CHAPTER 31

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 Handbook volumes describe various applications for secondary coolants. In the 2006 *ASHRAE Handbook—Refrigeration*, refrigeration systems are discussed in Chapter 4, their uses in food processing in Chapters 14 to 29, and ice rinks in Chapter 35. In the 2007 *ASHRAE Handbook—HVAC Applications*, solar energy use is discussed in Chapter 33, thermal storage in Chapter 34, and snow melting and freeze protection in Chapter 50.

This chapter describes physical properties of several secondary coolants and provides information on their use. Additional, less widely used secondary coolants such as ethyl alcohol or potassium formate are not included in this chapter, but their physical properties are summarized in Melinder (2007). The chapter also includes information on corrosion protection. Additional information on corrosion inhibition can be found in Chapter 48 of the 2007 *ASHRAE Handbook—HVAC Applications* and Chapter 4 of the 2006 *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. For calcium chloride brines, Figure 1 shows specific heat, Figure 2 shows the ratio of mass of solution to that of water, Figure 3 shows viscosity, and Figure 4 shows thermal conductivity. Figures 5 to 8 show the same properties for sodium chloride brines.

Table 1 Properties of Pure Calcium Chloride[a] Brines

Pure $CaCl_2$, % by Mass	Ratio of Mass to Water at 60°F	Relative Density, Degrees Baumé[c]	Specific Heat at 60°F, Btu/lb·°F	Crystallization Starts, °F	Mass per Unit Volume[b] at 60°F: $CaCl_2$, lb/gal	Brine, lb/gal	$CaCl_2$, lb/ft^3	Brine, lb/ft^3	Ratio of Mass at Various Temperatures to Water at 60°F: −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				

Source: CCI (1953)
[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.
[c]At 60°F.

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

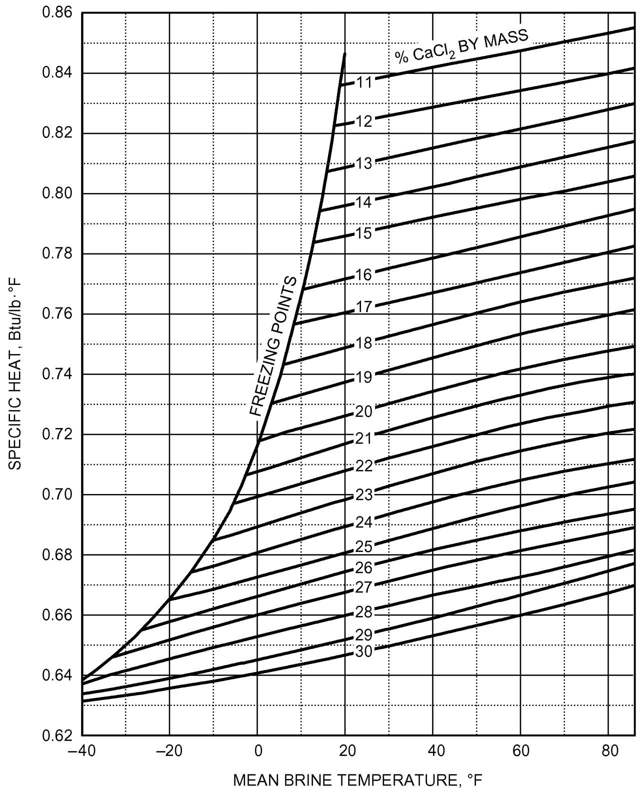

Fig. 1 Specific Heat of Calcium Chloride Brines
(CCI 1953)

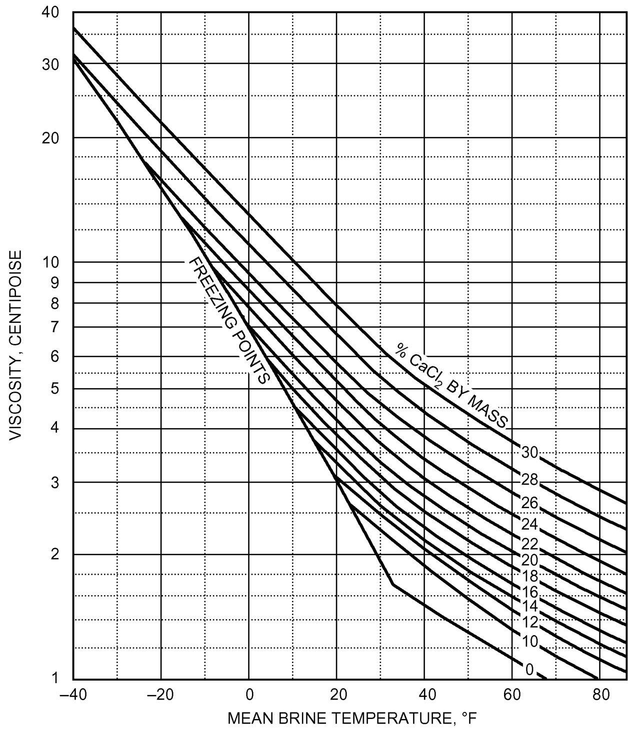

Fig. 3 Viscosity of Calcium Chloride Brines
(CCI 1953)

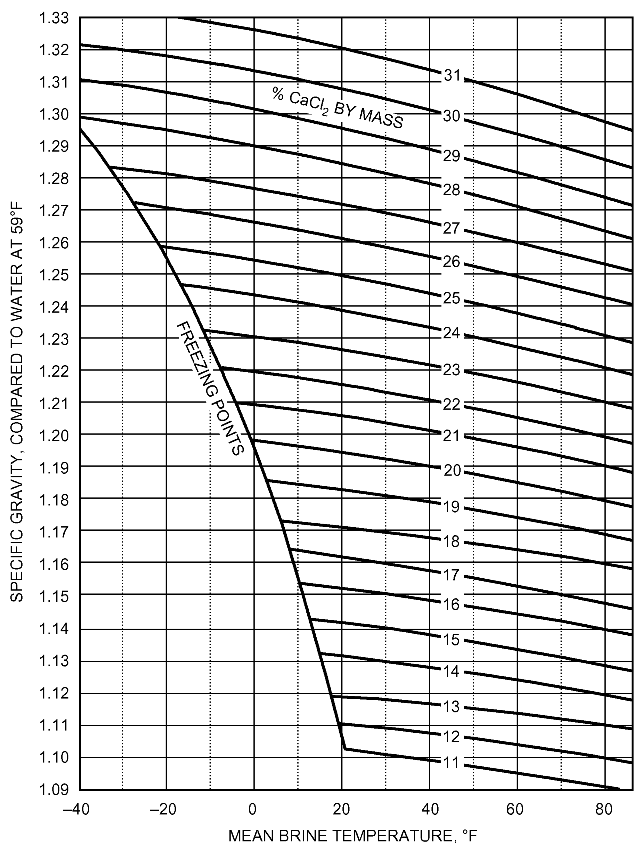

Fig. 2 Specific Gravity of Calcium Chloride Brines
(CCI 1953)

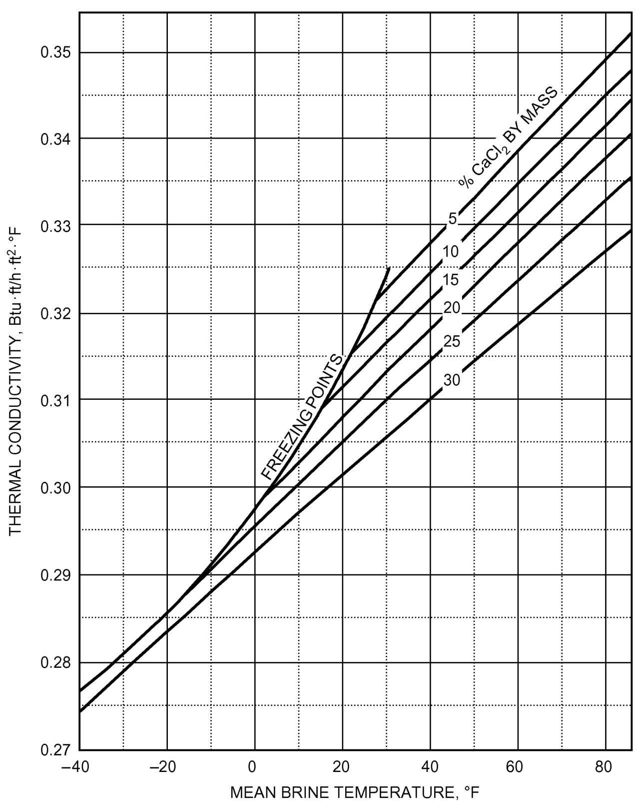

Fig. 4 Thermal Conductivity of Calcium Chloride Brines
(CCI 1953)

Table 2 Properties of Pure Sodium Chloride[a] Brines

Pure NaCl, % by Mass	Ratio of Mass to Water at 59°F	Relative Density, Degrees Baumé[b]	Specific Heat at 59°F, Btu/lb·°F	Crystallization Starts, °F	Mass per Unit Volume at 60°F				Ratio of Mass at Various Temperatures to Water at 60°F			
					NaCl, lb/gal	Brine, lb/gal	NaCl, lb/ft³	Brine, lb/ft³	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]At 60°F.

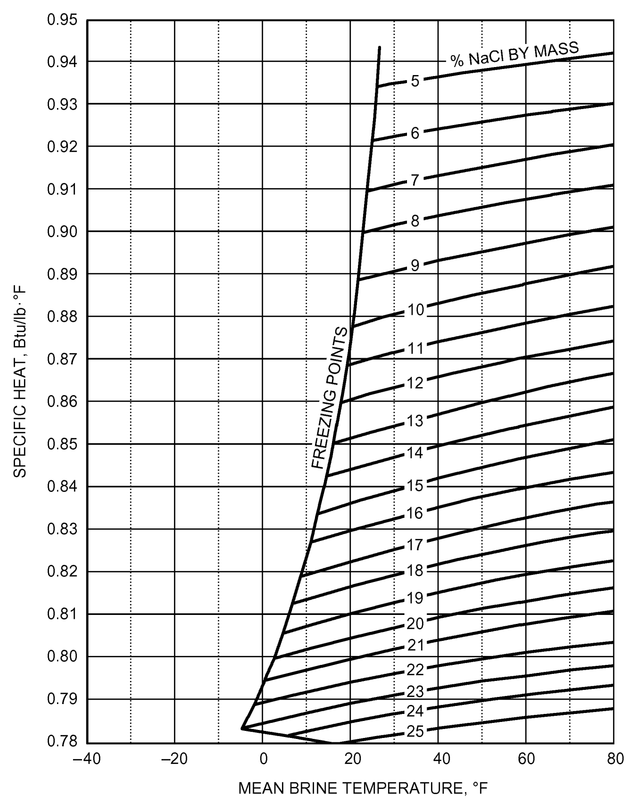

Fig. 5 Specific Heat of Sodium Chloride Brines
(adapted from Carrier 1959)

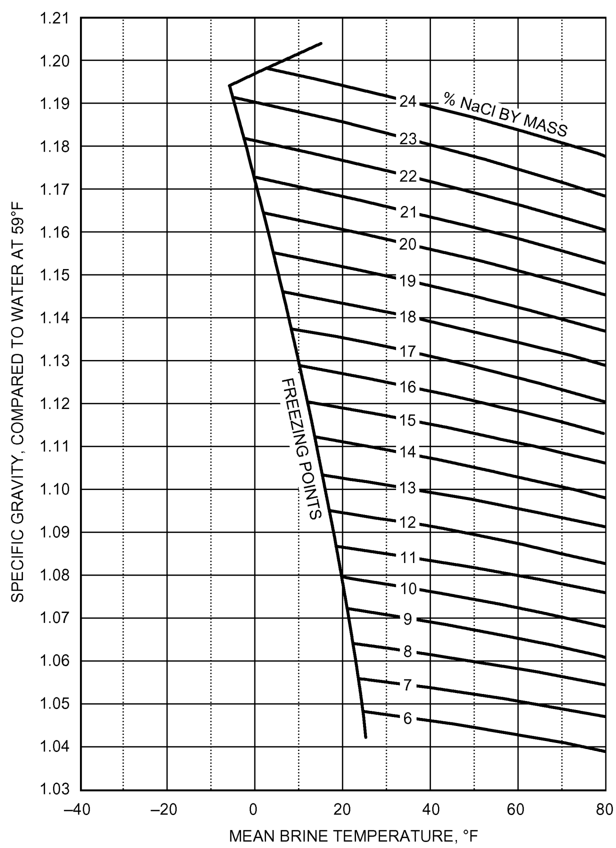

Fig. 6 Specific Gravity of Sodium Chloride Brines
(adapted from Carrier 1959)

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

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 to air-cool 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

All brine systems must be treated to control corrosion and deposits. Historically, chloride-based brines were maintained at neutral pH and treated with sodium chromate. However, using chromate as a corrosion inhibitor is no longer deemed acceptable because of its environmental effect. Instead, most brines use a sodium-nitrite-based inhibitor ranging from approximately 3000 ppm in calcium brines to 4000 ppm in sodium brines. Other, proprietary organic inhibitors are also available to mitigate the inherent corrosiveness of brines.

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

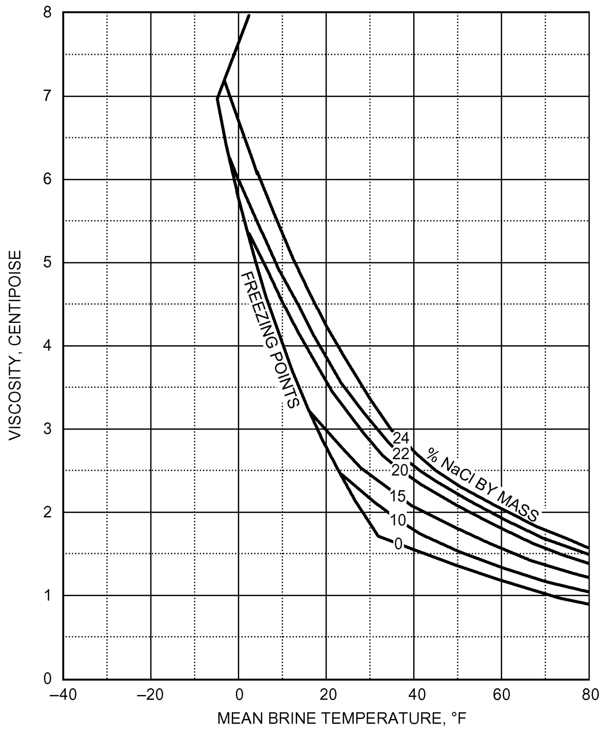

Fig. 7 Viscosity of Sodium Chloride Brines
(adapted from Carrier 1959)

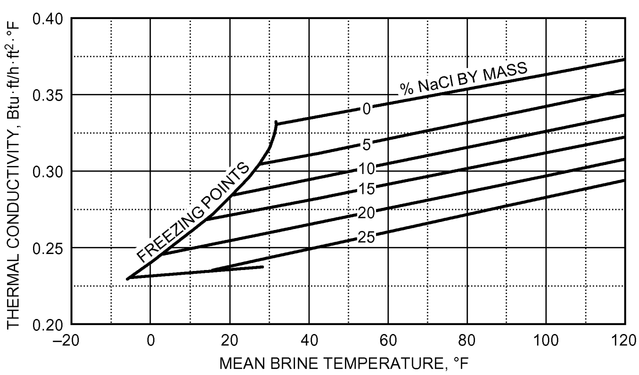

Fig. 8 Thermal Conductivity of Sodium Chloride Brines
(adapted from Carrier 1959)

INHIBITED GLYCOLS

Ethylene glycol and propylene glycol, when properly inhibited for corrosion control, are used as aqueous-freezing-point depressants (antifreeze) and heat transfer media. Their chief attributes are their ability to efficiently lower the freezing point of water, their low volatility, and their relatively low corrosivity when properly inhibited. Inhibited ethylene glycol solutions have better thermophysical 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 supercool and become a glass (a liquid with extremely high viscosity and the appearance and properties of a noncrystalline amorphous solid). On the dilute side of the eutectic (the mixture at which freezing produces a solid phase of the same composition), ice forms on freezing; on the concentrated side, solid glycol separates from solution on freezing.The

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/ft^3	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, lb/ft·h		
at 32°F	138.9	587.8
at 68°F	50.6	146.4
at 104°F	23.0	43.5
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

Sources: Dow Chemical (2001a, 2001b)

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

Percent Ethylene Glycol		Freezing Point, °F	Boiling Point, °F at 14.7 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	*	235
70.0	68.3	*	242
75.0	73.6	*	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

Source: Dow Chemical (2001b)
*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 14.7 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	*	227
70.0	70.0	*	230
75.0	75.0	*	237
80.0	80.0	*	245
85.0	85.0	*	257
90.0	90.0	*	270
95.0	95.0	*	310

Source: Dow Chemical (2001a)
*Above 60% by mass, solutions do not freeze but become a glass.

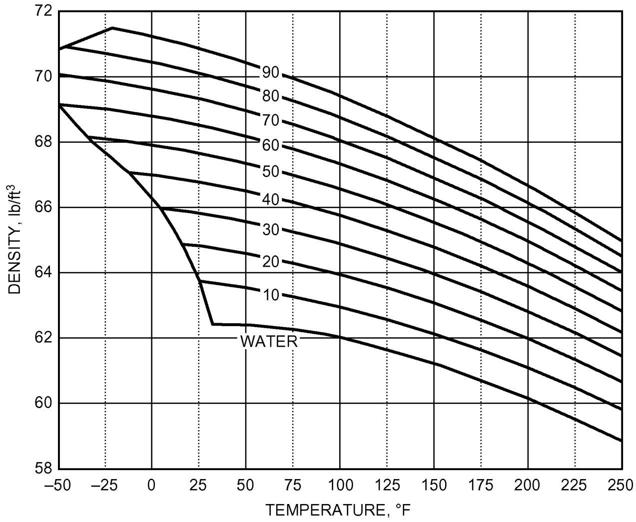

Fig. 9 Density of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)
(Dow Chemical 2001b)

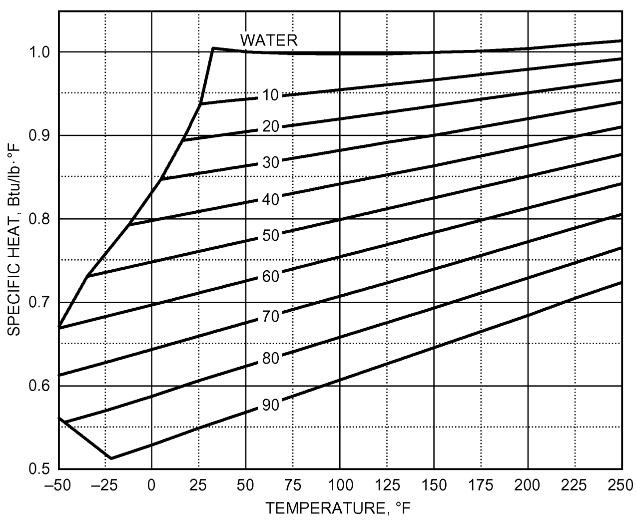

Fig. 10 Specific Heat of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)
(Dow Chemical 2001b)

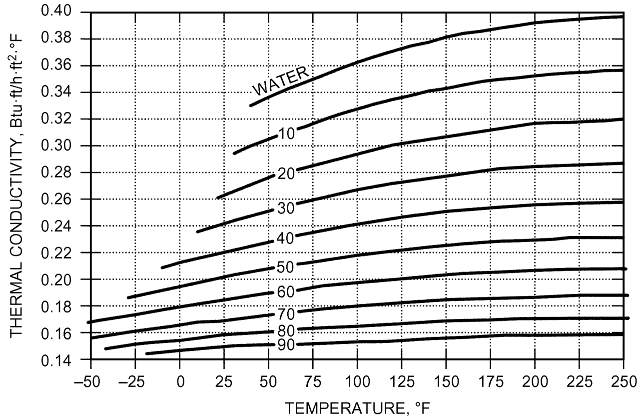

Fig. 11 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)
(Dow Chemical 2001b)

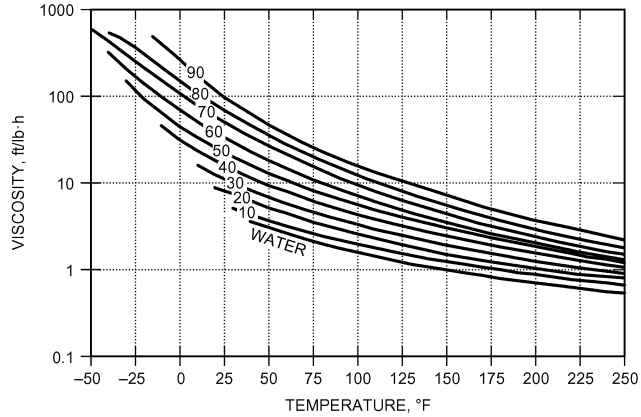

Fig. 12 Viscosity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)
(Dow Chemical 2001b)

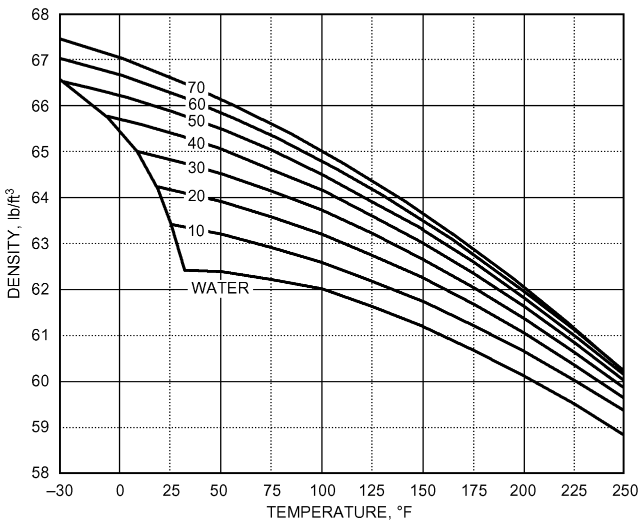

Fig. 13 Density of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)
(Dow Chemical 2001b)

freezing rate 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 to 9 and Figures 9 to 12; similar data for aqueous solutions of propylene glycol are in Tables 10 to 13 and Figures 13 to 16. Densities are for aqueous solutions of industrially inhibited glycols, and are somewhat higher than those for pure glycol and water alone. Typical corrosion inhibitor packages do not significantly affect other physical properties. Physical properties for the two fluids are similar, except for 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% by volume ethylene glycol or 35% by volume propylene glycol is sufficient. These

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

Source: Dow Chemical (2001b)   *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

Source: Dow Chemical (2001b)   *Note*: Specific heat in Btu/lb·°F.

Table 8 Thermal Conductivity of Aqueous Solutions of Ethylene Glycol

Temperature, °F	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
–30					0.187	0.173	0.161	0.151	
–20					0.190	0.175	0.163	0.153	0.145
–10				0.209	0.192	0.178	0.165	0.154	0.146
0				0.213	0.195	0.180	0.166	0.155	0.147
10			0.236	0.216	0.198	0.182	0.168	0.156	0.148
20		0.263	0.240	0.219	0.200	0.184	0.169	0.158	0.148
30	0.294	0.268	0.244	0.222	0.203	0.186	0.171	0.159	0.149
40	0.300	0.273	0.248	0.225	0.205	0.188	0.172	0.160	0.150
50	0.305	0.277	0.251	0.228	0.208	0.190	0.174	0.161	0.151
60	0.310	0.281	0.255	0.231	0.210	0.191	0.175	0.162	0.151
70	0.314	0.285	0.258	0.234	0.212	0.193	0.177	0.163	0.152
80	0.319	0.289	0.261	0.236	0.214	0.195	0.178	0.164	0.153
90	0.323	0.292	0.264	0.239	0.216	0.196	0.179	0.164	0.153
100	0.327	0.296	0.267	0.241	0.218	0.198	0.180	0.165	0.154
110	0.331	0.299	0.269	0.243	0.220	0.199	0.181	0.166	0.154
120	0.334	0.301	0.272	0.245	0.221	0.200	0.182	0.167	0.155
130	0.337	0.304	0.274	0.247	0.223	0.201	0.183	0.167	0.155
140	0.340	0.306	0.276	0.248	0.224	0.202	0.183	0.168	0.156
150	0.342	0.309	0.277	0.250	0.225	0.203	0.184	0.168	0.156
160	0.345	0.310	0.279	0.251	0.226	0.204	0.185	0.169	0.156
170	0.347	0.312	0.280	0.252	0.227	0.204	0.185	0.169	0.157
180	0.349	0.314	0.282	0.253	0.228	0.205	0.186	0.169	0.157
190	0.350	0.315	0.283	0.254	0.228	0.206	0.186	0.170	0.157
200	0.351	0.316	0.284	0.255	0.229	0.206	0.186	0.170	0.157
210	0.352	0.317	0.284	0.255	0.229	0.206	0.186	0.170	0.157
220	0.353	0.318	0.285	0.256	0.230	0.207	0.187	0.170	0.157
230	0.354	0.318	0.285	0.256	0.230	0.207	0.187	0.170	0.157
240	0.355	0.319	0.286	0.256	0.230	0.207	0.187	0.170	0.157
250	0.355	0.319	0.286	0.257	0.230	0.207	0.187	0.170	0.157

Source: Dow Chemical (2001b) *Note*: Thermal conductivity in Btu·ft/h·ft^2·°F.

Table 9 Viscosity of Aqueous Solutions of Ethylene Glycol

Temperature, °F	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
–30					154.07	216.92	311.55	448.06	
–20					97.68	146.26	217.55	317.67	688.18
–10				47.37	65.97	101.72	153.61	222.27	410.83
0				33.29	46.79	72.77	110.26	157.34	260.71
10			16.52	24.51	34.50	53.37	80.58	113.43	173.86
20		9.43	13.01	18.72	26.25	40.06	59.97	83.41	120.81
30	5.23	7.60	10.47	14.73	20.51	30.67	45.41	62.51	86.87
40	4.40	6.27	8.56	11.88	16.38	23.95	34.96	47.68	64.32
50	3.77	5.27	7.14	9.77	13.30	18.99	27.36	36.99	48.82
60	3.27	4.50	6.02	8.18	11.01	15.31	21.70	29.15	37.86
70	2.85	3.89	5.15	6.94	9.22	12.51	17.47	23.27	29.92
80	2.52	3.41	4.45	5.95	7.81	10.35	14.22	18.84	24.02
90	2.25	3.00	3.87	5.15	6.68	8.66	11.73	15.43	19.59
100	2.01	2.69	3.41	4.52	5.78	7.33	9.77	12.77	16.16
110	1.81	2.39	3.02	3.97	5.03	6.24	8.22	10.67	13.50
120	1.64	2.18	2.69	3.53	4.40	5.39	6.97	9.02	11.39
130	1.50	1.96	2.42	3.14	3.89	4.67	5.98	7.67	9.70
140	1.38	1.79	2.18	2.83	3.46	4.09	5.15	6.58	8.35
150	1.28	1.64	1.98	2.54	3.10	3.60	4.50	5.68	7.21
160	1.19	1.52	1.81	2.30	2.78	3.19	3.94	4.96	6.29
170	1.11	1.40	1.64	2.10	2.52	2.85	3.46	4.35	5.52
180	1.04	1.31	1.52	1.91	2.27	2.56	3.07	3.82	4.86
190	0.97	1.21	1.40	1.77	2.06	2.30	2.76	3.39	4.33
200	0.90	1.14	1.31	1.62	1.89	2.08	2.47	3.02	3.87
210	0.85	1.04	1.21	1.48	1.72	1.89	2.23	2.71	3.46
220	0.80	0.99	1.11	1.38	1.60	1.74	2.01	2.44	3.12
230	0.77	0.92	1.04	1.28	1.45	1.60	1.84	2.20	2.81
240	0.73	0.87	0.97	1.19	1.35	1.48	1.67	2.01	2.56
250	0.70	0.82	0.92	1.09	1.26	1.35	1.52	1.81	2.32

Source: Dow Chemical (2001b) *Note*: Viscosity in ft/lb·h.

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

Source: Dow Chemical (2001a)

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

Source: Dow Chemical (2001a)

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						0.156	0.140	0.127	0.117
–20					0.175	0.158	0.142	0.129	0.118
–10					0.178	0.160	0.143	0.130	0.119
0				0.201	0.181	0.162	0.145	0.131	0.119
10			0.228	0.205	0.183	0.164	0.146	0.132	0.120
20			0.232	0.208	0.186	0.166	0.148	0.133	0.121
30		0.263	0.236	0.211	0.188	0.168	0.149	0.134	0.122
40	0.298	0.267	0.240	0.214	0.191	0.170	0.151	0.135	0.122
50	0.303	0.272	0.243	0.217	0.193	0.171	0.152	0.136	0.123
60	0.308	0.276	0.247	0.220	0.195	0.173	0.153	0.137	0.123
70	0.312	0.280	0.250	0.223	0.198	0.175	0.154	0.137	0.124
80	0.317	0.284	0.253	0.225	0.200	0.176	0.155	0.138	0.124
90	0.321	0.287	0.256	0.228	0.202	0.178	0.156	0.139	0.125
100	0.325	0.291	0.259	0.230	0.203	0.179	0.157	0.139	0.125
110	0.329	0.294	0.261	0.232	0.205	0.180	0.158	0.140	0.125
120	0.332	0.296	0.264	0.234	0.206	0.181	0.159	0.140	0.126
130	0.335	0.299	0.266	0.236	0.208	0.183	0.160	0.141	0.126
140	0.338	0.301	0.268	0.237	0.209	0.183	0.160	0.141	0.126
150	0.340	0.304	0.270	0.239	0.210	0.184	0.161	0.142	0.126
160	0.343	0.305	0.271	0.240	0.211	0.185	0.161	0.142	0.126
170	0.345	0.307	0.273	0.241	0.212	0.185	0.162	0.142	0.126
180	0.347	0.309	0.274	0.242	0.213	0.186	0.162	0.142	0.126
190	0.348	0.310	0.275	0.243	0.213	0.186	0.162	0.142	0.126
200	0.349	0.311	0.276	0.243	0.214	0.187	0.162	0.142	0.126
210	0.350	0.312	0.276	0.244	0.214	0.187	0.162	0.142	0.126
220	0.351	0.313	0.277	0.244	0.214	0.187	0.162	0.142	0.126
230	0.352	0.313	0.277	0.244	0.214	0.187	0.162	0.142	0.126
240	0.353	0.313	0.277	0.245	0.214	0.187	0.162	0.142	0.125
250	0.353	0.314	0.278	0.245	0.214	0.187	0.162	0.142	0.125

Source: Dow Chemical (2001a) *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						1203.67	2092.20	3299.03	8600.39
–20					374.64	722.70	1194.86	1985.06	4402.06
–10					230.25	442.60	704.63	1199.09	2378.08
0				98.99	149.55	277.95	429.94	735.26	1350.63
10			32.46	65.29	97.49	179.47	271.42	460.62	803.19
20		12.97	23.92	44.75	66.82	119.24	177.13	295.85	498.11
30	6.77	10.23	18.05	31.74	47.22	81.47	119.31	195.12	320.94
40	5.52	8.25	13.91	23.22	34.33	57.21	82.78	132.18	214.11
50	4.57	6.75	10.93	17.44	25.62	41.25	59.05	91.90	147.40
60	3.87	5.61	8.76	13.45	19.57	30.46	43.20	65.56	104.41
70	3.34	4.72	7.11	10.60	15.26	23.01	32.37	47.87	75.89
80	2.90	4.02	5.88	8.52	12.14	17.76	24.80	35.78	56.49
90	2.54	3.46	4.93	6.97	9.82	13.96	19.35	27.31	42.94
100	2.25	3.02	4.19	5.81	8.08	11.18	15.41	21.26	33.29
110	2.01	2.66	3.60	4.91	6.75	9.10	12.46	16.86	26.27
120	1.81	2.35	3.14	4.19	5.71	7.52	10.23	13.60	21.07
130	1.64	2.10	2.76	3.63	4.89	6.31	8.54	11.13	17.15
140	1.50	1.89	2.44	3.17	4.23	5.37	7.21	9.24	14.15
150	1.38	1.72	2.20	2.81	3.70	4.62	6.14	7.79	11.83
160	1.26	1.55	1.98	2.52	3.27	4.02	5.30	6.65	9.99
170	1.16	1.43	1.79	2.25	2.90	3.51	4.62	5.73	8.52
180	1.06	1.31	1.64	2.06	2.59	3.12	4.09	5.01	7.35
190	0.99	1.21	1.50	1.86	2.35	2.78	3.63	4.40	6.39
200	0.92	1.11	1.40	1.72	2.13	2.52	3.24	3.89	5.59
210	0.87	1.04	1.31	1.60	1.96	2.27	2.93	3.51	4.93
220	0.82	0.97	1.21	1.48	1.79	2.08	2.66	3.17	4.40
230	0.77	0.92	1.14	1.38	1.67	1.91	2.42	2.88	3.94
240	0.73	0.87	1.06	1.28	1.55	1.77	2.23	2.64	3.56
250	0.68	0.82	1.02	1.21	1.43	1.64	2.06	2.42	3.22

Source: Dow Chemical (2001a) *Note*: Viscosity in ft/lb·h.

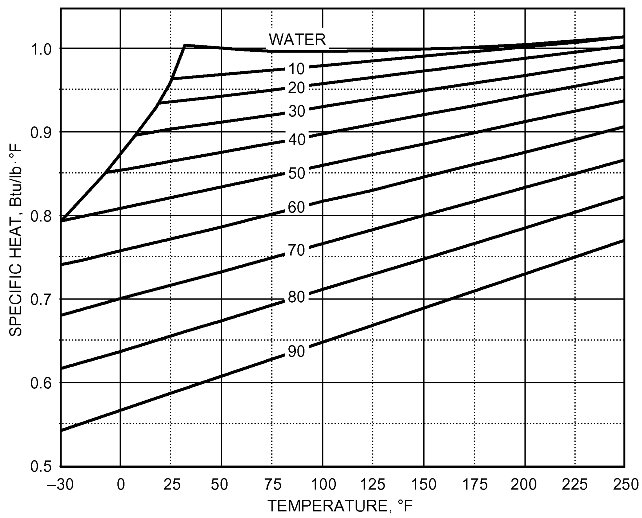

Fig. 14 Specific Heat of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)
(Dow Chemical 2001b)

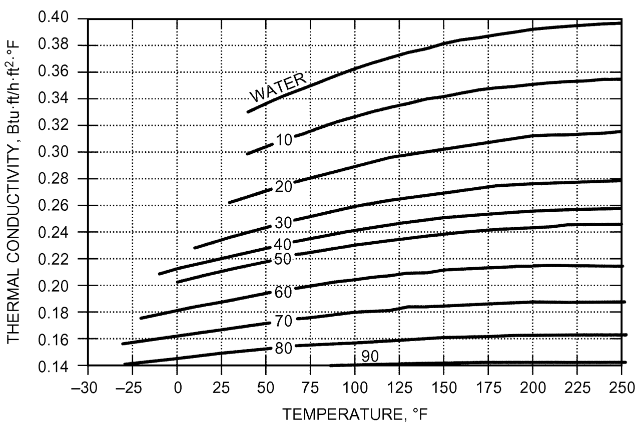

Fig. 15 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)
(Dow Chemical 2001b)

concentrations 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, use a concentration with a freezing point 5°F below the lowest expected temperature. Avoid excessive glycol concentration because it increases initial cost and adversely affects the fluid's physical properties.

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

Corrosion Inhibition

Interestingly, ethylene glycol and propylene glycol, when not diluted with water, are actually less corrosive than water is with common construction metals. However, once diluted with water (as is typical), all aqueous glycol solutions are more corrosive than the water from which they are prepared. This is because uninhibited glycols oxidize with use to form acidic degradation products, and become increasingly more corrosive if not properly inhibited. The amount of oxidation is influenced by temperature, degree of aeration, and type of metal components to which the glycol solution is exposed. It is therefore necessary to use not only corrosion inhibitors that are effective for water-based fluids, but also additional additives to buffer or neutralize the acidic glycol degradation products that form during use. Corrosion inhibitors form a surface barrier that protects metal from attack, but their effectiveness is highly dependent on solution pH. Failure to compensate for glycol degradation leads to a downward shift in solution pH, which negates the usefulness of the corrosion inhibitor at protecting iron-based alloys (particularly cast iron and carbon steels, but also solders). Properly inhibited glycol products are available from several suppliers.

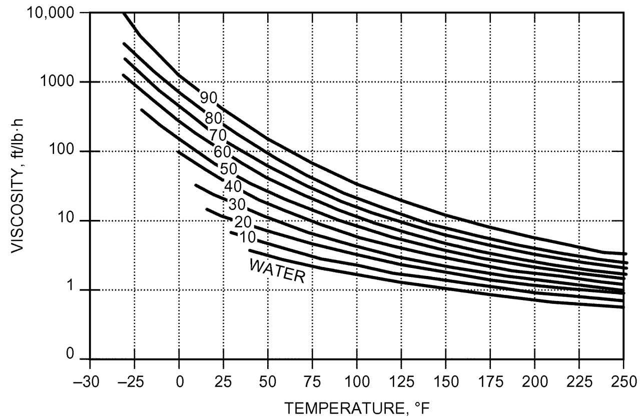

Fig. 16 Viscosity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)
(Dow Chemical 2001a)

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, so 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 150°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 for a recirculating fluid are typically –20°F for ethylene glycol solutions and 0°F for propylene glycol solutions. Operation below these temperatures is generally impractical, because the fluids' viscosity 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 metals, which form insoluble zinc salts with the corrosion inhibitors. This depletes corrosion inhibitors below effective limits, and can cause excessive insoluble salt (sludge) formation.

Because 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. A protective coating may be necessary (e.g., novolac-based vinyl ester resins, high-bake phenolic resins, polypropylene, polyvinylidene fluoride). To ensure the coating is suitable for a particular application and temperature, consult the manufacturer. Because 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. Bypass or inline filters are recommended to remove suspended particles, which can abrade seal surfaces. 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 newly installed fluid 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 exhibit a maximum at 70 to 75% concentration.

An effective inhibitor monitoring and maintenance schedule is essential to keep a glycol solution relatively noncorrosive for a long period. Inspection immediately after installation, and annually thereafter, is normally an effective practice. Visual inspection of solution and filter residue can often detect potential system problems.

Many manufacturers of inhibited glycol-based heat transfer fluids provide analytical service to ensure that their product 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.

HALOCARBONS

Many common refrigerants are used as secondary coolants as well as primary refrigerants. Their favorable properties as heat transfer fluids include low freezing points, low viscosities, nonflammability, and good stability. Chapters 29 and 30 present physical and thermodynamic properties for common refrigerants.

Tables 1 and 2 in Chapter 29 summarizes comparative safety characteristics for halocarbons. ACGIH has more information on halocarbon toxicity threshold limit values and biological exposure indices (see the Bibliography).

Construction materials and stability factors in halocarbon use are discussed in Chapter 29 of this volume and Chapter 5 of the 2006 *ASHRAE Handbook—Refrigeration*.

Table 14 Properties of a Polydimethylsiloxane Heat Transfer Fluid

Temperature, °F	Vapor Pressure, psia	Viscosity, lb/ft·h	Density, lb/ft^3	Heat Capacity, Btu/lb·°F	Thermal Conductivity, Btu/h·ft·°F
–100	0.00	30.24	57.8	0.337	0.0748
–90	0.00	25.40	57.5	0.340	0.0742
–80	0.00	21.34	57.2	0.344	0.0736
–70	0.00	18.14	56.9	0.347	0.0730
–60	0.00	15.55	56.6	0.350	0.0724
–50	0.00	13.43	56.3	0.354	0.0717
–40	0.00	11.68	56.0	0.357	0.0711
–30	0.00	10.21	55.7	0.361	0.0705
–20	0.00	9.00	55.4	0.364	0.0699
–10	0.00	7.96	55.1	0.367	0.0692
0	0.00	7.09	54.8	0.371	0.0686
10	0.00	6.34	54.5	0.374	0.0679
20	0.00	5.71	54.2	0.378	0.0673
30	0.00	5.15	53.9	0.381	0.0666
40	0.01	4.67	53.6	0.384	0.0659
50	0.01	4.26	53.3	0.388	0.0652
60	0.02	3.87	53.0	0.391	0.0646
70	0.03	3.56	52.7	0.395	0.0639
80	0.04	3.27	52.4	0.398	0.0632
90	0.05	3.02	52.1	0.402	0.0625
100	0.08	2.78	51.8	0.405	0.0618
110	0.11	2.59	51.5	0.408	0.0610
120	0.15	2.40	51.1	0.412	0.0603
130	0.20	2.24	50.8	0.415	0.0596
140	0.27	2.09	50.5	0.419	0.0589
150	0.35	1.96	50.2	0.422	0.0581
160	0.46	1.84	49.8	0.425	0.0574
170	0.60	1.73	49.5	0.429	0.0567
180	0.76	1.63	49.2	0.432	0.0559
190	0.96	1.54	48.8	0.436	0.0551
200	1.20	1.45	48.5	0.439	0.0544
210	1.49	1.38	48.1	0.442	0.0536
220	1.84	1.31	47.8	0.446	0.0528
230	2.24	1.24	47.4	0.449	0.0521
240	2.72	1.18	47.0	0.453	0.0513
250	3.27	1.12	46.7	0.456	0.0505
260	3.91	1.07	46.3	0.459	0.0497
270	4.65	1.03	45.9	0.463	0.0489
280	5.50	0.98	45.5	0.466	0.0481
290	6.46	0.94	45.1	0.470	0.0473
300	7.55	0.90	44.7	0.473	0.0465
310	8.78	0.86	44.3	0.476	0.0457
320	10.16	0.83	43.9	0.480	0.0449
330	11.71	0.80	43.5	0.483	0.0441
340	13.43	0.77	43.1	0.487	0.0432
350	15.33	0.74	42.6	0.490	0.0424
360	17.45	0.71	42.2	0.494	0.0416
370	19.77	0.69	41.7	0.497	0.0407
380	22.32	0.67	41.3	0.500	0.0399
390	25.12	0.64	40.8	0.504	0.0390
400	28.17	0.62	40.4	0.507	0.0382
410	31.49	0.60	39.9	0.511	0.0373
420	35.10	0.59	39.4	0.514	0.0365
430	39.00	0.57	38.9	0.517	0.0356
440	43.21	0.55	38.4	0.521	0.0348
450	47.75	0.53	37.9	0.524	0.0339
460	52.63	0.52	37.4	0.528	0.0330
470	57.86	0.51	36.8	0.531	0.0321
480	63.46	0.49	36.3	0.534	0.0313
490	69.44	0.48	35.8	0.538	0.0304
500	75.81	0.46	35.2	0.541	0.0295

Table 15 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

Source: Dow Corning (1989).

Table 16 Physical Properties of d-Limonene

Temperature, °F	Specific Heat, Btu/lb·°F	Viscosity, lb/ft·h	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F
–100	0.30	9.2	57.1	0.0794
–50	0.34	6.8	55.8	0.0764
0	0.37	5.1	54.5	0.0734
50	0.41	3.9	53.2	0.0704
100	0.44	2.9	51.8	0.0674
150	0.48	2.2	50.4	0.0644
200	0.51	1.7	49.0	0.0614
250	0.54	1.5	47.6	0.0584
300	0.58	1.0	46.0	0.0554

NONHALOCARBON, NONAQUEOUS FLUIDS

Numerous additional secondary refrigerants, used primarily by the chemical processing and pharmaceutical industries, have been used rarely in the HVAC and allied industries because of 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 14 to 16 list physical properties for 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 (molecular formula $C_{10}H_{16}$) is derived as an extract from orange and lemon oils.

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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