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SUMMARY

Amsco 125-82, an odorless mineral spirit resembling kerosene in its physical properties, is recommended as a replacement for the Freon-11 in the HRT secondary refrigeration systems for both the reactor cell and the chemical processing cell. This fluid is a suitable compromise of the stringent requirements for resistance to radiation damage, formation of insoluble residues, compatibility with the materials of the system, low freezing point, suitable pumping and heat transfer characteristics, and being reasonably safe from fire, explosion and toxicity standpoints.

No changes are required in the refrigeration systems in making this substitution, and the change-over can be made at first opportunity after draining the Freon-11, pumping down to a vacuum, and flushing with fresh Amsco, as outlined in this memorandum. The 128°F flashpoint of Amsco necessitates certain fire precautions, such as installation of an exhaust fan, and the stationing of carbon dioxide fire extinguishing equipment. The heating element on the warmed-fluid circulating system should be disconnected. (A new 3-hp canned rotor circulating pump for the chilled refrigerant is on order to replace the present 1.5-hp mechanical seal unit, but this change was not necessitated by the refrigerant substitution).

The chloride content of Amsco 125-82 was measured to be less than 1 ppm and samples of materials from the refrigeration system immersed in Amsco have shown no ill effects. Operational tests should include testing the Amsco for pH, free water, viscosity, and chlorides. Radiation damage studies indicate that there will be some gassing, which can be vented through the presently installed bleed-off points; but that a charge of Amsco probably can be used at least several months without need for replacement insofar as irradiation effects are concerned. Evaporation tests made on Amsco indicate that no

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2

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2 a

insoluble residues will be left in freeze jackets located on process lines heated to about 300°C.

Triethyl phosphate is a second choice for a replacement refrigerant, being equal or superior to Amsco in all respects except for the formation of insoluble residues when heated to about 300°C.

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3

INTRODUCTION

Early in the design of the HRT it was realized that selection of a refrigerant for chilling of the cold traps and freeze jackets would pose a problem because of the susceptibility of many low freezing temperature fluids to radiation and thermal damage. Choice of a secondary type refrigeration system using a circulated chilled liquid rather than a direct-expansion type system was motivated in large measure by the greater freedom of choice of fluids than that allowed by a ~~single~~^{two}-phase system. Freon-11 has been used as an interim secondary refrigerant for the preliminary testing of the reactor system, although there was evidence that F-11 would not be suitable from a radiation-damage standpoint unless it were replaced frequently. (1)(2)(3)(7) The more recent concern for the presence of chloride-bearing fluids inside the reactor cell due to stainless steel stress corrosion problems lent urgency to replacing the F-11 at the earliest opportunity.

This memorandum covers the immediate problem of the selection of a secondary refrigerant for the existing HRT refrigeration system. Liquids, such as pressurized carbon dioxide, would undoubtedly be given serious consideration in a new design. (A generalized treatment of the problem of secondary refrigerants for reactor installations is planned for a subsequent ORNL report).

Physical changes in the HRT refrigeration system have been considered as a means of ameliorating the stringent requirements for a secondary refrigerant. While these changes would be helpful in some instances, they are not solutions to the problem, particularly for the refrigeration system in the chemical processing cell, therefore the major effort has been directed toward finding a fluid with characteristics that could be tolerated in the existing systems.

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4

The major requirements for the fluid to be circulated in the existing HRT secondary refrigeration systems are:

- a. Have a freezing point below about -50°F .
- b. Not be corrosive to the copper, brass, black iron, galvanized steel, stainless steels, and the composition (teflon, etc.) valve discs comprising the secondary refrigerant loop.
- c. Be sufficiently resistant to radiation damage to allow a reasonable frequency of replacement, and to not form products corrosive to the materials of the system.
- d. Must contain less than 1 ppm chlorides or fluorides (although stress corrosion effects of the latter are not well known).
- e. Have low enough viscosity (less than 30 centipoise at -40°F) and density to allow reasonable pumping requirements.
- f. Have a vapor pressure at about 100°F of less than the 100 psig design pressure for the system.
- g. When virgin or irradiated materials are evaporated up to about 600°F products are not formed which are insoluble in the parent liquid.
- h. Acute exposure of personnel to high concentrations of vapor must not cause permanent injury.
- i. The flash point should be in excess of about 120°F , the auto-ignition temperature in excess of about 200°F , and thus be considered reasonably non-explosive to the conditions of a spill in the control room or cell.
- j. Have a specific heat in excess of about 0.2 Btu/lb to allow reasonable circulation rates and line velocities.
- k. Have other physical properties to allow liquid film heat transfer coefficients of better than 20 to 30 Btu/hr-sqft- $^{\circ}\text{F}$ in the cold trap annulus.

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Item (g) of the above requirements regarding the formation of insoluble residues up to 600°F, may need special mention. The highest temperature to which an appreciable fraction of the refrigerant would be exposed is the cell temperature, which is estimated to not exceed 150 to 175°F. Drained freeze jackets wrapped around process lines, however, may retain up to a few hundred milliliters of refrigerant which could be heated to the process line temperature on resumption of reactor operation. The maximum process line temperature is estimated to be in the order of 300°C. Although provisions could be made to purge the freeze jackets of residual refrigerant, the difficulties of providing purge facilities, or of replacement of a freeze jacket, make it highly desirable that the refrigerant not form residues which would plug the refrigerant flow in event that some were formed in the freeze jacket coil.

REJECTED REFRIGERANTS

Most fluids having sufficiently low freezing points (or eutectic point if an aqueous solution) are unsuitable for a variety of factors. At least one reason is noted below for each material:

Ammonia	NH_3	Corrosion and high pressure (600 psig)
Butane	C_4H_{10}	Fire hazard
Calcium chloride	CaCl_2	Contains Cl
Carbon dioxide	CO_2	High pressure (1500 psig)
Cellosolve	$\text{C}_4\text{H}_{10}\text{O}_2$	High viscosity and probable radiation damage. (11)
Ethane	C_2H_6	Fire hazard and high pressure
Ethyl alcohol	$\text{C}_2\text{H}_5\text{OH}$	Fire hazard (8)(9)(10)
Ethyl ether	$\text{C}_4\text{H}_{10}\text{O}$	Fire hazard
Ethylamine	$\text{C}_2\text{H}_5\text{NH}_2$	Fire hazard and corrosion

Ethylene	C_2H_4	Fire hazard
Dichloroethylene	$C_2H_2Cl_2$	Contains Cl
Ethyl chloride	C_2H_5Cl	Contains Cl and fire hazard
Freon (Carrene)		Contains Cl and/or F ⁽¹⁾⁽²⁾⁽³⁾⁽⁷⁾
Glycerol	$C_3H_5(OH)_3$	Excessive viscosity at -50°F
Isobutane	C_4H_{10}	Fire hazard
Methane	CH_4	Fire hazard
Methyl alcohol	CH_3OH	Fire hazard and toxicity ⁽¹⁰⁾
Methyl chloride	CH_3Cl	Contains Cl
Methylene chloride	CH_2Cl_2	Contains Cl
Methylamine	CH_3NH_2	Fire hazard and corrosion
Methyl formate	$C_2H_4O_2$	Fire hazard
Nitrous oxide	N_2O	Toxicity
Potassium carbonate	K_2CO_3	Large change in freezing temperature with small concentration change
Propane	C_3H_8	Fire hazard
Propylene	C_3H_6	Fire hazard
Sulfur dioxide	SO_2	Toxicity ⁽⁴⁾⁽⁵⁾
Tetralin	$C_{10}H_{12}$	Solidifies at -22°F ⁽⁶⁾
Trichloroethylene	C_2HCl_3	Contains Cl

AMSCO ORDORLESS MINERAL SPIRITS

Amsco 125-82, which consists of synthetic branched chain hydrocarbons in the C_8 to C_{12} range and is very similar to kerosene in its physical properties, appears to be the most suitable substitute refrigerant available. It is recommended that the F-11 in the HRT refrigeration system be replaced by Amsco at the earliest opportunity. All physical characteristics of Amsco

are within the tolerable limits, and with the exception of special precautions necessitated by its fairly low flashpoint of 128°F, no changes will be required in the HRT refrigeration system. Its low cost of twenty to twenty-five cents per gallon makes it particularly attractive if frequent replacement is found to be necessary.

Radiation Damage

Amsco has been irradiated at room and at boiling temperatures to a level of 3.7×10^{22} ev/ml by an electron beam from a van de Graaf generator, as reported by Silverman.⁽¹²⁾ This radiation dose is roughly equivalent to that received in the HRT cold traps at 10-mw power level over a two-year period, assuming about 14% residence time in the traps.⁽¹⁾⁽¹⁴⁾⁽¹⁵⁾ The viscosity increased during the irradiation, and there was some gassing, but no residues were formed which were not soluble in the parent fluid.

Evaporation tests were made on Amsco⁽¹³⁾ at temperatures up to 300°C for both virgin samples and samples irradiated at both room and boiling temperatures. The tests showed no appreciable residue for the virgin sample, but the irradiated samples evaporated to a small amount of yellow, viscous liquid which readily dissolves in fresh Amsco. Viscosity tests⁽¹³⁾ made on virgin and irradiated samples are reported in Table I, below:

Table I

Viscosity of Virgin and Irradiated Amsco

<u>Condition</u>	<u>At Room Temp.</u>	<u>At -40°F</u>
Virgin	1.4 centipoises	8.2 centipoises
Irradiated at room temp.	1.5 centipoises	12.5 centipoises
Irradiated at boiling temp.	3.7 centipoises	37.9 centipoises

The viscosity increase under radiation at low temperatures is not considered serious, nor is the high gain in viscosity at the boiling temperature of any great concern because of the few milliliters exposed to high temperatures in comparison to the total volume (100 gal) in the system. In any event, the Amsco may be replaced frequently with relatively little expense. Simple room temperature viscosity tests probably will be sufficient indication when the refrigerant needs replacement during the HRT operation.

Fire Hazard

Possibly the major disadvantage from the use of Amsco is its relatively low flashpoint of 128°F (closed cup). Vapors of a similar material, kerosene, are explosive in concentrations of 1.2 to 6.0% by volume. In general, fluids with flashpoints above 120°F are considered only moderately hazardous, provided simple precautions are taken. The large amount (approx. 100 gallons) stored in the confined control room lower level, however, prompts the following recommendations:

a. Installation of an exhaust fan in the outside emergency stair well to positively remove Amsco vapors (estimated to be four to five times heavier than air) from the lower level and to discharge at ground level. This fan may have a flexible inlet duct, or hose, which may be temporarily placed near a point of spillage. Since the air conditioning for the control room area is a closed system, emergency operation of the exhaust fan with the doors to the stairwell open would cause air to be pulled down the stairwell to ventilate the lower level. Sketches of the discharge duct and fan installation are in preparation and procurement of a fan from plant surplus is being investigated.

b. Installation of a flamability meter, adjusted to annunciate an alarm should the concentration of Amsco vapors reach about 1/5 of the explosive concentration. An indicating type meter is not judged necessary, and the less expensive annunciating type is recommended (16).

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9

c. Continued "No Smoking" rules in the lower control room area and the stationing of CO₂ fire extinguishing equipment both on the lower control room level and the floor above.

d. That the replacement circulating chilled liquid pump be of the canned-rotor type, as covered in a subsequent section of this memorandum.

The vent for relief valves and rupture disc discharges would be through the 55-gal collection tank, float-operated alarm switch, and vent to the ground level, as presently installed.

Corrosion

Amsco 125-82 is believed to be compatible with all the materials in the HRT refrigeration system. Samples of the valve poppet materials (teflon, etc.), brass, copper, carbon and stainless steels immersed in Amsco 125-82 at room and at elevated temperatures have shown no apparent deteriorating effects. Other grades of Amsco, which may contain sulfur, etc., should be avoided.⁽¹⁸⁾ Spectrographic analysis of Amsco 125-82 indicated less than 1 ppm of chlorides which is considered acceptable for preventing stress-corrosion cracking of the stainless steels⁽¹⁹⁾. The free water content should be kept low, as discussed below.

Free Water

Since water is practically insoluble in Amsco it will be necessary to continue use of the silica-gel driers in the circulating systems in order to minimize corrosion effects and the presence of ice crystals in the system which could cause line stoppages.⁽²⁷⁾ Amsco has been demonstrated to be compatible with silica-gel and that this dessicant effectively removes water from solution. The water content of the Amsco should be checked at least monthly during HRT operation. Free water determinations may be made by the Karl Fischer method as discussed in connection with operational tests

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with use of Freon.⁽²⁰⁾ An indicating oil-in-water meter is not considered justified at this time.

Physical Properties

The freezing point of Amsco has been determined to be about -67°F .⁽²⁸⁾ Other physical properties are shown in Table II, together with the properties of Freon-11 and triethyl phosphate. Data for the specific heats and thermal conductivity of Amsco were not obtainable at this writing and were therefore estimated from data on kerosene and decane. As may be noted in the table, the viscosity of Amsco is somewhat higher than that of Freon-11, but the greater specific heat of the former reduces the mass flow rate required for a given quantity of heat absorption, so that the line pressures losses and overall pumping requirements probably are about the same. The estimated heat transfer coefficient of Amsco is also shown in the table to be somewhat lower than that of Freon-11, but is not considered to be of concern.

Physiological Effects

Detailed information on the physiological effects of Amsco are not readily available. Kerosene can cause dermatitis by its de-fatting action on the skin, or it may cause allergic dermatitis. It can cause conjunctivitis and visual hallucinations. It is not volatile enough to be considered as an anesthetic. Personnel showing effects of irritation or dermatitis quickly recover on removal from contact.⁽¹⁷⁾ It is considered an inoffensive solvent in industry and victims of overexposure suffer no lasting ill effects.

Rupture Discs

Difficulty has been experienced with premature failure of rupture discs on the system when using Freon-11. It is believed that this was caused in large part by the vacuum created when the system was cooled from room to operating temperature. Special vacuum-supported rupture discs were

purchased but were not installed awaiting the decision as to the replacement refrigerant to be used; in the meantime the system has been operating during the pre-testing program with rupture disc openings blanked off and with all valves that could cause harmful pressure build-ups in the circulating system tagged "open". Substitution of Amsco for Freon will reduce the range of the pressure changes in the system, but a vacuum could still be formed on initial chilling of the tank. The relatively low vapor pressure of Amsco as compared to Freon would make it possible to operate the system with continuous vent to atmosphere through an elevated expansion tank, but it is recommended that the presently installed system using the vacuum-supported rupture discs and spring-loaded relief valves be retained. An inexpensive vacuum-breaker valve will be installed on the storage tank as an additional precaution in protecting the rupture discs.

Operational Tests Associated with Use of Amsco

The recommended operational tests are for: pH, viscosity, chloride content, and for free water. It is judged that the pH could be measured weekly, and the others on a monthly basis. The Oswald viscosity tests should perhaps be made at more frequent intervals after the reactor has reached full power operation. These tests could be made at room temperature, although determinations at -40 to -50⁰ F, as indicated in Table I and III, magnify the effect of irradiation on the viscosity.

Circulating Pumps

The existing chilled liquid circulating pump in the HRT refrigeration system was sized for normal operation of the cold traps. Subsequent to its installation, the need for refrigerating some freeze jackets with the reactor (and cold traps) in operation became evident, the number and size of lines judged necessary to be frozen increased, and the Type C⁽²⁵⁾ freeze jackets with relatively long supply and return lines were adopted, and as a result the chilled liquid circulating pump requirement was sharply increased.

UNCLASSIFIED

12

It has been recommended that the present 1.5-hp chilled liquid pump, having a rated capacity of 10 gpm at 44-ft head, and equipped with a Crane-type mechanical seal, be replaced with a canned-rotor type pump of 3.0 hp with a capacity of about 35 gpm at 150 ft head. A stainless steel pump of this description (together with a set of replacement bearings) is now on order from Chempump Corporation at a cost of about \$800. (26)

The canned rotor type pump will reject all of the motor input energy to the refrigerating fluid except that actually used for the pumping. Since the overall efficiency of this type of unit is relatively low, in the order of 25%, an estimate has been made of the temperature rise of the Amsco through the new pump, see Appendix II. At 35 gpm, the temperature would increase 2 to 3°F, but at reduced rates of flow the rise could be as high as 5°F.

Defrosting Fluid Circulating System

The 10 gpm (at 44 ft head) warm refrigerant circulating pump, used for defrosting of the cold traps, has had no change in the pumping capacity requirements. The mechanical seal on this unit is not as desirable as a canned rotor type pump, but since the existing unit has operated satisfactorily with little or no leakage, it is recommended that its use be continued until such time as need for a canned rotor type becomes apparent.

Preliminary operation of the defrosting system has disclosed that the fluid is warmed sufficiently in its circulation in the pump loop to make use of the 380-watt electric heating elements in the storage tank unnecessary. With Amsco in the system the possibility of the heating elements reaching the auto-ignition temperature of the liquid leads to the recommendation that the heating elements be disconnected altogether. The elements should be left in place, however.

UNCLASSIFIED

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13

Substitution Procedure

The recommended procedure for replacing the Freon-11 with Amsco is:

- a. Draining of the Freon-11 from both the warm and chilled liquid refrigeration systems as completely as possible. Removal of the silica gel drier cartridges in the circulating system, equipment Item No.'s 106 and 107.
- b. Pumping the system down to a vacuum of at least 20" Hg for several hours.
- c. Filling the systems with Amsco 125-82 (about 100 gal) and operation of both circulating pumps for several hours, during which time all cold traps would be turned on and all freeze jackets would be operated in turn for at least about ten minutes each.
- d. Draining and discarding the Amsco, samples of which should be analyzed for chloride content, and refilling of the system with fresh Amsco. The drier should be re-charged with new silica gel cartridges. After several days operation, samples of the Amsco should be analyzed for chloride content, and if exceeding about 3-5 ppm, this charge should be drained and replaced. After about one to two weeks operation fresh silica gel cartridges should be installed. Cartridges used in the Freon system should be re-used only after thorough rinses in Amsco.

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Table II

Comparison of Properties of F-11, T.E.P., and Amsco

	F-11 (4)	T.E.P. TriEthyl Phosphate	Amsco Solvent
Chemical Formula	C Cl ₃ F	(C ₂ H ₅ O) ₃ PO	C ₈ -C ₁₂ branched chain hydrocarbon 99.4% Sat.
Molecular Weight	137.4	182.2	-
Critical Temperature	388°F	-	-
Critical Pressure	635 psia	-	-
Flash Point	-	242°F	128°F
Apparent Ignition Temp.	-	289°F	-
Vapor Pressure	-25°F 72°F 100°F	1.2 psia 14.0 23.6	0.0001 psia 0.0073 0.0191
			0.0005 psia (n- 0.0180 Decane) 0.0721 "
Boiling Temperature at Atmospheric Pressure	74.7°F	420°F	352°F
Freezing Temperature at Atmospheric Pressure	-168°F	-69°F	-67°F
Viscosity	-20°F 80°F	0.801 centipoise 0.417	4.91 centipoise 1.57
			5.62 centipoise 1.30
Liquid Density	-20°F 68°F	94.5 lb/ft ³ (Est.) 92.85	69.7 lb/ft ³ (Est.) 66.68
			47.20 lb/ft ³ (60°F)
Specific Heats	-20°F 72°F	0.19 Btu/lb°F 0.21	- -
			0.40 Btu/lb°F (Est.) 0.46 (Est.)
Thermal Conductivity	5°F	0.07 $\frac{\text{Btu-ft}}{\text{hr-ft}^2\text{-°F}}$	-
			0.085 $\frac{\text{Btu-ft}}{\text{hr-ft}^2\text{-°F}}$ (Est.)
Water Solubility at 32°F	0.0036 gm/100 gm	Soluble	Insoluble
Odor	Ethereal	Mild	None
Oil Miscibility	Good	Good	Good
Calculated heat transfer Coefficient in Cold Traps (for fission heat, the major load)	38.2 $\frac{\text{Btu}}{\text{hr-ft}^2\text{-°F}}$	-	31.7 $\frac{\text{Btu}}{\text{hr-ft}^2\text{-°F}}$

UNCLASSIFIED

15

Table II (Cont.)

	<u>F-11</u>	<u>T.E.P. TriEthyl Phosphate</u>	<u>Amsco Solvent</u>
Estimated Circulation Rate	8.0 gpm	-	8.3 gpm
Friction Loss due to Flow	0.088 psi/ft	-	0.096 psi/ft
Comparative Cost (In Drums)	5.00 \$/gal	3.66 \$/gal	0.20-0.25 \$/gal ⁽¹⁸⁾

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TRIETHYL PHOSPHATE

Triethyl phosphate (TEP), with the chemical formula $(C_2H_5)_3PO_4$, meets practically all of the requirements and is recommended as a second choice for a substitute refrigerant. Its flash point of $242^{\circ}F^{(21)}$ makes it much safer from the fire hazard standpoint and it is also miscible with water, making the entry of water into the system less of a problem. Its physical properties⁽²¹⁾, as shown in Table II, are in the acceptable range, and its physiological effects are considered benign with only slight degree of hazard from acute vapor exposures.

Triethyl phosphate exhibits acceptable resistance to irradiation⁽¹²⁾, but when either pure or irradiated samples are evaporated at about $300^{\circ}C$, the viscous residue carbonizes to form products insoluble in the parent TEP. This effect would be important only in five or six freeze jackets in the HRT reactor cell, but a substantial majority of the jackets in the chemical processing cell are subjected to elevated temperatures. These jackets would possibly experience plugging of the refrigerant flow from this effect unless rather extensive modifications were made to the system for draining and purging.

The viscosity of TEP is not significantly different from that of Amsco except at $-40^{\circ}F$ (for samples irradiated at room temperature). Samples of CP-grade TEP were irradiated at room temperatures in an electron beam from a van de Graaf generator to a level of 3.7×10^{22} ev/ml, as reported by Silverman⁽¹²⁾, and the viscosities found⁽¹³⁾ to be shown in Table III, below:

Table III

Viscosity of Virgin and Irradiated Triethyl Phosphate

<u>Condition</u>	<u>Room Temperature</u>	<u>$-40^{\circ}F$</u>
Virgin	1.63 centipoises	7.9 centipoises
Irradiation at Room Temp.	3.20 "	28.6 "

UNCLASSIFIED

17

Except for the tendency to form insoluble products when evaporated to dryness at temperatures approaching 300°C, the properties of triethyl phosphate make it a more desirable secondary refrigerant than Amsco. The cost of commercial grade TEP from Tennessee Eastman Corporation is \$3.66 per gallon and it would thus be considerably more expensive to replace than would Amsco at about \$0.20 per gallon. Commercial grade TEP was judged to be sufficiently pure, the chloride content being specified at less than 5 ppm. (21)

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NOMENCLATURE

- A = Cross sectional area, A_i is the inner cross sectional area, A_m is the mean cross sectional area, and A_o is the outer cross sectional area, sq. ft
- c_p = Specific heat, Btu/lb °F
- D = Diameter, D_i is the inside diameter, D_o is the outside diameter, D_e is the equivalent diameter, ft
- E = Line voltage, volts
- f = Fanning friction factor
- G = Mass velocity, lbs/(sq ft)(sec)
- g = Acceleration due to gravity, ft/(sec)²
- h_a = Heat transfer coefficient, Btu/(hr)(sq ft)(°F)
- I = Line current, amperes
- k_a = Thermal conductivity of fluid, Btu/(hr)(sq ft)(°F per ft)
- L = Heat length, ft
- Δp = Pressure drop, psi
- P = Power, Btu/hr
- Δt = Temperature change, °F
- U = Overall heat transfer coefficient, Btu/(hr)(sq ft)(°F)
- u = Fluid velocity, ft/sec
- w = Mass flow rate, lb/hr
- Δx = Wall thickness, ft
- β = Coefficient of volumetric expansion, (°F⁻¹)
- θ = Power factor phase angle
- μ = Viscosity, lb/(hr)(ft)
- ρ = Density, lb/cu ft

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19

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UNCLASSIFIED

20

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APPENDIX I

Circulation Rate, Heat Transfer and Pumping Properties of AmscoA. Circulation Rate

The fission load on the fuel-side cold traps at 10-Mw operation is 0.691 kw or 2360 Btu per hour⁽¹⁵⁾. The sensible heat removed to cool the oxygen is 26 Btu per hour, and the heat removed in condensing the water is 118 Btu per hour. Hence, the total amount of heat that must be removed from the fuel side cold traps is 2504 Btu per hour. If 40% allowance is made for the thermal gains through the refrigerant lines, the total rate of heat removal from the fuel side cold trap system of the HRT is about 3500 Btu per hour.

The specific heat of Amsco is assumed to be about 0.50 Btu/°F lb and the density is 47.2 lbs/cu ft.⁽²²⁾ The required circulation rate for an 8°F temperature rise is:

$$\frac{3500}{60 \times 8 \times 0.40} = 18.2 \text{ lb/min}$$

or,

$$\frac{7.48 \times 18.2}{47.2} = 2.89 \text{ gpm}$$

Similarly, the fission load on the blanket side cold traps at 10 Mw operation is 0.138 kw or 472 Btu per hour⁽¹⁵⁾. The sensible heat removal from the oxygen is 26 Btu per hour, and that removed in condensing the water is 118 Btu per hour. Hence, the total rate of heat removal from the blanket side cold traps is 616 Btu per hour. Again allowing a 40% thermal gain through the refrigeration lines, the total rate of heat removal from the blanket side of HRT cold trap system is about 865 Btu per hour.

Assuming the same physical properties for Amsco as stated above and allowing a 5°F temperature rise, the required circulation rate is

$$\frac{865}{60 \times 8 \times 0.40} = 7.2 \text{ lb/min.}$$

or,

$$\frac{7.48 \times 7.2}{47.2} = 1.28 \text{ gpm}$$

If it is assumed that the use of the freeze jackets will double the thermal load on the HRT refrigeration system, the total required circulation rate of the refrigerant would be:

$$2(2.89) + 2(1.28) = 8.35 \text{ gpm}$$

B. Heat Transfer Characteristics of Amsco in the HRT Cold Traps

McAdams⁽²³⁾ recommends the following relation for calculating laminar heat transfer coefficients in concentric annular spaces.

$$\frac{h_a D_e}{k_b} = \left(\frac{D_2}{D_1} \right)^{0.8} \left(\frac{w c_p}{\mu L} \right)^{0.45} \left(\frac{\Delta t D_e^3 \rho^2 g}{\mu^2} \right)^{0.05}$$

The inner diameter of the annular space of the HRT cold traps is 4.5 inches and the outer diameter is 6.065 inches. A film temperature drop Δt of 5° F is assumed and the other properties of Amsco are either known or estimated from the physical properties of kerosene and decane.⁽²³⁾⁽²⁴⁾ The heat transfer coefficient for the Amsco film in the cold trap is then

$$\begin{aligned} h_a &= \frac{(0.085)}{(1.565/12)} \left(\frac{6.065}{4.500} \right)^{0.8} \left(\frac{18.2 \times 60 \times 0.40}{0.85 \times 5.0} \right)^{0.45} \\ &\quad \left(\frac{5 \times (1.165)^3 \times 0.00055 \times (47.20)^2 \times 4.17 \times 10^8}{(12)^3 \times (8.3 \times 2.42)^2} \right)^{0.05} \\ &= 30.3 \text{ Btu/(hr)(sq ft)(°F)} \end{aligned}$$

The heat transfer coefficient based on the inside area of the cold traps may be based on the following relation:

$$\frac{1}{U} = \frac{\Delta x}{k} + \frac{A_i}{A_m} + \frac{A_i}{h_a A_o}$$

This relation includes the wall heat transfer resistance. For the HRT cold traps, this relation becomes

$$\frac{1}{U} = \frac{(0.237/12)(1.055)}{(9.33)(1.112)} + \frac{1.055}{(30.3)(1.18)} = 0.0315 \text{ (hr)(sq ft)(°F)/Btu}$$

or $U = 31.7 \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F})$

C. Friction Loss Due to Flow of Amsco

It can be assumed that the bulk of the refrigerant in the HRT refrigeration system is pumped through 1/2 inch Type L copper tubing, having an inside diameter of 0.0454 feet and a cross sectional area of 0.001625 square feet. Assuming a circulating rate of 18.2 pounds per minute, the Reynolds number is:

$$Re = \frac{DG}{\mu} = \frac{(0.0454)(18.2)}{(8.3)(0.000672)(60)(0.001625)} = 1515$$

The corresponding friction factor is $0.014^{(13)}$.

The pressure drop through this line may be then found by the Fanning equation:

$$\Delta p = \frac{4fpu^2}{2g D}$$

$$= \frac{(4)(0.014)(47.2)(18.2)^2}{(2)(32.2)(0.0454)(60)^2(47.2)^2(144)} = 0.0984 \text{ psi/ft}$$

Assuming 150 equivalent feet of pipe in the refrigeration system, the pressure drop then becomes:

$$0.0984 \times 150 = 14.8 \text{ psi}$$

APPENDIX II

Heating of Amsco in a Canned Rotor
Refrigerant Circulating Pump

Electrical energy put into the canned rotor type refrigerant circulating pump not actually used for moving the refrigerant is dissipated as heat. This heat contributes to the temperature rise of the refrigerant.

The pump selected for the HRT application is a Series CFH-3 "Chempump." This pump is driven by a 3-phase, 220-volt motor, drawing 13 amperes at full load when delivering 35 gallons per minute of water at 155-foot (of water) head. (26)

Assuming a delta-connected three-phase motor, the power input to the pump is:

$$P = \sqrt{3} E I \cos \theta$$

Assuming unity power factor, power input to the circulating pump is:

$$P = \sqrt{3} \times 220 \times 13 \times 1 \times 3.413 = 16,920 \text{ Btu/hr}$$

The power pumping effort that the pump delivers is:

$$\frac{155 \times 35 \times 62.4 \times 60}{7.48 \times 778} = 3,490 \text{ Btu/hr}$$

Therefore, the rate at which energy is being dissipated to the pumped fluid as heat is:

$$16,920 - 3490 = 13,430 \text{ Btu/hr}$$

The Amsco is assumed to flow at a rate of 35 gallons per minute, or

$$\frac{35 \times .8 \times 62.4 \times 60}{7.48} = 14,000 \text{ lb/hr}$$

Assuming the specific heat of Amsco to be 0.4 Btu per pound per degree Fahrenheit, its temperature rise is:

$$\Delta t = \frac{13430}{0.4 \times 14000} = 2.4^{\circ}\text{F}$$

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25

At lower rates of flow the heat energy to be dissipated would not change appreciably but would be distributed over a lesser amount of fluid, resulting in higher temperature rises.

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0-25