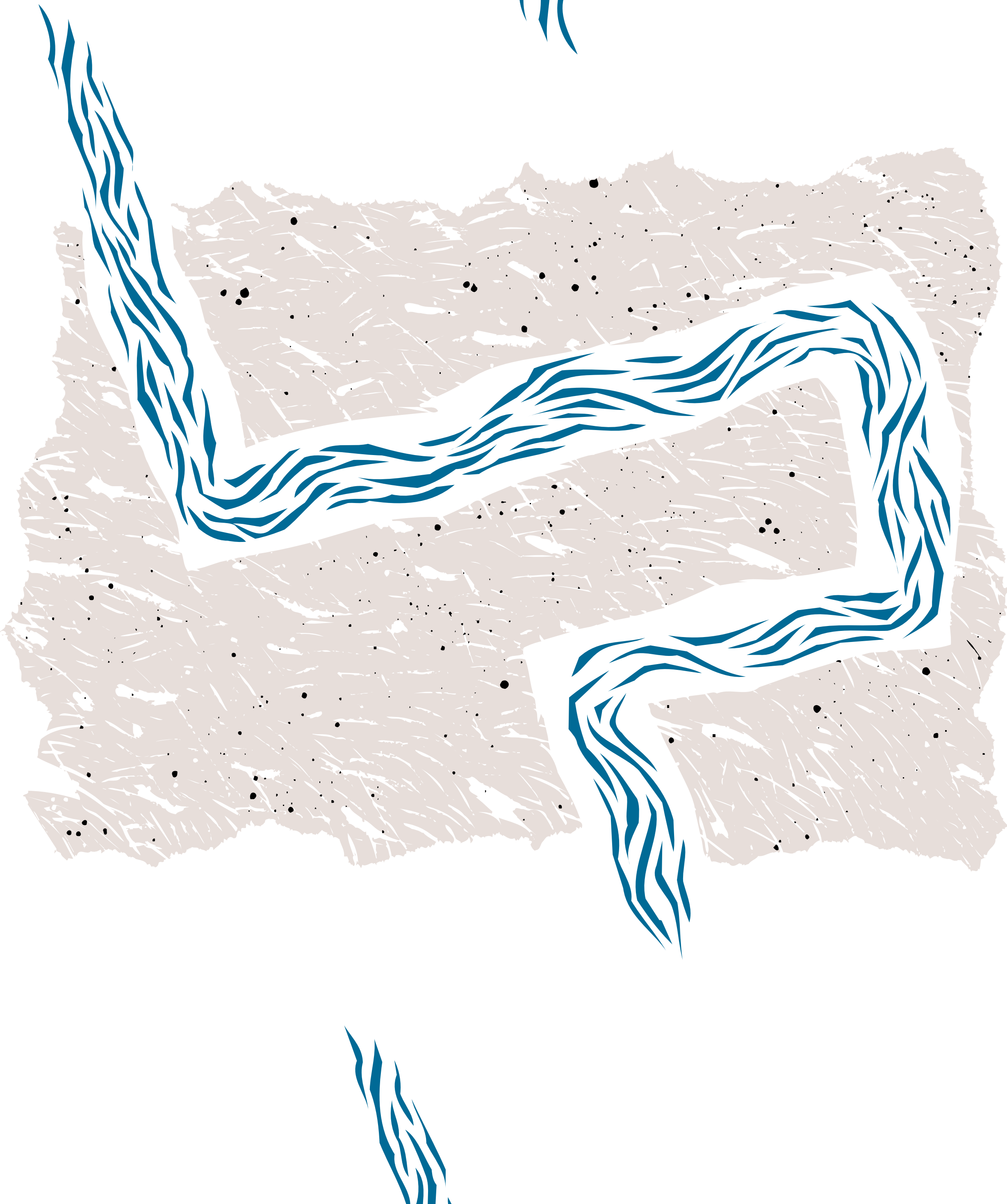
Engineering Guide

for NORKOOL/UCARTHERM
Heat Transfer Fluids



NORKOOL UCARTHERM

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Dow's heat transfer fluids, coolants, corrosion inhibitors and three-part cleaning system set the standard in quality and performance. With more than 60 years of experience in ethylene glycol, Dow has a long history of meeting customer demands through superior technical expertise and service. Dow's products are endorsed by equipment manufacturers because of Dow's continued dedication to solving coolant and cleaning needs in the field.

About this book...

This book is a general guide providing engineering data on Dow's ethylene glycol-based heat transfer fluids. The graphs, equations, tables, and technical data are provided to help your technical representatives choose the correct fluid for your application.

Proper specification of the heat transfer fluid is important. Alternative fluids may be ineffective and also may jeopardize the performance of the heating/cooling system, resulting in major equipment damage. If you need help selecting a fluid or would like more information on Dow's products, call our toll-free customer service center or the sales office nearest you.

End-Use Applications

Dow's heat transfer fluids and coolants find use in a variety of industrial applications, including:

Heating, Ventilating and Air Conditioning (HVAC) and Related Uses

- Heating, ventilating and air conditioning
- Refrigeration
- Thermal storage
- Water chiller systems
- Ice rinks
- Process heating and cooling
- Waste heat recovery
- Solar and radiant heating systems
- Ground loop heating system

Oil and Gas Industries

- Natural gas compressor station coolants
- Natural gas well-head and pipeline heaters
- Liquid-cooled cogeneration and industrial engines
- Drilling equipment
- Heat tracing systems
- Crude oil/battery heaters
- LNG vaporizers

Generators and Engines

- Standby generators and engines
- Marine engines
- High-speed stationary engines
- Air compressor engines

Product Profiles

Ethylene Glycol-Based Fluids

In general, the maximum use temperature for Dow's ethylene glycol-based coolants is 275(F°135°C). Additional products are available for high-temperature uses and applications where there is a potential for food contact.

UCARTHERM™ Heat Transfer Fluids

UCARTHERM heat transfer fluids (HTFs) are biodegradable ethylene glycol (EG)-based fluids that provide outstanding freeze and burst protection. Formulated with an extensive and synergistic inhibitor package, they also provide corrosion protection—meeting or surpassing all ASTM requirements for glycol-based engine coolants. UCARTHERM HTFs are shipped in concentrated form or in water dilutions of 25, 30, 40, 50, 55, and 65 percent ethylene glycol.

NORKOOL™ Coolants

NORKOOL industrial coolants include patented formulas providing excellent protection against ferrous metal corrosion, including cavitation and crevice corrosion. These inhibited ethylene glycol-based fluids have been shown to be effective in mitigating liner cavitation corrosion in both high-speed and low-speed engines.

UCAR™ HTF Inhibitors

Complementing the coolant product line are various inhibitor packages, which serve to reinhibit the fluid/coolant over time as the initial inhibitors deplete.

Proper selection and maintenance of the inhibitors through the sample analysis program are important to maintain corrosion protection and the buffering capacity of the fluid.

UCAR HTF System Cleaner, Degreaser and Surface Modifier

NORKOOL and UCARTHERM industrial cleaners and degreasers can clean rust, scale, and hydrocarbon foulants from dirty cooling system pipes, manifolds and passages. Clean heat transfer surfaces are important in maintaining the integrity of the heating/cooling system.

UCAR 2244 surface modifier HTF passivates the cleaned metal surfaces and helps to prevent flash rusting so the inhibitor package in the new coolant is not depleted.

Additional Products

Dow has additional products available for high-temperature applications and where there is a potential for food contact. For specific engineering data on these products, call Dow's toll-free customer service center (listed on the back cover).

UCAR FOODFREEZE™ Fluid

UCAR FOODFREEZE heat transfer fluid is a Food Chemicals Codex (FCC) grade polypropylene glycol-based fluid for use where there is the potential for food contact. Typical applications include dairies, breweries, immersion freezing and food chilling. This is the only heat transfer fluid recommended for potential food contact.

UCAR PROTHERM™ Heat Transfer Fluid

UCAR PROTHERM heat transfer fluid is a propylene glycol-based fluid specially formulated fluid with a freeze point depression that protects to -60°F(-51°C).

UCARTritherm™ Fluid and UCAR Thermofluid-18

These products are triethylene glycol (TEG) based fluids for high-temperature applications [up to 360°F (182°C)] requiring greater efficiency than traditional non-aqueous high-temperature fluids.

Fluid Selection and Use

Proper specification of the heat transfer fluid is important so that ineffective alternatives are not substituted during any stage of system construction or installation. Such substitutes can jeopardize the performance of the heating/cooling system and result in major equipment damage.

Maximum use temperature for ethylene glycol-based coolants is 275°F (135°C). For higher temperature applications, consider UCARTritherm or UCAR PROTHERM fluid. For food applications, use UCAR FOODFREEZE fluid.

System Preparation

System cleanliness is critical to help prevent corrosion and obtain optimum performance from industrial coolants. When industrial coolant is being added to a system for the first time, the system should be inspected for cleanliness.

Older systems need to be inspected for rust, scale, oil, hydrocarbons and other contaminants. Systems using water-based fluids as the heat transfer medium are prone to the formation of mineral and corrosion scales. These deposits can build up on the walls of the system, acting like an insulator and reducing heat transfer performance and increasing the rate of corrosion. Scale buildup may crack cylinder heads due to lack of cooling capacity: a 1” piece of steel coated with 1/16” of scale has the same heat transfer characteristics as a 4” piece of steel.

A sample of the coolant or water previously used should be sent to our laboratory to help identify the chemical composition of any system scales or contaminants. If the heat transfer fluid has been temporarily stored, it may require filtering before being reinstalled. A clean older system can be flushed with high-quality dilution water.

UCAR HTF system cleaner is effective in cleaning scales and deposits from dirty systems and restoring heat transfer performance. UCAR HTF system degreaser is a water-based liquid containing surfactant that when used properly can effectively remove hydrocarbon-based foulants such as oils, greases, waxes, gums, tars and coke. The combined use of these cleaning products offers the advantage of cleaning and degreasing in a single step.

New systems may contain dirt, debris, metal filings, minor grease, oil and pipe dope. They may also have flash rusting due to atmospheric corrosion. A preliminary chemical cleaning is recommended, using a single application of the cleaner. A water flush may be adequate.

Following cleaning, thoroughly flush using high-quality dilution water (See Recommended Dilution Water Quality, **Table 2**).

Maintaining Maximum Performance

Selecting Coolant Concentration

Coolant concentration is determined by first deciding what freeze and/or burst protection is appropriate for your application, considering your operating temperatures and/or ambient temperatures.

Ethylene glycol HTF can give added protection against system damage from bursting. On freezing, water expands about nine percent. This volume change may rupture piping and cause catastrophic system failure. The addition of ethylene glycol can significantly reduce the expansion the solution undergoes on freezing, reducing the likelihood of system pipes bursting. The higher the ethylene glycol concentration, the less the expansion. Pure ethylene glycol does not expand at all upon freezing.

Table 5 provides guidelines for freeze and burst protection. In systems not operational in winter, it may be sufficient to choose a lower fluid concentration, one that merely protects against bursting, since some crystal formation in the fluid will not be harmful.

It may be necessary to make concentration adjustments when decreasing or increasing the freeze point. **Table 1** will help you to calculate adjustment amounts.

Dilution Water Quality

To ensure corrosion protection, the dilution water must be of high quality (as outlined in **Table 2**). Poor-quality water contains too many ions that make the fluid “hard” and corrosive. Calcium and magnesium hardness ions build up as scale on the walls of the system and reduce heat transfer. These ions may also react with the corrosion inhibitors in the heat transfer fluid, causing them to precipitate out of solution and rendering them ineffective in protecting against corrosion. These effects are magnified at higher temperatures; therefore, higher dilution water quality is required at higher temperatures.

Table 1
Heat Transfer Fluid Concentration Adjustment

	Decrease Freeze Point (Increase HTF Concentrate)	Increase Freeze Point (Add Water)
Remove/Add	$G_C \approx \dfrac{V_S \text{ x } (C_D - C_I)}{100 - C_I}$	$G_W \approx \dfrac{V_S \text{ x } (C_I - C_D)}{C_I}$
Add Only	$G_C \approx \dfrac{V_I \text{ x } (C_D - C_I)}{100 - C_D}$	$G_W \approx \dfrac{V_I \text{ x } (C_I - C_D)}{C_D}$

G_C = Volume of Concentrate (100%)
G_W = Volume of Water
C_I = Initial Concentration (%)
C_D = Desired Concentration (%)
V_S = System Volume
V_I = Initial Volume

Table 2

Recommended Dilution Water Quality

	For Use Below 125°F (†ppm)	For Use Above 125°F (†ppm)
pH at 25°C	5.0 - 8.0	5.0 - 8.0
Total Hardness as $CaCO_3$	<100†	<10†
Calcium	<25†	<1†
Magnesium	<25†	<1†
Iron	<1†	<1†
Copper	<1†	<1†
Silica, SiO_2	<25†	<25†
Chloride	<25†	<25†
Sulfate	<25†	<25†

In addition, high concentrations of corrosive ions, such as chloride and sulfate, will eat through any protective layer that the corrosion inhibitors form on the walls of the system.

Ideally, deionized water should be used for dilution, since deionizing removes both corrosive and hardness ions. Distilled water and zeolite-softened water are also often acceptable. Softened water, although free of hardness ions, may actually have increased concentrations of corrosive ions and, therefore, its quality must be monitored.

For systems where high-quality dilution water is not available, Dow offers prediluted mixtures.

UCARTHERM fluids are available in 25, 30, 40, 50, 55 and 65 volume percent, using only the highest quality water. NORKOOL industrial coolants are offered with water dilutions from Dow or an authorized NORKOOL coolant distributor.

Optimum Corrosion Protection

UCARTHERM and NORKOOL products have been specially formulated with corrosion inhibitors to provide corrosion protection and to buffer the fluid, which helps to prevent glycol degradation and promote long-lasting fluids. In addition, NORKOOL SLH coolants have a unique patented inhibitor package to help prevent liner cavitation corrosion for stationary engines. Typical corrosion rates are shown in **Table 3**.

Materials Compatibility

When installing heat transfer fluids, it is important to check the system to ensure that all components are compatible. DOW industrial coolants are compatible with many plastics, rubbers, elastomers, and other non-metallic materials used in engines and other heat transfer equipment, including polyethylene, polypropylene, polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), and many types of fiberglass-reinforced plastic. However, as with any material, it is important to adhere to the manufacturer's guidelines for maximum and minimum recommended use temperatures. The coolants are also compatible with most metals but not with galvanized steel.

In general, our industrial coolants are compatible with most elastomers and seals used for water service as demonstrated in **Table 4**.

Nevertheless, although both water and glycol may be compatible with a seal material, switching a system from water service to glycol service sometimes requires replacement of the seals. During service the elastomer will swell a characteristic amount, depending on the fluid in the system; if the fluid is replaced with another, the elastomer may fail. Therefore, to prevent failure, it is recommended that if the fluid is changed, a seal change also take place.

Table 3

Typical Heat Transfer Fluid Corrosion Rates

	Corrosion Rate, mils per year (mpy)			
Material of Construction	UCARTHERM Heat Transfer Fluid	NORKOOL SLH Coolant	Uninhibited Ethylene Glycol	ASTM Maximum
Copper	0.14	0.12	0.2	0.45
Brass	0.097	0.19	0.3	0.47
Solder	0.16	0.01	6	1.17
Steel	0.02	0.02	15	0.51
Cast Iron	0.02	0.00	7	0.56
Aluminum	2.2	1.3	4.2	4.4

Table 4

Compatibility of Various Materials with UCARTHERM and NORKOOL Heat Transfer Fluids

	Temperature		
	20°F (-7°C)	77°F (25°C)	176°F (80°C)
Adriprene L-100[1]	Good	Good	Poor
Black Rubber 3773	Good	Good	Poor
Buna N	Good	Good	Good
Buna S	Good	Good	Fair
Butyl Rubber	Good	Good	Good
EPDM	Good	Good	Good
EPR Rubber	Good	Good	Good
Hycar D-24[2]	Good	Good	Fair
Hypalon[3]	Good	Good	Poor
Kalrez[4]	Good	Good	Good
Natural Rubber Gum	Good	Good	Poor
Neoprene 7797	Good	Good	Fair
Red Rubber #107	Good	Good	Poor
Saraloy 300[5]	Good	Good	Poor
Silicone No. 65	Good	Good	Good
Viton A[6]	Good	Good	Good

✔ *Good* *Good resistance of the material to UCARTHERM HTF.*

✔ *Fair* *Some limited service may be achieved with the material. However, the elastomer may undergo moderate softening and swelling, or, conversely, some moderate hardening and shrinkage.*

✔ *Poor* *The material is not suitable because of severe softening and swelling or deterioration and brittleness.*

Note: *The use temperature is very significant in determining the suitability of the material.*

Optimal System Maintenance

Monitoring the condition of your coolant is critical. Dow has developed an analytical service program to provide systematic technical service contact with users of NORKOOL and UCARTHERM products.

Providing both analysis and interpretation of the chemistry of coolants and inhibitors in use, the laboratory relies on over 25 analyses on each sample measured using advanced analytical equipment. It integrates these into a customer database containing analytical data from previous samples and other information about the mechanical system. The resulting recommendations are designed to help maximize the useful life of both the equipment and the heat transfer fluid, and to maintain optimum heat transfer efficiency.

A pre-fill analysis includes an analysis of the system's previous fill and the dilution water. Inspection of the system interior is also recommended to check for scale buildup and the need for cleaning. Therefore an annual analysis is encouraged.

Typical Properties of UCARTHERM and NORKOOL Heat Transfer Fluids

The typical specifications for UCARTHERM fluids and NORKOOL coolants are shown below. Automotive antifreeze, uninhibited glycol and field-inhibited glycol do not meet these specifications. NOTE: The values shown are representative only for a typical fluid. Each product has its own set of specifications that must be consulted before selecting a heat tranfer fluid.

Base Fluid - The industrial grade ethylene glycol fluid base contains less than 0.5 % by weight of diethylene glycol or other glycols.

Biodegradable - UCARTHERM and NORKOOL HTFs are biodegradable in tests simulating river conditions. And in waste-water treatment plants, where concentrations of microorganisms are far higher, biodegradation can take place in a matter of hours.

Corrosion Inhibitors - Glycol-compatible corrosion inhibitors protect ferrous and copper-based metals and work synergistically to prevent corrosion of metal surfaces.

Buffers - Buffers can extend the life of the ethylene glycol component by resisting fluid oxidation. The buffering capacity, as measured by the reserve alkalinity, has a minimum value of 22 for the concentrated HTF. The reserve alkalinity of prediluted blends of the fluid concentrate is 22 times the HTF concentration (for example, for a 40% solution, the reserve alkalinity is 22 times 0.4, or 8.8).

pH - The pH of the industrial heat transfer fluid concentrate is 8.5 to 9.2 and 8.0 to 9.2 for prediluted blends.

Antifoams - Antifoaming agents minimize foaming and air entrainment in the system.

Dyes - Dyes are incorporated to distinguish the heat transfer fluid from other fluids, and a fluorescing agent is added to facilitate leak detection.

Corrosion Rates - Corrosion rates are less than 0.02 mils per year for steel and iron, and less than 0.2 mils per year for copper and brass, as measured by ASTM D1384.

Specific Gravity - The specific gravity of the concentrate at 68/68°F (20/20°C) is 1.133.

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[1] Adriprene is a registered trademark of __________.

[2] Hycar is a registered trademark of B.F. Goodrich.

[3] Hypalon is a registered trademark of DuPont Dow Elastomers.

[4] Kalrez is a registered trademark of DuPont Dow Elastomers.

[5] Saraloy is a registered trademark of __________.

[6] Viton is a registered trademark of DuPont Dow Elastomers.

Flash Point - There is no flash point when diluted for use.

Impurities - Fluids contain no silicates, nitrates or molybdates.

Chloride Content - The industrial heat transfer fluid concentrate and its factory-supplied dilutions have a chloride content of less than 5 ppm.

Coolant Analysis Program - UCARTHERM heat transfer fluids and NORKOOL coolants are able to be analyzed through samples submitted by customers. This analysis is able to monitor the following fluid properties and chemistries:

- Glycol content/freezing point: makes a calculation of concentration range. Calculations for glycol concentration adjustments are available in **Table 1**.
- pH/reserve alkalinity: analyzes the buffering capacity of fluid
- Inhibitor levels: indicates whether levels are high enough to optimize corrosion protection
- Solids: analyzes the presence of corrosion products or contaminants that could cause sandblasting-like erosion
- Corrosion products: indicates past or ongoing
- Contaminants: identifies certain substances that can shorten the life of the fluid and may undermine the benefits of the inhibitors

Heat Transfer Properties

Fluid Concentration	Specific Heat at 50°F, BTU/lb°F	Thermal Conductivity at 50°F, BTU/hr ft°F
50-volume %	0.800	0.221
25-volume %	0.914	0.272

Table 5
Freeze and Burst Protection

Fluid	Freeze Protection	Burst Protection
Concentrate	-12°F (-24.5°C)	—
50-volume % solution	-36°F (-37.8°C)	-100°F (-75°C)
25-volume % solution	10°F (-12.2°C)	-5°F (-20°C)

Storage and Handling

Because Dow ethylene glycol-based coolants have a comprehensive corrosion inhibitor package, they can be stored in carbon steel, epoxy/phenolic-lined, and polyethylene or polypropylene storage tanks. For drum storage, the drums should be well-sealed to prevent fluid contamination. Under ambient storage conditions above the fluid's freezing point, the fluid is designed not to separate, precipitate or undergo any non-reversible change in properties. If appropriately handled, these ethylene glycol-based coolants are expected to be able to be stored for two years. Unused fluid more than two years old should be tested before use for compliance with specifications.

The fluids have a low viscosity and are able to be pumped at low temperatures. A centrifugal pump is generally suitable for pumping the fluids.

Product Safety

When considering the use of any Dow products in a particular application, you should review Dow's latest Material Safety Data Sheets and ensure that the use you intend can be accomplished safely. For Material Safety Data Sheets and other product safety information, contact the Dow sales office nearest you. Before handling any other products mentioned in the text, you should obtain available product safety information and take necessary steps to ensure safety of use.

No chemical should be used as or in a food, drug, medical device, or cosmetic, or in a product or process in which it may contact a food, drug, medical device, or cosmetic until the user has determined the suitability and legality of the use. Since government regulations and use conditions are subject to change, it is the user's responsibility to determine that this information is appropriate and suitable under current, applicable laws and regulations.

Dow requests that the customer read, understand, and comply with the information contained in this publication and the current Material Safety Data Sheet(s). The customer should furnish the information in this publication to its employees, contractors, and customers, or any other users of the product(s), and request that they do the same.

Emergency Service

Dow maintains 24-hour emergency service for its products. The American Chemical Council (CHEMTREC), Transport Canada (CANUTEC), and the National Chemical Emergency Center maintain 24-hour emergency service:

Location	Dow Products	All Chemical Products (in case of emergency)
United States and Puerto Rico	800-DOW CHEM	Phone CHEMTREC: 800-424-9300
Canada	519-339-3711 (collect)	Phone CANUTEC: 613-996-6666 (collect)
Europe Middle East North and Central Africa	49 41 469 12333	
Latin America, Asia/Pacific, South Africa, and any other location worldwide	Phone United States: 989-636-4400 (collect)	

At sea, radio U.S. Coast Guard, who can directly contact:
Dow…800-DOW CHEM or **CHEMTREC…800-424-9300.**

DO NOT WAIT. Phone if in doubt. You will be referred to a specialist for advice.

Typical Physical Properties Data

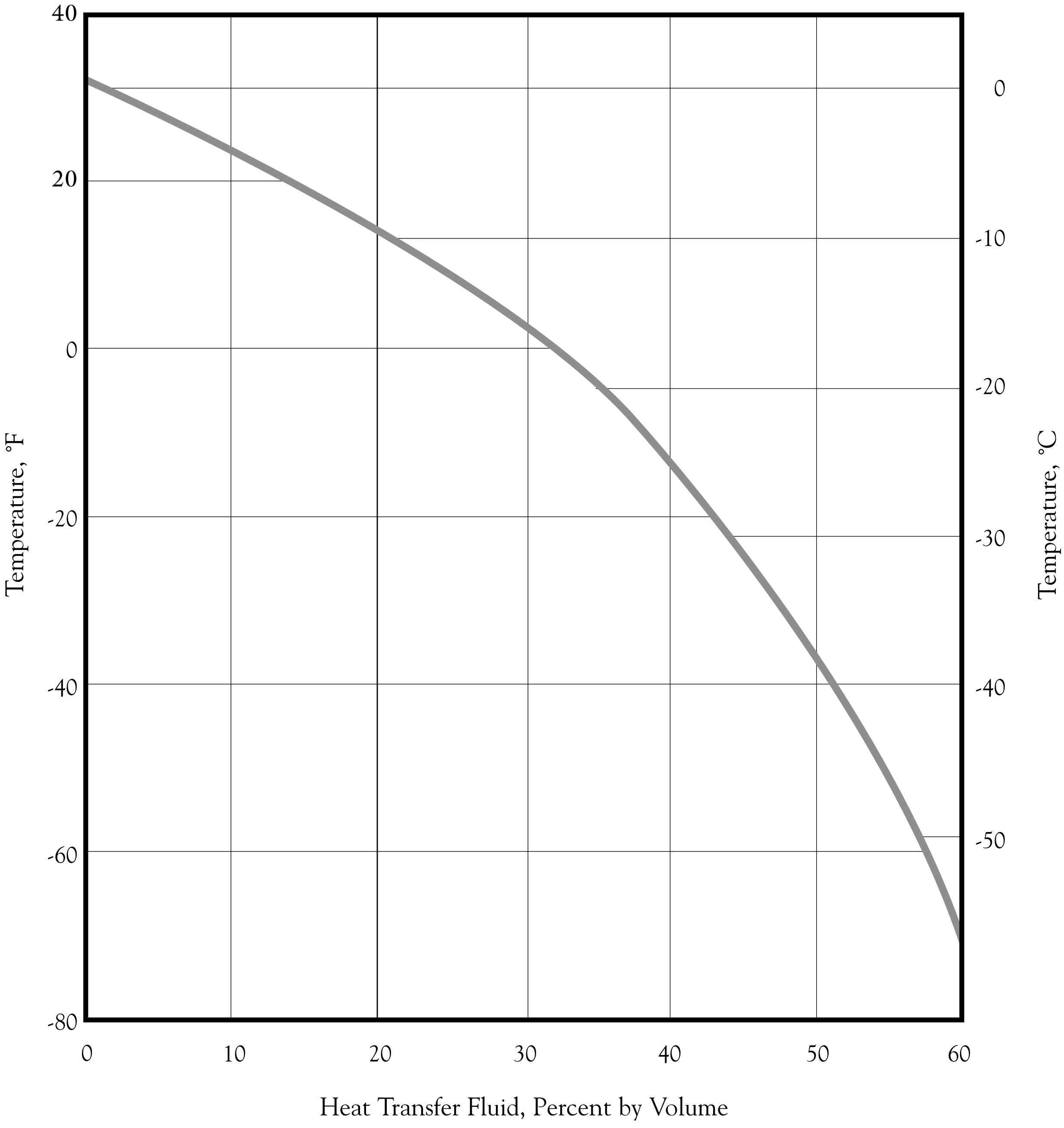
The following section provides information on a number of important physical properties of heat transfer fluids. The values were determined using typical commercial material and are not intended to be used for specification purposes. For information on the specifications of individual products, contact a Dow sales office listed on the back cover.

Table 6 • Typical Physical Properties of Heat Transfer Fluids

Volume %	Weight %	Freezing Point		Burst Protection		Boiling Point		Refractive Index
		°F	°C	°F	°C	°F	°C	
0	0	32	0	32	0	212.0	100.0	1.3322
10	11.1	24.2	-4.3	20	-5.0	212.6	100.2	1.3433
20	22.0	14.9	-9.5	5	-15.0	215.1	101.7	1.3542
25	27.3	9.3	-12.6	-5	-20.0	216.7	102.5	1.3595
26	28.4	8.1	-13.3	-10	-20.0	217.0	102.7	1.3605
27	29.5	6.9	-13.9	-10	-20.0	217.3	102.9	1.3616
28	30.5	5.7	-14.6	-10	-25.0	217.6	103.1	1.3626
29	31.6	4.4	-15.4	-15	-25.0	217.9	103.2	1.3637
30	32.6	3.0	-16.1	-15	-25.0	218.2	103.4	1.3647
31	33.7	1.6	-16.9	-20	-25.0	218.5	103.6	1.3657
32	34.7	0.2	-17.7	-20	-25.0	218.9	103.8	1.3668
33	35.8	-1.2	-18.5	-20	-30.0	219.2	103.9	1.3678
34	36.8	-2.8	-19.3	-25	-30.0	219.5	104.1	1.3688
35	37.8	-4.3	-20.2	-30	-30.0	219.8	104.3	1.3699
36	38.9	-6.0	-21.1	-35	-35.0	220.1	104.5	1.3709
37	39.9	-7.6	-22.0	-40	-40.0	220.4	104.6	1.3719
38	40.9	-9.4	-23.0	-45	-40.0	220.8	104.8	1.3729
39	42.0	-11.2	-24.0	-55	-45.0	221.1	105.0	1.3739
40	43.0	-13.1	-25.0	-65	-55.0	221.4	105.2	1.3749
41	44.0	-15.0	-26.1	-75	-60.0	221.7	105.4	1.3760
42	45.0	-17.0	-27.2	-90	-65.0	222.1	105.5	1.3770
43	46.1	-19.1	-28.4	-100	-75.0	222.4	105.7	1.3780
44	47.1	-21.3	-29.6	<-100	<-75	222.8	105.9	1.3790
45	48.1	-23.5	-30.9	<-100	<-75	223.1	106.1	1.3800
46	49.1	-25.9	-32.2	<-100	<-75	223.5	106.3	1.3810
47	50.1	-28.3	-33.5	<-100	<-75	223.9	106.5	1.3819
48	51.1	-30.8	-34.9	<-100	<-75	224.2	106.7	1.3829
49	52.1	-33.5	-36.4	<-100	<-75	224.6	106.9	1.3839
50	53.1	-36.2	-37.9	<-100	<-75	225.1	107.2	1.3849
51	54.1	-39.1	-39.5	<-100	<-75	225.5	107.4	1.3859
52	55.1	-42.0	-41.1	<-100	<-75	226.0	107.6	1.3869
53	56.1	-45.1	-42.8	<-100	<-75	226.4	107.9	1.3878
54	57.1	-48.3	-44.6	<-100	<-75	226.9	108.1	1.3888
55	58.1	-51.6	-46.5	<-100	<-75	227.4	108.4	1.3898
56	59.1	-55.1	-48.4	<-100	<-75	228.0	108.7	1.3907
57	60.1	-58.7	-50.4	<-100	<-75	228.6	109.0	1.3917
58	61.0	-62.4	-52.4	<-100	<-75	229.2	109.4	1.3927
59	62.0	-66.3	-54.6	<-100	<-75	229.8	109.7	1.3936
60	63.0	-70.3	-56.8	<-100	<-75	230.5	110.1	1.3946
61	64.0	<-70	<-60	<-100	<-75	231.2	110.4	1.3955
62	64.9	<-70	<-60	<-100	<-75	232.0	110.9	1.3965
63	65.9	<-70	<-60	<-100	<-75	232.8	111.3	1.3974
64	66.9	<-70	<-60	<-100	<-75	233.6	111.8	1.3983
65	67.8	<-70	<-60	<-100	<-75	234.5	112.2	1.3993
70	72.6	NA	NA	NA	NA	239.9	115.2	1.4039
80	82.0	NA	NA	NA	NA	256.4	124.2	1.4130
90	91.1	NA	NA	NA	NA	284.0	139.6	1.4218
100	100.0	-12.3	-24.6	NA	NA	327.7	164.0	1.4303

Weight % = 0.010258 + 1.12476 x (volume %) - 0.00125 x (volume %)^2
Volume % = 0.041050 + 0.87482 x (weight %) + 0.001244 x (weight %)^2

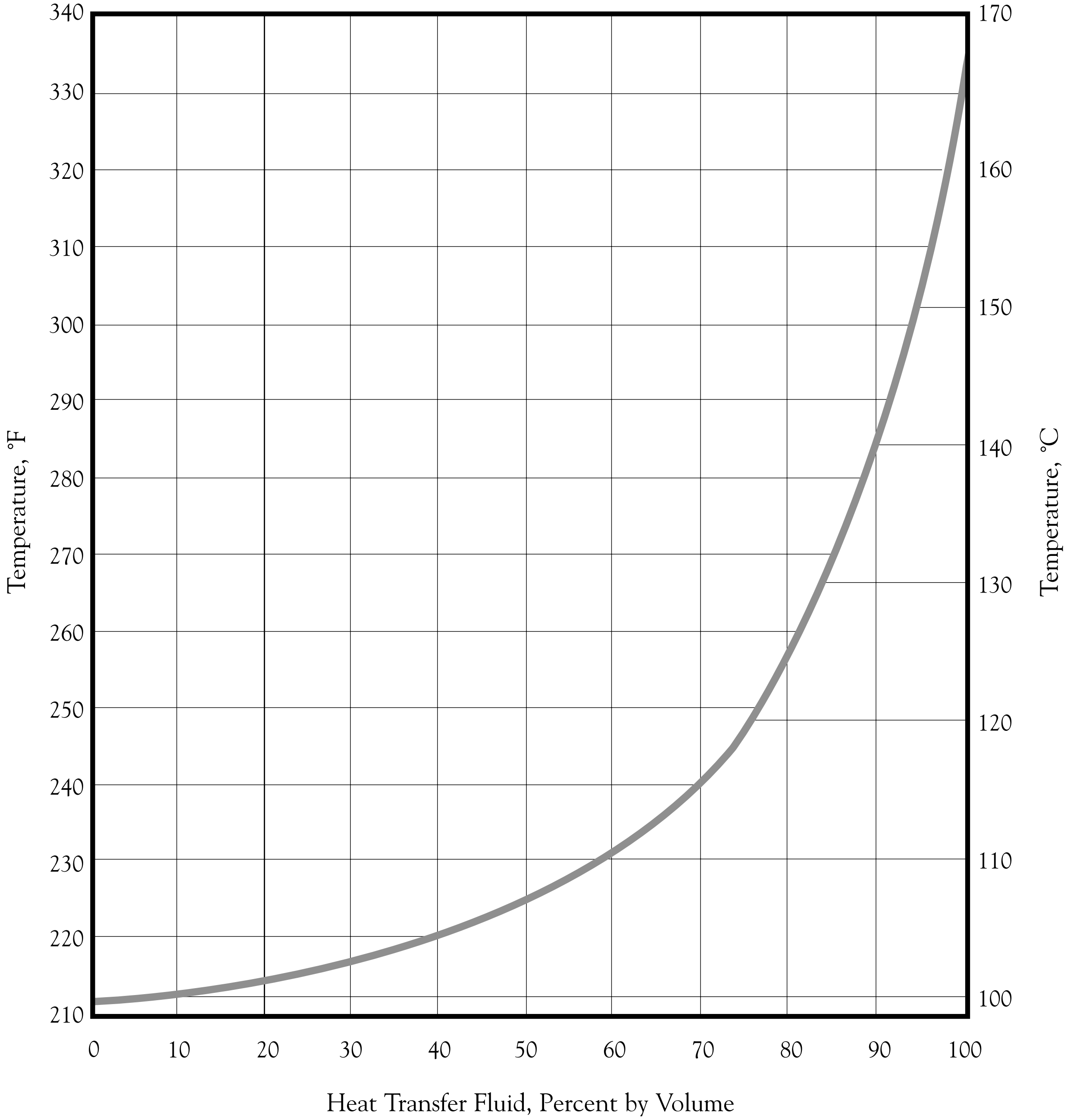
Figure 1 • Freezing Points of Heat Transfer Fluids



Freezing Point = $A + Bx + Cx^2 + Dx^3 + Ex^4$, where x = vol% HTF

	A	B	C	D	E
°F	31.97	-0.693	-0.00884	0.000119	-4.21E-6
°C	0.00	-0.387	-0.00484	0.000065	-2.33E-6

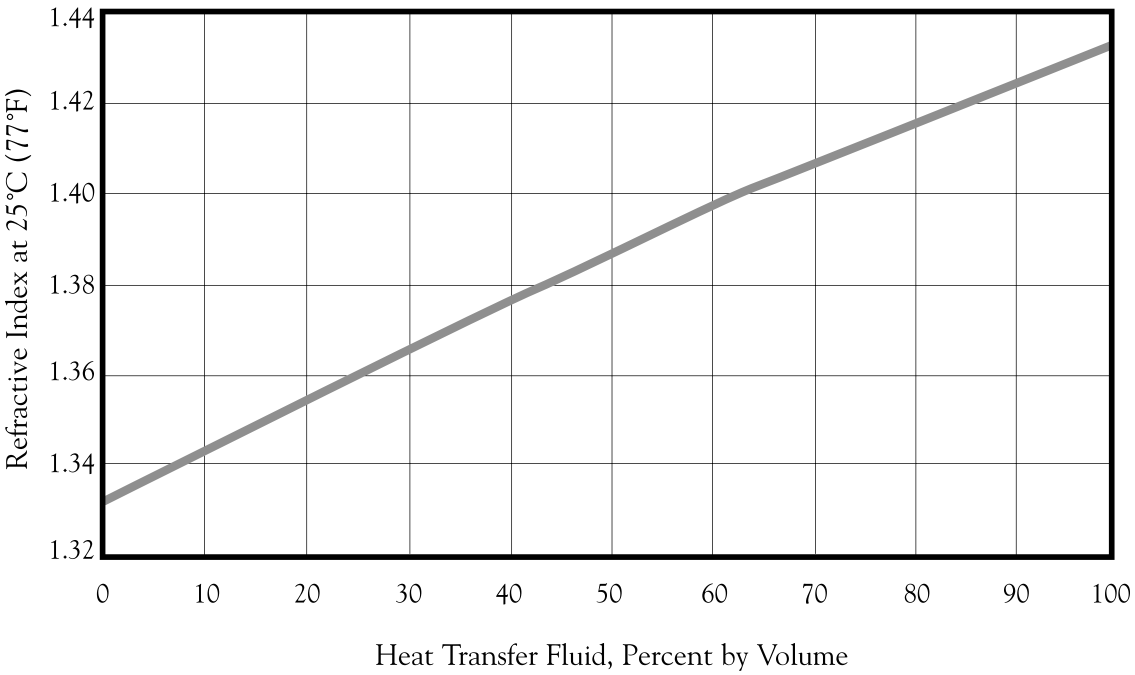
Figure 2 • Boiling Points of Heat Transfer Fluids



Boiling Point = $A + Bx + Cx^2 + Dx^3 + Ex^4$, where x = vol% HTF

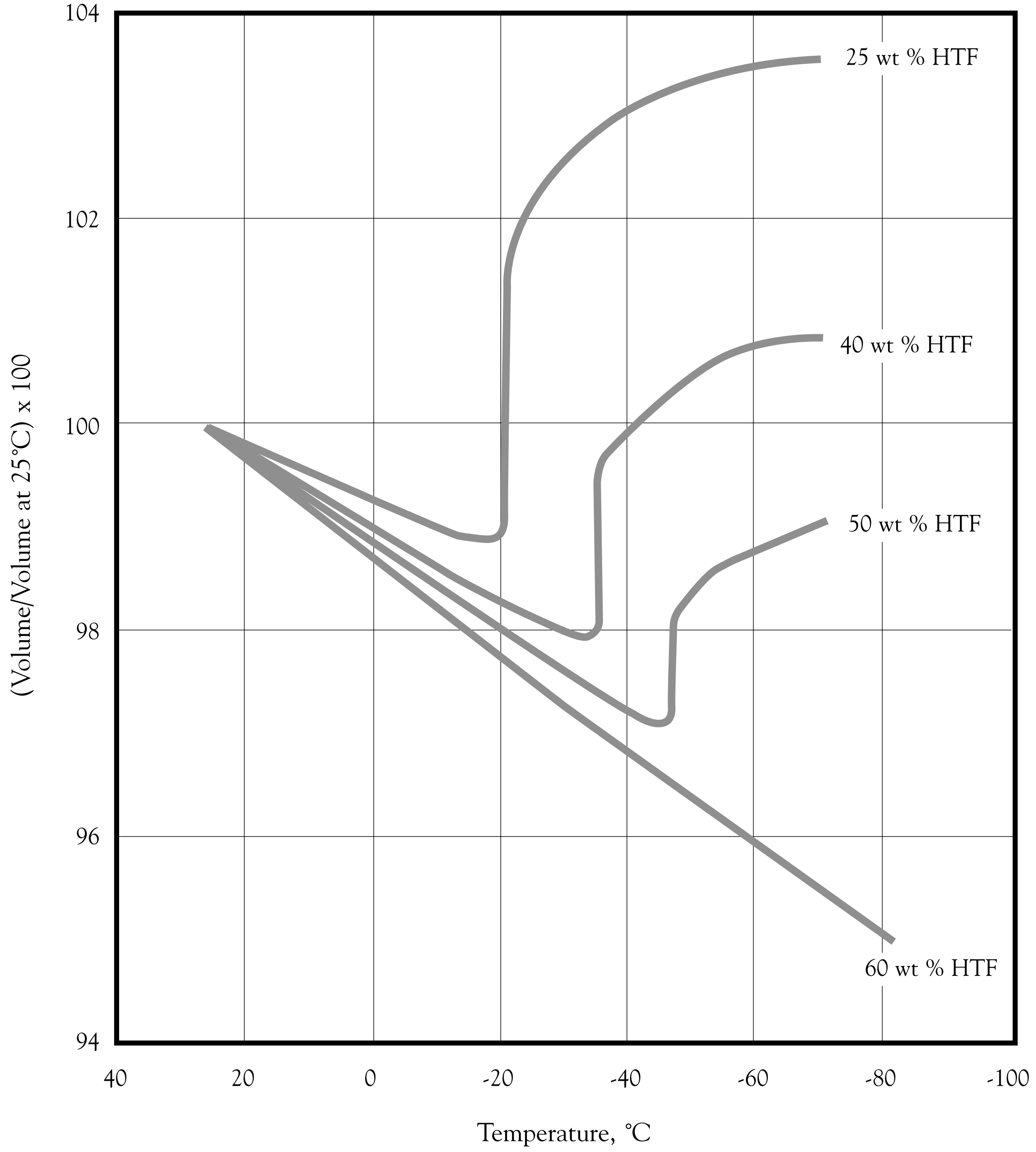
	A	B	C	D	E
°F	212.00	-0.111950	0.021090	-0.000461	3.77E-6
°C	100.00	-0.000664	-0.011717	-0.000256	-2.09E-6

Figure 3 • Refractive Indices of Heat Transfer Fluids



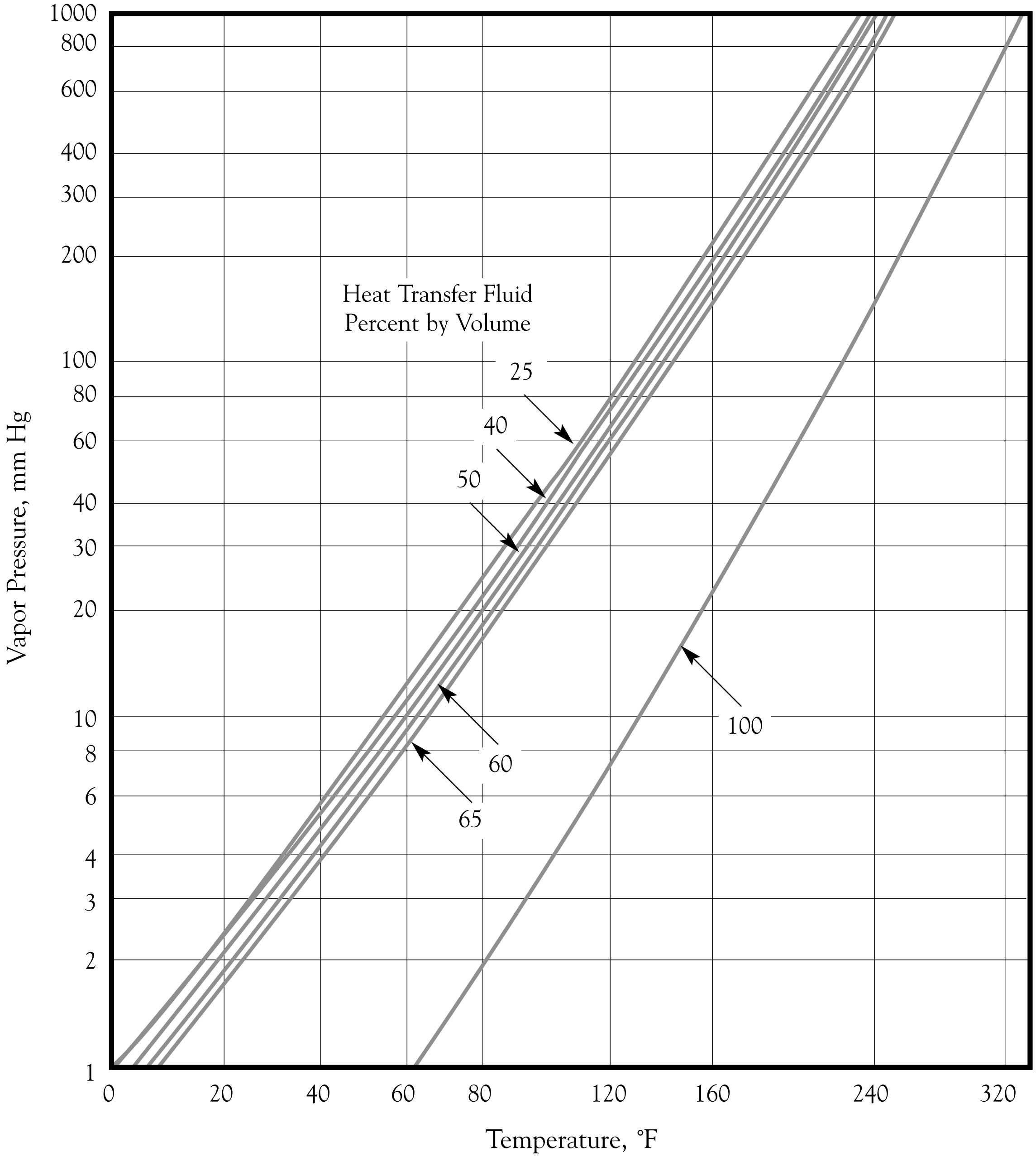
Refractive Index at 25°C (77°F) = 1.3322 + 0.001127x - 1.46E-6x^2, where x = vol% HTF
Volume % HTF = 1582-3239 (Refractive Index) + 1540 (Refractive Index)^2

Figure 4 • Expansion of Aqueous Heat Transfer Fluids on Freezing



Note : For pure water, $\frac{\text{Volume at 0°C}}{\text{Volume at 25°C}}$ x 100 = 108.76

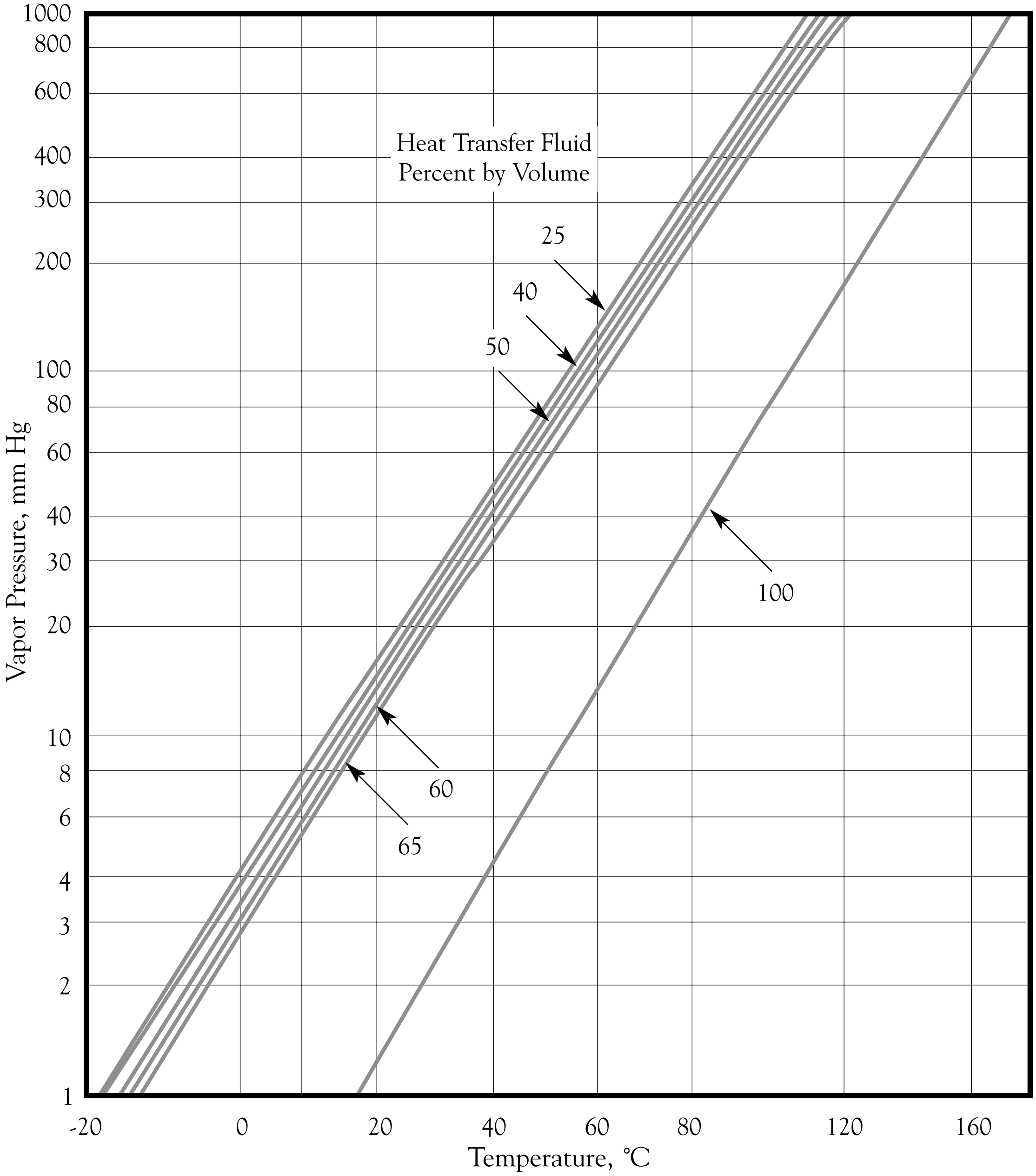
Figure 5 • Vapor Pressures of Heat Transfer Fluids



$$\text{Log (Pressure, mm Hg)} = A - \frac{B}{(x+C)}$$ where x = temperature °F, Log = base 10

Volume % HTF	A	B	C
25	8.005342	3085.918	385.325
30	8.008000	3098.284	386.166
40	8.181273	3326.055	406.319
50	7.980060	3127.310	388.149
60	8.045083	3244.381	397.875
65	7.903458	3113.846	386.003
100	8.198480	4014.108	426.763

Figure 6 • Vapor Pressures of Heat Transfer Fluids



$$\text{Log (Pressure, mm Hg)} = A - \frac{B}{(x+C)} \quad \text{where } x = \text{temperature °C, Log = base 10}$$

Volume % HTF	A	B	C
25	7.999925	1711.051	231.547
30	8.013316	1724.640	232.623
40	8.178430	1845.962	243.349
50	7.981278	1738.250	233.502
60	8.041001	1799.845	238.594
65	7.901482	1728.723	232.122
100	8.180710	2218.342	254.015

Table 7 • Vapor Pressures of Heat Transfer Fluids

Temperature	Volume % Heat Transfer Fluid							Temperature
°F	25	30	40	50	60	65	100	°C
0	NA	NA	0.990	0.838	0.778	0.686	0.062	-18
10	NA	1.539	1.556	1.335	1.232	1.097	0.102	-12
14	1.895	1.843	1.854	1.598	1.472	1.315	0.123	-10
20	2.465	2.398	2.396	2.079	1.910	1.714	0.164	-7
30	3.760	3.657	3.616	3.170	2.901	2.620	0.257	-1
32	4.082	3.970	3.918	3.441	3.146	2.845	0.281	0
40	5.622	5.468	5.359	4.740	4.322	3.927	0.397	4
50	8.252	8.027	7.805	6.958	6.326	5.776	0.601	10
60	11.906	11.581	11.187	10.041	9.106	8.352	0.895	16
68	15.778	15.349	14.757	13.310	12.051	11.087	1.217	20
70	16.902	16.443	15.792	14.259	12.906	11.882	1.312	21
80	23.637	22.998	21.980	19.948	18.026	16.651	1.894	27
86	28.709	27.935	26.630	24.234	21.882	20.247	2.345	30
90	32.592	31.715	30.187	27.518	24.835	23.004	2.696	32
100	44.349	43.163	40.943	37.462	33.777	31.362	3.786	38
104	49.988	48.653	46.097	42.234	38.068	35.376	4.321	40
110	59.601	58.016	54.880	50.373	45.387	42.226	5.250	43
120	79.167	77.076	72.746	66.949	60.296	56.189	7.193	49
122	83.679	81.472	76.865	70.773	63.737	59.412	7.650	50
130	104.003	101.276	95.420	88.007	79.244	73.945	9.744	54
140	135.220	131.700	123.924	114.497	103.094	96.301	13.061	60
150	174.090	169.593	159.437	147.511	132.840	124.187	17.329	66
158	211.666	206.235	193.797	179.452	161.642	151.185	21.576	70
160	222.066	216.377	203.311	188.296	169.620	158.633	22.771	71
170	280.791	273.659	257.080	238.264	214.727	200.930	29.649	77
176	321.945	313.810	294.803	273.306	246.388	230.588	34.591	80
180	352.111	343.246	322.474	299.004	269.621	252.344	38.271	82
190	438.086	427.154	401.448	372.292	335.935	314.415	48.993	88
194	477.084	465.221	437.314	405.556	366.060	342.599	53.960	90
200	541.000	527.622	496.159	460.101	415.492	388.826	62.226	93
210	663.371	647.119	609.015	564.608	510.308	477.431	78.443	99
212	690.419	673.536	633.992	587.720	531.295	497.031	82.090	100
220	807.960	788.352	742.664	688.206	622.606	582.269	98.180	104
230	977.776	954.274	900.012	833.504	754.819	705.566	122.046	110
240	1176.087	1148.092	1084.232	1003.340	909.599	849.742	150.726	116
248	1357.612	1325.549	1253.261	1158.931	1051.597	981.866	177.650	120
250	1406.419	1373.268	1298.768	1200.783	1089.824	1017.412	184.989	121
260	1672.563	1633.529	1547.346	1429.137	1298.602	1211.394	225.690	127
266	1851.117	1808.174	1714.489	1582.449	1438.954	1341.660	253.592	130
270	1978.579	1932.862	1833.978	1691.941	1539.275	1434.707	273.778	132
275	2147.880	2098.500	1992.897	1837.434	1672.682	1558.362	300.917	135

Vapor Pressures are reported in millimeters of mercury (mm Hg)
Conversions: atmosphere (atm) = mm Hg / 760
lb/in^2 (psi) = (mm Hg / 760) x 14.7

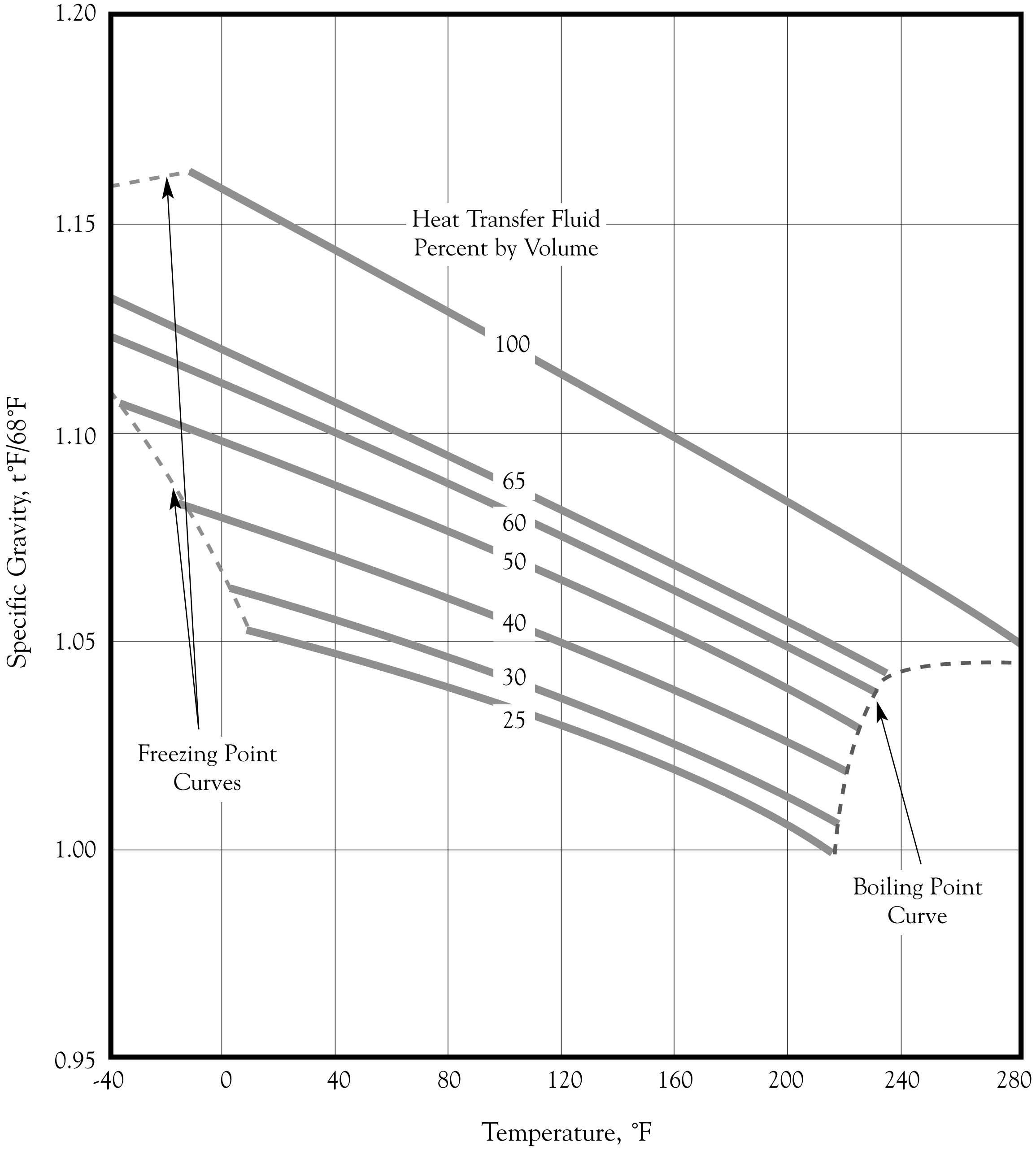
Table 8 • Specific Gravities of Heat Transfer Fluids

Temperature	Volume % Heat Transfer Fluid							Temperature
°F	25	30	40	50	60	65	100	°C
0	NA	NA	1.080	1.098	1.114	1.121	1.159	-18
10	NA	1.059	1.078	1.095	1.111	1.118	1.156	-12
14	1.049	1.058	1.077	1.094	1.109	1.117	1.154	-10
20	1.048	1.057	1.075	1.092	1.108	1.115	1.152	-7
30	1.047	1.056	1.073	1.089	1.105	1.111	1.148	-1
32	1.046	1.055	1.073	1.089	1.104	1.111	1.148	0
40	1.045	1.054	1.071	1.087	1.102	1.108	1.145	4
50	1.043	1.052	1.068	1.084	1.098	1.105	1.141	10
60	1.041	1.049	1.065	1.081	1.095	1.101	1.137	16
68	1.040	1.047	1.063	1.078	1.093	1.098	1.134	20
70	1.039	1.047	1.063	1.077	1.092	1.098	1.133	21
80	1.037	1.044	1.060	1.074	1.089	1.094	1.130	27
86	1.035	1.043	1.058	1.072	1.087	1.092	1.127	30
90	1.034	1.042	1.057	1.071	1.086	1.090	1.126	32
100	1.032	1.039	1.054	1.068	1.083	1.087	1.122	38
104	1.031	1.038	1.052	1.066	1.081	1.085	1.120	40
110	1.029	1.036	1.050	1.064	1.079	1.083	1.118	43
120	1.026	1.033	1.047	1.061	1.076	1.079	1.114	49
122	1.026	1.033	1.046	1.060	1.075	1.078	1.113	50
130	1.023	1.030	1.044	1.057	1.073	1.075	1.110	54
140	1.020	1.027	1.040	1.053	1.069	1.071	1.106	60
150	1.016	1.023	1.037	1.050	1.066	1.068	1.102	66
158	1.014	1.020	1.034	1.046	1.063	1.064	1.099	70
160	1.013	1.020	1.033	1.046	1.063	1.064	1.098	71
170	1.009	1.016	1.029	1.042	1.059	1.059	1.094	77
176	1.007	1.014	1.027	1.039	1.057	1.057	1.092	80
180	1.005	1.012	1.025	1.038	1.056	1.055	1.090	82
190	1.001	1.008	1.021	1.034	1.052	1.051	1.086	88
194	1.000	1.007	1.020	1.032	1.051	1.049	1.084	90
200	0.997	1.004	1.017	1.029	1.049	1.047	1.082	93
210	0.993	1.000	1.013	1.025	1.045	1.043	1.078	99
212	0.992	0.999	1.012	1.024	1.044	1.042	1.077	100
220	0.988	0.996	1.009	1.021	1.041	1.038	1.073	104
230	0.984	0.991	1.004	1.016	1.038	1.034	1.069	110
240	0.979	0.987	1.000	1.012	1.034	1.030	1.065	116
248	0.975	0.983	0.996	1.008	1.031	1.026	1.062	120
250	0.974	0.982	0.995	1.007	1.031	1.025	1.061	121
260	0.969	0.977	0.991	1.002	1.027	1.020	1.056	127
266	0.966	0.974	0.988	1.000	1.025	1.018	1.054	130
270	0.963	0.972	0.986	0.998	1.023	1.016	1.052	132
275	0.961	0.969	0.984	0.995	1.021	1.014	1.050	135

Conversions: density, t(°F) = specific gravity, t/68°F x water density, 68°F
density, t(°C) = specific gravity, t/20°C x water density, 20°C

g/cm^3 = specific gravity x 0.99823 g/cm^3
lb/gal = specific gravity x 8.32 lb/gal
lb/ft^3 = specific gravity x 62.32 lb/ft^3
kg/m = specific gravity x 998.23 kg/m

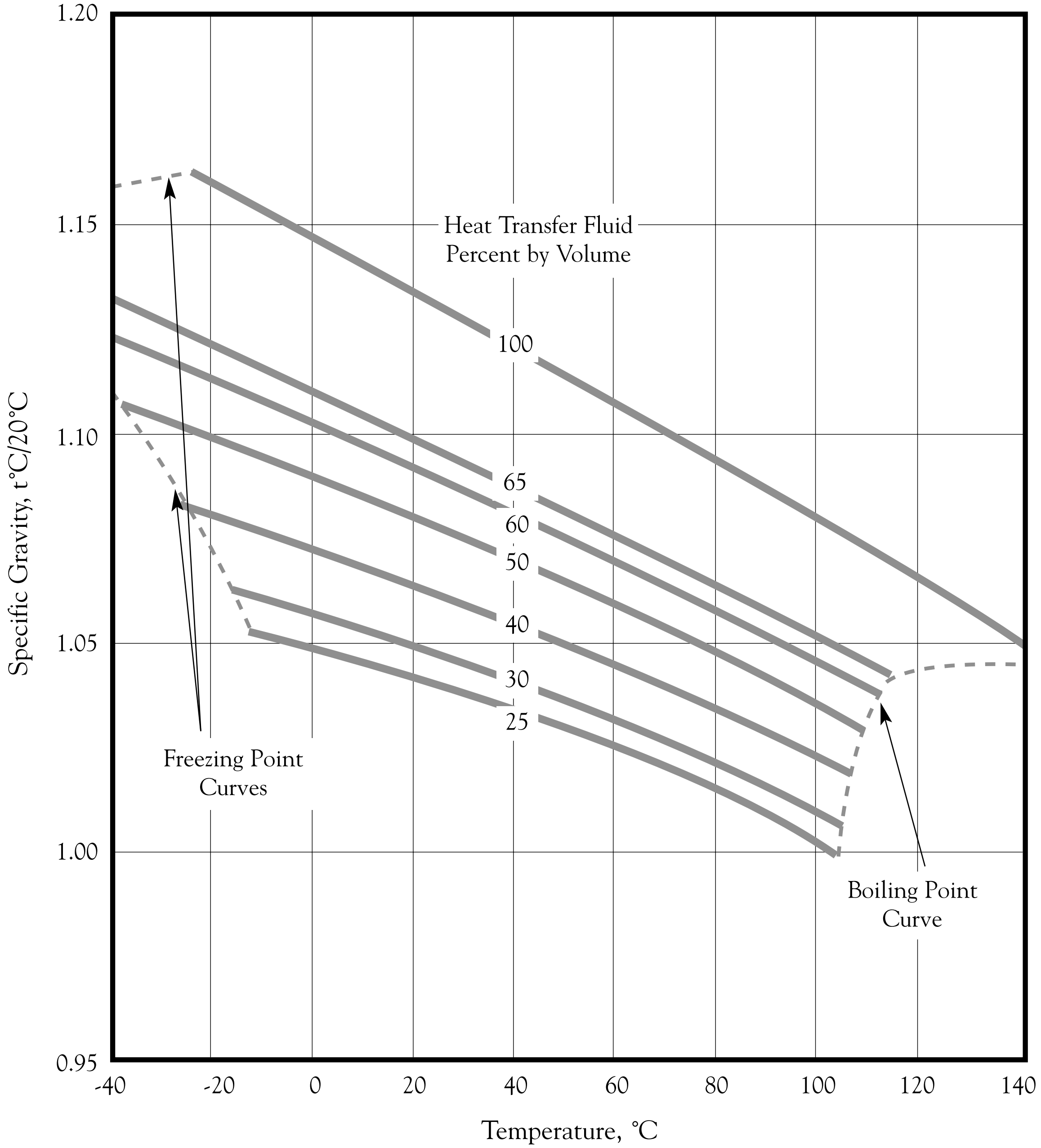
Figure 7 • Specific Gravities of Heat Transfer Fluids



Specific Gravity, t°F/68°F = $A + Bx + Cx^2 + Dx^3$, where x = temperature °F, valid from freezing point to 275°F

Volume % HTF	A	B	C	D
25	1.050611	-0.00011	-7.9E-7	-3.00E-22
30	1.060726	-0.00015	-6.6E-7	-1.50E-20
40	1.079935	-0.00021	-5.0E-7	1.82E-20
50	1.097586	-0.00026	-4.2E-7	7.09E-21
60	1.113669	-0.00030	-3.3E-7	1.41E-20
65	1.121091	-0.00032	-2.7E-7	6.25E-21
100	1.159293	-0.00036	-1.4E-7	-3.50E-21

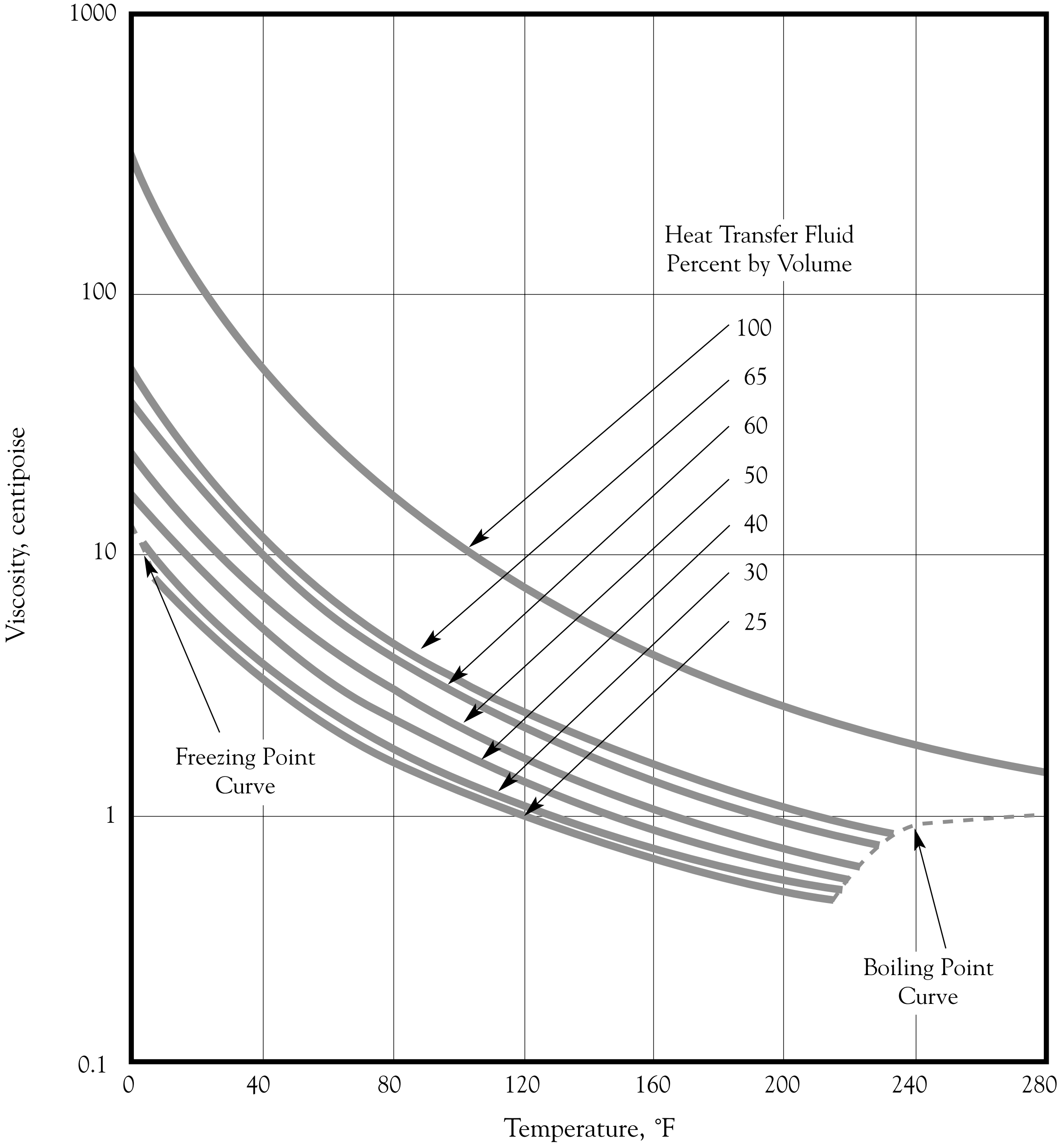
Figure 8 • Specific Gravities of Heat Transfer Fluids



Specific Gravity, t°C/20°C = $A + Bx + Cx^2 + Dx^3$, where x = temperature °C, valid from freezing point to 135°C

Volume % HTF	A	B	C	D
25	1.046316	-0.00029	-2.6E-06	3.46E-20
30	1.055222	-0.00035	-2.1E-06	1.29E-20
40	1.072582	-0.00044	-1.6E-06	7.87E-21
50	1.088908	-0.00051	-1.3E-06	4.35E-20
60	1.103828	-0.00057	-1.1E-06	2.85E-20
65	1.110689	-0.00060	-8.8E-07	-5.80E-20
100	1.147661	-0.00066	-4.6E-07	1.59E-20

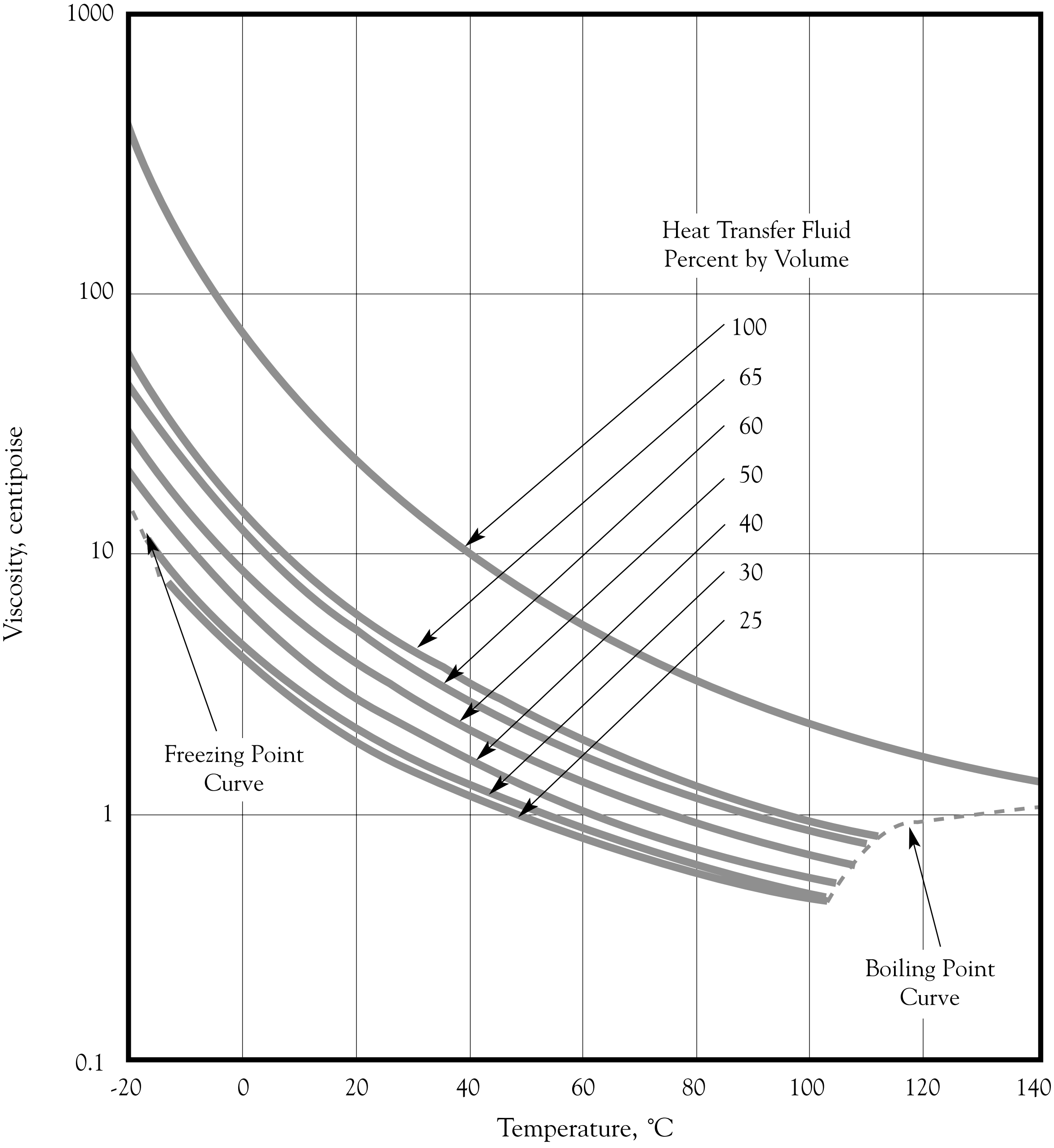
Figure 9 • Viscosities of Heat Transfer Fluids



$$\text{Log (Viscosity, centipoise)} = A + \frac{B}{(x+C)}$$ where x = temperature °F, Log = base 10 valid from freezing point to boiling point

Volume % HTF	A	B	C
25	-1.159703	277.851	130.360
30	-1.214523	308.950	136.812
40	-1.261740	354.758	143.934
50	-1.324105	404.037	150.220
60	-1.243863	406.875	145.572
65	-1.214004	412.195	143.897
100	-0.987503	448.112	128.056

Figure 10 • Viscosities of Heat Transfer Fluids



$$\text{Log (Viscosity, centipoise)} = A + \frac{B}{(x+C)}$$ where x = temperature °C, Log = base 10, valid from freezing point to boiling point

Volume % HTF	A	B	C
25	-1.333170	185.933	98.563
30	-1.421912	211.099	103.504
40	-1.417042	226.143	104.297
50	-1.323948	224.435	101.227
60	-1.333230	243.224	102.133
65	-1.312031	247.471	101.318
100	-1.088400	266.107	91.718

Table 9 • Viscosities of Heat Transfer Fluids

Temperature	Volume % Heat Transfer Fluid							Temperature
°F	25	30	40	50	60	65	100	°C
0	NA	NA	15.958	23.202	35.575	44.721	324.965	-18
10	NA	7.760	11.037	15.764	23.523	29.133	181.286	-12
14	5.821	6.824	9.649	13.685	20.227	24.919	146.882	-10
20	4.878	5.697	7.985	11.208	16.350	19.997	109.429	-7
30	3.741	4.341	5.996	8.276	11.846	14.333	70.411	-1
32	3.561	4.127	5.684	7.820	11.155	13.471	64.895	0
40	2.960	3.410	4.645	6.309	8.885	10.652	47.746	4
50	2.403	2.750	3.694	4.942	6.864	8.163	33.821	10
60	1.995	2.266	3.005	3.962	5.437	6.421	24.852	16
68	1.742	1.968	2.583	3.368	4.584	5.386	19.867	20
70	1.687	1.903	2.492	3.240	4.401	5.165	18.839	21
80	1.449	1.623	2.101	2.697	3.630	4.236	14.666	27
86	1.332	1.486	1.910	2.434	3.259	3.793	12.762	30
90	1.262	1.405	1.798	2.280	3.043	3.534	11.682	32
100	1.113	1.231	1.558	1.953	2.588	2.993	9.493	38
104	1.061	1.171	1.476	1.842	2.435	2.810	8.781	40
110	0.991	1.090	1.366	1.693	2.229	2.567	7.850	43
120	0.891	0.974	1.209	1.483	1.942	2.228	6.592	49
122	0.874	0.953	1.181	1.446	1.891	2.169	6.376	50
130	0.808	0.878	1.080	1.311	1.708	1.954	5.610	54
140	0.738	0.797	0.972	1.170	1.517	1.729	4.833	60
150	0.678	0.729	0.881	1.051	1.357	1.544	4.208	66
158	0.637	0.681	0.819	0.970	1.249	1.417	3.793	70
160	0.627	0.670	0.804	0.951	1.224	1.388	3.699	71
170	0.583	0.620	0.738	0.866	1.110	1.256	3.281	77
176	0.559	0.593	0.703	0.821	1.051	1.187	3.064	80
180	0.544	0.576	0.681	0.793	1.014	1.144	2.932	82
190	0.510	0.538	0.632	0.730	0.930	1.048	2.639	88
194	0.498	0.524	0.614	0.707	0.900	1.014	2.535	90
200	0.480	0.504	0.588	0.675	0.858	0.965	2.390	93
210	0.454	0.475	0.550	0.627	0.795	0.893	2.178	99
212	0.449	0.469	0.543	0.619	0.783	0.879	2.139	100
220	0.430	0.448	0.516	0.585	0.740	0.829	1.995	104
230	0.409	0.424	0.486	0.548	0.691	0.773	1.837	110
240	0.390	0.403	0.459	0.514	0.648	0.724	1.698	116
248	0.376	0.388	0.440	0.490	0.617	0.688	1.600	120
250	0.372	0.384	0.435	0.485	0.609	0.680	1.577	121
260	0.357	0.366	0.414	0.458	0.575	0.641	1.470	127
266	0.348	0.357	0.401	0.443	0.556	0.619	1.411	130
270	0.342	0.351	0.394	0.434	0.544	0.605	1.375	132
275	0.336	0.343	0.385	0.423	0.529	0.589	1.331	135

Viscosity values are reported in centipoise (cP)

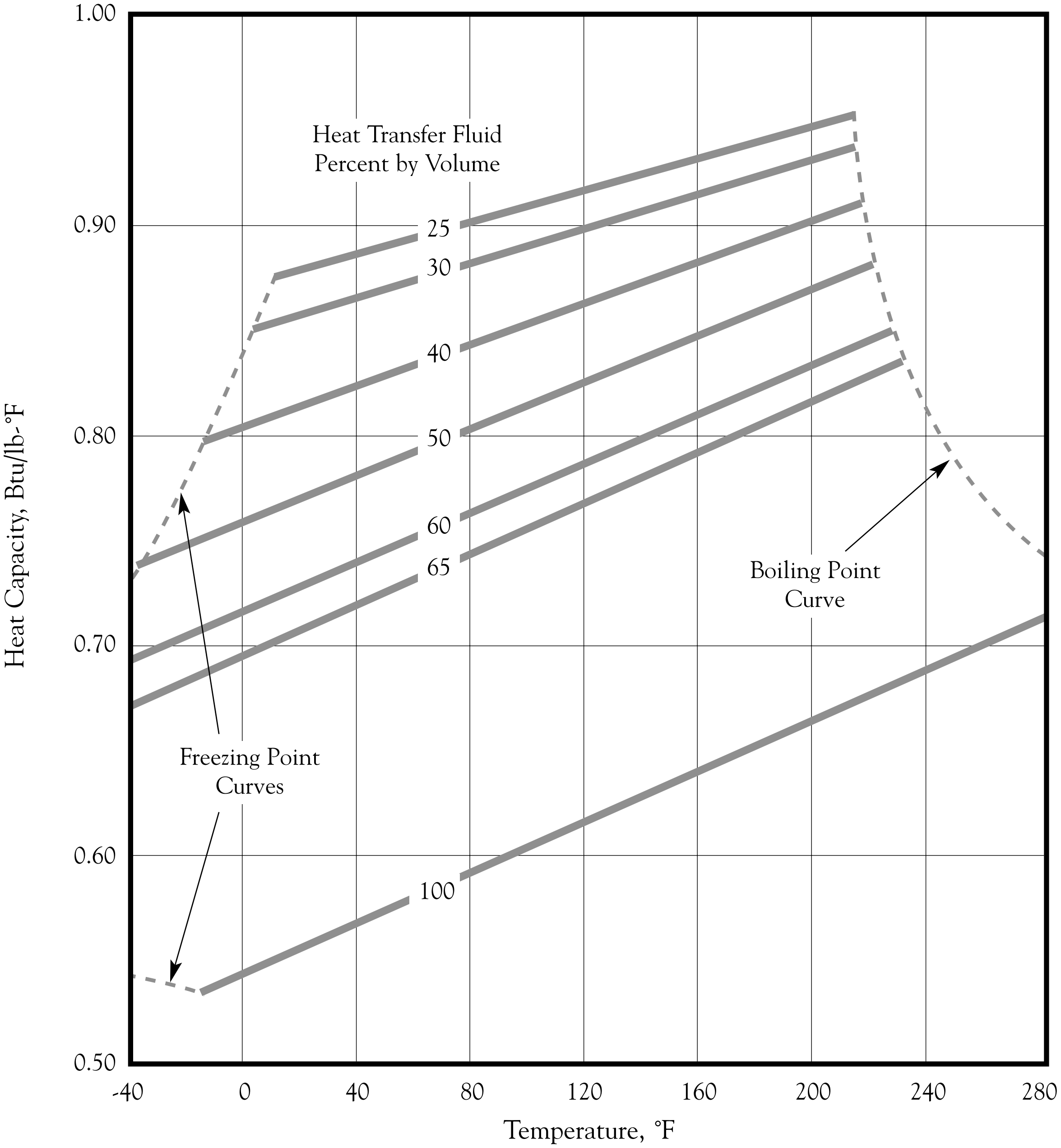
Conversions: kg/m - sec = cP x 0.001
lb/ft - hr = cP x 2.4191
centistokes (cSt) = centipoise (cP) g/m - density (g/cm^3)

Table 10 • Specific Heats of Heat Transfer Fluids

Temperature °F	Volume % Heat Transfer Fluid							Temperature °C
	25	30	40	50	60	65	100	
0	NA	NA	0.805	0.757	0.710	0.687	0.533	-18
10	NA	0.857	0.810	0.763	0.716	0.693	0.539	-12
14	0.883	0.859	0.812	0.765	0.719	0.696	0.542	-10
20	0.885	0.862	0.815	0.768	0.722	0.700	0.546	-7
30	0.889	0.866	0.820	0.774	0.729	0.706	0.552	-1
32	0.890	0.866	0.821	0.775	0.730	0.708	0.553	0
40	0.892	0.870	0.825	0.780	0.735	0.713	0.559	4
50	0.896	0.874	0.830	0.785	0.741	0.719	0.565	10
60	0.900	0.878	0.835	0.791	0.747	0.725	0.571	16
68	0.903	0.881	0.839	0.769	0.752	0.730	0.576	20
70	0.903	0.882	0.840	0.797	0.753	0.732	0.578	21
80	0.907	0.886	0.845	0.802	0.760	0.738	0.584	27
86	0.909	0.889	0.848	0.806	0.763	0.742	0.588	30
90	0.911	0.890	0.850	0.808	0.766	0.745	0.590	32
100	0.914	0.895	0.855	0.814	0.772	0.751	0.597	38
104	0.916	0.896	0.857	0.816	0.775	0.753	0.599	40
110	0.918	0.899	0.860	0.819	0.778	0.757	0.603	43
120	0.921	0.903	0.865	0.825	0.784	0.764	0.609	49
122	0.922	0.904	0.866	0.826	0.786	0.765	0.611	50
130	0.925	0.907	0.870	0.831	0.791	0.770	0.616	54
140	0.929	0.911	0.875	0.837	0.797	0.776	0.622	60
150	0.932	0.915	0.880	0.842	0.803	0.783	0.629	66
158	0.935	0.918	0.884	0.847	0.808	0.788	0.634	70
160	0.936	0.919	0.885	0.848	0.809	0.789	0.635	71
170	0.939	0.923	0.890	0.854	0.815	0.796	0.641	77
176	0.942	0.926	0.893	0.857	0.819	0.799	0.645	80
180	0.943	0.927	0.895	0.859	0.822	0.802	0.648	82
190	0.947	0.932	0.900	0.865	0.828	0.808	0.654	88
194	0.948	0.933	0.902	0.867	0.830	0.811	0.657	90
200	0.950	0.936	0.905	0.871	0.834	0.815	0.660	93
210	0.954	0.940	0.910	0.876	0.840	0.821	0.667	99
212	0.955	0.941	0.911	0.878	0.842	0.822	0.668	100
220	0.958	0.944	0.915	0.882	0.846	0.828	0.673	104
230	0.961	0.948	0.920	0.888	0.853	0.834	0.679	110
240	0.965	0.952	0.925	0.893	0.859	0.840	0.686	116
248	0.968	0.956	0.929	0.898	0.864	0.845	0.691	120
250	0.968	0.956	0.930	0.899	0.865	0.847	0.692	121
260	0.972	0.960	0.935	0.905	0.871	0.853	0.699	127
266	0.974	0.963	0.938	0.908	0.875	0.857	0.702	130
270	0.976	0.965	0.940	0.911	0.877	0.859	0.705	132
275	0.977	0.967	0.942	0.913	0.881	0.863	0.708	135

Specific Heat values are reported in BTU/lb-°F = cal/g-°C
joule/kg-°C = 4184 x cal/g-°C

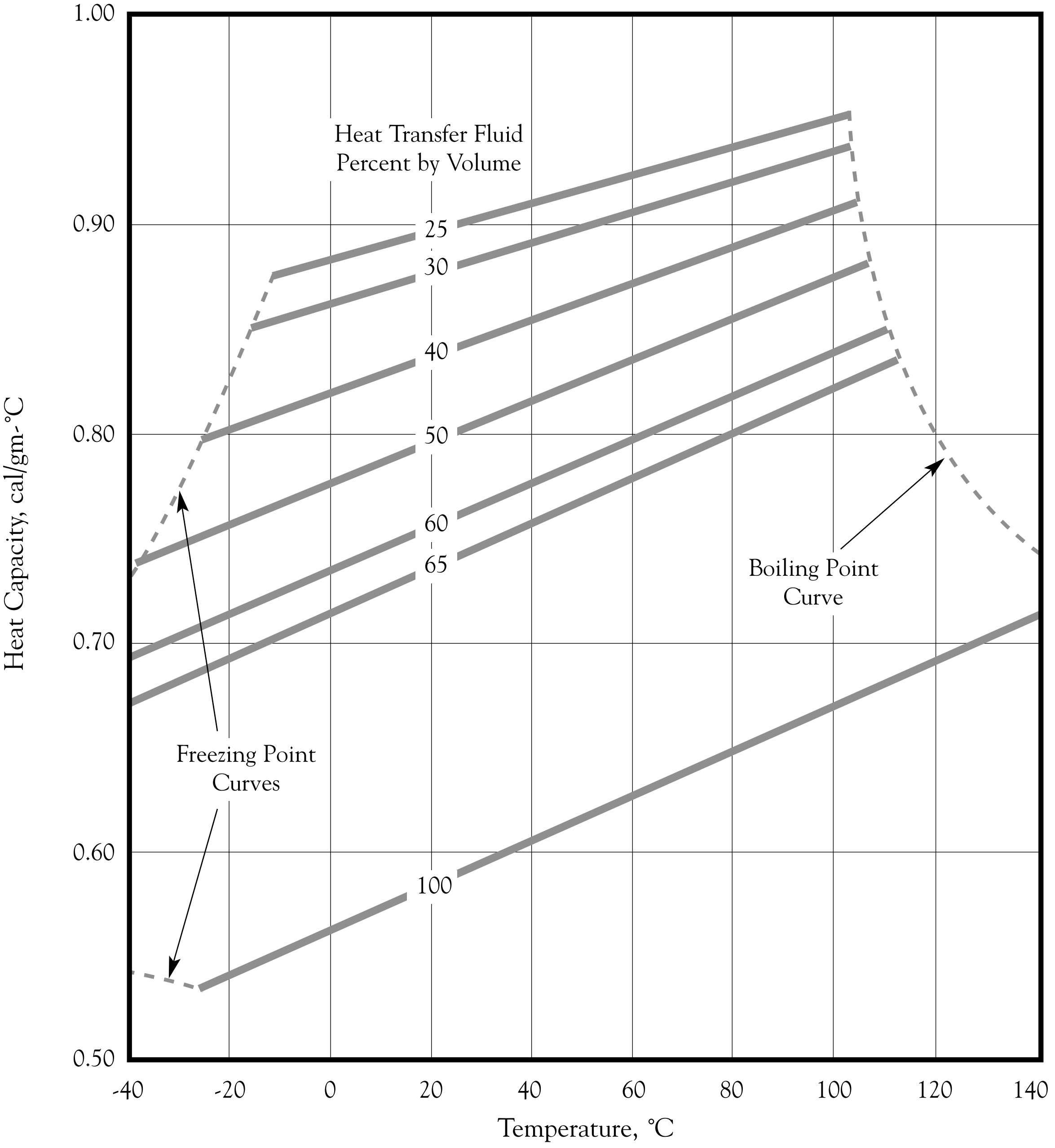
Figure 11 • Specific Heats of Heat Transfer Fluids



Heat Capacity, Btu/lb-°F = A + Bx + Cx^2, where x = temperature °F, valid from freezing point to 275°F

Volume % HTF	A	B	C
25	0.878003	0.000361	-3.20E-20
30	0.856268	0.000412	-4.00E-19
40	0.804543	0.000500	9.48E-21
50	0.756811	0.000569	1.27E-19
60	0.710073	0.000620	-1.40E-19
65	0.687077	0.000638	3.89E-19
100	0.533057	0.000637	1.46E-19

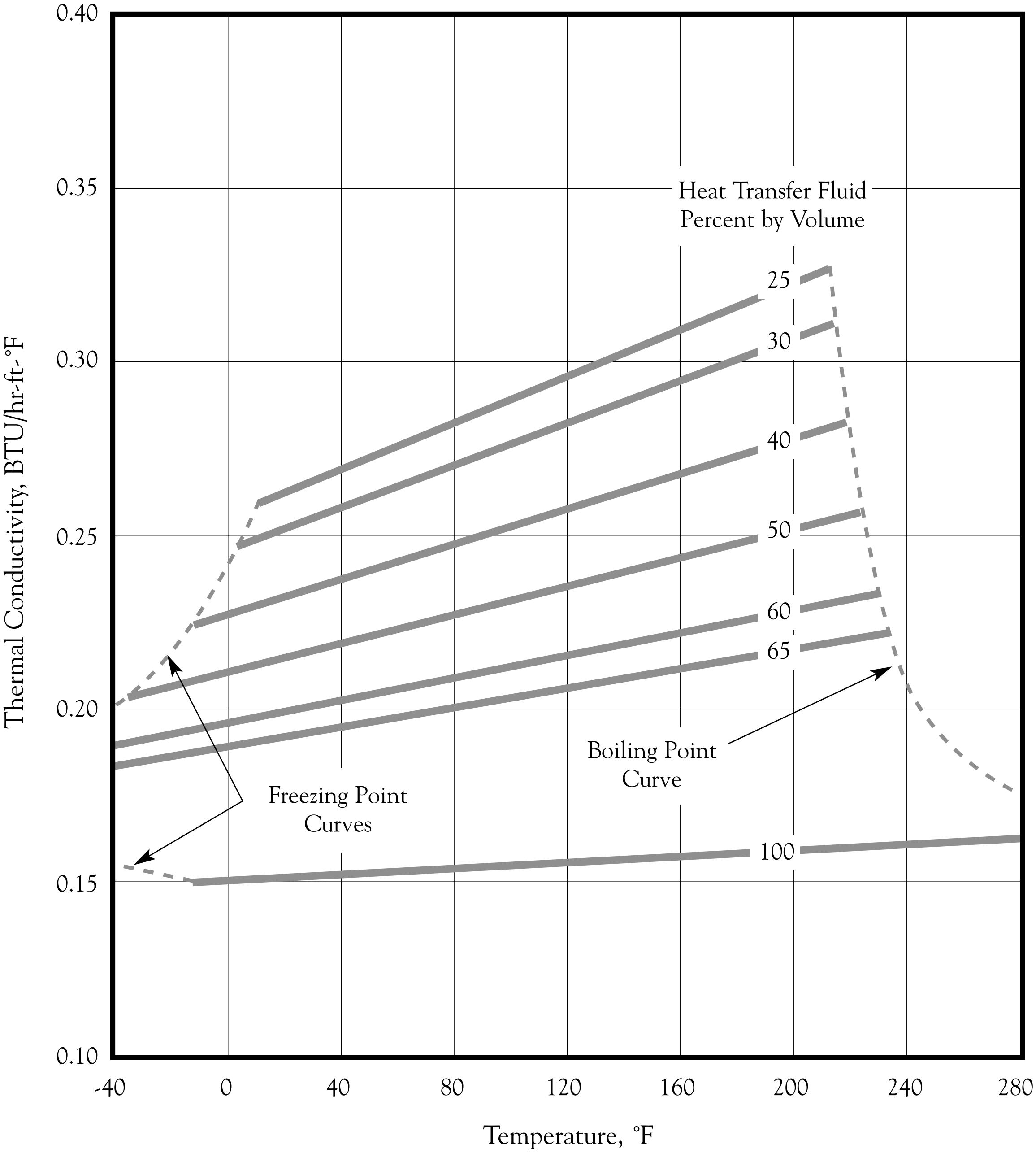
Figure 12 • Specific Heats of Heat Transfer Fluids



Heat Capacity, cal/gm-°C = A + Bx + Cx^2, where x = temperature °C, valid from freezing point to 135°C

Volume % HTF	A	B	C
25	0.889569	0.000651	2.23E-19
30	0.866462	0.000746	3.09E-19
40	0.820547	0.000900	-6.06E-20
50	0.775031	0.001025	-2.24E-19
60	0.729913	0.001116	-5.59E-20
65	0.707504	0.001149	1.54E-19
100	0.553430	0.001146	-1.77E-19

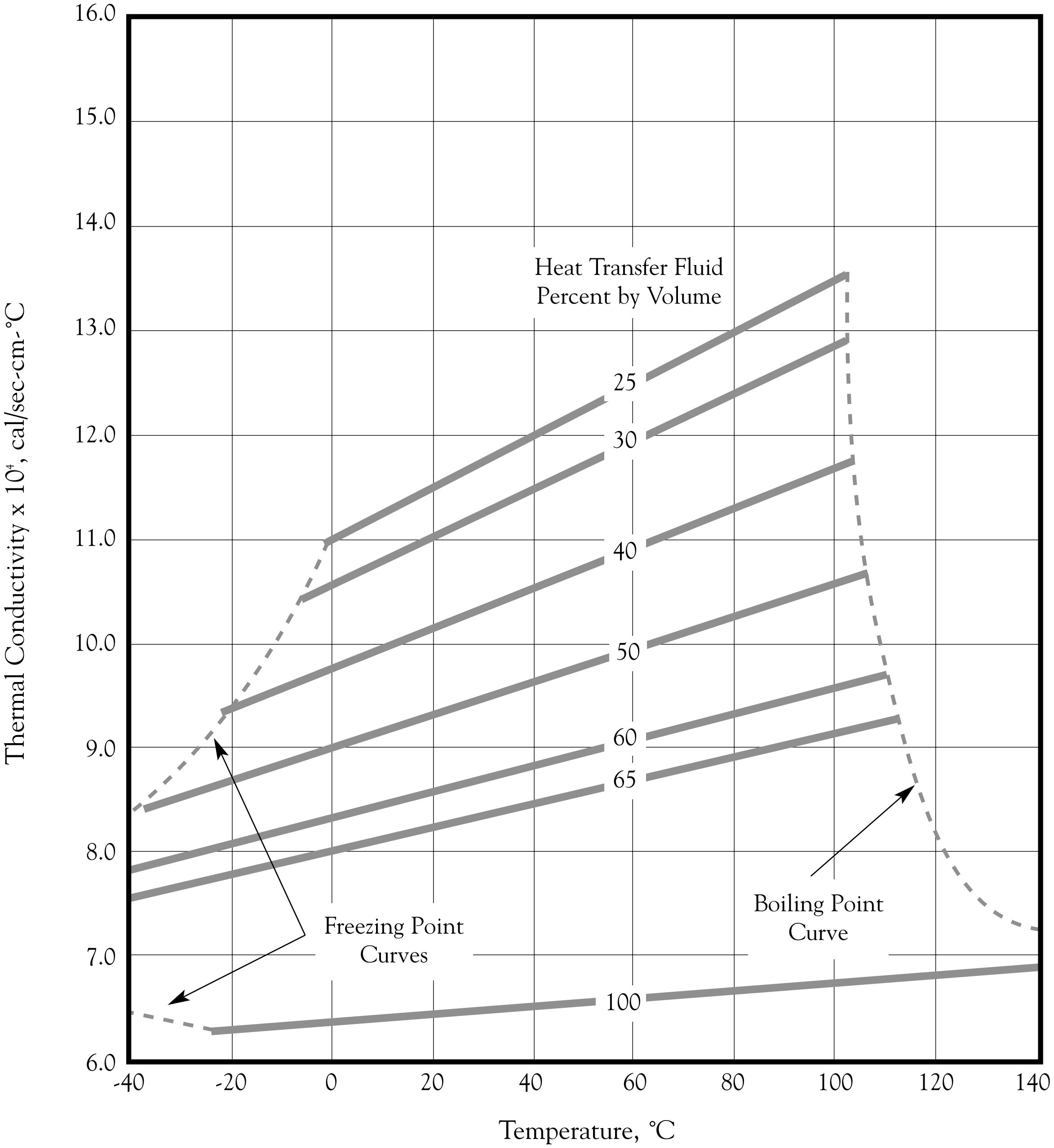
Figure 13 • Thermal Conductivities of Heat Transfer Fluids



Thermal Conductivity, BTU/hr-ft-°F = A + Bx, where x = temperature °F,
valid from freezing point to 275°F

Volume % HTF	A	B
25	0.25559571	3.32E-4
30	0.24583404	3.04E-4
40	0.22750438	2.51E-4
50	0.21076690	2.04E-4
60	0.19561980	1.61E-4
65	0.18864510	1.42E-4
100	0.15094955	4.26E-5

Figure 14 • Thermal Conductivities of Heat Transfer Fluids



Thermal Conductivity, cal/sec-cm-°C = A + Bx, where x = temperature °C, valid from freezing point to 135°C

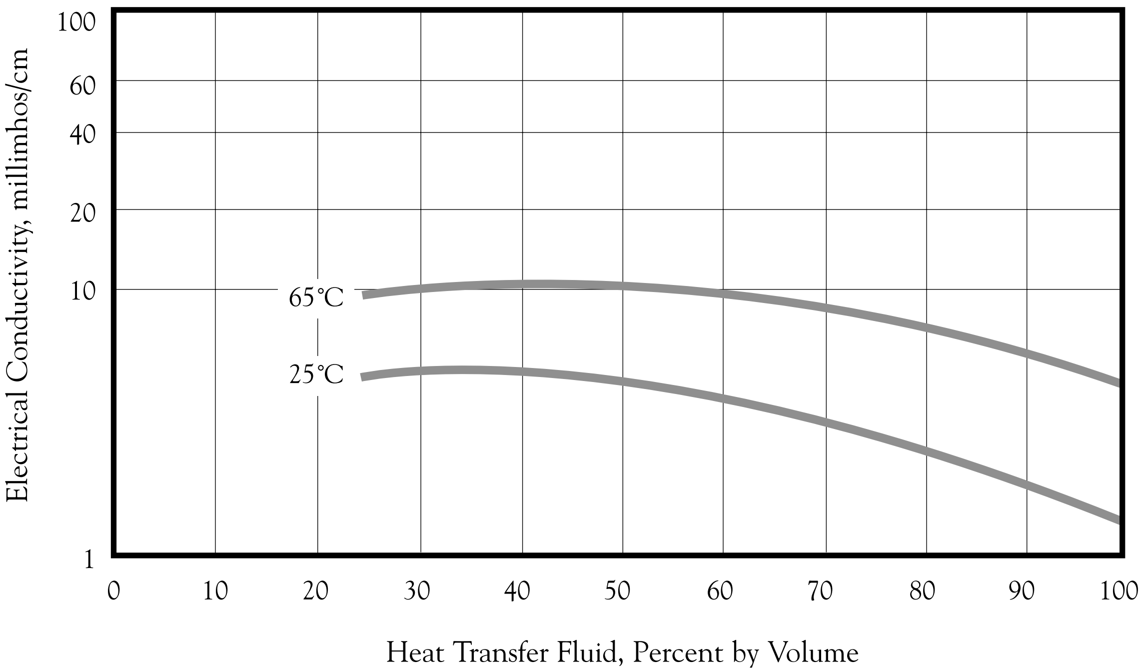
Volume % HTF	A	B
25	0.00110045	2.74E-6
30	0.00105638	2.26E-6
40	0.00097367	1.87E-6
50	0.00089822	1.52E-6
60	0.00083000	1.20E-6
65	0.00079862	1.06E-6
100	0.00062963	3.17E-6

Table 11 • Thermal Conductivities of Heat Transfer Fluids

Temperature	Volume % Heat Transfer Fluid							Temperature
°F	25	30	40	50	60	65	100	°C
0	NA	NA	0.2275	0.2108	0.1956	0.1886	0.1509	-18
10	NA	0.2489	0.2300	0.2128	0.1977	0.1901	0.1514	-12
14	0.2602	0.2501	0.2310	0.2136	0.1985	0.1906	0.1515	-10
20	0.2622	0.2519	0.2325	0.2148	0.1997	0.1915	0.1518	-7
30	0.2656	0.2550	0.2350	0.2169	0.2017	0.1929	0.1522	-1
32	0.2662	0.2556	0.2355	0.2173	0.2021	0.1932	0.1523	0
40	0.2689	0.2580	0.2375	0.2189	0.2038	0.1943	0.1527	4
50	0.2722	0.2610	0.2401	0.2210	0.2058	0.1957	0.1531	10
60	0.2755	0.2641	0.2426	0.2230	0.2079	0.1972	0.1535	16
68	0.2782	0.2665	0.2446	0.2246	0.2095	0.1983	0.1538	20
70	0.2788	0.2671	0.2451	0.2250	0.2099	0.1986	0.1539	21
80	0.2822	0.2702	0.2476	0.2271	0.2119	0.2000	0.1544	27
86	0.2841	0.2720	0.2491	0.2283	0.2132	0.2009	0.1546	30
90	0.2855	0.2732	0.2501	0.2291	0.2140	0.2014	0.1548	32
100	0.2888	0.2762	0.2526	0.2312	0.2160	0.2028	0.1552	38
104	0.2901	0.2775	0.2536	0.2320	0.2168	0.2034	0.1554	40
110	0.2921	0.2793	0.2551	0.2332	0.2181	0.2043	0.1556	43
120	0.2954	0.2823	0.2576	0.2352	0.2201	0.2057	0.1561	49
122	0.2961	0.2829	0.2581	0.2357	0.2205	0.2060	0.1561	50
130	0.2988	0.2854	0.2601	0.2373	0.2221	0.2071	0.1565	54
140	0.3021	0.2884	0.2626	0.2393	0.2242	0.2085	0.1569	60
150	0.3054	0.2914	0.2652	0.2414	0.2262	0.2099	0.1573	66
158	0.3081	0.2939	0.2672	0.2430	0.2279	0.2111	0.1577	70
160	0.3087	0.2945	0.2677	0.2434	0.2283	0.2114	0.1578	71
170	0.3120	0.2975	0.2702	0.2454	0.2303	0.2128	0.1582	77
176	0.3140	0.2993	0.2717	0.2467	0.2315	0.2136	0.1584	80
180	0.3154	0.3006	0.2727	0.2475	0.2323	0.2142	0.1586	82
190	0.3187	0.3036	0.2752	0.2495	0.2344	0.2156	0.1590	88
194	0.3200	0.3048	0.2762	0.2503	0.2352	0.2162	0.1592	90
200	0.3220	0.3066	0.2777	0.2516	0.2364	0.2170	0.1595	93
210	0.3253	0.3097	0.2802	0.2536	0.2385	0.2185	0.1599	99
212	0.3260	0.3103	0.2807	0.2540	0.2389	0.2187	0.1600	100
220	0.3286	0.3127	0.2827	0.2556	0.2405	0.2199	0.1603	104
230	0.3320	0.3158	0.2852	0.2577	0.2425	0.2213	0.1607	110
240	0.3353	0.3188	0.2877	0.2597	0.2446	0.2227	0.1612	116
248	0.3379	0.3212	0.2898	0.2614	0.2462	0.2239	0.1615	120
250	0.3386	0.3218	0.2903	0.2618	0.2466	0.2241	0.1616	121
260	0.3419	0.3249	0.2928	0.2638	0.2487	0.2256	0.1620	127
266	0.3439	0.3267	0.2943	0.2650	0.2499	0.2264	0.1623	130
270	0.3452	0.3279	0.2953	0.2658	0.2507	0.2270	0.1625	132
275	0.3469	0.3294	0.2965	0.2669	0.2517	0.2277	0.1627	135

Thermal conductivities are reported in BTU/hr-ft - °F
Conversions: cal/sec cm °C = 0.00413 x BTU/hr-ft - °F
J/sec cm °C = 0.0173 x BTU/hr-ft - °F

Figure 15 • Electrical Conductivities of Heat Transfer Fluids



Electrical Conductivity, millimhos/cm = A + Bx + Cx^2 + Dx^3, where x = vol% HTF.
Equation is valid for 25 to 100% HTF, in solution with deionized water.

	A	B	C	D
25°C (77°F)	2.027	0.1902	-0.003606	1.633E-5
65°C (150°F)	4.519	0.3168	-0.004901	1.698E-5

Note: The quality of the water used for dilution can significantly affect electrical conductivity.

Heat Transfer Calculations

Heat transfer coefficient and pressure drop inside smooth tubes and clean commercial pipe may be estimated by the following method.

Step 1: Calculate the cross-sectional flow area.

$A = N \times \pi D^2/4$

A = Cross-sectional flow area
N = Number of tubes in parallel
π = 3.1416
D = Tube inside diameter

Step 2: Calculate the velocity in the tubes.

$V = W/(A \times \rho)$

V = Velocity
W = Mass flow rate
r = Fluid density

Step 3: Determine the dimensionless Reynolds number using Figure 16 or the following equation:

$N_R = \rho \times V \times D/\mu_B$

N_R = Reynolds number
μ_B = Absolute viscosity at average bulk temperature

Step 4: Determine Colburn J Factor from Figure 17 or from equations below.

$J = 1.86 \times N_R^{-2/3} \times (L/D)^{-1/3} \quad N_R < 2100$

$J = 0.023 \times N_R^{-0.2} \quad N_R > 8000$

J = Colburn J Factor
L = Tube Length

Note: The flow condition defined by the values of the Reynolds number between 2100 and 8000 represents a region of unsteady state and should be avoided in system design and operation. A rough value may be estimated from Figure 17.

Step 5: Determine Moody friction factor, F, from Figure 18.

Step 6: Calculate the dimensionless Prandtl Number.

$Np = \mu_B \times Cp/k$

Np = Prandtl Number
Cp = Fluid specific heat
k = Thermal Conductivity

Step 7: Calculate the heat transfer coefficient.

$H = Cp \times \rho \times V \times J \times N_P^{-2/3} \times (\mu_B/\mu_W)^{0.14}$

H = Heat transfer coefficient
μ_W = Absolute viscosity at average tube wall temperature

Figure 19 can also be used to determine the heat transfer coefficient. Figure 19 is based on a 25 volume % HTF, at 0°C. Figures 19a and 19b should be used to correct the HTC to your specific conditions.

Step 8: Calculate the pressure drop.

$\Delta P = [K_F + (F \times L/D) \times (\mu_W/\mu_B)^{0.14}] \times \rho \times V^2/(2 \times G_C)$

ΔP = Pressure drop
K_F = Fitting losses (1.5 for entrance and exit)
G_C = Unit conversion constant

Alternatively, Figures 20 or 21 can be used to estimate pressure drop. Figure 20, with a correction from Figure 20a, should be used for systems operating in the laminar flow region, with $N_{RE} < 2100$. Figure 21, with a correction from 21a, should be used when $N_{RE} > 3000$.

Acknowledgement:

Heat transfer coefficients and pressure drop are adapted from the methods of Colburn (1), Sieder and Tate (2), and Moody (3).

(1) A.P. Colburn, “Method of Correlating Forced Heat Transfer Data and a Comparison with Fluid Friction,” Trans. *ASME*, Vol 29 (1933), p. 174.
(2) E.N. Sieder and C.E. Tate, “Heat Transfer and Pressure Drop of Liquids in Tubes,” *Ind. Eng. Chem.*, Vol 28 (1936), p. 1429.
(3) L.F. Moody, “Friction Factor for Pipe Flow,” Trans. *ASME*, Vol. 66, 1944.

Example Problem:

200,000 lb/hr of 30% UCARTHERM HTF by volume is used to cool an organic liquid from 180°F to 30°F. The UCARTHERM HTF enters the tube heat exchanger at 15°F and exits at 25°F. The single pass tubeside heat exchanger contains 357, ⅝ inch, 16 BWG (ID = 0.495 inches) tubes, 16 feet long. Calculate the heat transfer coefficient and the pressure drop inside the tubes.

Step 1: Area for flow.

$$A = \frac{N \times \pi D^2}{4} = \frac{357 \times \pi \times 0.495^2}{4}$$

$$A = \frac{68.7}{144} = \frac{in^2 \bullet ft^2}{in^2} = 0.477\ ft^2$$

Step 2: Velocity.

$$\rho = 1.057 \times 62.32 = 66.1 \frac{lb}{ft^3}$$ (Table 7: 20°F, 30%)

$$V = \frac{W}{A x \rho} = \frac{200{,}000\ lb/hr}{0.477 ft^2 \times 66.1\ lb/ft^3}$$

$$V = 6343\ ft/hr \times \frac{1}{3600}\ \frac{hr}{sec} = 1.76\ ft/sec$$

Step 3: Reynolds Number.

$$\mu_B = 5.697 cP \times 2.4191\ lb/(ft \bullet hr \bullet cP)$$

(Table 8: 20°F, 30%)

$$= 13.78\ lb/(ft \bullet hr)$$

$$D = 0.495\ in = 0.04125\ ft$$

$$N_R = \frac{\rho V D}{\mu_B} = \frac{66.1\ lb/ft^2 \times 6343\ ft/hr \times 0.04125\ ft}{13.78\ lb/(ft \bullet hr)}$$

$$N_R = 1255$$

Step 4: J-Factor.

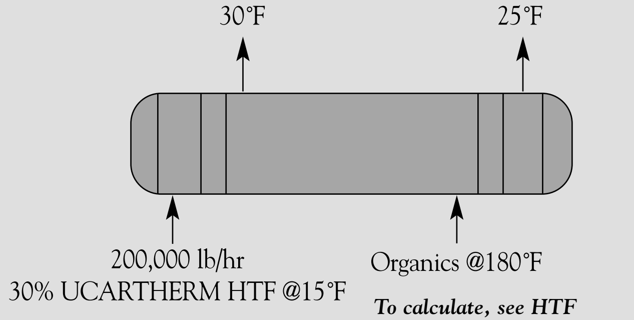
Because $N_R < 2100$, use $J = 1.86 N_R^{-2/3} \left(\frac{L}{D}\right)^{-1/3}$

$$J = 1.86 \times (1255)^{-2/3} \times \left(\frac{16}{.04125}\right)^{-1/3} = 0.0022$$

Step 5: Moody Friction Factor.

From Figure 18 @ $N_R = 1248 \Rightarrow F = 0.051$

Flow Rate, Gallons per Minute



To calculate, see HTF calculations page 32, step 3

Step 6: Prandtl Number.

$$k = 0.2519\ BTU/(hr \bullet ft \bullet °F)$$ (Table 10: 20°F, 30%)

$$Cp = 0.862\ BTU/(lb \bullet °F) \bullet$$ (Table 9: 20°F, 30%)

$$Np = \frac{13.78\ lb/(hr \bullet ft) \times 0.884\ BTU/(lb \bullet °F)}{0.2519\ BTU/(hr \bullet ft \bullet °F)}$$

$$= 48.36$$

Step 7: Heat Transfer Coefficient: Assume average tube wall temperature equals average process temperature.

$$T_W = \frac{180 + 30}{2} = 105°F$$

$$\mu_W = 1.156\ cP$$ (Table 8: 105°F, 30%)

$$H = Cp \times \rho \times V \times J \times N_P^{-2/3} \times \left(\frac{\mu_B}{\mu_W}\right)^{0.14}$$

$$H = 0.862\ \frac{BTU}{lb \bullet °F} \times 66.1 \frac{lb}{ft^2} \times 6343\ \frac{ft}{hr}$$

$$\times\ 0.0022 \times (48.36)^{-2/3} \times \left(\frac{5.697}{1.156}\right)^{0.14}$$

$$H = 79.3\ \frac{BTU}{(hr \bullet ft^2 \bullet °F)}$$

Step 8: Pressure Drop.

$$K_F = 1.5 \text{ for entrance and exit losses.}$$

$$g_C = 32.2\ \frac{lb_{mass} \bullet ft}{lb_{force} \bullet sec^2}$$

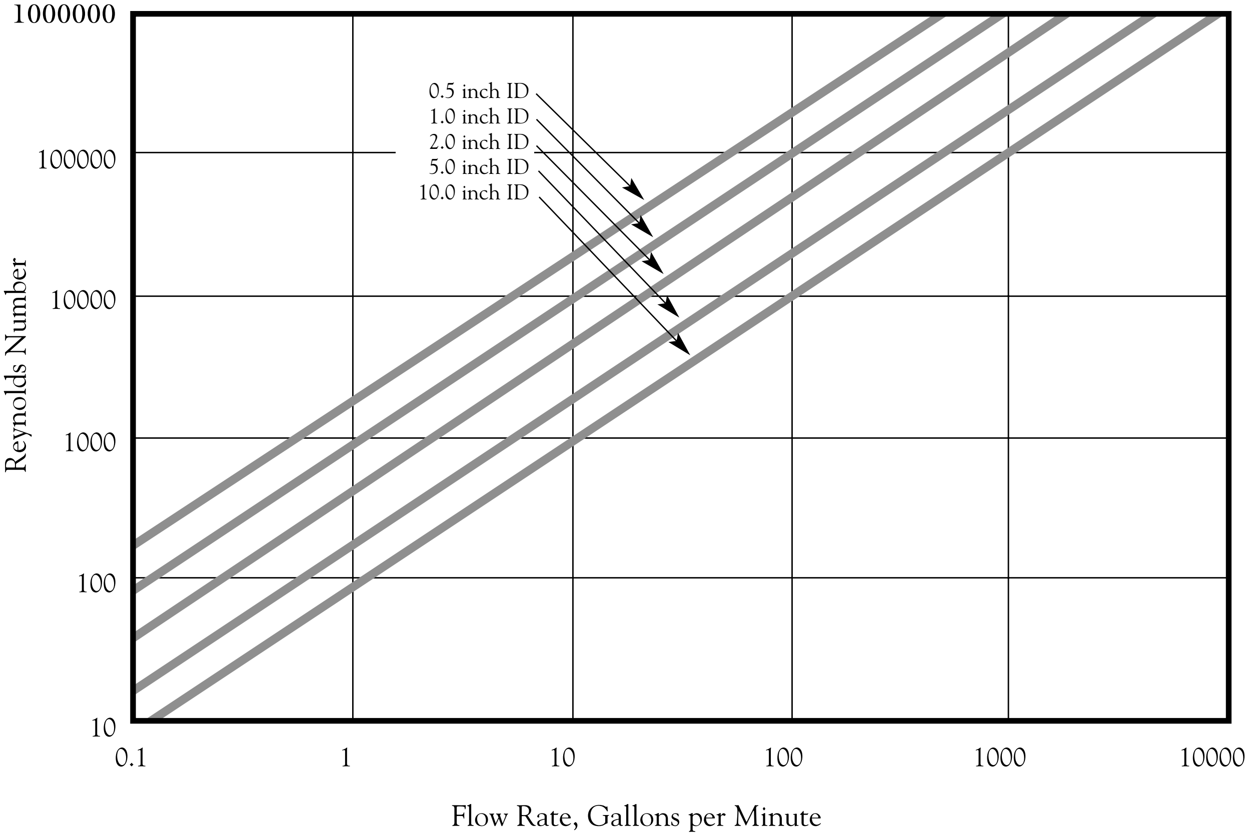
$$\Delta P = \left[K_F + \frac{F \times L}{D} \times \left(\frac{\mu_W}{\mu_B}\right)^{0.14}\right] \times \frac{\rho \times V^2}{2 g_c}$$

$$\Delta P = \left[1.5 + \left(\frac{0.051 \times 16\ ft}{0.04125\ ft}\right)\left(\frac{1.156}{5.697}\right)^{0.14}\right]$$

$$\times\ \frac{66.1\ lb_{mass}/ft^3 \times (1.76\ ft/sec)^2}{2 \times 32.2\ lb_{mass} \bullet ft/(lb_{force} \bullet sec^2)}$$

$$\Delta P = 55.0\ \frac{lb_{force}}{ft^2} = 0.38\ \frac{lb_{force}}{in^2} = 0.38\ psi$$

Figure 16 • Reynolds Number



To calculate, see HTF calculations page 32, step 3

Figure 16a • Temperature/Composition Multiplier

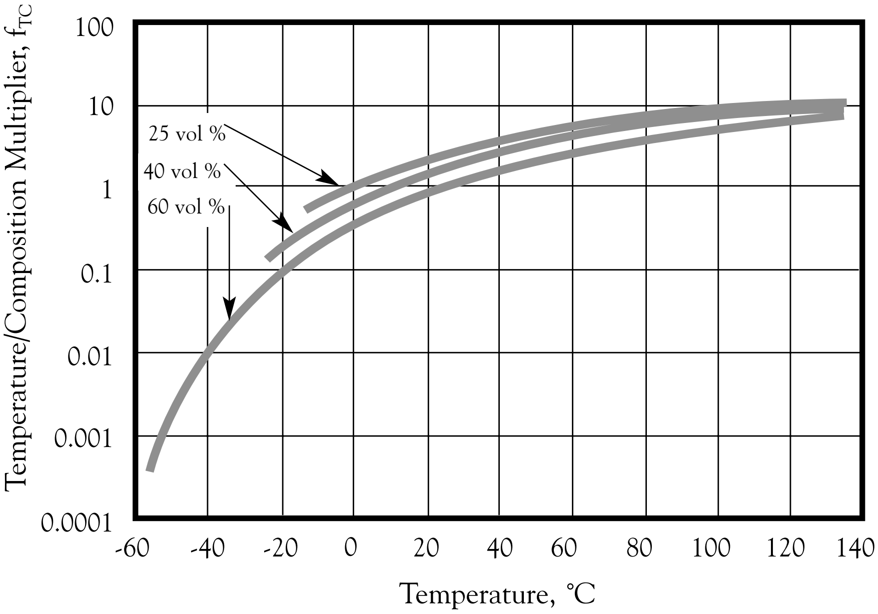


Figure 17 • Colburn J Factor: Transfer Inside Tubes

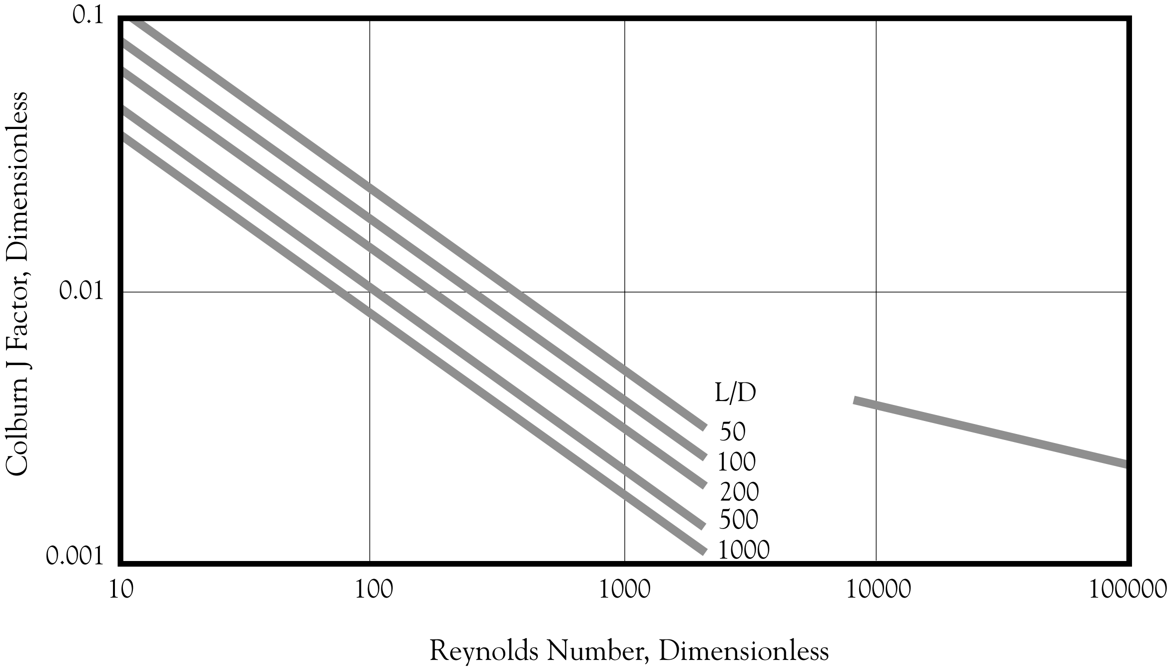


Figure 18 • Moody Friction Factor: Pressure Drop Inside Tubes

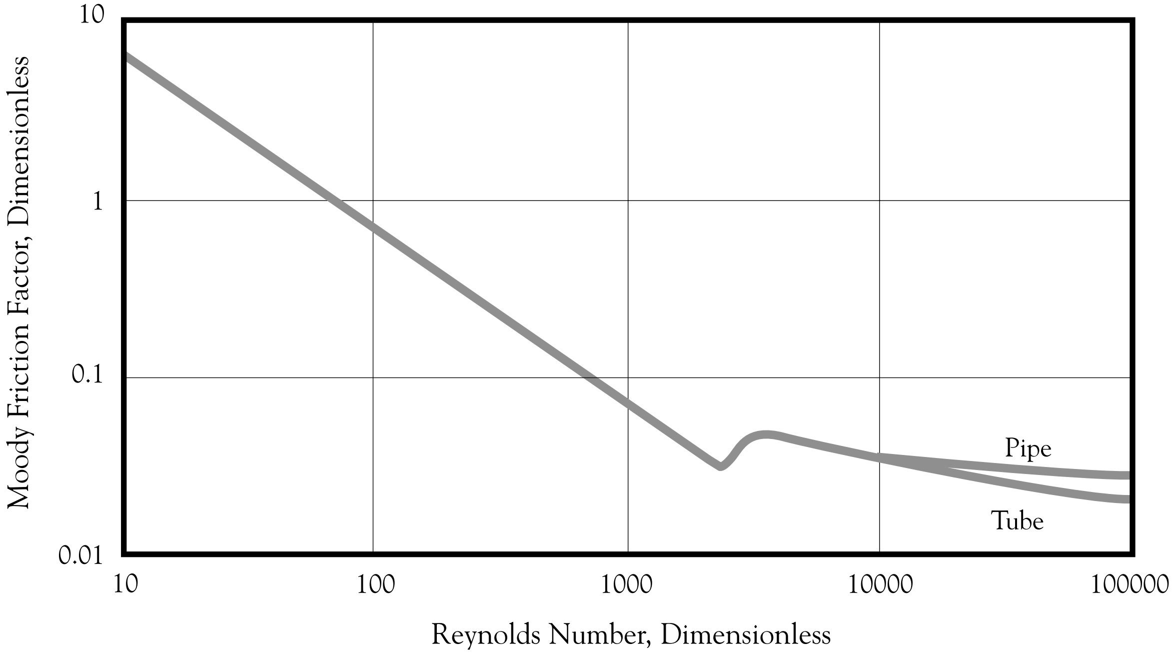
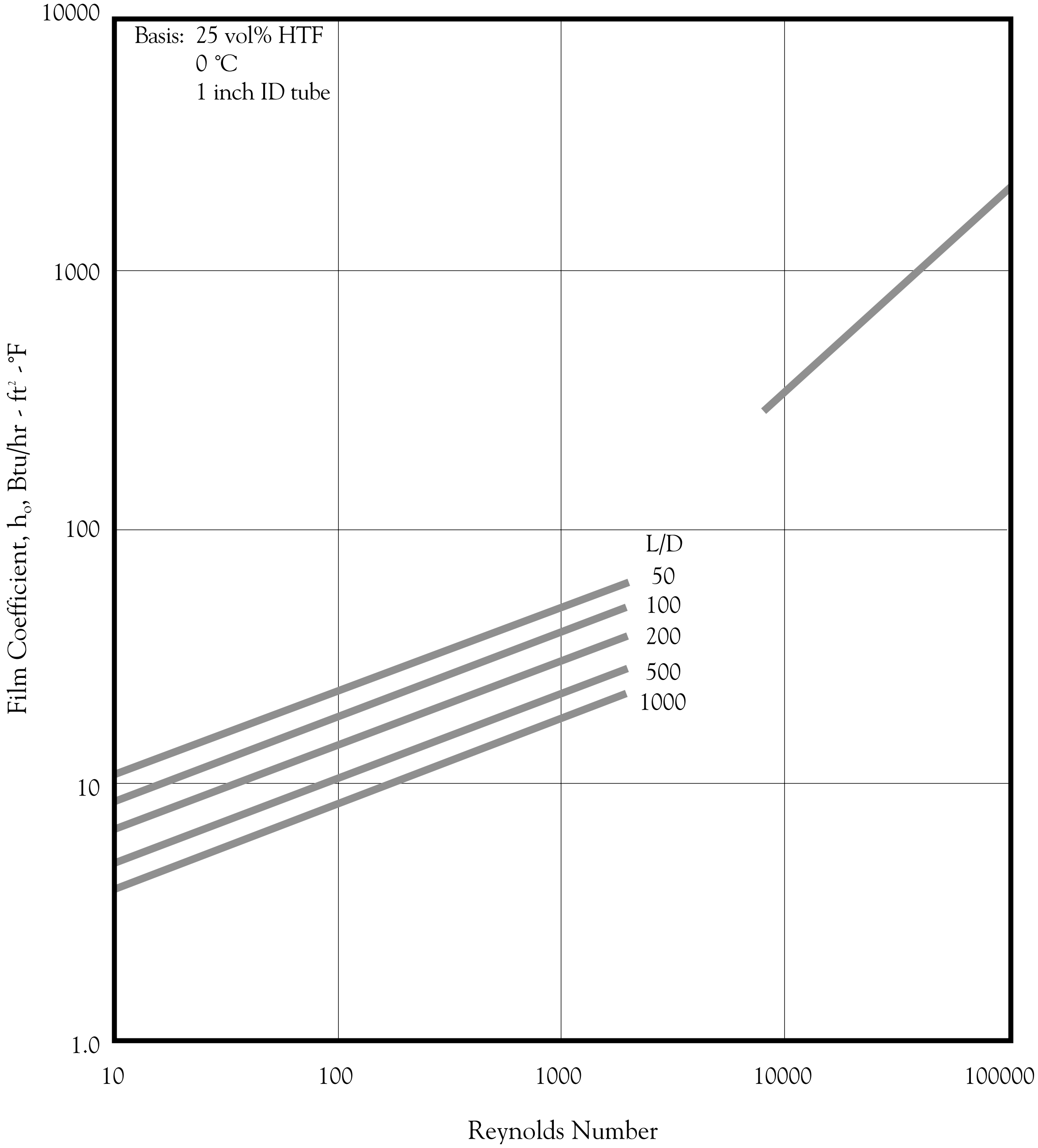


Figure 19 • Heat Transfer Coefficient Inside Tubes



$$h = h_o \bullet f_{TC} \bullet f_d \bullet \left(\frac{\mu_B}{\mu_W}\right)^{0.14}$$

Figure 19a • Temperature/Composition Multiplier

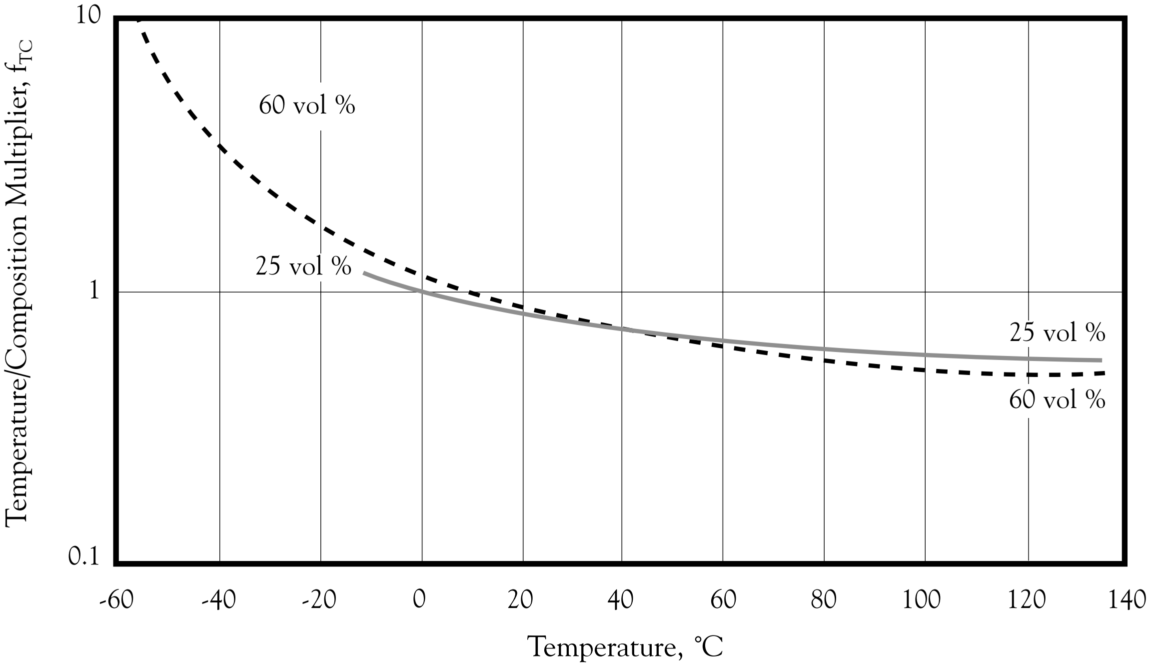


Figure 19b • Diameter Multiplier

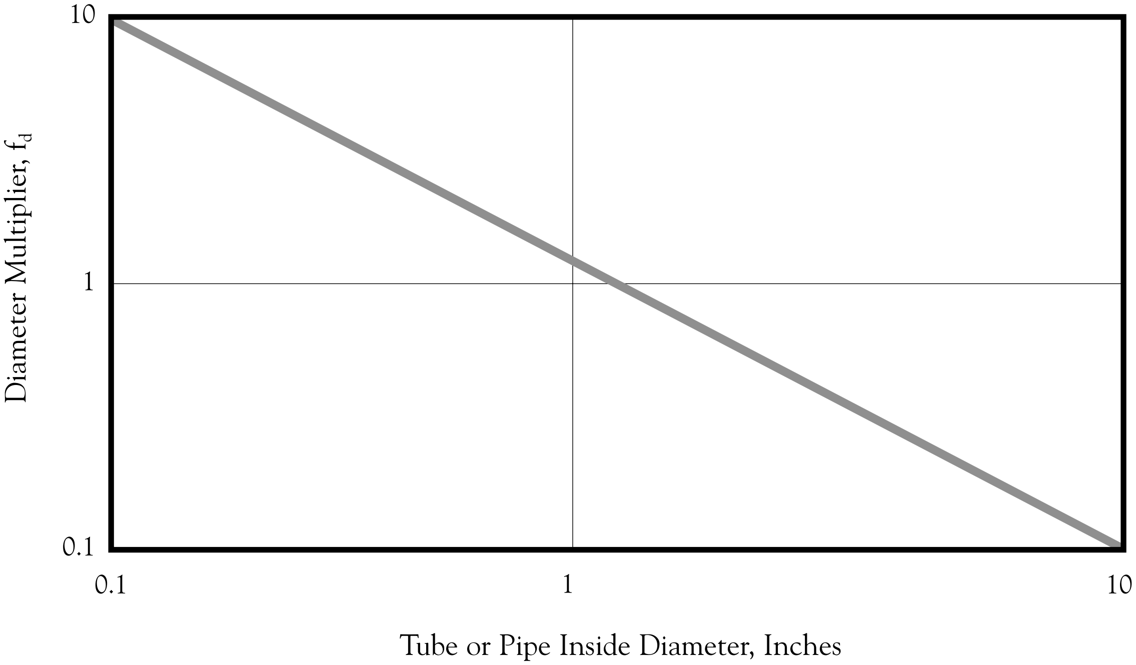
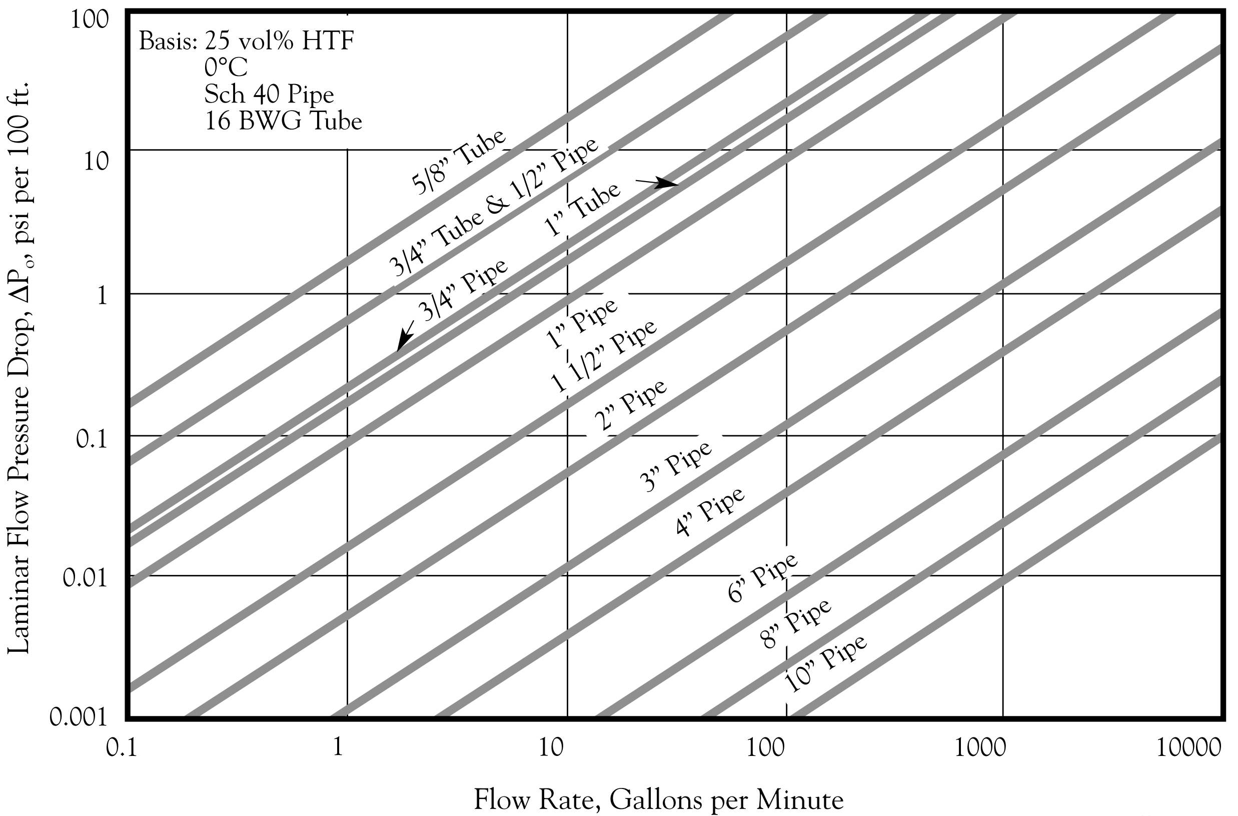


Figure 20 • Pressure Drop for Re<2100: Laminar Flow



$$\Delta P = \Delta P_o \bullet f_{TC} \bullet \left(\frac{\mu_W}{\mu_B}\right)^N$$

N = 0.14 for heat exchangers

N = 0 for pipe

Figure 20a • Temperature/Composition Multiplier

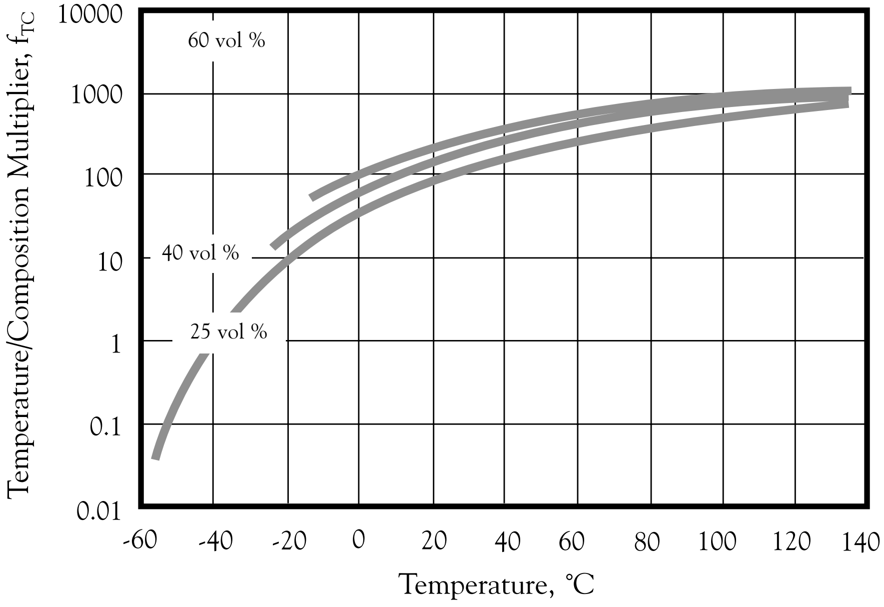
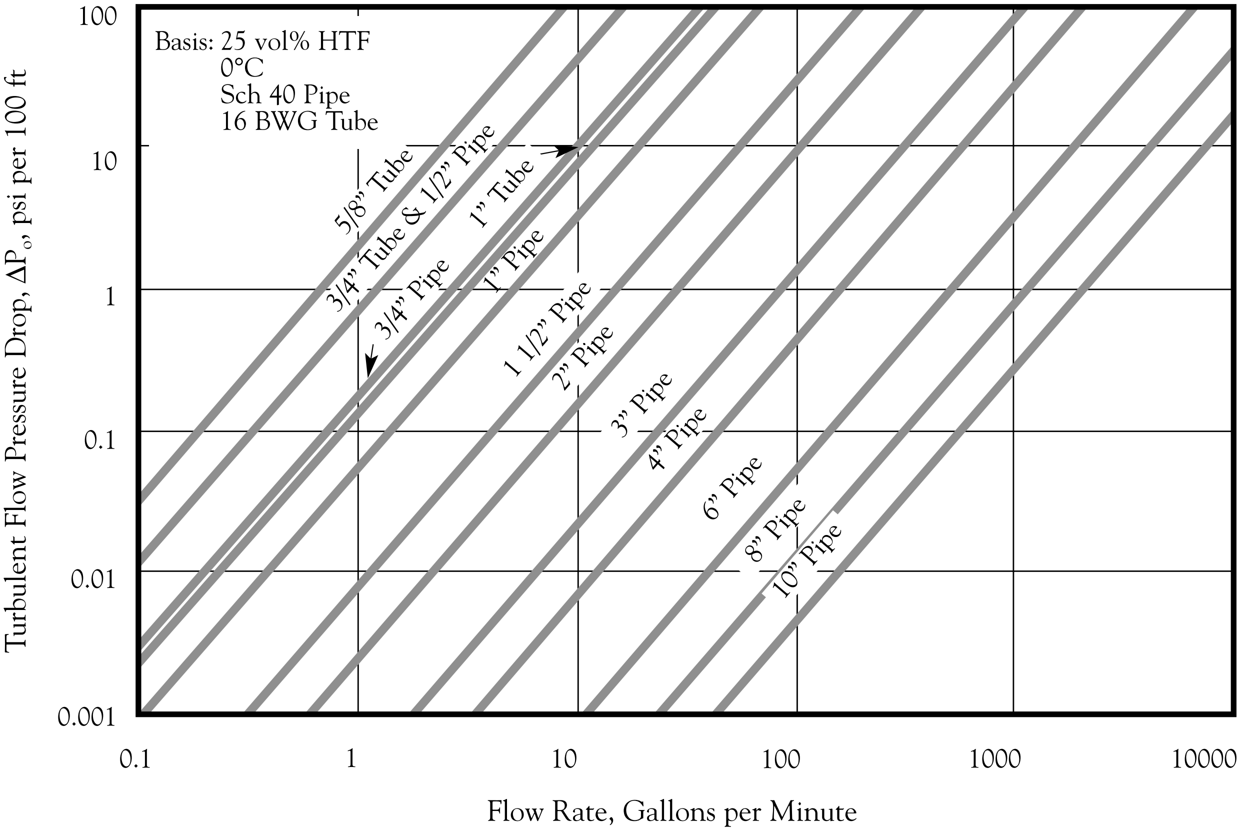


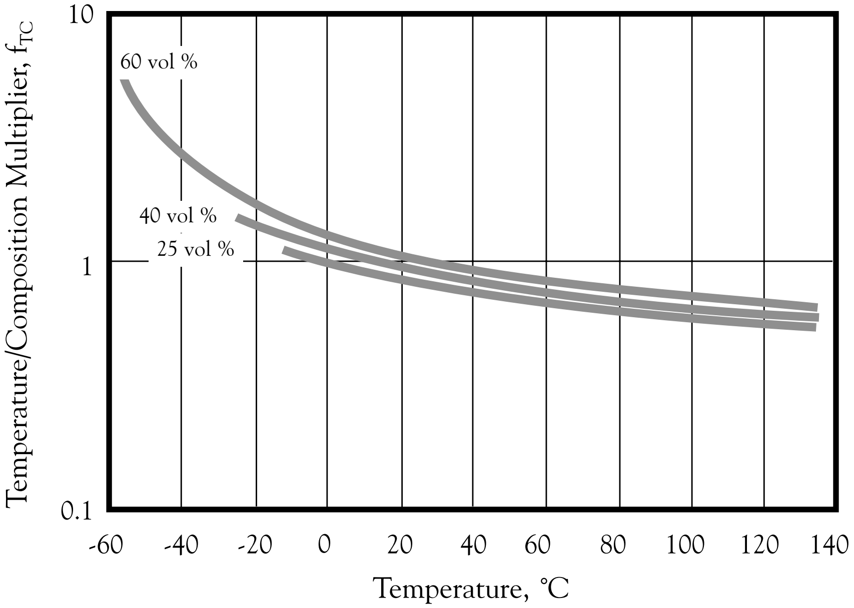
Figure 21 • Pressure Drop for Re>3000: Transition and Turbulent Flow



$$\Delta P = \Delta P_o \bullet f_{TC} \bullet \left(\frac{\mu_W}{\mu_B}\right)^N$$

N = 0.14 for heat exchangers
N = 0 for pipe

Figure 21a • Temperature/Composition Multiplier



Engineering Guide *for NORKOOL/UCARTHERM Heat Transfer Fluids*

To learn more contact…

The Dow Chemical Company
Midland, Michigan 48674 U.S.A.

In the United States and Canada: call 1-800-447-4369 • fax 1-989-832-1465
In Europe: call toll-free +800 3 694 6367 • call +32 3 450 2240 • fax +32 3 450 2815
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