

REFRIGERANTS

<i>Refrigerant Properties</i>	29.1
<i>Refrigerant Performance</i>	29.6
<i>Safety</i>	29.6
<i>Leak Detection</i>	29.9
<i>Compatibility with Construction Materials</i>	29.10

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 not in systems operating on a gas cycle using a fluid such as air. (See Chapter 2 for more information on refrigeration cycles.) The design of the refrigeration equipment depends strongly on the selected refrigerant's properties. Tables 1 and 2 list standard refrigerant designations, some properties, and safety classifications from ASHRAE *Standard 34*.

Refrigerant selection involves compromises between conflicting desirable thermophysical 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 an essential characteristic. Safety codes may require a nonflammable refrigerant of low toxicity for some applications. Environmental consequences of refrigerant leaks must also be considered. Cost, availability, efficiency, compatibility with compressor lubricants and equipment materials, and local and national regulations are other concerns.

Latent heat of vaporization is another important property. On a molar basis, fluids with similar boiling points have almost the same latent heat. Because compressor displacement is defined on a volumetric basis, refrigerants with similar boiling points produce similar refrigeration effect with a given compressor. On a mass basis, latent heat varies widely among fluids. Efficiency of a theoretical vapor compression cycle is maximized by fluids with low vapor heat capacity. This property is associated with fluids having a simple molecular structure and low molecular mass.

Transport properties (e.g., thermal conductivity and viscosity) affect 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; consequently, various refrigerants are used. This chapter describes the basic characteristics of various refrigerants, and Chapter 30 lists thermophysical properties.

1. REFRIGERANT PROPERTIES

Global Environmental Properties

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) can affect both stratospheric ozone and climate change, whereas hydrofluorocarbons (HFCs) can affect climate change. Minimizing all refrigerant releases from systems is important not only because of environmental impacts, but also because charge losses lead to insufficient system charge levels, which in turn result in suboptimal operation and lowered efficiency.

Stratospheric Ozone Depletion. The stratospheric ozone layer filters out the UV-B portion of the sun's ultraviolet (UV) radiation. Overexposure to this radiation increases the risk of skin cancer,

cataracts, and impaired immune systems. It also can damage sensitive crops, reduce crop yields, and stress marine phytoplankton (and thus human food supplies from the oceans). In addition, exposure to UV radiation degrades plastics and wood.

Stratospheric ozone depletion has been linked to the presence of chlorine and bromine in the stratosphere. Chemicals with long atmospheric lifetimes can migrate to the stratosphere, where the molecules break down from interaction with ultraviolet light or through chemical reaction. Chemicals such as CFCs and HCFCs release chlorine, which reacts with stratospheric ozone.

Ozone-depleting substances, including CFCs and HCFCs, are to be phased out of production under the Montreal Protocol (UNEP 2009). In the United States, production and importation of CFCs were banned completely in 1996. HCFCs are being phased down, with complete phaseout set for 2030. In 2010, to meet the Montreal Protocol phasedown schedule, U.S. regulations banned production and importation of HCFC-142b and HCFC-22 for use in new equipment. Reclaimed CFC and HCFC refrigerants that meet the requirements of AHRI *Standard 700* can continue to be used for servicing existing systems. A complete list of U.S. regulations for CFC and HCFC refrigerants, including phaseout schedules, may be found at www.epa.gov/ozone-layer-protection. A summary of the phaseout schedules for CFCs and HCFCs for both developed and developing countries may be found at www.unep.org/ozonaction/topics/hcfc.asp.

Global Climate Change. The average global temperature is determined by the balance of energy from the sun heating the earth and its atmosphere and of energy radiated from the earth and the atmosphere to space. **Greenhouse gases (GHGs)**, such as CO₂ and water vapor, as well as small particles trap heat at and near the surface, maintaining the average temperature of the Earth's surface about 61°F warmer than would be the case if these gases and particles were not present (the **greenhouse effect**).

Global warming (also called **global climate change**) is a concern because of an increase in the greenhouse effect from increasing concentrations of GHGs attributed to human activities. The major GHG of concern is CO₂ released to the atmosphere when fossil fuels (coal, oil, and natural gas) are burned for energy. Methane (CH₄), nitrous oxide (N₂O), CFCs, HCFCs, HFCs, hydrofluoroethers (HFEs), hydrofluoro-olefins (HFOs), perfluorocarbons (PFCs), nitrogen trifluoride (NF₃), and sulfur hexafluoride (SF₆) are also GHGs.

In 1988, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) to provide an objective source of information about the causes of climate change, its potential environmental and socioeconomic consequences, and the adaptation and mitigation options to respond to it. According to the IPCC (2014), atmospheric concentration of carbon dioxide has increased by more than 40% over the past 250 years, primarily from burning fossil fuels, with some contribution from forestry and land use. Concentration of methane has increased by over 150%, and of nitrous oxide by about 20%. IPCC (2014) deems atmospheric concentrations of fluorocarbons, including fluorocarbon gases

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Table 1 Refrigerant Data and Safety Classifications

Refrigerant Number	Chemical Name ^{a,b}	Chemical Formula ^a	Molecular Mass ^a	Normal Boiling Point, ^a °F	Safety Group
Methane Series					
11	Trichlorofluoromethane	CCl ₃ F	137.4	75	A1
12	Dichlorodifluoromethane	CCl ₂ F ₂	120.9	-22	A1
12B1	Bromochlorodifluoromethane	CBrClF ₂	165.4	25	
13	Chlorotrifluoromethane	CClF ₃	104.5	-115	A1
13B1	Bromotrifluoromethane	CBrF ₃	148.9	-72	A1
14	Tetrafluoromethane (carbon tetrafluoride)	CF ₄	88.0	-198	A1
21	Dichlorofluoromethane	CHCl ₂ F	102.9	48	B1
22	Chlorodifluoromethane	CHClF ₂	86.5	-41	A1
23	Trifluoromethane	CHF ₃	70.0	-116	A1
30	Dichloromethane (methylene chloride)	CH ₂ Cl ₂	84.9	104	B2
31	Chlorofluoromethane	CH ₂ ClF	68.5	16	
32	Difluoromethane (methylene fluoride)	CH ₂ F ₂	52.0	-62	A2L
40	Chloromethane (methyl chloride)	CH ₃ Cl	50.4	-12	B2
41	Fluoromethane (methyl fluoride)	CH ₃ F	34.0	-109	
50	Methane	CH ₄	16.0	-259	A3
Ethane Series					
113	1,1,2-trichloro-1,2,2-trifluoroethane	CCl ₂ FCClF ₂	187.4	118	A1
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	CClF ₂ CClF ₂	170.9	38	A1
115	Chloropentafluoroethane	CClF ₂ CF ₃	154.5	-38	A1
116	Hexafluoroethane	CF ₃ CF ₃	138.0	-109	A1
123	2,2-dichloro-1,1,1-trifluoroethane	CHCl ₂ CF ₃	153.0	81	B1
124	2-chloro-1,1,1,2-tetrafluoroethane	CHClF ₂ CF ₃	136.5	10	A1
125	Pentafluoroethane	CHF ₂ CF ₃	120.0	-55	A1
134a	1,1,1,2-tetrafluoroethane	CH ₂ FCF ₃	102.0	-15	A1
141b	1,1-dichloro-1-fluoroethane	CH ₂ CCl ₂ F	117.0	90	
142b	1-chloro-1,1-difluoroethane	CH ₃ CClF ₂	100.5	14	A2
143a	1,1,1-trifluoroethane	CH ₃ CF ₃	84.0	-53	A2L
152a	1,1-difluoroethane	CH ₃ CHF ₂	66.0	-11	A2
170	Ethane	CH ₃ CH ₃	30.0	-128	A3
Ethers					
E170	Dimethyl ether	CH ₃ OCH ₃	46.0	-13	A3
Propane Series					
218	Octafluoropropane	CF ₃ CF ₂ CF ₃	188.0	-35	A1
227ea	1,1,1,2,3,3,3-heptafluoropropane	CF ₃ CHFCF ₃	170.0	3	A1
236fa	1,1,1,3,3,3-hexafluoropropane	CF ₃ CH ₂ CF ₃	152.0	29	A1
245fa	1,1,1,3,3-pentafluoropropane	CF ₃ CH ₂ CHF ₂	134.0	59	B1
290	Propane	CH ₃ CH ₂ CH ₃	44.0	-44	A3
Cyclic Organic Compounds (see Table 2 for blends)					
C318	Octafluorocyclobutane	-(CF ₂) ₄ -	200.0	21	A1
Miscellaneous Organic Compounds					
Hydrocarbons					
600	Butane	CH ₃ CH ₂ CH ₂ CH ₃	58.1	31	A3
600a	2-methylpropane (isobutane)	CH(CH ₃) ₂ CH ₃	58.1	11	A3
601	Pentane	CH ₃ (CH ₂) ₃ CH ₃	72.15	97	A3
601a	2-methylbutane (isopentane)	(CH ₃) ₂ CHCH ₂ CH ₃	72.15	82	A3
Oxygen Compounds					
610	Ethyl ether	CH ₃ CH ₂ OCH ₂ CH ₃	74.1	94	
611	Methyl formate	HCOOCH ₃	60.0	89	B2
Sulfur Compounds					
620	(Reserved for future assignment)				
Nitrogen Compounds					
630	Methanamine (methyl amine)	CH ₃ NH ₂	31.1	20	
631	Ethanamine (ethyl amine)	CH ₃ CH ₂ (NH ₂)	45.1	62	

Table 1 Refrigerant Data and Safety Classifications (Continued)

Refrigerant Number	Chemical Name ^{a,b}	Chemical Formula ^a	Molecular Mass ^a	Normal Boiling Point, °F	Safety Group
Inorganic Compounds					
702	Hydrogen	H ₂	2.0	-423	A3
704	Helium	He	4.0	-452	A1
717	Ammonia	NH ₃	17.0	-28	B2L
718	Water	H ₂ O	18.0	212	A1
720	Neon	Ne	20.2	-411	A1
728	Nitrogen	N ₂	28.1	-320	A1
732	Oxygen	O ₂	32.0	-297	
740	Argon	Ar	39.9	-303	A1
744	Carbon dioxide	CO ₂	44.0	-109 ^c	A1
744A	Nitrous oxide	N ₂ O	44.0	-129	
764	Sulfur dioxide	SO ₂	64.1	14	B1
Unsaturated Organic Compounds					
1150	Ethene (ethylene)	CH ₂ =CH ₂	28.1	-155	A3
1233zd(E)	Trans-1-chloro-3,3,3-trifluoro-1-propene	CF ₃ CH=CHCl	130.5	64	A1
1234yf	2,3,3,3-tetrafluoro-1-propene	CF ₃ CF=CH ₂	114.0	-20.9	A2L
1234ze(E)	Trans-1,3,3,3-tetrafluoro-1-propene	CF ₃ CH=CHF	114.0	-2.2	A2L
1270	Propene (propylene)	CH ₃ CH=CH ₂	42.1	-54	A3
1336mzz(Z)	Cis-1,1,1,4,4,4-hexafluoro-2-butene	CF ₃ CH=CHCF ₃	164.1	92	A1

Source: ANSI/ASHRAE Standard 34-2010.

^aChemical name, chemical formula, molecular mass, and normal boiling point are not part of this standard.^bPreferred chemical name is followed by the popular name in parentheses.^cSublimes.

Table 2 Data and Safety Classifications for Refrigerant Blends

Refrig. No.	Composition (Mass %)	Composition Tolerances	Molecular Mass ^a	Normal Bubble Point, °F	Normal Dew Point, °F	Safety Group
Zeotropes						
400	R-12/114 (must be specified)					A1
401A	R-22/152a/124 (53.0/13.0/34.0)	(±2.0 /+0.5, -1.5/±1.0)	94.4	-29.9	-19.8	A1
401B	R-22/152a/124 (61.0/11.0/28.0)	(±2/+0.5, -1.5/±1.0)	92.8	-32.3	-23.4	A1
401C	R-22/152a/124 (33.0/15.0/52.0)	(±2/+0.5, -1.5/±1.0)	101	-22.9	-10.8	A1
402A	R-125/290/22 (60.0/2.0/38.0)	(±2.0/+0.1, -1.0/±2.0)	101.6	-56.6	-52.6	A1
402B	R-125/290/22 (38.0/2.0/60.0)	(±2/+0.1, -1/±2)	94.7	-53.0	-48.8	A1
403A	R-290/22/218 (5.0/75.0/20.0)	(+0.2, -2/±2/±2)	92	-47.2	-44.1	A1
403B	R-290/22/218 (5.0/56.0/39.0)	(+0.2, -2/±2/±2)	103.3	-46.8	-44.1	A1
404A	R-125/143a/134a (44.0/52.0/4.0)	(±2/±1/±2)	97.6	-51.9	-50.4	A1
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5)	(±2/±1/±1 /±2) sum of R-152a and R-142b = (+0.0, -2.0)	111.9	-27.2	-12.1	
406A	R-22/600a/142b (55.0/4.0/41.0)	(±2/±1/±1)	89.9	-26.9	-10.3	A2
407A	R-32/125/134a (20.0/40.0/40.0)	(±2/±2/±2)	90.1	-49.4	-37.7	A1
407B	R-32/125/134a (10.0/70.0/20.0)	(±2/±2/±2)	102.9	-52.2	-44.3	A1
407C	R-32/125/134a (23.0/25.0/52.0)	(±2/±2/±2)	86.2	-46.8	-34.1	A1
407D	R-32/125/134a (15.0/15.0/70.0)	(±2/±2/±2)	91	-38.9	-26.9	A1
407E	R-32/125/134a (25.0/15.0/60.0)	(±2, ±2, ±2)	83.8	-45.0	-32.1	A1
407F	R-32/125/134a (30.0/30.0/40.0)	(±2, ±2, ±2)	82.1	-51.0	-39.5	A1
408A	R-125/143a/22 (7.0/46.0/47.0)	(±2/±1/±2)	87	-49.9	-49.0	A1
409A	R-22/124/142b (60.0/25.0/15.0)	(±2/±2/±1)	97.4	-31.7	-17.5	A1
409B	R-22/124/142b (65.0/25.0/10.0)	(±2/±2/±1)	96.7	-33.7	-21.5	A1
410A	R-32/125 (50.0/50.0)	(+0.5, -1.5/+1.5, -0.5)	72.6	-60.9	-60.7	A1
410B	R-32/125 (45.0/55.0)	(±1/±1)	75.6	-60.7	-60.5	A1
411A	R-1270/22/152a (1.5/87.5/11.0)	(+0, -1/+2, -0/+0, -1)	82.4	-39.5	-35.0	A2
411B	R-1270/22/152a (3.0/94.0/3.0)	(+0, -1/+2, -0/+0, -1)	83.1	-42.9	-42.3	A2
412A	R-22/218/142b (70.0/5.0/25.0)	(±2/±2/±1)	92.2	-33.5	-19.8	A2
413A	R-218/134a/600a (9.0/88.0/3.0)	(±1/±2/±0, -1)	104	-20.7	-17.7	A2
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5)	(±2/±2/±0.5/+0.5, -1)	96.9	-29.2	-14.4	A1
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5)	(±2/±2/±0.5/+0.5, -1)	101.6	-29.9	-15.0	A1
415A	R-22/152a (82.0/18.0)	(±1/±1)	81.9	-35.5	-30.5	A2
415B	R-22/152a (25.0/75.0)	(±1/±1)	70.2	-17.8	-15.2	A2
416A	R-134a/124/600 (59.0/39.5/1.5)	(+0.5, -1/+1, -0.5/+1, -0.2)	111.9	-10.1	-7.2	A1
417A	R-125/134a/600 (46.6/50.0/3.4)	(±1.1/±1/+0.1, -0.4)	106.7	-36.4	-27.2	A1
417B	R-125/134a/600 (79.0/18.3/2.7)	(±1/±1/+0.1, -0.5)	113.1	-48.8	-42.7	A1
418A	R-290/22/152a (1.5/96.0/2.5)	(±0.5/±1/±0.5)	84.6	-42.2	-40.2	A2
419A	R-125/134a/E170 (77.0/19.0/4.0)	(±1/±1/±1)	109.3	-44.7	-32.8	A2
420A	R-134a/142b (88.0/12.0)	(±1, -0/+0, -1)	101.8	-13.0	-11.6	A1
421A	R-125/134a (58.0/42.0)	(±1/±1)	111.8	-41.5	-31.9	A1

Dynatemp v. R421A - IPR2020-01660

Table 2 Data and Safety Classifications for Refrigerant Blends (Continued)

Refrig. No.	Composition (Mass %)	Composition Tolerances	Molecular Mass ^a	Normal Boiling Point, °F	Normal Dew Point, °F	Safety Group
421B	R-125/134a (85.0/15.0)	(±1/±1)	116.9	-50.2	-44.6	A1
422A	R-125/134a/600a (85.1/11.5/3.4)	(±1/±1/+0.1,-0.4)	113.6	-51.7	-47.4	A1
422B	R-125/134a/600a (55.0/42.0/3.0)	(±1/±1/+0.1,-0.5)	108.5	-40.9	-32.2	A1
422C	R-125/134a/600a (82.0/15.0/3.0)	(±1/±1/+0.1,-0.5)	116.3	-49.5	-44.2	A1
422D	R-125/134a/600a (65.1/31.5/3.4)	(+0.9,-1.1/±1/+0.1,-0.4)	109.9	-45.8	-37.1	A1
423A	R-134a/227ea (52.5/47.5)	(±1/±1)	126	-11.6	-10.3	A1
424A	R-125/134a/600a/600i/601a (50.5/47.0/0.9/1.0/0.6)	(±1/±1/+0.1,-0.2/+0.1,-0.2/+0.1,-0.2)	108.4	-38.4	-27.9	A1
425A	R-32/134a/227ea (18.5/69.5/12.0)	(±0.5/±0.5/±0.5)	90.3	-36.6	-24.3	A1
426A*	R-125/134a/600a/601a (5.1/93.0/1.3/0.6)	(±1/±1/+0.1,-0.2/+0.1,-0.2)	101.6	-19.3	-16.1	A1
427A*	R-32/125/143a/134a (15.0/25.0/10.0/50.0)	(±2/±2/±2/±2)	90.4	-45.4	-33.3	A1
428A*	R-125/143a/290/600a (77.5/20.0/0.6/1.9)	(±1/±1/+0.1,-0.2/+0.1,-0.2)	107.5	-54.9	-53.5	A1
429A	R-E170/152a/600a (60.0/10.0/30.0)	(±1/±1/±1)	50.8	-14.8	-14.1	A3
430A	R-152a/600a (76.0/24.0)	(±1/±1)	64	-17.7	-17.3	A3
431A	R-290/152a (71.0/29.0)	(±1/±1)	48.8	-45.6	-45.6	A3
432A	R-1270/E170 (80.0/20.0)	(±1/±1)	42.8	-51.9	-50.1	A3
433A	R-1270/290 (30.0/70.0)	(±1/±1)	43.5	-48.3	-47.6	A3
433B	R-1270/290 (5.0/95.0)	(±1/±1)	44	-44.9	-44.5	A3
433C	R-1270/290 (25.0/75.0)	(±1/±1)	43.6	-47.7	-47.0	A3
434A	R-125/143a/134a/600a (63.2/18.0/16.0/2.8)	(±1/±1/±1/+0.1,-0.2)	105.7	-49.0	-44.1	A1
435A	R-E170/152a (80.0/20.0)	(±1/±1)	49.04	-15.0	-14.6	A3
436A	R-290/600a (56.0/44.0)	(±1/±1)	49.33	-29.7	-16.2	A3
436B	R-290/600a (52.0/48.0)	(±1/±1)	49.87	-28.1	-13.0	A3
437A	R-125/134a/600i/601 (19.5/78.5/1.4/0.6)	(+0.5,-1.8/+1.5,-0.7/+0.1,-0.2/+0.1,-0.2)	103.7	-27.2	-20.6	A1
438A	R-32/125/134a/600i/601a (8.5/45.0/44.2/1.7/0.6)	(+0.5,-1.5/+1.5/±1.5/+0.1,-0.2/+0.1,-0.2)	99.1	-45.4	-33.5	A1
439A	R-32/125/600a (50.0/47.0/3.0)	(±1/±1)	71.2	-61.6	-61.2	A2
440A	R-290/134a/152a (0.6/1.6/97.8)	(±0.1/±0.6/±0.5)	66.2	-13.9	-11.7	A2
441A	R-170/290/600a/600 (3.1/54.8/6.0/36.1)	(±0.3/±2/±0.6/±2)	48.2	-43.4	-4.7	A3
442A	R-32/125/134a/152a/227ea (31.0/31.0/30.0/3.0/5.0)	(±1.0/±1.0/±1.0/±0.5/±1.0)	81.77	-51.7	-39.8	A1
443A	R-1270/290/600a (55.0/40.0/5.0)	(±2.0/±2.0/±1.2)	43.47	-48.6	-42.2	A3
444A	R-32/152a/1234ze(E) (42.0/5.0/83.0)	(±1.0/±1.0/±2.0)	96.7	-29.7	-11.7	A2L
444B	R-32/152a/1234ze(E) (41.5/10.0/48.5)	(±1.0/±1.0/±1.0)	92.78	-48.3	-30.8	A2L
445A	R-744/134a/1234ze(E) (6.0/9.0/85.0)	(±1.0/±1.0/±2.0)	103.1	-58.5	-10.3	A2L
446A	R-32/1234ze(E)/600 (68.0/2.0/3.0) 29	(+0.5,-1.0/+2.0,-0.6/+1.0,-1.0)	62	-36.9	-47.2	A2L
447A	R-32/125/1234ze(E) (68.0/3.5/28.5)	(+1.5,-0.5/+1.5,-0.5/+1.0,-1.0)	63.04	-56.7	-47.6	A2L
448A	R-32/125/1234yf/134a/1234ze(E) (26.0/26.0/20.0/21.0/7.0)	(+0.5,-2.0/+2.0,-0.5/+0.5,-2.0/+2.0,-1.0/+0.5,-2.0)	86.28	-50.6	-39.6	A1
449A	R-32/125/1234yf/134a (24.3/24.7/25.3/25.7)	(+2.0,-1.0/+1.0,-0.2/+0.2,-1.0/+1.0,-0.2)	87.21	-50.8	-39.8	A1
449B	R-32/125/1234yf/134a (25.2/24.3/23.2/27.3)	(+0.3,-1.5/+1.5,-0.3/+0.3,-1.5/+1.5,-0.3)	86.37	-51.0	-40.4	A1
450A	R-134a/1234ze(E) (42.0/58.0)	(±2.0/±2.0)	108.67	-10.1	-9.0	A1
451A	R-1234yf/134a (89.8/10.2)	(±0.2/±0.2)	72.76	-23.4	-22.9	A2L
451B	R-1234yf/134a (88.8/11.2)	(±0.2/±0.2)	112.56	-23.8	-23.1	A2L
452A	R-32/125/1234yf (11.0/59.0/30.0)	(±1.7/±1.8/+0.1,-1.0)	112.56	-23.8	-23.1	A2L
453A	R32/125/134a/227ea/600/601a (20.0/20.0/53.8/5.0/0.6/0.6)	(±1.0/±1.0/±1.0/±0.5/+0.1,-0.2/+0.1,-0.2)	88.78	-44.0	-31.0	A1
454A	R-32/1234yf (35/65)	(±2.0/±2.0)	80.47	-55.1	-42.9	A2L
454B	R-32/1234yf (68.0/31.1)	(±1.0/±1.0)	62.61	-59.6	-58.0	A2L

Azeotropes^b

Refrig. No.	Composition (Mass %)	Composition Tolerances	Azeotropic Temperatures, °F	Molecular Mass ^a	Normal Boiling Point, °F	Safety Group
500	R-12/152a (73.8/26.2)		32	99.3	-27	A1
501	R-22/12 (75.0/25.0)		-42	93.1	-42	A1
502	R-22/115 (48.8/51.2)		66	112.0	-49	A1
503	R-23/13 (40.1/59.9)		-126	87.5	-126	
504	R-32/115 (48.2/51.8)		63	79.2	-71	
505	R-12/31 (78.0/22.0)		239	103.5	-22	
506	R-31/114 (55.1/44.9)		64	93.7	10	
507A ^d	R-125/143a (50.0/50.0)		-40	98.9	-52.1	A1
508A ^d	R-23/116 (39.0/61.0)		-122	100.1	-122	A1
508B	R-23/116 (46.0/54.0)		-50.1	95.4	-126.9	A1
509A ^d	R-22/218 (44.0/56.0)		32	124.0	-53	A1
510A	R-E170/600a (88.0/12.0)	(±0.5/±0.5)	-13.4	47.24	-13.4	A3
511A	R-290/E170 (95.0/5.0)	(±1/±1)	-4 to 104	44.19	-43.7	A3
512A	R-134a/152a (5.0/95.0)	(±1/±1)	-4 to 104	67.24	-11.2	A2
513A	R-1234yf/134a (56.0/44.0)	(±1.0/±1.0)	81	108.4	-20.4	A1

Source: ANSI/ASHRAE Standard 34-2010.

^aMolecular mass and normal boiling point are not part of this standard.^bAzeotropic refrigerants exhibit some segregation of components at conditions of temperature and pressure other than those at which they were formulated. Extent of segregation depends on the particular azeotrope and hardware system configuration.^cExact composition of this azeotrope is in question, and additional experimental studies are needed.^dR-507, R-508, and R-509 are allowed designations for R-507A, R-508A, and R-509A because of a change in designations after assignment of R-500 through R-509. Corresponding changes were not made for R-500 through R-506.

(CFCs, HCFCs, and HFCs) and sulfur hexafluoride, to be about 2% of the 2010 GHG (CO₂ equivalent) emissions.

Global Environmental Characteristics of Refrigerants. Atmospheric release of CFC and HCFC refrigerants (see Table 3) contributes to depletion of the ozone layer. The measure of a material's ability to deplete stratospheric ozone is its **ozone depletion potential (ODP)**, a value relative to R-11's value of 1.0. It is the nonzero ODP of these refrigerants that led to the phaseout of their production and use under the Montreal Protocol.

The **global warming potential (GWP)** of a GHG is an index describing its relative ability to trap radiant energy compared to CO₂ (R-744), which has a very long atmospheric lifetime. Measurements of climate impact of refrigerant emissions are hence often reported in CO₂ equivalents. GWP may be calculated for any particular **integration time horizon (ITH)**. Typically, a 100 year ITH is used for calculation of GWPs for regulatory purposes, and may be designated as GWP₁₀₀. Halocarbons (CFCs, HCFCs, and HFCs) and many nonhalocarbons (e.g., hydrocarbons, carbon dioxide) are GHGs. HFOs, or unsaturated HFCs, and blends using them are being developed and promoted as low-GWP alternatives to the existing halocarbon refrigerants. HFOs are also GHGs but their GWPs are drastically lower than those of HFCs.

The energy refrigeration appliances consume is often produced from fossil fuels, which results in emission of CO₂, a contributor to global warming. This indirect effect associated with energy consumption is frequently much larger than the direct effect of refrigerant emissions. The **total equivalent warming impact (TEWI)** of an HVAC&R system is the sum of direct refrigerant emissions expressed in terms of CO₂ equivalents, and indirect emissions of CO₂ from the system's energy use over its service life (Fischer et al. 1991). Another measure is **life-cycle climate performance (LCCP)**, which includes TEWI and adds direct and indirect emissions effects associated with manufacturing the refrigerant and end-of-life disposal (ARAP 1999).

Ammonia (R-717), hydrocarbons, HCFCs, most HFCs, and HFOs have shorter atmospheric lifetimes than CFCs because they are largely destroyed in the lower atmosphere by reactions with OH

radicals. A shorter atmospheric lifetime generally results in lower ODP and GWP₁₀₀ values.

Table 3A gives values for atmospheric lifetime, ODP, and GWP₁₀₀ of refrigerants being phased out under the Montreal Protocol and of their replacements, alone or as components of blends from the IPCC (2007). Table 3B shows the latest scientific assessment values for these refrigerants and for new refrigerants developed since IPCC (2007) was published. Because HFCs do not contain chlorine or bromine, their ODP values are negligible (Ravishankara et al. 1994) and thus are shown as 0 in Tables 3A and 3B. Nonhalocarbon refrigerants listed have zero ODP and very low GWP₁₀₀.

As shown in Tables 3A and 3B, there are differences between the values stipulated for reporting under the Montreal and Kyoto protocols and the latest scientific values. These differences are not large enough to significantly alter design decisions based on the numbers in the table. All these values have rather wide error bands and may change with each assessment of the science. Changes in GWP assessments are largely dominated by changes in understanding of CO₂, which is the reference chemical.

Table 4 provides ODP values for blends based on Montreal Protocol reporting values of the component fluids (Table 3A). It also gives IPCC (2007, 2013) GWP₁₀₀ values based on component fluid values in Tables 3A and 3B, respectively.

Table 3B Refrigerant Environmental Properties

Refrigerant	Atmospheric Lifetime, years ^a	ODP ^b	GWP ₁₀₀ ^a
CFC-11	45	1	4660
CFC-12	100	0.73	10,800
CFC-13	640	1	13,900
CFC-113	85	0.81	5820
CFC-114	190	0.50	8590
CFC-115	1020	0.26	7670
HCFC-22	11.9	0.034	1760
HCFC-123	1.3	0.01	79
HCFC-124	5.9	0.02	527
HCFC-142b	17.2	0.057	1980
HCFO-1233zd(E)	0.071	0.00034	1
HE-E170	0.015 ^b	0.00	1 ^b
HFC-23	222	0.00	12,400 (11,700) ^c
HFC-32	5.2	0.00	677 (650) ^c
HFC-125	28.2	0.00	3170 (2800) ^c
HFC-134a	13.4	0.00	1300 (1300) ^c
HFC-143a	47.1	0.00	4800 (3800) ^c
HFC-152a	1.5	0.00	138 (140) ^c
HFC-227ea	38.9	0.00	3350 (2900) ^c
HFC-236fa	242	0.00	8060 (6300) ^c
HFC-245fa	7.7	0.00	858
HFO-1234yf	0.029	0.00	<1
HFO-1234ze(E)	0.045	0.00	<1
HFO-1336mzz(Z)	0.07	0.00	2
PFC-116	10,000	0.00	11,100 (9200) ^c
PFC-218	2600	0.00	8900 (7000) ^c
C318	3200	0.00	9540 (8700) ^c
HC-290	0.034 ^b	0.00	5 ^b
HC-600		0.00	4 ^b
HC-600a	0.016 ^b	0.00	~20 ^b
HC-601a	0.009 ^b	0.00	~20 ^b
HC-1270	0.001 ^b	0.00	1.8 ^b
R-717		0.00	
R-744		0.00	1 (1) ^c

Sources: IPCC (2013).

^aAtmospheric lifetimes and GWP₁₀₀s from IPCC (2013) except where indicated.

^bFrom Table 2-7 of Calm et al. (2015)

^cGWP₁₀₀ values stipulated for reporting under Kyoto Protocol from Table 2-5 of Calm et al. (2015).

Table 3A Refrigerant Environmental Properties

Refrigerant	Atmospheric Lifetime, years ^a	ODP ^b	GWP ₁₀₀ ^a
CFC-11	45	1	4750
CFC-12	100	1	10,900
CFC-13	640	1	14,400
CFC-113	85	0.8	6130
CFC-114	300	1	10,000
CFC-115	1700	0.6	7370
HCFC-22	12	0.055	1810
HCFC-123	1.3	0.02	77
HCFC-124	5.8	0.022	609
HCFC-142b	17.9	0.065	2310
HFC-23	270	0	14,800
HFC-32	4.9	0	675
HFC-125	29	0	3500
HFC-134a	14	0	1430
HFC-143a	52	0	4470
HFC-152a	1.4	0	124
HFC-227ca	34.2	0	3220
HFC-236fa	240	0	9810
HFC-245fa	7.6	0	1030
PFC-116	10,000	0	12,200
PFC-218	2600	0	8830
C318	3200	0.00	10,300
R-744		0.00	1

Sources: IPCC (2007), UNEP (2009).

^aAtmospheric lifetimes and GWP₁₀₀s from Table 2.14 of IPCC (2007).

^bODP values stipulated for reporting under the Montreal Protocol from UNEP (2009), Section 1.1, Annexes A, B, and C, pp. 25-27.

Table 4 Environmental Properties of Refrigerant Blends; based on Montreal Protocol Reporting ODP and IPCC AR4 and AR5 GWP₁₀₀ of Components

Refrigerant	ODP*	GWP ₁₀₀ *		Refrigerant	ODP*	GWP ₁₀₀ *	
		AR4	AR5			AR4	AR5
401A	0.02	1180	1130	428A	0.00	3610	3120
401B	0.03	1290	1240	429A	0.00	19	20
401C	0.02	933	876	430A	0.00	99	110
402A	0.01	2790	2570	431A	0.00	38	44
402B	0.02	2420	2260	432A	0.00	2	2
403A	0.03	3120	3100	433A	0.00	3	4
403B	0.02	4460	4460	433B	0.00	3	5
404A	0.00	3920	3940	433C	0.00	3	4
405A	0.02	5330	4970	434A	0.00	3250	3080
406A	0.04	1940	1780	435A	0.00	26	28
407A	0.00	2110	1920	436A	0.00	11	12
407B	0.00	2800	2550	436B	0.00	11	12
407C	0.00	1770	1620	437A	0.00	1810	1640
407D	0.00	1630	1490	438A	0.00	2260	2060
407E	0.00	1550	1420	439A	0.00	1980	1830
407F	0.00	1820	1670	440A	0.00	144	156
408A	0.02	3150	3260	441A	0.00	5	5
409A	0.03	1580	1480	442A	0.00	1890	1750
409B	0.03	1560	1470	443A	0.00	2.5	4
410A	0.00	2090	1920	444A	0.00	93	89
410B	0.00	2230	2050	444B	0.00	296	295
411A	0.03	1600	1560	445A	0.00	135	118
411B	0.03	1710	1660	446A	0.00	461	461
412A	0.04	2290	2170	447A	0.00	584	572
413A	0.00	2050	1950	448A	0.00	1390	1360
414A	0.03	1480	1380	449A	0.00	1400	1280
414B	0.03	1360	1270	449B	0.00	1410	1300
415A	0.03	1510	1470	450A	0.00	605	547
415B	0.009	546	544	451A	0.00	150	133
416A	0.008	1080	975	451B	0.00	164	146
417A	0.00	2350	2130	452A	0.00	2140	1950
417B	0.00	3030	2740	453A	0.00	1770	1640
418A	0.03	1740	1690	454A	0.00	239	238
419A	0.00	2970	2690	454B	0.00	466	467
420A	0.007	1540	1380	500	0.50	8080	8010
421A	0.00	2630	2380	501	0.29	4080	4020
421B	0.00	3190	2890	502	0.20	4660	4790
422A	0.00	3140	2850	503	0.60	14,600	13,300
422B	0.00	2530	2290	504	0.10	4140	4300
422C	0.00	3090	2800	507A	0.00	3990	3990
422D	0.00	2730	2470	508A	0.00	13,200	11,600
423A	0.00	2280	2270	508B	0.00	13,400	11,700
424A	0.00	2440	2210	509A	0.01	5740	5760
425A	0.00	1510	1430	510A	0.00	3	3
426A	0.00	1510	1370	511A	0.00	3	5
427A	0.00	2140	2020	512A	0.00	189	196
				513A	0.00	631	573

*Derived based on weighted averages of blend component values.
AR4 = IPCC (2007) AR5 = IPCC (2013)

Physical Properties

Table 5 lists some physical properties of commonly used refrigerants, a few very-low-boiling-point cryogenic fluids, some newer refrigerants, and some older refrigerants of historical interest, arranged in increasing order of atmospheric boiling point.

Table 5 also includes the freezing point, critical properties, and refractive index. Of these properties, normal boiling point is most important because it is a direct indicator of the temperature 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 for pure fluids. 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 (e.g., cycles using carbon dioxide) are also possible.

Lithium Bromide/Water and Ammonia/Water Solutions. These are the most commonly used working fluids in absorption refrigeration systems. (See Chapter 30 for property data.)

Electrical Properties

Tables 6 and 7 list electrical characteristics of refrigerants that are especially important in hermetic systems.

Sound Velocity

The practical velocity of a gas in piping or through openings is limited by the velocity of sound in the gas. Chapter 30 has sound velocity data for many refrigerants. The velocity increases when temperature is increased and decreases when pressure is increased. REFPROP software (NIST 2010) can be used to calculate the sound velocity at superheated conditions. The velocity of sound can be calculated from the equation

$$V_a = \sqrt{g_c (dp/d\rho)_S} = \sqrt{\gamma g_c (dp/d\rho)_T} \quad (1)$$

where

V_a = sound velocity, ft/s

g_c = gravitational constant = 32.1740 lb_m·ft/lb_f·s²

p = pressure, lb_f/ft²

ρ = density, lb_m/ft³

$\gamma = c_p/c_v$ = ratio of specific heats

S = entropy, Btu/lb·°R

T = temperature, °R

Sound velocity can be estimated from tables of thermodynamic properties. Change in pressure with a change in density ($dp/d\rho$) can be estimated at either constant entropy or constant temperature. It is simpler to estimate at constant temperature, but the ratio of specific heats must also be known.

2. REFRIGERANT PERFORMANCE

Chapter 2 describes several methods of calculating refrigerant performance, and Chapter 30 includes tables of thermodynamic properties of refrigerants.

Table 8 shows the theoretical calculated performance of a number of refrigerants for a standard cycle of various evaporation temperatures and 86°F condensation. For blend refrigerants, the average temperature in the evaporator and condenser is used. In most cases, suction vapor is assumed to be saturated, and compression is assumed adiabatic or at constant entropy. For R-113 and R-600a, for example, these assumptions cause some liquid in the discharge vapor. In these cases, it is assumed that discharge vapor is saturated and that suction vapor is slightly superheated. Note that actual operating conditions and performance may differ significantly from numbers in the table because of additional factors such as compressor efficiency and transport properties.

3. SAFETY

Tables 1 and 2 summarize 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 letter designates toxicity class based on allowable exposure:

- Class A: Refrigerants that have an occupational exposure limit (OEL) of 400 ppm or greater.
- Class B: Refrigerants that have an OEL of less than 400 ppm.