CHAPTER 19

REFRIGERANTS

[Phaseout of Refrigerants](#) 19.1
Refrigerant Properties 19.4
Refrigerant Performance 19.6
Safety 19.6
Leak Detection 19.7
Effect on Construction Materials 19.11

REFRIGERANTS are the working fluids in refrigeration, air-conditioning, and heat pumping systems. They absorb heat from one area, such as an air-conditioned space, and reject it into another, such as outdoors, usually through evaporation and condensation, respectively. These phase changes occur both in absorption and mechanical vapor compression systems, but they do not occur in systems operating on a gas cycle using a fluid such as air. (See Chapter 1 for more information on refrigeration cycles.) The design of the refrigeration equipment depends strongly on the properties of the selected refrigerant. Table 1 lists ASHRAE standard refrigerant designations from ASHRAE *Standard* 34.

Refrigerant selection involves compromises between conflicting desirable thermodynamic properties. A refrigerant must satisfy many requirements, some of which do not directly relate to its ability to transfer heat. Chemical stability under conditions of use is the most important characteristic. Safety codes may require a nonflammable refrigerant of low toxicity for some applications. Cost, availability, efficiency, and compatibility with compressor lubricants and materials with which the equipment is constructed are other concerns.

The environmental consequences of a refrigerant that leaks from a system must also be considered. Because of their great stability, fully halogenated compounds, such as **chlorofluorocarbons** (CFCs), persist in the atmosphere for many years and eventually diffuse into the stratosphere. The molecules of CFCs, such as R-11 and R-12, contain only carbon and the halogens chlorine and fluorine. Once in the upper atmosphere, CFC molecules break down and release chlorine, which destroys ozone (**ozone depletion**). In the lower atmosphere, these molecules absorb infrared radiation, which may contribute to the warming of the earth. Substitution of a hydrogen atom for one or more of the halogens in a CFC molecule greatly reduces its atmospheric lifetime and lessens its environmental impact. These compounds are called **hydrochlorofluorocarbons** (HCFCs). A similar class of compounds used as fire extinguishing agents and called halons also cause ozone depletion. **Halons** are compounds containing bromine, fluorine, and carbon. Like CFCs, halons break down, but release bromine, which is even more destructive to stratospheric ozone than chlorine.

Latent heat of vaporization is another important property. On a molar basis, fluids with similar boiling points have almost the same latent heat. Since the compressor operates on volumes of gas, refrigerants with similar boiling points produce similar capacities in a given compressor. On a mass basis, latent heat varies widely among fluids. The maximum efficiency of a theoretical vapor compression cycle is achieved by fluids with low vapor heat capacity. This property is associated with fluids having a simple molecular structure and low molecular weight.

Transport properties of thermal conductivity and viscosity affect the performance of heat exchangers and piping. High thermal conductivity and low viscosity are desirable.

No single fluid satisfies all the attributes desired of a refrigerant; as a result, a variety of refrigerants is used. This chapter describes the basic characteristics of various refrigerants, and Chapter 20 lists thermophysical properties.

PHASEOUT OF REFRIGERANTS

The Montreal Protocol is an international treaty that controls the production of ozone-depleting substances, including refrigerants containing chlorine and/or bromine (U.N. 1994, 1996). The original Protocol was signed September 16, 1987, by the European Economic Community (currently the European Union) and 24 nations, including the United States. It entered into force on January 1, 1989, and limits the 1998 production of specified CFCs to 50% of their 1986 levels. Starting in 1992, the production of specified halons (including R-13B1) was frozen at 1986 levels. Developing countries were granted additional time to meet these deadlines.

The original Protocol contained provisions for periodic revision. Four such revisions, referred to as the London, Copenhagen, Montreal, and Beijing Amendments, were agreed to in 1990, 1992, 1997 and 1999, respectively. As of February, 2000, the Montreal Protocol had been ratified by 172 parties, the London Amendment by 138 parties, and the Copenhagen Amendment by 104 parties; the Beijing amendment has yet to be ratified.

The Copenhagen Amendment entered into force on June 14, 1994. It called for a complete cessation of the production of CFCs by January 1, 1996, and of halons by January 1, 1994. Continued use from existing (reclaimed or recycled) stock is permitted. Allowance is also provided for continued production for very limited essential uses. In addition, HCFCs (such as R-22 and R-123) are to be phased out relative to a 1989 reference level for developed countries. Production was frozen at the reference level on January 1, 1996. Production will be limited to 65% of the reference level by January 1, 2004; to 35% by January 1, 2010; to 10% by January 1, 2015; and to 0.5% of the reference level by January 1, 2020. Complete cessation of the production of HCFCs is called for by January 1, 2030. In addition to the international agreement, individual countries may have domestic regulations for ozone-depleting compounds.

The Beijing Amendment will regulate the production of HCFCs in developed countries. A production cap will begin in 2004 and will be equal to the original HCFC use cap plus an additional 15% allowance to meet developing country needs. At this time, there is no provision for reductions to this production cap.

The production and use of hydrofluorocarbon (HFC) refrigerants (such as R-32, R-125, R-134a, R-143a, and their mixtures, including R-404A, R-407C, and R-410A) are not regulated by the Montreal Protocol.

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

Table 1 Standard Designation of Refrigerants (ASHRAE *Standard* 34)

Refrigerant Number	Chemical Name or Composition (% by mass)	Chemical Formula
Methane Series		
10	tetrachloromethane (carbon tetrachloride)	CCl_4
11	trichlorofluoromethane	CCl_3F
12	dichlorodifluoromethane	CCl_2F_2
12B1	bromochlorodifluoromethane	$CBrClF_2$
12B2	dibromodifluoromethane	CBr_2F_2
13	chlorotrifluoromethane	$CClF_3$
13B1	bromotrifluoromethane	$CBrF_3$
14	tetrafluoromethane (carbon tetrafluoride)	CF_4
20	trichloromethane (chloroform)	$CHCl_3$
21	dichlorofluoromethane	$CHCl_2F$
22	chlorodifluoromethane	$CHClF_2$
22B1	bromodifluoromethane	$CHBrF_2$
23	trifluoromethane	CHF_3
30	dichloromethane (methylene chloride)	CH_2Cl_2
31	chlorofluoromethane	CH_2ClF
32	difluoromethane (methylene fluoride)	CH_2F_2
40	chloromethane (methyl chloride)	CH_3Cl
41	fluoromethane (methyl fluoride)	CH_3F
50	methane	CH_4
Ethane Series		
110	hexachloroethane	CCl_3CCl_3
111	pentachlorofluoroethane	CCl_3CCl_2F
112	1,1,2,2-tetrachloro-1,2-difluoroethane	CCl_2FCCl_2F
112a	1,1,1,2-tetrachloro-2,2-difluoroethane	CCl_3CClF_2
113	1,1,2-trichloro-1,2,2-trifluoroethane	CCl_2FCClF_2
113a	1,1,1-trichloro-2,2,2-trifluoroethane	CCl_3CF_3
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	$CClF_2CClF_2$
114a	1,1-dichloro-1,2,2,2-tetrafluoroethane	CCl_2FCF_3
114B2	1,2-dibromo-1,1,2,2-tetrafluoroethane	$CBrF_2CBrF_2$
115	chloropentafluoroethane	$CClF_2CF_3$
116	hexafluoroethane	CF_3CF_3
120	pentachloroethane	$CHCl_2CCl_3$
123	2,2-dichloro-1,1,1-trifluoroethane	$CHCl_2CF_3$
123a	1,2-dichloro-1,1,2-trifluoroethane	$CHClFCClF_2$
124	2-chloro-1,1,1,2-tetrafluoroethane	$CHClFCF_3$
124a	1-chloro-1,1,2,2-tetrafluoroethane	CHF_2CClF_2
125	pentafluoroethane	CHF_2CF_3
133a	2-chloro-1,1,1-trifluoroethane	CH_2ClCF_3
134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3
140a	1,1,1-trichloroethane (methyl chloroform)	CH_3CCl_3
141b	1,1-dichloro-1-fluoroethane	CCl_2FCH_3
142b	1-chloro-1,1-difluoroethane	$CClF_2CH_3$
143a	1,1,1-trifluoroethane	CF_3CH_3
150a	1,1-dichloroethane	$CHCl_2CH_3$
152a	1,1-difluoroethane	CHF_2CH_3
160	chloroethane (ethyl chloride)	CH_3CH_2Cl
170	ethane	CH_3CH_3
Propane Series		
216ca	1,3-dichloro-1,1,2,2,3,3-hexafluoropropane	$CClF_2CF_2CClF_2$
218	octafluoropropane	$CF_3CF_2CF_3$
245cb	1,1,1,2,2-pentafluoropropane	$CF_3CF_2CH_3$
290	propane	$CH_3CH_2CH_3$
Cyclic Organic Compounds		
C316	1,2-dichloro-1,2,3,3,4,4-hexafluorocyclobutane	$C_4Cl_2F_6$
C317	chloroheptafluorocyclobutane	C_4ClF_7
C318	octafluorocyclobutane	C_4F_8
Zeotropic Blends (% by mass)		
400	R-12/114 (must be specified)	
401A	R-22/152a/124 (53/13/34)	
401B	R-22/152a/124 (61/11/28)	
401C	R-22/152a/124 (33/15/52)	
402A	R-125/290/22 (60/2/38)	
402B	R-125/290/22 (38/2/60)	
403A	R-290/22/218 (5/75/20)	
403B	R-290/22/218 (5/56/39)	
404A	R-125/143a/134a (44/52/4)	
405A	R-22/152a/142b/C318 (45/7/5.5/42.5)	
406A	R-22/600a/142b (55/4/41)	
407A	R-32/125/134a (20/40/40)	
407B	R-32/125/134a (10/70/20)	
407C	R-32/125/134a (23/25/52)	
407D	R-32/125/134a (15/15/70)	
408A	R-125/143a/22 (7/46/47)	
409A	R-22/124/142b (60/25/15)	
409B	R-22/124/142b (65/25/10)	
410A	R-32/125 (50/50)	
410B	R-32/125 (45/55)	
411A	R-1270/22/152a (1.5/87.5/11.0)	
411B	R-1270/22/152a (3/94/3)	
412A	R-22/218/142b (70/5/25)	
413A	R-218/134a/600a (9/88/3)	
Azeotropic Blends (% by mass)		
500	R-12/152a (73.8/26.2)	
501	R-22/12 (75.0/25.0)*	
502	R-22/115 (48.8/51.2)	
503	R-23/13 (40.1/59.9)	
504	R-32/115 (48.2/51.8)	
505	R-12/31 (78.0/22.0)*	
506	R-31/114 (55.1/44.9)	
507A	R-125/143a (50/50)	
508A	R-23/116 (39/61)	
508B	R-23/116 (46/54)	
509A	R-22/218 (44/56)	
Miscellaneous Organic Compounds		
Hydrocarbons		
600	butane	$CH_3CH_2CH_2CH_3$
600a	2-methyl propane (isobutane)	$CH(CH_3)_3$
Oxygen Compounds		
610	ethyl ether	$C_2H_5OC_2H_5$
611	methyl formate	$HCOOCH_3$
Sulfur Compounds		
620	(Reserved for future assignment)	
Nitrogen Compounds		
630	methyl amine	CH_3NH_2
631	ethyl amine	$C_2H_5NH_2$
Inorganic Compounds		
702	hydrogen	H_2
704	helium	He
717	ammonia	NH_3
718	water	H_2O
720	neon	Ne
728	nitrogen	N_2
732	oxygen	O_2
740	argon	Ar
744	carbon dioxide	CO_2
744A	nitrous oxide	N_2O
764	sulfur dioxide	SO_2
Unsaturated Organic Compounds		
1112a	1,1-dichloro-2,2-difluoroethene	$CCl_2{=}CF_2$
1113	1-chloro-1,2,2-trifluoroethene	$CClF{=}CF_2$
1114	tetrafluoroethene	$CF_2{=}CF_2$
1120	trichloroethene	$CHCl{=}CCl_2$
1130	1,2-dichloroethene (trans)	$CHCl{=}CHCl$
1132a	1,1 difluoroethene (vinylidene fluoride)	$CF_2{=}CH_2$
1140	1-chloroethene (vinyl chloride)	$CHCl{=}CH_2$
1141	1-fluoroethene (vinyl fluoride)	$CHF{=}CH_2$
1150	ethene (ethylene)	$CH_2{=}CH_2$
1270	propene (propylene)	$CH_3CH{=}CH_2$

*The exact composition of this azeotrope is in question.

Table 2 Physical Properties of Selected Refrigerants[a]

Refrigerant									
No.	Chemical Name or Composition (% by mass)	Chemical Formula	Molecular Mass	Boiling Pt. (NBP) at 14.696 psia, °F	Freezing Point, °F	Critical Temper-ature, °F	Critical Pressure, psia	Critical Volume, ft^3/lb	Refractive Index of Liquid[b,c]
704	Helium	He	4.0026	–452.1	None	–450.3	33.21	0.2311	1.021 (NBP) 5461 Å
702p	Hydrogen, para	H_2	2.0159	–423.2	–434.8	–400.3	187.5	0.5097	1.09 (NBP)[f]
702n	Hydrogen, normal	H_2	2.0159	–423.0	–434.5	–399.9	190.8	0.5320	1.097 (NBP) 5791 Å
720	Neon	Ne	20.183	–410.9	–415.5	–379.7	493.1	0.03316	—
728	Nitrogen	N_2	28.013	–320.4	–346.0	–232.4	492.9	0.05092	1.205 (83 K) 5893 Å
729	Air	—	28.97	–317.8	—	–220.95	548.9	0.0530	—
						–221.1	546.3	0.05007	—
740	Argon	Ar	39.948	–302.55	–308.7	–188.48	704.9	0.0301	1.233 (84 K) 5893 Å
732	Oxygen	O_2	31.9988	–297.332	–361.8	–181.424	731.4	0.03673	1.221 (92 K) 5893 Å
50	Methane	CH_4	16.04	–258.7	–296	–116.5	673.1	0.099	—
14	Tetrafluoromethane	CF_4	88.01	–198.3	–299	–50.2	543	0.0256	—
1150	Ethylene	C_2H_4	28.05	–154.7	–272	48.8	742.2	0.070	1.363(–148)[1]
744A [2]	Nitrous oxide	N_2O	44.02	–129.1	–152	97.7	1048	0.0355	—
170	Ethane	C_2H_6	30.07	–127.85	–297	90.0	709.8	0.0830	—
503	R-23/13 (40.1/59.9)	—	87.5	–127.6	—	67.1	607	0.0326	—
508A [9]	R-23/116 (39/61)	—	100.1	–125.34	—	51.82	536.78	0.0279	—
508B [9]	R-23/116 (46/54)	—	95.39	–125.28	—	53.71	556.07	0.0280	—
23	Trifluoromethane	CHF_3	70.02	–115.7	–247	78.1	701.4	0.0311	—
13	Chlorotrifluoromethane	$CClF_3$	104.47	–114.6	–294	83.9	561	0.0277	1.146 (77)[4]
744	Carbon dioxide	CO_2	44.01	–109.2[d]	–69.9[e]	87.9	1070.0	0.0342	1.195 (59)
13B1	Bromotrifluoromethane	$CBrF_3$	148.93	–71.95	–270	152.6	575	0.0215	1.239 (77)[4]
504	R-32/115 (48.2/51.8)	—	79.2	–71.0	—	151.5	690.5	0.0324	—
32	Difluoromethane	CH_2F_2	52.02	–61.1	–213	173.14	845.6	0.03726	—
410A [9]	R-32/125 (50/50)	—	72.6	–60.83	—	158.4	694.87	0.0293	—
125	Pentafluoroethane	C_2HF_5	120.03	–55.43	–153.67	151.34	526.57	—	—
1270	Propylene	C_3H_6	42.09	–53.86	–301	197.2	670.3	0.0720	1.3640 (–58)[1]
143a [9]	Trifluoroethane	CH_3CF_3	84	–53.039	–169.26	162.87	545.49	0.0372	—
507A [9]	R-125/143a (50/50)	—	98.9	–52.80	—	159.34	538.97	0.0325	—
404A [9]	R-125/143a/134a (44/52/4)	—	97.6	–51.66	—	162.5	597.5	0.0279	—
502 [5]	R-22/115 (48.8/51.2)	—	111.63	–49.8	—	179.9	591.0	0.0286	—
407C [9]	R-32/125/134a (23/25/52)	—	86.2	–46.22	—	186.9	672.2	0.0317	—
290	Propane	C_3H_8	44.10	–43.76	–305.8	206.1	616.1	0.0726	1.3397 (–43)
22	Chlorodifluoromethane	$CHClF_2$	86.48	–41.36	–256	204.8	721.9	0.0305	1.234 (77)[4]
115	Chloropentafluoroethane	$CClF_2CF_3$	154.48	–38.4	–159	175.9	457.6	0.0261	1.221 (77)[4]
500	R-12/152a (73.8/26.2)	—	99.31	–28.3	–254	221.9	641.9	0.0323	—
717	Ammonia	NH_3	17.03	–28.0	–107.9	271.4	1657	0.068[d]	1.325 (61.7)
12	Dichlorodifluoromethane	CCl_2F_2	120.93	–21.62	–252	233.6	596.9	0.0287	1.288 (77)[4]
134a	Tetrafluoroethane	CF_3CH_2F	102.03	–15.08	–141.9	214.0	589.8	0.029	—
152a	Difluoroethane	CHF_2CH_3	66.05	–13.0	–178.6	236.3	652	0.0439	—
40 [2]	Methyl chloride	CH_3Cl	50.49	–11.6	–144	289.6	968.7	0.0454	—
124	Chlorotetrafluoroethane	$CHClFCF_3$	136.47	8.26	–326.47	252.5	530.84	—	—
600a	Isobutane	C_4H_{10}	58.13	10.89	–255.5	275.0	529.1	0.0725	1.3514 (–13)[1]
764 [6]	Sulfur dioxide	SO_2	64.07	14.0	–103.9	315.5	1143	0.0306	—
142b	Chlorodifluoroethane	$CClF_2CH_3$	100.5	14.4	–204	278.8	598	0.0368	—
630 [6]	Methyl amine	CH_3NH_2	31.06	19.9	–134.5	314.4	1082		1.432 (63.5)
C318	Octafluorocyclobutane	C_4F_8	200.04	21.5	–42.5	239.6	403.6	0.0258	—
600	Butane	C_4H_{10}	58.13	31.1	–217.3	305.6	550.7	0.0702	1.3562 (5)[1]
114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	170.94	38.8	–137	294.3	473	0.0275	1.294 (77)
21 [7]	Dichlorofluoromethane	$CHCl_2F$	102.92	47.8	–211	353.3	750	0.0307	1.332 (77)[4]
160 [2]	Ethyl chloride	C_2H_5Cl	64.52	54.32	–216.9	369.0	764.4	0.0485	—
631 [6]	Ethyl amine	$C_2H_5NH_2$	45.08	61.88	–113	361.4	815.6	—	—
11	Trichlorofluoromethane	CCl_3F	137.38	74.87	–168	388.4	639.5	0.0289	1.362 (77)[4]
123	Dichlorotrifluoroethane	$CHCl_2CF_3$	152.93	82.17	–160.87	362.82	532.87	—	—
611[6]	Methyl formate	$C_2H_4O_2$	60.05	89.2	–146	417.2	870	0.0459	—
141b	Dichlorofluoroethane	CCl_2FCH_3	116.95	89.6	—	399.6	616.4	—	—
610 [6]	Ethyl ether	$C_4H_{10}O$	74.12	94.3	–177.3	381.2	523	0.0607	1.3526 (68)
216ca	Dichlorohexafluoropropane	$C_3Cl_2F_6$	220.93	96.24	–193.7	356.0	399.5	0.0279	—
30 [6]	Methylene chloride	CH_2Cl_2	84.93	104.4	–142	458.6	882	—	1.4244 (68)[3]
113	Trichlorotrifluoroethane	CCl_2FCClF_2	187.39	117.63	–31	417.4	498.9	0.0278	1.357 (77)[4]
1130 [8]	Dichloroethylene	$CHCl{=}CHCl$	96.95	118	–58	470	795	—	—
1120 [6]	Trichloroethylene	$CHCl{=}CCl_2$	131.39	189.0	–99	520	728	—	1.4782(68)[3]
718 [6]	Water	H_2O	18.02	212	32	705.18	3200	0.0498	—

Notes for Table 2

[a] Data from ASHRAE *Thermodynamic Properties of Refrigerants* (Stewart et al. 1986) or from McLinden (1990), unless otherwise noted.

[b] Temperature of measurement (°F, unless kelvin is noted) shown in parentheses. Data from CRC *Handbook of Chemistry and Physics* (CRC 1987), unless otherwise noted.

[c] For the sodium D line.

[d] Sublimes.

[e] At 76.4 psia.

[f] Dielectric constant data.

References

[1] Kirk and Othmer (1956).

[2] *Matheson Gas Data Book* (1966).

[3] Electrochemicals Department, E.I. duPont de Nemours & Co.

[4] *Bulletin* B-32A (duPont).

[5] *Bulletin* T-502 (duPont 1980).

[6] *Handbook of Chemistry* (1967).

[7] *Bulletin* G-1 (duPont).

[8] CRC *Handbook of Chemistry and Physics* (CRC 1987).

[9] NIST *Standard Reference Database* 23, Version 6.01.

REFRIGERANT PROPERTIES

Physical Properties

Table 2 lists some physical properties of commonly used refrigerants, a few very low-boiling cryogenic fluids, some newer refrigerants, and some older refrigerants of historical interest. These refrigerants are arranged in increasing order of atmospheric boiling point, from helium at –452.1°F to water at 212°F.

Table 2 also includes the freezing point, critical properties, and refractive index. Of these properties, the boiling point is most important because it is a direct indicator of the temperature level at which a refrigerant can be used. The freezing point must be lower than any contemplated usage. The critical properties describe a material at the point where the distinction between liquid and gas is lost. At higher temperatures, no separate liquid phase is possible. In refrigeration cycles involving condensation, a refrigerant must be chosen that allows this change of state to occur at a temperature somewhat below the critical. Cycles that reject heat at supercritical temperatures (such as cycles using carbon dioxide) are also possible.

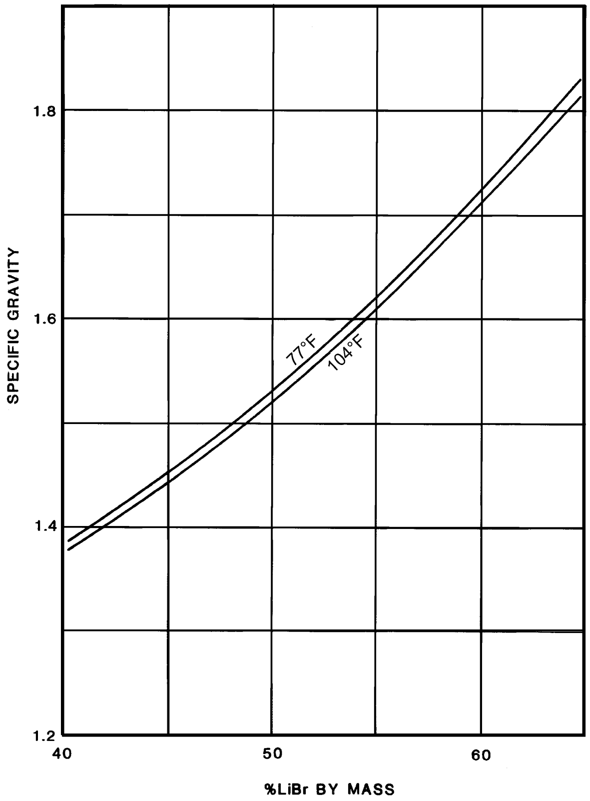

Fig. 1 Specific Gravity of Aqueous Solutions of Lithium Bromide

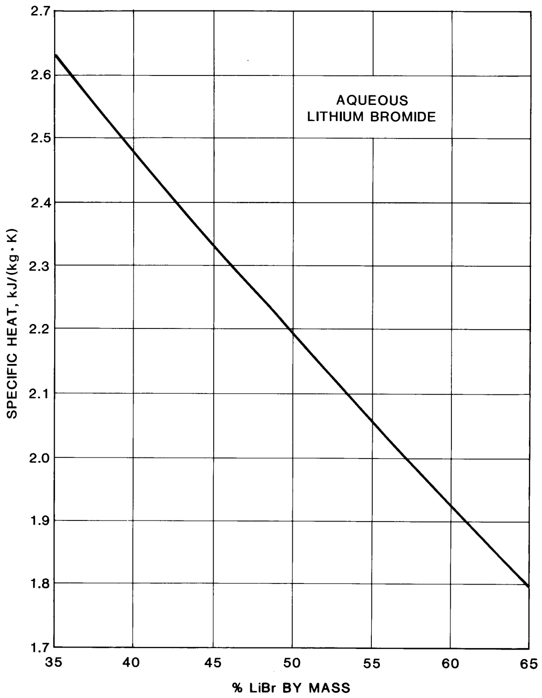

Fig. 2 Specific Heat of Aqueous Lithium Bromide Solutions

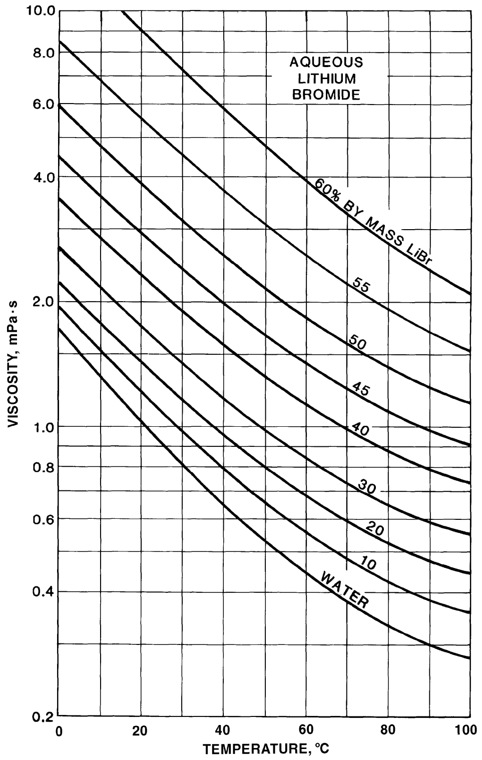

Fig. 3 Viscosity of Aqueous Solutions of Lithium Bromide

Lithium Bromide-Water and Ammonia-Water Solutions. These are the most commonly used working fluids in absorption refrigeration systems. Figure 1 shows specific gravity, Figure 2 shows specific heat, and Figure 3 shows viscosity of lithium bromide-water solutions. Chapter 20 has an enthalpy-concentration diagram and a vapor pressure diagram for lithium bromide-water solutions. Chapter 20 also has equilibrium properties of water-ammonia solutions.

Electrical Properties

Table 3 and Table 4 list the electrical characteristics of refrigerants that are especially important in hermetic systems.

Table 3 Electrical Properties of Liquid Refrigerants

Refrigerant		Temp., °F	Dielectric Constant	Volume Resistivity, MΩ·m	Ref.
No.	Chemical Name or Composition (% by mass)				
11	Trichlorofluoromethane	84	2.28		1
		a	1.92	63680	2
		77	2.5	90	3
12	Dichlorodifluoromethane	84	2.13		1
		a	1.74	53900	2
		77	2.1	> 120	3
		77	2.100		4
13	Chlorotrifluoromethane	–22	2.3	120	4
		68	1.64		
22	Chlorodifluoromethane	75	6.11		1
		a	6.12	0.83	2
		77	6.6	75	3
23	Trifluoromethane	–22	6.3		3
		68	5.51		4
32	Difluoromethane	a	14.27	-	6
113	Trichlorotrifluoroethane	86	2.44		1
		a	1.68	45490	2
		77	2.6	> 120	3
114	Dichlorotetrafluoroethane	88	2.17		1
		a	1.83	66470	2
		77	2.2	> 70	3
123	2,2-dichloro-1,1,1-trifluoroethane	a	4.50	14700	7
124a	Chlorotetrafluoroethane	77	4.0	50	3
125	Pentafluoroethane	68	4.94	-	8
134a	1,1,1,2-tetrafluoroethane	a	9.51	17700	7
290	Propane	a	1.27	73840	2
404A	R-125/143a/134a (44/52/4)	a	7.58	8450	9
407C	R-32/125/134a (23/25/52)	a	8.74	7420	9
410A	R-32/125 (50/50)	a	7.78	3920	9
500	R-12/152a (73.8/26.2)	a	1.80	55750	2
507A	R-125/143a (50/50)	a	6.97	5570	9
508A	R-23/116 (39/61)	–22	6.60	-	1
		32	5.02		1
508B	R-23/116 (46/54)	–22	7.24	-	1
		32	5.48		1
717	Ammonia	69	15.5		5
744	Carbon dioxide	32	1.59		5

a = ambient temperature

References:

1 Data from E.I. duPont de Nemours & Co., Inc. Used by permission.
2 Beacham and Divers (1955)
3 Eiseman (1955)
4 Makita et al. (1976)
5 CRC *Handbook of Chemistry and Physics* (CRC 1987).
6 Bararo et al. (1997)
7 Fellows et al. (1991)
8 Pereira et al. (1999)
9 Meurer et al. (2000)

Table 4 Electrical Properties of Refrigerant Vapors

Refrigerant		Pressure, atm.	Temp., °F	Dielectric Constant	Relative Dielectric Strength, Nitrogen = 1	Volume Resistivity, GΩ·m	Ref.
No.	Chemical Name or Composition (% by mass)						
11	Trichlorofluoromethane	0.5	79	1.0019			3
		a	b	1.009		74.35	2
		1.0	73		3.1		4
12	Dichlorodifluoromethane	0.5	84	1.0016			3
		a	b	1.012	452[c]	72.77	2
		1.0	73		2.4		4
		4.9	68	1.019			5
13	Chlorotrifluoromethane	0.5	84	1.0013			3
		1.0	73		1.4		4
		4.9	68	1.013			5
		19.5	90	1.055			6
14	Tetrafluoromethane	0.5	76	1.0006			3
		1.0	73		1.0		4
22	Chlorodifluoromethane	0.5	78	1.0035			3
		a	b	1.004	460[c]	2113	2
		1.0	73		1.3		4
		4.9	68	1.033			5
23	Trifluoromethane	4.9	68	1.042			5
113	Trichlorotrifluoroethane	a	b	1.010	440[c]	94.18	2
		0.4	73		2.6		4
114	Dichlorotetrafluoroethane	0.5	80	1.0021			3
		a	b	1.002	295[c]	148.3	2
		1.0	73		2.8		4
116	Hexafluoroethane	0.94	73	1.002			3
133a	Chlorotrifluoroethane	0.94	80	1.010			3
142b	Chlorodifluoroethane	0.93	81	1.013			3
143a	Trifluoroethane	0.85	77	1.013			3
170	Ethane	1.0	32	1.0015			1
290	Propane	a	b	1.009	440[c]	105.3	2
500	R-12/152a (73.8/26.2)	a	b	1.024	470[c]	76.45	2
508A	R-23/116 (39/61)	a	–22	1.12			7
		a	32	1.31			7
508B	R-23/116 (46/54)	a	–22	1.13			7
		a	32	1.34			7
717	Ammonia	1.0	32	1.0072			1
		a	32		0.82		4
729	Air	1.0	32	1.00059			1
744	Carbon dioxide	1.0	32	1.00099			1
		1.0	b		0.88		4
1150	Ethylene	1.0	32	1.00144			1
		1.0	73		1.21		4

Notes:
a = saturation vapor pressure
b = ambient temperature
c = measured breakdown voltage, volts/mil

References:
1 CRC *Handbook of Chemistry and Physics* (CRC 1987)
2 Beacham and Divers (1955)
3 Fuoss (1938)
4 Charlton and Cooper (1937)
5 Makita et al. (1976)
6 Hess et al. (1962)
7 Data from E.I. duPont de Nemours & Co., Inc. Used by permission.

Sound Velocity

Table 5 gives examples of the velocity of sound in the vapor phase of various fluorinated refrigerants. Chapter 20 has sound velocity data for many refrigerants. The velocity increases when the temperature is increased and decreases when the pressure is increased. The velocity of sound can be calculated from the equation

$$V_a = \left(g_c \frac{dp}{d\rho}\right)_S^{0.5} = \left[\gamma g_c \left(\frac{dp}{d\rho}\right)_T\right]^{0.5} \qquad (1)$$

where

V_a = sound velocity, ft/s
g_c = gravitational constant = 32.1740 $\text{lb}_\text{m} \cdot \text{ft/lb}_\text{f} \cdot \text{s}^2$
p = absolute pressure, $\text{lb}_\text{f}/\text{ft}^2$
ρ = density, $\text{lb}_\text{m}/\text{ft}^2$
γ = c_p/c_v = ratio of specific heats
S = entropy, Btu/lb·°R
T = temperature, °R

The sound velocity can be estimated from the tables of thermodynamic properties. The change in pressure with a change in density ($dp/d\rho$) can be estimated either at constant entropy or at constant temperature. It is simpler to estimate at constant temperature but then the ratio of specific heats must also be known. The practical velocity of a gas in piping or through openings is limited by the velocity of sound in the gas.

Latent Heat of Vaporization

An empirical rule of chemistry (Trouton's rule) states that the latent heat of vaporization at the boiling point on a molar basis, divided by the temperature in absolute units, is a constant for most materials. This rule is applied to refrigerants in Table 6. It applies fairly well to these refrigerants, although the result is not entirely constant. The rule helps in comparing different refrigerants and in understanding the operation of refrigeration systems.

REFRIGERANT PERFORMANCE

Chapter 1 describes several methods of calculating refrigerant performance, and Chapter 20 includes tables of thermodynamic properties of the various refrigerants.

Table 7 shows the theoretical calculated performance of a number of refrigerants for the U.S. standard cycle of 5°F evaporation and 86°F condensation. Calculated data for other conditions are given in Table 8. The tables can be used to compare the properties of different refrigerants, but actual operating conditions are somewhat different from the calculated data. In most cases, the suction vapor is assumed to be saturated, and the compression is assumed adiabatic or at constant entropy. For R-113 and R-114, these assumptions would cause some liquid in the discharge vapor. In these cases, it is assumed that the discharge vapor is saturated and that the suction vapor is slightly superheated. In Section F of Table 8, the temperature of the suction gas is assumed to be 65°F (−10°F saturated evaporating plus 75°F superheat). Comparison with Section E illustrates the effect of suction gas superheating on refrigerant performance.

SAFETY

Table 9 summarizes the toxicity and flammability characteristics of many refrigerants. In ASHRAE *Standard* 34, refrigerants are classified according to the hazard involved in their use. The toxicity and flammability classifications yield six safety groups (A1, A2, A3, B1, B2, and B3) for refrigerants. Group A1 refrigerants are the least hazardous, Group B3 the most hazardous.

The safety classification in ASHRAE *Standard* 34 consists of a capital letter and a numeral. The capital letter designates the toxicity of the refrigerant at concentrations below 400 ppm by volume:

Table 5 Velocity of Sound in Refrigerant Vapors

Refrigerant	Pressure, psia	Temperature, °F		
		50	100	150
		Velocity of Sound, ft/s		
11	10	b	469	490
12	10	480	503	525
	100	b	457	490
	200	b	b	442
22	10	583	610	635
	100	b	574	607
	200	b	523	572
23	10	657	685	712
	100	631	666	699
	200	600	644	682
32	10	775	809	840
	100	726	774	815
	200	b	730	784
113	10	b	435	456
114	10	391	411	430
123	10	b	435	456
	100	b	b	b
	200	b	b	b
124	10	443	465	486
	100	b	b	439
	200	b	b	b
125	10	477	500	521
	100	b	466	497
	200	b	420	467
134a	10	517	543	566
	100	b	490	528
	200	b	b	476
143a	10	576	603	629
	100	513	558	595
	200	b	495	552
290	10	799	835	870
	100	b	771	820
	200	b	b	754
404A	10	532	557	581
	100	473	515	549
	200	b	456	509
407C	10	573	600	625
	100	b	558	594
	200	b	500	555
410A	10	635	664	691
	100	587	629	665
	200	b	585	634
502	10	501	525	547
	100	450	488	519
	200	b	435	483
507A	10	529	554	577
	100	471	512	546
	200	b	454	507
508A	10	n.a.	n.a.	n.a.
	100	538	538	538
	200	549	549	549
508B	10	n.a.	572	595
	100	n.a.	553	581
	200	489	531	565
600	10	678	712	743
	100	b	b	652
	200	b	b	b
600a	10	680	713	744
	100	b	b	666
	200	b	b	b
717	10	1388	1453	1513
	100	b	1403	1477
	200	b	1336	1432
744	10	862	899	935
	100	843	885	924
	200	820	869	912

Source: NIST *Standard Reference Database* 23, Version 6.01 (NIST 1996).
b = Below saturation temperature. n.a. = Not available

Table 6 Latent Heat of Vaporization Versus Boiling Point

Refrigerant		Normal Boiling Point, °F	Latent Heat λ at NBP, Btu/lb·mol	Trouton Constant, λ/°R [b]	Ref.
No.	**Chemical Name or Composition (% by mass)**				
717	Ammonia	–28.0	10,036	23.256	1
630	Methyl amine [a]	23.0	11,141	23.086	4
764	Sulfur dioxide	13.6	10,705	22.626	2
631	Ethyl amine	68.0	11,645	22.076	4
611	Methyl formate [a]	100.0	12,094	21.616	4
134a	Tetrafluoroethane	–15.07	9,531	21.44	5
504	R-32/115 (48.2/51.8)	–71.0	8,282	21.316	1
23	Trifluoromethane	–115.7	7,325	21.29	1
124	Chlorotetrafluoroethane	8.26	9,742	20.82	5
C318	Octafluorocyclobutane	21.5	10,017	20.81	1
21	Dichlorofluoromethane	47.8	10,557	20.80	3
22	Chlorodifluoromethane	–41.4	8,687	20.76	1
40	Methyl chloride	–10.8	9,305	20.73	3
123	Dichlorotrifluoroethane	82.17	11,215	20.70	5
506	R-31/114 (55.1/44.9)	9.9	9,644	20.54	3
125	Pentafluoroethane	–55.43	8,295	20.52	5
113	Trichlorotrifluoroethane	117.6	11,828	20.49	1
152a	Difluoroethane	–13.0	9,045	20.25	1
502	R-22/115 (48.8/51.2)	–49.9	8,280	20.21	3
114	Dichlorotetrafluoroethane	38.8	10,005	20.07	1
216ca	Dichlorohexafluoropropane	96.2	11,154	20.07	1
505	R-12/31 (78.0/22.0) [c]	–21.8	8,735	19.95	3
11	Trichlorofluoromethane	74.9	10,648	19.92	1
500	R-12/152a (73.8/26.2)	–28.3	8,588	19.91	1
14	Tetrafluoromethane	–198.3	5,146	19.69	1
30	Methylene chloride [a]	120.0	11,398	19.66	4
600	Butane	31.1	9,641	19.64	1
13B1	Bromotrifluoromethane	–72.0	7,607	19.62	1
12	Dichlorodifluoromethane	–21.6	8,591	19.61	1
142b	Chlorodifluoroethane	14.4	9,297	19.61	1
115	Chloropentafluoroethane	–38.4	8,245	19.57	1
1270	Propylene	–53.9	7,931	19.55	1
503	R-23/13 (40.1/59.9)	–126.1	6,483	19.43	1
600a	Isobutane	10.9	9,103	19.34	1
13	Chlorotrifluoromethane	–114.6	6,670	19.33	1
290	Propane	–43.7	8,026	19.29	1
1150	Ethylene	–154.7	5,793	19.00	1
170	Ethane	–127.9	6,296	18.98	1
50	Methane	–258.7	3,521	17.52	1

Notes:
[a] Not at normal atmospheric pressure
[b] Normal boiling temperatures
[c] The exact composition of this azeotrope is in question.
References:
1 ASHRAE *Thermodynamic Properties of Refrigerants* (Stewart et al. 1986)
2 CRC *Handbook of Chemistry and Physics* (CRC 1987)
3 ASHRAE (1977)
4 *Chemical Engineer's Handbook* (1973)
5 NIST *Standard Reference Database* 23 (NIST 1996)

• Class A	Toxicity not identified
• Class B	Evidence of toxicity identified

The numeral denotes the flammability of the refrigerant:

• Class 1	No flame propagation in air at 65°F and 14.7 psia
• Class 2	Lower flammability limit (LFL) greater than 0.00625 lb/ft^3 at 70°F and 14.7 psia *and* heat of combustion less than 8174 Btu/lb
• Class 3	Highly flammable as defined by LFL less than or equal to 0.00625 lb/ft^3 at 70°F and 14.7 psia *or* heat of combustion greater than or equal to 8174 Btu/lb

LEAK DETECTION

Leak detection in refrigeration equipment is a major problem for manufacturers and service engineers. The following sections describe several leak detection methods.

Electronic Detection

The electronic detector is widely used in the manufacture and assembly of refrigeration equipment. Instrument operation depends on the variation in current flow caused by ionization of decomposed refrigerant between two oppositely charged platinum electrodes. This instrument can detect any of the halogenated refrigerants except R-14; however, *it is not recommended for use in atmospheres that contain explosive or flammable vapors.* Other vapors, such as alcohol and carbon monoxide, may interfere with the test.

The electronic detector is the most sensitive of the various leak detection methods, reportedly capable of sensing a leak of 1/100 oz of R-12 per year. A portable model is available for field testing. Other models are available with automatic balancing systems that correct for refrigerant vapors that might be present in the atmosphere around the test area.

Halide Torch

The halide torch is a fast and reliable method of detecting leaks of chlorinated refrigerants. Air is drawn over a copper element heated by a methyl alcohol or hydrocarbon flame. If halogenated vapors are present, they decompose, and the color of the flame changes to bluish-green. Although not as sensitive as the electronic detector, this method is suitable for most purposes.

Bubble Method

The object to be tested is pressurized with air or nitrogen. A pressure corresponding to operating conditions is generally used. The object is immersed in water, and any leaks are detected by observing bubbles in the liquid. Adding a detergent to the water decreases the surface tension, prevents escaping gas from clinging to the side of the object, and promotes the formation of a regular stream of small bubbles. Kerosene or other organic liquids are sometimes used for the same reason. A solution of soap or detergent can be brushed or poured onto joints or other spots where leakage is suspected. Leaking gas forms soap bubbles that can be readily detected.

Leaks can also be determined by pressurizing or evacuating and observing the change in pressure or vacuum over a period of time. This is effective in checking the tightness of the system but does not locate the point of leakage.

Ammonia and Sulfur Dioxide Leaks

Ammonia can be detected by burning a sulfur candle in the vicinity of the suspected leak or by bringing a solution of hydrochloric acid near the object. If ammonia vapor is present, a white cloud or smoke of ammonium sulfite or ammonium chloride forms. Ammonia can also be detected with indicator paper that changes color in the presence of a base.

Sulfur dioxide can be detected by the appearance of white smoke when aqueous ammonia is brought near the leak.

Table 7 Comparative Refrigerant Performance per Ton of Refrigeration

Refrigerant No.	Refrigerant Chemical Name or Composition (% by mass)	Evaporator Pressure, psia	Condenser Pressure, psia	Compression Ratio	Net Refrigerating Effect, Btu/lb$_m$	Refrigerant Circulated, lb$_m$/min	Liquid Circulated, in^3/min	Specific Volume of Suction Gas, ft^3/lb$_m$	Compressor Displacement, cfm	Power Consumption, hp	Coefficient of Performance	Comp. Discharge Temp., °F
170	Ethane	236.41	674.71	2.85	69.27	2.887	289.13	0.534	1.543	1.73	2.72	123
744	Carbon dioxide	332.38	1045.36	3.15	57.75	3.463	158.53	0.264	0.914	1.68	2.81	156
13B1	Bromotrifluoromethane	77.82	264.13	3.39	28.45	7.029	129.78	0.380	2.669	1.13	4.16	104
1270	Propylene	52.70	189.44	3.59	123.15	1.624	90.71	2.049	3.327	1.04	4.56	108
290	Propane	42.37	156.82	3.70	120.30	1.663	95.04	2.459	4.088	1.03	4.57	98
502	R-22/115 (48.8/51.2)	50.56	191.29	3.78	44.91	4.453	103.35	0.802	3.569	1.07	4.42	98
507A	R125/R-143a (50/50)	55.3	212.4	3.84	47.28	4.230	114.03	0.810	3.427	1.13	4.18	95
125	Pentafluoroethane	58.87	228.11	3.87	37.69	5.306	126.82	0.628	3.333	1.28	3.67	108
404A	R125/143a/134a (44/52/4)	53.3	206.8	3.88	48.98	4.083	110.79	0.856	3.494	1.12	4.21	96
410A	R-32/125 (50/50)	69.7	272.6	3.91	72.09	2.775	74.33	0.868	2.409	1.07	4.41	124
22	Chlorodifluoromethane	42.94	172.63	4.02	70.46	2.838	66.88	1.258	3.573	1.02	4.65	129
12	Dichlorodifluoromethane	26.51	107.99	4.07	50.25	3.980	85.23	1.465	5.830	0.99	4.75	100
500	R-12/152a (73.8/26.2)	31.06	127.50	4.10	60.64	3.298	80.19	1.502	4.955	1.01	4.69	105
407C	R-32/125/134a (23/25/52)	42.0	183.4	4.37	69.77	2.867	70.34	1.280	3.656	1.05	4.51	117
600a	Isobutane	12.92	59.29	4.59	113.00	1.770	90.01	6.419	11.361	1.07	4.41	80
134a	Tetrafluoroethane	23.79	111.62	4.69	64.51	3.100	72.37	1.959	6.076	1.02	4.60	96
717	Ammonia	34.17	168.80	4.94	474.20	0.422	19.61	8.179	3.450	0.99	4.77	210
124	Chlorotetrafluoroethane	12.96	64.59	4.98	50.93	3.927	81.16	2.714	10.658	1.05	4.47	90
600	Butane	8.18	41.19	5.04	125.55	1.593	77.78	10.206	16.258	0.95	4.95	88
114	Dichlorotetrafluoroethane [a]	6.75	36.49	5.41	43.02	4.649	89.56	4.340	20.176	1.02	4.65	86
11	Trichlorofluoromethane	2.94	18.32	6.24	67.21	2.976	56.26	12.240	36.425	0.94	5.02	110
123	Dichlorotrifluoroethane	2.26	15.93	7.06	61.42	3.256	62.19	14.337	46.684	0.97	4.86	90
113	Trichlorotrifluoroethane [a]	1.01	7.88	7.83	52.08	3.840	68.60	26.285	100.945	1.11	4.27	86

Notes: Data based on 5°F evaporation, 86°F condensation, 0°F subcool, and 0°F superheat.

[a] Saturated suction except R-113 and R-114. Enough superheat was added to give saturated discharge.

Table 8 Comparative Refrigerant Performance per Ton at Various Evaporating and Condensing Temperatures

Refrigerant No.	Refrigerant Chemical Name or Composition (% by mass)	Suction Temp., °F	Evaporator Pressure, psia	Condenser Pressure, psia	Compression Ratio	Net Refrigerating Effect, Btu/lb$_m$	Refrigerant Circulated, lb$_m$/min	Specific Volume of Suction Gas, ft^3/lb$_m$	Compressor Displacement, cfm	Power Consumption, hp
A. –130°F Saturated Evaporating, 0°F Suction Superheat, –40°F Saturated Condensing										
1150	Ethylene	–130	30.89	210.67	6.82	142.01	1.408	3.853	5.43	1.756
170	Ethane	–130	13.62	112.79	8.28	156.58	1.277	8.357	10.68	1.633
13	Chlorotrifluoromethane	–130	9.06	88.04	9.72	45.82	4.365	3.625	15.82	1.685
23	Trifluoromethane	–130	9.06	103.03	11.37	79.38	2.520	5.458	13.75	1.753
508A	R-23/116 (39/61)	–130	12.6	122.2	9.70	44.12	4.533	2.68	12.15	1.738
508B	R-23/116 (46/54)	–130	12.4	122.8	9.90	47.50	4.210	2.86	12.05	1.734
B. –100°F Saturated Evaporating, 0°F Suction Superheat, –30°F Saturated Condensing										
170	Ethane	–100	31.27	134.73	4.31	157.76	1.268	3.867	4.90	1.118
23	Trifluoromethane	–100	23.74	125.99	5.31	79.37	2.520	2.219	5.59	1.178
13	Chlorotrifluoromethane	–100	22.28	106.29	4.77	46.23	4.326	1.563	6.76	1.153
125	Pentafluoroethane	–100	3.78	27.76	7.34	56.43	3.544	8.390	29.73	1.101
22	Chlorodifluoromethane	–100	2.38	19.63	8.25	90.75	2.204	18.558	40.90	1.074
508A	R-23/116 (39/61)	–100	31.0	147.5	4.76	44.28	4.517	1.15	5.18	1.180
508B	R-23/116 (46/54)	–100	30.9	148.4	4.80	47.53	4.208	1.21	5.10	1.173
C. –76°F Saturated Evaporating, 0°F Suction Superheat, 5°F Saturated Condensing										
1150	Ethylene	–76	109.37	416.24	3.81	116.95	1.710	1.167	1.99	1.478
170	Ethane	–76	54.63	235.44	4.31	322.65	0.620	2.291	1.42	0.566
23	Trifluoromethane	–76	45.41	237.18	5.22	69.60	2.874	1.203	3.46	1.394
13	Chlorotrifluoromethane	–76	40.87	192.14	4.70	39.42	5.074	0.880	4.47	1.382
125	Pentafluoroethane	–76	8.21	58.87	7.17	50.62	3.951	4.072	16.09	1.277
290	Propane	–76	6.15	42.37	6.89	147.39	1.357	14.856	20.16	1.196
22	Chlorodifluoromethane	–76	5.44	42.96	7.90	84.24	2.374	8.593	20.40	1.195
717	Ammonia	–76	3.18	34.26	10.79	540.63	0.37	75.784	28.04	1.247
12	Dichlorodifluoromethane	–76	3.28	26.50	8.09	58.61	3.412	10.245	34.96	1.191
134a	Tetrafluoroethane	–76	2.3	23.77	10.32	78.1	2.561	17.304	44.32	1.182
410A	R-32/125 (50/50)	–76	9.4	69.7	7.41	92.86	2.153	5.84	12.57	1.204
407C	R-32/125/134a (23/25/52)	–76	4.9	43.5	8.88	86.88	2.302	9.74	22.43	1.200
404A	R125/143a/134a (44/52/4)	–76	7.2	53.4	7.42	65.25	3.065	5.73	17.55	1.219

Table 8 Comparative Refrigerant Performance per Ton at Various Evaporating and Condensing Temperatures *(Continued)*

Refrigerant		Suction Temp., °F	Evaporator Pressure, psia	Condenser Pressure, psia	Compression Ratio	Net Refrigerating Effect, Btu/lb_m	Refrigerant Circulated, lb_m/min	Specific Volume of Suction Gas, ft^3/lb_m	Compressor Displacement, cfm	Power Consumption, hp
No.	Chemical Name or Composition (% by mass)									
C. −76°F Saturated Evaporating, 0°F Suction Superheat, 5°F Saturated Condensing (*Concluded*)										
507A	R125/143a (50/50)	−76	7.6	55.3	7.28	63.43	3.153	5.34	16.84	1.219
508A	R-23/116 (39/61)	−76	56.8	267.8	4.71	35.23	5.677	0.642	3.64	1.468
508B	R-23/116 (46/54)	−76	56.8	270.0	4.75	38.22	5.233	0.675	3.53	1.447
D. −40°F Saturated Evaporating, 0°F Suction Superheat, 68°F Saturated Condensing										
744	Carbon dioxide	−40	145.77	830.5	5.70	77.22	2.590	0.613	1.59	2.208
23	Trifluoromethane	−40	103.03	597.9	5.80	45.67	4.379	0.545	2.39	2.442
125	Pentafluoroethane	−40	21.84	175.1	8.02	37.44	5.342	1.625	8.68	1.962
290	Propane	−40	16.01	121.6	7.55	119.33	1.676	6.083	10.20	1.670
22	Chlorodifluoromethane	−40	15.27	132.0	8.65	70.65	2.831	3.280	9.29	1.606
717	Ammonia	−40	10.4	124.3	11.95	486.55	0.411	25.144	10.33	1.576
12	Dichlorodifluoromethane	−40	9.30	82.3	8.84	49.44	4.046	3.887	15.73	1.596
134a	Tetrafluoroethane	−40	7.42	83.0	11.19	63.17	3.166	5.790	18.33	1.597
410A	R-32/125 (50/50)	−40	25.5	208.9	8.19	74.42	2.69	2.28	6.12	1.643
407C	R-32/125/134a (23/25/52)	−40	14.1	138.7	9.84	70.34	2.84	3.60	10.23	1.624
404A	R125/143a/134a (44/52/4)	−40	19.5	158.9	8.15	49.36	4.05	2.24	9.07	1.735
507A	R125/143a (50/50)	−40	20.4	163.4	8.01	47.68	4.19	2.10	8.82	1.747
E. −10°F Saturated Evaporating, 0°F Suction Superheat, 100°F Saturated Condensing										
124	Chlorotetrafluoroethane	−10	8.95	80.9	9.04	44.99	4.445	3.841	17.08	1.649
134a	Tetrafluoroethane	−10	16.62	139.0	8.36	56.57	3.535	2.711	9.59	1.589
12	Dichlorodifluoromethane	−10	19.20	131.7	6.86	44.89	4.456	1.980	8.82	1.606
717	Ammonia	−10	23.73	212.0	8.93	461.25	0.434	11.677	5.07	1.494
22	Chlorodifluoromethane	−10	31.23	210.7	6.75	64.07	3.122	1.676	5.23	1.602
502	R-22/115 (48.8/51.2)	−10	37.26	230.9	6.20	39.05	5.122	1.073	5.49	1.904
125	Pentafluoroethane	−10	43.32	277.0	6.39	31.09	6.433	0.846	5.44	2.172
410A	R-32/125 (50/50)	−10	51.1	331.6	6.49	64.70	3.09	1.17	3.63	1.672
407C	R-32/125/134a (23/25/52)	−10	29.7	225.0	7.58	62.45	3.20	1.78	5.69	1.627
404A	R125/143a/134a (44/52/4)	−10	39.0	251.0	6.44	41.62	4.80	1.16	5.55	1.814
507A	R125/143a (50/50)	−10	40.7	257.6	6.33	39.96	5.00	1.09	5.46	1.834
F. −10°F Saturated Evaporating, 75°F Suction Superheat (Included in Refrigeration Effect), 100°F Saturated Condensing										
123	Dichlorotrifluoroethane	65	1.48	20.8	14.07	67.3	2.972	24.797	73.70	1.387
11	Trichlorofluoromethane	65	1.92	23.4	12.2	71.88	2.783	21.276	59.21	1.403
124	Chlorotetrafluoroethane	65	8.95	80.9	9.04	57.33	3.489	4.531	15.81	1.506
134a	Tetrafluoroethane	65	16.62	139.0	8.36	71.25	2.807	3.236	9.08	1.513
12	Dichlorodifluoromethane	65	19.20	131.7	6.86	55.83	3.583	2.360	8.45	1.539
717	Ammonia	65	23.73	212.0	8.93	498.44	0.401	13.751	5.51	1.612
22	Chlorodifluoromethane	65	31.23	210.7	6.75	75.95	2.633	2.012	5.30	1.623
502	R-22/115 (48.8/51.2)	65	37.26	230.9	6.20	51.23	3.904	1.302	5.08	1.761
125	Pentafluoroethane	65	43.32	277.0	6.39	45.13	4.432	1.028	4.56	1.773
410A	R-32/125 (50/50)	65	51.1	331.6	6.49	80.50	2.48	1.44	3.58	1.657
407C	R-32/125/134a (23/25/52)	65	29.7	225.0	7.58	77.48	2.58	2.14	5.51	1.585
404A	R125/143a/134a (44/52/4)	65	39.0	251.0	6.44	57.29	3.49	1.41	4.91	1.636
507A	R125/143a (50/50)	65	40.7	257.6	6.33	55.56	3.60	1.33	4.79	1.644
G. 40°F Saturated Evaporating, 0°F Suction Superheat, 100°F Saturated Condensing										
125	Pentafluoroethane	40	111.7	275.7	2.47	35.85	5.58	0.331	1.84	0.788
290	Propane	40	78.6	188.6	2.40	119.47	1.67	1.356	2.27	0.692
22	Chlorodifluoromethane	40	83.25	210.7	2.53	68.71	2.911	0.656	1.91	0.696
717	Ammonia	40	73.3	212.0	2.89	480.33	0.416	4.084	1.70	0.653
500	R-12/152a (73.8/26.2)	40	60.72	155.8	2.57	60.54	3.303	0.792	2.62	0.692
12	Dichlorodifluoromethane	40	51.71	131.7	2.55	50.50	3.960	0.778	3.08	0.689
134a	Tetrafluoroethane	40	49.77	139.0	2.79	63.72	3.139	0.952	2.99	0.679
124	Chlorotetrafluoroethane	40	27.89	80.9	2.90	52.06	3.842	1.318	5.06	0.698
600a	Isobutane	40	26.75	73.4	2.74	115.83	1.727	3.256	5.62	0.693
600	Butane	40	17.68	51.7	2.92	129.22	1.548	4.975	7.70	0.669
11	Trichlorofluoromethane	40	6.99	23.4	3.34	68.04	2.939	5.455	16.03	0.624
123	Dichlorotrifluoroethane	40	5.79	20.8	3.59	62.82	3.184	5.921	18.85	0.635
113	Trichlorotrifluoroethane	40	2.7	10.5	3.89	54.58	3.67	10.5	38.44	0.638
410A	R-32/125 (50/50)	40	132.9	331.6	2.50	69.08	2.89	0.456	1.32	0.721
407C	R-32/125/134a (23/25/52)	40	84.2	225.0	2.67	68.60	2.92	0.648	1.89	0.699

Table 9 Comparison of Safety Group Classifications in ASHRAE *Standard* 34-1989 and ASHRAE *Standard* 34-1997

Refrigerant Number	Chemical Formula	Safety Group	
		Old	New
10	CCl_4	2	B1
11	CCl_3F	1	A1
12	CCl_2F_2	1	A1
13	$CClF_3$	1	A1
13B1	$CBrF_3$	1	A1
14	CF_4	1	A1
21	$CHCl_2F$	2	B1
22	$CHClF_2$	1	A1
23	CHF_3		A1
30	CH_2Cl_2	2	B2
32	CH_2F_2		A2
40	CH_3Cl	2	B2
50	CH_4	3a	A3
113	CCl_2FCClF_2	1	A1
114	$CClF_2CClF_2$	1	A1
115	$CClF_2CF_3$	1	A1
116	CF_3CF_3		A1
123	$CHCl_2CF_3$		B1
124	$CHClFCF_3$		A1
125	CHF_2CF_3		A1
134a	CF_3CH_2F		A1
142b	$CClF_2CH_3$	3b	A2
143a	CF_3CH_3		A2
152a	CHF_2CH_3	3b	A2
170	CH_3CH_3	3a	A3
218	$CF_3CF_2CF_3$		A1
290	$CH_3CH_2CH_3$	3a	A3
C318	C_4F_8	1	A1
400	R-12/114 (must be specified)	1	A1/A1
500	R-12/152a (73.8/26.2)	1	A1
501	R-22/12 (75.0/25.0)*	1	A1
502	R-22/115 (48.8/51.2)	1	A1
507A	R-125/143a (50/50)		A1
508A	R-23/116 (39/61)		A1
508B	R-23/116 (46/54)		A1/A1
509A	R-22/218 (44/56)		A1
600	$CH_3CH_2CH_2CH_3$	3a	A3
600a	$CH(CH_3)_3$	3a	A3
611	$HCOOCH_3$	2	B2
702	H_2		A3
704	He		A1
717	NH_3	2	B2
718	H_2O		A1
720	Ne		A1
728	N_2		A1
740	Ar		A1
744	CO_2	1	A1
764	SO_2	2	B1
1140	$CHCl{=}CH_2$		B3
1150	$CH_2{=}CH_2$	3a	A3
1270	$CH_3CH{=}CH_2$	3a	A3

*The exact composition of this azeotrope is in question.

Table 10 Swelling of Elastomers in Liquid Refrigerants at Room Temperature

	Linear Swell, %							
Refrig. No.	Buna N	Buna S (GR-S)	Butyl (GR-1)	Natural Rubber	Neoprene GN	Thiokol FA	Viton B	Silicone
11	6	21	41	23	17	2	6	38
12	2	3	6	6	0	1	9	—
13	1	1	0	1	0	0	4	—
13B1	1	1	2	1	2	—	7	—
21	48	49	24	34	28	28	22	—
22	26	4	1	6	2	4	20	20
30	52	26	23	34	37	59	—	—
40	35	20	16	26	22	11	—	—
113	1	9	21	17	3	1	7	34
114	0	2	2	2	0	0	9	—
502	7	3	—	4	1	—	—	—
600	1	8	20	16	3	0	—	—

Adapted from Eiseman (1949).

Table 11 Diffusion of Water and R-22 Through Elastomers

	Diffusion Rate	
Elastomer	Water[a]	R-22[b]
Neoprene	0.717	1.31
Buna N	0.109	19.7
Hypalon 40	0.457	0.52
Butyl	0.043	0.30
Viton	—	3.61
Polyethylene	0.123	—
Natural	1.428	—

Adapted from Eiseman (1966).

[a] 0.003 in. film, 100% rh at 100°F. Water diffusion rate is in pounds per hour per 1000 ft^2 of elastomer.

[b] Film thickness = 0.001 in.; temperature = 77°F. Gas at 1 atm. and 32°F. Diffusion rate per day in ft^3 of gas per ft^2 of elastomer.

Table 12 Swelling of Plastics in Liquid Refrigerants at Room Temperature

	Linear Swell, %						
	Refrigerant						
Plastic	11	12	21	30	113	114a	22
Phenol formaldehyde resin	0	0	0	0	−0.2	−0.2	n.a.
Cellulose acetate	0.4	0	b	b	0	−0.1	n.a.
Cellulose nitrate	0.6	0	b	b	0	−0.1	n.a.
Nylon	0	0	0	0	0	−0.2	1
Methyl methacrylate resin	0	−0.1	b	b	−0.2	−0.2	a
Polyethylene	6.7	0.4	4.5	4.6	2.3	0.6	2
Polystyrene	b	−0.1	b	b	−0.2	−0.2	n.a.
Polyvinyl alcohol	0.3	−0.7	12.9	9.1	−0.1	0.2	n.a.
Polyvinyl chloride	0	0	15.1	b	0	0.1	n.a.
Polyvinylidene chloride	−0.2	0	1.0	2.4	−0.1	0	4
Polytetrafluoroethylene	0	−0.7	0.1	0	0	−0.3	1

Adapted from Brown (1960)
n.a. = data not available
a = sample completely disintegrated

EFFECT ON CONSTRUCTION MATERIALS

Metals

Halogenated refrigerants can be used satisfactorily under normal conditions with most common metals, such as steel, cast iron, brass, copper, tin, lead, and aluminum. Under more severe conditions, various metals affect such properties as hydrolysis and thermal decomposition in varying degrees. The tendency of metals to promote thermal decomposition of halogenated compounds is in the following order:

(least decomposition) Inconel < 18-8 stainless steel < nickel
< copper < 1340 steel < aluminum < bronze < brass < zinc
< silver (most decomposition)

This order is only approximate, and exceptions may be found for individual compounds or for special use conditions. The effect of metals on hydrolysis is probably similar.

Magnesium, zinc, and aluminum alloys containing more than 2% magnesium are not recommended for use with halogenated compounds where even trace amounts of water may be present.

Warning: Never use methyl chloride with aluminum in any form. A highly flammable gas is formed, and the explosion hazard is great.

Ammonia should never be used with copper, brass, or other alloys containing copper. When water is present in sulfur dioxide systems, sulfurous acid is formed and can attack iron or steel rapidly and other metals at a slower rate.

Further discussion of the compatibility of refrigerants and lubricants with construction materials may be found in Chapter 5 of the *ASHRAE Handbook—Refrigeration*.

Elastomers

The linear swelling of some elastomers in the liquid phase of various refrigerants is shown in Table 10. Swelling data can be used to a limited extent in comparing the effect of refrigerants on elastomers. However, other factors, such as the amount of extraction, tensile strength, and degree of hardness of the exposed elastomer must be considered. When other fluids are present in addition to the refrigerant, the combined effect on elastomers should be determined. In some instances, somewhat higher swelling of elastomers is found in mixtures of R-22 and lubricating oil than in either fluid alone. Table 11 shows the diffusion rate of water and R-22 through elastomers.

Plastics

The effect of a refrigerant on a plastic material should be thoroughly examined under the conditions of intended use. Plastics are often mixtures of two or more basic types, and it is difficult to predict the effect of the refrigerant. The linear swelling of some plastic materials in refrigerants is shown in Table 12. Swelling data can be used as a guide but, as with elastomers, the effect on the properties of the plastic should also be examined. Comparable data for R-22 is limited, but the effect on plastics is generall*y more severe than that of R-12, but not as severe as that of R-21. The effect of R-114 is very similar to that of R-114a.

REFERENCES

ASHRAE. 1977. *ASHRAE Handbook—Fundamentals,* Chapter 16.

ASHRAE. 1997. Number designation and safety classification of refrigerants. ANSI/ASHRAE *Standard* 34-1997.

Bararo, M.T., U.V. Mardolcar, and C.A. Nieto de Castro. 1997. Molecular properties of alternative refrigerants derived from dielectric-constant measurements. *Journal of Thermophysics* 18(2):419-438.

Beacham, E.A. and R.T. Divers. 1955. Some aspects of the dielectric properties of refrigerants. *Refrigerating Engineering* 7:33.

Brown, J.A. 1960. Effect of propellants on plastic valve components. *Soap and Chemical Specialties* 3:87.

Charlton, E.E. and F.S. Cooper. 1937. Dielectric strengths of insulating fluids. *General Electric Review* 865(9):438.

Chemical engineer's handbook, 5th ed. 1973. McGraw-Hill, New York.

CRC Handbook of chemistry and physics, 68th ed. 1987. CRC Press, Boca Raton, FL.

duPont. *Bulletin* B-32A. Freon Products Division. E.I. duPont de Nemours & Co., Inc., Wilmington, DE.

duPont. *Bulletin* G-1. Freon Products Division. E.I. duPont de Nemours & Co., Inc., Wilmington, DE.

duPont. 1980. *Bulletin* T-502. Freon Products Division. E.I. duPont de Nemours & Co., Inc., Wilmington, DE.

Eiseman, B.J., Jr. 1949. Effect on elastomers of Freon compounds and other halohydrocarbons. *Refrigerating Engineering* 12:1171.

Eiseman, B.J., Jr. 1955. How electrical properties of Freon compounds affect hermetic system's insulation. *Refrigerating Engineering* 4:61.

Fellows, B.R., R.G. Richard, and I.R. Shankland. 1991. Electrical characterization of alternate refrigerants. *Actes Congr. Int. Froid*, 18th, Vol. 2. International Institute of Refrigeration, Paris.

Fuoss, R.M. 1938. Dielectric constants of some fluorine compounds. *Journal of the American Chemical Society*, 1633.

Handbook of chemistry, 10th ed. 1967. McGraw-Hill, New York.

Handbook of chemistry and physics, 41st ed. 1959-60. The Chemical Rubber Publishing Co., Cleveland, OH.

Kirk and Othmer. 1956. *The encyclopedia of chemical technology.* The Interscience Encyclopedia, Inc., New York.

Matheson gas data book. 1966. The Matheson Company, Inc., East Rutherford, NJ.

McLinden, M.O. 1990. *International Journal of Refrigeration* 13:149-62.

Meurer C., G. Pietsch, and M. Haacke M. 2000. Electrical properties of CFC- and HCFC-substitutes. *Int. Journal of Refrigeration*.

NIST. 1996. *Standard Reference Database* 23, Version 6.01. National Institute of Standards and Technology, Gaithersburg, MD.

Pereira L.F., F.E. Brito, A.N. Gurova, U.V. Mardolcar, and C.A. Nieta de Castro. 1999. Dipole moment, expansivity and compressibility coefficients of HFC 125 derived from dielectric constant measurements. 1st Int. Workshop on Thermochemical, Thermodynamic and Transport Properties of Halogenated Hydrocarbons and Mixtures, Pisa, Italy.

Stewart, R.B., R.T. Jacobsen, and S.G. Penoncello. 1986. *ASHRAE Thermodynamic properties of refrigerants.* ASHRAE.

U.N. 1994. *1994 Report of the refrigeration, air conditioning, and heat pumps technical options committee.* United Nations Environment Programme, Nairobi, Kenya. ISBN 92-807-1455-4.

U.N. 1996. OzonAction (The Newsletter of the United Nations Environment Programme Industry and Environment OzonAction Programme). October (No. 20):10.