PART 4

ENERGY, POWER, AND POLLUTION CONTROL TECHNOLOGY

CHAPTER 39
THERMOPHYSICAL PROPERTIES OF FLUIDS

Peter E. Liley
School of Mechanical Engineering
Purdue University
West Lafayette, Indiana

Mechanical Engineers' Handbook, 2nd ed., Edited by Myer Kutz.
ISBN 0-471-13007-9

In this chapter, information is usually presented in the System International des Unités, called in English the International System of Units and abbreviated SI. Various tables of conversion factors from other unit systems into the SI system and vice versa are available. The following table is only intended to enable rapid conversion to be made with moderate, that is, five significant figure, accuracy, usually acceptable in most engineering calculations. The references listed should be consulted for more exact conversions and defintions.

Table 39.1 Conversion Factors[a]

Density: 1 kg/m^3 = 0.06243 lb$_m$/ft^3 = 0.01002 lb$_m$/U.K. gallon = 8.3454 × 10^{-3} lb$_m$/U.S. gallon = 1.9403 × 10^{-3} slug/ft^3 = 10^{-3} g/cm^3

Energy: 1 kJ = 737.56 ft · lb$_f$ = 239.01 cal$_{th}$ = 0.94783 Btu = 3.7251 × 10^{-4} hp hr = 2.7778 × 10^{-4} kWhr

Specific energy: 1 kJ/kg = 334.54 ft · lb$_f$/lb$_m$ = 0.4299 Btu/lb$_m$ = 0.2388 cal/g

Specific energy per degree: 1 kJ/kg · K = 0.23901 Btu$_{th}$/lb · °F = 0.23901 cal$_{th}$/g · °C

Mass: 1 kg = 2.20462 lb$_m$ = 0.06852 slug = 1.1023 × 10^{-3} U.S. ton = 10^{-3} tonne = 9.8421 × 10^{-4} U.K. ton

Pressure: 1 bar = 10^5 N/m^2 = 10^5 Pa = 750.06 mm Hg at 0°C = 401.47 in. H_2O at 32°F = 29.530 in. Hg at 0°C = 14.504 lb/in.^{2} = 14.504 psia = 1.01972 kg/cm^2 = 0.98692 atm = 0.1 MPa

Temperature: T(K) = T(°C) + 273.15 = [T(°F) + 459.69]/1.8 = T(°R)/1.8

Temperature difference: ΔT(K) = ΔT(°C) = ΔT(°F)/1.8 = ΔT(°R)/1.8

Thermal conductivity: 1 W/m · K = 0.8604 kcal/m · hr · °C = 0.5782 Btu/ft · hr · °F = 0.01 W/cm · K = 2.390 × 10^{-3} cal/cm · sec · °C

Thermal diffusivity: 1 m^2/sec = 38750 ft^2/hr = 3600 m^2/hr = 10.764 ft^2/sec

Viscosity, dynamic: 1 N · sec/m^2 = 1 Pa · sec = 10^7 μP = 2419.1 lb$_m$/ft · hr = 10^3 cP = 75.188 slug/ft · hr = 10 P = 0.6720 lb$_m$/ft · sec = 0.02089 lb$_f$ · sec/ft^2

Viscosity, kinematic (*see* thermal diffusivity)

[a]E. Lange, L. F. Sokol, and V. Antoine, *Information on the Metric System and Related Fields,* 6th ed., G. C. Marshall Space Flight Center, AL (exhaustive bibliography); C. H. Page and P. Vigoureux, *The International System of Units,* NBS S.P. 330, Wahsington, D.C., 1974; E. A. Mechtly, *The International System of Units. Physical Constants and Conversion Factors,* NASA S.P. 9012, 1973. Numerous revisions periodically appear: see, for example, *Pure Appl. Chem.,* **51,** 1–41 (1979) and later issues.

Table 39.2 Phase Transition Data for the Elements[a]

Name	Symbol	Formula Weight	T_m (K)	Δh_{fus} (kJ/kg)	T_b (K)	T_c (K)
Actinium	Ac	227.028	1323	63	3475	
Aluminum	Al	26.9815	933.5	398	2750	7850
Antimony	Sb	121.75	903.9	163	1905	5700
Argon	Ar	39.948	83	30	87.2	151
Arsenic	As	74.9216	885			2100
Barium	Ba	137.33	1002	55.8		4450
Beryllium	Be	9.01218	1560	1355	2750	6200
Bismuth	Bi	208.980	544.6	54.0	1838	4450
Boron	B	10.81	2320	1933	4000	3300
Bromine	Br	159.808	266	66.0	332	584
Cadmium	Cd	112.41	594	55.1	1040	2690
Calcium	Ca	40.08	1112	213.1	1763	4300
Carbon	C	12.011	3810		4275	7200
Cerium	Ce	140.12	1072	390		9750
Cesium	Cs	132.905	301.8	16.4	951	2015
Chlorine	Cl_2	70.906	172	180.7	239	417
Chromium	Cr	51.996	2133	325.6	2950	5500
Cobalt	Co	58.9332	1766	274.7	3185	6300

Table 39.2 (*Continued*)

Name	Symbol	Formula Weight	T_m (K)	Δh_{fus} (kJ/kg)	T_b (K)	T_c (K)
Copper	Cu	63.546	1357	206.8	2845	8280
Dysprosium	Dy	162.50	1670	68.1	2855	6925
Erbium	Er	167.26	1795	119.1	3135	7250
Europium	Eu	151.96	1092	60.6	1850	4350
Fluorine	F_2	37.997	53.5	13.4	85.0	144
Gadolinum	Gd	157.25	1585	63.8	3540	8670
Gallium	Ga	69.72	303	80.1	2500	7125
Germanium	Ge	72.59	1211	508.9	3110	8900
Gold	Au	196.967	1337	62.8	3130	7250
Hafnium	Hf	178.49	2485	134.8	4885	10400
Helium	He	4.00260	3.5	2.1	4.22	5.2
Holmium	Ho	164.930	1744	73.8	2968	7575
Hydrogen	H_2	2.0159	14.0		20.4	
Indium	In	114.82	430	28.5	2346	6150
Iodine	I_2	253.809	387	125.0	457	785
Iridium	Ir	192.22	2718	13.7	4740	7800
Iron	Fe	55.847	1811	247.3	3136	8500
Krypton	Kr	83.80	115.8	19.6	119.8	209.4
Lanthanum	La	138.906	1194	44.6	3715	10500
Lead	Pb	207.2	601	23.2	2025	5500
Lithium	Li	6.941	454	432.2	1607	3700
Lutetium	Lu	174.967	1937	106.6	3668	
Magnesium	Mg	24.305	922	368.4	1364	3850
Manganese	Mn	54.9380	1518	219.3	2334	4325
Mercury	Hg	200.59	234.6	11.4	630	1720
Molybdenum	Mo	95.94	2892	290.0	4900	1450
Neodymium	Nd	144.24	1290	49.6	3341	7900
Neon	Ne	20.179	24.5	16.4	27.1	44.5
Neptunium	Np	237.048	910		4160	12000
Nickel	Ni	58.70	1728	297.6	3190	8000
Niobium	Nb	92.9064	2740	283.7	5020	12500
Nitrogen	N_2	28.013	63.2	25.7	77.3	126.2
Osmium	Os	190.2	3310	150.0	5300	12700
Oxygen	O_2	31.9988	54.4	13.8	90.2	154.8
Palladium	Pd	106.4	1826	165.0	3240	7700
Phosphorus	P	30.9738	317		553	995
Platinum	Pt	195.09	2045	101	4100	10700
Plutonium	Pu	244	913	11.7	3505	10500
Potassium	K	39.0983	336.4	60.1	1032	2210
Praseodymium	Pr	140.908	1205	49	3785	8900
Promethium	Pm	145	1353		2730	
Protactinium	Pa	231	1500	64.8	4300	
Radium	Ra	226.025	973		1900	
Radon	Rn	222	202	12.3	211	377
Rhenium	Re	186.207	3453	177.8	5920	18900
Rhodium	Rh	102.906	2236	209.4	3980	7000
Rubidium	Rb	85.4678	312.6	26.4	964	2070
Ruthenium	Ru	101.07	2525	256.3	4430	9600
Samarium	Sm	150.4	1345	57.3	2064	5050
Scandium	Sc	44.9559	1813	313.6	3550	6410

Table 39.2 (*Continued*)

Name	Symbol	Formula Weight	T_m (K)	Δh_{fus} (kJ/kg)	T_b (K)	T_c (K)
Selenium	Se	78.96	494	66.2	958	1810
Silicon	Si	28.0855	1684	1802	3540	5160
Silver	Ag	107.868	1234	104.8	2435	6400
Sodium	Na	22.9898	371	113.1	1155	2500
Strontium	Sr	87.62	1043	1042	1650	4275
Sulfur	S	32.06	388	53.4	718	1210
Tantalum	Ta	180.948	3252	173.5	5640	16500
Technetium	Tc	98	2447	232	4550	11500
Tellurium	Te	127.60	723	137.1	1261	2330
Terbium	Tb	158.925	1631	67.9	3500	8470
Thallium	Tl	204.37	577	20.1	1745	4550
Thorium	Th	232.038	2028	69.4	5067	14400
Thulium	Tm	168.934	1819	99.6	2220	6450
Tin	Sn	118.69	505	58.9	2890	7700
Titanium	Ti	47.90	1943	323.6	3565	5850
Tungsten	W	183.85	3660	192.5	5890	15500
Uranium	U	238.029	1406	35.8	4422	12500
Vanadium	V	50.9415	2191	410.7	3680	11300
Xenon	Xe	131.30	161.3	17.5	164.9	290
Ytterbium	Yb	173.04	1098	44.2	1467	4080
Yttrium	Y	88.9059	1775	128.2	3610	8950
Zinc	Zn	65.38	692.7	113.0	1182	
Zirconium	Zr	91.22	2125	185.3	4681	10500

[a]T_m = normal melting point; Δh_{fus} = enthalpy of fusion; T_b = normal boiling point; T_c = critical temperature.

Table 39.3 Phase Transition Data for Compounds[a]

Substance	T_m (K)	Δh_m (kJ/kg)	T_b (K)	Δh_v (kJ/kg)	T_c (K)	P_c (bar)
Acetaldehyde	149.7	73.2	293.4	584	461	55.4
Acetic acid	289.9	195.3	391.7	405	594	57.9
Acetone	178.6	98	329.5	501	508	47
Acetylene		96.4	189.2	687	309	61.3
Air	60				133	37.7
Ammonia	195.4	331.9	239.7	1368	405.6	112.8
Aniline	267.2	113.3	457.6	485	699	53.1
Benzene	267.7	125.9	353.3	394	562	49
n-Butane	134.8	80.2	261.5	366	425.2	38
Butanol	188	125.2	391.2	593	563	44.1
Carbon dioxide	216.6	184	194.7	573	304.2	73.8
Carbon disulfide	161	57.7	319.6	352	552	79
Carbon monoxide	68.1	29.8	81.6	215	133	35
Carbon tetrachloride	250.3	173.9	349.9	195	556	45.6
Carbon tetrafluoride	89.5		145.2	138	227.9	37.4
Chlorobenzene	228		405	325	632.4	45.2
Chloroform	210	77.1	334.4	249	536.6	54.7
m-Cresol	285.1		475.9	421	705	45.5
Cyclohexane	279.6	31.7	356	357	554.2	40.7
Cyclopropane	145.5	129.4	240.3	477	397.8	54.9

Table 39.3 (*Continued*)

Substance	T_m (K)	Δh_m (kJ/kg)	T_b (K)	Δh_v (kJ/kg)	T_c (K)	P_c (bar)
n-Decane	243.2	202.1	447.3	276	617	21
Ethane	89.9	94.3	184.6	488	305.4	48.8
Ethanol	158.6	109	351.5	840	516	63.8
Ethyl acetate	190.8	119	350.2	366	523.3	38.3
Ethylene	104	119.5	169.5	480	283.1	51.2
Ethylene oxide	161.5	117.6	283.9	580	469	71.9
Formic acid	281.4	246.4	373.9	502	576	34.6
Heptane	182.6	140.2	371.6	316	540	27.4
Hexane	177.8	151.2	341.9	335	507	29.7
Hydrazine	274.7	395	386.7	1207	653	147
Hydrogen peroxide	271.2	310	431	1263		
iso-Butane	113.6	78.1	272.7	386	408.1	36.5
Methane	90.7	58.7	111.5	512	191.1	46.4
Methanol	175.4	99.2	337.7	1104	513.2	79.5
Methyl acetate	174.8		330.2	410	507	46.9
Methyl bromide	180	62.9	277.7	252	464	71.2
Methyl chloride	178.5	127.4	249.3	429	416.3	66.8
Methyl formate	173.4	125.5	305	481	487.2	60
Methylene chloride	176.4	54.4	312.7	328	510.2	60.8
Naphthalene	353.2	148.1	491	341	747	39.5
Nitric oxide	111	76.6	121.4	460	180.3	65.5
Octane	216.4	180.6	398.9	303	569.4	25
Pentane	143.7	116.6	309.2	357	469.8	33.7
Propane	86	80	231.1	426	370	42.5
Propanol	147	86.5	370.4	696	537	51.7
Propylene	87.9	71.4	225.5	438	365	46.2
Refrigerant 12	115	34.3	243.4	165	385	41.2
Refrigerant 13	92		191.8	148	302.1	38.7
Refrigerant 13B1	105.4		215.4	119	340	39.6
Refrigerant 21	138		282.1	242	451.7	51.7
Refrigerant 22	113	47.6	232.4	234	369	49.8
Steam/water	273.2	334	373.2	2257	647.3	221.2
Sulfuric acid	283.7	100.7	*v*	*v*	*v*	*v*
Sulfur dioxide	197.7	115.5	268.4	386	430.7	78.8
Toluene	178.2		383.8	339	594	41

[a] v = variable; T_m = normal melting point; Δh_m = enthalpy of fusion; T_b = normal boiling point; Δh_v = enthalpy of vaporization; T_c = critical temperature; P_c = critical pressure.

Table 39.4 Thermodynamic Properties of Liquid and Saturated Vapor Air[a]

T (K)	P_f (MPa)	P_g (MPa)	v_f (m³/kg)	v_g (m³/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg · K)	s_g (kJ/kg · K)
60	0.0066	0.0025	0.001027	6.876	−144.9	59.7	2.726	6.315
65	0.0159	0.0077	0.001078	2.415	−144.8	64.5	2.727	6.070
70	0.0340	0.0195	0.001103	1.021	−144.0	69.1	2.798	5.875
75	0.0658	0.0424	0.001130	0.4966	−132.8	73.5	2.896	5.714
80	0.1172	0.0826	0.001160	0.2685	−124.4	77.5	3.004	5.580
85	0.1954	0.1469	0.001193	0.1574	−115.2	81.0	3.114	5.464
90	0.3079	0.2434	0.001229	0.0983	−105.5	84.1	3.223	5.363
95	0.4629	0.3805	0.001269	0.0644	−95.4	86.5	3.331	5.272
100	0.6687	0.5675	0.001315	0.0439	−84.8	88.2	3.436	5.189
105	0.9334	0.8139	0.001368	0.0308	−73.8	89.1	3.540	5.110
110	1.2651	1.1293	0.001432	0.0220	−62.2	89.1	3.644	5.033
115	1.6714	1.5238	0.001512	0.0160	−49.7	87.7	3.750	4.955
120	2.1596	2.0081	0.001619	0.0116	−35.9	84.5	3.861	4.872
125	2.743	2.614	0.001760	0.0081	−19.7	78.0	3.985	4.770
132.5[b]	3.770	3.770	0.00309	0.0031	33.6	33.6	4.38	4.38

[a] v = specific volume; h = specific enthalpy; s = specific entropy; f = saturated liquid; g = saturated vapor. 1 MPa = 10 bar.
[b] Approximate critical point. Air is a multicomponent mixture.

Table 39.5 Ideal Gas Thermophysical Properties of Air[a]

T (K)	v (m^3/kg)	h (kJ/kg)	s (kJ/kg · K)	c_p (kJ/kg · K)	γ	$\bar{V}_s$ (m/sec)	η (N · sec/m^2)	λ (W/m · K)	Pr
200	0.5666	−103.0	6.4591	1.008	1.398	283.3	1.33.−5[b]	0.0183	0.734
210	0.5949	−92.9	6.5082	1.007	1.399	290.4	1.39.−5	0.0191	0.732
220	0.6232	−82.8	6.5550	1.006	1.399	297.3	1.44.−5	0.0199	0.730
230	0.6516	−72.8	6.5998	1.006	1.400	304.0	1.50.−5	0.0207	0.728
240	0.6799	−62.7	6.6425	1.005	1.400	310.5	1.55.−5	0.0215	0.726
250	0.7082	−52.7	6.6836	1.005	1.400	317.0	1.60.−5	0.0222	0.725
260	0.7366	−42.6	6.7230	1.005	1.400	323.3	1.65.−5	0.0230	0.723
270	0.7649	−32.6	6.7609	1.004	1.400	329.4	1.70.−5	0.0237	0.722
280	0.7932	−22.5	6.7974	1.004	1.400	335.5	1.75.−5	0.0245	0.721
290	0.8216	−12.5	6.8326	1.005	1.400	341.4	1.80.−5	0.0252	0.720
300	0.8499	−2.4	6.8667	1.005	1.400	347.2	1.85.−5	0.0259	0.719
310	0.8782	7.6	6.8997	1.005	1.400	352.9	1.90.−5	0.0265	0.719
320	0.9065	17.7	6.9316	1.006	1.399	358.5	1.94.−5	0.0272	0.719
330	0.9348	27.7	6.9625	1.006	1.399	364.0	1.99.−5	0.0279	0.719
340	0.9632	37.8	6.9926	1.007	1.399	369.5	2.04.−5	0.0285	0.719
350	0.9916	47.9	7.0218	1.008	1.398	374.8	2.08.−5	0.0292	0.719
360	1.0199	57.9	7.0502	1.009	1.398	380.0	2.12.−5	0.0298	0.719
370	1.0482	68.0	7.0778	1.010	1.397	385.2	2.17.−5	0.0304	0.719
380	1.0765	78.1	7.1048	1.011	1.397	390.3	2.21.−5	0.0311	0.719
390	1.1049	88.3	7.1311	1.012	1.396	395.3	2.25.−5	0.0317	0.719
400	1.1332	98.4	7.1567	1.013	1.395	400.3	2.29.−5	0.0323	0.719
410	1.1615	108.5	7.1817	1.015	1.395	405.1	2.34.−5	0.0330	0.719
420	1.1898	118.7	7.2062	1.016	1.394	409.9	2.38.−5	0.0336	0.719
430	1.2181	128.8	7.2301	1.018	1.393	414.6	2.42.−5	0.0342	0.718
440	1.2465	139.0	7.2535	1.019	1.392	419.3	2.46.−5	0.0348	0.718
450	1.2748	149.2	7.2765	1.021	1.391	423.9	2.50.−5	0.0355	0.718
460	1.3032	159.4	7.2989	1.022	1.390	428.3	2.53.−5	0.0361	0.718
470	1.3315	169.7	7.3209	1.024	1.389	433.0	2.57.−5	0.0367	0.718
480	1.3598	179.9	7.3425	1.026	1.389	437.4	2.61.−5	0.0373	0.718

490	1.3882	190.2	7.3637	1.028	1.388	441.8	2.65.−5	0.0379	0.718
500	1.4165	200.5	7.3845	1.030	1.387	446.1	2.69.−5	0.0385	0.718
520	1.473	221.1	7.4249	1.034	1.385	454.6	2.76.−5	0.0398	0.718
540	1.530	241.8	7.4640	1.038	1.382	462.9	2.83.−5	0.0410	0.718
560	1.586	262.6	7.5018	1.042	1.380	471.0	2.91.−5	0.0422	0.718
580	1.643	283.5	7.5385	1.047	1.378	479.0	2.98.−5	0.0434	0.718
600	1.700	304.5	7.5740	1.051	1.376	486.8	3.04.−5	0.0446	0.718
620	1.756	325.6	7.6086	1.056	1.374	494.4	3.11.−5	0.0458	0.718
640	1.813	346.7	7.6422	1.060	1.371	501.9	3.18.−5	0.0470	0.718
660	1.870	368.0	7.6749	1.065	1.369	509.3	3.25.−5	0.0482	0.717
680	1.926	389.3	7.7067	1.070	1.367	516.5	3.32.−5	0.0495	0.717
700	1.983	410.8	7.7378	1.075	1.364	523.6	3.38.−5	0.0507	0.717
720	2.040	432.3	7.7682	1.080	1.362	530.6	3.45.−5	0.0519	0.716
740	2.096	453.9	7.7978	1.084	1.360	537.5	3.51.−5	0.0531	0.716
760	2.153	475.7	7.8268	1.089	1.358	544.3	3.57.−5	0.0544	0.716
780	2.210	497.5	7.8551	1.094	1.356	551.0	3.64.−5	0.0556	0.716
800	2.266	519.4	7.8829	1.099	1.354	557.6	3.70.−5	0.0568	0.716
820	2.323	541.5	7.9101	1.103	1.352	564.1	3.76.−5	0.0580	0.715
840	2.380	563.6	7.9367	1.108	1.350	570.6	3.82.−5	0.0592	0.715
860	2.436	585.8	7.9628	1.112	1.348	576.8	3.88.−5	0.0603	0.715
880	2.493	608.1	7.9885	1.117	1.346	583.1	3.94.−5	0.0615	0.715
900	2.550	630.4	8.0136	1.121	1.344	589.3	4.00.−5	0.0627	0.715
920	2.606	652.9	8.0383	1.125	1.342	595.4	4.05.−5	0.0639	0.715
940	2.663	675.5	8.0625	1.129	1.341	601.5	4.11.−5	0.0650	0.714
960	2.720	698.1	8.0864	1.133	1.339	607.5	4.17.−5	0.0662	0.714
980	2.776	720.8	8.1098	1.137	1.338	613.4	4.23.−5	0.0673	0.714
1000	2.833	743.6	8.1328	1.141	1.336	619.3	4.28.−5	0.0684	0.714
1050	2.975	800.8	8.1887	1.150	1.333	633.8	4.42.−5	0.0711	0.714
1100	3.116	858.5	8.2423	1.158	1.330	648.0	4.55.−5	0.0738	0.715
1150	3.258	916.6	8.2939	1.165	1.327	661.8	4.68.−5	0.0764	0.715
1200	3.400	975.0	8.3437	1.173	1.324	675.4	4.81.−5	0.0789	0.715
1250	3.541	1033.8	8.3917	1.180	1.322	688.6	4.94.−5	0.0814	0.716
1300	3.683	1093.0	8.4381	1.186	1.319	701.6	5.06.−5	0.0839	0.716

Table 39.5 (*Continued*)

T (K)	v (m³/kg)	h (kJ/kg)	s (kJ/kg · K)	c_p (kJ/kg · K)	γ	$\bar{v}_s$ (m/sec)	η (N · sec/m²)	λ (W/m · K)	Pr
1350	3.825	1152.3	8.4830	1.193	1.317	714.4	5.19.−5	0.0863	0.717
1400	3.966	1212.2	8.5265	1.199	1.315	726.9	5.31.−5	0.0887	0.717
1450	4.108	1272.3	8.5686	1.204	1.313	739.2	5.42.−5	0.0911	0.717
1500	4.249	1332.7	8.6096	1.210	1.311	751.3	5.54.−5	0.0934	0.718
1550	4.391	1393.3	8.6493	1.215	1.309	763.2	5.66.−5	0.0958	0.718
1600	4.533	1454.2	8.6880	1.220	1.308	775.0	5.77.−5	0.0981	0.717
1650	4.674	1515.3	8.7256	1.225	1.306	786.5	5.88.−5	0.1004	0.717
1700	4.816	1576.7	8.7622	1.229	1.305	797.9	5.99.−5	0.1027	0.717
1750	4.958	1638.2	8.7979	1.233	1.303	809.1	6.10.−5	0.1050	0.717
1800	5.099	1700.0	8.8327	1.237	1.302	820.2	6.21.−5	0.1072	0.717
1850	5.241	1762.0	8.8667	1.241	1.301	831.1	6.32.−5	0.1094	0.717
1900	5.383	1824.1	8.8998	1.245	1.300	841.9	6.43.−5	0.1116	0.717
1950	5.524	1886.4	8.9322	1.248	1.299	852.6	6.53.−5	0.1138	0.717
2000	5.666	1948.9	8.9638	1.252	1.298	863.1	6.64.−5	0.1159	0.717
2050	5.808	2011.6	8.9948	1.255	1.297	873.5	6.74.−5	0.1180	0.717
2100	5.949	2074.4	9.0251	1.258	1.296	883.8	6.84.−5	0.1200	0.717
2150	6.091	2137.3	9.0547	1.260	1.295	894.0	6.95.−5	0.1220	0.717
2200	6.232	2200.4	9.0837	1.263	1.294	904.0	7.05.−5	0.1240	0.718
2250	6.374	2263.6	9.1121	1.265	1.293	914.0	7.15.−5	0.1260	0.718
2300	6.516	2327.0	9.1399	1.268	1.293	923.8	7.25.−5	0.1279	0.718
2350	6.657	2390.5	9.1672	1.270	1.292	933.5	7.35.−5	0.1298	0.719
2400	6.800	2454.0	9.1940	1.273	1.291	943.2	7.44.−5	0.1317	0.719
2450	6.940	2517.7	9.2203	1.275	1.291	952.7	7.54.−5	0.1336	0.720
2500	7.082	2581.5	9.2460	1.277	1.290	962.2	7.64.−5	0.1354	0.720

[a] v = specific volume; h = specific enthalpy; s = specific entropy; c_p = specific heat at constant pressure; γ = specific heat ratio, c_p/c_v (dimensionless); $\bar{v}_s$ = velocity of sound; η = dynamic viscosity; λ = thermal conductivity; Pr = Prandtl number (dimensionless). Condensed from S. Gordon, *Thermodynamic and Transport Combustion Properties of Hydrocarbons with Air*, NASA Technical Paper 1906, 1982, Vol. 1. These properties are based on constant gaseous composition. The reader is reminded that, at the higher temperatures, the influence of pressure can affect the composition and the thermodynamic properties.

[b] The notation 1.33.−5 signifies 1.33×10^{-5}.

Table 39.6 Thermophysical Properties of the U.S. Standard Atmosphere[a]

Z (m)	H (m)	T (K)	P (bar)	ρ (kg/m³)	g (m/sec²)	$\bar{v}_s$ (m/sec)
0	0	288.15	1.0133	1.2250	9.8067	340.3
1000	1000	281.65	0.8988	1.1117	9.8036	336.4
2000	1999	275.15	0.7950	1.0066	9.8005	332.5
3000	2999	268.66	0.7012	0.9093	9.7974	328.6
4000	3997	262.17	0.6166	0.8194	9.7943	324.6
5000	4996	255.68	0.5405	0.7364	9.7912	320.6
6000	5994	249.19	0.4722	0.6601	9.7882	316.5
7000	6992	242.70	0.4111	0.5900	9.7851	312.3
8000	7990	236.22	0.3565	0.5258	9.7820	308.1
9000	8987	229.73	0.3080	0.4671	9.7789	303.9
10000	9984	223.25	0.2650	0.4135	9.7759	299.5
11000	10981	216.77	0.2270	0.3648	9.7728	295.2
12000	11977	216.65	0.1940	0.3119	9.7697	295.1
13000	12973	216.65	0.1658	0.2667	9.7667	295.1
14000	13969	216.65	0.1417	0.2279	9.7636	295.1
15000	14965	216.65	0.1211	0.1948	9.7605	295.1
16000	15960	216.65	0.1035	0.1665	9.7575	295.1
17000	16954	216.65	0.0885	0.1423	9.7544	295.1
18000	17949	216.65	0.0756	0.1217	9.7513	295.1
19000	18943	216.65	0.0647	0.1040	9.7483	295.1
20000	19937	216.65	0.0553	0.0889	9.7452	295.1
22000	21924	218.57	0.0405	0.0645	9.7391	296.4
24000	23910	220.56	0.0297	0.0469	9.7330	297.7
26000	25894	222.54	0.0219	0.0343	9.7269	299.1
28000	27877	224.53	0.0162	0.0251	9.7208	300.4
30000	29859	226.51	0.0120	0.0184	9.7147	301.7
32000	31840	228.49	0.00889	0.01356	9.7087	303.0
34000	33819	233.74	0.00663	0.00989	9.7026	306.5
36000	35797	239.28	0.00499	0.00726	9.6965	310.1
38000	37774	244.82	0.00377	0.00537	9.6904	313.7
40000	39750	250.35	0.00287	0.00400	9.6844	317.2
42000	41724	255.88	0.00220	0.00299	9.6783	320.7
44000	43698	261.40	0.00169	0.00259	9.6723	324.1
46000	45669	266.93	0.00131	0.00171	9.6662	327.5
48000	47640	270.65	0.00102	0.00132	9.6602	329.8
50000	49610	270.65	0.00080	0.00103	9.6542	329.8

[a] Z = geometric attitude; H = geopotential attitude; ρ = density; g = acceleration of gravity; $\bar{v}_s$ = velocity of sound. Condensed and in some cases converted from *U.S. Standard Atmosphere 1976,* National Oceanic and Atmospheric Administration and National Aeronautics and Space Administration, Washington, DC. Also available as NOAA-S/T 76-1562 and Government Printing Office Stock No. 003-017-00323-0.

Table 39.7 Thermophysical Properties of Condensed and Saturated Vapor Carbon Dioxide from 200 K to the Critical Point[a]

		Specific Volume		Specific Enthalpy		Specific Entropy		Specific Heat (c_p)		Thermal Conductivity		Viscosity		Prandtl Number	
T (K)	*P* (bar)	Condensed[b]	Vapor	Condensed[b]	Vapor	Condensed[b]	Vapor	Condensed[b]	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
200	1.544	0.000644	0.2362	164.8	728.3	1.620	4.439								
205	2.277	0.000649	0.1622	171.5	730.0	1.652	4.379								
210	3.280	0.000654	0.1135	178.2	730.9	1.682	4.319								
215	4.658	0.000659	0.0804	185.0	731.3	1.721	4.264								
216.6	5.180	0.000661	0.0718	187.2	731.5	1.736	4.250								
216.6	5.180	0.000848	0.0718	386.3	731.5	2.656	4.250	1.707	0.958	0.182	0.011	2.10	0.116	1.96	0.96
220	5.996	0.000857	0.0624	392.6	733.1	2.684	4.232	1.761	0.985	0.178	0.012	1.86	0.118	1.93	0.97
225	7.357	0.000871	0.0515	401.8	735.1	2.723	4.204	1.820	1.02	0.171	0.012	1.75	0.120	1.87	0.98
230	8.935	0.000886	0.0428	411.1	736.7	2.763	4.178	1.879	1.06	0.164	0.013	1.64	0.122	1.84	0.99
235	10.75	0.000901	0.0357	420.5	737.9	2.802	4.152	1.906	1.10	0.160	0.013	1.54	0.125	1.82	1.01
240	12.83	0.000918	0.0300	430.2	738.9	2.842	4.128	1.933	1.15	0.156	0.014	1.45	0.128	1.80	1.02
245	15.19	0.000936	0.0253	440.1	739.4	2.882	4.103	1.959	1.20	0.148	0.015	1.36	0.131	1.80	1.04
250	17.86	0.000955	0.0214	450.3	739.6	2.923	4.079	1.992	1.26	0.140	0.016	1.28	0.134	1.82	1.06
255	20.85	0.000977	0.0182	460.8	739.4	2.964	4.056	2.038	1.34	0.134	0.017	1.21	0.137	1.84	1.08
260	24.19	0.001000	0.0155	471.6	738.7	3.005	4.032	2.125	1.43	0.128	0.018	1.14	0.140	1.89	1.12
265	27.89	0.001026	0.0132	482.8	737.4	3.047	4.007	2.237	1.54	0.122	0.019	1.08	0.144	1.98	1.17
270	32.03	0.001056	0.0113	494.4	735.6	3.089	3.981	2.410	1.66	0.116	0.020	1.02	0.150	2.12	1.23
275	36.59	0.001091	0.0097	506.5	732.8	3.132	3.954	2.634	1.81	0.109	0.022	0.96	0.157	2.32	1.32
280	41.60	0.001130	0.0082	519.2	729.1	3.176	3.925	2.887	2.06	0.102	0.024	0.91	0.167	2.57	1.44
285	47.10	0.001176	0.0070	532.7	723.5	3.220	3.891	3.203	2.40	0.095	0.028	0.86	0.178	2.90	1.56
290	53.15	0.001241	0.0058	547.6	716.9	3.271	3.854	3.724	2.90	0.088	0.033	0.79	0.191	3.35	1.68
295	59.83	0.001322	0.0047	562.9	706.3	3.317	3.803	4.68		0.081	0.042	0.71	0.207	4.1	1.8
300	67.10	0.001470	0.0037	585.4	690.2	3.393	3.742			0.074	0.065	0.60	0.226		
304.2[c]	73.83	0.002145	0.0021	636.6	636.6	3.558	3.558								

[a]Specific volume, m^3/kg; specific enthalpy, kJ/kg; specific entropy, kJ/kg · K; specific heat at constant pressure, kJ/kg · K; thermal conductivity, W/m · K; viscosity, 10^{-4} Pa · sec. Thus, at 250 K the viscosity of the saturated liquid is 1.28×10^{-4} N · sec/m^2 = 0.000128 N · sec/m^2 = 0.000128 Pa · sec. The Prandtl number is dimensionless.

[b]Above the solid line the condensed phase is solid; below the line, it is liquid.

[c]Critical point.

Table 39.8 Thermophysical Properties of Gaseous Carbon Dioxide at 1 Bar Pressure[a]

	T (K)														
	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
v (m^3/kg)	0.5639	0.6595	0.7543	0.8494	0.9439	1.039	1.133	1.228	1.332	1.417	1.512	1.606	1.701	1.795	1.889
h (kJ/kg)	809.3	853.1	899.1	947.1	997.0	1049	1102	1156	1212	1269	1327	1386	1445	1506	1567
s (kJ/kg · K)	4.860	4.996	5.118	5.231	5.337	5.435	5.527	5.615	5.697	5.775	5.850	5.922	5.990	6.055	6.120
c_p (kJ/kg · K)	0.852	0.898	0.941	0.980	1.014	1.046	1.075	1.102	1.126	1.148	1.168	1.187	1.205	1.220	1.234
λ (W/m · K)	0.0166	0.0204	0.0243	0.0283	0.0325	0.0364	0.0407	0.0445	0.0481	0.0517	0.0551	0.0585	0.0618	0.0650	0.0682
μ (10^{-4} Pa · sec)	0.151	0.175	0.198	0.220	0.242	0.261	0.281	0.299	0.317	0.334	0.350	0.366	0.381	0.396	0.410
Pr	0.778	0.770	0.767	0.762	0.755	0.750	0.742	0.742	0.742	0.742	0.742	0.742	0.742	0.743	0.743

[a] v = specific volume; h = enthalpy; s = entropy; c_p = specific heat at constant pressure; λ = thermal conductivity; η = viscosity (at 300 K the gas viscosity is 0.0000151 $N \cdot sec/m^2$ = 0.0000151 Pa · sec); Pr = Prandtl number.

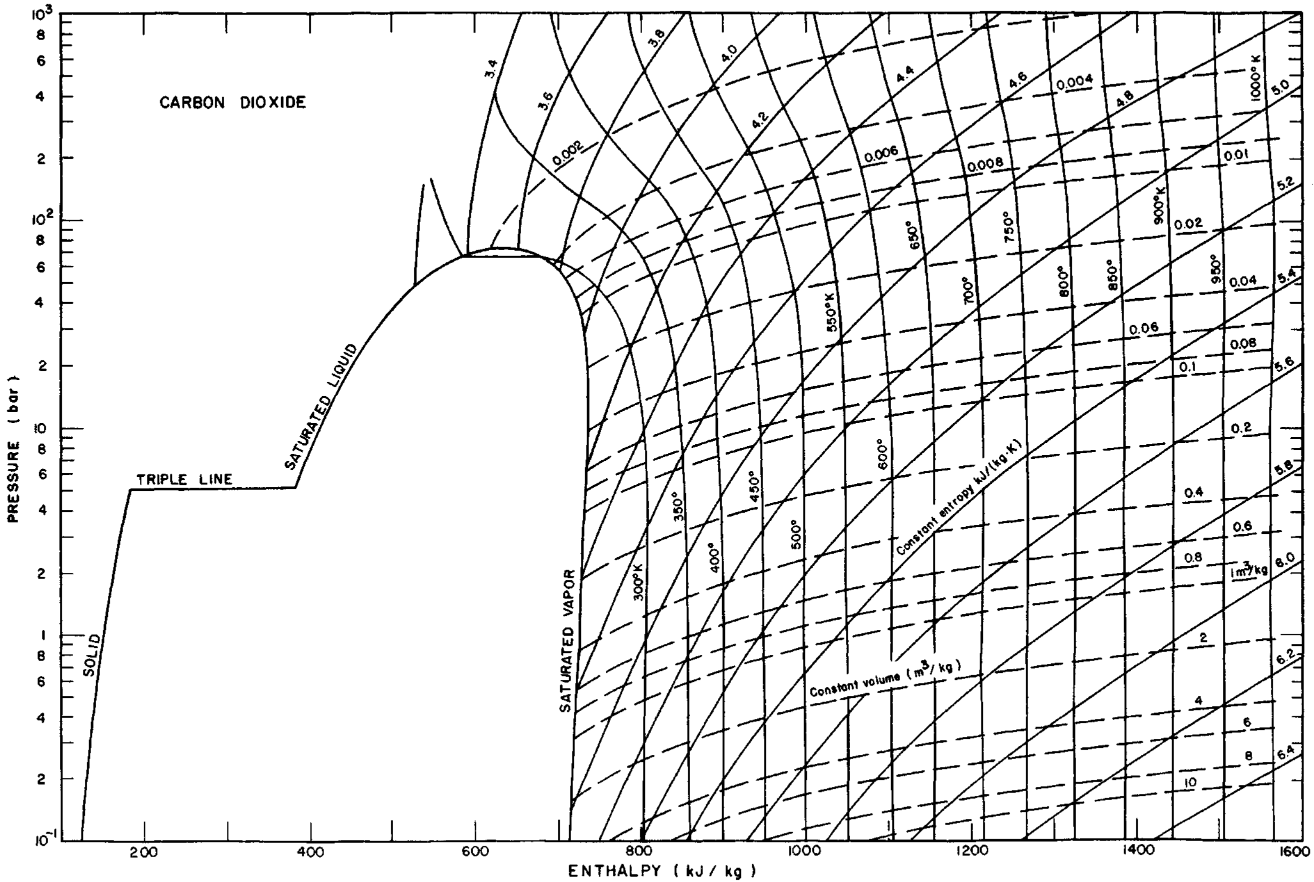

Fig. 39.1 Enthalpy–log pressure diagram for carbon dioxide.

Table 39.9 Thermodynamic Properties of Saturated Mercury[a]

T (K)	P (bar)	v (m^3/kg)	h (kJ/kg)	s (kJ/kg · K)	c_p (kJ/kg · K)
0		6.873.−5[b]	0	0	0
20		6.875.−5	0.466	0.0380	0.0513
40		6.884.−5	1.918	0.0868	0.0894
60		6.897.−5	3.897	0.1267	0.1067
80		6.911.−5	6.129	0.1588	0.1156
100		6.926.−5	8.497	0.1852	0.1209
120		6.942.−5	10.956	0.2076	0.1248
140		6.958.−5	13.482	0.2270	0.1278
160		6.975.−5	16.063	0.2443	0.1304
180		6.993.−5	18.697	0.2598	0.1330
200		7.013.−5	21.386	0.2739	0.1360
220		7.034.−5	24.139	0.2870	0.1394
234.3	7.330.−10	7.050.−5	26.148	0.2959	0.1420
234.3	7.330.−10	7.304.−5	37.585	0.3447	0.1422
240	1.668.−9	7.311.−5	38.395	0.3481	0.1420
260	6.925.−8	7.339.−5	41.224	0.3595	0.1409
280	5.296.−7	7.365.−5	44.034	0.3699	0.1401
300	3.075.−6	7.387.−5	46.829	0.3795	0.1393
320	1.428.−5	7.413.−5	49.609	0.3885	0.1386
340	5.516.−5	7.439.−5	52.375	0.3969	0.1380
360	1.829.−4	7.472.−5	55.130	0.4048	0.1375
380	5.289.−4	7.499.−5	57.874	0.4122	0.1370
400	1.394.−3	7.526.−5	60.609	0.4192	0.1366
450	0.01053	7.595.−5	67.414	0.4352	0.1357
500	0.05261	7.664.−5	74.188	0.4495	0.1353
550	0.1949	7.735.−5	80.949	0.4624	0.1352
600	0.5776	7.807.−5	87.716	0.4742	0.1356
650	1.4425	7.881.−5	94.508	0.4850	0.1360
700	3.153	7.957.−5	101.343	0.4951	0.1372
750	6.197	8.036.−5	108.242	0.5046	0.1382
800	11.181	8.118.−5	115.23	0.5136	0.1398
850	18.816	8.203.−5	122.31	0.5221	0.1416
900	29.88	8.292.−5	129.53	0.5302	0.1439
950	45.23	8.385.−5	137.16	0.5381	0.1464
1000	65.74	8.482.−5	144.41	0.5456	0.1492

[a] v = specific volume; h = specific enthalpy; s = specific entropy, c_p = specific heat at constant pressure. Properties above the solid line are for the solid; below they are for the liquid. Condensed, converted, and interpolated from the tables of M. P. Vukalovich, A. I. Ivanov, L. R. Fokin, and A. T. Yakovlev, *Thermophysical Properties of Mercury,* Standartov, Moscow, USSR, 1971.

[b] The notation 6.873.−5 signifies 6.873×10^{-5}.

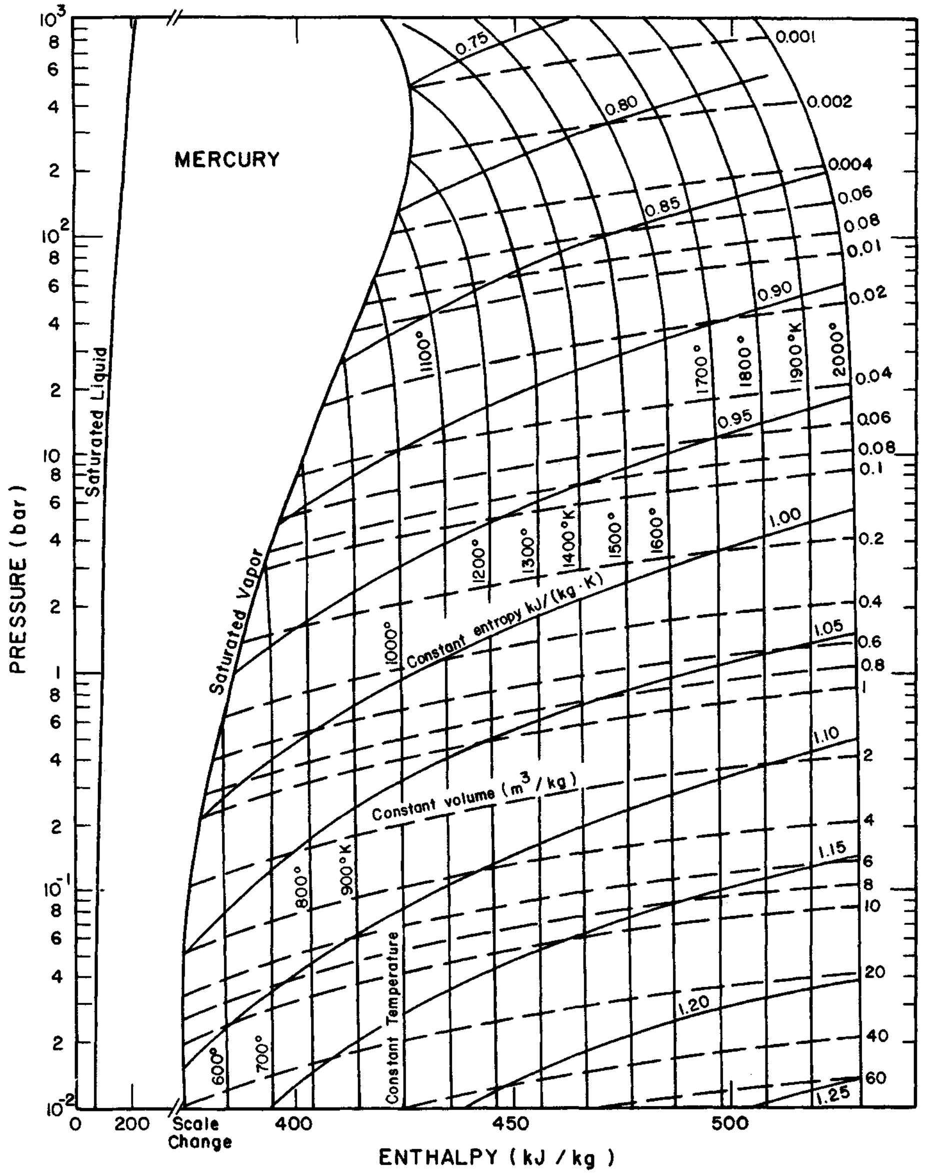

Fig. 39.2 Enthalpy–log pressure diagram for mercury.

Table 39.10 Thermodynamic Properties of Saturated Methane[a]

T (K)	P (bar)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg · K)	s_g (kJ/kg · K)	c_{p_f} (kJ/kg · K)	$\bar{v}_s$ (m/sec)
90.68	0.117	2.215.−3[b]	3.976	216.4	759.9	4.231	10.225	3.288	1576
92	0.139	2.226.−3	3.410	220.6	762.4	4.279	10.168	3.294	1564
96	0.223	2.250.−3	2.203	233.2	769.5	4.419	10.006	3.326	1523
100	0.345	2.278.−3	1.479	246.3	776.9	4.556	9.862	3.369	1480
104	0.515	2.307.−3	1.026	259.6	784.0	4.689	9.731	3.415	1437
108	0.743	2.337.−3	0.732	273.2	791.0	4.818	9.612	3.458	1393
112	1.044	2.369.−3	0.536	287.0	797.7	4.944	9.504	3.497	1351
116	1.431	2.403.−3	0.401	301.1	804.2	5.068	9.405	3.534	1308
120	1.919	2.438.−3	0.306	315.3	810.8	5.187	9.313	3.570	1266
124	2.523	2.475.−3	0.238	329.7	816.2	5.305	9.228	3.609	1224
128	3.258	2.515.−3	0.187	344.3	821.6	5.419	9.148	3.654	1181
132	4.142	2.558.−3	0.150	359.1	826.5	5.531	9.072	3.708	1138
136	5.191	2.603.−3	0.121	374.2	831.0	5.642	9.001	3.772	1093
140	6.422	2.652.−3	0.0984	389.5	834.8	5.751	8.931	3.849	1047
144	7.853	2.704.−3	0.0809	405.2	838.0	5.858	8.864	3.939	999
148	9.502	2.761.−3	0.0670	421.3	840.6	5.965	8.798	4.044	951
152	11.387	2.824.−3	0.0558	437.7	842.2	6.072	8.733	4.164	902
156	13.526	2.893.−3	0.0467	454.7	843.2	6.177	8.667	4.303	852
160	15.939	2.971.−3	0.0392	472.1	843.0	6.283	8.601	4.470	802
164	18.647	3.059.−3	0.0326	490.1	841.6	6.390	8.533	4.684	749
168	21.671	3.160.−3	0.0278	508.9	839.0	6.497	8.462	4.968	695
172	25.034	3.281.−3	0.0234	528.6	834.6	6.606	8.385	5.390	637
176	28.761	3.428.−3	0.0196	549.7	827.9	6.720	8.301	6.091	570
180	32.863	3.619.−3	0.0162	572.9	818.1	6.843	8.205	7.275	500
184	37.435	3.890.−3	0.0131	599.7	802.9	6.980	8.084	9.831	421
188	42.471	4.361.−3	0.0101	634.0	776.4	7.154	7.912	19.66	327
190.56	45.988	6.233.−3	0.0062	704.4	704.4	7.516	7.516		

[a] v = specific volume; h = specific enthalpy; s = specific entropy; c_p = specific heat at constant pressure; $\bar{v}_s$ = velocity of sound; f = saturated liquid; g = saturated vapor. Condensed and converted from R. D. Goodwin, N.B.S. Technical Note 653, 1974.

[b] The notation 2.215.−3 signifies 2.215×10^{-3}.

Table 39.11 Thermophysical Properties of Methane at Atmospheric Pressure[a]

	Temperature (K)									
	250	300	350	400	450	500	550	600	650	700
v	1.275	1.532	1.789	2.045	2.301	2.557	2.813	3.068	3.324	3.580
h	1090	1200	1315	1437	1569	1709	1857	2016	2183	2359
s	11.22	11.62	11.98	12.30	12.61	12.91	13.19	13.46	13.73	14.00
c_p	2.04	2.13	2.26	2.43	2.60	2.78	2.96	3.16	3.35	3.51
Z	0.997	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$\bar{v}_s$	413	450	482	511	537	562	585	607	629	650
λ	0.0276	0.0342	0.0417	0.0486	0.0571	0.0675	0.0768	0.0863	0.0956	0.1052
η	0.095	0.112	0.126	0.141	0.154	0.168	0.180	0.192	0.202	0.214
Pr	0.701	0.696	0.683	0.687	0.690	0.693	0.696	0.700	0.706	0.714

[a] v = specific volume (m^3/kg); h = specific enthalpy (kJ/kg); s = specific entropy (kJ/kg · K); c_p = specific heat at constant pressure (kJ/kg · K); Z = compressibility factor = Pv/RT; $\bar{v}_s$ = velocity of sound (m/sec); λ = thermal conductivity (W/m · K); η = viscosity 10^{-4} N · sec/m^2 (thus, at 250 K the viscosity is 0.095×10^{-4} N · sec/m^2 = 0.0000095 Pa · sec); Pr = Prandtl number.

Table 39.12 Thermophysical Properties of Saturated Refrigerant 22[a]

		v (m³/kg)		h (kJ/kg)		s (kJ/kg · K)		c_p	η	λ	τ
T (K)	P (bar)	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	(Liquid)	(Liquid)	(Liquid)	(Liquid)
150	0.0017	6.209.−4[b]	83.40	268.2	547.3	3.355	5.215	1.059		0.161	
160	0.0054	6.293.−4	28.20	278.2	552.1	3.430	5.141	1.058		0.156	
170	0.0150	6.381.−4	10.85	288.3	557.0	3.494	5.075	1.057	0.770	0.151	
180	0.0369	6.474.−4	4.673	298.7	561.9	3.551	5.013	1.058	0.647	0.146	
190	0.0821	6.573.−4	2.225	308.6	566.8	3.605	4.963	1.060	0.554	0.141	
200	0.1662	6.680.−4	1.145	318.8	571.6	3.657	4.921	1.065	0.481	0.136	0.024
210	0.3116	6.794.−4	0.6370	329.1	576.5	3.707	4.885	1.071	0.424	0.131	0.022
220	0.5470	6.917.−4	0.3772	339.7	581.2	3.756	4.854	1.080	0.378	0.126	0.021
230	0.9076	7.050.−4	0.2352	350.6	585.9	3.804	4.828	1.091	0.340	0.121	0.019
240	1.4346	7.195.−4	0.1532	361.7	590.5	3.852	4.805	1.105	0.309	0.117	0.0172
250	2.174	7.351.−4	0.1037	373.0	594.9	3.898	4.785	1.122	0.282	0.112	0.0155
260	3.177	7.523.−4	0.07237	384.5	599.0	3.942	4.768	1.143	0.260	0.107	0.0138
270	4.497	7.733.−4	0.05187	396.3	603.0	3.986	4.752	1.169	0.241	0.102	0.0121
280	6.192	7.923.−4	0.03803	408.2	606.6	4.029	4.738	1.193	0.225	0.097	0.0104
290	8.324	8.158.−4	0.02838	420.4	610.0	4.071	4.725	1.220	0.211	0.092	0.0087
300	10.956	8.426.−4	0.02148	432.7	612.8	4.113	4.713	1.257	0.198	0.087	0.0071
310	14.17	8.734.−4	0.01643	445.5	615.1	4.153	4.701	1.305	0.186	0.082	0.0055
320	18.02	9.096.−4	0.01265	458.6	616.7	4.194	4.688	1.372	0.176	0.077	0.0040
330	22.61	9.535.−4	9.753.−3	472.4	617.3	4.235	4.674	1.460	0.167	0.072	0.0026
340	28.03	1.010.−3	7.479.−3	487.2	616.5	4.278	4.658	1.573	0.151	0.067	0.0014
350	34.41	1.086.−3	5.613.−3	503.7	613.3	4.324	4.637	1.718	0.130	0.062	0.0008
360	41.86	1.212.−3	4.036.−3	523.7	605.5	4.378	4.605	1.897	0.106		
369.3	49.89	2.015.−3	2.015.−3	570.0	570.0	4.501	4.501	∝	—	—	0

[a] c_p in units of kJ/kg · K; η = viscosity (10^{-4} Pa · sec); λ = thermal conductivity (W/m · K); τ = surface tension (N/m). Sources: P, v, T, h, s interpolated and extrapolated from I. I. Perelshteyn, *Tables and Diagrams of the Thermodynamic Properties of Freons 12, 13, 22,* Moscow, USSR, 1971. c_p, η, λ interpolated and converted from *Thermophysical Properties of Refrigerants,* ASHRAE, New York, 1976. τ calculated from V. A. Gruzdev et al., *Fluid Mech. Sov. Res.*, **3**, 172 (1974).

[b] The notation 6.209.−4 signifies 6.209×10^{-4}.

Table 39.13 Thermophysical Properties of Refrigerant 22 at Atmospheric Pressure[a]

	Temperature (K)					
	250	300	350	400	450	500
v	0.2315	0.2802	0.3289	0.3773	0.4252	0.4723
h	597.8	630.0	664.5	702.5	740.8	782.3
s	4.8671	4.9840	5.0905	5.1892	5.2782	5.3562
c_p	0.587	0.647	0.704	0.757	0.806	0.848
Z	0.976	0.984	0.990	0.994	0.995	0.996
$\bar{v}_s$	166.4	182.2	196.2	209.4	220.0	233.6
λ	0.0080	0.0110	0.0140	0.0170	0.0200	0.0230
η	0.109	0.130	0.151	0.171	0.190	0.209
Pr	0.800	0.765	0.759	0.761	0.766	0.771

[a] v = specific volume (m^3/kg); h = specific enthalpy (kJ/kg); s = specific entropy (kJ/kg · K); c_p = specific heat at constant pressure (kJ/kg · K); Z = compressibility factor = Pv/RT; $\bar{v}_s$ = velocity of sound (m/sec); λ = thermal conductivity (W/m · K); η = viscosity 10^{-4} N · sec/m^2 (thus, at 250 K the viscosity is 0.109×10^{-4} N sec/m^2 = 0.0000109 Pa · sec); Pr = Prandtl number.

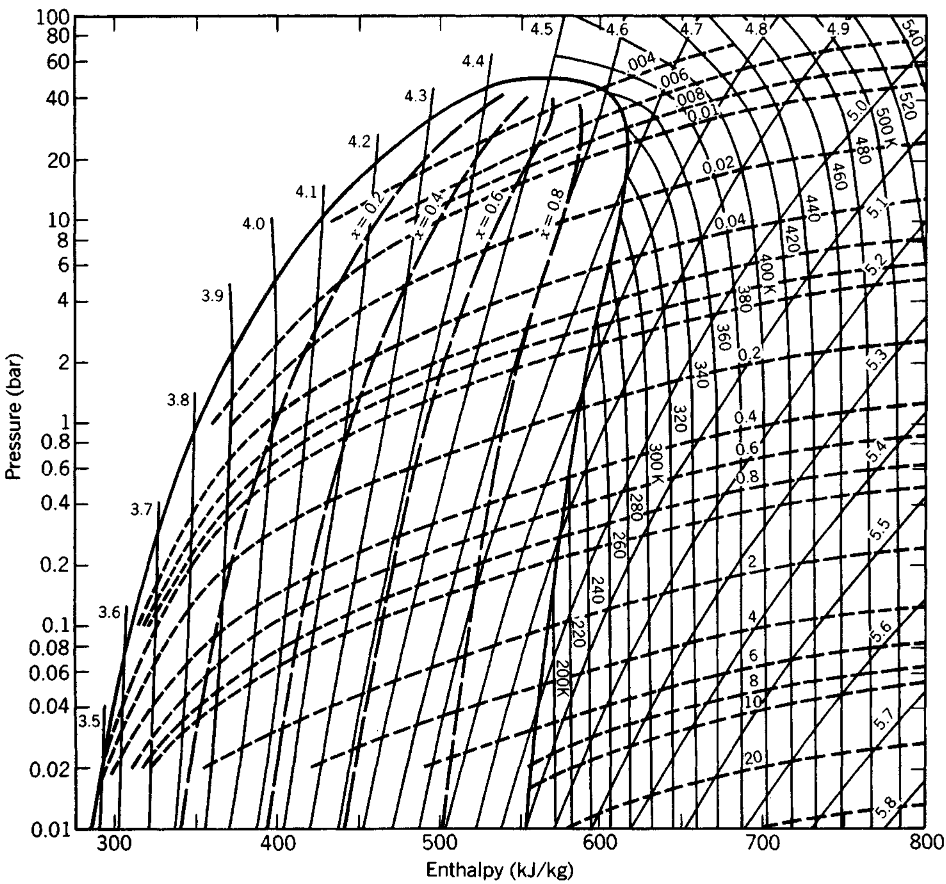

Fig. 39.3 Enthalpy–log pressure diagram for Refrigerant 22.

Table 39.14 Thermodynamic Properties of Saturated Refrigerant 134a[a]

P (bar)	t (°C)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg · K)	s_g (kJ/kg · K)	c_{pf} (kJ/kg · K)	c_{pg} (kJ/kg · K)
0.5	−40.69	0.000 707	0.3690	−0.9	225.5	−0.0036	0.9698	1.2538	0.7476
0.6	−36.94	0.000 712	0.3109	3.3	227.5	0.0165	0.9645	1.2600	0.7584
0.7	−33.93	0.000 716	0.2692	7.7	229.4	0.0324	0.9607	1.2654	0.7680
0.8	−31.12	0.000 720	0.2375	11.2	231.2	0.0472	0.9572	1.2707	0.7771
0.9	−28.65	0.000 724	0.2126	14.4	233.0	0.0601	0.9545	1.2755	0.7854
1	−26.52	0.000 729	0.1926	16.8	234.2	0.0720	0.9519	1.2799	0.7931
1.5	−17.26	0.000 742	0.1314	28.6	240.0	0.1194	0.9455	1.2992	0.8264
2	−10.18	0.000 754	0.1001	37.8	243.6	0.1547	0.9379	1.3153	0.8540
2.5	−4.38	0.000 764	0.0809	45.5	247.3	0.1834	0.9340	1.3297	0.8782
3	0.59	0.000 774	0.0679	52.1	250.1	0.2077	0.9312	1.3428	0.9002
4	8.86	0.000 791	0.0514	63.3	254.9	0.2478	0.9270	1.3670	0.9400
5	15.68	0.000 806	0.0413	72.8	258.8	0.2804	0.9241	1.3894	0.9761
6	21.54	0.000 820	0.0344	81.0	262.1	0.3082	0.9219	1.4108	0.9914
8	31.35	0.000 846	0.0257	95.0	267.1	0.3542	0.9185	1.4526	1.0750
10	39.41	0.000 871	0.0204	106.9	270.9	0.3921	0.9157	1.4948	1.1391
12	46.36	0.000 894	0.01672	117.5	273.9	0.4246	0.9132	1.539	1.205
14	52.48	0.000 918	0.01411	127.0	276.2	0.4533	0.9107	1.586	1.276
16	57.96	0.000 941	0.01258	135.7	277.9	0.4794	0.9081	1.637	1.353
18	62.94	0.000 965	0.01056	143.9	279.3	0.5031	0.9052	1.695	1.439
20	67.52	0.000 990	0.00929	151.4	280.1	0.5254	0.9021	1.761	1.539
22.5	72.74	0.001 023	0.00800	160.9	280.8	0.5512	0.8976	1.859	1.800
25	77.63	0.001 058	0.00694	169.8	280.8	0.5756	0.8925	1.983	1.883
27.5	82.04	0.001 096	0.00605	178.2	280.3	0.5989	0.8865	2.151	2.149
30	86.20	0.001 141	0.00528	186.5	279.4	0.6216	0.8812	2.388	2.527
35	93.72	0.001 263	0.00397	203.7	274.1	0.6671	0.8589	3.484	4.292
40	100.34	0.001 580	0.00256	227.4	257.2	0.7292	0.8090	26.33	37.63
40.59	101.06	0.001 953	0.00195	241.5	241.5	0.7665	0.7665		

[a]Converted and reproduced from R. Tillner-Roth and H. D. Baehr, *J. Phys. Chem. Ref. Data,* **23** (5), 657–730 (1994). $h_f = s_f = 0$ at 233.15K = −40°C.

Table 39.15 Interim Thermophysical Properties of Refrigerant 134a[a]

t (°C)	Property	P (bar) 1	2.5	5	7.5	10	12.5	15	Sat. Vapor
0	c_p (kJ/kg · K)	0.8197	0.8740						0.8975
	μ (10^{-6} Pas)	11.00	10.95						10.94
	k (W/m · K)	0.0119	0.0120						0.0120
	Pr	0.763	0.798						0.809
10	c_p (kJ/kg · K)	0.8324	0.8815						0.9408
	μ (10^{-6} Pas)	11.38	11.42						11.42
	k (W/m · K)	0.0126	0.0127						0.0129
	Pr	0.753	0.786						0.821
20	c_p (kJ/kg · K)	0.8458	0.8726	0.9642					0.9864
	μ (10^{-6} Pas)	11.78	11.83	11.91					11.93
	k (W/m · K)	0.0134	0.0135	0.0138					0.0139
	Pr	0.747	0.774	0.830					0.838
30	c_p (kJ/kg · K)	0.8602	0.8900	0.9587	1.044				1.048
	μ (10^{-6} Pas)	12.27	12.28	12.29	12.36				12.37
	k (W/m · K)	0.0141	0.0143	0.0145	0.0150				0.0150
	Pr	0.743	0.764	0.805	0.857				0.859
40	c_p (kJ/kg · K)	0.8747	0.8998	0.9547	1.027	1.134			1.145
	μ (10^{-6} Pas)	12.57	12.61	12.66	12.75	12.88			12.89
	k (W/m · K)	0.0148	0.0150	0.0153	0.0156	0.0161			0.0161
	Pr	0.740	0.757	0.789	0.839	0.907			0.916

50	c_p (kJ/kg · K)	0.8891	0.9112	0.9555	1.017	1.120	1.213		1.246
	μ (10^{-6} Pas)	12.96	13.00	13.05	13.14	13.23	13.33		13.47
	k (W/m · K)	0.0156	0.0158	0.0160	0.0163	0.0167	0.0171		0.0173
	Pr	0.739	0.752	0.778	0.820	0.887	0.946		0.960
60	c_p (kJ/kg · K)	0.9045	0.9230	0.9589	1.003	1.060	1.151	1.248	1.387
	μ (10^{-6} Pas)	13.35	13.39	13.44	13.51	13.60	13.75	13.96	14.16
	k (W/m · K)	0.0164	0.0165	0.0167	0.0170	0.0173	0.0178	0.0184	0.0185
	Pr	0.739	0.750	0.772	0.801	0.829	0.889	0.935	1.059
70	c_p (kJ/kg · K)	0.9201	0.9359	0.9652	0.9972	1.046	1.100	1.175	1.606
	μ (10^{-6} Pas)	13.74	13.77	13.82	13.89	13.97	14.10	14.27	15.04
	k (W/m · K)	0.0171	0.0172	0.0174	0.0176	0.0179	0.0183	0.0189	0.0197
	Pr	0.739	0.750	0.759	0.787	0.813	0.848	0.886	1.226
80	c_p (kJ/kg · K)	0.9359	0.9520	0.9715	0.9992	1.038	1.222	1.313	2.026
	μ (10^{-6} Pas)	14.11	14.14	14.19	14.25	14.33	14.43	14.59	16.31
	k (W/m · K)	0.0178	0.0179	0.0180	0.0182	0.0185	0.0188	0.0193	0.0205
	Pr	0.741	0.752	0.757	0.782	0.804	0.938	0.993	1.612
sat. vapor	c_p (kJ/kg · K)	0.7931	0.8782	0.9761	1.059	1.139	1.223	1.314	—
	μ (10^{-6} Pas)			11.72	12.34	12.86	13.34	13.81	—
	k (W/m · K)			0.0136	0.0149	0.0161	0.0173	0.0184	—
	Pr			0.841	0.877	0.910	0.943	0.986	—

[a]Some significant differences presently exist between different sets of property measurements. Definitive values were still awaited in 1997.

At 0°C, 1 bar the viscosity is 11 × 10^{-6} Pas.; Pr = Prandtl number.