

King Abdul-Aziz University

Mechanical Engineering Department

ME451

Refrigeration and Air Conditioning

Refrigerants

Outline

- Desirable characteristics in ideal refrigerant
- Definition of some terms (CFC, HCFC, HFC, etc
- Ozone Depletion
- Safety groups
- Numbering system
- Azeotropes and Zeotropes

Desired properties in Refrigerants

Thermodynamics characteristics

- High latent heat of vaporization
- Low freezing temperature
- Relatively high critical temperature
- Positive evaporator pressure
- Relatively low condensing pressure

Desired properties in Refrigerants

Physical and chemical characteristics

- High dielectric strength of vapor
- Good heat transfer characteristics
- Satisfactory oil solubility
- Low water solubility
- Inertness and stability

Desired properties in Refrigerants

Safety

- Non-flammable
- Non-toxic
- Non-irritable

Additional characteristics of refrigerants

- Low cost
- Environment friendly (Not affecting ozone layer)
- Easy to detect in case of leak

Definitions

Hydrocabons: Hydrogen carbon compounds such as methane (CH_4 , Ethane C_2H_6 etc.)

Halons : Chlorine (Cl) , Fluorine (F) or Bromine (B)

Halocabons Originally hydrocarbons which contain Halons, (Ex. CCl_2FH)

CFC Hydrocarbons fully halogenated by Cl and/or F atoms (Ex. CCl_2F_2)

HCFC Hydrocarbons partially halogenated by Cl and/or F (CHF_2Cl)

HFC Hydrocarbons partially halogenated by F atoms only (CHF_3)

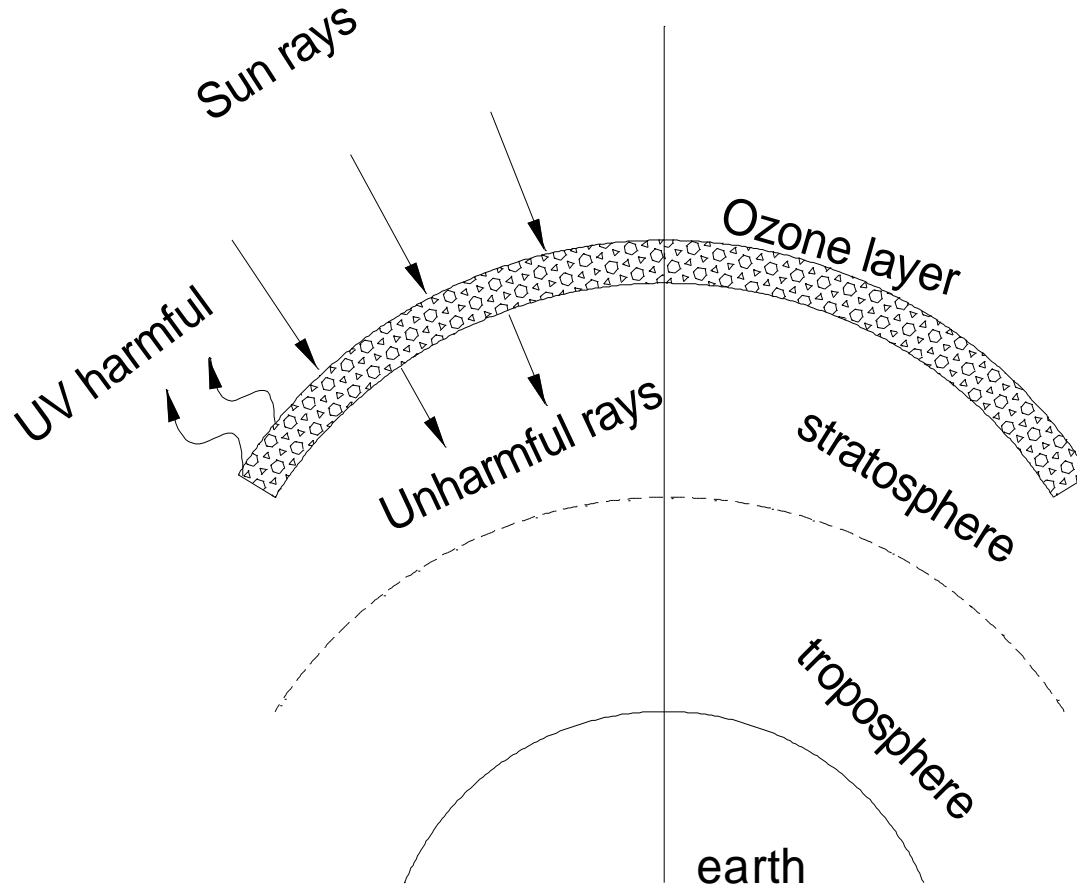
ODP Ozone depletion potential [An index to indicate ability of substance to deplete the Ozone layer]

GWP Global warming potential [An index to indicate a substance green house effect]

Ozone Depletion

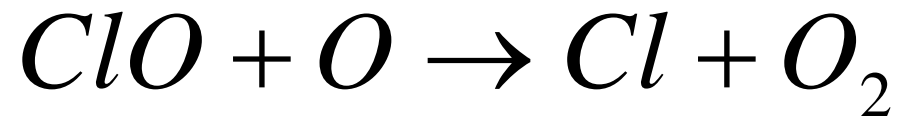
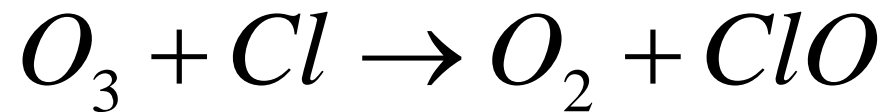
- Ozone (O₃) layer about 20-80 km above ground
- It Protects earth from harmful UV (0.4 to 0.01 μm) solar radiation
- UV affects life on earth
- Mainly Cl atoms react with O₃ and destroy it
- CFC and HCFC contain Cl
- International regulation to reduce and stop substances that deplete Ozone layer
- HFC's such as R-134a has no chlorine atoms, and therefore does not affect the ozone layer

Ozone Depletion



Ozone Depletion

Chemical reaction behind Ozone depletion



Effects of Ozone Depletion

1- Troposphere air quality (formation of harmful chemicals)

2-Human health (Diseases like cancer)

3-Plant life (reduce yields)

4-Animal and marine life

5-Material damage

Safety Groups of Refrigerant

Increasing flammability

Higher flammability	A3	B3
Lower flammability	A2	B2
No flame propagation	A1	B1
	Lower Toxicity	Higher Toxicity

Table 15-1 Properties of Selected Refrigerants

Refrigerant Number	Chemical Name	Chemical Formula	Molecular Mass	Normal Boiling Point		Safety Group
				C	F	
Methane series						
11	Trichlorofluoromethane	CCl ₃ F	137.4	-24	75	A1
12	Dichlorodifluoromethane	CCl ₂ F ₂	120.9	-30	-22	A1
13	Chlorotrifluoromethane	CClF ₃	104.5	-81	-115	A1
14	Carbon tetrafluoride	CF ₄	88.0	-128	-198	A1
21	Dichlorofluoromethane	CHCl ₂ F	102.9	9	48	B1
22	Chlorodifluoromethane	CHClF ₂	86.5	-41	-41	A1
23	Trifluoromethane	CHF ₃	70.0	-82	-116	
50	Methane	CH ₄	16.0	-161	-259	A3
Ethane series						
114	1,2-Dichlorotetrafluoroethane	CClF ₂ CClF ₂	170.9	4	38	A1
123	2,2-Dichloro-1,1,1-trifluoroethane	CHCl ₂ CF ₃	153.0	27	81	B1
124	2-Chloro-1,1,1,2-tetrafluoroethane	CHClF ₂ CF ₃	136.5	-12	10	
125	Pentafluoroethane	CHF ₂ CF ₃	120.0	-49	-56	
134a	1,1,1,2-Tetrafluoroethane	CH ₂ FCF ₃	102.0	-26	-15	A1
143a	1,1,1-Trifluoroethane	CH ₃ CF ₃	84.0	-47	-53	
152a	1,1-Difluoroethane	CH ₃ CHF ₂	66.0	-25	-13	A2
170	Ethane	CH ₃ CH ₃	30.0	-89	-128	A3
Propane series						
290	Propane	CH ₃ CH ₂ CH ₃	44.0	-42	-44	A3
Inorganic compounds						
717	Ammonia	NH ₃	17.0	-33	-28	B2
718	Water	H ₂ O	18.0	100	212	A1
744	Carbon dioxide	CO ₂	44.0	-78 ^a	-109 ^a	A1
764	Sulfur dioxide	SO ₂	64.1	-10	14	B1
Zeotropes						
400	R-12/114 (must be specified)	None	None			A1/A1
Azeotropes						
502	R-22/115 (48.8-51.2)	19 66	112.0	-45	-49	A1

Numbering System of Refrigerants

Hydrocarbons and derivatives

1. The first digit on the right is the number of fluorine (**F**) atoms in the compound.
2. The second digit from the right is **one more** than the number of hydrogen (**H**) atoms in the compound.
3. The third digit from the right is **one less** than the number of carbon (**C**) atoms in the compound. When this digit is zero, it is omitted from the number.

Numbering of refrigerants

4. Blends are designated by their respective refrigerant numbers and weight proportions, named in the order of increasing normal boiling points of the components, for example R-22/12 (90/10)
5. Zeotropes blends that have been commercialized are assigned an identifying number in the 400 series accompanied by the weight proportion of the components, for example R-400(90/10) for mixtures of R-12 and R-114.
6. Azeotropes that have been commercialized are assigned an identifying number in the 500 series with no composition shown.

Numbering of refrigerants

7. Miscellaneous Organic refrigerants are assigned serial numbers in the 600 series.
8. Inorganic compounds are designated by adding 700 to their molecular mass; for example, **water** is 718.
9. The letter C is used before number designations to identify cyclic derivatives. Lowercase letters are appended after numbers to distinguish isomers refrigerants with the same chemical composition but with differing molecular structures.

R

C-1

H+1

F

Example

Di-Chloro-fluoro-methane



C-1

H+1

F

R

0

2

1

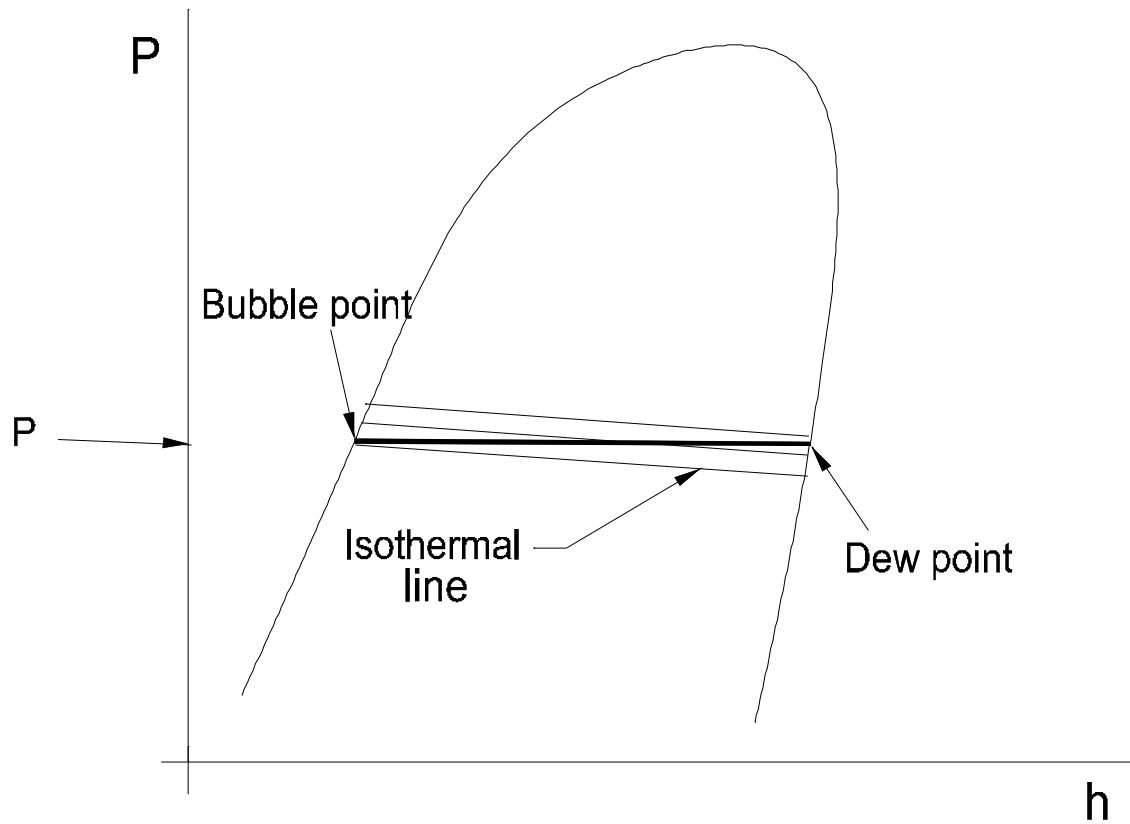
R-21

Zeotrope and Azeotropes

Azeotropes: Evaporation and condensation occur at a single temperature [Just like pure substances]

Zeotrope: Evaporation and condensation occur at different temperatures

Temperature Glide For Zeotropes



Azeotropes, Zeotropes and Temperature glide

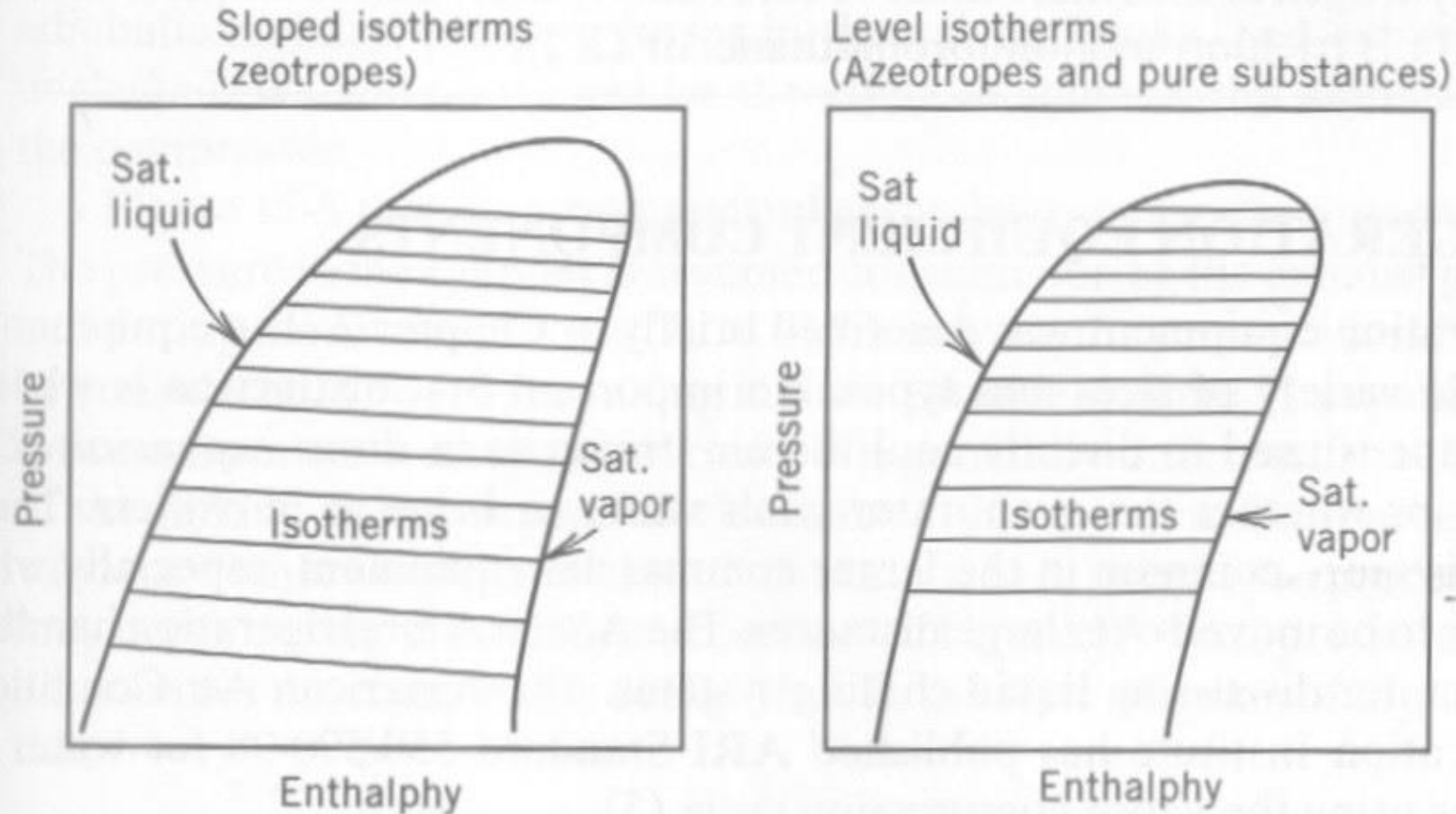


Figure 15-4 Comparison of pressure–enthalpy diagrams for a zeotrope and an azeotrope.

Methane series

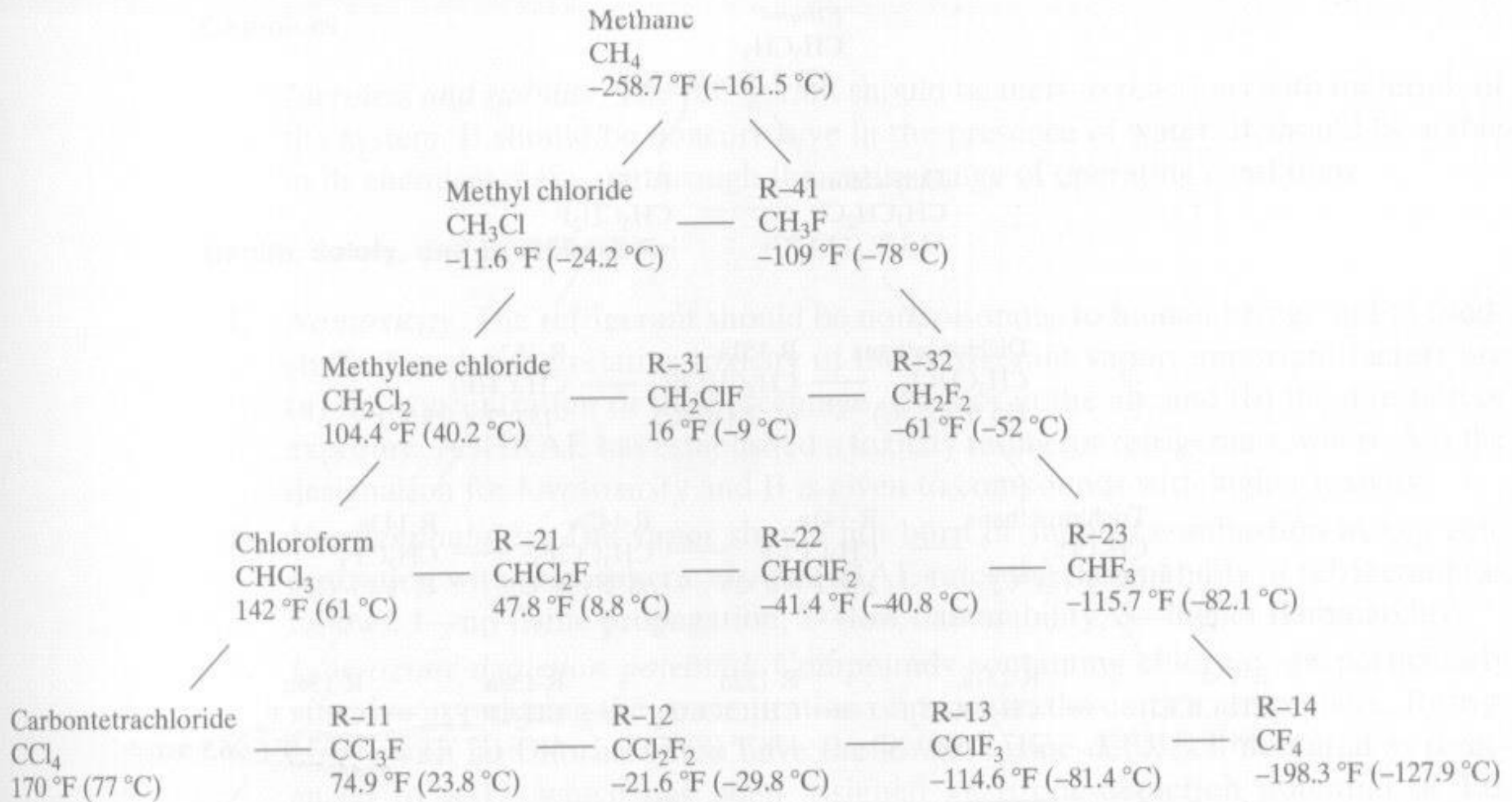


Figure 4.1 Normal boiling points in °F (°C) for the methane series of chloro-fluorocarbon refrigerants arranged according to molecular structure.

Refrigerant 407C [R-32/125/134a (23/25/52)] Properties of Liquid on the Bubble Line and Vapor on the Dew Line

Absolute Pressure, MPa	Temperature*, °C		Density, kg/m ³	Volume, m ³ /kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c _p , kJ/(kg·K)			Velocity of Sound, m/s		Absolute Pressure, MPa
	Bubble	Dew			Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	c _p /c _v	
			Liquid	Vapor										
0.0100	-82.79	-74.95	1496.9	1.897	91.30	365.97	0.5293	1.9442	1.245	0.662	1.180	1025.	149.1	0.01000
0.0200	-72.79	-65.14	1468.5	0.9907	103.81	372.02	0.5934	1.9078	1.257	0.685	1.179	968.	151.9	0.02000
0.0400	-61.48	-54.06	1435.6	0.5176	118.11	378.83	0.6627	1.8739	1.271	0.714	1.180	908.	154.6	0.04000
0.0600	-54.16	-46.88	1413.8	0.3539	127.48	383.20	0.7061	1.8553	1.282	0.734	1.182	869.	156.2	0.06000
0.0800	-48.59	-41.42	1397.1	0.2701	134.64	386.48	0.7384	1.8427	1.291	0.751	1.184	841.	157.2	0.08000
0.1000	-44.04	-36.97	1383.2	0.2190	140.53	389.13	0.7643	1.8333	1.298	0.765	1.187	818.	157.9	0.10000
0.101520	-43.77	-36.70	1382.3	0.2163	140.89	389.29	0.7658	1.8328	1.299	0.766	1.187	816.	157.9	0.10132
0.1200	-40.17	-33.18	1371.2	0.1844	145.58	391.35	0.7861	1.8258	1.305	0.778	1.189	798.	158.4	0.12000
0.1400	-36.78	-29.85	1360.6	0.1594	150.03	393.28	0.8050	1.8196	1.312	0.790	1.192	781.	158.8	0.14000
0.1600	-33.75	-26.89	1351.1	0.1405	154.02	394.99	0.8217	1.8143	1.318	0.801	1.195	766.	159.1	0.16000
0.1800	-31.00	-24.20	1342.3	0.1256	157.65	396.51	0.8367	1.8098	1.324	0.811	1.197	752.	159.4	0.18000
0.2000	-28.48	-21.73	1334.2	0.1137	161.00	397.90	0.8504	1.8058	1.329	0.821	1.200	740.	159.5	0.20000
0.2200	-26.15	-19.45	1326.7	0.1038	164.11	399.16	0.8630	1.8022	1.335	0.830	1.203	728.	159.7	0.22000
0.2400	-23.98	-17.33	1319.6	0.09552	167.02	400.33	0.8746	1.7989	1.340	0.839	1.206	717.	159.8	0.24000
0.2600	-21.95	-15.34	1312.9	0.08847	169.75	401.41	0.8855	1.7960	1.345	0.847	1.208	707.	159.8	0.26000
0.2800	-20.03	-13.46	1306.5	0.08240	172.34	402.42	0.8957	1.7933	1.349	0.855	1.211	697.	159.9	0.28000
0.3000	-18.22	-11.69	1300.5	0.07712	174.80	403.36	0.9053	1.7908	1.354	0.863	1.214	688.	159.9	0.30000
0.3200	-16.49	-10.00	1294.7	0.07247	177.14	404.25	0.9144	1.7885	1.359	0.871	1.217	680.	159.9	0.32000
0.3400	-14.85	-8.39	1289.1	0.06835	179.38	405.09	0.9231	1.7863	1.363	0.879	1.220	672.	159.9	0.34000
0.3600	-13.28	-6.86	1283.8	0.06467	181.53	405.88	0.9313	1.7843	1.368	0.886	1.222	664.	159.8	0.36000
0.3800	-11.78	-5.39	1278.6	0.06137	183.59	406.63	0.9392	1.7824	1.372	0.893	1.225	656.	159.8	0.38000
0.4000	-10.33	-3.98	1273.6	0.05838	185.58	407.34	0.9467	1.7806	1.376	0.900	1.228	649.	159.7	0.40000
0.4200	-8.94	-2.62	1268.7	0.05567	187.50	408.02	0.9539	1.7789	1.380	0.907	1.231	642.	159.6	0.42000
0.4400	-7.60	-1.31	1264.0	0.05320	189.36	408.67	0.9609	1.7772	1.385	0.914	1.234	636.	159.5	0.44000
0.4600	-6.30	-0.04	1259.5	0.05094	191.16	409.29	0.9676	1.7757	1.389	0.921	1.237	629.	159.4	0.46000
0.4800	-5.05	1.18	1255.0	0.04885	192.91	409.88	0.9741	1.7742	1.393	0.928	1.240	623.	159.3	0.48000
0.5000	-3.84	2.36	1250.7	0.04693	194.61	410.45	0.9803	1.7728	1.397	0.934	1.242	617.	159.2	0.50000
0.5500	-0.95	5.18	1240.3	0.04272	198.65	411.77	0.9951	1.7695	1.407	0.950	1.250	603.	158.9	0.55000
0.6000	1.74	7.80	1230.4	0.03919	202.46	412.97	1.0089	1.7665	1.416	0.966	1.257	589.	158.6	0.60000
0.6500	4.26	10.26	1221.0	0.03618	206.05	414.07	1.0217	1.7637	1.426	0.981	1.265	577.	158.2	0.65000
0.7000	6.64	12.58	1212.0	0.03359	209.47	415.07	1.0339	1.7611	1.436	0.997	1.273	565.	157.8	0.70000
0.7500	8.90	14.78	1203.4	0.03133	212.72	416.00	1.0453	1.7587	1.445	1.012	1.280	553.	157.4	0.75000
0.8000	11.05	16.87	1195.0	0.02934	215.84	416.85	1.0562	1.7564	1.455	1.027	1.288	543.	157.0	0.80000
0.8500	13.10	18.86	1187.0	0.02758	218.83	417.65	1.0665	1.7542	1.464	1.042	1.297	532.	156.5	0.85000
0.9000	15.06	20.77	1179.1	0.02601	221.71	418.38	1.0764	1.7522	1.474	1.056	1.305	522.	156.1	0.90000
0.9500	16.94	22.59	1171.5	0.02460	224.49	419.06	1.0858	1.7502	1.483	1.071	1.314	513.	155.6	0.95000
1.0000	18.75	24.35	1164.1	0.02333	227.18	419.69	1.0949	1.7483	1.493	1.086	1.322	504.	155.1	1.00000
1.1000	22.17	27.67	1149.8	0.02111	232.31	420.83	1.1121	1.7446	1.512	1.116	1.340	487.	154.1	1.10000

Refrigerant Number	Chemical Name ^{a,b}	Chemical Formula ^a	Molecular Mass ^a	Normal Boiling Point, ^a °C	Safety Group
Methane Series					
11	Trichlorofluoromethane	CCl ₃ F	137.4	24	A1
12	Dichlorodifluoromethane	CCl ₂ F ₂	120.9	-30	A1
12B1	Bromochlorodifluoromethane	CBrClF ₂	165.4	-4	
13	Chlorotrifluoromethane	CClF ₃	104.5	-81	A1
14	Tetrafluoromethane (carbon tetrafluoride)	CF ₄	88.0	-128	A1
21	Dichlorofluoromethane	CHCl ₂ F	102.9	9	B1
22	Chlorodifluoromethane	CHClF ₂	86.5	-41	A1
23	Trifluoromethane	CHF ₃	70.0	-82	A1
30	Dichloromethane (methylene chloride)	CH ₂ Cl ₂	84.9	40	B2
31	Chlorofluoromethane	CH ₂ ClF	68.5	-9	
32	Difluoromethane (methylene fluoride)	CH ₂ F ₂	52.0	-52	A2
40	Chloromethane (methyl chloride)	CH ₃ Cl	50.4	-24	B2
41	Fluoromethane (methyl fluoride)	CH ₃ F	34.0	-	
50	Methane	CH ₄	16.0	-161	A3
Ethane Series					
113	1,1,2-trichloro-1,2,2-trifluoroethane	CCl ₂ FCCLF ₂	187.4	48	A1
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	CClF ₂ CClF ₂	170.9	4	A1
115	Chloropentafluoroethane	CClF ₂ CF ₃	154.5	-39	A1
116	Hexafluoroethane	C ₂ F ₆	138.0	-78	A1
123	2,2-dichloro-1,1,1-trifluoroethane	CHCl ₂ CF ₃	153.0	27	B1
124	2-chloro-1,1,1,2-tetrafluoroethane	CHClF ₂ CF ₃	136.5	-12	A1
125	Pentafluoroethane	CHF ₂ CF ₃	120.0	-49	A1
134a	1,1,1,2-tetrafluoroethane	CH ₂ FCF ₃	102.0	-26	A1
141b	1,1-dichloro-1-fluoroethane	CH ₃ CCl ₂ F	117.0	32	
142b	1-chloro-1,1-difluoroethane	CH ₃ CCF ₂	100.5	-10	A2
143a	1,1,1-trifluoroethane	CH ₃ CF ₃	84.0	-47	A2
152a	1,1-difluoroethane	CH ₃ CHF ₂	66.0	-25	A2
170	Ethane	CH ₃ CH ₃	30.0	-89	A3
Ethers					
E170	Dimethyl ether	CH ₃ OCH ₃	46.0	-25	A3
Propane Series					
218	Octafluoropropane	CF ₃ CF ₂ CF ₃	188.0	-37	A1
236fa	1,1,1,3,3,3-hexafluoropropane	CF ₃ CH ₂ CF ₃	152.0	-1	A1
245a	1,1,1,3,3-pentafluoropropane	CF ₃ CH ₂ CHF ₂	134.0	15	B1
290	Propane	CH ₃ CH ₂ CH ₃	44.0	-42	A3
Cyclic Organic Compounds (see Table 2 for blends)					
C318	Octafluorocyclobutane	-(CF ₂) ₄ -	200.0	-6	A1
Miscellaneous Organic Compounds					
Hydrocarbons					
600	Butane	CH ₃ CH ₂ CH ₂ CH ₃	58.1	0	A3
600a	Isobutane	CH(CH ₃) ₂ CH ₃	58.1	-12	A3
Oxygen Compounds					
610	Ethyl ether	CH ₃ CH ₂ OCH ₂ CH ₃	74.1	35	
611	Methyl formate	HCOOCH ₃	60.0	32	B2
Sulfur Compounds					
620	<i>(Reserved for future assignment)</i>				
Nitrogen Compounds					
630	Methyl amine	CH ₃ NH ₂	31.1	-7	
631	Ethyl amine	CH ₃ CH ₂ (NH ₂)	45.1	17	
Inorganic Compounds					
702	Hydrogen	H ₂	2.0	-253	A3
704	Helium	He	4.0	-269	A1
717	Ammonia	NH ₃	17.0	-33	B2
718	Water	H ₂ O	18.0	100	A1
720	Neon	Ne	20.2	-246	A1
728	Nitrogen	N ₂	28.1	-196	A1
732	Oxygen	O ₂	32.0	-183	
740	Argon	Ar	39.9	-186	A1
744	Carbon dioxide	CO ₂	44.0	-78	A1

Comparative Refrigerant Performance per Kilowatt of Refrigeration

No.	Refrigerant Chemical Name or Composition (% by mass)	Evap- orator Pressure, MPa	Con- denser Pressure, MPa	Com- pression Ratio	Net Refrig- erating Effect, kJ/kg	Refrig- erant Circulated, g/s	Liquid Circu- lated, L/s	Specific Volume of Suction Gas, m ³ /kg	Comp- ressor Displacem ent, L/s	Power Consump- tion, kW	Coeffi- cient of Perform- ance	Com- pressor Discharge Temp., K
170	Ethane	1.608	4.639	2.88	161.71	6.10	0.0219	0.0338	0.206	0.365	2.70	323
744	Carbon dioxide	2.254	7.18	3.19	133.23	3.88	0.0064	0.0168	0.065	0.192	2.69	343
1270	Propylene	0.358	1.304	3.64	286.17	3.46	0.0070	0.1299	0.449	0.220	4.50	315
290	Propane	0.286	1.075	3.76	277.90	3.53	0.0073	0.1562	0.551	0.218	4.50	309
502	R-22/115 (48.8/51.2)	0.343	1.312	3.83	105.95	9.43	0.0079	0.0508	0.479	0.228	4.38	311
507A	R-125/143a (50/50)	0.379	1.459	3.85	110.14	9.07	0.0089	0.0508	0.461	0.239	4.18	308
404A	R-125/143a/134a (44/52/4)	0.365	1.42	3.89	114.15	8.75	0.0086	0.0537	0.470	0.237	4.21	309
410A	R-32/125 (50/50)	0.478	1.872	3.92	167.89	5.84	0.0056	0.0545	0.318	0.222	4.41	324
125	Pentafluoroethane	0.403	1.561	3.87	85.30	11.41	0.0098	0.0394	0.449	0.244	3.99	304
22	Chlorodifluoro- methane	0.295	1.187	4.02	162.67	6.13	0.0052	0.0779	0.478	0.214	4.66	326
12	Dichlorodifluoro- methane	0.181	0.741	4.09	117.02	8.49	0.0066	0.0923	0.784	0.212	4.70	311
500	R-12/152a (73.8/26.2)	0.214	0.876	4.09	139.68	7.08	0.0063	0.0939	0.665	0.212	4.66	314
407C	R-32/125/134a (23/25/52)	0.288	1.26	4.38	163.27	6.11	0.0054	0.0805	0.492	0.222	4.50	321
600a	Isobutane*	0.088	0.403	4.58	263.91	3.76	0.0069	0.4073	1.533	0.215	4.62	303
134a	Tetrafluoroethane	0.163	0.767	4.71	148.03	6.71	0.0056	0.1214	0.814	0.216	4.60	310
124	Chlorotetrafluoro- ethane*	0.088	0.443	5.03	117.83	8.41	0.0063	0.1711	1.439	0.214	4.62	303
717	Ammonia	0.235	1.162	4.94	1103.14	0.90	0.0015	0.5117	0.463	0.210	4.76	372
600	Butane*	0.056	0.283	5.05	292.24	3.53	0.0062	0.6446	2.274	0.218	4.74	303
11	Trichlorofluoro- methane	0.02	0.125	6.25	155.95	6.36	0.0043	0.7689	4.891	0.197	5.02	316
123	Dichlorotrifluoro- ethane	0.016	0.109	6.81	142.28	7.02	0.0048	0.8914	6.259	0.204	4.90	306
113	Trichlorotrifluoro- ethane*	0.007	0.054	7.71	122.58	7.84	0.0051	1.6818	13.187	0.200	4.81	303

*Superheat required.

$$T_E=256\text{K}, T_C=303\text{K}$$