## CHAPTER 29

# REFRIGERANTS

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, and compatibility with compressor lubricants and equipment materials 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.

## 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 results 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 2003, 2006). U.S. regulations for CFC and HCFC refrigerants, including phaseout schedules, may be found at http://www.epa.gov/ozone/strathome.html. The Alliance for Responsible Atmospheric Policy (http://www.arap.org/regs/) also briefly summarizes regulations for several countries. Reclaimed CFC and HCFC refrigerants that meet the requirements of ARI *Standard* 700 can continue to be used for servicing existing systems.

**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 carbon dioxide ($CO_2$) 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 $CO_2$ released to the atmosphere when fossil fuels (coal, oil, and natural gas) are burned for energy. Methane ($CH_4$), nitrous oxide ($N_2O$), CFCs, HCFCs, HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$) 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 IPCC (2007a), atmospheric concentration of carbon dioxide has increased by more than 35% over the past 250 years, primarily from burning fossil fuels, with some contribution from deforestation. Concentration of methane has increased by over 145%, and nitrous oxide by about 18%. IPCC (2007a) deems atmospheric concentrations of fluorochemicals, including fluorocarbon gases (CFCs, HCFCs, and HFCs) and sulfur hexafluoride, to be a smaller contributor to global climate change. On whether observed warming is attributable to human influence, IPCC (2007b) concludes that "Most of the observed increase in global averaged temperatures since the mid-twentieth century [about 1.2°F] is very likely [90% confident] due to the observed increase in anthropogenic greenhouse gas concentrations."

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

**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 | $CCl_3F$ | 137.4 | 75 | A1 |
| 12 | Dichlorodifluoromethane | $CCl_2F_2$ | 120.9 | –20 | A1 |
| 12B1 | Bromochlorodifluoromethane | $CBrClF_2$ | 165.4 | 25 | |
| 13 | Chlorotrifluoromethane | $CClF_3$ | 104.5 | –115 | A1 |
| 14 | Tetrafluoromethane (carbon tetrafluoride) | $CF_4$ | 88.0 | –198 | A1 |
| 21 | Dichlorofluoromethane | $CHCl_2F$ | 102.9 | 48 | B1 |
| 22 | Chlorodifluoromethane | $CHClF_2$ | 86.5 | –41 | A1 |
| 23 | Trifluoromethane | $CHF_3$ | 70.0 | –116 | A1 |
| 30 | Dichloromethane (methylene chloride) | $CH_2Cl_2$ | 84.9 | 104 | B2 |
| 31 | Chlorofluoromethane | $CH_2ClF$ | 68.5 | 16 | |
| 32 | Difluoromethane (methylene fluoride) | $CH_2F_2$ | 52.0 | –62 | A2 |
| 40 | Chloromethane (methyl chloride) | $CH_3Cl$ | 50.4 | –12 | B2 |
| 41 | Fluoromethane (methyl fluoride) | $CH_3F$ | 34.0 | –109 | |
| 50 | Methane | $CH_4$ | 16.0 | –259 | A3 |
| **Ethane Series** | | | | | |
| 113 | 1,1,2-trichloro-1,2,2-trifluoroethane | $CCl_2FCClF_2$ | 187.4 | 118 | A1 |
| 114 | 1,2-dichloro-1,1,2,2-tetrafluoroethane | $CClF_2CClF_2$ | 170.9 | 38 | A1 |
| 115 | Chloropentafluoroethane | $CClF_2CF_3$ | 154.5 | –38 | A1 |
| 116 | Hexafluoroethane | $CF_3CF_3$ | 138.0 | –109 | A1 |
| 123 | 2,2-dichloro-1,1,1-trifluoroethane | $CHCl_2CF_3$ | 153.0 | 81 | B1 |
| 124 | 2-chloro-1,1,1,2-tetrafluoroethane | $CHClFCF_3$ | 136.5 | 10 | A1 |
| 125 | Pentafluoroethane | $CHF_2CF_3$ | 120.0 | –56 | A1 |
| 134a | 1,1,1,2-tetrafluoroethane | $CH_2FCF_3$ | 102.0 | –15 | A1 |
| 141b | 1,1-dichloro-1-fluoroethane | $CH_3CCl_2F$ | 117.0 | 90 | |
| 142b | 1-chloro-1,1-difluoroethane | $CH_3CClF_2$ | 100.5 | 14 | A2 |
| 143a | 1,1,1-trifluoroethane | $CH_3CF_3$ | 84.0 | –53 | A2 |
| 152a | 1,1-difluoroethane | $CH_3CHF_2$ | 66.0 | –13 | A2 |
| 170 | Ethane | $CH_3CH_3$ | 30.0 | –128 | A3 |
| **Ethers** | | | | | |
| E170 | Dimethyl ether | $CH_3OCH_3$ | 46.0 | –13 | A3 |
| **Propane Series** | | | | | |
| 218 | Octafluoropropane | $CF_3CF_2CF_3$ | 188.0 | –35 | A1 |
| 236fa | 1,1,1,3,3,3-hexafluoropropane | $CF_3CH_2CF_3$ | 152.0 | 29 | A1 |
| 245fa | 1,1,1,3,3-pentafluoropropane | $CF_3CH_2CHF_2$ | 134.0 | 59 | B1 |
| 290 | Propane | $CH_3CH_2CH_3$ | 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 | $CH_3CH_2CH_2CH_3$ | 58.1 | 31 | A3 |
| 600a | Isobutane | $CH(CH_3)_2CH_3$ | 58.1 | 11 | A3 |
| 601 | Pentane | $CH_3(CH_2)_3CH_3$ | 72.15 | 97 | A3 |
| 601a | Isopentane | $(CH_3)_2CHCH_2CH_3$ | 72.15 | 82 | A3 |
| **Oxygen Compounds** | | | | | |
| 610 | Ethyl ether | $CH_3CH_2OCH_2CH_3$ | 74.1 | 94 | |
| 611 | Methyl formate | $HCOOCH_3$ | 60.0 | 89 | B2 |
| **Sulfur Compounds** | | | | | |
| 620 | (Reserved for future assignment) | | | | |
| **Nitrogen Compounds** | | | | | |
| 630 | Methyl amine | $CH_3NH_2$ | 31.1 | 20 | |
| 631 | Ethyl amine | $CH_3CH_2(NH_2)$ | 45.1 | 62 | |
| **Inorganic Compounds** | | | | | |
| 702 | Hydrogen | $H_2$ | 2.0 | –423 | A3 |
| 704 | Helium | $He$ | 4.0 | –452 | A1 |
| 717 | Ammonia | $NH_3$ | 17.0 | –28 | B2 |
| 718 | Water | $H_2O$ | 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 | $N_2O$ | 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 |
| 1270 | Propene (propylene) | $CH_3CH{=}CH_2$ | 42.1 | –54 | A3 |

*Source*: ANSI/ASHRAE *Standard* 34-2007.

[a] Chemical name, chemical formula, molecular mass, and normal boiling point are not part of this standard.

[b] Preferred chemical name is followed by the popular name in parentheses.

[c] Sublimes.

Table 2 Data and Safety Classifications for Refrigerant Blends

| Refrigerant Number | Composition (Mass %) | Composition Tolerances | Azeotropic Temperature, °F | Molecular Mass[a] | Normal Boiling Point, °F | Safety Group |
|---|---|---|---|---|---|---|
| **Zeotropes** | | | | | | |
| 400 | R-12/114 (must be specified) | | none | | | A1 |
| 401A | R-22/152a/124 (53.0/13.0/34.0) | (±2/+0.5,–1.5/±1) | | | | A1 |
| 401B | R-22/152a/124 (61.0/11.0/28.0) | (±2/+0.5,–1.5/±1) | | | | A1 |
| 401C | R-22/152a/124 (33.0/15.0/52.0) | (±2/+0.5,–1.5/±1) | | | | A1 |
| 402A | R-125/290/22 (60.0/2.0/38.0) | (±2/±0.1,–1/±2) | | | | A1 |
| 402B | R-125/290/22 (38.0/2.0/60.0) | (±2/±0.1,–1/±2) | | | | A1 |
| 403A | R-290/22/218 (5.0/75.0/20.0) | (+0.2,–2/±2/±2) | | | | A1 |
| 403B | R-290/22/218 (5.0/56.0/39.0) | (+0.2,–2/±2/±2) | | | | A1 |
| 404A | R-125/143a/134a (44.0/52.0/4.0) | (±2/±1/±2) | | | | A1 |
| 405A | R-22/152a/142b/C318 (45.0/7.0/5.5/42.5) | (±2/±1/±1/±2) | | | | |
| 406A | R-22/600a/142b (55.0/4.0/41.0) | (±2/±1/±1) | | | | A2 |
| 407A | R-32/125/134a (20.0/40.0/40.0) | (±2/±2/±2) | | | | A1 |
| 407B | R-32/125/134a (10.0/70.0/20.0) | (±2/±2/±2) | | | | A1 |
| 407C | R-32/125/134a (23.0/25.0/52.0) | (±2/±2/±2) | | | | A1 |
| 407D | R-32/125/134a (15.0/15.0/70.0) | (±2/±2/±2) | | | | A1 |
| 407E | R-32/125/134a (25.0/15.0/60.0) | (±2,±2,±2) | | | | A1 |
| 408A | R-125-143a-22 (7.0/46.0/47.0) | (±2/±1/±2) | | | | A1 |
| 409A | R-22/124/142b (60.0/25.0/15.0) | (±2/±2/±1) | | | | A1 |
| 409B | R-22/124/142b (65.0/25.0/10.0) | (±2/±2/±1) | | | | A1 |
| 410A | R-32/125 (50.0/50.0) | (+0.5,–1.5/+1.5,–0.5) | | | | A1 |
| 410B | R-32/125 (45.0/55.0) | (±1/±1) | | | | A1 |
| 411A | R-1270/22/152a (1.5/87.5/11.0) | (+0,–1/+2,–0/+0,–1) | | | | A2 |
| 411B | R-1270/22/152a (3.0/94.0/3.0) | (+0,–1/+2,–0/+0,–1) | | | | A2 |
| 412A | R-22/218/142b (70.0/5.0/25.0) | (±2/±1/±1) | | | | A2 |
| 413A | R-218/134a/600a (9.0/88.0/3.0) | (±1/±2/±0,–1) | | | | A2 |
| 414A | R-22/124/600a/142b (51.0/28.5/4.0/16.5) | (±2/±2/±0.5/±0.5,–1) | | | | A1 |
| 414B | R-22/124/600a/142b (50.0/39.0/1.5/9.5) | (±2/±2/±0.5/±0.5,–1) | | | | A1 |
| 415A | R-22/152a (82.0/18.0) | (±1/±1) | | | | A2 |
| 415B | R-22/152a (25.0/75.0) | (±1/±1) | | | | A2 |
| 416A | R-134a/124/600 (59.0/39.5/1.5) | (+0.5,–1/+1,–0.5/+1,–0.2) | | | | A1 |
| 417A | R-125/134a/600 (46.6/50.0/3.4) | (±1/±1/±0.1,–0.4) | | | | A1 |
| 418A | R-290/22/152a (1.5/96.0/2.5) | (±0.5/±1/±0.5 | | | | A2 |
| 419A | R-125/134a/E170 (77.0/19.0/4.0) | (±1/±1/±1) | | | | A2 |
| 420A | R-134a/142b (88.0/12.0) | (±1,–0,+0,–1) | | | | A1 |
| 421A | R-125/134a (58.0/42.0) | (±1/ ±1) | | | | A1 |
| 421B | R125/134a (85.0/15.0) | (±1/±1) | | | | A1 |
| 422A | R-125/134a/600a (85.1/11.5/3.4) | (±1/ ±1/+0.1,–0.4) | | | | A1 |
| 422B | R-125/134a/600a (55.0/42.0/3.0) | (±1/ ±1/+0.1,–0.5) | | | | A1 |
| 422C | R-125/134a/600a (82.0/15.0/3.0) | (±1/ ±1/+0.1,–0.5) | | | | A1 |
| 423A | R-134a/227ea (52.5/47.5) | (±1/±1) | | | | A1 |
| 424A | R-125/134a/600a/600/601a (50.5/47.0/0.9/1.0/0.6) | (±1/ ±1/+0.1,–0.2/+0.1, –0.2/+0.1,–0.2) | | | | A1 |
| 425A | R-32/134a/227ea (18.5/69.5/12.0) | (±0.5/±0.5/±0.5) | | | | 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) | | | | A1 |
| 427A | R-32/125/143a/134a (15.0/25.0/10.0/50.0) | (±2/ ±2/±2/ ±2) | | | | 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) | | | | A1 |
| **Azeotropes[b]** | | | | | | |
| 500 | R-12/152a (73.8/26.2) | | 32 | 99.3 | –27 | A1 |
| 501 | R-22/12 (75.0/25.0)[c] | | –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)[c] | | 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 |

*Source*: ANSI/ASHRAE *Standard* 34-2007.

[a] Molecular mass and normal boiling point are not part of this standard.

[b] Azeotropic 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.

[c] Exact composition of this azeotrope is in question, and additional experimental studies are needed.

[d] R-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.

**Global Environmental Characteristics of Refrigerants.** Atmospheric release of CFC and HCFC refrigerants such as R-11, R-12, R-22, and R-502 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 that of R-11 which is 1.0.

Halocarbons (CFCs, HCFCs, and HFCs) and many nonhalocarbons (e.g., hydrocarbons, carbon dioxide) are also greenhouse gases. The **global warming potential (GWP)** of a GHG is an index describing its relative ability to trap radiant energy compared to CO$_2$ (R-744), which has a very long atmospheric lifetime. GWP may be calculated for any particular **integration time horizon (ITH)**. Typically, a 100 year ITH is used for regulatory purposes, and may be designated as GWP$_{100}$.

The energy refrigeration appliances consume is often produced from fossil fuels, which results in emission of CO$_2$, 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 CO$_2$ equivalents, and indirect emissions of CO$_2$ from the system's energy use over its service life. Another measure is **life-cycle climate performance (LCCP)**, which includes TEWI and adds direct and indirect emissions effects associated with manufacturing the refrigerant.

Ammonia (R-717), hydrocarbons, HCFCs, and most HFCs 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 GWP$_{100}$ values. Environmentally preferred refrigerants (1) have low or zero ODP, (2) have relatively short atmospheric lifetimes, (3) have low GWP$_{100}$, (4) provide good system efficiency, (5) have appropriate safety properties, and (6) yield a low TEWI or LCCP in system applications (i.e., leaks are minimized or prevented, and performance is optimized).

**Table 3 Refrigerant Environmental Properties**

| Refrigerant | Atmospheric Lifetime, years[a] | ODP[b] | GWP$_{100}$[c] |
|---|---|---|---|
| R-11 | 45 | 1 | 4750 |
| R-12 | 100 | 1 | 10,900 |
| R-13 | 640 | 1 | 14,400 |
| R-22 | 12 | 0.055 | 1810 |
| R-23 | 270 | 0 | 14,800 |
| R-32 | 4.9 | 0 | 675 |
| R-113 | 85 | 0.8 | 6130 |
| R-114 | 300 | 1 | 10,000 |
| R-115 | 1700 | 0.6 | 7370 |
| R-116 | 10,000 | 0 | 12,200 |
| R-123 | 1.3 | 0.02 | 77 |
| R-124 | 5.8 | 0.022 | 609 |
| R-125 | 29 | 0 | 3500 |
| R-134a | 14 | 0 | 1430 |
| R-141b | 9.3 | 0.11 | 725 |
| R-142b | 17.9 | 0.065 | 2310 |
| R-143a | 52 | 0 | 4470 |
| R-152a | 1.4 | 0 | 124 |
| R-218 | 2600 | 0 | 8830 |
| R-227ea | 34.2 | 0 | 3220 |
| R-236fa | 240 | 0 | 9810 |
| R-245ca | 6.2[d] | 0 | 693[d] |
| R-245fa | 7.6 | 0 | 1030 |
| R-C318 | 3200 | 0 | 10,300 |
| R-744 | Variable | 0 | 1 |
| R-290 | 0.41[d] | 0 | ~20[d] |
| R-600 | 0.018[d] | 0 | ~20[d] |
| R-600a | 0.019[d] | 0 | ~20[d] |
| R-601a | 0.01[d] | 0 | ~20[d] |
| R-717 | 0.01[d] | 0 | <1[d] |
| R-1270 | 0.001[d] | 0 | ~20[d] |

[a] Atmospheric lifetimes from Table 2.14 of IPCC (2007b) except where indicated.
[b] ODP from UNEP (2006), Section 1.1, Annexes A, B, and C, pp. 23-25.
[c] GWP$_{100}$ from Table 2.14 of IPCC (2007b) except where indicated.
[d] Calm and Hourahan (2007).

Table 3 shows atmospheric lifetime, ODP, and GWP$_{100}$ of refrigerants being phased out under the Montreal Protocol and of refrigerants being used to replace them, alone or as components of blends. Because HFCs do not contain chlorine or bromine, their ODP values are negligible (Ravishankara et al. 1994) and thus are shown as 0 in Table 3. Nonhalocarbon refrigerants listed have zero ODP and very low GWP$_{100}$.

There are some differences between the values stipulated for reporting under the Montreal and Kyoto protocols and the latest scientific values. These are not of sufficient magnitude 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 CO$_2$, which is the reference chemical.

Table 4 shows the calculated ODPs and GWP$_{100}$s for refrigerant blends, using the latest scientific assessment values as reported in Calm and Hourahan (2007).

## 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. These refrigerants are 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

**Table 4 Environmental Properties of Refrigerant Blends**

| Refrigerant Number | ODP* | GWP$_{100}$* | Refrigerant Number | ODP* | GWP$_{100}$* |
|---|---|---|---|---|---|
| 401A | 0.033 | 1200 | 415B | 0.013 | 550 |
| 401B | 0.036 | 1300 | 416A | 0.008 | 1100 |
| 401C | 0.027 | 930 | 417A | 0.000 | 2300 |
| 402A | 0.019 | 2800 | 418A | 0.048 | 1700 |
| 402B | 0.030 | 2400 | 419A | 0 | 3000 |
| 403A | 0.038 | 3100 | 420A | 0.008 | 1500 |
| 403B | 0.028 | 4500 | 421A | 0 | 2600 |
| 404A | 0 | 3900 | 421B | 0 | 3200 |
| 405A | 0.026 | 5300 | 422A | 0 | 3100 |
| 406A | 0.056 | 1900 | 422B | 0 | 2500 |
| 407A | 0 | 2100 | 422C | 0 | 3100 |
| 407B | 0 | 2800 | 422D | 0 | 2700 |
| 407C | 0 | 1800 | 423A | 0 | 2300 |
| 407D | 0 | 1600 | 424A | 0 | 2400 |
| 407E | 0 | 1600 | 425A | 0 | 1500 |
| 408A | 0.024 | 3200 | 426A | 0 | 1500 |
| 409A | 0.046 | 1600 | 427A | 0 | 2100 |
| 409B | 0.045 | 1600 | 428A | 0 | 3600 |
| 410A | 0 | 2100 | 500 | 0.738 | 8100 |
| 411A | 0.044 | 1600 | 502 | 0.250 | 4700 |
| 411B | 0.047 | 1700 | 503 | 0.599 | 15,000 |
| 412A | 0.053 | 2300 | 507A | 0 | 4000 |
| 413A | 0 | 2100 | 508A | 0 | 13,000 |
| 414A | 0.043 | 1500 | 508B | 0 | 13,000 |
| 414B | 0.039 | 1400 | 509A | 0.022 | 5700 |
| 415A | 0.028 | 1500 | | | |

*ODPs and GWP$_{100}$s from Calm and Hourahan (2007), computed based on mass-weighted averages of values for individual components.

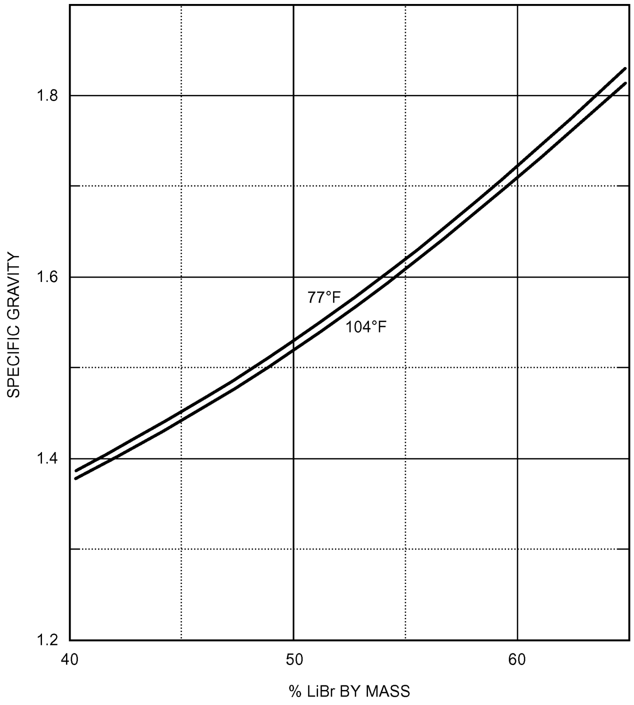

**Fig. 1 Specific Gravity of Aqueous Solutions of Lithium Bromide**

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 (such as 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. Figure 1 shows gravity, Figure 2 shows specific heat, and Figure 3 shows viscosity of lithium bromide/water solutions. Chapter 30 has an enthalpy-concentration diagram and a vapor pressure diagram for lithium bromide/water solutions. Chapter 30 also has equilibrium properties of water/ammonia solutions.

## Electrical Properties

Tables 6 and 7 list the 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.

Table 8 gives examples of the velocity of sound in the vapor phase of various refrigerants. Chapter 30 has sound velocity data for many refrigerants. The velocity increases when temperature is increased and decreases when pressure is increased. The velocity of sound can be calculated from the equation

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

*where*

$V_a$ = sound velocity, ft/s
$g_c$ = gravitational constant = 32.1740 $\mathrm{lb_m \cdot ft/lb_f \cdot s^2}$
$p$ = pressure, $\mathrm{lb_f/ft^2}$
$\rho$ = density, $\mathrm{lb_m/ft^3}$
$\gamma$ = $c_p/c_v$ = ratio of specific heats
$S$ = entropy, Btu/lb·°R
$T$ = temperature, °R

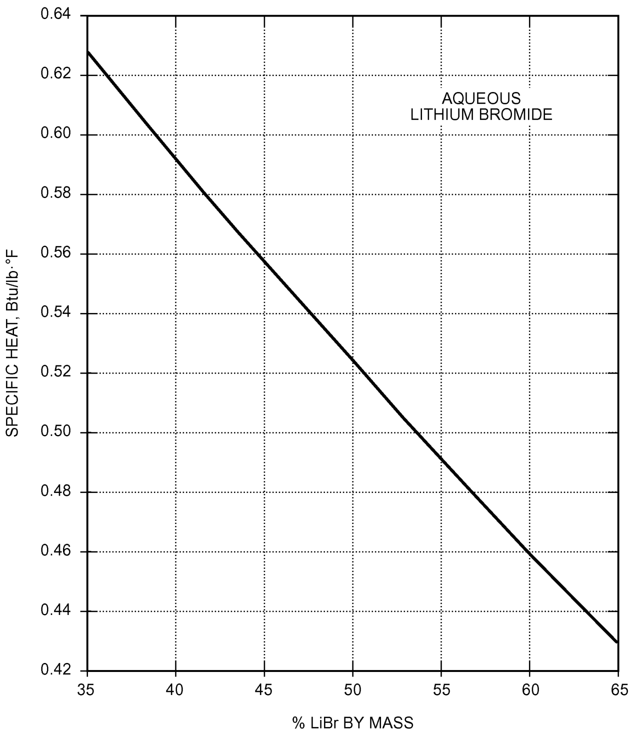

**Fig. 2 Specific Heat of Aqueous Lithium Bromide Solutions**

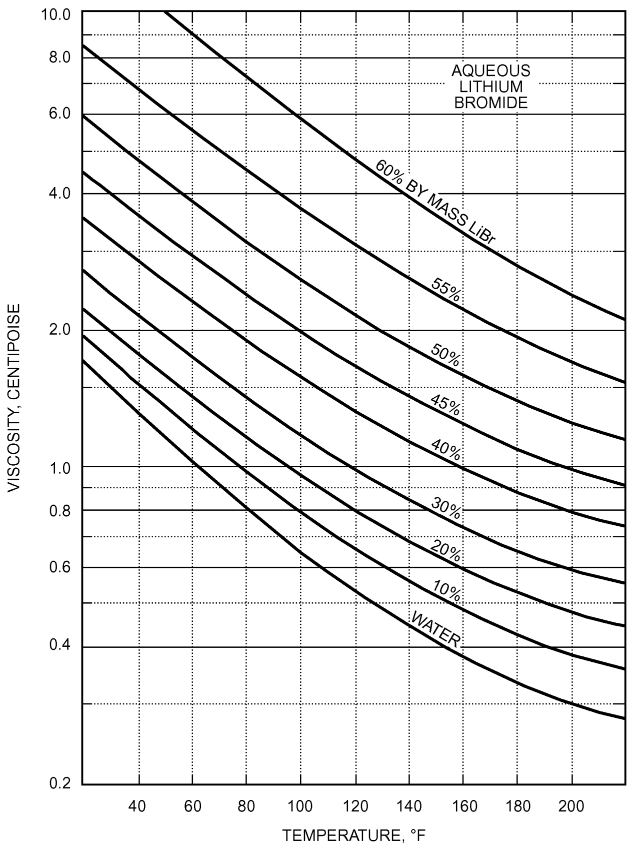

**Fig. 3 Viscosity of Aqueous Solutions of Lithium Bromide**

**Table 5 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 Temperature, °F | Critical Pressure, psi | Critical Density, $lb/ft^3$ | Refractive Index of Liquid[b,c] |
| 728 | Nitrogen | $N_2$ | 28.013 | –320.44 | –346 | –232.528 | 492.5 | 19.56 | 1.205 (83 K) 589.3 nm |
| 729 | Air | — | 28.959 | –317.65 | — | –221.062 | 549.6 | 20.97 | — |
| 740 | Argon | Ar | 39.948 | –302.53 | –308.812 | –188.428 | 705.3 | 33.44 | 1.233 (84 K) 589.3 nm |
| 732 | Oxygen | $O_2$ | 31.999 | –297.328 | –361.822 | –181.426 | 731.4 | 27.23 | 1.221 (92 K) 589.3 nm |
| 50 | Methane | $CH_4$ | 16.043 | –258.664 | –296.428 | –116.6548 | 667.1 | 10.15 | — |
| 14 | Tetrafluoromethane | $CF_4$ | 88.005 | –198.49 | –298.498 | –50.152 | 543.9 | 39.06 | — |
| 170 | Ethane | $C_2H_6$ | 30.07 | –127.4764 | –297.01 | 89.924 | 706.6 | 12.87 | — |
| 503 | R-23/13 (40.1/59.9) | — | 87.247 | –125.968 | — | 65.1506 | 620.8 | 35.31 | — |
| 508A[4] | R-23/116 (39/61) | — | 100.1 | –125.02 | — | 50.346 | 529.5 | 35.43 | — |
| 508B[4] | R-23/116 (46/54) | — | 95.394 | –124.97 | — | 52.170 | 547.0 | 35.49 | — |
| 23 | Trifluoromethane | $CHF_3$ | 70.014 | –115.6324 | –247.234 | 79.0574 | 700.8 | 32.87 | — |
| 13 | Chlorotrifluoromethane | $CClF_3$ | 104.46 | –114.664 | –294.07 | 83.93 | 562.6 | 36.39 | 1.146 (25)[2] |
| 744 | Carbon dioxide | $CO_2$ | 44.01 | –109.12[d] | –69.8044[e] | 87.7604 | 1070.0 | 29.19 | 1.195 (15) |
| 504 | R-32/115 (48.2/51.8) | — | 79.249 | –72.23 | — | 143.85 | 642.3 | 31.51 | — |
| 32 | Difluoromethane | $CH_2F_2$ | 52.024 | –60.9718 | –214.258 | 172.589 | 838.6 | 26.47 | — |
| 410A | R-32/125 (50/50) | — | 72.585 | –60.5974 | — | 160.4444 | 711.1 | 28.69 | — |
| 125 | Pentafluoroethane | $C_2HF_5$ | 120.02 | –54.562 | –149.134 | 150.8414 | 524.7 | 35.81 | — |
| 1270 | Propylene | $C_3H_6$ | 42.08 | –53.716 | –301.35 | 195.91 | 660.6 | 14.36 | 1.3640 (–50)[1] |
| 143a | Trifluoroethane | $CH_3CF_3$ | 84.041 | –53.0338 | –169.258 | 162.8726 | 545.5 | 26.91 | — |
| 507A | R-125/143a (50/50) | — | 98.859 | –52.1338 | — | 159.1106 | 537.4 | 30.64 | — |
| 404A | R-125/143a/134a (44/52/4) | — | 97.604 | –51.1996 | — | 161.6828 | 540.8 | 30.37 | — |
| 502 | R-22/115 (48.8/51.2) | — | 111.63 | –49.3132 | — | 178.71 | 582.6 | 35.50 | — |
| 407C | R-32/125/134a (23/25/52) | — | 86.204 | –46.5286 | — | 186.8612 | 671.5 | 30.233 | — |
| 290 | Propane | $C_3H_8$ | 44.096 | –43.805 | –305.72 | 206.13 | 616.58 | 13.76 | 1.3397 (–42) |
| 22 | Chlorodifluoromethane | $CHClF_2$ | 86.468 | –41.458 | –251.356 | 205.061 | 723.7 | 32.70 | 1.234 (25)[2] |
| 115 | Chloropentafluoroethane | $CClF_2CF_3$ | 154.47 | –38.65 | –146.92 | 175.91 | 453.8 | 38.38 | 1.221 (25)[2] |
| 500 | R-12/152a (73.8/26.2) | — | 99.303 | –28.4854 | — | 215.762 | 604.6 | 30.91 | — |
| 717 | Ammonia | $NH_3$ | 17.03 | –27.9886 | –107.779 | 270.05 | 1643.7 | 14.05[d] | 1.325 (16.5) |
| 12 | Dichlorodifluoromethane | $CCl_2F_2$ | 120.91 | –21.5536 | –250.69 | 233.546 | 599.9 | 35.27 | 1.288 (25)[2] |
| 134a | Tetrafluoroethane | $CF_3CH_2F$ | 102.03 | –14.9332 | –153.94 | 213.908 | 588.8 | 31.96 | — |
| 152a | Difluoroethane | $CHF_2CH_3$ | 66.051 | –11.2414 | –181.462 | 235.868 | 655.1 | 22.97 | — |
| 124 | Chlorotetrafluoroethane | $CHClFCF_3$ | 136.48 | 10.4666 | –326.47 | 252.104 | 525.7 | 34.96 | — |
| 600a | Isobutane | $C_4H_{10}$ | 58.122 | 10.852 | –254.96 | 274.39 | 526.34 | 14.08 | 1.3514 (–25)[1] |
| 142b | Chlorodifluoroethane | $CClF_2CH_3$ | 100.5 | 15.53 | –202.774 | 278.798 | 590.3 | 27.84 | — |
| C318 | Octafluorocyclobutane | $C_4F_8$ | 200.03 | 21.245 | –39.64 | 239.414 | 402.8 | 38.70 | |
| 600 | Butane | $C_4H_{10}$ | 58.122 | 31.118 | –216.86 | 305.564 | 550.6 | 14.23 | 1.3562 (–15)[1] |
| 114 | Dichlorotetrafluoroethane | $CClF_2CClF_2$ | 170.92 | 38.4548 | –137.47 | 294.224 | 472.4 | 36.21 | 1.294 (25) |
| 11 | Trichlorofluoromethane | $CCl_3F$ | 137.37 | 74.6744 | –166.846 | 388.328 | 639.3 | 34.59 | 1.362 (25)[2] |
| 123 | Dichlorotrifluoroethane | $CHCl_2CF_3$ | 152.93 | 82.08 | –160.87 | 362.624 | 531.1 | 34.34 | — |
| 141b | Dichlorofluoroethane | $CCl_2FCH_3$ | 116.95 | 89.69 | –154.25 | 399.83 | 610.9 | 28.63 | — |
| 113 | Trichlorotrifluoroethane | $CCl_2FCClF_2$ | 187.38 | 117.653 | –33.196 | 417.308 | 492.0 | 34.96 | 1.357 (25)[2] |
| 718[3] | Water | $H_2O$ | 18.015 | 211.9532 | 32.018 | 705.11 | 3200.1 | 20.10 | — |

*Notes*:

[a] Data from NIST (2007) REFPROP v. 8.0.

[b] Temperature of measurement (°C, unless kelvin is noted) shown in parentheses. Data from CRC (1987), unless otherwise noted.

[c] For the sodium D line.

[d] Sublimes.

[e] At 76.4 psi.

*References*:

[1] Kirk and Othmer (1956).

[2] *Bulletin* B-32A (DuPont).

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

[4] *NIST Standard Reference Database 23*, v. 7 (Lemmon et al. 2002).

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.

## REFRIGERANT PERFORMANCE

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

Table 9 shows the theoretical calculated performance of a number of refrigerants for a standard cycle of 5°F evaporation and 86°F condensation. In most cases, suction vapor is assumed to be saturated, and compression is assumed adiabatic or at constant entropy. For R-113 and R-114, 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 differ somewhat from numbers in the table because of additional factors such as compressor efficiency and transport properties.

### Table 6 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 | 63,680 | 2 |
| | | 77 | 2.5 | 90 | 3 |
| | | 77 | 2.32 | | 10 |
| 12 | Dichlorodifluoromethane | 84 | 2.13 | | 1 |
| | | a | 1.74 | 53,900 | 2 |
| | | 77 | 2.1 | >120 | 3 |
| | | 77 | 2.100 | | 4 |
| | | 77 | 2.14 | | 10 |
| 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 |
| | | 77 | 6.42 | | 10 |
| 23 | Trifluoromethane | –22 | 6.3 | | 3 |
| | | 68 | 5.51 | | 4 |
| 32 | Difluoromethane | a | 14.27 | | 6 |
| | | 77 | 14.67 | | 10 |
| 113 | Trichlorotrifluoroethane | 86 | 2.44 | | 1 |
| | | a | 1.68 | 45,490 | 2 |
| | | 77 | 2.6 | >120 | 3 |
| 114 | Dichlorotetrafluoroethane | 88 | 2.17 | | 1 |
| | | a | 1.83 | 66,470 | 2 |
| | | 77 | 2.2 | >70 | 3 |
| 123 | 2,2-dichloro-1,1,1-trifluoroethane | a | 4.50 | 14,700 | 7 |
| 124 | 2-chloro-1,1,1,2-tetrafluoroethane | 77 | 4.89 | | 10 |
| 124a | Chlorotetrafluoroethane | 77 | 4.0 | 50 | 3 |
| 125 | Pentafluoroethane | 68 | 4.94 | | 8 |
| | | 77 | 5.10 | | 10 |
| 134a | 1,1,1,2-tetrafluoroethane | a | 9.51 | 17,700 | 7 |
| | | 77 | 9.87 | | 10 |
| 143a | 1,1,1-trifluoroethane | 77 | 9.78 | | 10 |
| 236fa | 1,1,1,3,3,3-hexafluoropropane | 77 | 7.89 | | 10 |
| 245fa | 1,1,1,3,3-pentafluoropropane | 77 | 6.82 | | 10 |
| 290 | Propane | a | 1.27 | 73,840 | 2 |
| 404A | R-125/143a/134a (44/52/4) | a | 7.58 | 8450 | 9 |
| | | 77 | 8.06 | | 10 |
| 407C | R-32/125/134a (23/25/52) | a | 8.74 | 7420 | 9 |
| | | 77 | 10.21 | | 10 |
| 410A | R-32/125 (50/50) | a | 7.78 | 3920 | 9 |
| | | 77 | 5.37 | | 10 |
| 500 | R-12/152a (73.8/26.2) | a | 1.80 | 55,750 | 2 |
| 507A | R-125/143a (50/50) | a | 6.97 | 5570 | 9 |
| | | 77 | 7.94 | | 10 |
| 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.
2 Beacham and Divers (1955)
3 Eiseman (1955)
4 Fellows et al. (1991)
5 CRC (1987)
6 Bararo et al. (1997)
7 Fellows et al. (1991)
8 Pereira et al. (1999)
9 Meurer et al. (2001)
10 Gbur (2005)

### Table 7 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 |
| | | 1.01 | 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 |
| | | 1.0 | 77 | 1.0064 | | | 6 |
| 13 | Chlorotrifluoromethane | 0.5 | 84 | 1.0013 | | | 3 |
| | | 1.0 | 73 | | 1.4 | | 4 |
| 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 |
| | | 1.0 | 77 | 1.0068 | | | 6 |
| 32 | Difluoromethane | 1.0 | 77 | 1.0102 | | | 6 |
| 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 |
| 124 | 2-chloro-1,1,1,2-tetrafluoroethane | 1.0 | 77 | 1.0060 | | | 6 |
| 125 | Pentafluoroethane | 1.0 | 77 | 1.0072 | | | 6 |
| 134a | 1,1,1,2-tetrafluoroethane | 1.0 | 77 | 1.0125 | | | 6 |
| 142b | Chlorodifluoroethane | 0.93 | 81 | 1.013 | | | 3 |
| 143a | Trifluoroethane | 0.85 | 77 | 1.013 | | | 3 |
| | | 1.0 | 77 | 1.0170 | | | 6 |
| 170 | Ethane | 1.0 | 32 | 1.0015 | | | 1 |
| 236fa | 1,1,1,3,3,3-hexafluoropropane | 1.0 | 77 | 1.0121 | | | 6 |
| 245fa | 1,1,1,3,3-pentafluoropropane | 1.0 | 77 | 1.0066 | | | 6 |
| 290 | Propane | a | b | 1.009 | $440^c$ | 105.3 | 2 |
| 404A | R-125/143a/134a (44/52/4) | 1.0 | 77 | 1.0121 | | | 6 |
| 407C | R-32/125/134a (23/25/52) | 1.0 | 77 | 1.0113 | | | 6 |
| 410A | R-32/125 (50/50) | 1.0 | 77 | 1.0078 | | | 6 |
| 500 | R-12/152a (73.8/26.2) | a | b | 1.024 | $470^c$ | 76.45 | 2 |
| 507A | R-125/143a (50/50) | 1.0 | 77 | 1.0119 | | | 6 |
| 508A | R-23/116 (39/61) | a | –22 | 1.12 | | | 5 |
| | | a | 32 | 1.31 | | | 5 |
| | | 1.0 | 77 | 1.0042 | | | 6 |
| 508B | R-23/116 (46/54) | a | –22 | 1.13 | | | 5 |
| | | a | 32 | 1.34 | | | 5 |
| | | 1.0 | 77 | 1.0042 | | | 6 |
| 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 (1987)
2 Beacham and Divers (1955)
3 Fuoss (1938)
4 Charlton and Cooper (1937)
5 Data from E.I. DuPont de Nemours & Co., Inc.
6 Gbur (2005)

**Table 8 Velocity of Sound in Refrigerant Vapors**

| Refrigerant | Pressure, psia | Temperature, °F<br>50 | <br>122 | <br>212 |
|---|---|---|---|---|
| | | Velocity of Sound, ft/s | | |
| 11 | 14.5 | b | 474.1 | 512.0 |
| 12 | 14.5 | 478.8 | 512.5 | 551.0 |
| | 145.0 | b | 448.2 | 511.9 |
| | 217.6 | b | b | 487.0 |
| 22 | 14.5 | 581.0 | 619.5 | 663.5 |
| | 145.0 | b | 570.8 | 633.5 |
| | 217.6 | b | 537.3 | 615.4 |
| 23 | 14.5 | 655.6 | 696.6 | 744.0 |
| | 145.0 | 617.5 | 672.3 | 729.3 |
| | 217.6 | 593.5 | 658.3 | 721.2 |
| 32 | 14.5 | 772.6 | 821.3 | 876.1 |
| | 145.0 | 695.9 | 776.5 | 849.0 |
| | 217.6 | b | 748.6 | 833.4 |
| 113 | 14.5 | b | 392.5 | 426.5 |
| 114 | 14.5 | 387.3 | 417.3 | 450.8 |
| 123 | 14.5 | b | 440.6 | 477.2 |
| | 145.0 | b | b | b |
| | 217.6 | b | b | b |
| 124 | 14.5 | 439.5 | 472.3 | 508.9 |
| | 145.0 | b | b | 457.8 |
| | 217.6 | b | b | 422.7 |
| 134a | 14.5 | 515.8 | 552.5 | 593.8 |
| | 145.0 | b | 481.9 | 553.1 |
| | 217.6 | b | b | 527.8 |
| 143a | 14.5 | 573.3 | 612.7 | 657.6 |
| | 145.0 | b | 510.2 | 574.3 |
| | 217.6 | b | 511.8 | 599.3 |
| 404A | 14.5 | 529.5 | 566.3 | 608.2 |
| | 145.0 | b | 510.2 | 574.3 |
| | 217.6 | b | 472.2 | 554.4 |
| 407C | 14.5 | 570.4 | 609.3 | 653.5 |
| | 145.0 | b | 555.4 | 621.3 |
| | 217.6 | b | 518.8 | 602.2 |
| 410A | 14.5 | 632.7 | 674.4 | 722.0 |
| | 145.0 | 558.2 | 630.5 | 695.3 |
| | 217.6 | b | 603.0 | 679.9 |
| 502 | 14.5 | 498.7 | 533.0 | 572.3 |
| | 145.0 | b | 483.6 | 541.9 |
| | 217.6 | b | 448.5 | 523.6 |
| 507A | 14.5 | 526.0 | 572.3 | 604.1 |
| | 145.0 | b | 507.4 | 570.9 |
| | 217.6 | b | 470.3 | 551.3 |
| 508A | 14.5 | 530.4 | 492.1 | 606.1 |
| | 145.0 | 492.1 | 541.0 | 591.3 |
| | 217.6 | 468.2 | 527.1 | 583.5 |
| 508B | 14.5 | 545.4 | 581.2 | 622.6 |
| | 145.0 | 507.3 | 556.9 | 608.0 |
| | 217.6 | 483.8 | 543.1 | 600.2 |
| 600 | 14.5 | 671.2 | 721.4 | 777.0 |
| | 145.0 | b | b | 676.4 |
| | 217.6 | b | b | 595.6 |
| 600a | 14.5 | 674.5 | 723.3 | 778.1 |
| | 145.0 | b | b | 689.5 |
| | 217.6 | b | b | 624.2 |
| 717 | 14.5 | 1384.6 | 1477.8 | 1581.9 |
| | 145.0 | b | 1413.1 | 1544.3 |
| | 217.6 | b | 1370.9 | 1522.1 |
| 744 | 14.5 | 860.8 | 914.3 | 976.5 |
| | 145.0 | 833.3 | 896.4 | 965.6 |
| | 217.6 | 816.8 | 886.2 | 959.6 |

*Source*: *NIST Standard Reference Database 23*, v.7.0 (Lemmon et al. 2002)
b = Below saturation temperature.

## 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 safety classification in ASHRAE *Standard* 34 consists of a capital letter and a numeral. The capital letter designates a toxicity class based on allowable exposure:

- Class A: Toxicity has not been identified at concentrations less than or equal to 400 ppm by volume, based on data used to determine threshold limit value/time-weighted average (TLV/TWA) or consistent indices.
- Class B: There is evidence of toxicity at concentrations below 400 ppm by volume, based on data used to determine TLV/TWA or consistent indices.

The numeral denotes flammability:

- Class 1: No flame propagation in air at 70°F and 14.7 psia
- Class 2: Lower flammability limit (LFL) greater than 0.00625 $\text{lb/ft}^3$ 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 $\text{lb/ft}^3$ 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 of major importance for manufacturers and service engineers.

### Electronic Detection

Electronic detectors are widely used in 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.

### Bubble Method

The object to be tested is pressurized with air or nitrogen. A pressure corresponding to operating conditions is generally used. If possible, the object is immersed in water, and any leaks are detected by observing bubbles in the liquid. Adding a detergent to the water decreases surface tension, prevents escaping gas from clinging to the side of the object, and promotes 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 system tightness but does not locate the point of leakage.

### UV Dye Method

A stable UV-fluorescent dye is introduced into the system to be tested. Operating the system mixes the UV dye uniformly in the

**Table 9 Comparative Refrigerant Performance per Ton of Refrigeration**

| Refrigerant | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Chemical Name or Composition (% by mass) | Evaporator Pressure, psia | Condenser Pressure, psia | Compression Ratio | Net Refrigerating Effect, Btu/lb | Refrigerant Circulated, lb/min | Liquid Circulated, gal/min | Specific Volume of Suction Gas, ft$^3$/lb | Compressor Displacement, gal/min | Power Consumption, hp | Coefficient of Performance | Compressor Discharge Temp., °F |
| 170 | Ethane | 233.2 | 672.8 | 2.88 | 69.5 | 0.81 | 0.35 | 0.541 | 3.27 | 0.489 | 2.7 | 121.73 |
| 744 | Carbon dioxide | 326.9 | 1041.4 | 3.19 | 57.3 | 0.51 | 0.10 | 0.269 | 1.03 | 0.257 | 2.69 | 157.73 |
| 1270 | Propylene | 51.9 | 189.1 | 3.64 | 123.0 | 0.46 | 0.11 | 2.081 | 7.12 | 0.295 | 4.5 | 107.33 |
| 290 | Propane | 41.5 | 155.9 | 3.76 | 119.5 | 0.47 | 0.12 | 2.502 | 8.73 | 0.292 | 4.5 | 96.53 |
| 502 | R-22/115 (48.8/51.2) | 49.7 | 190.3 | 3.83 | 45.6 | 1.25 | 0.13 | 0.814 | 7.59 | 0.306 | 4.38 | 100.13 |
| 507A | R-125/143a (50/50) | 55.0 | 211.6 | 3.85 | 47.4 | 1.20 | 0.14 | 0.814 | 7.31 | 0.321 | 4.18 | 94.73 |
| 404A | R-125/143a/134a (44/52/4) | 52.9 | 206.0 | 3.89 | 49.1 | 1.16 | 0.14 | 0.860 | 7.45 | 0.318 | 4.21 | 96.53 |
| 410A | R-32/125 (50/50) | 69.3 | 271.5 | 3.92 | 72.2 | 0.77 | 0.09 | 0.873 | 5.04 | 0.298 | 4.41 | 123.53 |
| 125 | Pentafluoroethane | 58.5 | 226.4 | 3.87 | 36.7 | 1.51 | 0.16 | 0.631 | 7.12 | 0.327 | 3.99 | 87.53 |
| 22 | Chlorodifluoromethane | 42.8 | 172.2 | 4.02 | 69.9 | 0.81 | 0.08 | 1.248 | 7.58 | 0.287 | 4.66 | 127.13 |
| 12 | Dichlorodifluoromethane | 26.3 | 107.5 | 4.09 | 50.3 | 1.12 | 0.10 | 1.479 | 12.43 | 0.284 | 4.7 | 100.13 |
| 500 | R-12/152a (73.8/26.2) | 31.0 | 127.1 | 4.09 | 60.1 | 0.94 | 0.10 | 1.504 | 10.54 | 0.284 | 4.66 | 105.53 |
| 407C | R-32/125/134a (23/25/52) | 41.8 | 182.7 | 4.38 | 70.2 | 0.81 | 0.09 | 1.289 | 7.80 | 0.298 | 4.5 | 118.13 |
| 600a | Isobutane* | 12.8 | 58.5 | 4.58 | 113.5 | 0.50 | 0.11 | 6.524 | 24.30 | 0.288 | 4.62 | 85.73 |
| 134a | Tetrafluoroethane | 23.6 | 111.2 | 4.71 | 63.6 | 0.89 | 0.09 | 1.945 | 12.90 | 0.290 | 4.6 | 98.33 |
| 124 | Chlorotetrafluoroethane* | 12.8 | 64.3 | 5.03 | 50.7 | 1.11 | 0.10 | 2.741 | 22.81 | 0.287 | 4.62 | 85.73 |
| 717 | Ammonia | 34.1 | 168.5 | 4.94 | 474.3 | 0.12 | 0.02 | 8.197 | 7.34 | 0.282 | 4.76 | 209.93 |
| 600 | Butane* | 8.1 | 41.0 | 5.05 | 125.6 | 0.47 | 0.10 | 10.325 | 36.04 | 0.292 | 4.74 | 85.73 |
| 11 | Trichlorofluoromethane | 2.9 | 18.1 | 6.25 | 67.0 | 0.84 | 0.07 | 12.317 | 77.52 | 0.264 | 5.02 | 109.13 |
| 123 | Dichlorotrifluoroethane | 2.3 | 15.8 | 6.81 | 61.2 | 0.93 | 0.08 | 14.279 | 99.21 | 0.274 | 4.9 | 91.13 |
| 113 | Trichlorotrifluoroethane* | 1.0 | 7.8 | 7.71 | 52.7 | 1.04 | 0.08 | 26.940 | 209.02 | 0.268 | 4.81 | 85.73 |

*Superheat required.

**Table 10 Swelling of Elastomers in Liquid Refrigerants at Room Temperature, % Linear Swell**

| Refrigerant Number | Polyisoprene (Sulfur Cure) | Polychloroprene | Butyl Rubber | Styrene Butadiene Rubber | Nitrile Rubber | Fluoroelastomer |
|---|---|---|---|---|---|---|
| 22 | 10.2 | 6.1 | 3.9 | 9.8 | 51.4 | 33.2 |
| 123 | 48.0 | 15.3 | 16.3 | 40.8 | 83.7 | 31.6 |
| 124 | 5.8 | 2.8 | 3.2 | 4.1 | 45.9 | 29.0 |
| 142b | 10.2 | 6.5 | 6.2 | 7.3 | 8.7 | 31.8 |
| 32 | 2.7 | 1.0 | 1.0 | 2.0 | 8.3 | 23.2 |
| 125 | 4.2 | 2.7 | 2.6 | 3.6 | 3.9 | 11.7 |
| 134a | 1.2 | 1.2 | 0.6 | 1.0 | 5.1 | 25.6 |
| 143a | 1.9 | 1.2 | 1.3 | 1.5 | 2.0 | 13.6 |
| 152a | 4.2 | 3.0 | 1.7 | 2.8 | 8.8 | 3.91 |

oil/refrigerant system. The dye, which usually prefers oil, shows up at the leak's location, and can be detected using an appropriate UV lamp. Ensure that the dye is compatible with system components and that no one is exposed to UV radiation from the lamp. This method is often more effective for liquid leaks than for vapor.

Another, more expensive method is to use dispersive and nondispersive infrared analyzers. Although these analyzers are expensive, they can not only find the refrigerant leak but also identify the refrigerant.

### Ammonia Leaks

Ammonia can be detected by any of the previously described methods, or by bringing a solution of hydrochloric acid near the object. If ammonia vapor is present, a white cloud or smoke of ammonium chloride forms. Ammonia can also be detected with indicator paper that changes color in the presence of a base.

## 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 properties such 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 < 1040 steel < aluminum < bronze < brass < zinc
< silver (most decomposition)

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

Magnesium alloys and aluminum containing more than 2% magnesium are not recommended for use with halogenated compounds where even trace amounts of water may be present. Zinc is not recommended for use with CFC-113. Experience with zinc and other fluorinated compounds has been limited, but no unusual reactivity has been observed under normal conditions of use in dry systems.

Ammonia should never be used with copper, brass, or other alloys containing copper. Further discussion of the compatibility of refrigerants and lubricants with construction materials may be found in Chapter 5 of the 2006 *ASHRAE Handbook—Refrigeration*.

### Elastomers

Linear swelling of some elastomers in the liquid phase of HCFC and HFC 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 (e.g., lubricants) are present in addition to the refrigerant, the combined effect on elastomers should be determined. Extensive test data for compatibility of elastomers and gasketing materials with refrigerants and lubricants are reported by Hammed et al. (1994). Diffusion of fluids through elastomers is another consideration; Table 11 shows the diffusion rate of water and R-22 through elastomers.

**Table 11 Diffusion of Water and R-22 Through Elastomers**

| | Diffusion Rate | |
|---|---|---|
| **Elastomer** | **Water[a]** | **R-22[b]** |
| Polychloroprene | 0.717 | 1.31 |
| Nitrile rubber | 0.109 | 19.7 |
| Chlorosulfonated polyethylene | 0.457 | 0.52 |
| Butyl rubber | 0.043 | 0.30 |
| Fluoroelastomer | — | 3.61 |
| Polyethylene | 0.123 | — |
| Natural | 1.428 | — |

Adapted from Eiseman (1955).

[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 cubic feet of gas per square foot of elastomer.

## Plastics

The effect of a refrigerant on a plastic material should be thoroughly examined under conditions of intended use, including the presence of lubricants. Plastics are often mixtures of two or more basic types, and it is difficult to predict the refrigerant's effect. Swelling data can be used as a general guide of effect, but, as with elastomers, the effect on properties of the plastic should also be examined. Extensive test data for compatibility of plastics with refrigerants and lubricants are reported by Cavestri (1993), including 23 plastics, 10 refrigerants, 7 lubricants, and 17 refrigerant/lubricant combinations. Refrigerants and lubricants had little effect on most of the plastics. Three plastics (acrylonitrile-butadiene-styrene, polyphenylene oxide, and polycarbonate) were affected enough to be considered incompatible. In a separate study by DuPont Fluoroproducts, two additional plastics (acrylic and polystyrene plastics) were determined to have questionable compatibility with HCFC and HFC refrigerants.

## REFERENCES

ASHRAE. 2007. Designation and safety classification of refrigerants. ANSI/ASHRAE *Standard* 34-2004.

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.

Calm, J.M. and G.C. Hourahan. 2007. Refrigerant data update. *Heating/Piping/Air Conditioning Engineering* 79(1):50-64.

Cavestri, R.C. 1993. Compatibility of refrigerants and lubricants with engineering plastics. *Report* DOE/CE/23810-15. Air Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA.

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., Wilmington, DE.

DuPont Fluoroproducts. *Technical Information Bulletins for HFC-134a, R-407C and R-410A*. E.I. DuPont de Nemours & Co., Wilmington, DE.

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 Congrès International du Froid* 18(2). International Institute of Refrigeration, Paris.

Fuoss, R.M. 1938. Dielectric constants of some fluorine compounds. *Journal of the American Chemical Society* 64:1633.

Hammed, G.R., R.H. Seiple, and O. Taikum. 1994. Compatibility of refrigerants and lubricants with elastomers. *Report* DOE/CE/23810-14. Air Conditioning and Refrigeration Technology Institute, Arlington, VA.

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

*Handbook of chemistry and physics*, 41st ed. 1959-1960. Chemical Rubber Publishing, Cleveland, OH.

IPCC. 2007a. *Climate change 2007: Synthesis report. Contribution of working groups I, II, and III to the fourth assessment report of the Intergovernmental Panel on Climate Change*. B.P. Jallow, L. Kajfez-Bogataj, R. Bojaru, D. Hawkins, S. Diaz, H. Lee, A. Allali, I. Elgizouli, D. Wratt, O. Hohmeyer, D. Griggs, and N. Leary, eds. http:// www.ipcc.ch/ipccreports/ar4-syr.htm.

IPCC. 2007b. *Climate change 2007: The physical science basis*. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, eds. Cambridge University Press, Cambridge, U.K. http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

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

Lemmon, E.W., M.O. McLinden, and M.L. Huber. 2002. *NIST standard reference database 23*, v. 7.0. National Institute of Standards and Technology, Gaithersburg, MD.

*Matheson gas data book*. 1966. Matheson Company, East Rutherford, NJ.

Meurer C., G. Pietsch, and M. Haacke M. 2001. Electrical properties of CFC- and HCFC-substitutes. *International Journal of Refrigeration* 24(2):171-175.

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 International Workshop on Thermochemical, Thermodynamic and Transport Properties of Halogenated Hydrocarbons and Mixtures, Pisa, Italy.

Ravishankara, A.R., A.A. Turnipseed, N.R. Jensen, and R.F. Warren. 1994. Do hydrofluorocarbons destroy stratospheric ozone? *Science* 248:1217-1219.

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

U.N. 1994. *1994 report of the refrigeration, air conditioning, and heat pumps technical options committee*. United Nations Environment Programme, Nairobi, Kenya.

UNEP. 2003. *Handbook for the international treaties for the protection of the ozone layer*. United Nations Environment Programme, Nairobi, Kenya.

UNEP. 2006. *Handbook for the international treaties for the protection of the ozone layer*, 7th ed. UNEP Ozone Secretariat, Nairobi, Kenya. http://ozone.unep.org/Publications/MP_Handbook/.

## BIBLIOGRAPHY

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

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

U.N. 1996. World policy roundup. *OzonAction: The Newsletter of the United Nations Environment Programme Industry and Environment OzonAction Programme* 20(October):10.

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