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PHYSICAL, SAFETY, AND ENVIRONMENTAL DATA FOR CURRENT AND ALTERNATIVE REFRIGERANTS

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ABSTRACT

This paper summarizes key physical, safety, and environmental data for refrigerants including those widely used historically, in common use today, and under consideration for future use. The text outlines the progression through successive generations of refrigerants. Two tables, one sorted by standard designations to facilitate location of specific refrigerants and the second sorted by normal boiling points, present data for 284 refrigerants, many of them blends. The paper explains the tabulated parameters and identifies the data sources used. Additional tables contrast the latest scientific data with corresponding regulatory values. The authors have published similar summaries in the past, on approximately a four-year cycle, to support international assessments and other studies. The successive updates accommodate both new fluids and new or refined data. This version adds approximately 100 refrigerants, among them unsaturated fluorochemicals even though not yet in use except for testing by component and equipment manufacturers.

1. INTRODUCTION

More than 60 new refrigerants were commercialized for use either in new equipment or as service fluids (to maintain or convert existing equipment) in the past four years, since the preceding summary by Calm and Hourahan (2007). Of them, 21 obtained standardized designations and safety classifications while most of the remainder are marketed with only proprietary identifiers (some without public disclosure of compositions). Most of the new blends comprise hydrofluorocarbons (HFCs) or, in some cases, blends of HFCs and hydrocarbons (HCs).

Additional refrigerants, including blend components, still are being developed to enable completion of scheduled phase-outs of ozone-depleting substances (ODSs). Significant focus is on alternatives, including blend components, offering lower global warming potentials (GWPs) to address climate change. That pursuit forces more attention than in the past on flammable – primarily low-flammability – candidates. Considerable effort continues for examination of broader use of ammonia (NH_3, R-717), carbon dioxide (CO_2, R-744), and HCs as well as blends of them or them with low-GWP HFCs. Additional research seeks to increase and improve the physical, safety, and environmental data for refrigerants, to enable screening and to optimize equipment performance.

Despite the number of new introductions, approximately 20 older and new refrigerants, some of them blends, constitute the vast majority of usage on a global basis. Even this number is likely to decline to approximately 10 or 12 – excluding those for niche applications – as older equipment (using ODSs or high-GWP options) is retired or replaced and as manufacturers converge on preferred refrigerants for the future. Likewise, dependence on service fluids for retrofit equipment also will decline with retirements and replacements.

1.1. Refrigerant Progression

The historic progression of refrigerants encompasses four generations based on defining selection criteria identified by Calm (2008):

Calm JM, Hourahan GC, 2011. “Physical, Safety, and Environmental Data for Current and Alternative Refrigerants,” *Refrigeration for Sustainable Development* (proceedings of the 23rd International Congress of Refrigeration (ICR 2011, Prague, Czech Republic, 2011.08.21-26), International Institute of Refrigeration (IIR/IIF), Paris, France

- 1830s-1930s – <u>whatever worked</u>: primarily familiar solvents and other volatile fluids including ethers, carbon dioxide (CO_2, R-744), ammonia (NH_3, R-717), sulfur dioxide (SO_2, R-764), methyl formate ($HCOOCH_3$, R-611), HCs, water (H_2O, R-718), carbon tetrachloride (CCl_4, R-10), hydrochlorocarbons (HCCs), and others; many of them are now regarded as "natural refrigerants."

- 1931-1990s – <u>safety and durability</u>: primarily chlorofluorocarbons (CFCs), HCFCs, HFCs, ammonia, and water.

- 1990-2010s – <u>stratospheric ozone protection</u>: primarily HCFCs (for transition use), HFCs, ammonia, water, hydrocarbons, and carbon dioxide.

- 2011-? – <u>global warming mitigation</u>: still in determination, but likely to include refrigerants with very low or no ozone depletion potential (ODP), low global warming potential (GWP), and high efficiency; candidates include, at least initially, low-GWP HFCs, unsaturated hydrofluorochemicals (hydrofluoro-olefins, HFOs, and hydrochlorofluoro-olefins, HCFOs, discussed below), ammonia, carbon dioxide, hydrocarbons, and water.

GWP demarcation for acceptability is defined, at present, as having a GWP relative to CO_2 for 100 yr integration of 150 or less, predicated on European regulations for mobile air conditioning (EU, 2006a and 2006b). A further classification scheme proposed by the UNEP Technical and Economic Assessment Panel (2010) distinguishes between very low (or ultra-low) with GWP < ~30, very low with GWP < ~100, low with GWP < ~300, moderate with GWP < ~1000, high with GWP < ~3,000, very high with GWP < ~10,000, and ultra-high with GWP > ~10,000. The rationale for approximate rather than rigid range delimiters (for example, ~30 rather than 30 or ~10,000 rather than 10,000) is unclear.

1.2. Unsaturated Hydrofluorochemicals

Facing regulatory pressures to eliminate refrigerants with high GWPs, the major refrigerant manufacturers have aggressively pursued unsaturated fluorochemicals (Calm, 2008; Brown 2009; Leck, 2010). They are chemicals consisting of two or more carbon atoms with at least one double or triple bond between two or more of them as well as fluorine, hydrogen, and possibly also chlorine or other halogens.

Contrary to widespread perceptions, use of unsaturated compounds as refrigerants is not completely new. Two unsaturated hydrocarbons, ethylene (CH_2=CH_2, R-1150) and propylene (CH_3CH=CH_2, R-1270), have been used as refrigerants for more than half a century. Interestingly, the first refrigerants used in large chillers with turbo (centrifugal) compressors were unsaturated hydrochlorocarbons (HCCs), namely R-1130 (a blend of cis- and trans-stereoisomers of CHCl=CHCl, "dielene" as then known) and R-1120 (CHCl=CCl_2, "trielene"), introduced in 1922 and 1925, respectively (Calm and Didion, 1997). Several blends emerged in the late 1990s that incorporated R-1216 (CF_2=$CFCF_3$, hexafluoropropene), an unsaturated fluorocarbon (FC or FO) also identified as an unsaturated perfluorocarbon (PFC or PFO), though the choice was unfortunate in light of its toxicity. The renewed focus on unsaturated chemicals, primarily unsaturated fluorochemicals, seeks to minimize both the ODP and GWP of future refrigerants.

Unsaturated fluorocarbons also are identified as fluoro-olefins or more specifically as fluoro-alkenes with a double bond or fluoro-alkynes with a triple bond. The double or especially triple carbon-carbon bond(s) make(s) the compounds more reactive. That leads to rapid decomposition in the lower atmosphere, because such fluoro-alkenes and fluoro-alkynes are less stable in the presence of oxidative reactants there. Some also are subject to photolytic decomposition. The result is short atmospheric lifetime and, thereby, very low ODP and GWP. The higher reactivity also leads, in some cases, to higher toxicity, thus disqualifying some candidates. The higher molecular complexity increases production costs as do both process stringency and finishing steps to minimize associated impurities that are highly toxic or other otherwise undesirable.

The unsaturated HFC (hydrofluoro-alkene or hydrofluoro-olefin, HFO) family is a focal example. Such compounds have different extents of fluorination, selected to obtain desired properties and as a trade-off between flammability, with low fluorine content, and typically increasing GWP and cost with higher fluorine content. Chemical producers are pursuing alternatives for the most widely used low-, medium-, and high-pressure refrigerants. Among the unsaturated HFCs, various R-1225 isomers previously pursued seem abandoned predicated on toxicity findings. R-1234yf (CH_2=$CFCF_3$) in particular is being widely considered both as a single-compound refrigerant and as a blend component. Manufacturer announcements also indicate pursuit of R-1234ze(E) (CHF=$CHCF_3$), R-1243zf (CH_2=$CHCF_3$), and other R-1234 and R-1243 isomers and enantiomers. Some manufacturers are pursuing unsaturated HCFCs (also identified as hydrochlorofluoro-alkenes or hydrochlorofluoro-olefins, HCFOs), notably R-1233 isomers, to obtain similar benefits with reduced or avoided flammability, but they introduce a trade-off concern with ODP albeit still extremely low.

Opponents of unsaturated fluorochemicals argue, often vehemently, that they pose additional environmental or safety hazards not justified with existence of available "natural refrigerant" alternatives. The extent of long-term acceptability of unsaturated HFCs (HFOs) or more broadly unsaturated hydrohalochemicals is uncertain, though a number of initial studies by Papasavva *et al.* (2009), Kajihara *et al.* (2010), Luecken *et al.* (2010), and others suggest potentially tolerable environmental consequences.

2. DATA SUMMARY

Tables 1 and 2 provide summary data for refrigerants in historic or current use – among them some undergoing renewed interest for broader application – as well as candidates recently examined and/or under consideration for future use. The tables cover both single-compound refrigerants and blends, but exclude proprietary blends for which the composition (the components) and/or formulation (the component proportions) have not been disclosed.

The data presented, from left to right in the tables, are:

IDENTIFIERS

- refrigerant number, if assigned, in accordance with American Society of Heating, Refrigerating, and Air-Conditioning Engineers Standard 34 (ASHRAE, 2010a and 2010b): A revision to an international standard (ISO, 2005b and 2008) is in preparation, but not yet final, as the primary document for designation and safety criteria, but the proposed designation systems are essentially consistent.
- chemical formula, in accordance with the International Union of Pure and Applied Chemistry convention (IUPAC, 1979) or, for blends, the blend composition and formulation, the latter expressed as percentages by mass, in accordance with ASHRAE Standard 34 (ASHRAE, 2010a and 2010b)

PHYSICAL DATA

- molecular mass calculated using the updated IUPAC atomic weights (Wieser and Berglund, 2009)
- normal boiling point (NBP) or, for blends, the bubble point temperature at 101.325 kPa (14.696 psia) based for those included on REFPROP 9.0 (Lemmon *et al.*, 2010)
- critical temperature (T_C) or, for blends, the calculated pseudo-critical temperature based for those included on REFPROP 9.0 (Lemmon *et al.*, 2010)
- critical pressure (P_C) or, for blends, the calculated pseudo-critical pressure based for those included on REFPROP 9.0 (Lemmon *et al.*, 2010)

SAFETY DATA

- occupational exposure limit (OEL) in ppm v/v for an 8 (sometimes 10) hr day and 40 hr work week on a time-weighted average (TWA): They include the Threshold Limit Value (TLV) assigned by the American Conference of Governmental Industrial Hygienists (ACGIH), Workplace Environmental Exposure Level (WEEL) by the American Industrial Hygiene Association (AIHA), Recommended Exposure Limit (REL) by the U.S National Institute for Occupational Safety and Health (NIOSH), maximale Arbeitsplatz-Konzentration (MAK values) by Deutsche Forschungsgemeinschaft (DFG), OEL by the Japan Society for Occupational Health (JSOH), Permissible Exposure Limit (PEL) by the U.S. Occupational Safety and Health Administration (OSHA) though somewhat older, or a consistent limit by manufacturers or other sources if none of the preceding exist. The OEL value is preceded by a "C" for values that are ceiling limits, not to be exceeded, rather than TWA limits.

Table 1: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
10	CCl4 — carbon tetrachloride	153.82	76.7	170.1	283.3	541.9	4.56	661	5	none				26	0.820	1400
11	CCl3F	137.37	23.7	74.7	198.0	388.4	4.41	640	C1000	none	0.9	387	A1	45	1.000	4750
12B1	CBrClF2	165.36	-4.0	24.8	154.0	309.2	4.10	595		none				16	7.900	1890
12	CCl2F2	120.91	-29.8	-21.6	112.0	233.6	4.14	600	1000	none	-0.8	-344	A1	100	0.820	10900
13B1	CBrF3	148.91	-58.7	-73.7	67.1	152.8	3.97	576	1000	none			A1	65	15.900	7140
13	CClF3	104.46	-81.5	-114.7	28.9	84.0	3.88	563	1000	none	-3.0	-1290	A1	640	1.000	14400
13I1	CF3I – trifluoroiodomethane	195.91	-21.9	-7.4	123.3	253.9	3.95	573		none				0.011	0.018	1
14	CF4 – carbon tetrafluoride	88.00	-128.0	-198.4	-45.6	-50.1	3.75	544	1000	none			A1	50000	0.000	7390
20	CHCl3 – chloroform	119.38	61.2	142.2	263.4	506.1	5.38	780	10	none				0.408	0.000	30
21	CHCl2F	102.92	8.9	48.0	178.3	352.9	5.18	751	10	none			B1	1.7	0.040	151
22	CHClF2	86.47	-40.8	-41.4	96.1	205.0	4.99	724	1000	none	2.2	946	A1	11.9	0.040	1790
23	CHF3 – fluoroform	70.01	-82.0	-115.6	26.1	79.0	4.83	701	1000	none	-12.5	-5374	A1	222	0.000	14200
30	CH2Cl2 – methylene chloride	84.93	40.2	104.4	237.0	458.6	6.08	882	50	13			B2	0.394		10
31	CH2ClF	68.48	-9.1	15.6	151.8	305.2	5.13	744	0.1					1.3	0.010	
32	CH2F2 – methylene fluoride	52.02	-51.7	-61.1	78.1	172.6	5.78	838	1000	14.4	9.4	4041	A2L r	5.2	0.000	716
40B1	CH3Br – methyl bromide	94.94	4.6	40.3	194.0	381.2	5.22	757	1	10				0.8	0.660	5
40	CH3Cl – methyl chloride	50.49	-24.2	-11.6	143.1	289.6	6.67	967	50	8.0			B2	1.0	0.020	13
41	CH3F – methyl fluoride	34.03	-78.3	-108.9	44.1	111.4	5.90	856						2.8	0.000	107
50	CH4 – methane	16.04	-161.5	-258.7	-82.6	-116.7	4.60	667	1000	4.8			A3	12.0	0.000	23
112	CCl2FCCl2F	203.83	92.8	199.0	278.0	532.4	4.83	701	500	none						
112a	CCl3CClF2	203.83	91.7	197.1	279.2	534.6	4.83	701	500	none						
113	CCl2FCClF2	187.38	47.6	117.7	214.1	417.4	3.39	492	1000	none	0.1	43	A1	85	0.850	6130
114	CClF2CClF2	170.92	3.6	38.5	145.7	294.3	3.26	473	1000	none	-3.1	-1333	A1	190	0.580	9180
114a	CCl2FCF3	259.82	3.6	38.5	145.7	294.3	4.92	714						100.0		
115	CClF2CF3	154.47	-39.2	-38.6	80.0	176.0	3.13	454	1000	none	-2.1	-903	A1	1020	0.570	7230
116	CF3CF3 – perfluoroethane	138.01	-78.1	-108.6	19.9	67.8	3.05	442	1000	none			A1	10000	0.000	12200
123	CHCl2CF3	152.93	27.8	82.0	183.7	362.7	3.66	531	50	none	2.1	903	B1	1.3	0.010	77
124	CHClFCF3	136.48	-12.0	10.4	122.3	252.1	3.62	525	1000	none	0.9	387	A1	5.9	0.020	619
125	CHF2CF3	120.02	-48.1	-54.6	66.0	150.8	3.62	525	1000	none	-1.5	-645	A1	28.2	0.000	3420
E125	CHF2OCF3	136.02	-42.0	-43.6	81.3	178.3	3.35	486						119	0.000	14200
134	CHF2CHF2	102.03	-17.6	0.3	119.0	246.2	4.64	673	1000	none	4.3	1849		9.7	0.000	1110
134a	CH2FCF3	102.03	-26.1	-15.0	101.1	214.0	4.06	589	1000	none	4.2	1806	A1	13.4	0.000	1370
E134	CHF2OCHF2	118.03	5.5	41.9	147.1	296.8	4.23	614		none				24.4	0.000	5960
141b	CH3CCl2F	116.95	32.0	89.6	204.4	399.9	4.21	611	500	5.8	8.6	3697		9.2	0.120	717
142b	CH3CClF2	100.50	-9.1	15.6	137.1	278.8	4.06	589	1000	8.0	9.8	4213	A2	17.2	0.060	2220
143	CH2FCHF2	84.04	5.0	41.0	156.7	314.1	5.24	760		5.8	10.9	4686		3.5	0.000	352
143a	CH3CF3	84.04	-47.2	-53.0	72.7	162.9	3.76	545	1000	8.2	10.4	4471	A2L r	47.1	0.000	4180
E143a	CH3OCF3	100.04	-24.1	-11.4	104.9	220.8	3.63	526						4.8	0.000	840
152a	CH3CHF2	66.05	-24.0	-11.2	113.3	235.9	4.52	656	1000	4.8	17.4	7481	A2	1.5	0.000	133
160	CH3CH2Cl – ethyl chloride	64.51	13.1	55.6	187.3	369.1	5.27	764	100	3.6	20.6	8856		0.107	0.020	
160I1	CH3CH2I – iodoethane	155.97	72.4	162.3										0.011		
161	CH3CH2F – ethyl fluoride	48.06	-37.6	-35.7	102.2	216.0	5.09	738		3.8				0.18	0.000	12
170	CH3CH3 – ethane	30.07	-88.6	-127.5	32.2	90.0	4.87	706	1000	3.1			A3	0.21	0.000	~20
E170	CH3OCH3 – DME	46.07	-24.8	-12.6	127.2	261.0	5.34	775	1000	3.4	31.8	13672	A3	0.015	0.000	
218	CF3CF2CF3 – perfluoropropane	188.02	-36.8	-34.2	71.9	161.4	2.64	383	1000	none			A1	2600	0.000	8830
225ca	CHCl2CF2CF3	202.94	51.1	124.0					10					1.9	0.020	122

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Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molec-	NBP		Tc		Pc				HOC		Std 34	atmos-		
	chemical formula or blend	ular							OEL	LFL			safety	pheric life		GWP
number	composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	(PPMv)	(%)	MJ/kg	Btu/lb	group	(yr)	ODP	100 yr
225cb	CHClFCF2CClF2	202.94	56.1	133.0					200					5.9	0.030	606
227ea	CF3CHFCF3	170.03	-16.3	2.7	101.8	215.2	2.93	425	1000	none	3.3	1419	A1	38.9	0.000	3580
236cb	CH2FCF2CF3	152.04	-1.4	29.5	130.2	266.4	3.12	453						13.1	0.000	1290
236ea	CHF2CHFCF3	152.04	6.2	43.2	139.3	282.7	3.50	508	1000	none	5.4	2322		11.0	0.000	1410
236fa	CF3CH2CF3	152.04	-1.4	29.5	124.9	256.8	3.20	464	1000	none			A1	242	0.000	9820
E236fa1	CF3OCH2CF3	168.04	5.7	42.3	128.8	263.8	2.74	397						7.5	0.000	988
245ca	CH2FCF2CHF2	134.05	25.1	77.2	174.4	345.9	3.93	570		7.1	8.4	3611		6.5	0.000	726
245fa	CHF2CH2CF3	134.05	15.1	59.2	154.0	309.2	3.65	529	300	none	6.1	2623	B1	7.7	0.000	1050
E245cb1	CH3OCF2CF3	150.05	5.9	42.6	133.7	272.7	2.89	419						4.9	0.000	680
E245fa1	CHF2OCH2CF3	150.05	29.3	84.7	170.9	339.6	3.42	496						5.5	0.000	740
E254cb1	CH3OCF2CHF2	132.06	37.2	99.0										2.5	0.000	345
263fb	CH3CH2CF3	98.07	-13.0	8.6										1.2	0.000	104
C270	-CH2-CH2-CH2- – cyclopropane	42.08	-31.5	-24.7	125.2	257.4	5.58	809		2.4	49.7	21367		0.44	0.000	~20
290	CH3CH2CH3 – propane	44.10	-42.1	-43.8	96.7	206.1	4.25	616	1000	2.1	50.4	21668	A3	0.041	0.000	~20
C318	-CF2-CF2-CF2-CF2-	200.03	-6.0	21.2	115.2	239.4	2.78	403	1000	none			A1	3200	0.000	10300
329mcc	CHF2CF2CF2CF3	220.04	15.1	59.2	140.2	284.4	2.39	347		none				28.4	0.000	2530
338mcc	CH2FCF2CF2CF3	202.05	27.5	81.5	158.8	317.8	2.73	396							0.000	
338mcf	CF3CH2CF2CF3	202.05	19.9	67.8	150.6	303.1	2.50	363		none					0.000	
E338mcf2	CF3CH2OCF2CF3	218.05	27.9	82.2	148.5	299.3	2.33	338						7.5	0.000	963
E347mcc1	CH3OCF2CF2CF3	200.05	34.2	93.6	164.6	328.3	2.48	360		none				5.0	0.000	553
E347mmy1	CF3CF(OCH3)CF3	200.05	29.4	84.9	160.8	321.4	2.55	370						3.4	0.000	343
400 >>	R-12/114 (50.0/50.0) – "50/50"	141.63	-20.8	-5.4	129.1	264.4	3.94	571	1000	none			A1		0.700	10000
400 >>	R-12/114 (60.0/40.0) – "60/40"	136.94	-23.2	-9.8	125.6	258.1	4.01	582	1000	none			A1		0.724	10000
401A	R-22/152a/124 (53.0/13.0/34.0)	94.44	-32.9	-27.2	107.3	225.1	4.61	669	1000	none			A1		0.028	1200
401B	R-22/152a/124 (61.0/11.0/28.0)	92.84	-34.5	-30.1	105.6	222.1	4.69	680	1000	none	-2.7	-1161	A1		0.030	1300
401C	R-22/152a/124 (33.0/15.0/52.0)	101.03	-28.3	-18.9	111.7	233.1	4.37	634	1000	none			A1		0.024	930
402A	R-125/290/22 (60.0/2.0/38.0)	101.55	-48.9	-56.0	75.8	168.4	4.22	612	1000	none	-1.4	-602	A1		0.015	2700
402B	R-125/290/22 (38.0/2.0/60.0)	94.71	-47.0	-52.6	82.9	181.2	4.52	656	1000	none	-1.6	-688	A1		0.024	2400
403A	R-290/22/218 (5.0/75.0/20.0)	91.99	-47.7	-53.9	87.0	188.6	4.71	683	1000	wff			A2		0.030	3100
403B	R-290/22/218 (5.0/56.0/39.0)	103.26	-49.2	-56.6	79.6	175.3	4.33	628	1000	none			A1		0.022	4400
404A	R-125/143a/134a (44.0/52.0/4.0)	97.60	-46.2	-51.2	72.0	161.6	3.73	541	1000	none	-6.6	-2837	A1		0.000	3700
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5)	111.91	-32.6	-26.7	106.1	223.0	4.28	621	1000	none			d		0.021	5300
406A	R-22/600a/142b (55.0/4.0/41.0)	89.86	-32.5	-26.5	116.9	242.4	4.86	705	1000	8.2			A2		0.047	1900
407A	R-32/125/134a (20.0/40.0/40.0)	90.11	-45.0	-49.0	82.3	180.1	4.52	656	1000	none	-3.6	-1548	A1		0.000	2100
407B	R-32/125/134a (10.0/70.0/20.0)	102.94	-46.5	-51.7	75.0	167.0	4.13	599	1000	none	-1.8	-774	A1		0.000	2700
407C	R-32/125/134a (23.0/25.0/52.0)	86.20	-43.6	-46.5	86.0	186.8	4.63	672	1000	none	-4.9	-2107	A1		0.000	1700
407D	R-32/125/134a (15.0/15.0/70.0)	90.96	-39.2	-38.6	91.4	196.5	4.47	648	1000	none	-4.3	-1849	A1		0.000	1600
407E	R-32/125/134a (25.0/15.0/60.0)	83.78	-42.7	-44.9	88.5	191.3	4.70	682	1000	none	-4.8	-2064	A1		0.000	1500
407F	R-32/125/134a (30.0/30.0/40.0)	82.06	-46.1	-51.0	82.7	180.9	4.75	689	1000	none			A1		0.000	1800
———	R-32/125/134a (30.0/10.0/60.0)	80.13	-43.3	-45.9	88.6	191.5	4.82	699		none					0.000	1400
408A	R-125/143a/22 (7.0/46.0/47.0)	87.01	-44.6	-48.3	83.1	181.6	4.29	622	1000	none	5.7	2451	A1		0.019	3000
409A	R-22/124/142b (60.0/25.0/15.0)	97.43	-34.4	-29.9	109.3	228.7	4.70	682	1000	none	3.0	1290	A1		0.038	1600
409B	R-22/124/142b (65.0/25.0/10.0)	96.67	-35.6	-32.1	106.9	224.4	4.73	686	1000	none			A1		0.037	1500
410A	R-32/125 (50.0/50.0)	72.58	-51.4	-60.5	71.4	160.5	4.90	711	1000	none	-4.4	-1892	A1		0.000	2100
———	R-32/125 (60.0/40.0)	67.27	-51.6	-60.9	72.5	162.5	5.07	735		none					0.000	1800

Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molecular	NBP		Tc		Pc				HOC		Std 34	atmospheric		
number	chemical formula or blend composition - common name	molecular mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
410B	R-32/125 (45.0/55.0)	75.57	-51.3	-60.3	70.8	159.4	4.81	698		none			A1		0.000	2200
——–	R-32/125 (32.0/68.0)	84.63	-50.9	-59.6	69.5	157.1	4.55	660		none					0.000	2600
——–	R-1270/22/152a (3.0/95.5/1.5)	83.44	-41.8	-43.2	95.5	203.9	4.95	718		none					0.038	1700
412A	R-22/218/142b (70.0/5.0/25.0)	92.17	-38.0	-36.4	107.2	225.0	4.90	711	1000	8.7			A2		0.043	2200
413A	R-218/134a/600a (9.0/88.0/3.0)	103.95	-33.4	-28.1	96.6	205.9	4.02	583	1000	8.8			A2		0.000	2000
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5)	96.93	-33.0	-27.4	112.7	234.9	4.68	679	1000	none	3.6	1548	A1		0.036	1500
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5)	101.59	-32.9	-27.2	111.0	231.8	4.59	666	1000	none			A1		0.034	1300
415A	R-22/152a (82.0/18.0)	81.91	-37.2	-35.0	102.0	215.6	4.96	719	1000	5.6	2.7	1161	A2		0.033	1500
415B	R-22/152a (25.0/75.0)	70.19	-26.9	-16.4	111.4	232.5	4.65	674	1000	wff			A2		0.010	550
——–	R-22/152a (50.0/50.0)	74.89	-31.0	-23.8	108.4	227.1	4.80	696	1000						0.020	960
416A	R-134a/124/600 (59.0/39.5/1.5)	111.92	-23.9	-11.0	107.1	224.8	3.98	577	1000	none	7.8	3353	A1		0.008	1100
——–	R-134a/124/600 (59.0/39.0/2.0)	111.31	-24.1	-11.4	107.1	224.8	3.99	579		none					0.008	1100
417A	R-125/134a/600 (46.6/50.0/3.4)	106.75	-39.1	-38.4	87.1	188.8	4.04	586	1000	none			A1		0.000	2300
417B	R-125/134a/600 (79.0/18.3/2.7)	113.12	-44.9	-48.8	75.2	167.4	3.83	555	1000	none			A1		0.000	3000
418A	R-290/22/152a (1.5/96.0/2.5)	84.60	-41.7	-43.1	96.2	205.2	4.98	722	1000	8.9	1.7	731	A2		0.038	1700
419A	R-125/134a/E170 (77.0/19.0/4.0)	109.34	-42.6	-44.7	82.1	179.8	3.94	571	1000	wff	10.0	4299	A2		0.000	2900
420A	R-134a/142b (88.0/12.0)	101.84	-24.9	-12.8	104.8	220.6	4.09	593	1000	none			A1		0.007	1500
——–	R-134a/142b (80.6/19.4)	101.73	-24.2	-11.6	107.2	225.0	4.10	595		none					0.012	1500
421A	R-125/134a (58.0/42.0)	111.75	-40.7	-41.3	82.8	181.0	3.92	569	1000	none			A1		0.000	2600
421B	R-125/134a (85.0/15.0)	116.93	-45.6	-50.1	72.4	162.3	3.75	544	1000	none	-0.5	-215	A1		0.000	3100
422A	R-125/134a/600a (85.1/11.5/3.4)	113.60	-46.5	-51.7	71.7	161.1	3.75	544	1000	none			A1		0.000	3100
422B	R-125/134a/600a (55.0/42.0/3.0)	108.52	-41.3	-42.3	83.2	181.8	3.96	574	1000	none			A1		0.000	2500
422C	R-125/134a/600a (82.0/15.0/3.0)	113.40	-45.9	-50.6	73.1	163.6	3.78	548	1000	none	2.6	1118	A1		0.000	3000
422D	R-125/134a/600a (65.1/31.5/3.4)	109.93	-43.2	-45.8	79.6	175.3	3.91	567	1000	none			A1		0.000	2700
423A	R-134a/227ea (52.5/47.5)	125.96	-24.2	-11.6	99.1	210.4	3.56	516	1000	none			A1		0.000	2400
424A	R-125/134a/600a/600/601a (50.5/47.0/0.9/1.0/0.6)	108.41	-39.7	-39.5	85.9	186.6	4.00	580	970	none			A1		0.000	2400
425A	R-32/134a/227ea (18.5/69.5/12.0)	90.31	-38.2	-36.8	93.9	201.0	4.50	653	1000	none	5.1	2193	A1		0.000	1500
426A	R-125/134a/600/601a (5.1/93.0/1.3/0.6)	101.56	-28.4	-19.1	99.8	211.6	4.09	593	990	none	4.7	2021	A1		0.000	1400
——–	R-125/134a/600/601a (19.5/78.5/1.4/0.6)	103.84	-32.9	-27.2	95.3	203.5	4.08	592							0.000	1700
——–	R-125/134a/600/601a (50.0/47.0/2.7/0.3)	108.93	-39.6	-39.3	86.2	187.2	4.02	583							0.000	2400
427A	R-32/125/143a/134a (15.0/25.0/10.0/50.0)	90.44	-43.0	-45.4	85.3	185.5	4.39	637	1000	none			A1		0.000	2100
——–	R-32/125/143a/134a (2.0/41.0/50.0/7.0)	95.82	-46.4	-51.5	72.9	163.2	3.81	553		none					0.000	3600
——–	R-32/125/143a/134a (10.0/33.0/36.0/21.0)	90.80	-46.5	-51.7	76.8	170.2	4.12	598		none					0.000	3000
428A	R-125/143a/290/600a (77.5/20.0/0.6/1.9)	107.53	-48.3	-54.9	69.0	156.2	3.72	540	1000	none			A1		0.000	3500

Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
429A	R-E170/152a/600a (60.0/10.0/30.0)	50.76	-25.5	-13.9	123.5	254.3	4.86	705	1000	2.9			A3		0.000	20
430A	R-152a/600a (76.0/24.0)	63.96	-27.6	-17.7	107.0	224.6	4.09	593	1000				A3		0.000	110
———	R-152a/600a (70.0/30.0)	63.45	-27.7	-17.9	107.0	224.6	4.03	585		3.15					0.000	99
———	R-152a/600a (73.0/27.0)	63.70	-27.7	-17.9	106.9	224.4	4.06	589		3.2					0.000	100
431A	R-290/152a (71.0/29.0)	48.80	-43.2	-45.8	100.3	212.5	4.90	711	1000	2.2			A3		0.000	53
432A	R-1270/E170 (80.0/20.0)	42.82	-46.6	-51.9	97.3	207.1	4.76	690	710	2.2			A3		0.000	16
433A	R-1270/290 (30.0/70.0)	43.47	-44.4	-47.9	94.4	201.9	4.35	631	880	2.0			A3		0.000	~20
433B	R-1270/290 (5.0/95.0)	43.99	-42.5	-44.5	96.3	205.3	4.27	619	950	1.8	50.2	21582	A3		0.000	~20
433C	R-1270/290 (25.0/75.0)	43.57	-44.1	-47.4	94.8	202.6	4.33	628	790	1.8	50.0	21496	A3		0.000	~20
434A	R-125/143a/134a/600a (63.2/18.0/16.0/2.8)	105.74	-45.0	-49.0	75.5	167.9	3.84	557	1000	none			A1		0.000	3100
435A	R-E170/152a (80.0/20.0)	49.04	-26.1	-15.0	125.2	257.4	5.39	782	1000	3.5	28.9	12425	A3		0.000	27
436A	R-290/600a (56.0/44.0)	49.33	-34.3	-29.7	115.9	240.6	4.27	619	1000	1.7	49.9	21453	A3		0.000	~20
436B	R-290/600a (52.0/48.0)	49.87	-33.4	-28.1	117.4	243.3	4.25	616	1000	1.7	49.9	21453	A3		0.000	~20
———	R-290/600a (50.0/50.0)	50.15	-32.8	-27.0	118.2	244.8	4.24	615		2.0	49.8	21410			0.000	~20
437A	R-125/134a/600/601 (19.5/78.5/1.4/0.6)	103.71	-32.9	-27.2	96.3	205.3	4.09	593	990	none			A1		0.000	1700
438A	R-32/125/134a/600/601a (8.5/45.0/44.2/1.7/0.6)	99.10	-42.3	-44.1	85.3	185.5	4.30	624	990	6.2	10.7	4600	A1		0.000	2200
439A	R-32/125/600a (50.0/47.0/3.0)	71.21	-52.0	-61.6	72.0	161.6	4.95	718	1000	10.4	8.1	3482	A2 r		0.000	2000
440A	R-290/134a/152a (0.6/1.6/97.8)	66.23	-25.4	-13.7	112.9	235.2	4.54	658	1000	4.8			A2 r		0.000	150
441A	R-170/290/600a/600 (3.1/54.8/6.0/36.1)	46.81	-41.5	-42.7	117.3	243.1	4.40	638	1000	1.68	41.2	17713	A3 r		0.000	~20
———	R-22/124/600 (50.0/47.0/3.0)	102.64	-32.9	-27.2	110.4	230.7	4.59	666	900	none					0.029	1200
———	R-22/134a/21 (50.0/20.0/30.0)	93.83	-33.1	-27.6	119.1	246.4	5.15	747							0.020	1200
———	R-22/134a/21 (60.0/8.0/32.0)	92.32	-34.3	-29.7	119.9	247.8	5.26	763							0.024	1200
———	R-22/134a/21 (65.0/15.0/20.0)	91.49	-35.9	-32.6	111.0	231.8	5.10	740							0.026	1400
———	R-22/142b/21 (65.0/15.0/20.0)	91.01	-34.3	-29.7	114.0	237.2	4.96	719							0.044	1800
———	R-22/142b/21 (65.0/20.0/15.0)	91.20	-34.4	-29.9	116.3	241.3	5.07	735							0.038	1600
———	R-22/142b/21 (65.0/30.0/5.0)	91.30	-34.4	-29.9	117.6	243.7	5.13	744							0.035	1500
———	R-23/125/143a (20.0/36.0/44.0)	90.16	-64.7	-84.5	59.2	138.6	4.01	582							0.000	5900
———	R-23/32/134a (4.5/21.5/74.0)	83.14	-46.6	-51.9	90.8	195.4	4.78	693		none					0.000	1800
———	R-32/125/134a/600 (10.0/42.0/45.0/3.0)	96.64	-42.7	-44.9	85.6	186.1	4.38	635							0.000	2100
———	R-32/125/143a (10.0/45.0/45.0)	90.69	-49.0	-56.2	70.3	158.5	4.00	580		none					0.000	3500
———	R-32/125/161 (10.0/36.0/54.0)	61.89	-44.8	-48.6	92.3	198.1	5.10	740							0.000	1300
———	R-32/125/161 (13.6/40.0/46.4)	64.10	-46.2	-51.2	90.0	194.0	5.15	747							0.000	1500
———	R-32/125/161 (15.0/34.0/51.0)	61.24	-46.2	-51.2	91.3	196.3	5.24	760							0.000	1300
———	R-32/125/161 (15.9/30.0/54.1)	59.48	-46.2	-51.2	92.1	197.8	5.29	767							0.000	1100
———	R-32/125/161 (19.0/39.0/42.0)	59.48	-47.5	-53.5	88.6	191.5	5.26	763							0.000	1100
———	R-32/125/161 (20.0/32.0/48.0)	60.61	-47.3	-53.1	90.3	194.5	5.36	777							0.000	1200
———	R-32/125/161 (47.0/38.0/15.0)	65.27	-51.0	-59.8	79.2	174.6	5.44	789							0.000	1600
———	R-32/134a (25.0/75.0)	82.26	-40.2	-40.4	92.9	199.2	4.75	689		wff					0.000	1200
———	R-32/134a (30.0/70.0)	79.19	-41.7	-43.1	91.6	196.9	4.86	705	1000	wff					0.000	1200

Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
——	R-32/134a (33.8/66.2)	77.03	-42.7	-44.9	90.6	195.1	4.93	715							0.000	1100
——	R-32/227ea (35.0/65.0)	95.76	-46.0	-50.8	83.2	181.8	4.39	637							0.000	2600
——	R-32/600 (90.0/10.0)	52.58	-51.7	-61.1	78.3	172.9	5.66	821							0.000	650
——	R-32/600a (95.0/5.0)	52.30	-52.7	-62.9	75.8	168.4	5.50	798							0.000	680
——	R-32/1234ze(E) (50.0/50.0)	71.45	-47.5	-53.5	87.9	190.2	5.33	773							0.000	360
——	R-123/601a (75.0/25.0) – M523d	119.49	24.4	75.9	185.1	365.2	3.82	554							0.008	63
——	R-123/601a (80.0/20.0) – M523c	124.95	24.6	76.3	184.9	364.8	3.82	554							0.008	66
——	R-123/601a (85.0/15.0) – M523b	130.94	24.9	76.8	184.6	364.3	3.81	553							0.009	68
——	R-123/601a (90.0/10.0) – M523a	137.53	25.5	77.9	184.4	363.9	3.79	550							0.009	71
——	R-124/123 (42.0/58.0)	145.56	0.3	32.5	156.2	313.2	3.83	555							0.014	300
——	R-125/22 (70.0/30.0)	107.51	-47.4	-53.3	73.6	164.5	4.03	585		none					0.012	2900
——	R-125/134a/152a (35.0/40.0/25.0)	94.15	-34.9	-30.8	95.9	204.6	4.19	608	1000	wff					0.000	1800
——	R-125/134a/601 (10.6/86.0/3.4)	102.22	-28.6	-19.5	102.7	216.9	4.14	600	1000	none					0.000	1500
——	R-125/143a/290/22 (42.0/6.0/2.0/50.0)	95.70	-47.6	-53.7	80.6	177.1	4.41	640	1000	none					0.020	2600
——	R-125/152a/227ea (40.0/5.0/55.0)	136.53	-38.8	-37.8	86.5	187.7	3.54	513	1000	none					0.000	3300
——	R-125/290/218 (86.0/5.0/9.0)	113.92	-53.4	-64.1	64.2	147.6	3.73	541		none					0.000	3700
——	R-134a/152a (20.0/80.0)	71.06	-23.9	-11.0	111.5	232.7	4.44	644							0.000	380
——	R-134a/152a/13I1 (26.4/22.8/50.8)	115.84	-30.0	-22.0	112.6	234.7	4.91	712		none					0.009	
——	R-143a/22 (55.0/45.0)	85.12	-44.6	-48.3	83.0	181.4	4.26	618		none					0.018	3100
——	R-143a/134a (40.0/60.0)	93.98	-37.7	-35.9	89.5	193.1	4.00	580		9.5					0.000	2500
——	R-152a/13I1 (25.0/75.0)	131.35	-29.5	-21.1	118.3	244.9	4.96	719		none					0.014	
——	R-152a/227ea (25.0/75.0)	122.01	-20.2	-4.4	105.9	222.6	3.48	505		none					0.000	2700
——	R-161/13I1 (80.0/20.0)	56.60	-37.7	-35.9	103.4	218.1	5.16	748							0.004	10
——	R-161/218/13I1 (65.4/18.2/16.4)	64.88	-37.8	-36.0	101.4	214.5	4.96	719							0.003	1600
——	R-170/290 (6.0/94.0)	40.32	-51.5	-60.7	93.0	199.4	4.43	643		1.9					0.000	~20
——	R-290/22/124 (3.0/40.0/57.0)	105.45	-35.5	-31.9	108.6	227.5	4.46	647	500	none					0.027	1100
——	R-290/124/123 (3.0/40.0/57.0)	136.27	-15.4	4.3	151.1	304.0	3.99	579							0.014	290
——	R-290/134a/600a (3.1/93.0/3.9)	95.34	-38.0	-36.4	97.5	207.5	4.23	614							0.000	1300
——	R-600a/600 (50.0/50.0)	58.12	-6.7	19.9	145.2	293.4	3.80	551		1.6					0.000	~20
——	R-601/602 (90.1/9.9)	73.33	37.8	100.0	200.4	392.7	3.37	489							0.000	~20
——	R-601a/601 (37.0/63.0)	72.15	32.7	90.9	193.2	379.8	3.38	490							0.000	~20
——	R-744/32/134a (7.0/31.0/62.0)	73.39	-57.2	-71.0	84.2	183.6	5.15	747							0.000	1100
——	R-744/41 (56.4/43.6)	39.02	-84.5	-120.1	37.9	100.2	6.82	989		none					0.000	47
——	R-1132a/134a (5.0/95.0)	99.09			125.7	258.3	5.34	775							0.000	1300
500	R-12/152a (73.8/26.2)	99.30	-33.6	-28.5	102.1	215.8	4.17	605	1000	none			A1		0.605	8100
501	R-22/12 (75.0/25.0)	93.10	-40.7	-41.3	95.9	204.6	4.76	690	1000	none			A1		0.235	4100
502	R-22/115 (48.8/51.2)	111.63	-45.3	-49.5	81.5	178.7	4.02	583	1000	none			A1		0.311	4600
503	R-23/13 (40.1/59.9)	87.25	-87.8	-126.0	18.4	65.1	4.28	621	1000	none					0.000	14000
504	R-32/115 (48.2/51.8)	79.25	-57.9	-72.2	62.1	143.8	4.43	643	1000	none					0.295	4100
505	R-12/31 (78.0/22.0)	103.48	-30.0	-22.0	117.8	244.0	4.73	686		none					0.640	
506	R-31/114 (55.1/44.9)	93.69	-12.3	9.9	142.2	288.0	5.16	748		none					0.260	
507A	R-125/143a (50.0/50.0)	98.86	-46.7	-52.1	70.6	159.1	3.71	538	1000	none	-5.5	-2365	A1		0.000	3800

Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
number	chemical formula or blend composition - common name	molecular mass	NBP (°C)	NBP (°F)	Tc (°C)	Tc (°F)	Pc (MPa)	Pc (psia)	OEL (PPMv)	LFL (%)	HOC MJ/kg	HOC Btu/lb	Std 34 safety group	atmospheric life (yr)	ODP	GWP 100 yr
———	R-125/143a (45.0/55.0)	97.15	-46.7	-52.1	70.9	159.6	3.71	538		none					0.000	3800
508A	R-23/116 (39.0/61.0)	100.10	-87.6	-125.7	10.2	50.4	3.65	529	1000	none			A1		0.000	13000
508B	R-23/116 (46.0/54.0)	95.39	-87.6	-125.7	11.2	52.2	3.77	547	1000	none			A1		0.000	13000
509A	R-22/218 (44.0/56.0)	123.96	-49.7	-57.5	68.4	155.1	3.60	522	1000	none			A1		0.018	5700
510A	R-E170/600a (88.0/12.0)	47.24	-25.2	-13.4	127.9	262.2	5.33	773	1000	3.0	33.9	14574	A3		0.000	3
511A	R-290/E170 (95.0/5.0)	44.19	-42.0	-43.6	97.0	206.6	4.29	622		2.1			A3 r		0.000	19
———	R-32/600 (95.0/5.0)	52.30	-51.8	-61.2	77.8	172.0	5.70	827							0.000	680
———	R-32/600a (90.0/10.0)	52.58	-53.1	-63.6	74.1	165.4	5.26	763							0.000	650
———	R-134a/152a (85.0/15.0)	94.32	-25.1	-13.2	103.6	218.5	4.13	599							0.000	1200
———	R-170/717 (59.1/40.9)	9.37	-89.0	-128.2	68.4	155.1	6.39	927		4.0					0.000	~12
———	R-218/134/600 (32.7/62.8/4.5)	115.36	-21.5	-6.7	112.2	234.0	3.96	574							0.000	3600
———	R-218/134/600a (32.7/62.8/4.5)	115.36	-23.0	-9.4	109.3	228.7	3.90	566							0.000	3600
———	R-218/134a/600 (32.7/62.8/4.5)	115.36	-36.6	-33.9	89.9	193.8	3.85	558							0.000	3700
———	R-218/134a/600 (33.0/62.0/5.0)	115.05	-36.5	-33.7	90.1	194.2	3.86	560							0.000	3800
———	R-218/152a (83.5/16.5)	144.11	-35.3	-31.5	86.8	188.2	3.45	500							0.000	7400
———	R-225ca/225cb (45.0/55.0)	202.94	54.0	129.2					50	none						7400
———	R-717/E170 (60.0/40.0) – "R723"	22.77	-39.1	-38.4	118.7	245.7	8.94	1297		6.0	22.7	9759			0.000	<1
———	R-1270/161 (72.4/27.6)	43.57	-49.0	-56.2	94.9	202.8	5.20	754		2.7					0.000	7
600	CH3CH2CH2CH3 – butane	58.12	-0.5	31.1	152.0	305.6	3.80	551	1000	2.0	49.5	21281	A3	0.018	0.000	~20
600a	CH(CH3)2CH3 – isobutane	58.12	-11.7	10.9	134.7	274.5	3.63	526	1000	1.6	49.4	21238	A3	0.016	0.000	~20
601	CH3CH2CH2CH2CH3 – pentane	72.15	36.1	97.0	196.6	385.9	3.37	489	600	1.2			A3	0.009	0.000	~20
601a	(CH3)2CHCH2CH3 – isopentane	72.15	27.8	82.0	187.2	369.0	3.38	490	600	1.3	35.0	15047	A3	0.009	0.000	~20
601b	(CH3)4C – neopentane	72.15	9.5	49.1	160.6	321.1	3.20	464	600	1.4					0.000	~20
610	CH3CH2OCH2CH3 – ethyl ether	74.12	34.6	94.3	214.0	417.2	6.00	870	400	1.9					0.000	
611	HCOOCH3 – methyl formate	60.05	31.7	89.1	214.0	417.2	5.99	869	100	4.5			B2	0.197	0.000	
630	CH3(NH2) – methylamine	31.06	-6.7	19.9	156.9	314.4	7.43	1078	5	4.9						
631	CH3CH2(NH2) – ethylamine	45.08	16.6	61.9	183.0	361.4	5.62	815	5	3.5						
———	-(CH2)5- – cyclopentane	70.13	49.4	120.9	238.6	461.5	4.51	654	600	1.1				0.007	0.000	11
702	H2 – normal hydrogen	2.02	-252.8	-423.0	-240.0	-400.0	1.30	189		4.0			A3		0.000	
704	He – helium	4.00	-268.9	-452.0	-268.0	-450.4	0.23	33		none			A1		0.000	
717	NH3 – ammonia	17.03	-33.3	-27.9	132.3	270.1	11.33	1643	25	16.7	22.5	9673	B2L r	<0.02	0.000	<1
718	H2O – water	18.02	100.0	212.0	373.9	705.0	22.06	3200		none			A1		0.000	<1
720	Ne – neon	20.18	-246.0	-410.8	-228.7	-379.7	2.68	389		none			A1		0.000	
728	N2 – nitrogen	28.01	-195.8	-320.4	-147.0	-232.6	3.40	493		none			A1		0.000	
729	air - 78% N2, 21% O2, 1% Ar, +	28.97	-194.2	-317.6	-140.3	-220.5	3.85	558		none					0.000	0
740	Ar – argon	39.95	-185.8	-302.4	-122.5	-188.5	4.86	705		none			A1		0.000	
744	CO2 – carbon dioxide	44.01			31.0	87.8	7.38	1070	5000	none			A1	>50	0.000	1
764	SO2 – sulfur dioxide	64.06	-10.0	14.0	157.5	315.5	7.88	1143	2	none			B1		0.000	
784	Kr – krypton	83.80	-153.4	-244.1	-63.7	-82.7	5.53	802		none					0.000	
1120	CHCl=CCl2 – trielene	131.39	88.0	190.4					50	8				0.013	0.000	
1130(E)	CHCl=CHCl	96.94	47.5	117.5	234.1	453.4	5.19	753	200	9.7						
1130(Z)	CHCl=CHCl	96.94	60.3	140.5	234.1	453.4	5.19	753	200	3.3						
1130	CHCl=CHCl – dielene	96.94	47.8	118.0	243.3	469.9	5.48	795	200	5.6						
1130a	CH2=CCl2	96.94	37.0	98.6	230.1	446.2	7.08	1027	5	6.5				0.002		
1132	CHF=CHF	64.03	-28.0	-18.4											0.000	
1132a	CH2=CF2	64.03	-85.7	-122.3	30.1	86.2	4.43	643	500	4.7				0.011	0.000	1.7

Table 1 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by ASHRAE 34 designations)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
1150	CH2=CH2 – ethylene	28.05	-103.8	-154.8	9.2	48.6	5.04	731	200	3.1			A3	0.004	0.000	<20
1223xd(E)	CHCl=CClClF3	164.94													0.000	
1223xd(Z)	CHCl=CClClF3	164.94													0.000	
1225yc	CHF2CF=CF2	132.03	1.5	34.7											0.000	
1225ye(E)	CHF=CFCF3	132.03	-16.0	3.2	113.6	236.5	3.40	493						0.013	0.000	
1225ye(Z)	CHF=CFCF3	132.03	-21.0	-5.8	106.1	223.0	3.34	484		none				0.023	0.000	<3.6
1225zc	CF2=CHCF3	132.03	-21.8	-7.2	103.4	218.1	3.31	480							0.000	
1233xf	CH2=CClCF3	130.50	14.5	58.1											0.000	
1233yc	CH2ClCF=CF2	130.50													0.000	
1233zd(E)	CHCl=CHCF3	130.50	27.7	81.9										0.071	0.000	
1233zd(Z)	CHCl=CHCF3	130.50	27.7	81.9											0.000	
1234yc	CH2FCF=CF2	114.04													0.000	
1234ye(E)	CHF2CF=CHF	114.04	-22.0	-7.6	106.7	224.1	3.53	512							0.000	
1234ye(Z)	CHF2CF=CHF	114.04													0.000	
1234yf	CH2=CFCF3	114.04	-29.5	-21.1	94.7	202.5	3.38	490	500	6.2	10.7	4600	A2L r	0.029	0.000	<4.4
1234zc	CHF2CH=CF2	114.04													0.000	
1234ze(E)	CHF=CHCF3	114.04	-19.0	-2.2	109.4	228.9	3.64	528	1000	7.6				0.045	0.000	6
1234ze(Z)	CHF=CHCF3	114.04	9.0	48.2	153.6	308.5	3.97	576							0.000	
1243yc	CH3CF=CF2	96.05													0.000	
1243ye(E)	CH2FCF=CHF	96.05													0.000	
1243ye(Z)	CH2FCF=CHF	96.05													0.000	
1243yf	CH2=CFCHF2	96.05													0.000	
1243zc	CH2=CHCF3	96.05												0.021	0.000	
1243ze(E)	CHF=CHCHF2	96.05												0.045	0.000	
1243ze(Z)	CHF=CHCHF2	96.05													0.000	
1243zf	CH2=CHCF3	96.05	-25.2	-13.4	105.5	221.9	3.74	542		4.0					0.000	<150
1261yf	CH3CF=CH2	60.07	-24.0	-11.2											0.000	
1261zf	CH2=CHCH2F	60.07	-3.0	26.6										0.002	0.000	
1270	CH3CH=CH2 – propylene	42.08	-47.6	-53.7	91.1	196.0	4.56	661	500	2.7			A3	0.001	0.000	<20
2316	CF2=CFCF=CF2	162.03	6.5	43.7	139.6	283.3				7				0.003	0.000	

NBP = normal boiling point temperature; Tc = critical temperature; Pc = critical pressure; OEL = occupational exposure limit (8 hr time-weighted average unless value is preceded by C for ceiling); LFL = lower flammability limit (% volume in air), "wff" signifies that the worst case of fractionation is flammable; HOC = heat of combustion; ODP = ozone depletion potential; GWP = global warming potential (for 100 yr integration)

Suffixes to safety classifications indicate recommended changes that are not final yet ("d" for deletion and "r" for revision or addition) or classifications assigned as provisional ("p"); "d" alone indicates that a prior classification was deleted (withdrawn).

Data sources are identified in the Refrigerant Database; verify the data and associated limitations in those sources before use.

Table 2: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molecular	NBP		Tc		Pc				HOC		Std 34	atmospheric		
number	chemical formula or blend composition - common name	molecular mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
704	He – helium	4.00	-268.9	-452.0	-268.0	-450.4	0.23	33		none			A1		0.000	
702	H2 – normal hydrogen	2.02	-252.8	-423.0	-240.0	-400.0	1.30	189		4.0			A3		0.000	
720	Ne – neon	20.18	-246.0	-410.8	-228.7	-379.7	2.68	389		none			A1		0.000	
728	N2 – nitrogen	28.01	-195.8	-320.4	-147.0	-232.6	3.40	493		none			A1		0.000	
729	air - 78% N2, 21% O2, 1% Ar, +	28.97	-194.2	-317.6	-140.3	-220.5	3.85	558		none					0.000	0
740	Ar – argon	39.95	-185.8	-302.4	-122.5	-188.5	4.86	705		none			A1		0.000	
50	CH4 – methane	16.04	-161.5	-258.7	-82.6	-116.7	4.60	667	1000	4.8			A3	12.0	0.000	23
784	Kr – krypton	83.80	-153.4	-244.1	-63.7	-82.7	5.53	802		none					0.000	
14	CF4 – carbon tetrafluoride	88.00	-128.0	-198.4	-45.6	-50.1	3.75	544	1000	none			A1	50000	0.000	7390
1150	CH2=CH2 – ethylene	28.05	-103.8	-154.8	9.2	48.6	5.04	731	200	3.1			A3	0.004	0.000	<20
———	R-170/717 (59.1/40.9)	9.37	-89.0	-128.2	68.4	155.1	6.39	927		4.0					0.000	~12
170	CH3CH3 – ethane	30.07	-88.6	-127.5	32.2	90.0	4.87	706	1000	3.1			A3	0.21	0.000	~20
503	R-23/13 (40.1/59.9)	87.25	-87.8	-126.0	18.4	65.1	4.28	621	1000	none					0.000	14000
508A	R-23/116 (39.0/61.0)	100.10	-87.6	-125.7	10.2	50.4	3.65	529	1000	none			A1		0.000	13000
508B	R-23/116 (46.0/54.0)	95.39	-87.6	-125.7	11.2	52.2	3.77	547	1000	none			A1		0.000	13000
1132a	CH2=CF2	64.03	-85.7	-122.3	30.1	86.2	4.43	643	500	4.7				0.011	0.000	1.7
———	R-744/41 (56.4/43.6)	39.02	-84.5	-120.1	37.9	100.2	6.82	989		none					0.000	47
23	CHF3 – fluoroform	70.01	-82.0	-115.6	26.1	79.0	4.83	701	1000	none	-12.5	-5374	A1	222	0.000	14200
13	CClF3	104.46	-81.5	-114.7	28.9	84.0	3.88	563	1000	none	-3.0	-1290	A1	640	1.000	14400
41	CH3F – methyl fluoride	34.03	-78.3	-108.9	44.1	111.4	5.90	856						2.8	0.000	107
116	CF3CF3 – perfluoroethane	138.01	-78.1	-108.6	19.9	67.8	3.05	442	1000	none			A1	10000	0.000	12200
———	R-23/125/143a (20.0/36.0/44.0)	90.16	-64.7	-84.5	59.2	138.6	4.01	582							0.000	5900
13B1	CBrF3	148.91	-58.7	-73.7	67.1	152.8	3.97	576	1000	none			A1	65	15.900	7140
504	R-32/115 (48.2/51.8)	79.25	-57.9	-72.2	62.1	143.8	4.43	643	1000	none					0.295	4100
———	R-744/32/134a (7.0/31.0/62.0)	73.39	-57.2	-71.0	84.2	183.6	5.15	747							0.000	1100
———	R-125/290/218 (86.0/5.0/9.0)	113.92	-53.4	-64.1	64.2	147.6	3.73	541		none					0.000	3700
———	R-32/600a (90.0/10.0)	52.58	-53.1	-63.6	74.1	165.4	5.26	763							0.000	650
———	R-32/600a (95.0/5.0)	52.30	-52.7	-62.9	75.8	168.4	5.50	798							0.000	680
439A	R-32/125/600a (50.0/47.0/3.0)	71.21	-52.0	-61.6	72.0	161.6	4.95	718	1000	10.4	8.1	3482	A2 r		0.000	2000
———	R-32/600 (95.0/5.0)	52.30	-51.8	-61.2	77.8	172.0	5.70	827							0.000	680
32	CH2F2 – methylene fluoride	52.02	-51.7	-61.1	78.1	172.6	5.78	838	1000	14.4	9.4	4041	A2L r	5.2	0.000	716
———	R-32/600 (90.0/10.0)	52.58	-51.7	-61.1	78.3	172.9	5.66	821							0.000	650
———	R-32/125 (60.0/40.0)	67.27	-51.6	-60.9	72.5	162.5	5.07	735		none					0.000	1800
———	R-170/290 (6.0/94.0)	40.32	-51.5	-60.7	93.0	199.4	4.43	643		1.9					0.000	~20
410A	R-32/125 (50.0/50.0)	72.58	-51.4	-60.5	71.4	160.5	4.90	711	1000	none	-4.4	-1892	A1		0.000	2100
410B	R-32/125 (45.0/55.0)	75.57	-51.3	-60.3	70.8	159.4	4.81	698		none			A1		0.000	2200
———	R-32/125/161 (47.0/38.0/15.0)	65.27	-51.0	-59.8	79.2	174.6	5.44	789							0.000	1600
———	R-32/125 (32.0/68.0)	84.63	-50.9	-59.6	69.5	157.1	4.55	660		none					0.000	2600
509A	R-22/218 (44.0/56.0)	123.96	-49.7	-57.5	68.4	155.1	3.60	522	1000	none			A1		0.018	5700
403B	R-290/22/218 (5.0/56.0/39.0)	103.26	-49.2	-56.6	79.6	175.3	4.33	628	1000	none			A1		0.022	4400
———	R-1270/161 (72.4/27.6)	43.57	-49.0	-56.2	94.9	202.8	5.20	754		2.7					0.000	7
———	R-32/125/143a (10.0/45.0/45.0)	90.69	-49.0	-56.2	70.3	158.5	4.00	580		none					0.000	3500
402A	R-125/290/22 (60.0/2.0/38.0)	101.55	-48.9	-56.0	75.8	168.4	4.22	612	1000	none	-1.4	-602	A1		0.015	2700
428A	R-125/143a/290/600a (77.5/20.0/0.6/1.9)	107.53	-48.3	-54.9	69.0	156.2	3.72	540	1000	none			A1		0.000	3500
125	CHF2CF3	120.02	-48.1	-54.6	66.0	150.8	3.62	525	1000	none	-1.5	-645	A1	28.2	0.000	3420

Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
403A	R-290/22/218 (5.0/75.0/20.0)	91.99	-47.7	-53.9	87.0	188.6	4.71	683	1000	wff			A2		0.030	3100
——	R-125/143a/290/22 (42.0/6.0/2.0/50.0)	95.70	-47.6	-53.7	80.6	177.1	4.41	640	1000	none					0.020	2600
1270	CH3CH=CH2 – propylene	42.08	-47.6	-53.7	91.1	196.0	4.56	661	500	2.7			A3	0.001	0.000	<20
——	R-32/1234ze(E) (50.0/50.0)	71.45	-47.5	-53.5	87.9	190.2	5.33	773							0.000	360
——	R-32/125/161 (19.0/39.0/42.0)	59.48	-47.5	-53.5	88.6	191.5	5.26	763							0.000	1100
——	R-125/22 (70.0/30.0)	107.51	-47.4	-53.3	73.6	164.5	4.03	585		none					0.012	2900
——	R-32/125/161 (20.0/32.0/48.0)	60.61	-47.3	-53.1	90.3	194.5	5.36	777							0.000	1200
143a	CH3CF3	84.04	-47.2	-53.0	72.7	162.9	3.76	545	1000	8.2	10.4	4471	A2L r	47.1	0.000	4180
402B	R-125/290/22 (38.0/2.0/60.0)	94.71	-47.0	-52.6	82.9	181.2	4.52	656	1000	none	-1.6	-688	A1		0.024	2400
507A	R-125/143a (50.0/50.0)	98.86	-46.7	-52.1	70.6	159.1	3.71	538	1000	none	-5.5	-2365	A1		0.000	3800
——	R-125/143a (45.0/55.0)	97.15	-46.7	-52.1	70.9	159.6	3.71	538		none					0.000	3800
——	R-23/32/134a (4.5/21.5/74.0)	83.14	-46.6	-51.9	90.8	195.4	4.78	693		none					0.000	1800
432A	R-1270/E170 (80.0/20.0)	42.82	-46.6	-51.9	97.3	207.1	4.76	690	710	2.2			A3		0.000	16
407B	R-32/125/134a (10.0/70.0/20.0)	102.94	-46.5	-51.7	75.0	167.0	4.13	599	1000	none	-1.8	-774	A1		0.000	2700
422A	R-125/134a/600a (85.1/11.5/3.4)	113.60	-46.5	-51.7	71.7	161.1	3.75	544	1000	none			A1		0.000	3100
——	R-32/125/143a/134a (10.0/33.0/36.0/21.0)	90.80	-46.5	-51.7	76.8	170.2	4.12	598		none					0.000	3000
——	R-32/125/143a/134a (2.0/41.0/50.0/7.0)	95.82	-46.4	-51.5	72.9	163.2	3.81	553		none					0.000	3600
——	R-32/125/161 (13.6/40.0/46.4)	64.10	-46.2	-51.2	90.0	194.0	5.15	747							0.000	1500
——	R-32/125/161 (15.0/34.0/51.0)	61.24	-46.2	-51.2	91.3	196.3	5.24	760							0.000	1300
——	R-32/125/161 (15.9/30.0/54.1)	59.48	-46.2	-51.2	92.1	197.8	5.29	767							0.000	1100
404A	R-125/143a/134a (44.0/52.0/4.0)	97.60	-46.2	-51.2	72.0	161.6	3.73	541	1000	none	-6.6	-2837	A1		0.000	3700
407F	R-32/125/134a (30.0/30.0/40.0)	82.06	-46.1	-51.0	82.7	180.9	4.75	689	1000	none			A1		0.000	1800
——	R-32/227ea (35.0/65.0)	95.76	-46.0	-50.8	83.2	181.8	4.39	637							0.000	2600
422C	R-125/134a/600a (82.0/15.0/3.0)	113.40	-45.9	-50.6	73.1	163.6	3.78	548	1000	none	2.6	1118	A1		0.000	3000
421B	R-125/134a (85.0/15.0)	116.93	-45.6	-50.1	72.4	162.3	3.75	544	1000	none	-0.5	-215	A1		0.000	3100
502	R-22/115 (48.8/51.2)	111.63	-45.3	-49.5	81.5	178.7	4.02	583	1000	none			A1		0.311	4600
407A	R-32/125/134a (20.0/40.0/40.0)	90.11	-45.0	-49.0	82.3	180.1	4.52	656	1000	none	-3.6	-1548	A1		0.000	2100
434A	R-125/143a/134a/600a (63.2/18.0/16.0/2.8)	105.74	-45.0	-49.0	75.5	167.9	3.84	557	1000	none			A1		0.000	3100
417B	R-125/134a/600 (79.0/18.3/2.7)	113.12	-44.9	-48.8	75.2	167.4	3.83	555	1000	none			A1		0.000	3000
——	R-32/125/161 (10.0/36.0/54.0)	61.89	-44.8	-48.6	92.3	198.1	5.10	740							0.000	1300
——	R-143a/22 (55.0/45.0)	85.12	-44.6	-48.3	83.0	181.4	4.26	618		none					0.018	3100
408A	R-125/143a/22 (7.0/46.0/47.0)	87.01	-44.6	-48.3	83.1	181.6	4.29	622	1000	none	5.7	2451	A1		0.019	3000
433A	R-1270/290 (30.0/70.0)	43.47	-44.4	-47.9	94.4	201.9	4.35	631	880	2.0			A3		0.000	~20
433C	R-1270/290 (25.0/75.0)	43.57	-44.1	-47.4	94.8	202.6	4.33	628	790	1.8	50.0	21496	A3		0.000	~20
407C	R-32/125/134a (23.0/25.0/52.0)	86.20	-43.6	-46.5	86.0	186.8	4.63	672	1000	none	-4.9	-2107	A1		0.000	1700
——	R-32/125/134a (30.0/10.0/60.0)	80.13	-43.3	-45.9	88.6	191.5	4.82	699		none					0.000	1400
422D	R-125/134a/600a (65.1/31.5/3.4)	109.93	-43.2	-45.8	79.6	175.3	3.91	567	1000	none			A1		0.000	2700
431A	R-290/152a (71.0/29.0)	48.80	-43.2	-45.8	100.3	212.5	4.90	711	1000	2.2			A3		0.000	53
427A	R-32/125/143a/134a (15.0/25.0/10.0/50.0)	90.44	-43.0	-45.4	85.3	185.5	4.39	637	1000	none			A1		0.000	2100
——	R-32/125/134a/600 (10.0/42.0/45.0/3.0)	96.64	-42.7	-44.9	85.6	186.1	4.38	635							0.000	2100

Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
———	R-32/134a (33.8/66.2)	77.03	-42.7	-44.9	90.6	195.1	4.93	715							0.000	1100
407E	R-32/125/134a (25.0/15.0/60.0)	83.78	-42.7	-44.9	88.5	191.3	4.70	682	1000	none	-4.8	-2064	A1		0.000	1500
419A	R-125/134a/E170 (77.0/19.0/4.0)	109.34	-42.6	-44.7	82.1	179.8	3.94	571	1000	wff	10.0	4299	A2		0.000	2900
433B	R-1270/290 (5.0/95.0)	43.99	-42.5	-44.5	96.3	205.3	4.27	619	950	1.8	50.2	21582	A3		0.000	~20
438A	R-32/125/134a/600/601a (8.5/45.0/44.2/1.7/0.6)	99.10	-42.3	-44.1	85.3	185.5	4.30	624	990	6.2	10.7	4600	A1		0.000	2200
290	CH3CH2CH3 – propane	44.10	-42.1	-43.8	96.7	206.1	4.25	616	1000	2.1	50.4	21668	A3	0.041	0.000	~20
511A	R-290/E170 (95.0/5.0)	44.19	-42.0	-43.6	97.0	206.6	4.29	622		2.1			A3 r		0.000	19
E125	CHF2OCF3	136.02	-42.0	-43.6	81.3	178.3	3.35	486						119	0.000	14200
———	R-1270/22/152a (3.0/95.5/1.5)	83.44	-41.8	-43.2	95.5	203.9	4.95	718		none					0.038	1700
———	R-32/134a (30.0/70.0)	79.19	-41.7	-43.1	91.6	196.9	4.86	705	1000	wff					0.000	1200
418A	R-290/22/152a (1.5/96.0/2.5)	84.60	-41.7	-43.1	96.2	205.2	4.98	722	1000	8.9	1.7	731	A2		0.038	1700
411B	R-1270/22/152a (3.0/94.0/3.0)	83.07	-41.6	-42.9	95.9	204.6	4.94	716	980	7.0	6.5	2794	A2		0.038	1700
441A	R-170/290/600a/600 (3.1/54.8/6.0/36.1)	46.81	-41.5	-42.7	117.3	243.1	4.40	638	1000	1.68	41.2	17713	A3 r		0.000	~20
422B	R-125/134a/600a (55.0/42.0/3.0)	108.52	-41.3	-42.3	83.2	181.8	3.96	574	1000	none			A1		0.000	2500
22	CHClF2	86.47	-40.8	-41.4	96.1	205.0	4.99	724	1000	none	2.2	946	A1	11.9	0.040	1790
421A	R-125/134a (58.0/42.0)	111.75	-40.7	-41.3	82.8	181.0	3.92	569	1000	none			A1		0.000	2600
501	R-22/12 (75.0/25.0)	93.10	-40.7	-41.3	95.9	204.6	4.76	690	1000	none			A1		0.235	4100
———	R-32/134a (25.0/75.0)	82.26	-40.2	-40.4	92.9	199.2	4.75	689		wff					0.000	1200
424A	R-125/134a/600a/600/601a (50.5/47.0/0.9/1.0/0.6)	108.41	-39.7	-39.5	85.9	186.6	4.00	580	970	none			A1		0.000	2400
———	R-125/134a/600/601a (50.0/47.0/2.7/0.3)	108.93	-39.6	-39.3	86.2	187.2	4.02	583							0.000	2400
411A	R-1270/22/152a (1.5/87.5/11.0)	82.36	-39.5	-39.1	99.1	210.4	4.95	718	990	5.5			A2		0.035	1600
115	CClF2CF3	154.47	-39.2	-38.6	80.0	176.0	3.13	454	1000	none	-2.1	-903	A1	1020	0.570	7230
407D	R-32/125/134a (15.0/15.0/70.0)	90.96	-39.2	-38.6	91.4	196.5	4.47	648	1000	none	-4.3	-1849	A1		0.000	1600
417A	R-125/134a/600 (46.6/50.0/3.4)	106.75	-39.1	-38.4	87.1	188.8	4.04	586	1000	none			A1		0.000	2300
———	R-717/E170 (60.0/40.0) – "R723"	22.77	-39.1	-38.4	118.7	245.7	8.94	1297		6.0	22.7	9759			0.000	<1
———	R-125/152a/227ea (40.0/5.0/55.0)	136.53	-38.8	-37.8	86.5	187.7	3.54	513	1000	none					0.000	3300
425A	R-32/134a/227ea (18.5/69.5/12.0)	90.31	-38.2	-36.8	93.9	201.0	4.50	653	1000	none	5.1	2193	A1		0.000	1500
———	R-290/134a/600a (3.1/93.0/3.9)	95.34	-38.0	-36.4	97.5	207.5	4.23	614							0.000	1300
412A	R-22/218/142b (70.0/5.0/25.0)	92.17	-38.0	-36.4	107.2	225.0	4.90	711	1000	8.7			A2		0.043	2200
———	R-161/218/13I1 (65.4/18.2/16.4)	64.88	-37.8	-36.0	101.4	214.5	4.96	719							0.003	1600
———	R-143a/134a (40.0/60.0)	93.98	-37.7	-35.9	89.5	193.1	4.00	580		9.5					0.000	2500
———	R-161/13I1 (80.0/20.0)	56.60	-37.7	-35.9	103.4	218.1	5.16	748							0.004	10
161	CH3CH2F – ethyl fluoride	48.06	-37.6	-35.7	102.2	216.0	5.09	738		3.8				0.18	0.000	12
415A	R-22/152a (82.0/18.0)	81.91	-37.2	-35.0	102.0	215.6	4.96	719	1000	5.6	2.7	1161	A2		0.033	1500
218	CF3CF2CF3 – perfluoropropane	188.02	-36.8	-34.2	71.9	161.4	2.64	383	1000	none			A1	2600	0.000	8830
———	R-218/134a/600 (32.7/62.8/4.5)	115.36	-36.6	-33.9	89.9	193.8	3.85	558							0.000	3700
———	R-218/134a/600 (33.0/62.0/5.0)	115.05	-36.5	-33.7	90.1	194.2	3.86	560							0.000	3800
———	R-22/134a/21 (65.0/15.0/20.0)	91.49	-35.9	-32.6	111.0	231.8	5.10	740							0.026	1400
409B	R-22/124/142b (65.0/25.0/10.0)	96.67	-35.6	-32.1	106.9	224.4	4.73	686	1000	none			A1		0.037	1500
———	R-290/22/124 (3.0/40.0/57.0)	105.45	-35.5	-31.9	108.6	227.5	4.46	647	500	none					0.027	1100

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Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
———	R-218/152a (83.5/16.5)	144.11	-35.3	-31.5	86.8	188.2	3.45	500							0.000	7400
———	R-125/134a/152a (35.0/40.0/25.0)	94.15	-34.9	-30.8	95.9	204.6	4.19	608	1000	wff					0.000	1800
401B	R-22/152a/124 (61.0/11.0/28.0)	92.84	-34.5	-30.1	105.6	222.1	4.69	680	1000	none	-2.7	-1161	A1		0.030	1300
———	R-22/142b/21 (65.0/20.0/15.0)	91.20	-34.4	-29.9	116.3	241.3	5.07	735							0.038	1600
———	R-22/142b/21 (65.0/30.0/5.0)	91.30	-34.4	-29.9	117.6	243.7	5.13	744							0.035	1500
409A	R-22/124/142b (60.0/25.0/15.0)	97.43	-34.4	-29.9	109.3	228.7	4.70	682	1000	none	3.0	1290	A1		0.038	1600
———	R-22/134a/21 (60.0/8.0/32.0)	92.32	-34.3	-29.7	119.9	247.8	5.26	763							0.024	1200
———	R-22/142b/21 (65.0/15.0/20.0)	91.01	-34.3	-29.7	114.0	237.2	4.96	719							0.044	1800
436A	R-290/600a (56.0/44.0)	49.33	-34.3	-29.7	115.9	240.6	4.27	619	1000	1.7	49.9	21453	A3		0.000	~20
500	R-12/152a (73.8/26.2)	99.30	-33.6	-28.5	102.1	215.8	4.17	605	1000	none			A1		0.605	8100
413A	R-218/134a/600a (9.0/88.0/3.0)	103.95	-33.4	-28.1	96.6	205.9	4.02	583	1000	8.8			A2		0.000	2000
436B	R-290/600a (52.0/48.0)	49.87	-33.4	-28.1	117.4	243.3	4.25	616	1000	1.7	49.9	21453	A3		0.000	~20
717	NH3 – ammonia	17.03	-33.3	-27.9	132.3	270.1	11.33	1643	25	16.7	22.5	9673	B2L r	<0.02	0.000	<1
———	R-22/134a/21 (50.0/20.0/30.0)	93.83	-33.1	-27.6	119.1	246.4	5.15	747							0.020	1200
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5)	96.93	-33.0	-27.4	112.7	234.9	4.68	679	1000	none	3.6	1548	A1		0.036	1500
———	R-22/124/600 (50.0/47.0/3.0)	102.64	-32.9	-27.2	110.4	230.7	4.59	666	900	none					0.029	1200
401A	R-22/152a/124 (53.0/13.0/34.0)	94.44	-32.9	-27.2	107.3	225.1	4.61	669	1000	none			A1		0.028	1200
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5)	101.59	-32.9	-27.2	111.0	231.8	4.59	666	1000	none			A1		0.034	1300
———	R-125/134a/600/601a (19.5/78.5/1.4/0.6)	103.84	-32.9	-27.2	95.3	203.5	4.08	592							0.000	1700
437A	R-125/134a/600/601 (19.5/78.5/1.4/0.6)	103.71	-32.9	-27.2	96.3	205.3	4.09	593	990	none			A1		0.000	1700
———	R-290/600a (50.0/50.0)	50.15	-32.8	-27.0	118.2	244.8	4.24	615		2.0	49.8	21410			0.000	~20
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5)	111.91	-32.6	-26.7	106.1	223.0	4.28	621	1000	none			d		0.021	5300
406A	R-22/600a/142b (55.0/4.0/41.0)	89.86	-32.5	-26.5	116.9	242.4	4.86	705	1000	8.2			A2		0.047	1900
C270	-CH2-CH2-CH2- – cyclopropane	42.08	-31.5	-24.7	125.2	257.4	5.58	809		2.4	49.7	21367		0.44	0.000	~20
———	R-22/152a (50.0/50.0)	74.89	-31.0	-23.8	108.4	227.1	4.80	696	1000						0.020	960
———	R-134a/152a/13I1 (26.4/22.8/50.8)	115.84	-30.0	-22.0	112.6	234.7	4.91	712		none					0.009	
505	R-12/31 (78.0/22.0)	103.48	-30.0	-22.0	117.8	244.0	4.73	686		none					0.640	
12	CCl2F2	120.91	-29.8	-21.6	112.0	233.6	4.14	600	1000	none	-0.8	-344	A1	100	0.820	10900
1234yf	CH2=CFCF3	114.04	-29.5	-21.1	94.7	202.5	3.38	490	500	6.2	10.7	4600	A2L r	0.029	0.000	<4.4
———	R-152a/13I1 (25.0/75.0)	131.35	-29.5	-21.1	118.3	244.9	4.96	719		none					0.014	
———	R-125/134a/601 (10.6/86.0/3.4)	102.22	-28.6	-19.5	102.7	216.9	4.14	600	1000	none					0.000	1500
426A	R-125/134a/600/601a (5.1/93.0/1.3/0.6)	101.56	-28.4	-19.1	99.8	211.6	4.09	593	990	none	4.7	2021	A1		0.000	1400
401C	R-22/152a/124 (33.0/15.0/52.0)	101.03	-28.3	-18.9	111.7	233.1	4.37	634	1000	none			A1		0.024	930
1132	CHF=CHF	64.03	-28.0	-18.4											0.000	
———	R-152a/600a (70.0/30.0)	63.45	-27.7	-17.9	107.0	224.6	4.03	585		3.15					0.000	99
———	R-152a/600a (73.0/27.0)	63.70	-27.7	-17.9	106.9	224.4	4.06	589		3.2					0.000	100
430A	R-152a/600a (76.0/24.0)	63.96	-27.6	-17.7	107.0	224.6	4.09	593	1000				A3		0.000	110
415B	R-22/152a (25.0/75.0)	70.19	-26.9	-16.4	111.4	232.5	4.65	674	1000	wff			A2		0.010	550

Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec- ular	NBP		Tc		Pc				HOC		Std 34	atmos- pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
134a	CH2FCF3	102.03	-26.1	-15.0	101.1	214.0	4.06	589	1000	none	4.2	1806	A1	13.4	0.000	1370
435A	R-E170/152a (80.0/20.0)	49.04	-26.1	-15.0	125.2	257.4	5.39	782	1000	3.5	28.9	12425	A3		0.000	27
429A	R-E170/152a/600a (60.0/10.0/30.0)	50.76	-25.5	-13.9	123.5	254.3	4.86	705	1000	2.9			A3		0.000	20
440A	R-290/134a/152a (0.6/1.6/97.8)	66.23	-25.4	-13.7	112.9	235.2	4.54	658	1000	4.8			A2 r		0.000	150
1243zf	CH2=CHCF3	96.05	-25.2	-13.4	105.5	221.9	3.74	542		4.0					0.000	<150
510A	R-E170/600a (88.0/12.0)	47.24	-25.2	-13.4	127.9	262.2	5.33	773	1000	3.0	33.9	14574	A3		0.000	3
———	R-134a/152a (85.0/15.0)	94.32	-25.1	-13.2	103.6	218.5	4.13	599							0.000	1200
420A	R-134a/142b (88.0/12.0)	101.84	-24.9	-12.8	104.8	220.6	4.09	593	1000	none			A1		0.007	1500
E170	CH3OCH3 – DME	46.07	-24.8	-12.6	127.2	261.0	5.34	775	1000	3.4	31.8	13672	A3	0.015	0.000	
40	CH3Cl – methyl chloride	50.49	-24.2	-11.6	143.1	289.6	6.67	967	50	8.0			B2	1.0	0.020	13
———	R-134a/142b (80.6/19.4)	101.73	-24.2	-11.6	107.2	225.0	4.10	595		none					0.012	1500
423A	R-134a/227ea (52.5/47.5)	125.96	-24.2	-11.6	99.1	210.4	3.56	516	1000	none			A1		0.000	2400
———	R-134a/124/600 (59.0/39.0/2.0)	111.31	-24.1	-11.4	107.1	224.8	3.99	579		none					0.008	1100
E143a	CH3OCF3	100.04	-24.1	-11.4	104.9	220.8	3.63	526						4.8	0.000	840
1261yf	CH3CF=CH2	60.07	-24.0	-11.2											0.000	
152a	CH3CHF2	66.05	-24.0	-11.2	113.3	235.9	4.52	656	1000	4.8	17.4	7481	A2	1.5	0.000	133
———	R-134a/152a (20.0/80.0)	71.06	-23.9	-11.0	111.5	232.7	4.44	644							0.000	380
416A	R-134a/124/600 (59.0/39.5/1.5)	111.92	-23.9	-11.0	107.1	224.8	3.98	577	1000	none	7.8	3353	A1		0.008	1100
400 >>	R-12/114 (60.0/40.0) – "60/40"	136.94	-23.2	-9.8	125.6	258.1	4.01	582	1000	none			A1		0.724	10000
———	R-218/134/600a (32.7/62.8/4.5)	115.36	-23.0	-9.4	109.3	228.7	3.90	566							0.000	3600
1234ye(E)	CHF2CF=CHF	114.04	-22.0	-7.6	106.7	224.1	3.53	512							0.000	
13I1	CF3I – trifluoroiodomethane	195.91	-21.9	-7.4	123.3	253.9	3.95	573		none				0.011	0.018	1
1225zc	CF2=CHCF3	132.03	-21.8	-7.2	103.4	218.1	3.31	480							0.000	
———	R-218/134/600 (32.7/62.8/4.5)	115.36	-21.5	-6.7	112.2	234.0	3.96	574							0.000	3600
1225ye(Z)	CHF=CFCF3	132.03	-21.0	-5.8	106.1	223.0	3.34	484		none				0.023	0.000	<3.6
400 >>	R-12/114 (50.0/50.0) – "50/50"	141.63	-20.8	-5.4	129.1	264.4	3.94	571	1000	none			A1		0.700	10000
———	R-152a/227ea (25.0/75.0)	122.01	-20.2	-4.4	105.9	222.6	3.48	505		none					0.000	2700
1234ze(E)	CHF=CHCF3	114.04	-19.0	-2.2	109.4	228.9	3.64	528	1000	7.6				0.045	0.000	6
134	CHF2CHF2	102.03	-17.6	0.3	119.0	246.2	4.64	673	1000	none	4.3	1849		9.7	0.000	1110
227ea	CF3CHFCF3	170.03	-16.3	2.7	101.8	215.2	2.93	425	1000	none	3.3	1419	A1	38.9	0.000	3580
1225ye(E)	CHF=CFCF3	132.03	-16.0	3.2	113.6	236.5	3.40	493						0.013	0.000	
———	R-290/124/123 (3.0/40.0/57.0)	136.27	-15.4	4.3	151.1	304.0	3.99	579							0.014	290
263fb	CH3CH2CF3	98.07	-13.0	8.6										1.2	0.000	104
506	R-31/114 (55.1/44.9)	93.69	-12.3	9.9	142.2	288.0	5.16	748		none					0.260	
124	CHClFCF3	136.48	-12.0	10.4	122.3	252.1	3.62	525	1000	none	0.9	387	A1	5.9	0.020	619
600a	CH(CH3)2CH3 – isobutane	58.12	-11.7	10.9	134.7	274.5	3.63	526	1000	1.6	49.4	21238	A3	0.016	0.000	~20
764	SO2 – sulfur dioxide	64.06	-10.0	14.0	157.5	315.5	7.88	1143	2	none			B1		0.000	
142b	CH3CClF2	100.50	-9.1	15.6	137.1	278.8	4.06	589	1000	8.0	9.8	4213	A2	17.2	0.060	2220
31	CH2ClF	68.48	-9.1	15.6	151.8	305.2	5.13	744	0.1					1.3	0.010	
———	R-600a/600 (50.0/50.0)	58.12	-6.7	19.9	145.2	293.4	3.80	551		1.6					0.000	~20
630	CH3(NH2) – methylamine	31.06	-6.7	19.9	156.9	314.4	7.43	1078	5	4.9						
C318	-CF2-CF2-CF2-CF2-	200.03	-6.0	21.2	115.2	239.4	2.78	403	1000	none			A1	3200	0.000	10300
12B1	CBrClF2	165.36	-4.0	24.8	154.0	309.2	4.10	595		none				16	7.900	1890
1261zf	CH2=CHCH2F	60.07	-3.0	26.6										0.002	0.000	
236cb	CH2FCF2CF3	152.04	-1.4	29.5	130.2	266.4	3.12	453						13.1	0.000	1290

Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC		Std 34	atmos-pheric		
number	chemical formula or blend composition - common name	molecular mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	safety group	life (yr)	ODP	GWP 100 yr
236fa	CF3CH2CF3	152.04	-1.4	29.5	124.9	256.8	3.20	464	1000	none			A1	242	0.000	9820
600	CH3CH2CH2CH3 – butane	58.12	-0.5	31.1	152.0	305.6	3.80	551	1000	2.0	49.5	21281	A3	0.018	0.000	~20
———	R-124/123 (42.0/58.0)	145.56	0.3	32.5	156.2	313.2	3.83	555							0.014	300
1225yc	CHF2CF=CF2	132.03	1.5	34.7											0.000	
114	CClF2CClF2	170.92	3.6	38.5	145.7	294.3	3.26	473	1000	none	-3.1	-1333	A1	190	0.580	9180
114a	CCl2FCF3	259.82	3.6	38.5	145.7	294.3	4.92	714						100.0		
40B1	CH3Br – methyl bromide	94.94	4.6	40.3	194.0	381.2	5.22	757	1	10				0.8	0.660	5
143	CH2FCHF2	84.04	5.0	41.0	156.7	314.1	5.24	760		5.8	10.9	4686		3.5	0.000	352
E134	CHF2OCHF2	118.03	5.5	41.9	147.1	296.8	4.23	614		none				24.4	0.000	5960
E236fa1	CF3OCH2CF3	168.04	5.7	42.3	128.8	263.8	2.74	397						7.5	0.000	988
E245cb1	CH3OCF2CF3	150.05	5.9	42.6	133.7	272.7	2.89	419						4.9	0.000	680
236ea	CHF2CHFCF3	152.04	6.2	43.2	139.3	282.7	3.50	508	1000	none	5.4	2322		11.0	0.000	1410
2316	CF2=CFCF=CF2	162.03	6.5	43.7	139.6	283.3				7				0.003	0.000	
21	CHCl2F	102.92	8.9	48.0	178.3	352.9	5.18	751	10	none			B1	1.7	0.040	151
1234ze(Z)	CHF=CHCF3	114.04	9.0	48.2	153.6	308.5	3.97	576							0.000	
601b	(CH3)4C – neopentane	72.15	9.5	49.1	160.6	321.1	3.20	464	600	1.4					0.000	~20
160	CH3CH2Cl – ethyl chloride	64.51	13.1	55.6	187.3	369.1	5.27	764	100	3.6	20.6	8856		0.107	0.020	
1233xf	CH2=CClCF3	130.50	14.5	58.1											0.000	
245fa	CHF2CH2CF3	134.05	15.1	59.2	154.0	309.2	3.65	529	300	none	6.1	2623	B1	7.7	0.000	1050
329mcc	CHF2CF2CF2CF3	220.04	15.1	59.2	140.2	284.4	2.39	347		none				28.4	0.000	2530
631	CH3CH2(NH2) – ethylamine	45.08	16.6	61.9	183.0	361.4	5.62	815	5	3.5						
338mcf	CF3CH2CF2CF3	202.05	19.9	67.8	150.6	303.1	2.50	363		none					0.000	
11	CCl3F	137.37	23.7	74.7	198.0	388.4	4.41	640	C1000	none	0.9	387	A1	45	1.000	4750
———	R-123/601a (75.0/25.0) – M523d	119.49	24.4	75.9	185.1	365.2	3.82	554							0.008	63
———	R-123/601a (80.0/20.0) – M523c	124.95	24.6	76.3	184.9	364.8	3.82	554							0.008	66
———	R-123/601a (85.0/15.0) – M523b	130.94	24.9	76.8	184.6	364.3	3.81	553							0.009	68
245ca	CH2FCF2CHF2	134.05	25.1	77.2	174.4	345.9	3.93	570		7.1	8.4	3611		6.5	0.000	726
———	R-123/601a (90.0/10.0) – M523a	137.53	25.5	77.9	184.4	363.9	3.79	550							0.009	71
338mcc	CH2FCF2CF2CF3	202.05	27.5	81.5	158.8	317.8	2.73	396							0.000	
1233zd(E)	CHCl=CHCF3	130.50	27.7	81.9										0.071	0.000	
1233zd(Z)	CHCl=CHCF3	130.50	27.7	81.9											0.000	
123	CHCl2CF3	152.93	27.8	82.0	183.7	362.7	3.66	531	50	none	2.1	903	B1	1.3	0.010	77
601a	(CH3)2CHCH2CH3 – isopentane	72.15	27.8	82.0	187.2	369.0	3.38	490	600	1.3	35.0	15047	A3	0.009	0.000	~20
E338mcf2	CF3CH2OCF2CF3	218.05	27.9	82.2	148.5	299.3	2.33	338						7.5	0.000	963
E245fa1	CHF2OCH2CF3	150.05	29.3	84.7	170.9	339.6	3.42	496						5.5	0.000	740
E347mmy1	CF3CF(OCH3)CF3	200.05	29.4	84.9	160.8	321.4	2.55	370						3.4	0.000	343
611	HCOOCH3 – methyl formate	60.05	31.7	89.1	214.0	417.2	5.99	869	100	4.5			B2	0.197	0.000	
141b	CH3CCl2F	116.95	32.0	89.6	204.4	399.9	4.21	611	500	5.8	8.6	3697		9.2	0.120	717
———	R-601a/601 (37.0/63.0)	72.15	32.7	90.9	193.2	379.8	3.38	490							0.000	~20
E347mcc1	CH3OCF2CF2CF3	200.05	34.2	93.6	164.6	328.3	2.48	360		none				5.0	0.000	553
610	CH3CH2OCH2CH3 – ethyl ether	74.12	34.6	94.3	214.0	417.2	6.00	870	400	1.9					0.000	
601	CH3CH2CH2CH2CH3 – pentane	72.15	36.1	97.0	196.6	385.9	3.37	489	600	1.2			A3	0.009	0.000	~20
1130a	CH2=CCl2	96.94	37.0	98.6	230.1	446.2	7.08	1027	5	6.5				0.002		
E254cb1	CH3OCF2CHF2	132.06	37.2	99.0										2.5	0.000	345
———	R-601/602 (90.1/9.9)	73.33	37.8	100.0	200.4	392.7	3.37	489							0.000	~20
30	CH2Cl2 – methylene chloride	84.93	40.2	104.4	237.0	458.6	6.08	882	50	13			B2	0.394		10

Table 2 continued: Physical, Safety, and Environmental Data for Refrigerants (sorted by normal boiling point)

refrigerant		physical data							safety data					environmental data		
		molec-ular	NBP		Tc		Pc				HOC			atmos-pheric		
number	chemical formula or blend composition - common name	mass	(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)	OEL (PPMv)	LFL (%)	MJ/kg	Btu/lb	Std 34 safety group	life (yr)	ODP	GWP 100 yr
1130(E)	CHCl=CHCl	96.94	47.5	117.5	234.1	453.4	5.19	753	200	9.7						
113	CCl2FCClF2	187.38	47.6	117.7	214.1	417.4	3.39	492	1000	none	0.1	43	A1	85	0.850	6130
1130	CHCl=CHCl – dielene	96.94	47.8	118.0	243.3	469.9	5.48	795	200	5.6						
———	-(CH2)5- – cyclopentane	70.13	49.4	120.9	238.6	461.5	4.51	654	600	1.1				0.007	0.000	11
225ca	CHCl2CF2CF3	202.94	51.1	124.0					10					1.9	0.020	122
———	R-225ca/225cb (45.0/55.0)	202.94	54.0	129.2					50	none						7400
225cb	CHClFCF2CClF2	202.94	56.1	133.0					200					5.9	0.030	606
1130(Z)	CHCl=CHCl	96.94	60.3	140.5	234.1	453.4	5.19	753	200	3.3						
20	CHCl3 – chloroform	119.38	61.2	142.2	263.4	506.1	5.38	780	10	none				0.408	0.000	30
160I1	CH3CH2I – iodoethane	155.97	72.4	162.3										0.011		
10	CCl4 – carbon tetrachloride	153.82	76.7	170.1	283.3	541.9	4.56	661	5	none				26	0.820	1400
1120	CHCl=CCl2 – trielene	131.39	88.0	190.4					50	8				0.013	0.000	
112a	CCl3CClF2	203.83	91.7	197.1	279.2	534.6	4.83	701	500	none						
112	CCl2FCCl2F	203.83	92.8	199.0	278.0	532.4	4.83	701	500	none						
718	H2O – water	18.02	100.0	212.0	373.9	705.0	22.06	3200		none			A1		0.000	<1

NBP = normal boiling point temperature; Tc = critical temperature; Pc = critical pressure; OEL = occupational exposure limit (8 hr time-weighted average unless value is preceded by C for ceiling); LFL = lower flammability limit (% volume in air), "wff" signifies that the worst case of fractionation is flammable; HOC = heat of combustion; ODP = ozone depletion potential; GWP = global warming potential (for 100 yr integration)

Suffixes to safety classifications indicate recommended changes that are not final yet ("d" for deletion and "r" for revision or addition) or classifications assigned as provisional ("p"); "d" alone indicates that a prior classification was deleted (withdrawn).

Data sources are identified in the Refrigerant Database; verify the data and associated limitations in those sources before use. (C) JMC-2011.02.07

- lower flammability limit (LFL) in % concentration in ambient air: Where evident, the included values are those determined in accordance with ASHRAE Standard 34 (ASHRAE, 2010a and 2010b). There is significant variation in reported values, due both to differences in measurements among separate laboratories and, in some cases, determination with older versions of the standard (for example using a different vessel size or ignition source) or different evaluation standards.
- heat of combustion (HOC) determined in accordance with ASHRAE 34 (ASHRAE, 2010a and 2010b)
- safety classification, if assigned, in accordance with ASHRAE 34 (ASHRAE, 2010a and 2010b): The leading letters A and B signify "lower" and "higher" toxicity, respectively, based on occupational exposure limits. The numbers 1, 2, and 3 indicate "no flame propagation," "lower flammability," and "higher flammability," respectively, at specified test conditions predicated on both LFL and heat of combustion. The acronym "wff" signifies that either the worst case of formulation or the worst case of fractionation for flammability, both as defined in Standard 34 (ASHRAE, 2010a), is flammable in either the vapor or liquid phase. A recent modification to this standard, also proposed for International Organization for Standardization Standard 817 (ISO, 2008), subdivides group 2 based on the burning velocity, with 2L implying those more difficult to ignite (ASHRAE, 2010a). Some of the classifications are followed or replaced by lower case letters that indicate:

  d: a prior classification was deleted and the refrigerant no longer has a safety classification

  p: a classification assigned on a provisional basis

  r: a recommended revision or addition as shown, but pending final approval and/or publication

  Note that ASHRAE 34 and ISO 817 classifications differ for blends predicated on an addendum to ASHRAE 34 that bases the flammability component of classifications on the worst case of fractionation (ASHRAE, 2010a, and ISO, 2008). ISO 817, at least at this point, continues to show dual classifications, namely with the flammability class as formulated and for the worst case of fractionation.

ENVIRONMENTAL DATA

- atmospheric lifetime (τ_{atm}) in years: Note that τ_{atm} normally is not indicated for blends since it is ambiguous whether the lifetime pertains to the blend as formulated, a modified formulation as some components decompose more rapidly than others, or the most enduring component.
- ozone depletion potential (ODP) relative to R-11 (a CFC): ODPs indicate the relative ability of refrigerants (and other chemicals) to destroy stratospheric ozone. The values included reflect the latest scientific consensus data as adopted in the WMO (2010) *Scientific Assessment*. Additional, consistent ODP data are included as available from other assessments or peer-reviewed publications for refrigerants for which consensus ODPs were not adopted. The ODPs indicated for blends are calculated mass-weighted averages (Calm, 2010) based on the latest accepted IUPAC atomic weights (Wieser and Berglund, 2009) for the components.
- global warming potential (GWP) relative to CO_2 for 100 year integration based on the values reported in the IPCC (2007) *Fourth Assessment Report* and as updated in the WMO (2010) *Scientific Assessment*. The values shown are direct GWPs. Indirect and net GWPs are discussed in IPCC (2007) and WMO (2010), and they should not be confused with TEWI- and LCCP-type analyses that are application-specific and combine direct-GWP with energy-related impacts (see, for example, UNEP, 2011). Despite reporting of consensus GWP values to three digits of precision, the documented uncertainties are of the order of ±35% (WMO, 2010, table 5a-4) and higher for some refrigerants and other chemicals. Accordingly, the actual precision is significantly lower than implied in the reported values. Future assessments are likely to continue to refine the data. Additional, consistent GWP data are similarly included from other assessments or peer-reviewed publications for refrigerants for which consensus GWPs were not adopted. The GWPs indicated for blends are calculated mass-weighted averages (Calm, 2010) based on the latest accepted IUPAC atomic weights (Wieser and Berglund, 2009) for the components. The GWP values shown as "~20" or "<20" in Tables 1 and 2 for hydrocarbons reflect uncertainty in calculation, for which there is no scientific consensus on averaged global values at this time. The approximations shown lie in the ranges of uncertainty. Further study is needed using three-dimensional (3D) models for diverse release scenarios to determine representative GWPs for chemicals with very short atmospheric lifetimes (IPCC, 2005 and 2007), including most saturated and especially unsaturated hydrocarbons, as discussed below.

The 284 refrigerants included in table 1 (slightly fewer in table 2 due to deletion of those without reliably known boiling points) represent less than a third of the 910 currently tracked in the Refrigerant Database (Calm, 2010). This database identifies the sources for specific data and, for most refrigerants, additional data as well as conflicting values reported by different investigators. The primary sources for the data presented herein are cited in the above discussion of parameters. The data and their limitations should be verified in the referenced source documents, particularly where use of the data would risk loss to life or property. Inclusion herein, and for safety data in particular, does not imply verification or endorsement. REFPROP (Lemmon *et al.*, 2010) and similar models can be used to calculate further properties for the included and additional refrigerants. Despite tabulation herein of 284 and tracking of 910 refrigerants, the bulk of historical and current use by original equipment manufacturers is much fewer – approximately a dozen at a given time – to accommodate various operating temperatures, compressor and heat exchanger types, and applications. The larger quantities reflect specialized needs, additional aftermarket service fluids for which there are many vendors with local and regional markets, publicized developmental blends, historical refrigerants of which most have been phased out, and abandoned candidates that had significance in recent years. The authors speculate that approximately a dozen refrigerants (single compound and blends) will again represent the majority of use upon completion of the current and subsequent transitions, to the fourth and predictable fifth generations, respectively.

2.1. ODP and GWP Data for Regulatory and Reporting Purposes

The ODP and GWP data in tables 1 and 2 reflect the latest consensus determinations based on scientific assessments. However, the reduction requirements and allocations under international agreements and provisions in many national regulations pursuant to them use older data or estimates. Table 3 compares the current scientific ODPs to the "regulatory" ODPs used in the Vienna Convention for the Protection of the Ozone Layer and the subordinate Montreal Protocol on Substances that Deplete the Ozone Layer. Table 4 similarly contrasts consensus GWPs with those for reporting and emission reductions under the United Nations Framework Convention on Climate Change and the subordinate Kyoto Protocol.

Table 3: Scientific and Regulatory ODPs for BFC, CFC, and HCFC Refrigerants

	ODP	
refrigerant	scientific [a]	regulatory [b]
11	1.0	1.0
12	0.82	1.0
12B1	7.9	3.0
13		1.0
13B1	15.9	10.0
21		0.04
22	0.04	0.055
113	0.85	0.8
114	0.58	1.0
115	0.57	0.6
123	0.01	0.02
124	0.02	0.022
142b	0.06	0.065

[a] as adopted in the latest *Scientific Assessment* (WMO, 2010). These ODPs are semi-empirical except for HCFC-123, which is a modeled value of 0.0098, based on its short atmospheric lifetime.
[b] Montreal Protocol (UNEP, 2009)

Table 4: Current Consensus and Reporting GWPs for HFC and PFC Refrigerants

	GWP [a]	
refrigerant	scientific [b]	reporting [c]
14	7,390	6,500
23	14,200	11,700
32	716	650
116	12,200	9,200
125	3,420	2,800
134a	1,370	1,300
143a	4,180	3,800
152a	133	140
218	8,830	7,000
227ea	3,580	2,900
236fa	9,820	6,300
C318	10,300	8,700
744	1	1

[a] for 100 yr integration
[b] as adopted in the latest *Scientific Assessment* (WMO, 2010)
[c] Kyoto Protocol (UNFCCC, 2004, and IPCC, 1995)

2.2. Ozone Depletion Potentials

The ODPs presented in tables 1 and 2 are semi-empirical values except that for R-123 (an HCFC), for which a model-derived value was adopted as more indicative in the latest international scientific assessment (WMO, 2010). Semi-empirical ODPs are calculated values that incorporate adjustments for observed atmospheric measurements. The approach is conceptually more accurate than other metrics, but the data needed are difficult to measure precisely and it is still evolving with further and improved measurements and understanding. Other ODP indices include modeled, time-dependent, and regulatory variants (Calm and Hourahan, 2007 and 2011; WMO, 2010). Modeled data are determined by large programs that calculate impacts based on decomposition paths, rates, atmospheric conditions, and the influences of additional ozone depleting substances. Determinations increasingly employ three-dimensional (3D) models, especially for refrigerants and other chemicals with short atmospheric lifetimes. Time-dependent ODPs use chemicals other than R-11 as the reference to emphasize impacts for selected, typically short, timeframes. Normalizing values to short-lived compounds accentuates near-term impacts, but discounts long-term effects. Time-dependent ODPs are not cited often, particularly since the release of ozone-depleting substances already has peaked and recovery of the stratospheric ozone layer is underway. Regulatory ODPs generally reflect old data used to set phaseout steps, determine compliance with the Montreal Protocol, and allocate production quotas in national regulations. The ODP values listed in the annexes to the Montreal Protocol, for example, have not been updated since 1987 for CFCs and 1992 for HCFCs. A note in the Protocol indicates that the values “are estimates based on existing knowledge and will be reviewed and revised periodically,” but that has not happened yet (UNEP, 2009).

2.3. Data for Very Short-Lived Substances (VSLSs)

Refrigerants and other chemicals with lifetimes of 0.5 yr or less fall in a special category identified as Very Short-Lived Substances (VSLSs) for atmospheric environmental metrics (WMO, 2010). Emissions of ODSs with very short lifetimes at equatorial latitudes have more stratospheric impact (deliver more chlorine, bromine, or iodine to the stratosphere) than those at mid- and high-latitudes. The difference results from atmospheric circulation patterns with predominantly downward convection at the poles (cold air sinking) and upward convection (warm air rising) at the equator. Longer transit times allow for more near-surface decomposition. Specific location, altitude, season, and local atmospheric conditions also come into play. While the longer-lived ODSs account for the majority of stratospheric halogen loading, halogenated VSLSs and their degradation products also contribute. Likewise, because VSLS emissions are unlikely to be evenly distributed globally, their radiative forcing (used to calculate GWPs) using global mean conditions may be subject to error (WMO, 2010).

The VSLS implications apply for some historic refrigerants such as R-30 (methylene chloride, an HCC) and to others gaining new or renewed attention, such as R-E170 (dimethyl ether) and R-13I1 (CF_3I, a fluoroiodocarbon, FIC). They also apply to many hydrocarbons and especially to unsaturated hydrocarbons such as R-1150 (ethylene) and R-1270 (propylene). Accordingly, the lifetimes for refrigerants included in tables 1 and 2 for VSLSs generally are local rather than global lifetimes. Likewise, VSLS ODP and GWP values are local approximations. Atmospheric scientists typically cite separate values for the mid-latitudes, where most population centers exist, and equatorial regions, for which resulting ODPs and GWPs typically are higher. Still, even the higher equatorial ODPs and GWPs generally are so much lower, than values for long-lived chemicals, that a single value – though imprecise globally – suggests an order of magnitude for comparisons.

For substances with lifetimes not significantly exceeding 0.5 yr (under approximately 1.5 or even 2 yr), global values based on 3D modelling, weighted for multiple emission locations, account for the significant decomposition fraction before reaching the upper atmosphere. The short atmospheric lifetime of 1.3 yr for R-123 (an HCFC) was the basis for the exception in its ODP determination, using a 3D-modeled rather than semi-empirical value, in the latest scientific assessment (WMO, 2010).

3. CONCLUSIONS

Driven by scientific findings, regulatory requirements, and market pressures, a fourth generation of refrigerants appears imminent. The governing selection criteria for the new generation will add low GWP – initially

150 or less for 100 yr integration – to old requirements for suitability, safety, and materials compatibility. The new generation must offer high efficiency or the change to address low GWP will backfire with increased, rather than decreased, net greenhouse gas emissions. The tabulated data identify and provide summary physical, safety, and environmental data to facilitate screening and comparisons for historic, current, and candidate refrigerants.

4. ACKNOWLEDGEMENTS

The authors have published tabular summaries of key physical, safety, and environmental data for refrigerants on approximately a four-year cycle, since 1989, to support international assessments, updates to commonly used handbooks and texts, and other studies; this version updates that by Calm and Hourahan (2007). A shortened version of table 1 as well as tables 3 and 4 are included in the *2010 Report of the United Nations Environment Programme (UNEP) Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee* (Calm and Hourahan, 2011; UNEP 2011).

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