CHAPTER 21

PHYSICAL PROPERTIES OF SECONDARY COOLANTS (BRINES)

IN MANY refrigeration applications, heat is transferred to a **secondary coolant**, which can be any liquid cooled by the refrigerant and used to transfer heat without changing state. These liquids are also known as **heat transfer fluids**, **brines**, or **secondary refrigerants**.

Other ASHRAE Handbooks describe various applications for secondary coolants. In the *ASHRAE Handbook—Refrigeration*, refrigeration systems are discussed in Chapter 4, their uses in food processing are found in Chapters 14 through 28, and ice rinks are discussed in Chapter 34. In the *ASHRAE Handbook—Applications*, solar energy use is discussed in Chapter 33, thermal storage in Chapter 34, and snow melting in Chapter 50.

This chapter describes the physical properties of several secondary coolants and provides information on their use. The chapter also includes information on corrosion protection. Additional information on corrosion inhibition can be found in Chapter 48 of the *ASHRAE Handbook—Applications* and Chapter 4 of the *ASHRAE Handbook—Refrigeration*.

BRINES

Physical Properties

Water solutions of calcium chloride and sodium chloride are the most common refrigeration brines. Tables 1 and 2 list the properties of pure calcium chloride brine and sodium chloride brine. For commercial grades, use the formulas in the footnotes to these tables. Figures 1 and 5 give the specific heats for calcium chloride and sodium chloride brines and are used for computation of heat loads with ordinary brine (Carrier 1959). Figures 2 and 6 show the ratio of the mass of the solution to that of water, which is commonly used as the measure of salt concentration. Viscosities are given in Figures 3 and 7. Figures 4 and 8 show thermal conductivity of calcium and sodium brines at varying temperatures and concentrations.

Brine applications in refrigeration are mainly in the industrial machinery field and in skating rinks. Corrosion is the principal problem for calcium chloride brines, especially in ice-making tanks where galvanized iron cans are immersed.

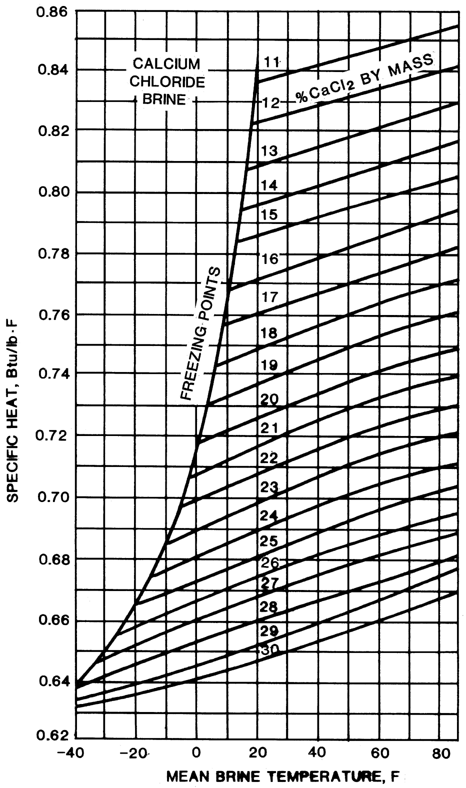

Fig. 1 Specific Heat of Calcium Chloride Brines

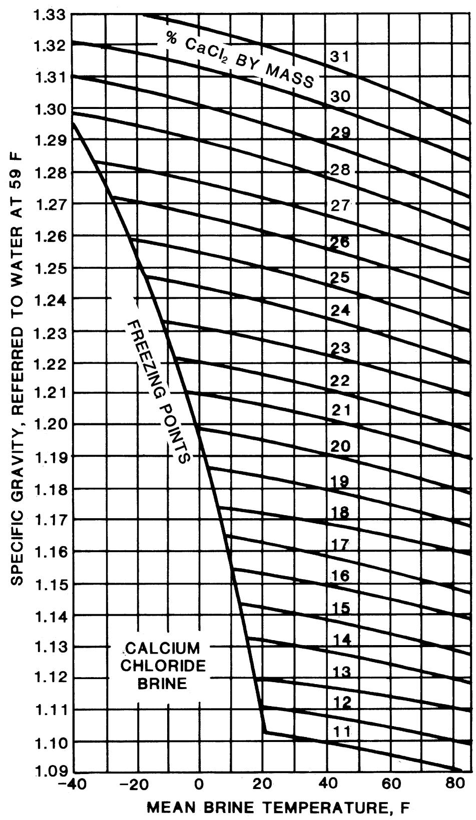

Fig. 2 Specific Gravity of Calcium Chloride Brines

The preparation of this chapter is assigned to TC 3.1, Refrigerants and Brines.

Table 1 Properties of Pure Calcium Chloride[a] Brines

Pure $CaCl_2$, % by Mass	Ratio of Mass to Water at 60°F	Baume Density at 60°F	Specific Heat at 60°F, Btu/lb·°F	Crystallization Starts, °F	Mass per Unit Volume[b] at 60°F				Ratio of Mass at Various Temperatures to Water at 60°F			
					$CaCl_2$, lb/gal	Brine, lb/gal	$CaCl_2$, lb/ft^3	Brine, lb/ft^3	−4°F	14°F	32°F	50°F
0	1.000	0.0	1.000	32.0	0.000	8.34	0.00	62.40				
5	1.044	6.1	0.924	27.7	0.436	8.717	3.26	65.15			1.043	1.042
6	1.050	7.0	0.914	26.8	0.526	8.760	3.93	65.52			1.052	1.051
7	1.060	8.2	0.898	25.9	0.620	8.851	4.63	66.14			1.061	1.060
8	1.069	9.3	0.884	24.6	0.714	8.926	5.34	66.70			1.071	1.069
9	1.078	10.4	0.869	23.5	0.810	9.001	6.05	67.27			1.080	1.078
10	1.087	11.6	0.855	22.3	0.908	9.076	6.78	67.83			1.089	1.087
11	1.096	12.6	0.842	20.8	1.006	9.143	7.52	68.33			1.098	1.096
12	1.105	13.8	0.828	19.3	1.107	9.227	8.27	68.95			1.108	1.105
13	1.114	14.8	0.816	17.6	1.209	9.302	9.04	69.51			1.117	1.115
14	1.124	15.9	0.804	15.5	1.313	9.377	9.81	70.08			1.127	1.124
15	1.133	16.9	0.793	13.5	1.418	9.452	10.60	70.64		1.139	1.137	1.134
16	1.143	18.0	0.779	11.2	1.526	9.536	11.40	71.26		1.149	1.146	1.143
17	1.152	19.1	0.767	8.6	1.635	9.619	12.22	71.89		1.159	1.156	1.153
18	1.162	20.2	0.756	5.9	1.747	9.703	13.05	72.51		1.169	1.166	1.163
19	1.172	21.3	0.746	2.8	1.859	9.786	13.90	73.13		1.180	1.176	1.173
20	1.182	22.1	0.737	−0.4	1.970	9.853	14.73	73.63		1.190	1.186	1.183
21	1.192	23.0	0.729	−3.9	2.085	9.928	15.58	74.19				
22	1.202	24.4	0.716	−7.8	2.208	10.037	16.50	75.00	1.215	1.211	1.207	1.203
23	1.212	25.5	0.707	−11.9	2.328	10.120	17.40	75.63				
24	1.223	26.4	0.697	−16.2	2.451	10.212	18.32	76.32	1.236	1.232	1.228	1.224
25	1.233	27.4	0.689	−21.0	2.574	10.295	19.24	76.94				
26	1.244	28.3	0.682	−25.8	2.699	10.379	20.17	77.56				
27	1.254	29.3	0.673	−31.2	2.827	10.471	21.13	78.25				
28	1.265	30.4	0.665	−37.8	2.958	10.563	22.10	78.94				
29	1.276	31.4	0.658	−49.4	3.090	10.655	23.09	79.62				
29.87	1.290	32.6	0.655	−67.0	3.16	10.75	23.65	80.45				
30	1.295	33.0	0.653	−50.8	3.22	10.80	24.06	80.76				
32	1.317	34.9	0.640	−19.5	3.49	10.98	26.10	82.14				
34	1.340	36.8	0.630	4.3	3.77	11.17	28.22	83.57				

[a]Mass of Type 1 (77% min.) $CaCl_2$ = (mass of pure $CaCl_2$)/(0.77). Mass of Type 2 (94% min.) $CaCl_2$ = (mass of pure $CaCl_2$)/(0.94).
[b]Mass of water per unit volume = Brine mass minus $CaCl_2$ mass.

Table 2 Properties of Pure Sodium Chloride[a] Brines

Pure NaCl, % by Mass	Ratio of Mass to Water at 59°F	Baume Density at 60°F	Specific Heat at 59°F, Btu/lb·°F	Crystallization Starts, °F	Mass per Unit Volume[b] at 60°F				Ratio of Mass at Various Temperatures to Water at 60°F			
					NaCl, lb/gal	Brine, lb/gal	NaCl, lb/ft^3	Brine, lb/ft^3	14°F	32°F	50°F	68°F
0	1.000	0.0	1.000	32.0	0.000	8.34	0.000	62.4				
5	1.035	5.1	0.938	26.7	0.432	8.65	3.230	64.6		1.0382	1.0366	1.0341
6	1.043	6.1	0.927	25.5	0.523	8.71	3.906	65.1		1.0459	1.0440	1.0413
7	1.050	7.0	0.917	24.3	0.613	8.76	4.585	65.5		1.0536	1.0515	1.0486
8	1.057	8.0	0.907	23.0	0.706	8.82	5.280	66.0		1.0613	1.0590	1.0559
9	1.065	9.0	0.897	21.6	0.800	8.89	5.985	66.5		1.0691	1.0665	1.0633
10	1.072	10.1	0.888	20.2	0.895	8.95	6.690	66.9		1.0769	1.0741	1.0707
11	1.080	10.8	0.879	18.8	0.992	9.02	7.414	67.4		1.0849	1.0817	1.0782
12	1.087	11.8	0.870	17.3	1.090	9.08	8.136	67.8		1.0925	1.0897	1.0857
13	1.095	12.7	0.862	15.7	1.188	9.14	8.879	68.3		1.1004	1.0933	1.0971
14	1.103	13.6	0.854	14.0	1.291	9.22	9.632	68.8		1.1083	1.1048	1.1009
15	1.111	14.5	0.847	12.3	1.392	9.28	10.395	69.3	1.1195	1.1163	1.1126	1.1086
16	1.118	15.4	0.840	10.5	1.493	9.33	11.168	69.8	1.1277	1.1243	1.1205	1.1163
17	1.126	16.3	0.833	8.6	1.598	9.40	11.951	70.3	1.1359	1.1323	1.1284	1.1241
18	1.134	17.2	0.826	6.6	1.705	9.47	12.744	70.8	1.1442	1.1404	1.1363	1.1319
19	1.142	18.1	0.819	4.5	1.813	9.54	13.547	71.3	1.1535	1.1486	1.1444	1.1398
20	1.150	19.0	0.813	2.3	1.920	9.60	14.360	71.8	1.1608	1.1568	1.1542	1.1478
21	1.158	19.9	0.807	0.0	2.031	9.67	15.183	72.3	1.1692	1.1651	1.1606	1.1559
22	1.166	20.8	0.802	−2.3	2.143	9.74	16.016	72.8	1.1777	1.1734	1.1688	1.1640
23	1.175	21.7	0.796	−5.1	2.256	9.81	16.854	73.3	1.1862	1.1818	1.1771	1.1721
24	1.183	22.5	0.791	3.8	2.371	9.88	17.712	73.8	1.1948	1.1902	1.1854	1.1804
25	1.191	23.4	0.786	16.1	2.488	9.95	18.575	74.3				
25.2	1.200			32.0								

[a]Mass of commercial NaCl required = (mass of pure NaCl required)/(% purity).
[b]Mass of water per unit volume = Brine mass minus NaCl mass.

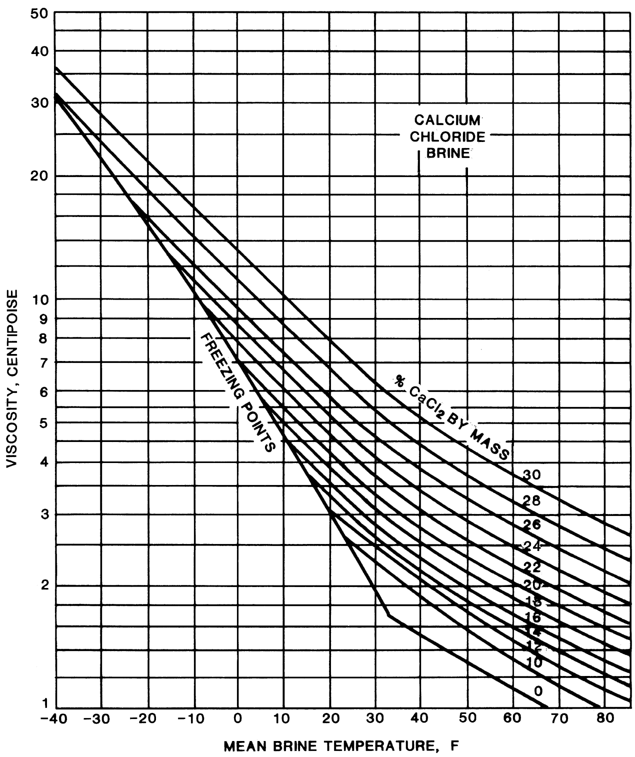

Fig. 3 Viscosity of Calcium Chloride Brines

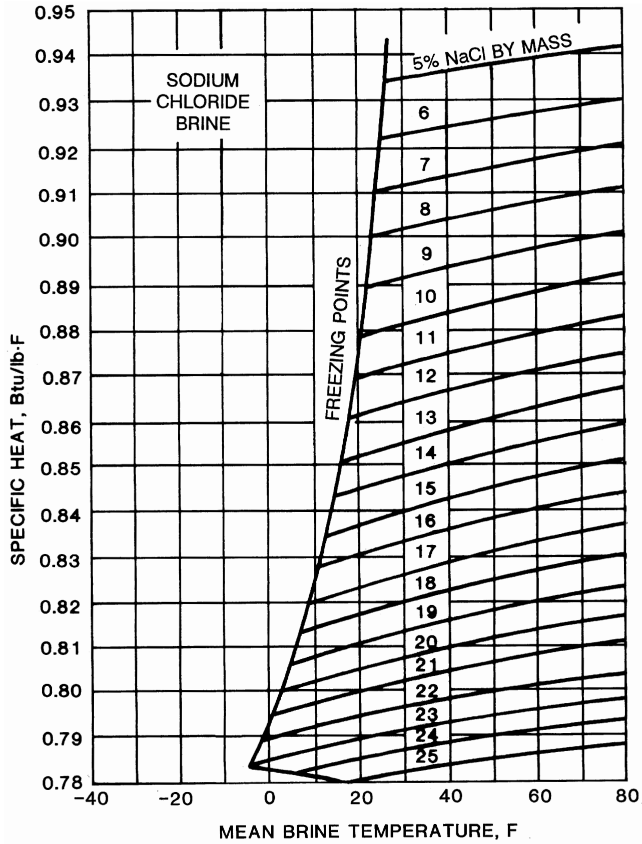

Fig. 5 Specific Heat of Sodium Chloride Brines

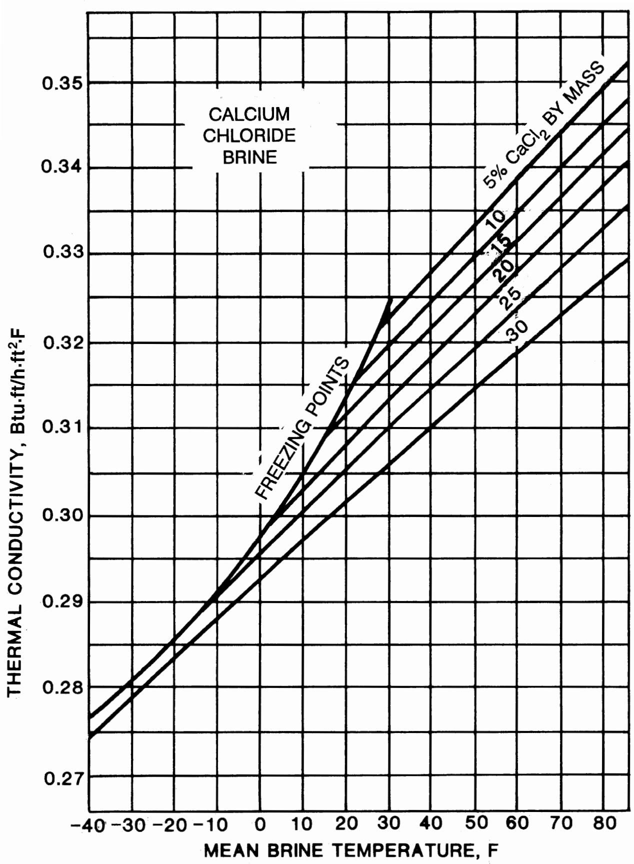

Fig. 4 Thermal Conductivity of Calcium Chloride Brines

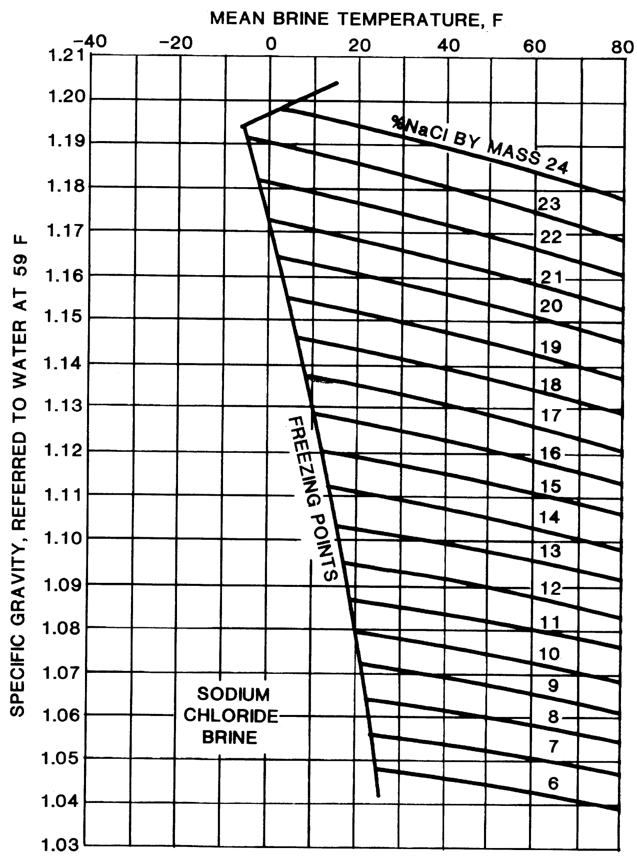

Fig. 6 Specific Gravity of Sodium Chloride Brines

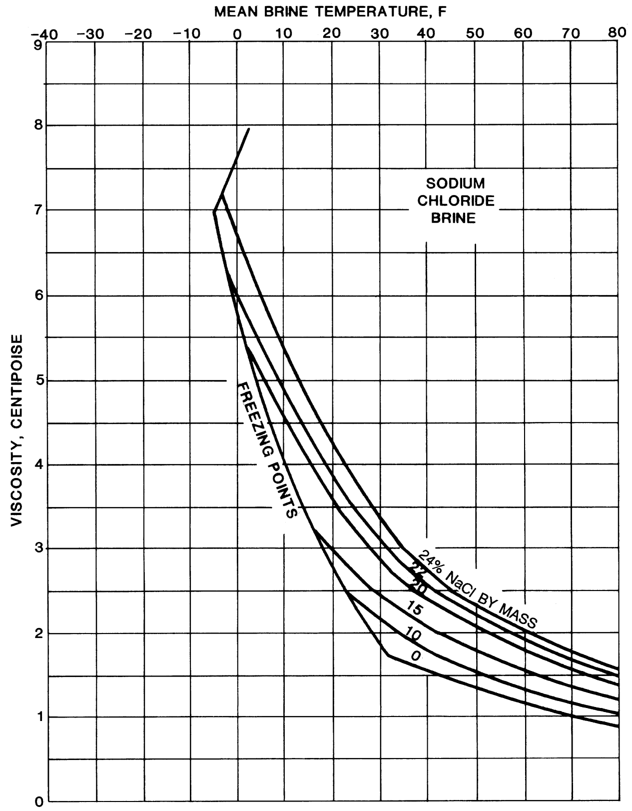

Fig. 7 Viscosity of Sodium Chloride Brines

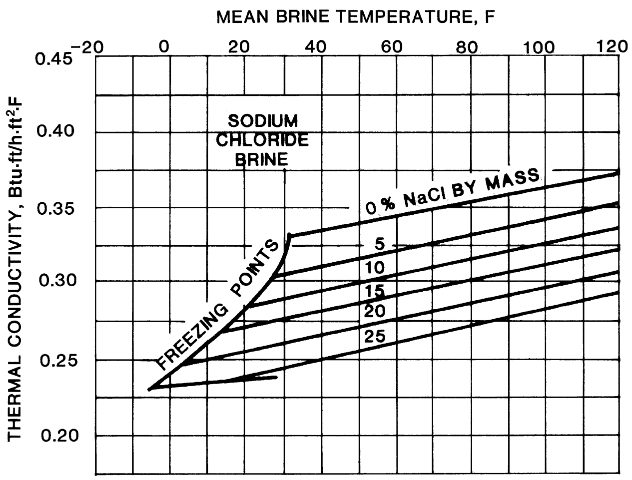

Fig. 8 Thermal Conductivity of Sodium Chloride Brines
(Carrier 1959)

Ordinary salt (sodium chloride) is used where contact with calcium chloride is intolerable (e.g., the brine fog method of freezing fish and other foods). It is used as a spray in air cooling of unit coolers to prevent frost formation on coils. In most refrigerating work, the lower freezing point of calcium chloride solution makes it more convenient to use.

Commercial calcium chloride, available as Type 1 (77% minimum) and Type 2 (94% minimum), is marketed in flake, solid, and solution forms; flake form is used most extensively. Commercial sodium chloride is available both in crude (rock salt) and refined grades. Because magnesium salts tend to form sludge, their presence in sodium or calcium chloride is undesirable.

Corrosion Inhibition

Brine systems must be treated to control corrosion and deposits. The standard chromate treatment program is the most effective. Calcium chloride brines require a minimum of 1800 ppm of sodium chromate with pH 6.5 to 8.5. Sodium chloride brines require a minimum of 3600 ppm of sodium chromate and a pH of 6.5 to 8.5. Sodium nitrite at 3000 ppm in calcium brines or 4000 ppm in sodium brines controls pH between 7.0 and 8.5, and it should provide adequate protection. Organic inhibitors are available that may provide adequate protection where neither chromates nor nitrites can be used.

Before using any chromate-based inhibitor package, review federal, state, and local regulations concerning the use and disposal of chromate-containing fluids. If the regulations prove too restrictive, an alternative inhibition system should be considered.

INHIBITED GLYCOLS

Ethylene glycol and propylene glycol, inhibited for corrosion control, are used as aqueous freezing point depressants (antifreeze) and heat transfer media. Their chief attributes are their ability to lower the freezing point of water, their low volatility, and their relatively low corrosivity when properly inhibited. Inhibited ethylene glycol solutions have better physical properties than propylene glycol solutions, especially at lower temperatures. However, the less toxic propylene glycol is preferred for applications involving possible human contact or where mandated by regulations.

Physical Properties

Ethylene glycol and propylene glycol are colorless, practically odorless liquids that are miscible with water and many organic compounds. Table 3 shows properties of the pure materials.

The freezing and boiling points of aqueous solutions of ethylene glycol and propylene glycol are given in Tables 4 and 5. Note that increasing the concentration of ethylene glycol above 60% by mass causes the freezing point of the solution to increase. Propylene glycol solutions above 60% by mass do not have freezing points. Instead of freezing, propylene glycol solutions become a glass (glass being an

Table 3 Physical Properties of Ethylene Glycol and Propylene Glycol

Property	Ethylene Glycol	Propylene Glycol
Molecular weight	62.07	76.10
Ratio of mass to water at 68/68°F	1.1155	1.0381
Density at 68°F		
lb/ft³	69.50	64.68
lb/gal	9.29	8.65
Boiling point, °F		
at 760 mm Hg	388	369
at 50 mm Hg	253	241
at 10 mm Hg	192	185
Vapor pressure at 68°F, mm Hg	0.05	0.07
Freezing point, °F	9.1	Sets to glass below −60°F
Viscosity, centipoise		
at 32°F	57.4	243
at 68°F	20.9	60.5
at 104°F	9.5	18.0
Refractive index n_D at 68°F	1.4319	1.4329
Specific heat at 68°F, Btu/lb·°F	0.561	0.593
Heat of fusion at 9.1°F, Btu/lb	80.5	—
Heat of vaporization at 1 atm, Btu/lb	364	296
Heat of combustion at 68°F, Btu/lb	8,280	10,312

Table 4 Freezing and Boiling Points of Aqueous Solutions of Ethylene Glycol

Percent Ethylene Glycol		Freezing Point, °F	Boiling Point, °F at 14.6 psia
By Mass	By Volume		
0.0	0.0	32.0	212
5.0	4.4	29.4	213
10.0	8.9	26.2	214
15.0	13.6	22.2	215
20.0	18.1	17.9	216
21.0	19.2	16.8	216
22.0	20.1	15.9	216
23.0	21.0	14.9	217
24.0	22.0	13.7	217
25.0	22.9	12.7	218
26.0	23.9	11.4	218
27.0	24.8	10.4	218
28.0	25.8	9.2	219
29.0	26.7	8.0	219
30.0	27.7	6.7	220
31.0	28.7	5.4	220
32.0	29.6	4.2	220
33.0	30.6	2.9	220
34.0	31.6	1.4	220
35.0	32.6	−0.2	221
36.0	33.5	−1.5	221
37.0	34.5	−3.0	221
38.0	35.5	−4.5	221
39.0	36.5	−6.4	221
40.0	37.5	−8.1	222
41.0	38.5	−9.8	222
42.0	39.5	−11.7	222
43.0	40.5	−13.5	223
44.0	41.5	−15.5	223
45.0	42.5	−17.5	224
46.0	43.5	−19.8	224
47.0	44.5	−21.6	224
48.0	45.5	−23.9	224
49.0	46.6	−26.7	224
50.0	47.6	−28.9	225
51.0	48.6	−31.2	225
52.0	49.6	−33.6	225
53.0	50.6	−36.2	226
54.0	51.6	−38.8	226
55.0	52.7	−42.0	227
56.0	53.7	−44.7	227
57.0	54.7	−47.5	228
58.0	55.7	−50.0	228
59.0	56.8	−52.7	229
60.0	57.8	−54.9	230
65.0	62.8	a	235
70.0	68.3	a	242
75.0	73.6	a	248
80.0	78.9	−52.2	255
85.0	84.3	−34.5	273
90.0	89.7	−21.6	285
95.0	95.0	−3.0	317

[a]Freezing points are below −60°F.

Table 5 Freezing and Boiling Points of Aqueous Solutions of Propylene Glycol

Percent Propylene Glycol		Freezing Point, °F	Boiling Point, °F at 14.6 psia
By Mass	By Volume		
0.0	0.0	32.0	212
5.0	4.8	29.1	212
10.0	9.6	26.1	212
15.0	14.5	22.9	212
20.0	19.4	19.2	213
21.0	20.4	18.3	213
22.0	21.4	17.6	213
23.0	22.4	16.6	213
24.0	23.4	15.6	213
25.0	24.4	14.7	214
26.0	25.3	13.7	214
27.0	26.4	12.6	214
28.0	27.4	11.5	215
29.0	28.4	10.4	215
30.0	29.4	9.2	216
31.0	30.4	7.9	216
32.0	31.4	6.6	216
33.0	32.4	5.3	216
34.0	33.5	3.9	216
35.0	34.4	2.4	217
36.0	35.5	0.8	217
37.0	36.5	−0.8	217
38.0	37.5	−2.4	218
39.0	38.5	−4.2	218
40.0	39.6	−6.0	219
41.0	40.6	−7.8	219
42.0	41.6	−9.8	219
43.0	42.6	−11.8	219
44.0	43.7	−13.9	219
45.0	44.7	−16.1	220
46.0	45.7	−18.3	220
47.0	46.8	−20.7	220
48.0	47.8	−23.1	221
49.0	48.9	−25.7	221
50.0	49.9	−28.3	222
51.0	50.9	−31.0	222
52.0	51.9	−33.8	222
53.0	53.0	−36.7	223
54.0	54.0	−39.7	223
55.0	55.0	−42.8	223
56.0	56.0	−46.0	223
57.0	57.0	−49.3	224
58.0	58.0	−52.7	224
59.0	59.0	−56.2	224
60.0	60.0	−59.9	225
65.0	65.0	a	227
70.0	70.0	a	230
75.0	75.0	a	237
80.0	80.0	a	245
85.0	85.0	a	257
90.0	90.0	a	270
95.0	95.0	a	310

[a]Above 60% by mass, solutions do not freeze but become a glass.

amorphous, undercooled liquid of extremely high viscosities that has all the appearances of a solid). On the dilute side of the eutectic, ice forms on freezing; on the concentrated side, solid glycol separates from solution on freezing. The freezing velocity of such solutions is often quite slow; but, in time, they set to a hard, solid mass.

Physical properties (i.e., density, specific heat, thermal conductivity, and viscosity) for aqueous solutions of ethylene glycol can be found in Tables 6 through 9 and Figures 9 through 12; similar data for aqueous solutions of propylene glycol can be found in Tables 10 through 13 and Figures 13 through 16. Densities are for aqueous solutions of industrially inhibited glycols. These densities are somewhat higher than those for pure glycol and water alone. Typical corrosion inhibitor packages do not significantly affect the other physical properties. The physical properties for the two fluids are similar, with the exception of viscosity. At the same concentration, aqueous solutions of propylene glycol are more viscous than solutions of ethylene glycol. This higher viscosity accounts for the majority of the performance difference between the two fluids.

The choice of glycol concentration depends on the type of protection required by the application. If the fluid is being used to prevent equipment damage during idle periods in cold weather, such as winterizing coils in an HVAC system, 30% ethylene glycol or 35% propylene glycol is sufficient. These concentrations will allow the fluid to freeze. As the fluid freezes, it forms a slush that expands and flows into any available space. Therefore, expansion volume must be included with this type of protection. If the application requires that the fluid remain entirely liquid, a concentration with a freezing point 5°F below the lowest expected temperature should be chosen. Avoid excessive glycol concentration because it increases initial cost and adversely affects the physical properties of the fluid.

Table 6 Density of Aqueous Solutions of Ethylene Glycol

	Concentrations in Volume Percent Ethylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30					68.12	69.03	69.90	70.75	
−20					68.05	68.96	69.82	70.65	71.45
−10				67.04	67.98	68.87	69.72	70.54	71.33
0				66.97	67.90	68.78	69.62	70.43	71.20
10			65.93	66.89	67.80	68.67	69.50	70.30	71.06
20		64.83	65.85	66.80	67.70	68.56	69.38	70.16	70.92
30	63.69	64.75	65.76	66.70	67.59	68.44	69.25	70.02	70.76
40	63.61	64.66	65.66	66.59	67.47	68.31	69.10	69.86	70.59
50	63.52	64.56	65.55	66.47	67.34	68.17	68.95	69.70	70.42
60	63.42	64.45	65.43	66.34	67.20	68.02	68.79	69.53	70.23
70	63.31	64.33	65.30	66.20	67.05	67.86	68.62	69.35	70.04
80	63.19	64.21	65.17	66.05	66.90	67.69	68.44	69.15	69.83
90	63.07	64.07	65.02	65.90	66.73	67.51	68.25	68.95	69.62
100	62.93	63.93	64.86	65.73	66.55	67.32	68.05	68.74	69.40
110	62.79	63.77	64.70	65.56	66.37	67.13	67.84	68.52	69.17
120	62.63	63.61	64.52	65.37	66.17	66.92	67.63	68.29	68.92
130	62.47	63.43	64.34	65.18	65.97	66.71	67.40	68.05	68.67
140	62.30	63.25	64.15	64.98	65.75	66.48	67.16	67.81	68.41
150	62.11	63.06	63.95	64.76	65.53	66.25	66.92	67.55	68.14
160	61.92	62.86	63.73	64.54	65.30	66.00	66.66	67.28	67.86
170	61.72	62.64	63.51	64.31	65.05	65.75	66.40	67.01	67.58
180	61.51	62.42	63.28	64.07	64.80	65.49	66.12	66.72	67.28
190	61.29	62.19	63.04	63.82	64.54	65.21	65.84	66.42	66.97
200	61.06	61.95	62.79	63.56	64.27	64.93	65.55	66.12	66.65
210	60.82	61.71	62.53	63.29	63.99	64.64	65.24	65.81	66.33
220	60.57	61.45	62.27	63.01	63.70	64.34	64.93	65.48	65.99
230	60.31	61.18	61.99	62.72	63.40	64.03	64.61	65.15	65.65
240	60.05	60.90	61.70	62.43	63.10	63.71	64.28	64.81	65.29
250	59.77	60.62	61.40	62.12	62.78	63.39	63.94	64.46	64.93

Note: Density in lb/ft^3.

Table 7 Specific Heat of Aqueous Solutions of Ethylene Glycol

	Concentrations in Volume Percent Ethylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30					0.734	0.680	0.625	0.567	
−20					0.739	0.686	0.631	0.574	0.515
−10				0.794	0.744	0.692	0.638	0.581	0.523
0				0.799	0.749	0.698	0.644	0.588	0.530
10			0.849	0.803	0.754	0.703	0.651	0.595	0.538
20		0.897	0.853	0.808	0.759	0.709	0.657	0.603	0.546
30	0.940	0.900	0.857	0.812	0.765	0.715	0.664	0.610	0.553
40	0.943	0.903	0.861	0.816	0.770	0.721	0.670	0.617	0.561
50	0.945	0.906	0.864	0.821	0.775	0.727	0.676	0.624	0.569
60	0.947	0.909	0.868	0.825	0.780	0.732	0.683	0.631	0.576
70	0.950	0.912	0.872	0.830	0.785	0.738	0.689	0.638	0.584
80	0.952	0.915	0.876	0.834	0.790	0.744	0.696	0.645	0.592
90	0.954	0.918	0.880	0.839	0.795	0.750	0.702	0.652	0.600
100	0.957	0.922	0.883	0.843	0.800	0.756	0.709	0.659	0.607
110	0.959	0.925	0.887	0.848	0.806	0.761	0.715	0.666	0.615
120	0.961	0.928	0.891	0.852	0.811	0.767	0.721	0.673	0.623
130	0.964	0.931	0.895	0.857	0.816	0.773	0.728	0.680	0.630
140	0.966	0.934	0.898	0.861	0.821	0.779	0.734	0.687	0.638
150	0.968	0.937	0.902	0.865	0.826	0.785	0.741	0.694	0.646
160	0.971	0.940	0.906	0.870	0.831	0.790	0.747	0.702	0.654
170	0.973	0.943	0.910	0.874	0.836	0.796	0.754	0.709	0.661
180	0.975	0.946	0.913	0.879	0.842	0.802	0.760	0.716	0.669
190	0.978	0.949	0.917	0.883	0.847	0.808	0.766	0.723	0.677
200	0.980	0.952	0.921	0.888	0.852	0.813	0.773	0.730	0.684
210	0.982	0.955	0.925	0.892	0.857	0.819	0.779	0.737	0.692
220	0.985	0.958	0.929	0.897	0.862	0.825	0.786	0.744	0.700
230	0.987	0.961	0.932	0.901	0.867	0.831	0.792	0.751	0.708
240	0.989	0.964	0.936	0.905	0.872	0.837	0.799	0.758	0.715
250	0.992	0.967	0.940	0.910	0.877	0.842	0.805	0.765	0.723

Note: Specific heat in Btu/lb·°F.

Table 8 Thermal Conductivity of Aqueous Solutions of Ethylene Glycol

	Concentrations in Volume Percent Ethylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
–30					0.190	0.178	0.167	0.158	
–20					0.193	0.181	0.170	0.160	0.151
–10				0.212	0.197	0.184	0.172	0.161	0.152
0				0.216	0.200	0.186	0.174	0.163	0.153
10			0.238	0.220	0.204	0.189	0.176	0.164	0.154
20		0.264	0.243	0.224	0.207	0.191	0.178	0.166	0.155
30	0.294	0.269	0.247	0.227	0.210	0.194	0.180	0.167	0.156
40	0.300	0.274	0.251	0.231	0.212	0.196	0.182	0.169	0.157
50	0.305	0.279	0.255	0.234	0.215	0.198	0.183	0.170	0.158
60	0.311	0.284	0.259	0.237	0.218	0.200	0.185	0.171	0.159
70	0.316	0.288	0.263	0.240	0.220	0.202	0.186	0.172	0.160
80	0.320	0.292	0.266	0.243	0.223	0.204	0.188	0.173	0.161
90	0.325	0.296	0.269	0.246	0.225	0.206	0.189	0.174	0.161
100	0.329	0.299	0.272	0.248	0.227	0.208	0.190	0.175	0.162
110	0.333	0.302	0.275	0.251	0.229	0.209	0.192	0.176	0.163
120	0.336	0.305	0.277	0.253	0.230	0.210	0.193	0.177	0.163
130	0.339	0.308	0.280	0.255	0.232	0.212	0.194	0.178	0.164
140	0.342	0.311	0.282	0.256	0.233	0.213	0.195	0.179	0.165
150	0.345	0.313	0.284	0.258	0.235	0.214	0.196	0.180	0.165
160	0.347	0.315	0.285	0.259	0.236	0.215	0.197	0.180	0.166
170	0.349	0.316	0.287	0.261	0.237	0.216	0.197	0.181	0.166
180	0.351	0.318	0.288	0.262	0.238	0.217	0.198	0.181	0.167
190	0.352	0.319	0.289	0.263	0.239	0.218	0.199	0.182	0.167
200	0.353	0.320	0.290	0.263	0.240	0.218	0.199	0.182	0.168
210	0.354	0.321	0.291	0.264	0.240	0.219	0.200	0.183	0.168
220	0.355	0.321	0.291	0.265	0.240	0.219	0.200	0.183	0.168
230	0.355	0.322	0.291	0.265	0.241	0.219	0.200	0.183	0.169
240	0.355	0.322	0.291	0.265	0.241	0.219	0.200	0.184	0.169
250	0.354	0.321	0.291	0.265	0.241	0.220	0.201	0.184	0.169

Note: Thermal conductivity in $Btu \cdot ft/h \cdot ft^2 \cdot °F$.

Table 9 Viscosity of Aqueous Solutions of Ethylene Glycol

	Concentrations in Volume Percent Ethylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
–30					63.69	89.67	128.79	185.22	
–20					40.38	60.46	89.93	131.32	284.48
–10				19.58	27.27	42.05	63.50	91.88	169.83
0				13.76	19.34	30.08	45.58	65.04	107.77
10			6.83	10.13	14.26	22.06	33.31	46.89	71.87
20		3.90	5.38	7.74	10.85	16.56	24.79	34.48	49.94
30	2.16	3.14	4.33	6.09	8.48	12.68	18.77	25.84	35.91
40	1.82	2.59	3.54	4.91	6.77	9.90	14.45	19.71	26.59
50	1.56	2.18	2.95	4.04	5.50	7.85	11.31	15.29	20.18
60	1.35	1.86	2.49	3.38	4.55	6.33	8.97	12.05	15.65
70	1.18	1.61	2.13	2.87	3.81	5.17	7.22	9.62	12.37
80	1.04	1.41	1.84	2.46	3.23	4.28	5.88	7.79	9.93
90	0.93	1.24	1.60	2.13	2.76	3.58	4.85	6.38	8.10
100	0.83	1.11	1.41	1.87	2.39	3.03	4.04	5.28	6.68
110	0.75	0.99	1.25	1.64	2.08	2.58	3.40	4.41	5.58
120	0.68	0.90	1.11	1.46	1.82	2.23	2.88	3.73	4.71
130	0.62	0.81	1.00	1.30	1.61	1.93	2.47	3.17	4.01
140	0.57	0.74	0.90	1.17	1.43	1.69	2.13	2.72	3.45
150	0.53	0.68	0.82	1.05	1.28	1.49	1.86	2.35	2.98
160	0.49	0.63	0.75	0.95	1.15	1.32	1.63	2.05	2.60
170	0.46	0.58	0.68	0.87	1.04	1.18	1.43	1.80	2.28
180	0.43	0.54	0.63	0.79	0.94	1.06	1.27	1.58	2.01
190	0.40	0.50	0.58	0.73	0.85	0.95	1.14	1.40	1.79
200	0.37	0.47	0.54	0.67	0.78	0.86	1.02	1.25	1.60
210	0.35	0.43	0.50	0.61	0.71	0.78	0.92	1.12	1.43
220	0.33	0.41	0.46	0.57	0.66	0.72	0.83	1.01	1.29
230	0.32	0.38	0.43	0.53	0.60	0.66	0.76	0.91	1.16
240	0.30	0.36	0.40	0.49	0.56	0.61	0.69	0.83	1.06
250	0.29	0.34	0.38	0.45	0.52	0.56	0.63	0.75	0.96

Note: Viscosity in centipoise.

Table 10 Density of Aqueous Solutions of an Industrially Inhibited Propylene Glycol

	Concentrations in Volume Percent Propylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30						67.05	67.47	68.38	68.25
−20					66.46	66.93	67.34	68.13	68.00
−10					66.35	66.81	67.20	67.87	67.75
0				65.71	66.23	66.68	67.05	67.62	67.49
10			65.00	65.60	66.11	66.54	66.89	67.36	67.23
20		64.23	64.90	65.48	65.97	66.38	66.72	67.10	66.97
30	63.38	64.14	64.79	65.35	65.82	66.22	66.54	66.83	66.71
40	63.30	64.03	64.67	65.21	65.67	66.05	66.35	66.57	66.44
50	63.20	63.92	64.53	65.06	65.50	65.87	66.16	66.30	66.18
60	63.10	63.79	64.39	64.90	65.33	65.68	65.95	66.04	65.91
70	62.98	63.66	64.24	64.73	65.14	65.47	65.73	65.77	65.64
80	62.86	63.52	64.08	64.55	64.95	65.26	65.51	65.49	65.37
90	62.73	63.37	63.91	64.36	64.74	65.04	65.27	65.22	65.09
100	62.59	63.20	63.73	64.16	64.53	64.81	65.03	64.95	64.82
110	62.44	63.03	63.54	63.95	64.30	64.57	64.77	64.67	64.54
120	62.28	62.85	63.33	63.74	64.06	64.32	64.51	64.39	64.26
130	62.11	62.66	63.12	63.51	63.82	64.06	64.23	64.11	63.98
140	61.93	62.46	62.90	63.27	63.57	63.79	63.95	63.83	63.70
150	61.74	62.25	62.67	63.02	63.30	63.51	63.66	63.55	63.42
160	61.54	62.03	62.43	62.76	63.03	63.22	63.35	63.26	63.13
170	61.33	61.80	62.18	62.49	62.74	62.92	63.04	62.97	62.85
180	61.11	61.56	61.92	62.22	62.45	62.61	62.72	62.68	62.56
190	60.89	61.31	61.65	61.93	62.14	62.29	62.39	62.39	62.27
200	60.65	61.05	61.37	61.63	61.83	61.97	62.05	62.10	61.97
210	60.41	60.78	61.08	61.32	61.50	61.63	61.69	61.81	61.68
220	60.15	60.50	60.78	61.00	61.17	61.28	61.33	61.51	61.38
230	59.89	60.21	60.47	60.68	60.83	60.92	60.96	61.21	61.08
240	59.61	59.91	60.15	60.34	60.47	60.55	60.58	60.91	60.78
250	59.33	59.60	59.82	59.99	60.11	60.18	60.19	60.61	60.48

Note: Density in lb/ft^3.

Table 11 Specific Heat of Aqueous Solutions of Propylene Glycol

	Concentrations in Volume Percent Propylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30						0.741	0.680	0.615	0.542
−20					0.799	0.746	0.687	0.623	0.550
−10					0.804	0.752	0.693	0.630	0.558
0				0.855	0.809	0.758	0.700	0.637	0.566
10			0.898	0.859	0.814	0.764	0.707	0.645	0.574
20		0.936	0.902	0.864	0.820	0.770	0.713	0.652	0.583
30	0.966	0.938	0.906	0.868	0.825	0.776	0.720	0.660	0.591
40	0.968	0.941	0.909	0.872	0.830	0.782	0.726	0.667	0.599
50	0.970	0.944	0.913	0.877	0.835	0.787	0.733	0.674	0.607
60	0.972	0.947	0.917	0.881	0.840	0.793	0.740	0.682	0.615
70	0.974	0.950	0.920	0.886	0.845	0.799	0.746	0.689	0.623
80	0.976	0.953	0.924	0.890	0.850	0.805	0.753	0.696	0.631
90	0.979	0.956	0.928	0.894	0.855	0.811	0.760	0.704	0.639
100	0.981	0.959	0.931	0.899	0.861	0.817	0.766	0.711	0.647
110	0.983	0.962	0.935	0.903	0.866	0.823	0.773	0.718	0.656
120	0.985	0.965	0.939	0.908	0.871	0.828	0.779	0.726	0.664
130	0.987	0.967	0.942	0.912	0.876	0.834	0.786	0.733	0.672
140	0.989	0.970	0.946	0.916	0.881	0.840	0.793	0.740	0.680
150	0.991	0.973	0.950	0.921	0.886	0.846	0.799	0.748	0.688
160	0.993	0.976	0.953	0.925	0.891	0.852	0.806	0.755	0.696
170	0.996	0.979	0.957	0.929	0.896	0.858	0.812	0.762	0.704
180	0.998	0.982	0.961	0.934	0.902	0.864	0.819	0.770	0.712
190	1.000	0.985	0.964	0.938	0.907	0.869	0.826	0.777	0.720
200	1.002	0.988	0.968	0.943	0.912	0.875	0.832	0.784	0.729
210	1.004	0.991	0.971	0.947	0.917	0.881	0.839	0.792	0.737
220	1.006	0.994	0.975	0.951	0.922	0.887	0.845	0.799	0.745
230	1.008	0.996	0.979	0.956	0.927	0.893	0.852	0.806	0.753
240	1.011	0.999	0.982	0.960	0.932	0.899	0.859	0.814	0.761
250	1.013	1.002	0.986	0.965	0.937	0.905	0.865	0.821	0.769

Note: Specific heat in Btu/lb·°F.

Table 12 Thermal Conductivity of Aqueous Solutions of Propylene Glycol

	Concentrations in Volume Percent Propylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30						0.171	0.159	0.147	0.137
−20					0.188	0.174	0.160	0.148	0.137
−10					0.191	0.176	0.161	0.148	0.136
0				0.211	0.194	0.178	0.162	0.149	0.136
10			0.235	0.215	0.196	0.179	0.163	0.149	0.136
20		0.262	0.239	0.218	0.199	0.181	0.164	0.150	0.136
30	0.293	0.267	0.243	0.222	0.201	0.183	0.165	0.150	0.135
40	0.299	0.272	0.247	0.225	0.204	0.184	0.166	0.150	0.135
50	0.304	0.277	0.251	0.227	0.206	0.186	0.167	0.150	0.135
60	0.310	0.281	0.254	0.230	0.208	0.187	0.168	0.150	0.134
70	0.315	0.285	0.258	0.233	0.210	0.188	0.168	0.151	0.134
80	0.319	0.289	0.261	0.235	0.211	0.189	0.169	0.151	0.134
90	0.323	0.292	0.263	0.237	0.213	0.190	0.169	0.151	0.133
100	0.327	0.295	0.266	0.239	0.214	0.191	0.170	0.151	0.133
110	0.331	0.298	0.268	0.241	0.215	0.192	0.170	0.151	0.132
120	0.334	0.301	0.270	0.243	0.217	0.193	0.170	0.150	0.132
130	0.338	0.304	0.272	0.244	0.218	0.193	0.170	0.150	0.131
140	0.340	0.306	0.274	0.245	0.218	0.194	0.171	0.150	0.131
150	0.343	0.308	0.276	0.246	0.219	0.194	0.171	0.150	0.130
160	0.345	0.309	0.277	0.247	0.220	0.194	0.171	0.150	0.130
170	0.347	0.311	0.278	0.248	0.220	0.195	0.171	0.149	0.129
180	0.348	0.312	0.279	0.249	0.221	0.195	0.170	0.149	0.129
190	0.350	0.313	0.280	0.249	0.221	0.195	0.170	0.148	0.128
200	0.351	0.314	0.280	0.249	0.221	0.194	0.170	0.148	0.127
210	0.351	0.314	0.280	0.249	0.221	0.194	0.169	0.147	0.127
220	0.352	0.314	0.280	0.249	0.220	0.194	0.169	0.147	0.126
230	0.352	0.314	0.280	0.249	0.220	0.193	0.168	0.146	0.125
240	0.351	0.314	0.280	0.249	0.220	0.193	0.168	0.146	0.125
250	0.351	0.314	0.279	0.248	0.219	0.192	0.167	0.145	0.124

Note: Thermal conductivity in Btu·ft/h·ft^2·°F.

Table 13 Viscosity of Aqueous Solutions of Propylene Glycol

	Concentrations in Volume Percent Propylene Glycol								
Temperature, °F	10%	20%	30%	40%	50%	60%	70%	80%	90%
−30						497.57	864.87	1363.75	3555.22
−20					156.08	298.75	493.93	820.58	1819.72
−10					95.97	182.96	291.28	495.68	983.05
0				40.99	61.32	114.90	177.73	303.94	558.32
10			13.44	27.17	40.62	74.19	112.20	190.41	332.02
20		5.36	9.91	18.64	27.83	49.29	73.22	122.30	205.91
30	2.80	4.23	7.47	13.20	19.66	33.68	49.32	80.66	132.67
40	2.28	3.41	5.75	9.63	14.28	23.65	34.22	54.64	88.51
50	1.89	2.79	4.52	7.22	10.65	17.05	24.41	37.99	60.93
60	1.60	2.32	3.61	5.55	8.13	12.59	17.86	27.10	43.16
70	1.38	1.95	2.94	4.36	6.34	9.51	13.38	19.79	31.37
80	1.20	1.66	2.43	3.50	5.04	7.34	10.25	14.79	23.35
90	1.05	1.43	2.04	2.86	4.08	5.77	8.00	11.29	17.75
100	0.93	1.25	1.73	2.37	3.35	4.62	6.37	8.79	13.76
110	0.83	1.10	1.49	2.00	2.79	3.76	5.15	6.97	10.86
120	0.75	0.97	1.30	1.71	2.36	3.11	4.23	5.62	8.71
130	0.68	0.87	1.14	1.49	2.02	2.61	3.53	4.60	7.09
140	0.62	0.78	1.01	1.30	1.75	2.22	2.98	3.82	5.85
150	0.57	0.71	0.90	1.16	1.53	1.91	2.54	3.22	4.89
160	0.52	0.64	0.82	1.03	1.35	1.66	2.19	2.75	4.13
170	0.48	0.59	0.74	0.93	1.20	1.45	1.91	2.37	3.52
180	0.44	0.54	0.68	0.85	1.08	1.29	1.69	2.07	3.04
190	0.41	0.50	0.62	0.78	0.97	1.15	1.50	1.82	2.64
200	0.38	0.46	0.58	0.72	0.88	1.04	1.34	1.61	2.31
210	0.36	0.43	0.54	0.67	0.81	0.94	1.21	1.45	2.04
220	0.34	0.40	0.50	0.62	0.74	0.86	1.10	1.31	1.82
230	0.32	0.38	0.47	0.59	0.69	0.79	1.00	1.19	1.63
240	0.30	0.36	0.45	0.55	0.64	0.73	0.92	1.09	1.47
250	0.28	0.34	0.42	0.52	0.59	0.68	0.85	1.00	1.33

Note: Viscosity in centipoise.

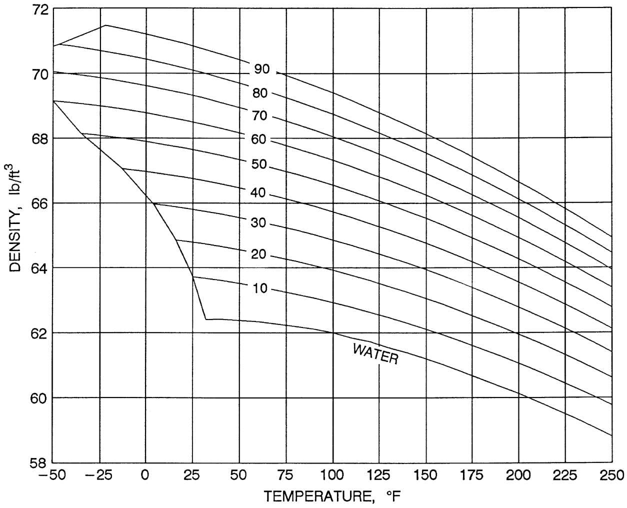

Fig. 9 Density of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

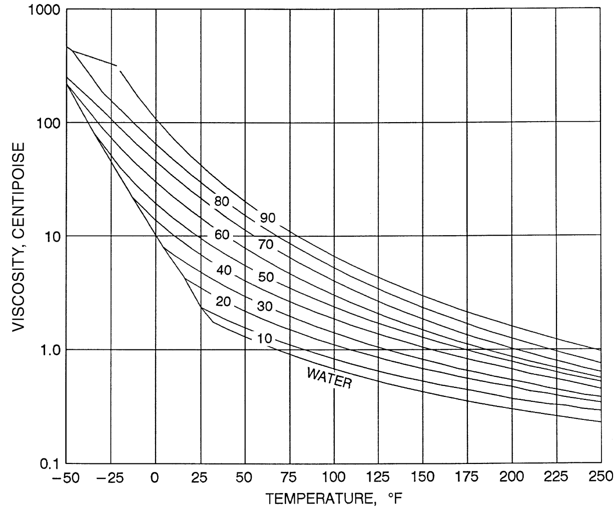

Fig. 12 Viscosity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

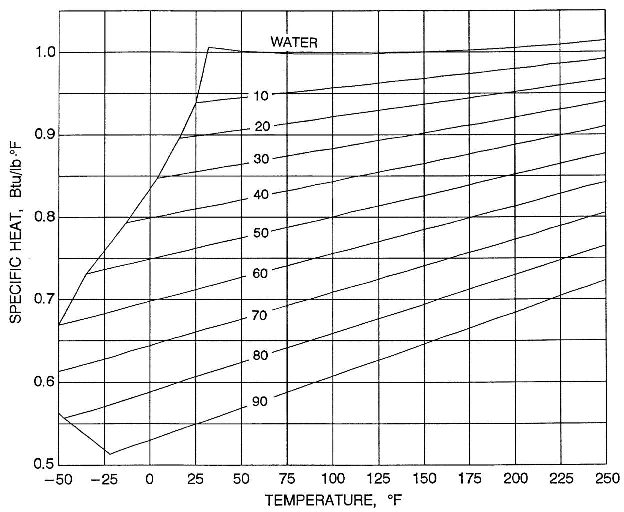

Fig. 10 Specific Heat of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

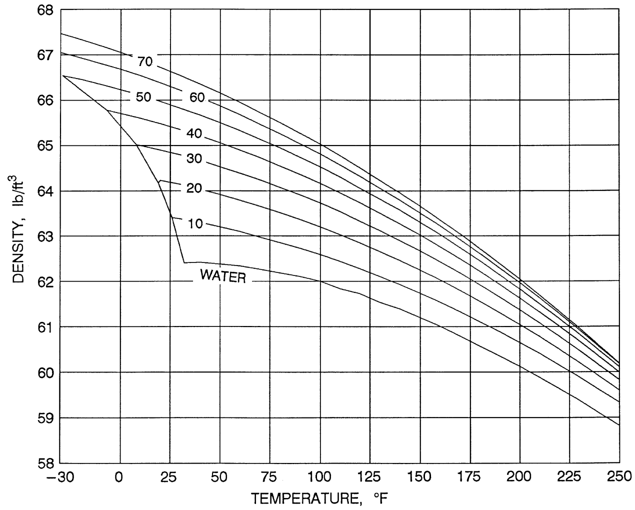

Fig. 13 Density of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

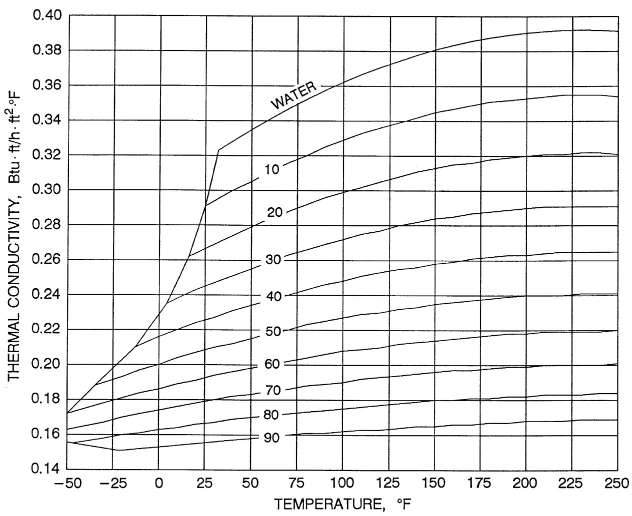

Fig. 11 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

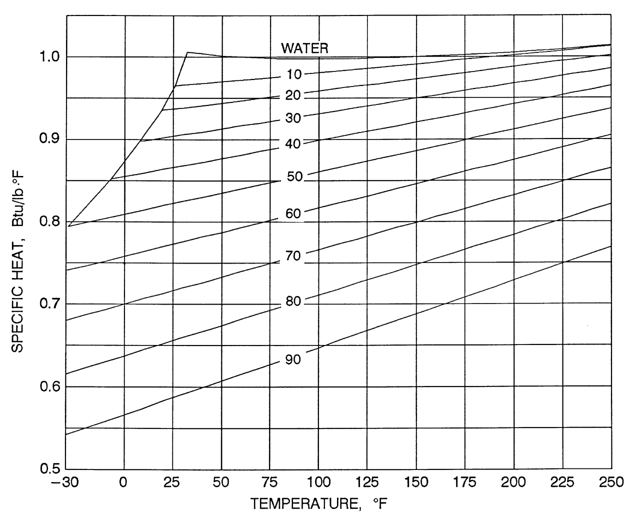

Fig. 14 Specific Heat of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

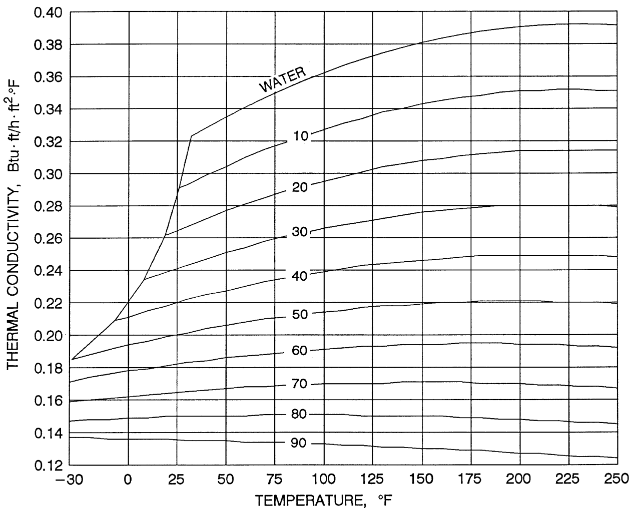

Fig. 15 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

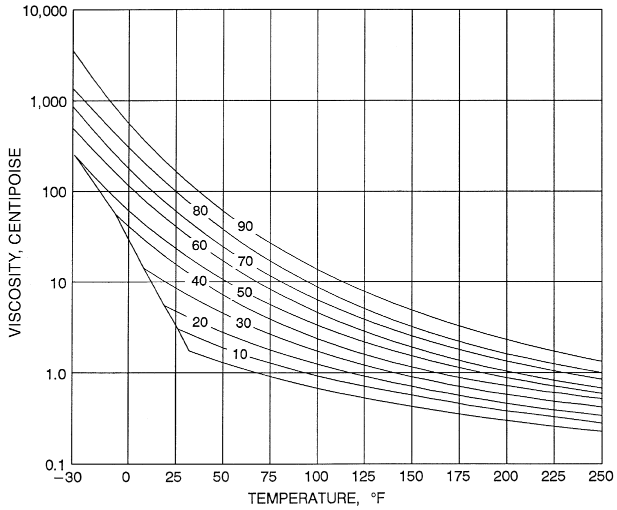

Fig. 16 Viscosity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

Additional physical property data is available from suppliers of industrially inhibited ethylene and propylene glycol.

Corrosion Inhibition

Commercial ethylene glycol or propylene glycol, when pure, is generally less corrosive than water to common metals used in construction. However, aqueous solutions of these glycols assume the corrosivity of the water from which they are prepared and can become increasingly corrosive with use if they are not properly inhibited. Without inhibitors, glycols oxidize into acidic end products. The amount of oxidation is influenced by temperature, degree of aeration, and, to some extent, the particular combination of metal components to which the glycol solution is exposed.

Corrosion inhibition can be described by classifying additives as either (1) corrosion inhibitors, or (2) environmental stabilizers and adjusters. **Corrosion inhibitors** form a surface barrier that protects the metal from attack. These barriers are usually formed by adsorption of the inhibitor by the metal, by reaction of the inhibitor with the metal, or by the incipient reaction product. In most cases, metal surfaces are covered by films of their oxides that inhibitors reinforce.

Environmental stabilizers or adjusters, while not corrosion inhibitors in the strict sense, decrease corrosion by stabilizing or favorably altering the overall environment. An alkaline buffer such as borax is an example of an environmental stabilizer, since its prime purpose is to maintain an alkaline condition (pH above 7). Some chelating agents function as stabilizers by removing from the solution certain deleterious ions that accelerate the corrosion process or mechanism; however, exercise caution in their use because improper combinations of pH and concentration may lead to excessive corrosion.

Certain oxidants, such as sodium chromate, should not be used with glycol solutions, because the glycol can oxidize prematurely. Generally, combinations of the two types of additives, inhibitors, and stabilizers offer the best corrosion resistance in a given system. Commercial inhibited glycols are available from several suppliers.

Service Considerations

Design Considerations. Inhibited glycols can be used at temperatures as high as 350°F. However, maximum-use temperatures vary from fluid to fluid. Therefore, the manufacturer's suggested temperature-use ranges should be followed. In systems with a high degree of aeration, the bulk fluid temperature should not exceed 180°F; however, temperatures up to 350°F are permissible in a pressurized system if air intake is eliminated. Maximum film temperatures should not exceed 50°F above the bulk temperature. Nitrogen blanketing minimizes oxidation when the system operates at elevated temperatures for extended periods.

Minimum operating temperatures are typically −10°F for ethylene glycol solutions and 0°F for propylene glycol solutions. Operation below these temperatures is generally impractical, because the viscosity of the fluids builds dramatically, thus increasing pumping horsepower requirements and reducing heat transfer film coefficients.

Standard materials can be used with most inhibited glycol solutions except galvanized steel, because the galvanizing material, zinc, reacts with a portion of the inhibitor package found in most formulated glycols.

Because the removal of sludge and other contaminants is critical, install suitable filters. If inhibitors are rapidly and completely adsorbed by such contamination, the fluid is ineffective for corrosion inhibition. Consider such adsorption when selecting filters.

Storage and Handling. Inhibited glycol concentrates are stable, relatively noncorrosive materials with high flash points. These fluids can be stored in mild steel, stainless steel, or aluminum vessels. However, aluminum should be used only when the fluid temperature is below 150°F. Corrosion in the vapor space of vessels may be a problem, because the fluid's inhibitor package cannot reach these surfaces to protect them. To prevent this problem, a coating may be used. Suitable coatings include novolac-based vinyl ester resins, high-bake phenolic resins, polypropylene, and polyvinylidene fluoride. To ensure the coating is suitable for a particular application and temperature, the manufacturer should be consulted. Since the chemical properties of an inhibited glycol concentrate differ from those of its dilutions, the effect of the concentrate on different containers should be known when selecting storage.

Choose transfer pumps only after considering temperature-viscosity data. Centrifugal pumps with electric motor drives are often used. Materials compatible with ethylene or propylene glycol should be used for pump packing material. Mechanical seals are also satisfactory. Welded mild steel transfer piping with a minimum diameter is normally used in conjunction with the piping, although flanged and gasketed joints are also satisfactory.

Preparation Before Application. Before an inhibited glycol is charged into a system, remove residual contaminants such as sludge, rust, brine deposits, and oil so the contained inhibitor functions properly. Avoid strong acid cleaners; if they are required, consider inhibited acids. Completely remove the cleaning agent before charging with inhibited glycol.

Dilution Water. Use distilled, deionized, or condensate water, because water from some sources contains elements that reduce the effectiveness of the inhibited formulation. If water of this quality is unavailable, water containing less than 25 ppm chloride, less than 25 ppm sulfate, and less than 100 ppm of total hardness may be used.

Fluid Maintenance. Glycol concentrations can be determined by refractive index, gas chromatography, or Karl Fischer analysis for water (assuming that the concentration of other fluid components, such as inhibitor, is known). Using density to determine glycol concentration is unsatisfactory because (1) density measurements are temperature sensitive, (2) inhibitor concentrations can change density, (3) values for propylene glycol are close to those of water, and (4) propylene glycol values are maximum at 70 to 75% concentration.

A rigorous inhibitor monitoring and maintenance schedule is essential to maintain a glycol solution in relatively noncorrosive condition for a long period. However, a specific schedule is not always easy to establish, because inhibitor depletion rate depends on the particular conditions of use. Analysis of samples immediately after installation, after two to three months, and after six months should establish the pattern for the schedule. Visually inspecting the solution and filter residue can detect active corrosion.

Many manufacturers of inhibited glycol-based heat transfer fluids provide analytical service to ensure that their heat transfer fluid remains in good condition. This analysis may include some or all of the following: percent of ethylene and/or propylene glycol, freezing point, pH, reserve alkalinity, corrosion inhibitor evaluation, contaminants, total hardness, metal content, and degradation products. If maintenance on the fluid is required, recommendations may be given along with the analysis results.

Properly inhibited and maintained glycol solutions provide better corrosion protection than brine solutions in most systems. A long, though not indefinite, service life can be expected. Avoid indiscriminate mixing of inhibited formulations. Exercise caution in replacing brine systems with inhibited glycols because brine components are incompatible with glycol formulations.

HALOCARBONS

Many common refrigerants are used as secondary coolants as well as primary refrigerating media. Their favorable properties as heat transfer fluids include low freezing points, low viscosities, nonflammability, and good stability. Chapters 19 and 20 present physical and thermodynamic properties for common refrigerants. Table 14 lists two halocarbon compounds that are commonly used as secondary coolants. Table 15 gives vapor pressure, specific heat, thermal conductivity, density, and viscosity values for methylene chloride (R-30). Table 16 gives the same properties for trichloroethylene (R-1120).

Table 9 in Chapter 19 summarizes comparative safety characteristics for halocarbons. *Threshold Limit Values and Biological Exposure Indices* (ACGIH) has more information on halocarbon toxicity.

Construction materials and stability factors in halocarbon use are discussed in Chapter 19 of this volume and Chapter 5 of the *ASHRAE Handbook—Refrigeration*. Note particularly that methylene chloride and trichloroethylene should not be used in contact with aluminum components.

NONHALOCARBON, NONAQUEOUS FLUIDS

In addition to the aforementioned fluids, numerous other secondary refrigerants are available. These fluids have been used primarily by the chemical processing and pharmaceutical industries. They

Table 14 Freezing and Boiling Points of Halocarbon Coolants

Refrigerant	Name	Freezing Point, °F	Boiling Point, °F
30	Methylene chloride	–142	103.6
1120	Trichloroethylene	–123	189

Table 15 Properties of Liquid Methylene Chloride (R-30)

Temperature, °F	Vapor Pressure, psia	Specific Heat, Btu/lb·°F	Thermal Conductivity, Btu/h·ft·°F	Density, lb/ft³	Viscosity, Centipoise
140	25.4	0.296	0.074	78.3	0.32
122	19.9	0.293	0.076	79.4	0.34
104	14.5	0.289	0.079	80.5	0.37
86	10.2	0.286	0.081	81.6	0.40
68	6.82	0.284	0.083	82.7	0.44
50	4.39	0.282	0.085	83.8	0.48
32	2.73	0.280	0.087	84.9	0.53
14	1.64	0.278	0.089	86.0	0.59
–4	0.97	0.277	0.091	87.1	0.66
–22	0.55	0.275	0.093	88.2	0.76
–40	0.32	0.274	0.094	89.3	0.88
–58	0.18	0.273	0.096	90.4	1.05
–76	0.10	0.273	0.098	91.5	1.29
–94	0.06	0.273	0.099	92.6	1.68
–112	0.03	0.272	0.101	93.7	2.50

Table 16 Properties of Liquid Trichloroethylene (R-1120)

Temperature, °F	Vapor Pressure, psia	Specific Heat, Btu/lb·°F	Thermal Conductivity, Btu/h·ft·°F	Density, lb/ft³	Viscosity, Centipoise
140	5.73	0.231	0.062	86.8	0.40
122	4.21	0.228	0.063	88.0	0.44
104	2.87	0.225	0.065	89.0	0.48
86	1.86	0.223	0.066	90.1	0.52
68	1.13	0.220	0.068	91.3	0.57
50	0.667	0.218	0.069	92.4	0.63
32	0.370	0.216	0.071	93.5	0.70
14	0.199	0.213	0.073	94.6	0.78
–4	0.102	0.211	0.074	95.6	0.87
–22	0.052	0.209	0.076	96.6	0.99
–40	0.024	0.207	0.077	97.7	1.14
–58	0.011	0.206	0.079	98.7	1.33
–76	0.005	0.204	0.080	99.7	1.60
–94	0.002	0.202	0.082	100.6	1.93
–112	0.001	0.201	0.084	101.6	2.45

Table 17 Summary of Physical Properties of Polydimethylsiloxane Mixture and d-Limonene

	Polydimethylsiloxane Mixture	d-Limonene
Flash point, °F, closed cup	116	115
Boiling point, °F	347	310
Freezing point, °F	–168	–142
Operational temperature range, °F	–100 to 500	None published

Table 18 Properties of a Polydimethylsiloxane Heat Transfer Fluid

Temperature, °F	Vapor Pressure, psia	Viscosity, Centipoise	Density, lb/ft³	Heat Capacity, Btu/lb·°F	Thermal Conductivity, Btu/h·ft·°F
–100	0.00	12.5	57.8	0.337	0.0748
–90	0.00	10.5	57.5	0.340	0.0742
–80	0.00	8.82	57.2	0.344	0.0736
–70	0.00	7.50	56.9	0.347	0.0730
–60	0.00	6.43	56.6	0.350	0.0724
–50	0.00	5.55	56.3	0.354	0.0717
–40	0.00	4.83	56.0	0.357	0.0711
–30	0.00	4.22	55.7	0.361	0.0705
–20	0.00	3.72	55.4	0.364	0.0699
–10	0.00	3.29	55.1	0.367	0.0692
0	0.00	2.93	54.8	0.371	0.0686
10	0.00	2.62	54.5	0.374	0.0679
20	0.00	2.36	54.2	0.378	0.0673
30	0.00	2.13	53.9	0.381	0.0666
40	0.01	1.93	53.6	0.384	0.0659
50	0.01	1.76	53.3	0.388	0.0652
60	0.02	1.60	53.0	0.391	0.0646
70	0.03	1.47	52.7	0.395	0.0639
80	0.04	1.35	52.4	0.398	0.0632
90	0.05	1.25	52.1	0.402	0.0625
100	0.08	1.15	51.8	0.405	0.0618
110	0.11	1.07	51.5	0.408	0.0610
120	0.15	0.993	51.1	0.412	0.0603
130	0.20	0.926	50.8	0.415	0.0596
140	0.27	0.865	50.5	0.419	0.0589
150	0.35	0.810	50.2	0.422	0.0581
160	0.46	0.760	49.8	0.425	0.0574
170	0.60	0.715	49.5	0.429	0.0567
180	0.76	0.673	49.2	0.432	0.0559
190	0.96	0.635	48.8	0.436	0.0551
200	1.20	0.601	48.5	0.439	0.0544
210	1.49	0.569	48.1	0.442	0.0536
220	1.84	0.540	47.8	0.446	0.0528
230	2.24	0.513	47.4	0.449	0.0521
240	2.72	0.488	47.0	0.453	0.0513
250	3.27	0.465	46.7	0.456	0.0505
260	3.91	0.443	46.3	0.459	0.0497
270	4.65	0.424	45.9	0.463	0.0489
280	5.50	0.405	45.5	0.466	0.0481
290	6.46	0.388	45.1	0.470	0.0473
300	7.55	0.372	44.7	0.473	0.0465
310	8.78	0.357	44.3	0.476	0.0457
320	10.16	0.343	43.9	0.480	0.0449
330	11.71	0.330	43.5	0.483	0.0441
340	13.43	0.317	43.1	0.487	0.0432
350	15.33	0.306	42.6	0.490	0.0424
360	17.45	0.295	42.2	0.494	0.0416
370	19.77	0.285	41.7	0.497	0.0407
380	22.32	0.275	41.3	0.500	0.0399
390	25.12	0.266	40.8	0.504	0.0390
400	28.17	0.257	40.4	0.507	0.0382
410	31.49	0.249	39.9	0.511	0.0373
420	35.10	0.242	39.4	0.514	0.0365
430	39.00	0.234	38.9	0.517	0.0356
440	43.21	0.227	38.4	0.521	0.0348
450	47.75	0.221	37.9	0.524	0.0339
460	52.63	0.214	37.4	0.528	0.0330
470	57.86	0.209	36.8	0.531	0.0321
480	63.46	0.203	36.3	0.534	0.0313
490	69.44	0.197	35.8	0.538	0.0304
500	75.81	0.192	35.2	0.541	0.0295

Table 19 Physical Properties of d-Limonene

Temperature, °F	Specific Heat, Btu/lb·°F	Viscosity, Centipoise	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F
–100	0.3	3.8	57.1	0.0794
–50	0.34	2.8	55.8	0.0764
0	0.37	2.1	54.5	0.0734
50	0.41	1.6	53.2	0.0704
100	0.44	1.2	51.8	0.0674
150	0.48	0.9	50.4	0.0644
200	0.51	0.7	49	0.0614
250	0.54	0.6	47.6	0.0584
300	0.58	0.4	46	0.0554

Note: Properties are estimated or based on incomplete data.

have been used rarely in the HVAC and allied industries due to their cost and relative novelty. Before choosing these types of fluids, consider electrical classifications, disposal, potential worker exposure, process containment, and other relevant issues.

Tables 17 through 19 contain physical property information on a mixture of dimethylsiloxane polymers of various relative molecular masses (Dow Corning 1989) and d-limonene. Information on d-limonene is limited; it is based on measurements made over small data temperature ranges or simply on standard physical property estimation techniques. The compound is an optically active terpene (molecular formula $C_{10}H_{16}$) derived as an extract from orange and lemon oils. The "d" indicates that the material is dextrorotatory, which is a physical property of the material that does not affect the transport properties of the material significantly.

The mixture of dimethylsiloxane polymers can be used with most standard construction materials; d-limonene, however, can be quite corrosive, easily autooxidizing at ambient temperatures. This fact should be understood and considered before using d-limonene in a system.

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