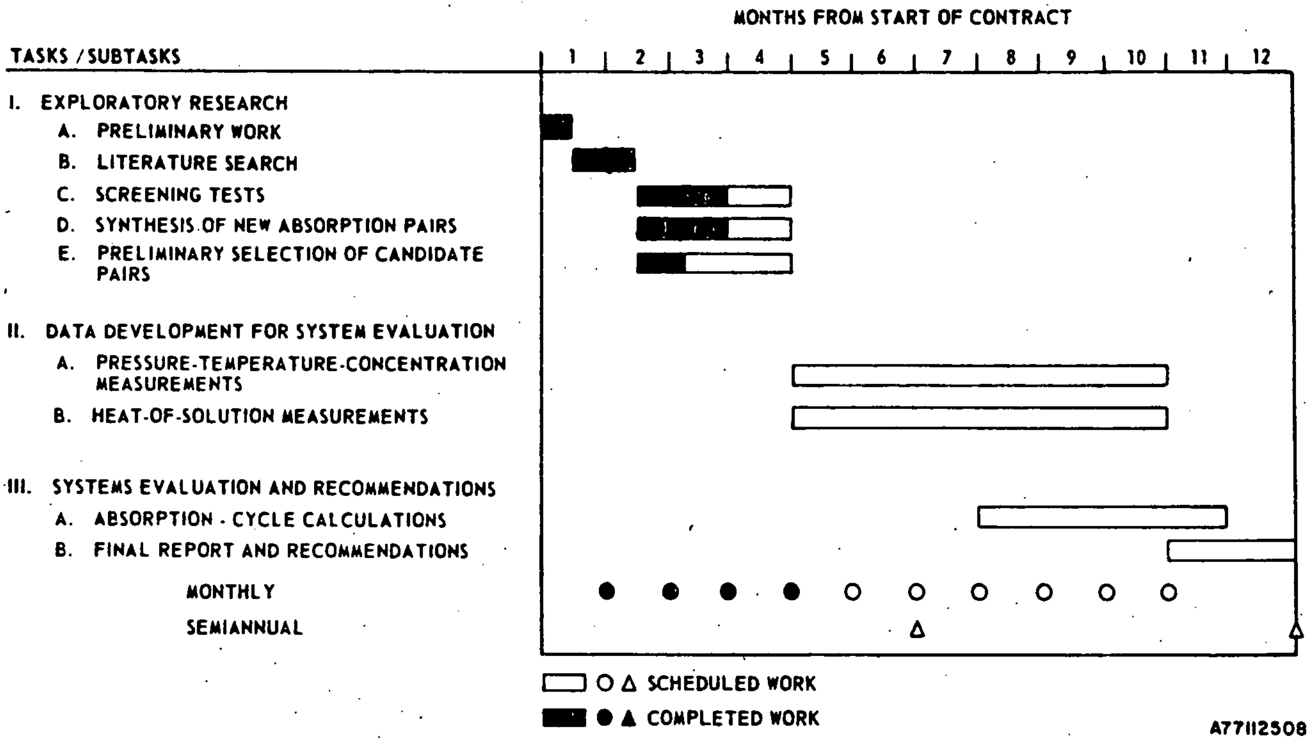

Figure VII-1. PROGRAM PLAN STATUS AND SCHEDULE