

CHAPTER 20

PHYSICAL PROPERTIES OF SECONDARY COOLANTS (BRINES)

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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 1998 *ASHRAE Handbook—Refrigeration*, refrigeration systems are discussed in Chapter 5; their uses in food processing are found in Chapters 15, 16, and 18; ice rinks are discussed in Chapter 34; and environmental test facilities are covered in Chapter 37. In the 1999 *ASHRAE Handbook—Applications*, solar energy utilization is discussed in Chapter 32, thermal storage in Chapter 33, and snow melting in Chapter 49.

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 47 of the 1999

ASHRAE Handbook—Applications and Chapter 4 of the 1998 *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

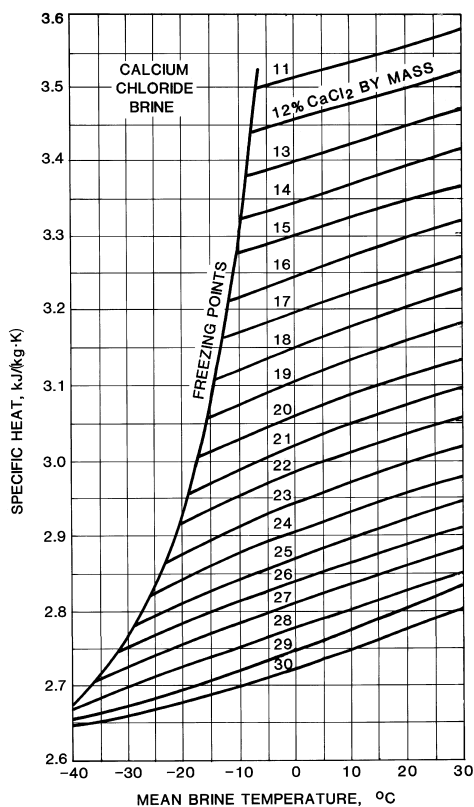


Fig. 1 Specific Heat of Calcium Chloride Brines

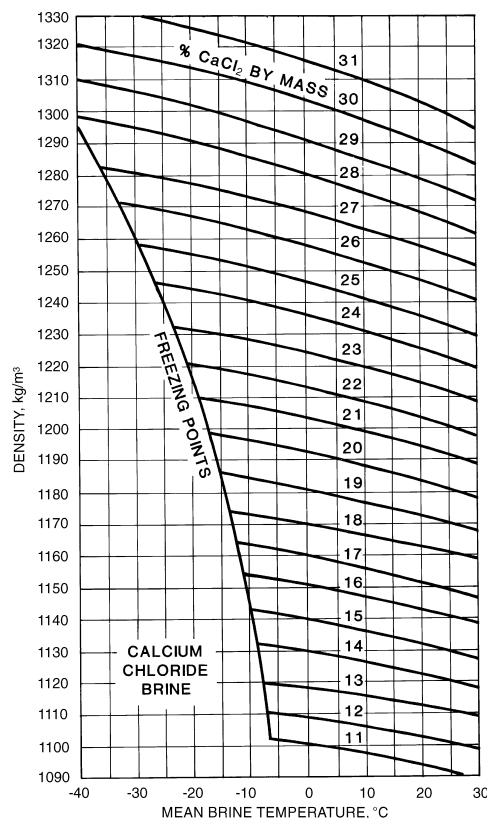


Fig. 2 Density of Calcium Chloride Brines

Table 1 Properties of Pure Calcium Chloride^a Brines

Pure CaCl ₂ , % by Mass	Specific Heat at 15°C, J/(kg·K)	Crystallization Starts, °C	Density at 16°C, kg/m ³		Density at Various Temperatures, kg/m ³			
			CaCl ₂	Brine	-20°C	-10°C	0°C	10°C
0	4184	0.0	0.0	999				
5	3866	-2.4	52.2	1044			1042	1041
6	3824	-2.9	63.0	1049			1051	1050
7	3757	-3.4	74.2	1059			1060	1059
8	3699	-4.1	85.5	1068			1070	1068
9	3636	-4.7	96.9	1078			1079	1077
10	3577	-5.4	108.6	1087			1088	1086
11	3523	-6.2	120.5	1095			1097	1095
12	3464	-7.1	132.5	1104			1107	1104
13	3414	-8.0	144.8	1113			1116	1114
14	3364	-9.2	157.1	1123			1126	1123
15	3318	-10.3	169.8	1132		1140	1136	1133
16	3259	-11.6	182.6	1141		1150	1145	1142
17	3209	-13.0	195.7	1152		1160	1155	1152
18	3163	-14.5	209.0	1161		1170	1165	1162
19	3121	-16.2	222.7	1171		1179	1175	1172
20	3084	-18.0	236.0	1180		1189	1185	1182
21	3050	-19.9	249.6	1189				
22	2996	-22.1	264.3	1201	1214	1210	1206	1202
23	2958	-24.4	278.7	1211				
24	2916	-26.8	293.5	1223	1235	1231	1227	1223
25	2882	-29.4	308.2	1232				
26	2853	-32.1	323.1	1242				
27	2816	-35.1	338.5	1253				
28	2782	-38.8	354.0	1264				
29	2753	-45.2	369.9	1275				
29.87	2741	-55.0	378.8	1289				
30	2732	-46.0	358.4	1294				
32	2678	-28.6	418.1	1316				
34	2636	-15.4	452.0	1339				

^aMass of Type 1 (77% min.) CaCl₂ = (mass of pure CaCl₂)/(0.77). Mass of Type 2 (94% min.) CaCl₂ = (mass of pure CaCl₂)/(0.94).

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 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 mg/kg of sodium chromate with pH 6.5 to 8.5. Sodium chloride brines require a minimum of 3600 mg/kg of sodium chromate and a pH of 6.5 to 8.5. Sodium nitrite at 3000 mg/kg in calcium brines or 4000 mg/kg in sodium brines controls pH between 7.0 and 8.5, and 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.

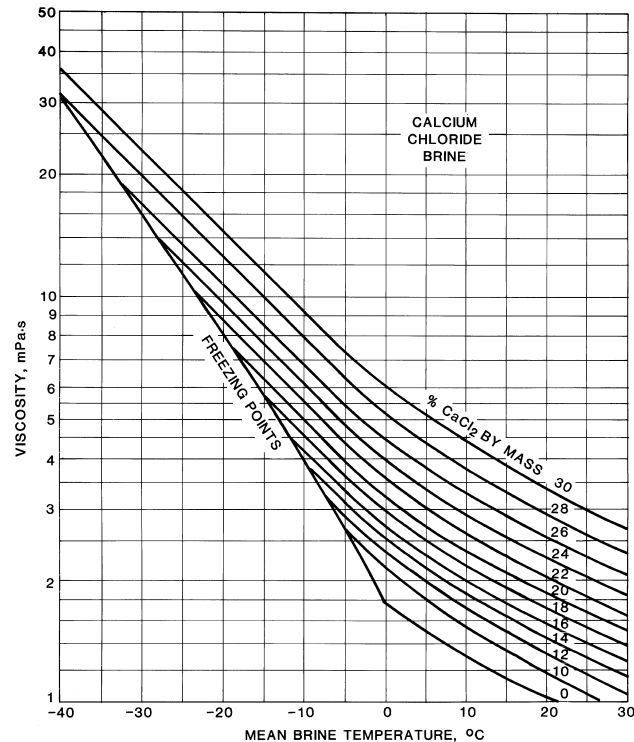


Fig. 3 Viscosity of Calcium Chloride Brines

Table 2 Properties of Pure Sodium Chloride^a Brines

Pure NaCl, % by Mass	Specific Heat at 15°C, J/(kg·K)	Crystallization Starts, °C	Density at 16°C, kg/m ³		Density at Various Temperatures, kg/m ³			
			NaCl	Brine	-10°C	-0°C	10°C	20°C
0	4184	0.0	0.0	1000				
5	3925	-2.9	51.7	1035		1038.1	1036.5	1034.0
6	3879	-3.6	62.5	1043		1045.8	1043.9	1041.2
7	3836	-4.3	73.4	1049		1053.7	1051.4	1048.5
8	3795	-5.0	84.6	1057		1061.2	1058.9	1055.8
9	3753	-5.8	95.9	1065		1069.0	1066.4	1063.2
10	3715	-6.6	107.2	1072		1076.8	1074.0	1070.6
11	3678	-7.3	118.8	1080		1084.8	1081.6	1078.1
12	3640	-8.2	130.3	1086		1092.4	1089.6	1085.6
13	3607	-9.1	142.2	1094		1100.3	1097.0	1093.2
14	3573	-10.1	154.3	1102		1108.2	1104.7	1100.8
15	3544	-10.9	166.5	1110	1119.4	1116.2	1112.5	1108.5
16	3515	-11.9	178.9	1118	1127.6	1124.2	1120.4	1116.2
17	3485	-13.0	191.4	1126	1135.8	1132.2	1128.3	1124.0
18	3456	-14.1	204.1	1134	1144.1	1140.3	1136.2	1131.8
19	3427	-15.3	217.0	1142	1153.4	1148.5	1144.3	1139.7
20	3402	-16.5	230.0	1150	1160.7	1156.7	1154.1	1147.7
21	3376	-17.8	243.2	1158	1169.1	1165.0	1160.5	1155.8
22	3356	-19.1	256.6	1166	1177.6	1173.3	1168.7	1163.9
23	3330	-20.6	270.0	1174	1186.1	1181.7	1177.0	1172.0
24	3310	-15.7	283.7	1182	1194.7	1190.1	1185.3	1180.3
25	3289	-8.8	297.5	1190				
25.2		0.0						

^aMass of commercial NaCl required = (mass of pure NaCl required)/(% purity).
^bMass of water per unit volume = Brine mass minus NaCl mass.

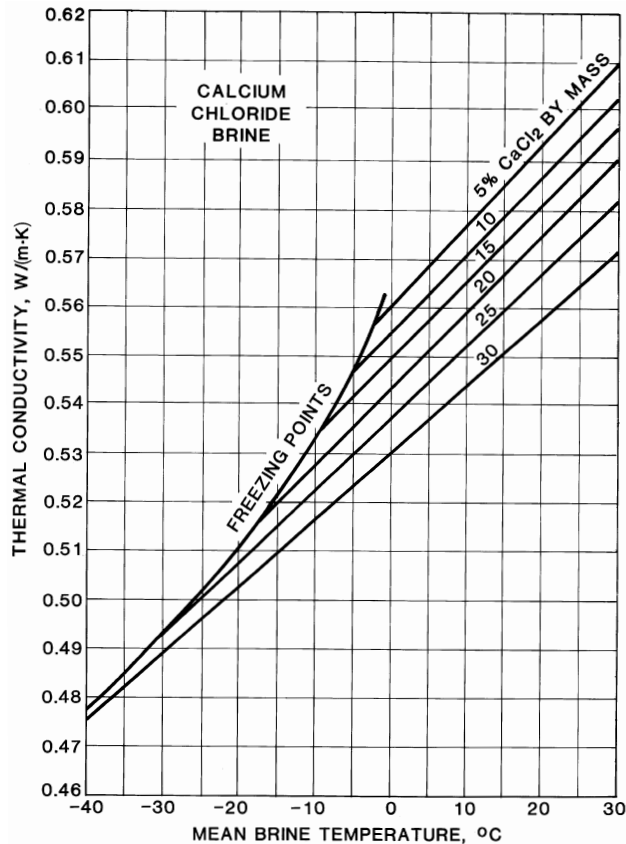


Fig. 4 Thermal Conductivity of Calcium Chloride Brines

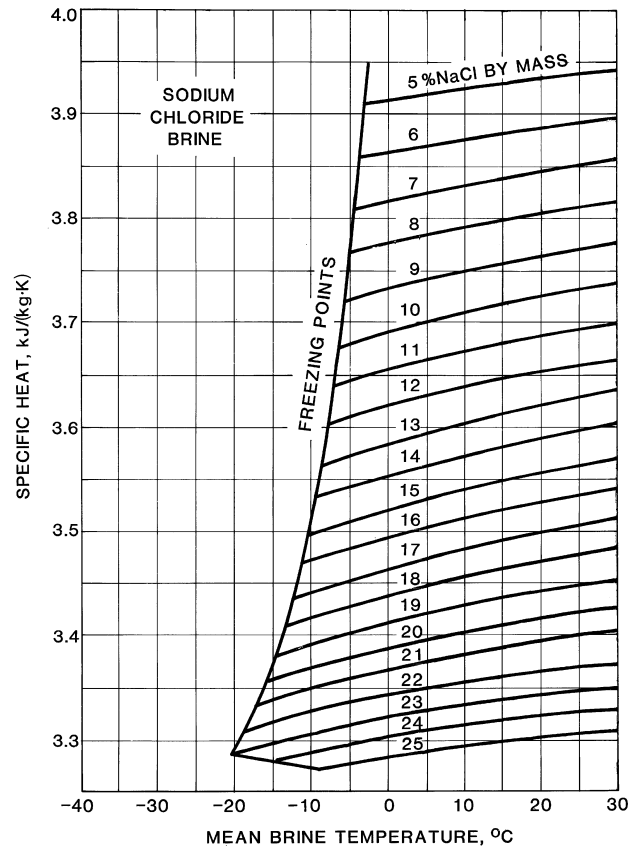


Fig. 5 Specific Heat of Sodium Chloride Brines

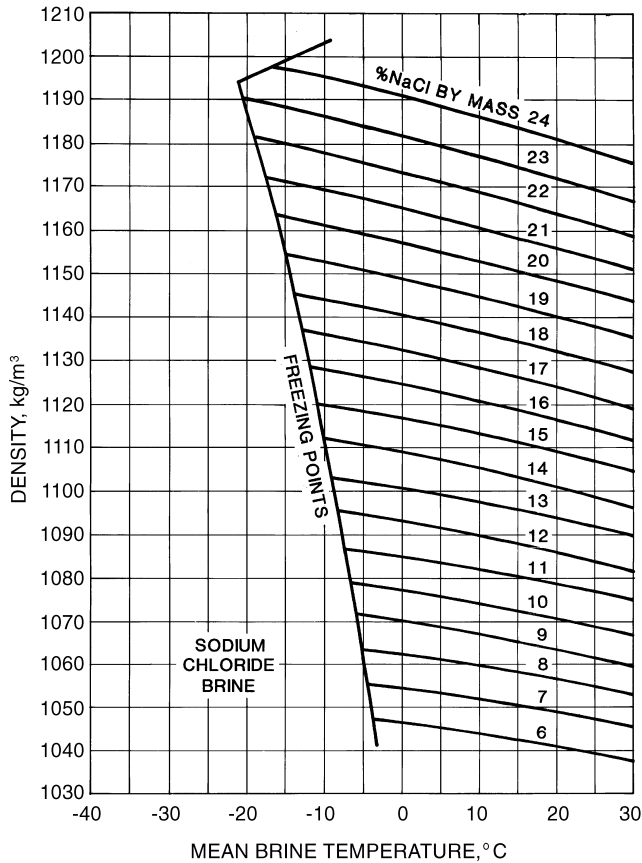


Fig. 6 Density of Sodium Chloride Brines

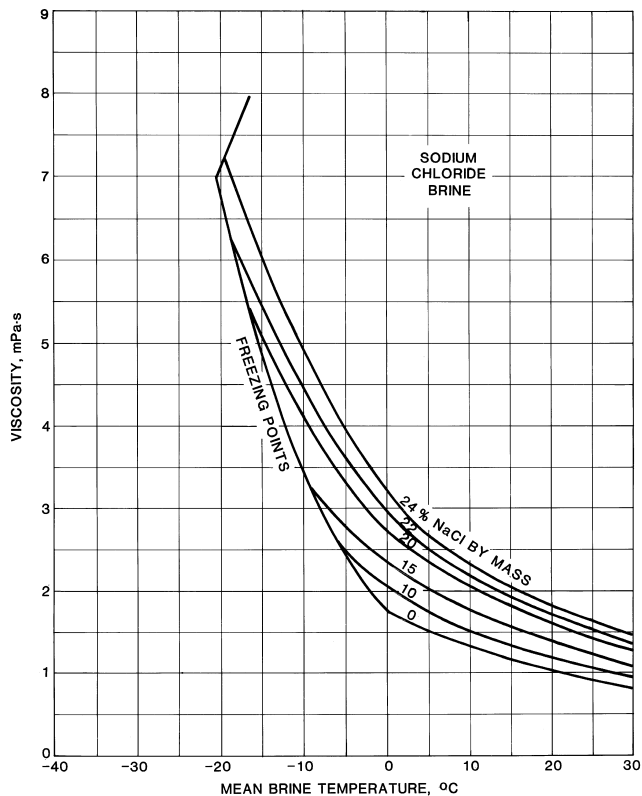


Fig. 7 Viscosity of Sodium Chloride Brines

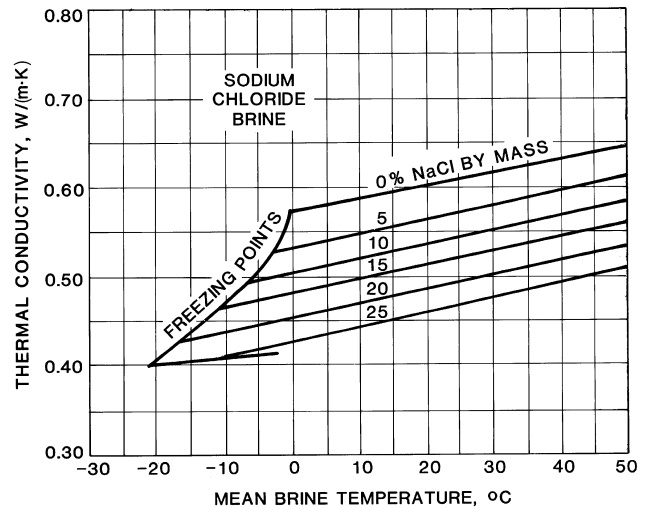


Fig. 8 Thermal Conductivity of Sodium Chloride Brines (Carrier 1959)

INHIBITED GLYCOLS

Ethylene glycol and propylene glycol, inhibited for corrosion control, are used as aqueous freezing point depressants (antifreeze) and heat transfer media in heating and cooling systems. Their chief attributes are their ability to lower the freezing point of water, and their low volatility, and 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.

Table 3 Physical Properties of Ethylene Glycol and Propylene Glycol

Property	Ethylene Glycol	Propylene Glycol
Relative molecular mass	62.07	76.10
Density at 20°C, kg/m ³	1113	1036
Boiling point, °C		
at 101.3 kPa	198	187
at 6.67 kPa	123	116
at 1.33 kPa	89	85
Vapor pressure at 20°C, Pa	6.7	9.3
Freezing point, °C	-12.7	Sets to glass below -51°C
Viscosity, mPa·s		
at 0°C	57.4	243
at 20°C	20.9	60.5
at 40°C	9.5	18.0
Refractive index <i>n_D</i> at 20°C	1.4319	1.4329
Specific heat at 20°C, kJ/(kg·K)	2.347	2.481
Heat of fusion at -12.7°C, kJ/kg	187	—
Heat of vaporization at 101.3 kPa, kJ/kg	846	688
Heat of combustion at 20°C, MJ/kg	19.246	23.969

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 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%

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

Percent Ethylene Glycol		Freezing Point, °C	Boiling Point, °C at 100.7 kPa
By Mass	By Volume		
0.0	0.0	0.0	100.0
5.0	4.4	-1.4	100.6
10.0	8.9	-3.2	101.1
15.0	13.6	-5.4	101.7
20.0	18.1	-7.8	102.2
21.0	19.2	-8.4	102.2
22.0	20.1	-8.9	102.2
23.0	21.0	-9.5	102.8
24.0	22.0	-10.2	102.8
25.0	22.9	-10.7	103.3
26.0	23.9	-11.4	103.3
27.0	24.8	-12.0	103.3
28.0	25.8	-12.7	103.9
29.0	26.7	-13.3	103.9
30.0	27.7	-14.1	104.4
31.0	28.7	-14.8	104.4
32.0	29.6	-15.4	104.4
33.0	30.6	-16.2	104.4
34.0	31.6	-17.0	104.4
35.0	32.6	-17.9	105.0
36.0	33.5	-18.6	105.0
37.0	34.5	-19.4	105.0
38.0	35.5	-20.3	105.0
39.0	36.5	-21.3	105.0
40.0	37.5	-22.3	105.6
41.0	38.5	-23.2	105.6
42.0	39.5	-24.3	105.6
43.0	40.5	-25.3	106.1
44.0	41.5	-26.4	106.1
45.0	42.5	-27.5	106.7
46.0	43.5	-28.8	106.7
47.0	44.5	-29.8	106.7
48.0	45.5	-31.1	106.7
49.0	46.6	-32.6	106.7
50.0	47.6	-33.8	107.2
51.0	48.6	-35.1	107.2
52.0	49.6	-36.4	107.2
53.0	50.6	-37.9	107.8
54.0	51.6	-39.3	107.8
55.0	52.7	-41.1	108.3
56.0	53.7	-42.6	108.3
57.0	54.7	-44.2	108.9
58.0	55.7	-45.6	108.9
59.0	56.8	-47.1	109.4
60.0	57.8	-48.3	110.0
65.0	62.8	a	112.8
70.0	68.3	a	116.7
75.0	73.6	a	120.0
80.0	78.9	-46.8	123.9
85.0	84.3	-36.9	133.9
90.0	89.7	-29.8	140.6
95.0	95.0	-19.4	158.3

^aFreezing points are below -50°C.

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

Percent Propylene Glycol		Freezing Point, °C	Boiling Point, °C at 100.7 kPa
By Mass	By Volume		
0.0	0.0	0.0	100.0
5.0	4.8	-1.6	100.0
10.0	9.6	-3.3	100.0
15.0	14.5	-5.1	100.0
20.0	19.4	-7.1	100.6
21.0	20.4	-7.6	100.6
22.0	21.4	-8.0	100.6
23.0	22.4	-8.6	100.6
24.0	23.4	-9.1	100.6
25.0	24.4	-9.6	101.1
26.0	25.3	-10.2	101.1
27.0	26.4	-10.8	101.1
28.0	27.4	-11.4	101.7
29.0	28.4	-12.0	101.7
30.0	29.4	-12.7	102.2
31.0	30.4	-13.4	102.2
32.0	31.4	-14.1	102.2
33.0	32.4	-14.8	102.2
34.0	33.5	-15.6	102.2
35.0	34.4	-16.4	102.8
36.0	35.5	-17.3	102.8
37.0	36.5	-18.2	102.8
38.0	37.5	-19.1	103.3
39.0	38.5	-20.1	103.3
40.0	39.6	-21.1	103.9
41.0	40.6	-22.1	103.9
42.0	41.6	-23.2	103.9
43.0	42.6	-24.3	103.9
44.0	43.7	-25.5	103.9
45.0	44.7	-26.7	104.4
46.0	45.7	-27.9	104.4
47.0	46.8	-29.3	104.4
48.0	47.8	-30.6	105.0
49.0	48.9	-32.1	105.0
50.0	49.9	-33.5	105.6
51.0	50.9	-35.0	105.6
52.0	51.9	-36.6	105.6
53.0	53.0	-38.2	106.1
54.0	54.0	-39.8	106.1
55.0	55.0	-41.6	106.1
56.0	56.0	-43.3	106.1
57.0	57.0	-45.2	106.7
58.0	58.0	-47.1	106.7
59.0	59.0	-49.0	106.7
60.0	60.0	-51.1	107.2
65.0	65.0	a	108.3
70.0	70.0	a	110.0
75.0	75.0	a	113.9
80.0	80.0	a	118.3
85.0	85.0	a	125.0
90.0	90.0	a	132.2
95.0	95.0	a	154.4

^aAbove 60% by mass, solutions do not freeze but become a glass.

Table 6 Density of Aqueous Solutions of Ethylene Glycol

Temperature, °C	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35					1089.94	1104.60	1118.61	1132.11	
-30					1089.04	1103.54	1117.38	1130.72	
-25					1088.01	1102.36	1116.04	1129.21	1141.87
-20				1071.98	1086.87	1101.06	1114.58	1127.57	1140.07
-15				1070.87	1085.61	1099.64	1112.99	1125.82	1138.14
-10			1054.31	1069.63	1084.22	1098.09	1111.28	1123.94	1136.09
-5		1036.85	1053.11	1068.28	1082.71	1096.43	1109.45	1121.94	1133.91
0	1018.73	1035.67	1051.78	1066.80	1081.08	1094.64	1107.50	1119.82	1131.62
5	1017.57	1034.36	1050.33	1065.21	1079.33	1092.73	1105.43	1117.58	1129.20
10	1016.28	1032.94	1048.76	1063.49	1077.46	1090.70	1103.23	1115.22	1126.67
15	1014.87	1031.39	1047.07	1061.65	1075.46	1088.54	1100.92	1112.73	1124.01
20	1013.34	1029.72	1045.25	1059.68	1073.35	1086.27	1098.48	1110.13	1121.23
25	1011.69	1027.93	1043.32	1057.60	1071.11	1083.87	1095.92	1107.40	1118.32
30	1009.92	1026.02	1041.26	1055.39	1068.75	1081.35	1093.24	1104.55	1115.30
35	1008.02	1023.99	1039.08	1053.07	1066.27	1078.71	1090.43	1101.58	1112.15
40	1006.01	1021.83	1036.78	1050.62	1063.66	1075.95	1087.51	1098.48	1108.89
45	1003.87	1019.55	1034.36	1048.05	1060.94	1073.07	1084.46	1095.27	1105.50
50	1001.61	1017.16	1031.81	1045.35	1058.09	1070.06	1081.30	1091.93	1101.99
55	999.23	1014.64	1029.15	1042.54	1055.13	1066.94	1078.01	1088.48	1098.36
60	996.72	1011.99	1026.36	1039.61	1052.04	1063.69	1074.60	1084.90	1094.60
65	994.10	1009.23	1023.45	1036.55	1048.83	1060.32	1071.06	1081.20	1090.73
70	991.35	1006.35	1020.42	1033.37	1045.49	1056.83	1067.41	1077.37	1086.73
75	988.49	1003.34	1017.27	1030.07	1042.04	1053.22	1063.64	1073.43	1082.61
80	985.50	1000.21	1014.00	1026.65	1038.46	1049.48	1059.74	1069.36	1078.37
85	982.39	996.96	1010.60	1023.10	1034.77	1045.63	1055.72	1065.18	1074.01
90	979.15	993.59	1007.09	1019.44	1030.95	1041.65	1051.58	1060.87	1069.53
95	975.80	990.10	1003.45	1015.65	1027.01	1037.55	1047.32	1056.44	1064.92
100	972.32	986.48	999.69	1011.74	1022.95	1033.33	1042.93	1051.88	1060.20
105	968.73	982.75	995.81	1007.71	1018.76	1028.99	1038.43	1047.21	1055.35
110	965.01	978.89	991.81	1003.56	1014.46	1024.52	1033.80	1042.41	1050.38
115	961.17	974.91	987.68	999.29	1010.03	1019.94	1029.05	1037.50	1045.29
120	957.21	970.81	983.43	994.90	1005.48	1015.23	1024.18	1032.46	1040.08
125	953.12	966.59	979.07	990.38	1000.81	1010.40	1019.19	1027.30	1034.74

Note: Density in kg/m³.

Table 7 Specific Heat of Aqueous Solutions of Ethylene Glycol

Temperature, °C	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35					3.068	2.844	2.612	2.370	
-30					3.088	2.866	2.636	2.397	
-25					3.107	2.888	2.660	2.423	2.177
-20				3.334	3.126	2.909	2.685	2.450	2.206
-15				3.351	3.145	2.931	2.709	2.477	2.235
-10			3.560	3.367	3.165	2.953	2.733	2.503	2.264
-5		3.757	3.574	3.384	3.184	2.975	2.757	2.530	2.293
0	3.937	3.769	3.589	3.401	3.203	2.997	2.782	2.556	2.322
5	3.946	3.780	3.603	3.418	3.223	3.018	2.806	2.583	2.351
10	3.954	3.792	3.617	3.435	3.242	3.040	2.830	2.610	2.380
15	3.963	3.803	3.631	3.451	3.261	3.062	2.854	2.636	2.409
20	3.972	3.815	3.645	3.468	3.281	3.084	2.878	2.663	2.438
25	3.981	3.826	3.660	3.485	3.300	3.106	2.903	2.690	2.467
30	3.989	3.838	3.674	3.502	3.319	3.127	2.927	2.716	2.496
35	3.998	3.849	3.688	3.518	3.339	3.149	2.951	2.743	2.525
40	4.007	3.861	3.702	3.535	3.358	3.171	2.975	2.770	2.554
45	4.015	3.872	3.716	3.552	3.377	3.193	3.000	2.796	2.583
50	4.024	3.884	3.730	3.569	3.396	3.215	3.024	2.823	2.612
55	4.033	3.895	3.745	3.585	3.416	3.236	3.048	2.850	2.641
60	4.042	3.907	3.759	3.602	3.435	3.258	3.072	2.876	2.670
65	4.050	3.918	3.773	3.619	3.454	3.280	3.097	2.903	2.699
70	4.059	3.930	3.787	3.636	3.474	3.302	3.121	2.929	2.728
75	4.068	3.941	3.801	3.653	3.493	3.324	3.145	2.956	2.757
80	4.077	3.953	3.816	3.669	3.512	3.345	3.169	2.983	2.786
85	4.085	3.964	3.830	3.686	3.532	3.367	3.193	3.009	2.815
90	4.094	3.976	3.844	3.703	3.551	3.389	3.218	3.036	2.844
95	4.103	3.987	3.858	3.720	3.570	3.411	3.242	3.063	2.873
100	4.112	3.999	3.872	3.736	3.590	3.433	3.266	3.089	2.902
105	4.120	4.010	3.886	3.753	3.609	3.454	3.290	3.116	2.931
110	4.129	4.022	3.901	3.770	3.628	3.476	3.315	3.143	2.960
115	4.138	4.033	3.915	3.787	3.647	3.498	3.339	3.169	2.989
120	4.147	4.045	3.929	3.804	3.667	3.520	3.363	3.196	3.018
125	4.155	4.056	3.943	3.820	3.686	3.542	3.387	3.223	3.047

Note: Specific heat in kJ/(kg·K).

Table 8 Thermal Conductivity of Aqueous Solutions of Ethylene Glycol

Temperature, °C	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35					0.328	0.307	0.289	0.274	
-30					0.333	0.312	0.293	0.276	
-25					0.339	0.316	0.296	0.279	0.263
-20				0.371	0.344	0.321	0.300	0.281	0.265
-15				0.377	0.349	0.325	0.303	0.283	0.266
-10			0.415	0.383	0.354	0.329	0.306	0.286	0.268
-5		0.460	0.422	0.389	0.359	0.333	0.309	0.288	0.269
0	0.511	0.468	0.429	0.395	0.364	0.336	0.312	0.290	0.271
5	0.520	0.476	0.436	0.400	0.368	0.340	0.314	0.292	0.272
10	0.528	0.483	0.442	0.405	0.373	0.343	0.317	0.294	0.274
15	0.537	0.490	0.448	0.410	0.377	0.346	0.320	0.296	0.275
20	0.545	0.497	0.453	0.415	0.380	0.349	0.322	0.298	0.276
25	0.552	0.503	0.459	0.419	0.384	0.352	0.324	0.299	0.278
30	0.559	0.509	0.464	0.424	0.387	0.355	0.327	0.301	0.279
35	0.566	0.515	0.469	0.428	0.391	0.358	0.329	0.303	0.280
40	0.572	0.520	0.473	0.431	0.394	0.360	0.331	0.304	0.281
45	0.577	0.525	0.477	0.435	0.397	0.363	0.332	0.306	0.282
50	0.583	0.529	0.481	0.438	0.399	0.365	0.334	0.307	0.283
55	0.588	0.534	0.485	0.441	0.402	0.367	0.336	0.308	0.284
60	0.592	0.538	0.488	0.444	0.404	0.369	0.337	0.310	0.285
65	0.596	0.541	0.491	0.446	0.406	0.371	0.339	0.311	0.286
70	0.600	0.544	0.494	0.449	0.408	0.372	0.340	0.312	0.287
75	0.603	0.547	0.496	0.451	0.410	0.374	0.341	0.313	0.288
80	0.606	0.549	0.498	0.452	0.411	0.375	0.342	0.314	0.288
85	0.608	0.551	0.500	0.454	0.413	0.376	0.343	0.314	0.289
90	0.610	0.553	0.501	0.455	0.414	0.377	0.344	0.315	0.290
95	0.612	0.555	0.503	0.456	0.415	0.378	0.345	0.316	0.290
100	0.613	0.556	0.504	0.457	0.416	0.379	0.346	0.316	0.291
105	0.614	0.556	0.504	0.458	0.416	0.379	0.346	0.317	0.291
110	0.614	0.557	0.505	0.458	0.417	0.380	0.347	0.317	0.292
115	0.614	0.557	0.505	0.458	0.417	0.380	0.347	0.318	0.292
120	0.613	0.556	0.504	0.458	0.417	0.380	0.347	0.318	0.293
125	0.612	0.555	0.504	0.458	0.417	0.380	0.347	0.318	0.293

Note: Thermal conductivity in W/(m·K).

Table 9 Viscosity of Aqueous Solutions of Ethylene Glycol

Temperature, °C	Concentrations in Volume Percent Ethylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35					66.93	93.44	133.53	191.09	
-30					43.98	65.25	96.57	141.02	
-25					30.50	46.75	70.38	102.21	196.87
-20				15.75	22.07	34.28	51.94	74.53	128.43
-15				11.74	16.53	25.69	38.88	55.09	87.52
-10			6.19	9.06	12.74	19.62	29.53	41.36	61.85
-5		3.65	5.03	7.18	10.05	15.25	22.76	31.56	45.08
0	2.08	3.02	4.15	5.83	8.09	12.05	17.79	24.44	33.74
5	1.79	2.54	3.48	4.82	6.63	9.66	14.09	19.20	25.84
10	1.56	2.18	2.95	4.04	5.50	7.85	11.31	15.29	20.18
15	1.37	1.89	2.53	3.44	4.63	6.46	9.18	12.33	16.04
20	1.21	1.65	2.20	2.96	3.94	5.38	7.53	10.05	12.95
25	1.08	1.46	1.92	2.57	3.39	4.52	6.24	8.29	10.59
30	0.97	1.30	1.69	2.26	2.94	3.84	5.23	6.90	8.77
35	0.88	1.17	1.50	1.99	2.56	3.29	4.42	5.79	7.34
40	0.80	1.06	1.34	1.77	2.26	2.84	3.76	4.91	6.21
45	0.73	0.96	1.21	1.59	2.00	2.47	3.23	4.19	5.30
50	0.67	0.88	1.09	1.43	1.78	2.16	2.80	3.61	4.56
55	0.62	0.81	0.99	1.29	1.59	1.91	2.43	3.12	3.95
60	0.57	0.74	0.90	1.17	1.43	1.69	2.13	2.72	3.45
65	0.53	0.69	0.83	1.06	1.29	1.51	1.88	2.39	3.03
70	0.50	0.64	0.76	0.97	1.17	1.35	1.67	2.11	2.67
75	0.47	0.59	0.70	0.89	1.07	1.22	1.49	1.87	2.37
80	0.44	0.55	0.65	0.82	0.98	1.10	1.33	1.66	2.12
85	0.41	0.52	0.60	0.76	0.89	1.00	1.20	1.49	1.90
90	0.39	0.49	0.56	0.70	0.82	0.92	1.09	1.34	1.71
95	0.37	0.46	0.52	0.65	0.76	0.84	0.99	1.21	1.54
100	0.35	0.43	0.49	0.60	0.70	0.77	0.90	1.10	1.40
105	0.33	0.40	0.46	0.56	0.65	0.71	0.82	1.00	1.27
110	0.32	0.38	0.43	0.53	0.60	0.66	0.76	0.91	1.16
115	0.30	0.36	0.41	0.49	0.56	0.61	0.70	0.83	1.07
120	0.29	0.34	0.38	0.46	0.53	0.57	0.64	0.77	0.98
125	0.28	0.33	0.36	0.43	0.49	0.53	0.60	0.71	0.90

Note: Viscosity in mPa·s.

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

Temperature, °C	Concentrations in Volume Percent Propylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35						1072.92	1079.67	1094.50	1092.46
-30						1071.31	1077.82	1090.85	1088.82
-25					1062.11	1069.58	1075.84	1087.18	1085.15
-20					1060.49	1067.72	1073.74	1083.49	1081.46
-15				1050.43	1058.73	1065.73	1071.51	1079.77	1077.74
-10			1039.42	1048.79	1056.85	1063.61	1069.16	1076.04	1074.00
-5		1027.24	1037.89	1047.02	1054.84	1061.37	1066.69	1072.27	1070.24
0	1013.85	1025.84	1036.24	1045.12	1052.71	1059.00	1064.09	1068.49	1066.46
5	1012.61	1024.32	1034.46	1043.09	1050.44	1056.50	1061.36	1064.68	1062.65
10	1011.24	1022.68	1032.55	1040.94	1048.04	1053.88	1058.51	1060.85	1058.82
15	1009.75	1020.91	1030.51	1038.65	1045.52	1051.13	1055.54	1057.00	1054.96
20	1008.13	1019.01	1028.35	1036.24	1042.87	1048.25	1052.44	1053.12	1051.09
25	1006.40	1016.99	1026.06	1033.70	1040.09	1045.24	1049.22	1049.22	1047.19
30	1004.54	1014.84	1023.64	1031.03	1037.18	1042.11	1045.87	1045.30	1043.26
35	1002.56	1012.56	1021.09	1028.23	1034.15	1038.85	1042.40	1041.35	1039.32
40	1000.46	1010.16	1018.42	1025.30	1030.98	1035.47	1038.81	1037.38	1035.35
45	998.23	1007.64	1015.62	1022.24	1027.69	1031.95	1035.09	1033.39	1031.35
50	995.88	1004.99	1012.69	1019.06	1024.27	1028.32	1031.25	1029.37	1027.34
55	993.41	1002.21	1009.63	1015.75	1020.72	1024.55	1027.28	1025.33	1023.30
60	990.82	999.31	1006.44	1012.30	1017.04	1020.66	1023.19	1021.27	1019.24
65	988.11	996.28	1003.13	1008.73	1013.23	1016.63	1018.97	1017.19	1015.15
70	985.27	993.12	999.69	1005.03	1009.30	1012.49	1014.63	1013.08	1011.04
75	982.31	989.85	996.12	1001.21	1005.24	1008.21	1010.16	1008.95	1006.91
80	979.23	986.44	992.42	997.25	1001.05	1003.81	1005.57	1004.79	1002.76
85	976.03	982.91	988.60	993.17	996.73	999.28	1000.86	1000.62	998.58
90	972.70	979.25	984.65	988.95	992.28	994.63	996.02	996.41	994.38
95	969.25	975.47	980.57	984.61	987.70	989.85	991.06	992.19	990.16
100	965.68	971.56	976.36	980.14	983.00	984.94	985.97	987.94	985.91
105	961.99	967.53	972.03	975.54	978.16	979.90	980.76	983.68	981.64
110	958.17	963.37	967.56	970.81	973.20	974.74	975.42	979.38	977.35
115	954.24	959.09	962.97	965.95	968.11	969.45	969.96	975.07	973.03
120	950.18	954.67	958.26	960.97	962.89	964.03	964.38	970.73	968.69
125	945.99	950.14	953.41	955.86	957.55	958.49	958.67	966.37	964.33

Note: Density in kg/m³.

Table 11 Specific Heat of Aqueous Solutions of Propylene Glycol

Temperature, °C	Concentrations in Volume Percent Propylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35						3.096	2.843	2.572	2.264
-30						3.118	2.868	2.600	2.295
-25					3.358	3.140	2.893	2.627	2.326
-20					3.378	3.162	2.918	2.655	2.356
-15				3.586	3.397	3.184	2.943	2.683	2.387
-10			3.765	3.603	3.416	3.206	2.968	2.710	2.417
-5		3.918	3.779	3.619	3.435	3.228	2.993	2.738	2.448
0	4.042	3.929	3.793	3.636	3.455	3.250	3.018	2.766	2.478
5	4.050	3.940	3.807	3.652	3.474	3.272	3.042	2.793	2.509
10	4.058	3.951	3.820	3.669	3.493	3.295	3.067	2.821	2.539
15	4.067	3.962	3.834	3.685	3.513	3.317	3.092	2.849	2.570
20	4.075	3.973	3.848	3.702	3.532	3.339	3.117	2.876	2.600
25	4.083	3.983	3.862	3.718	3.551	3.361	3.142	2.904	2.631
30	4.091	3.994	3.875	3.735	3.570	3.383	3.167	2.931	2.661
35	4.099	4.005	3.889	3.751	3.590	3.405	3.192	2.959	2.692
40	4.107	4.016	3.903	3.768	3.609	3.427	3.217	2.987	2.723
45	4.115	4.027	3.917	3.784	3.628	3.449	3.242	3.014	2.753
50	4.123	4.038	3.930	3.801	3.648	3.471	3.266	3.042	2.784
55	4.131	4.049	3.944	3.817	3.667	3.493	3.291	3.070	2.814
60	4.139	4.060	3.958	3.834	3.686	3.515	3.316	3.097	2.845
65	4.147	4.071	3.972	3.850	3.706	3.537	3.341	3.125	2.875
70	4.155	4.082	3.985	3.867	3.725	3.559	3.366	3.153	2.906
75	4.163	4.093	3.999	3.883	3.744	3.581	3.391	3.180	2.936
80	4.171	4.104	4.013	3.900	3.763	3.603	3.416	3.208	2.967
85	4.179	4.115	4.027	3.916	3.783	3.625	3.441	3.236	2.997
90	4.187	4.126	4.040	3.933	3.802	3.647	3.465	3.263	3.028
95	4.195	4.136	4.054	3.949	3.821	3.670	3.490	3.291	3.058
100	4.203	4.147	4.068	3.966	3.841	3.692	3.515	3.319	3.089
105	4.211	4.158	4.082	3.982	3.860	3.714	3.540	3.346	3.119
110	4.219	4.169	4.095	3.999	3.879	3.736	3.565	3.374	3.150
115	4.227	4.180	4.109	4.015	3.898	3.758	3.590	3.402	3.181
120	4.235	4.191	4.123	4.032	3.918	3.780	3.615	3.429	3.211
125	4.243	4.202	4.137	4.049	3.937	3.802	3.640	3.457	3.242

Note: Specific heat in kJ/(kg·K).

Table 12 Thermal Conductivity of Aqueous Solutions of Propylene Glycol

Temperature, °C	Concentrations in Volume Percent Propylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35						0.296	0.275	0.255	0.237
-30						0.300	0.277	0.256	0.237
-25					0.329	0.303	0.278	0.257	0.236
-20					0.334	0.306	0.280	0.257	0.236
-15				0.369	0.338	0.309	0.282	0.258	0.236
-10			0.410	0.375	0.342	0.312	0.284	0.259	0.235
-5		0.456	0.416	0.380	0.346	0.314	0.285	0.259	0.235
0	0.510	0.464	0.423	0.385	0.349	0.317	0.286	0.259	0.234
5	0.518	0.472	0.429	0.389	0.353	0.319	0.288	0.260	0.234
10	0.527	0.479	0.434	0.394	0.356	0.321	0.289	0.260	0.233
15	0.535	0.485	0.440	0.398	0.359	0.323	0.290	0.260	0.233
20	0.543	0.492	0.445	0.402	0.362	0.325	0.291	0.261	0.232
25	0.550	0.498	0.449	0.406	0.365	0.327	0.292	0.261	0.231
30	0.557	0.503	0.454	0.409	0.367	0.329	0.293	0.261	0.231
35	0.563	0.508	0.458	0.412	0.370	0.330	0.293	0.261	0.230
40	0.569	0.513	0.462	0.415	0.372	0.331	0.294	0.261	0.229
45	0.575	0.518	0.466	0.418	0.374	0.333	0.294	0.260	0.229
50	0.580	0.522	0.469	0.420	0.375	0.334	0.295	0.260	0.228
55	0.585	0.526	0.472	0.423	0.377	0.335	0.295	0.260	0.227
60	0.589	0.529	0.475	0.425	0.378	0.335	0.295	0.260	0.227
65	0.593	0.532	0.477	0.426	0.379	0.336	0.295	0.259	0.226
70	0.596	0.535	0.479	0.428	0.380	0.336	0.295	0.259	0.225
75	0.599	0.538	0.481	0.429	0.381	0.337	0.295	0.258	0.224
80	0.602	0.540	0.482	0.430	0.382	0.337	0.295	0.258	0.223
85	0.604	0.541	0.484	0.431	0.382	0.337	0.295	0.257	0.222
90	0.606	0.543	0.484	0.431	0.382	0.337	0.294	0.256	0.221
95	0.607	0.544	0.485	0.432	0.382	0.336	0.294	0.256	0.220
100	0.608	0.544	0.485	0.432	0.382	0.336	0.293	0.255	0.219
105	0.609	0.544	0.485	0.432	0.382	0.335	0.292	0.254	0.218
110	0.609	0.544	0.485	0.431	0.381	0.335	0.292	0.253	0.217
115	0.608	0.544	0.485	0.430	0.380	0.334	0.291	0.252	0.216
120	0.608	0.543	0.484	0.429	0.379	0.333	0.290	0.251	0.215
125	0.606	0.542	0.482	0.428	0.378	0.332	0.288	0.250	0.214

Note: Thermal conductivity in W/(m·K).

Table 13 Viscosity of Aqueous Solutions of Propylene Glycol

Temperature, °C	Concentrations in Volume Percent Propylene Glycol								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
-35						524.01	916.18	1434.22	3813.29
-30						330.39	551.12	908.47	2071.34
-25					110.59	211.43	340.09	575.92	1176.09
-20					73.03	137.96	215.67	368.77	696.09
-15				33.22	49.70	92.00	140.62	239.86	428.19
-10			11.87	23.27	34.78	62.78	94.23	159.02	272.94
-5		4.98	9.08	16.75	24.99	43.84	64.83	107.64	179.78
0	2.68	4.05	7.08	12.37	18.40	31.32	45.74	74.45	122.03
5	2.23	3.34	5.61	9.35	13.85	22.87	33.04	52.63	85.15
10	1.89	2.79	4.52	7.22	10.65	17.05	24.41	37.99	60.93
15	1.63	2.36	3.69	5.69	8.34	12.96	18.41	28.00	44.62
20	1.42	2.02	3.06	4.57	6.65	10.04	14.15	21.04	33.38
25	1.25	1.74	2.57	3.73	5.39	7.91	11.08	16.10	25.45
30	1.11	1.52	2.18	3.09	4.43	6.34	8.81	12.55	19.76
35	0.99	1.34	1.88	2.60	3.69	5.15	7.12	9.94	15.60
40	0.89	1.18	1.63	2.21	3.11	4.25	5.84	7.99	12.49
45	0.81	1.06	1.43	1.91	2.65	3.55	4.85	6.52	10.15
50	0.73	0.95	1.26	1.66	2.29	3.00	4.08	5.39	8.35
55	0.67	0.86	1.13	1.47	1.99	2.57	3.46	4.51	6.95
60	0.62	0.78	1.01	1.30	1.75	2.22	2.98	3.82	5.85
65	0.57	0.71	0.91	1.17	1.55	1.93	2.58	3.28	4.97
70	0.53	0.66	0.83	1.06	1.38	1.70	2.26	2.83	4.26
75	0.49	0.60	0.76	0.96	1.24	1.51	1.99	2.47	3.69
80	0.46	0.56	0.70	0.88	1.12	1.35	1.77	2.18	3.22
85	0.43	0.52	0.65	0.81	1.02	1.22	1.59	1.94	2.83
90	0.40	0.49	0.61	0.75	0.93	1.10	1.43	1.73	2.50
95	0.38	0.45	0.57	0.70	0.86	1.01	1.30	1.56	2.23
100	0.35	0.43	0.53	0.66	0.79	0.92	1.18	1.42	2.00
105	0.33	0.40	0.50	0.62	0.74	0.85	1.08	1.29	1.80
110	0.32	0.38	0.47	0.59	0.69	0.79	1.00	1.19	1.63
115	0.30	0.36	0.45	0.56	0.64	0.74	0.93	1.09	1.48
120	0.28	0.34	0.43	0.53	0.60	0.69	0.86	1.02	1.35
125	0.27	0.32	0.41	0.51	0.57	0.65	0.80	0.95	1.24

Note: Viscosity in mPa·s.

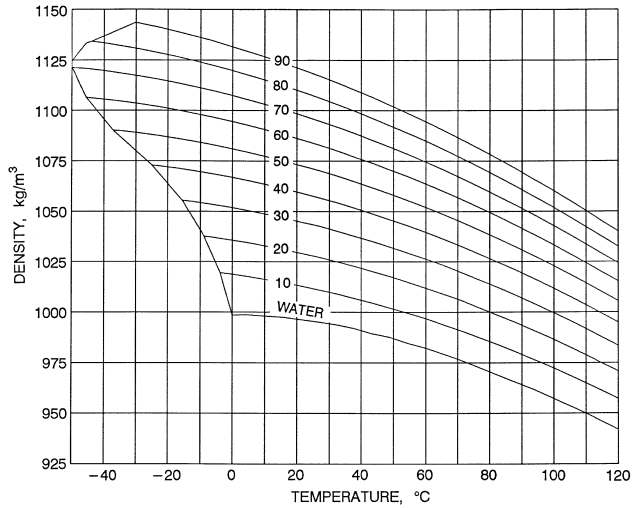


Fig. 9 Density of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

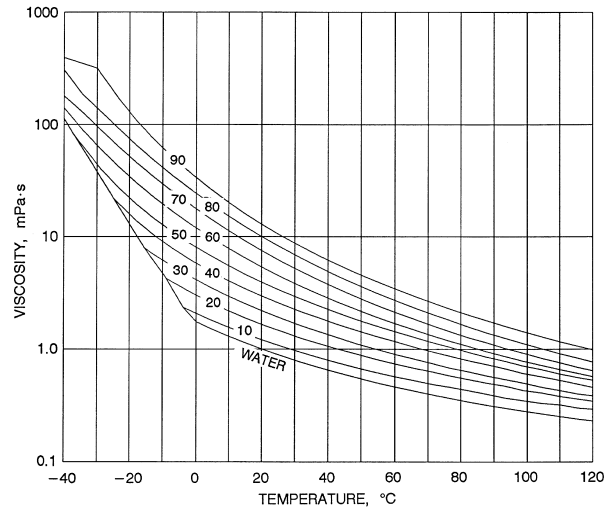


Fig. 12 Viscosity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

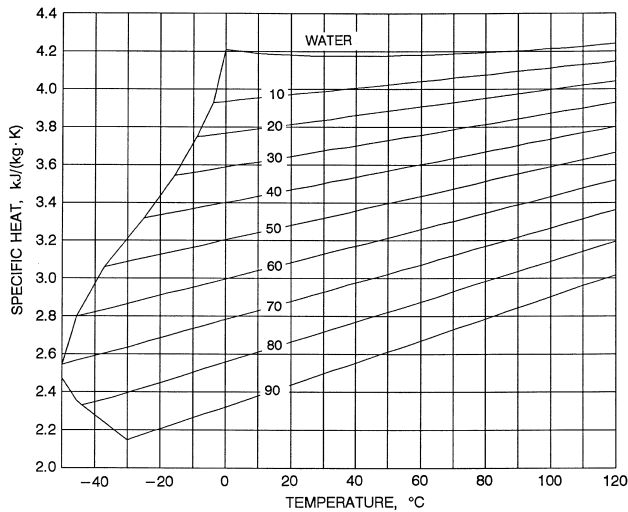


Fig. 10 Specific Heat of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

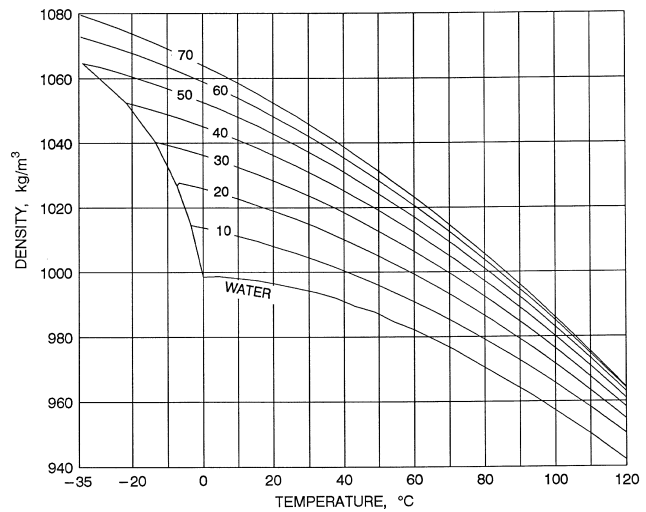


Fig. 13 Density of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

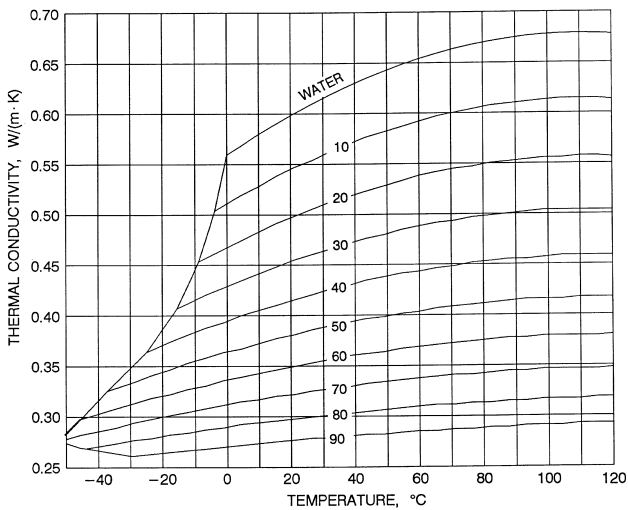


Fig. 11 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Ethylene Glycol (vol. %)

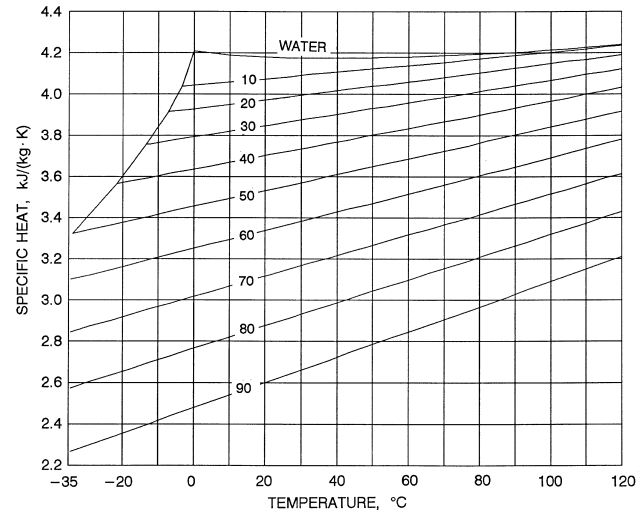


Fig. 14 Specific Heat of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

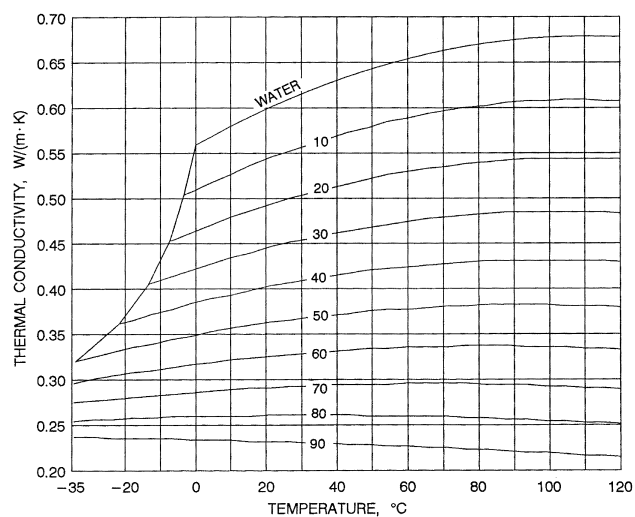


Fig. 15 Thermal Conductivity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

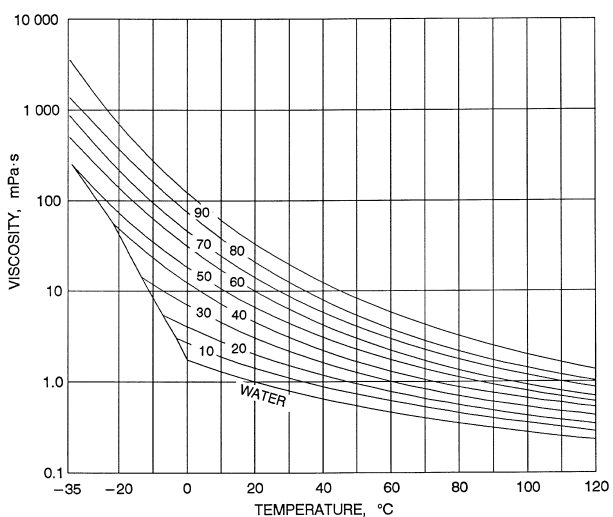


Fig. 16 Viscosity of Aqueous Solutions of Industrially Inhibited Propylene Glycol (vol. %)

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 3°C 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.

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 175°C. 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 82°C; however, temperatures up to 175°C are permissible in a pressurized system if air intake is eliminated. Maximum film temperatures should not exceed 28°C above the bulk temperature. Nitrogen blanketing minimizes oxidation when the system operates at elevated temperatures for extended periods.

Minimum operating temperatures are typically -23°C for ethylene glycol solutions and -18°C for propylene glycol solutions. Operation below these temperatures is generally impractical, because the viscosity of the fluids builds dramatically, thus increasing pumping power 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 66°C. 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.

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 mg/kg chloride, less than 25 mg/kg sulfate, and less than 100 mg/kg 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.

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 18 and 19 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 18 summarizes comparative safety characteristics for halocarbons. *Threshold Limit Values and Biological Exposure Indices* (ACGIH 1996) has more information on halocarbon toxicity.

Construction materials and stability factors in halocarbon use are discussed in Chapter 18 of this volume and Chapter 5 of the 1998 *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 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.

Table 14 Freezing and Boiling Points of Halocarbon Coolants

Refrigerant	Name	Freezing Point, °C	Boiling Point, °C
30	Methylene chloride	-96.7	39.8
1120	Trichloroethylene	-86.1	87.2

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

Temperature, °C	Vapor Pressure, kPa	Specific Heat, kJ/(kg·K)	Thermal Conductivity, W/(m·K)	Density, kg/m ³	Viscosity, mPa·s
60	175	1.24	0.128	1254	0.32
50	137	1.22	0.132	1271	0.34
40	100	1.21	0.136	1289	0.37
30	70.5	1.20	0.140	1307	0.40
20	47.0	1.19	0.144	1325	0.44
10	30.3	1.18	0.147	1342	0.48
0	18.8	1.17	0.150	1359	0.53
-10	11.3	1.16	0.154	1377	0.59
-20	6.7	1.16	0.157	1395	0.66
-30	3.8	1.15	0.160	1412	0.76
-40	2.18	1.15	0.163	1430	0.88
-50	1.22	1.14	0.166	1448	1.05
-60	0.69	1.14	0.169	1465	1.29
-70	0.38	1.14	0.171	1483	1.68
-80	0.21	1.14	0.174	1501	2.50

Table 16 Properties of Liquid Trichloroethylene (R-1120)

Temperature, °C	Vapor Pressure, kPa	Specific Heat, kJ/(kg·K)	Thermal Conductivity, W/(m·K)	Density, kg/m ³	Viscosity, mPa·s
60	39.5	0.965	0.107	1391	0.40
50	29.0	0.954	0.109	1409	0.44
40	19.8	0.943	0.112	1426	0.48
30	12.8	0.932	0.115	1444	0.52
20	7.8	0.922	0.118	1462	0.57
10	4.60	0.912	0.120	1480	0.63
0	2.55	0.902	0.123	1498	0.70
-10	1.37	0.892	0.126	1515	0.78
-20	0.70	0.883	0.128	1532	0.87
-30	0.36	0.875	0.131	1548	0.99
-40	0.168	0.867	0.134	1565	1.14
-50	0.076	0.860	0.137	1581	1.33
-60	0.033	0.853	0.139	1597	1.60
-70	0.014	0.846	0.142	1612	1.93
-80	0.006	0.840	0.145	1627	2.45

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

	Polydimethylsiloxane Mixture	d-Limonene
Flash point, °C, closed cup	46.7	46.1
Boiling point, °C	175	154.4
Freezing point, °C	-111.1	-96.7
Operational temperature range, °C	-73.3 to 260	None published

Table 18 Properties of a Polydimethylsiloxane Heat Transfer Fluid

Temperature, °C	Vapor Pressure, kPa	Viscosity, mPa·s	Density, kg/m ³	Heat Capacity, kJ/(kg·K)	Thermal Conductivity, W/(m·K)
-73	0.00	12.4	924.6	1.410	0.1294
-70	0.00	11.2	922.1	1.418	0.1288
-60	0.00	8.26	913.5	1.443	0.1269
-50	0.00	6.24	905.0	1.469	0.1251
-40	0.00	4.83	896.4	1.495	0.1231
-30	0.00	3.81	887.9	1.520	0.1212
-20	0.00	3.07	879.3	1.546	0.1192
-10	0.01	2.51	870.7	1.572	0.1171
0	0.03	2.09	862.0	1.597	0.1150
10	0.08	1.76	853.3	1.623	0.1129
20	0.16	1.49	844.5	1.649	0.1108
30	0.32	1.29	835.5	1.674	0.1086
40	0.61	1.12	826.5	1.700	0.1064
50	1.09	0.98	817.3	1.726	0.1042
60	1.85	0.86	807.9	1.751	0.1019
70	3.02	0.77	798.4	1.777	0.0996
80	4.76	0.69	788.7	1.803	0.0973
90	7.25	0.62	778.8	1.828	0.0949
100	10.73	0.56	768.7	1.854	0.0925
110	15.45	0.51	758.3	1.880	0.0901
120	21.75	0.47	747.7	1.905	0.0877
130	29.95	0.43	736.8	1.931	0.0852
140	40.45	0.40	725.6	1.957	0.0827
150	53.67	0.37	714.1	1.982	0.0802
160	70.06	0.34	702.3	2.008	0.0777
170	90.10	0.32	690.2	2.033	0.0751
180	114.29	0.30	677.7	2.059	0.0725
190	143.17	0.28	664.8	2.085	0.0699
200	177.27	0.26	651.6	2.110	0.0673
210	217.14	0.25	638.0	2.136	0.0646
220	263.36	0.24	623.9	2.162	0.0620
230	316.47	0.22	609.5	2.187	0.0593
240	377.03	0.21	594.5	2.213	0.0566
250	445.61	0.20	579.1	2.239	0.0538
260	522.74	0.19	563.3	2.264	0.0511

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. Note that the 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 C₁₀H₁₆) derived as an extract from orange and lemon oils. The “d” indicates that the material is

Table 19 Physical Properties of d-Limonene

Temperature, °C	Specific Heat, kJ/(kg·K)	Viscosity, mPa·s	Density, kg/m ³	Thermal Conductivity, W/(m·K)
-73	1.27	3.8	914.3	0.137
-50	1.39	3	897.1	0.133
-25	1.51	2.3	878.3	0.128
0	1.65	1.8	859.2	0.124
25	1.78	1.4	839.8	0.119
50	1.91	1.1	820.1	0.114
75	2.04	0.8	800	0.11
100	2.17	0.7	779.5	0.105
125	2.3	0.5	758.4	0.1
150	2.41	0.4	736.6	0.096

Note: Properties are estimated or based on incomplete data.

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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