

## CHAPTER 19

# REFRIGERANTS

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**R**EFRIGERANTS 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 mass.

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	Refrigerant Number	Chemical Name or Composition (% by mass)	Chemical Formula
<b>Methane Series</b>			403A	R-290/22/218 (5/75/20)	
10	tetrachloromethane (carbon tetrachloride)	CCl <sub>4</sub>	403B	R-290/22/218 (5/56/39)	
11	trichlorofluoromethane	CCl <sub>3</sub> F	404A	R-125/143a/134a (44/52/4)	
12	dichlorodifluoromethane	CCl <sub>2</sub> F <sub>2</sub>	405A	R-22/152a/142b/C318 (45/7/5.5/42.5)	
12B1	bromochlorodifluoromethane	CBrClF <sub>2</sub>	406A	R-22/600a/142b (55/4/41)	
12B2	dibromodifluoromethane	CBr <sub>2</sub> F <sub>2</sub>	407A	R-32/125/134a (20/40/40)	
13	chlorotrifluoromethane	CClF <sub>3</sub>	407B	R-32/125/134a (10/70/20)	
13B1	bromotrifluoromethane	CBrF <sub>3</sub>	407C	R-32/125/134a (23/25/52)	
14	tetrafluoromethane (carbon tetrafluoride)	CF <sub>4</sub>	407D	R-32/125/134a (15/15/70)	
20	trichloromethane (chloroform)	CHCl <sub>3</sub>	408A	R-125/143a/22 (7/46/47)	
21	dichlorofluoromethane	CHCl <sub>2</sub> F	409A	R-22/124/142b (60/25/15)	
22	chlorodifluoromethane	CHClF <sub>2</sub>	409B	R-22/124/142b (65/25/10)	
22B1	bromodifluoromethane	CBrF <sub>2</sub>	410A	R-32/125 (50/50)	
23	trifluoromethane	CHF <sub>3</sub>	410B	R-32/125 (45/55)	
30	dichloromethane (methylene chloride)	CH <sub>2</sub> Cl <sub>2</sub>	411A	R-1270/22/152a (1.5/87.5/11.0)	
31	chlorofluoromethane	CH <sub>2</sub> ClF	411B	R-1270/22/152a (3/94/3)	
32	difluoromethane (methylene fluoride)	CH <sub>2</sub> F <sub>2</sub>	412A	R-22/218/142b (70/5/25)	
40	chloromethane (methyl chloride)	CH <sub>3</sub> Cl	413A	R-218/134a/600a (9/88/3)	
41	fluoromethane (methyl fluoride)	CH <sub>3</sub> F	<b>Azeotropic Blends (% by mass)</b>		
50	methane	CH <sub>4</sub>	500	R-12/152a (73.8/26.2)	
<b>Ethane Series</b>			501	R-22/12 (75.0/25.0)*	
110	hexachloroethane	CCl <sub>3</sub> CCl <sub>3</sub>	502	R-22/115 (48.8/51.2)	
111	pentachlorofluoroethane	CCl <sub>3</sub> CCl <sub>2</sub> F	503	R-23/13 (40.1/59.9)	
112	1,1,2,2-tetrachloro-1,2-difluoroethane	CCl <sub>2</sub> FCCl <sub>2</sub> F	504	R-32/115 (48.2/51.8)	
112a	1,1,1,2-tetrachloro-2,2-difluoroethane	CCl <sub>3</sub> CClF <sub>2</sub>	505	R-12/31 (78.0/22.0)*	
113	1,1,2-trichloro-1,2,2-trifluoroethane	CCl <sub>2</sub> FCClF <sub>2</sub>	506	R-31/114 (55.1/44.9)	
113a	1,1,1-trichloro-2,2,2-trifluoroethane	CCl <sub>3</sub> CF <sub>3</sub>	507A	R-125/143a (50/50)	
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	CClF <sub>2</sub> CClF <sub>2</sub>	508A	R-23/116 (39/61)	
114a	1,1-dichloro-1,2,2,2-tetrafluoroethane	CCl <sub>2</sub> FCF <sub>3</sub>	508B	R-23/116 (46/54)	
114B2	1,2-dibromo-1,1,2,2-tetrafluoroethane	CBrF <sub>2</sub> CBrF <sub>2</sub>	509A	R-22/218 (44/56)	
115	chloropentafluoroethane	CClF <sub>2</sub> CF <sub>3</sub>	<b>Miscellaneous Organic Compounds</b>		
116	hexafluoroethane	CF <sub>3</sub> CF <sub>3</sub>	<i>Hydrocarbons</i>		
120	pentachloroethane	CHCl <sub>2</sub> CCl <sub>3</sub>	600	butane	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>
123	2,2-dichloro-1,1,1-trifluoroethane	CHCl <sub>2</sub> CF <sub>3</sub>	600a	2-methyl propane (isobutane)	CH(CH <sub>3</sub> ) <sub>3</sub>
123a	1,2-dichloro-1,1,2-trifluoroethane	CHClFCClF <sub>2</sub>	<i>Oxygen Compounds</i>		
124	2-chloro-1,1,1,2-tetrafluoroethane	CHClFCF <sub>3</sub>	610	ethyl ether	C <sub>2</sub> H <sub>5</sub> OC <sub>2</sub> H <sub>5</sub>
124a	1-chloro-1,1,2,2-tetrafluoroethane	CHF <sub>2</sub> CClF <sub>2</sub>	611	methyl formate	HCOOCH <sub>3</sub>
125	pentafluoroethane	CHF <sub>2</sub> CF <sub>3</sub>	<i>Sulfur Compounds</i>		
133a	2-chloro-1,1,1-trifluoroethane	CH <sub>2</sub> ClCF <sub>3</sub>	620	(Reserved for future assignment)	
134a	1,1,1,2-tetrafluoroethane	CH <sub>2</sub> FCF <sub>3</sub>	<b>Nitrogen Compounds</b>		
140a	1,1,1-trichloroethane (methyl chloroform)	CH <sub>3</sub> CCl <sub>3</sub>	630	methyl amine	CH <sub>3</sub> NH <sub>2</sub>
141b	1,1-dichloro-1-fluoroethane	CCl <sub>2</sub> FCH <sub>3</sub>	631	ethyl amine	C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub>
142b	1-chloro-1,1-difluoroethane	CClF <sub>2</sub> CH <sub>3</sub>	<b>Inorganic Compounds</b>		
143a	1,1,1-trifluoroethane	CF <sub>3</sub> CH <sub>3</sub>	702	hydrogen	H <sub>2</sub>
150a	1,1-dichloroethane	CHCl <sub>2</sub> CH <sub>3</sub>	704	helium	He
152a	1,1-difluoroethane	CHF <sub>2</sub> CH <sub>3</sub>	717	ammonia	NH <sub>3</sub>
160	chloroethane (ethyl chloride)	CH <sub>3</sub> CH <sub>2</sub> Cl	718	water	H <sub>2</sub> O
170	ethane	CH <sub>3</sub> CH <sub>3</sub>	720	neon	Ne
<b>Propane Series</b>			728	nitrogen	N <sub>2</sub>
216ca	1,3-dichloro-1,1,2,2,3,3-hexafluoropropane	CClF <sub>2</sub> CF <sub>2</sub> CClF <sub>2</sub>	732	oxygen	O <sub>2</sub>
218	octafluoropropane	CF <sub>3</sub> CF <sub>2</sub> CF <sub>3</sub>	740	argon	Ar
245cb	1,1,1,2,2-pentafluoropropane	CF <sub>3</sub> CF <sub>2</sub> CH <sub>3</sub>	744	carbon dioxide	CO <sub>2</sub>
290	propane	CH <sub>3</sub> CH <sub>2</sub> CH <sub>3</sub>	744A	nitrous oxide	N <sub>2</sub> O
<b>Cyclic Organic Compounds</b>			764	sulfur dioxide	SO <sub>2</sub>
C316	1,2-dichloro-1,2,3,3,4,4-hexafluorocyclobutane	C <sub>4</sub> Cl <sub>2</sub> F <sub>6</sub>	<b>Unsaturated Organic Compounds</b>		
C317	chloroheptafluorocyclobutane	C <sub>4</sub> ClF <sub>7</sub>	1112a	1,1-dichloro-2,2-difluoroethene	CCl <sub>2</sub> =CF <sub>2</sub>
C318	octafluorocyclobutane	C <sub>4</sub> F <sub>8</sub>	1113	1-chloro-1,2,2-trifluoroethene	CClF=CF <sub>2</sub>
<b>Zetropic Blends (% by mass)</b>			1114	tetrafluoroethene	CF <sub>2</sub> =CF <sub>2</sub>
400	R-12/114 (must be specified)		1120	trichloroethene	CHCl=CCl <sub>2</sub>
401A	R-22/152a/124 (53/13/34)		1130	1,2-dichloroethene (trans)	CHCl=CHCl
401B	R-22/152a/124 (61/11/28)		1132a	1,1 difluoroethene (vinylidene fluoride)	CF <sub>2</sub> =CH <sub>2</sub>
401C	R-22/152a/124 (33/15/52)		1140	1-chloroethene (vinyl chloride)	CHCl=CH <sub>2</sub>
402A	R-125/290/22 (60/2/38)		1141	1-fluoroethene (vinyl fluoride)	CHF=CH <sub>2</sub>
402B	R-125/290/22 (38/2/60)		1150	ethene (ethylene)	CH <sub>2</sub> =CH <sub>2</sub>
			1270	propene (propylene)	CH <sub>3</sub> CH=CH <sub>2</sub>

\*The exact composition of this azeotrope is in question.

Table 2 Physical Properties of Selected Refrigerants<sup>a</sup>

No.	Refrigerant		Molecular Mass	Boiling Pt.	Freezing Point, °C	Critical Temperature, °C	Critical Pressure, kPa	Critical Volume, L/kg	Refractive Index of Liquid <sup>b,c</sup>
	Chemical Name or Composition (% by mass)	Chemical Formula		(NBP) at 101.325 kPa, °C					
704	Helium	He	4.0026	-268.9	None	-267.9	228.8	14.43	1.021 (NBP) 546.1 nm
702p	Hydrogen, para	H <sub>2</sub>	2.0159	-252.9	-259.3	-240.2	1292	31.82	1.09 (NBP) <sup>f</sup>
702n	Hydrogen, normal	H <sub>2</sub>	2.0159	-252.8	-259.2	-239.9	1315	33.21	1.097 (NBP) 579.1 nm
720	Neon	Ne	20.183	-246.1	-248.6	-228.7	3397	2.070	—
728	Nitrogen	N <sub>2</sub>	28.013	-198.8	-210	-146.9	3396	3.179	1.205 (83 K) 589.3 nm
729	Air	—	28.97	-194.3	—	-140.53	3785	3.31	—
						-140.6	3764	3.126	—
740	Argon	Ar	39.948	-185.86	-189.3	-122.49	4860	1.88	1.233 (84 K) 589.3 nm
732	Oxygen	O <sub>2</sub>	31.9988	-182.962	-218.8	-118.569	5042.9	2.293	1.221 (92 K) 589.3 nm
50	Methane	CH <sub>4</sub>	16.04	-161.5	-182.2	-82.5	4638	6.181	—
14	Tetrafluoromethane	CF <sub>4</sub>	88.01	-127.9	-184.9	-45.7	3741	1.598	—
1150	Ethylene	C <sub>2</sub> H <sub>4</sub>	28.05	-103.7	-169	9.3	5114	4.37	1.363 (-100) <sup>1</sup>
744A <sup>2</sup>	Nitrous oxide	N <sub>2</sub> O	44.02	-89.5	-102	36.5	7221	2.216	—
170	Ethane	C <sub>2</sub> H <sub>6</sub>	30.07	-88.8	-183	32.2	4891	5.182	—
503	R-23/13 (40.1/59.9)	—	87.5	-88.7	—	19.5	4182	2.035	—
508A <sup>9</sup>	R-23/116 (39/61)	—	100.1	-87.41	—	11.01	3701	1.74	—
508B <sup>9</sup>	R-23/116 (46/54)	—	95.39	-87.38	—	12.06	3834	1.75	—
23	Trifluoromethane	CHF <sub>3</sub>	70.02	-82.1	-155	25.6	4833	1.942	—
13	Chlorotrifluoromethane	CClF <sub>3</sub>	104.47	-81.4	-181	28.8	3865	1.729	1.146 (25) <sup>4</sup>
744	Carbon dioxide	CO <sub>2</sub>	44.01	-78.4 <sup>d</sup>	-56.6 <sup>e</sup>	31.1	7372	2.135	1.195 (15)
13B1	Bromotrifluoromethane	CBrF <sub>3</sub>	148.93	-57.75	-168	67.0	3962	1.342	1.239 (25) <sup>4</sup>
504	R-32/115 (48.2/51.8)	—	79.2	-57.2	—	66.4	4758	2.023	—
32	Difluoromethane	CH <sub>2</sub> F <sub>2</sub>	52.02	-51.8	-136	78.4	5830	2.326	—
410A <sup>9</sup>	R-32/125 (50/50)	—	72.6	-51.57	—	70.2	4790	1.83	—
125	Pentafluoroethane	C <sub>2</sub> HF <sub>5</sub>	120.03	-48.57	-103.15	66.3	3630.6	—	—
1270	Propylene	C <sub>3</sub> H <sub>6</sub>	42.09	-47.7	-185	91.8	4618	4.495	1.3640 (-50) <sup>1</sup>
143a <sup>9</sup>	Trifluoroethane	CH <sub>3</sub> CF <sub>3</sub>	84	-47.24	-111.81	72.71	3761	2.32	—
507A <sup>9</sup>	R-125/143a (50/50)	—	98.9	-47.01	—	70.74	3709	2.03	—
404A <sup>9</sup>	R-125/143a/134a (44/52/4)	—	97.6	-46.48	—	72.5	3775	1.74	—
502 <sup>5</sup>	R-22/115 (48.8/51.2)	—	111.63	-45.4	—	82.2	4075	1.785	—
407C <sup>9</sup>	R-32/125/134a (23/25/52)	—	86.2	-43.79	—	86.1	4635	1.98	—
290	Propane	C <sub>3</sub> H <sub>8</sub>	44.10	-42.09	-187.7	96.70	4248	4.53	1.3397 (-42)
22	Chlorodifluoromethane	CHClF <sub>2</sub>	86.48	-40.76	-160	96.0	4974	1.904	1.234 (25) <sup>4</sup>
115	Chloropentafluoroethane	CClF <sub>2</sub> CF <sub>3</sub>	154.48	-39.1	-106	79.9	3153	1.629	1.221 (25) <sup>4</sup>
500	R-12/152a (73.8/26.2)	—	99.31	-33.5	-159	105.5	4423	2.016	—
717	Ammonia	NH <sub>3</sub>	17.03	-33.3	-77.7	133.0	11417	4.245 <sup>d</sup>	1.325 (16.5)
12	Dichlorodifluoromethane	CCl <sub>2</sub> F <sub>2</sub>	120.93	-29.79	-158	112.0	4113	1.792	1.288 (25) <sup>4</sup>
134a	Tetrafluoroethane	CF <sub>3</sub> CH <sub>2</sub> F	102.03	-26.16	-96.6	101.1	4067	1.81	—
152a	Difluoroethane	CHF <sub>2</sub> CH <sub>3</sub>	66.05	-25.0	-117	113.5	4492	2.741	—
40 <sup>2</sup>	Methyl chloride	CH <sub>3</sub> Cl	50.49	-12.4	-97.8	143.1	6674	2.834	—
124	Chlorotetrafluoroethane	CHClF <sub>2</sub> CF <sub>3</sub>	136.47	-13.19	-199.15	122.5	3660	—	—
600a	Isobutane	C <sub>4</sub> H <sub>10</sub>	58.13	-11.73	-160	135.0	3645	4.526	1.3514 (-25) <sup>1</sup>
764 <sup>6</sup>	Sulfur dioxide	SO <sub>2</sub>	64.07	-10.0	-75.5	157.5	7875	1.910	—
142b	Chlorodifluoroethane	CClF <sub>2</sub> CH <sub>3</sub>	100.5	-9.8	-131	137.1	4120	2.297	—
630 <sup>6</sup>	Methyl amine	CH <sub>3</sub> NH <sub>2</sub>	31.06	-6.7	-92.5	156.9	7455	—	1.432 (17.5)
C318	Octafluorocyclobutane	C <sub>4</sub> F <sub>8</sub>	200.04	-5.8	-41.4	115.3	2781	1.611	—
600	Butane	C <sub>4</sub> H <sub>10</sub>	58.13	-0.5	-138.5	152.0	3794	4.383	1.3562 (-15) <sup>1</sup>
114	Dichlorotetrafluoroethane	CClF <sub>2</sub> CClF <sub>2</sub>	170.94	3.8	-94	145.7	3259	1.717	1.294 (25)
21 <sup>7</sup>	Dichlorofluoromethane	CHCl <sub>2</sub> F	102.92	8.9	-135	178.5	5168	1.917	1.332 (25) <sup>4</sup>
160 <sup>2</sup>	Ethyl chloride	C <sub>2</sub> H <sub>5</sub> Cl	64.52	12.4	-138.3	187.2	5267	3.028	—
631 <sup>6</sup>	Ethyl amine	C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub>	45.08	16.6	-80.6	183.0	5619	—	—
11	Trichlorofluoromethane	CCl <sub>3</sub> F	137.38	23.82	-111	198.0	4406	1.804	1.362 (25) <sup>4</sup>
123	Dichlorotrifluoroethane	CHCl <sub>2</sub> CF <sub>3</sub>	152.93	27.87	-107.15	183.79	3674	—	—
611 <sup>6</sup>	Methyl formate	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	60.05	31.8	-99	214.0	5994	2.866	—
141b	Dichlorofluoroethane	CCl <sub>2</sub> FCH <sub>3</sub>	116.95	32	—	204.2	4250	—	—
610 <sup>6</sup>	Ethyl ether	C <sub>4</sub> H <sub>10</sub> O	74.12	34.6	-116.3	194.0	3603	3.790	1.3526 (20)
216ca	Dichlorohexafluoropropane	C <sub>3</sub> Cl <sub>2</sub> F <sub>6</sub>	220.93	35.69	-125.4	180.0	2753	1.742	—
30 <sup>6</sup>	Methylene chloride	CH <sub>2</sub> Cl <sub>2</sub>	84.93	40.2	-97	237.0	6077	—	1.4244 (20) <sup>3</sup>
113	Trichlorotrifluoroethane	CCl <sub>2</sub> FCClF <sub>2</sub>	187.39	47.57	-35	214.1	3437	1.736	1.357 (25) <sup>4</sup>
1130 <sup>8</sup>	Dichloroethylene	CHCl=CHCl	96.95	47.8	-50	243.3	5478	—	—
1120 <sup>6</sup>	Trichloroethylene	CHCl=CCl <sub>2</sub>	131.39	87.2	-73	271.1	5016	—	1.4782 (20) <sup>3</sup>
718 <sup>6</sup>	Water	H <sub>2</sub> O	18.02	100	0	373.99	22064	3.11	—

**Notes for Table 2**

- <sup>a</sup> Data from ASHRAE *Thermodynamic Properties of Refrigerants* (Stewart et al. 1986) or from McLinden (1990), unless otherwise noted.
- <sup>b</sup> Temperature of measurement (°C, unless kelvin is noted) shown in parentheses. Data from CRC *Handbook of Chemistry and Physics* (CRC 1987), unless otherwise noted.
- <sup>c</sup> For the sodium D line.
- <sup>d</sup> Sublimes.
- <sup>e</sup> At 527 kPa.
- <sup>f</sup> Dielectric constant data.

**References**

- <sup>1</sup> Kirk and Othmer (1956).
- <sup>2</sup> *Matheson Gas Data Book* (1966).
- <sup>3</sup> Electrochemicals Department, E.I. duPont de Nemours & Co.
- <sup>4</sup> *Bulletin B-32A* (duPont).
- <sup>5</sup> *Bulletin T-502* (duPont 1980).
- <sup>6</sup> *Handbook of Chemistry* (1967).
- <sup>7</sup> *Bulletin G-1* (duPont).
- <sup>8</sup> CRC *Handbook of Chemistry and Physics* (CRC 1987).
- <sup>9</sup> NIST *Standard Reference Database 23*, Version 6.01.

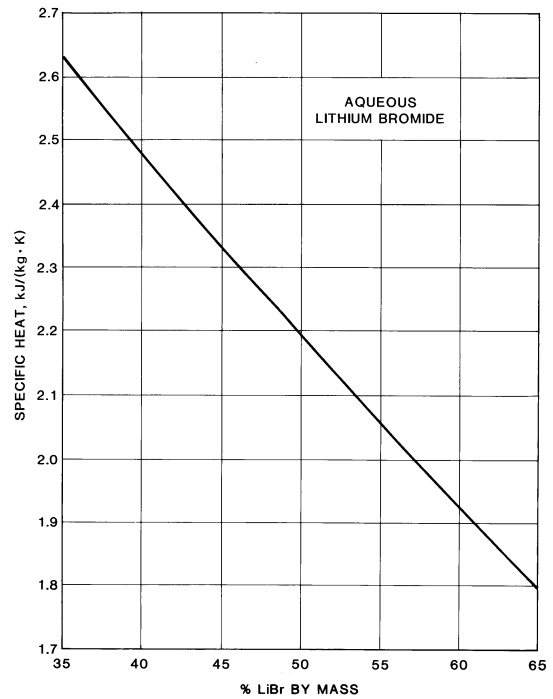
**REFRIGERANT PROPERTIES**

**Physical Properties**

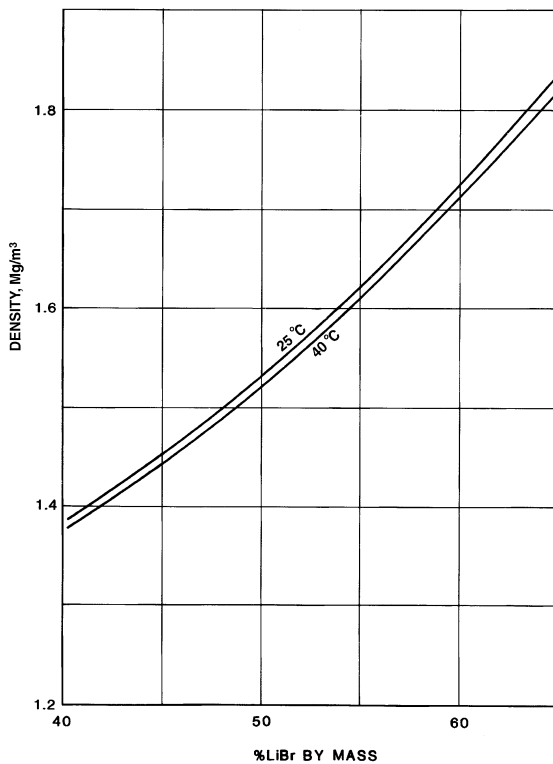
Table 2 lists some physical properties of commonly used refrigerants, a few very low-boiling cryogenic fluids, some newer refrigerants, and some older refrigerants of historical interest. These refrigerants are arranged in increasing order of atmospheric boiling point, from helium at -268.9°C to water at 100°C.

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

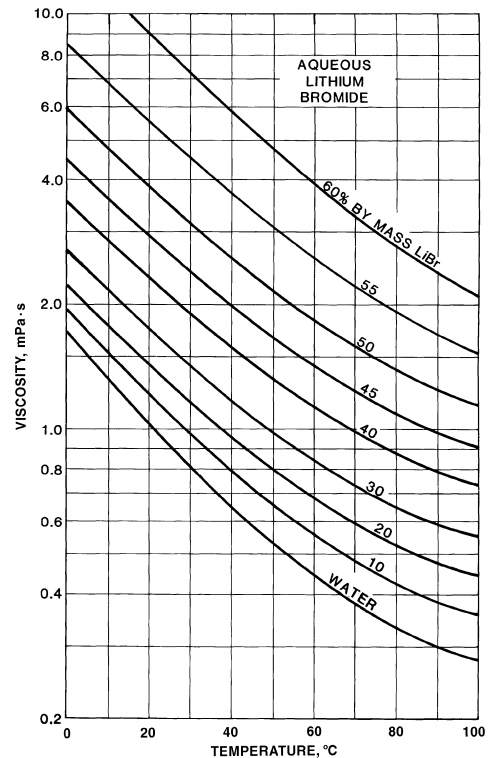
temperatures, no separate liquid phase is possible. In refrigeration cycles involving condensation, a refrigerant must be chosen that allows this change of state to occur at a temperature somewhat below the critical. Cycles that reject heat at supercritical temperatures (such as cycles using carbon dioxide) are also possible.



**Fig. 2 Specific Heat of Aqueous Lithium Bromide Solutions**



**Fig. 1 Specific Gravity of Aqueous Solutions of Lithium Bromide**



**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 density, 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., °C	Dielectric Constant	Volume Resistivity, MΩ·m	Ref.
No.	Chemical Name or Composition (% by mass)				
11	Trichlorofluoromethane	28.9	2.28	1	1
		a	1.92	63680	2
		25	2.5	90	3
12	Dichlorodifluoromethane	28.9	2.13	1	1
		a	1.74	53900	2
		25	2.1	> 120	3
		25	2.100		4
13	Chlorotrifluoromethane	-30	2.3	120	4
		20	1.64		
22	Chlorodifluoromethane	23.9	6.11	1	1
		a	6.12	0.83	2
		25	6.6	75	3
23	Trifluoromethane	-30	6.3	3	3
		20	5.51		4
32	Difluoromethane	a	14.27	-	6
113	Trichlorotrifluoroethane	30	2.44	1	1
		a	1.68	45490	2
		25	2.6	> 120	3
114	Dichlorotetrafluoroethane	31.1	2.17	1	1
		a	1.83	66470	2
		25	2.2	> 70	3
123	2,2-dichloro-1,1,1-trifluoroethane	a	4.50	14700	7
124a	Chlorotetrafluoroethane	25	4.0	50	3
125	Pentafluoroethane	20	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)	-30	6.60	-	1
		0	5.02		1
508B	R-23/116 (46/54)	-30	7.24	-	1
		0	5.48		1
717	Ammonia	20.6	15.5		5
744	Carbon dioxide	0	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 No.	Chemical Name or Composition (% by mass)	Pressure, Temp., °C		Dielectric Constant	Relative Dielectric Strength, Nitrogen = 1	Volume Resistivity, GΩ·m	Ref.
		kPa	°C				
11	Trichlorofluoromethane	50.7	26.1	1.0019			3
		a	b	1.009		74.35	2
			22.8		3.1		4
12	Dichlorodifluoromethane	50.7	28.9	1.0016			3
		a	b	1.012	452 <sup>c</sup>	72.77	2
			22.8		2.4		4
			20	1.019			5
13	Chlorotrifluoromethane	50.7	28.9	1.0013			3
			22.8		1.4		4
			20	1.013			5
		1975	32.2	1.055			6
14	Tetrafluoromethane	50.7	24.4	1.0006			3
			22.8		1.0		4
22	Chlorodifluoromethane	50.7	25.6	1.0035			3
		a	b	1.004	460 <sup>c</sup>	2113	2
			22.8		1.3		4
			20	1.033			5
23	Trifluoromethane		20	1.042			5
113	Trichlorotrifluoroethane	a	b	1.010	440 <sup>c</sup>	94.18	2
		40.5	22.8		2.6		4
114	Dichlorotetrafluoroethane	50.7	26.7	1.0021			3
		a	b	1.002	295 <sup>c</sup>	148.3	2
			22.8		2.8		4
116	Hexafluoroethane	95.2	22.8	1.002			3
133a	Chlorotrifluoroethane	95.2	26.7	1.010			3
142b	Chlorodifluoroethane	94.2	27.2	1.013			3
143a	Trifluoroethane	86.1	25	1.013			3
170	Ethane		0	1.0015			1
290	Propane	a	b	1.009	440 <sup>c</sup>	105.3	2
500	R-12/152a (73.8/26.2)	a	b	1.024	470 <sup>c</sup>	76.45	2
508A	R-23/116 (39/61)	a	-30	1.12			7
		a	0	1.31			7
508B	R-23/116 (46/54)	a	-30	1.13			7
		a	0	1.34			7
717	Ammonia		0	1.0072			1
		a	0		0.82		4
729	Air		0	1.00059			1
744	Carbon dioxide		0	1.00099			1
			b		0.88		4
1150	Ethylene		0	1.00144			1
			22.8		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

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

where

- $V_a$  = sound velocity, m/s
- $p$  = pressure, Pa
- $\rho$  = density, kg/m<sup>3</sup>
- $\gamma = c_p/c_v$  = ratio of specific heats
- $S$  = entropy, kJ/(kg·K)
- $T$  = temperature, K

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 258 K evaporation and 303 K 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 291 K (250 K saturated evaporating plus 41 K 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 mL/m<sup>3</sup>:

**Table 5 Velocity of Sound in Refrigerant Vapors<sup>b</sup>**

Refrigerant	Pressure, kPa	Temperature, °C			
		10	50	100	
		Velocity of Sound, m/s			
11	100	b	145	156	
	12	100	144	155	167
		1000	b	138	156
22	1500	b	b	148	
	100	176	188	201	
	1000	b	173	193	
23	1500	b	164	187	
	100	200	212	227	
	1000	188	205	222	
32	1500	181	201	220	
	100	236	250	267	
	1000	212	236	259	
113	1500	b	228	254	
	100	b	120	130	
	114	100	118	127	137
123	100	b	134	145	
	1000	b	b	b	
	1500	b	b	b	
124	100	134	144	155	
	1000	b	b	140	
	1500	b	b	128	
134a	100	157	169	181	
	1000	b	149	170	
	1500	b	b	163	
143a	100	175	187	200	
	1000	b	168	189	
	1500	b	156	183	
290	100	242	258	277	
	1000	b	232	266	
	1500	b	212	249	
404A	100	161	173	185	
	1000	b	155	175	
	1500	b	144	169	
407C	100	174	186	199	
	1000	b	169	189	
	1500	b	158	183	
410A	100	193	206	220	
	1000	170	192	211	
	1500	b	183	207	
502	100	151	162	173	
	1000	129	148	166	
	1500	b	138	159	
507A	100	160	171	184	
	1000	b	155	174	
	1500	b	143	168	
508A	100	n.a.	172	185	
	1000	n.a.	165	180	
	1500	142	161	178	
508B	100	166	177	190	
	1000	155	170	186	
	1500	149	166	183	
600	100	205	220	234	
	1000	b	b	206	
	1500	b	b	181	
600a	100	206	221	237	
	1000	b	b	210	
	1500	b	b	190	
717	100	422	450	482	
	1000	b	431	471	
	1500	b	418	464	
744	100	263	279	298	
	1000	254	273	294	
	1500	249	270	292	

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**

No.	Refrigerant Chemical Name or Composition (% by mass)	Normal Boiling Pt., °C	Latent Heat $\lambda$ at NBP, kJ/kg·mol	Trouton Constant, $\lambda/K^b$	Ref.
717	Ammonia	-33.3	23 343	97.32	1
630	Methyl amine <sup>a</sup>	-5.0	25 914	96.64	4
764	Sulfur dioxide	-10.2	24 900	94.69	2
631	Ethyl amine	20.0	27 086	92.40	4
611	Methyl formate <sup>a</sup>	37.8	28 131	90.47	4
134a	Tetrafluoroethane	-26.15	22 160	89.77	5
504	R-32/115 (48.2/51.8)	-57.2	19 264	89.21	1
23	Trifluoromethane	-82.1	17 039	89.19	1
124	Chlorotetrafluoroethane	-13.19	22 654	87.14	5
C318	Octafluorocyclobutane	-5.8	23 298	87.14	1
21	Dichlorodifluoromethane	8.8	24 556	87.09	3
22	Chlorodifluoromethane	-40.8	20 207	86.97	1
40	Methyl chloride	-23.8	21 644	86.80	3
123	Dichlorotrifluoroethane	27.87	26 005	86.43	5
506	R-31/114 (55.1/44.9)	-12.3	22 431	85.99	3
125	Pentafluoroethane	-48.57	19 276	85.89	5
113	Trichlorotrifluoroethane	47.6	27 513	85.78	1
152a	Difluoroethane	-25.0	21 039	84.78	1
502	R-22/115 (48.8/51.2)	-45.5	19 258	84.59	3
114	Dichlorotetrafluoroethane	3.8	23 273	84.03	1
216ca	Dichlorohexafluoropropane	35.7	25 943	84.00	1
505	R-12/31 (78.0/22.0) <sup>c</sup>	-29.9	20 319	83.53	3
11	Trichlorofluoromethane	23.8	24 768	83.41	1
500	R-12/152a (73.8/26.2)	-33.5	19 975	83.35	1
14	Tetrafluoromethane	-127.9	11 969	82.40	1
30	Methylene chloride <sup>a</sup>	48.9	26 511	82.32	4
600	Butane	-0.5	22 425	82.25	1
13B1	Bromotrifluoromethane	-57.8	17 695	82.17	1
12	Dichlorodifluoromethane	-29.8	19 982	82.11	1
142b	Chlorodifluoroethane	-9.8	21 624	82.11	1
115	Chloropentafluoroethane	-39.1	19 178	81.94	1
1270	Propylene	-47.7	18 448	81.83	1
503	R-23/13 (40.1/59.9)	-87.8	15 080	81.36	1
600a	Isobutane	-11.7	21 174	80.99	1
13	Chlorotrifluoromethane	-81.4	15 515	80.91	1
290	Propane	-42.1	18 669	80.80	1
1150	Ethylene	-103.7	13 475	79.52	1
170	Ethane	-88.8	14 645	79.44	1
50	Methane	-161.5	8 191	73.36	1

Notes:

<sup>a</sup>Not at normal atmospheric pressure.<sup>b</sup>Normal boiling temperatures.<sup>c</sup>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 18°C and 101 kPa
- Class 2 Lower flammability limit (LFL) greater than 0.10 kg/m<sup>3</sup> at 21°C and 101 kPa *and* heat of combustion less than 19 000 kJ/kg
- Class 3 Highly flammable as defined by LFL less than or equal to 0.10 kg/m<sup>3</sup> at 21°C and 101 kPa *or* heat of combustion greater than or equal to 19 000 kJ/kg

## 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 0.3 g 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 Kilowatt of Refrigeration**

No.	Refrigerant Chemical Name or Composition (% by mass)	Evaporator Pressure, MPa	Condenser Pressure, MPa	Com- pression Ratio	Net Refriger- ating Effect, kJ/kg	Refriger- ant Circu- lated, g/s	Liquid Circu- lated, L/s	Specific Volume of Suction Gas, m <sup>3</sup> /kg	Com- pressor Displace- ment, L/s	Power Con- sump- tion, kW	Coeffi- cient of Perform- ance	Comp. Dis- charge Temp., K
170	Ethane	1.623	4.637	2.86	162.44	6.16	0.0232	0.0335	0.206	0.364	2.74	324
744	Carbon dioxide	2.291	7.208	3.15	134.24	7.45	0.0123	0.0087	0.065	0.338	2.96	343
13B1	Bromotrifluoromethane	0.536	1.821	3.39	66.14	15.12	0.0101	0.0237	0.358	0.274	3.65	313
1270	Propylene	0.362	1.304	3.60	286.48	3.49	0.0070	0.1285	0.449	0.221	4.54	375
290	Propane	0.291	1.077	3.71	279.88	3.57	0.0074	0.1542	0.551	0.211	4.74	320
502	R-22/115 (48.8/51.2)	0.349	1.319	3.78	104.39	9.58	0.0080	0.0500	0.479	0.226	4.43	310
507A	R-125/143a (50/50)	0.381	1.465	3.84	109.98	9.09	0.0089	0.0506	0.461	0.239	4.18	308
404A	R-125/143a/134a (44/52/4)	0.367	1.426	3.88	113.93	8.78	0.0086	0.0534	0.470	0.237	4.21	309
410A	R-32/125 (50/50)	0.481	1.88	3.91	167.68	5.96	0.0058	0.0542	0.318	0.227	4.41	324
125	Pentafluoroethane	0.400	1.570	3.93	87.76	11.39	0.0098	0.0394	0.449	0.272	3.68	315
22	Chlorodifluoromethane	0.296	1.190	4.02	163.79	6.09	0.0052	0.0785	0.478	0.215	4.65	327
12	Dichlorodifluoromethane	0.183	0.745	4.07	116.58	8.58	0.0066	0.0914	0.784	0.213	4.69	311
500	R-12/152a (73.8/26.2)	0.214	0.879	4.11	140.95	7.09	0.0062	0.0938	0.665	0.213	4.69	314
407C	R-32/125/134a (23/25/52)	0.290	1.264	4.36	162.28	6.16	0.0055	0.0796	0.492	0.222	4.51	320
600a	Isobutane	0.089	0.407	4.60	262.84	3.80	0.0070	0.4029	1.533	0.220	4.55	318
134a	Tetrafluoroethane	0.164	0.770	4.69	149.95	6.66	0.0056	0.1223	0.814	0.217	4.60	309
124	Chlorotetrafluoroethane	0.090	0.440	4.89	118.49	8.44	0.0063	0.1705	1.439	0.224	4.47	305
717	Ammonia	0.236	1.164	4.94	1102.23	0.91	0.0015	0.5106	0.463	0.207	4.84	371
600	Butane	0.056	0.283	5.05	292.01	3.42	0.0060	0.6641	2.274	0.214	4.68	318
114	Dichlorotetrafluoroethane <sup>a</sup>	0.047	0.252	5.41	99.19	10.08	0.0070	0.2700	2.722	0.225	4.44	303
11	Trichlorofluoromethane	0.020	0.126	6.24	156.22	6.40	0.0044	0.7641	4.891	0.196	5.09	313
123	Dichlorotrifluoroethane	0.016	0.110	7.06	142.76	7.00	0.0048	0.8953	6.259	0.205	4.86	305
113	Trichlorotrifluoroethane <sup>a</sup>	0.007	0.054	7.84	127.34	7.85	0.0051	1.6793	13.187	0.205	4.88	303

Notes: Data based on 258 K evaporation, 303 K condensation, 0 K subcool, and 0 K superheat.

<sup>a</sup> Saturated suction except R-113 and R-114. Enough superheat was added to give saturated discharge.

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

No.	Refrigerant Chemical Name or Composition (% by mass)	Suction Temp., K	Evaporator Pressure, MPa	Con- denser Pressure, MPa	Com- pression Ratio	Net Refriger- ating Effect, kJ/kg	Refriger- ant Circu- lated, g/s	Specific Volume of Suction Gas, m <sup>3</sup> /kg	Com- pressor Displace- ment, L/s	Power Consump- tion, kW
<b>A. 183 K Saturated Evaporating, 0 K Suction Superheat, 233 K Saturated Condensing</b>										
1150	Ethylene	183	0.211	1.446	6.84	330.40	3.03	0.2422	0.733	0.373
170	Ethane	183	0.093	0.774	8.31	364.21	2.75	0.5257	1.443	0.347
13	Chlorotrifluoromethane	183	0.062	0.607	9.72	106.49	9.39	0.2263	2.125	0.358
23	Trifluoromethane	183	0.062	0.706	11.41	184.56	5.42	0.3438	1.863	0.372
508A	R-23/116 (39/61)	183	0.087	0.843	9.69	102.63	9.74	0.167	1.635	0.369
508B	R-23/116 (46/54)	183	0.086	0.847	9.85	110.49	9.05	0.179	1.620	0.368
<b>B. 200 K Saturated Evaporating, 0 K Suction Superheat, 238 K Saturated Condensing</b>										
170	Ethane	200	0.212	0.909	4.29	503.14	1.99	0.2396	0.476	0.168
23	Trifluoromethane	200	0.165	0.847	5.13	185.66	5.39	0.1373	0.740	0.242
13	Chlorotrifluoromethane	200	0.156	0.719	4.61	108.17	9.24	0.0961	0.888	0.237
125	Pentafluoroethane	200	0.026	0.186	7.06	132.08	7.57	0.5182	3.923	0.226
22	Chlorodifluoromethane	200	0.017	0.132	7.87	211.70	4.72	1.1347	5.360	0.221
508A	R-23/116 (39/61)	200	0.214	1.017	4.75	103.00	9.71	0.0716	0.697	0.251
508B	R-23/116 (46/54)	200	0.213	1.023	4.80	110.56	9.05	0.0757	0.686	0.249
<b>C. 213 K Saturated Evaporating, 0 K Suction Superheat, 258 K Saturated Condensing</b>										
1150	Ethylene	213	0.755	2.859	3.79	272.31	3.67	0.0729	0.268	0.314
170	Ethane	213	0.377	1.623	4.31	322.65	3.10	0.1430	0.443	0.279
23	Trifluoromethane	213	0.311	1.628	5.23	162.02	6.17	0.0756	0.467	0.296
13	Chlorotrifluoromethane	213	0.282	1.325	4.70	91.63	10.91	0.0549	0.600	0.293
125	Pentafluoroethane	213	0.056	0.404	7.20	117.76	8.49	0.2561	2.175	0.271
290	Propane	213	0.042	0.291	6.91	342.79	2.92	0.9343	2.726	0.254
22	Chlorodifluoromethane	213	0.037	0.296	7.90	195.80	5.11	0.5364	2.740	0.253
717	Ammonia	213	0.022	0.234	10.83	1242.9	0.81	4.7738	3.822	0.265
12	Dichlorodifluoromethane	213	0.023	0.183	8.09	138.57	7.22	0.6396	4.615	0.248
134a	Tetrafluoroethane	213	0.016	0.163	10.36	181.3	5.52	1.0904	6.012	0.251
410A	R-32/125 (50/50)	213	0.065	0.481	7.40	215.99	4.63	0.364	1.691	0.255
407C	R-32/125/134a (23/25/52)	213	0.034	0.300	8.82	202.07	4.95	0.608	3.017	0.255



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

No.	Refrigerant Chemical Name or Composition (% by mass)	Suction Temp., K	Evaporator Pressure, MPa	Condenser Pressure, MPa	Compression Ratio	Net Refrigerating Effect, kJ/kg	Refrigerant Circulated, g/s	Specific Volume of Suction Gas, m <sup>3</sup> /kg	Compressor Displacement, L/s	Power Consumption, kW
<b>C. 213 K Saturated Evaporating, 0 K Suction Superheat, 258 K Saturated Condensing (Concluded)</b>										
404A	R125/143a/134a (44/52/4)	213	0.049	0.368	7.51	151.76	6.59	0.357	2.361	0.258
507A	R125/143a (50/50)	213	0.052	0.381	7.33	147.54	6.78	0.333	2.265	0.258
508A	R-23/116 (39/61)	213	0.392	1.847	4.71	81.95	12.20	0.0401	0.490	0.311
508B	R-23/116 (46/54)	213	0.392	1.862	4.75	88.90	12.49	0.0421	0.475	0.307
<b>D. 233 K Saturated Evaporating, 0 K Suction Superheat, 293 K Saturated Condensing</b>										
744	Carbon dioxide	233	1.005	5.726	5.70	179.50	5.57	0.0383	0.213	0.469
125	Pentafluoroethane	233	0.150	1.202	8.03	87.16	11.47	0.1021	1.171	0.416
290	Propane	233	0.110	0.835	7.57	277.61	3.60	0.3821	1.376	0.354
22	Chlorodifluoromethane	233	0.105	0.910	8.65	164.21	6.09	0.2048	1.247	0.341
717	Ammonia	233	0.071	0.853	11.99	1114.5	0.90	1.5860	1.400	0.335
12	Dichlorodifluoromethane	233	0.064	0.567	8.84	114.91	8.70	0.2426	2.112	0.339
134a	Tetrafluoroethane	233	0.051	0.569	11.23	146.7	6.82	0.3645	2.485	0.339
410A	R-32/125 (50/50)	233	0.176	1.440	8.18	173.09	5.78	0.142	0.824	0.348
407C	R-32/125/134a (23/25/52)	233	0.097	0.957	9.87	163.61	6.11	0.225	1.375	0.344
404A	R-125/143a/134a (44/52/4)	233	0.134	1.096	8.18	114.82	8.71	0.140	1.220	0.368
507A	R-125/143a (50/50)	233	0.141	1.127	7.99	110.89	9.02	0.131	1.187	0.370
<b>E. 250 K Saturated Evaporating, 0 K Suction Superheat, 310 K Saturated Condensing</b>										
124	Chlorotetrafluoroethane	250	0.062	0.543	8.74	105.75	9.46	0.2379	2.250	0.340
134a	Tetrafluoroethane	250	0.115	0.934	8.09	133.	26.4	0.1678	4.433	0.328
12	Dichlorodifluoromethane	250	0.134	0.891	6.64	105.80	9.45	0.1221	1.154	0.330
717	Ammonia	250	0.165	1.423	8.63	1077.23	3.27	0.7245	2.367	0.309
22	Chlorodifluoromethane	250	0.218	1.390	6.37	150.09	6.66	0.1033	0.688	0.326
502	R-22/115 (48.8/51.2)	250	0.260	1.563	6.01	91.91	10.88	0.0662	0.720	0.391
125	Pentafluoroethane	250	0.301	1.867	6.21	73.70	13.57	0.0525	0.712	0.444
410A	R-32/125 (50/50)	250	0.353	2.286	6.48	150.49	6.64	0.0733	0.488	0.355
407C	R-32/125/134a (23/25/52)	250	0.205	1.551	7.57	145.26	6.88	0.111	0.765	0.345
404A	R-125/143a/134a (44/52/4)	250	0.269	1.731	6.43	96.80	10.33	0.0721	0.747	0.385
507A	R-125/143a (50/50)	250	0.280	1.776	6.34	92.94	10.76	0.0681	0.734	0.389
<b>F. 250 K Saturated Evaporating, 41 K Suction Superheat (Including Refrigeration Effect), 310 K Saturated Condensing</b>										
123	Dichlorotetrafluoroethane	291	0.010	0.139	13.5	157.07	22.38	1.5302	34.25	0.291
11	Trichlorofluoromethane	291	0.013	0.158	11.73	167.61	20.97	1.3140	27.55	0.291
124	Chlorotetrafluoroethane	291	0.062	0.543	8.74	133.95	7.47	0.2800	2.090	0.312
134a	Tetrafluoroethane	291	0.155	0.934	8.09	166.58	21.10	0.1998	4.217	0.313
12	Dichlorodifluoromethane	291	0.134	0.891	6.64	130.33	7.67	0.1451	1.113	0.318
717	Ammonia	291	0.164	1.423	8.63	1162.31	3.02	0.8508	2.567	0.335
22	Chlorodifluoromethane	291	0.218	1.390	6.37	177.29	5.64	0.1237	0.698	0.330
502	R-22/115 (48.8/51.2)	291	0.260	1.563	6.01	119.81	8.35	0.0796	0.665	0.361
125	Pentafluoroethane	291	0.301	1.867	6.21	105.80	9.45	0.0636	0.601	0.366
410A	R-32/125 (50/50)	291	0.353	2.286	2.28	187.23	5.34	0.0898	0.481	0.351
407C	R-32/125/134a (23/25/52)	291	0.205	1.551	7.57	180.22	5.55	0.1330	0.741	0.336
404A	R-125/143a/134a (44/52/4)	291	0.269	1.731	6.43	133.24	7.51	0.0878	0.660	0.347
507A	R-125/143a (50/50)	291	0.280	1.776	6.34	129.23	7.74	0.0830	0.644	0.349
<b>G. 277 K Saturated Evaporating, 0 K Suction Superheat, 310 K Saturated Condensing</b>										
125	Pentafluoroethane	277	0.756	1.858	2.46	84.51	11.83	0.0210	0.249	0.165
290	Propane	277	0.533	1.272	2.39	279.91	3.57	0.0863	0.308	0.145
22	Chlorodifluoromethane	277	0.566	1.390	2.46	160.57	6.23	0.0415	0.258	0.142
717	Ammonia	277	0.494	1.423	2.88	1120.41	3.13	0.2606	0.817	0.137
500	R-12/152a (73.8/26.2)	277	0.413	1.053	2.55	141.50	7.07	0.0501	0.354	0.145
12	Dichlorodifluoromethane	277	0.352	0.891	2.53	117.99	8.48	0.0493	0.417	0.145
134a	Tetrafluoroethane	277	0.336	0.934	2.78	149.15	23.57	0.0608	1.433	0.144
124	Chlorotetrafluoroethane	277	0.188	0.543	2.89	126.55	7.90	0.0840	0.663	0.141
600a	Isobutane	277	0.181	0.493	2.73	270.81	3.69	0.2072	0.765	0.145
600	Butane	277	0.119	0.347	2.91	301.82	3.31	0.3170	1.050	0.141
11	Trichlorofluoromethane	277	0.047	0.156	3.33	158.67	22.15	0.3484	7.717	0.133
123	Dichlorotrifluoroethane	277	0.039	0.139	3.57	146.61	23.97	0.3790	9.083	0.135
113	Trichlorotrifluoroethane	277	0.018	0.070	3.87	127.46	7.85	0.6720	5.274	0.134
410A	R-32/125 (50/50)	277	0.916	2.286	2.5	160.67	6.22	0.0284	0.177	0.153
407C	R-32/125/134a (23/25/52)	277	0.581	1.551	2.67	159.54	6.27	0.0404	0.254	0.148

**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 <sub>4</sub>	2	B1
11	CCl <sub>3</sub> F	1	A1
12	CCl <sub>2</sub> F <sub>2</sub>	1	A1
13	CClF <sub>3</sub>	1	A1
13B1	CBrF <sub>3</sub>	1	A1
14	CF <sub>4</sub>	1	A1
21	CHCl <sub>2</sub> F	2	B1
22	CHClF <sub>2</sub>	1	A1
23	CHF <sub>3</sub>		A1
30	CH <sub>2</sub> Cl <sub>2</sub>	2	B2
32	CH <sub>2</sub> F <sub>2</sub>		A2
40	CH <sub>3</sub> Cl	2	B2
50	CH <sub>4</sub>	3a	A3
113	CCl <sub>2</sub> FCClF <sub>2</sub>	1	A1
114	CClF <sub>2</sub> CClF <sub>2</sub>	1	A1
115	CClF <sub>2</sub> CF <sub>3</sub>	1	A1
116	CF <sub>3</sub> CF <sub>3</sub>		A1
123	CHCl <sub>2</sub> CF <sub>3</sub>		B1
124	CHClF <sub>2</sub> CF <sub>3</sub>		A1
125	CHF <sub>2</sub> CF <sub>3</sub>		A1
134a	CF <sub>3</sub> CH <sub>2</sub> F		A1
142b	CClF <sub>2</sub> CH <sub>3</sub>	3b	A2
143a	CF <sub>3</sub> CH <sub>3</sub>		A2
152a	CHF <sub>2</sub> CH <sub>3</sub>	3b	A2
170	CH <sub>3</sub> CH <sub>3</sub>	3a	A3
218	CF <sub>3</sub> CF <sub>2</sub> CF <sub>3</sub>		A1
290	CH <sub>3</sub> CH <sub>2</sub> CH <sub>3</sub>	3a	A3
C318	C <sub>4</sub> F <sub>8</sub>	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 <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	3a	A3
600a	CH(CH <sub>3</sub> ) <sub>3</sub>	3a	A3
611	HCOOCH <sub>3</sub>	2	B2
702	H <sub>2</sub>		A3
704	He		A1
717	NH <sub>3</sub>	2	B2
718	H <sub>2</sub> O		A1
720	Ne		A1
728	N <sub>2</sub>		A1
740	Ar		A1
744	CO <sub>2</sub>	1	A1
764	SO <sub>2</sub>	2	B1
1140	CHCl=CH <sub>2</sub>		B3
1150	CH <sub>2</sub> =CH <sub>2</sub>	3a	A3
1270	CH <sub>3</sub> CH=CH <sub>2</sub>	3a	A3

\*The exact composition of this azeotrope is in question.

**Table 10 Swelling of Elastomers in Liquid Refrigerants at Room Temperature**

Refrigerant No.	Linear Swell, %							
	Buna N (GR-S)	Buna S (GR-1)	Butyl Rubber	Natural Rubber	Neo-			
					prene 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**

Elastomer	Diffusion Rate	
	Water <sup>a</sup>	R-22 <sup>b</sup>
Neoprene	970	4.63
Buna N	150	69.4
Hypalon 40	620	1.85
Butyl	58	1.04
Viton	—	12.7
Polyethylene	167	—
Natural	1940	—

Adapted from Eiseman (1966).

<sup>a</sup> 75 μm film, 100% rh at 38°C. Water diffusion rate is in micrograms per second per square metre of elastomer.<sup>b</sup> Film thickness = 25 μm; temperature = 25°C. Gas at 101.3 kPa and 0°C. Diffusion rate per day in cubic centimetres of gas per second per square metre of elastomer.**Table 12 Swelling of Plastics in Liquid Refrigerants at Room Temperature**

Plastic	Linear Swell, %						
	Refrigerant						
	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 1998 *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 generally 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.

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