

Fig. 39.4 Compressibility factor of Refrigerant 134a.

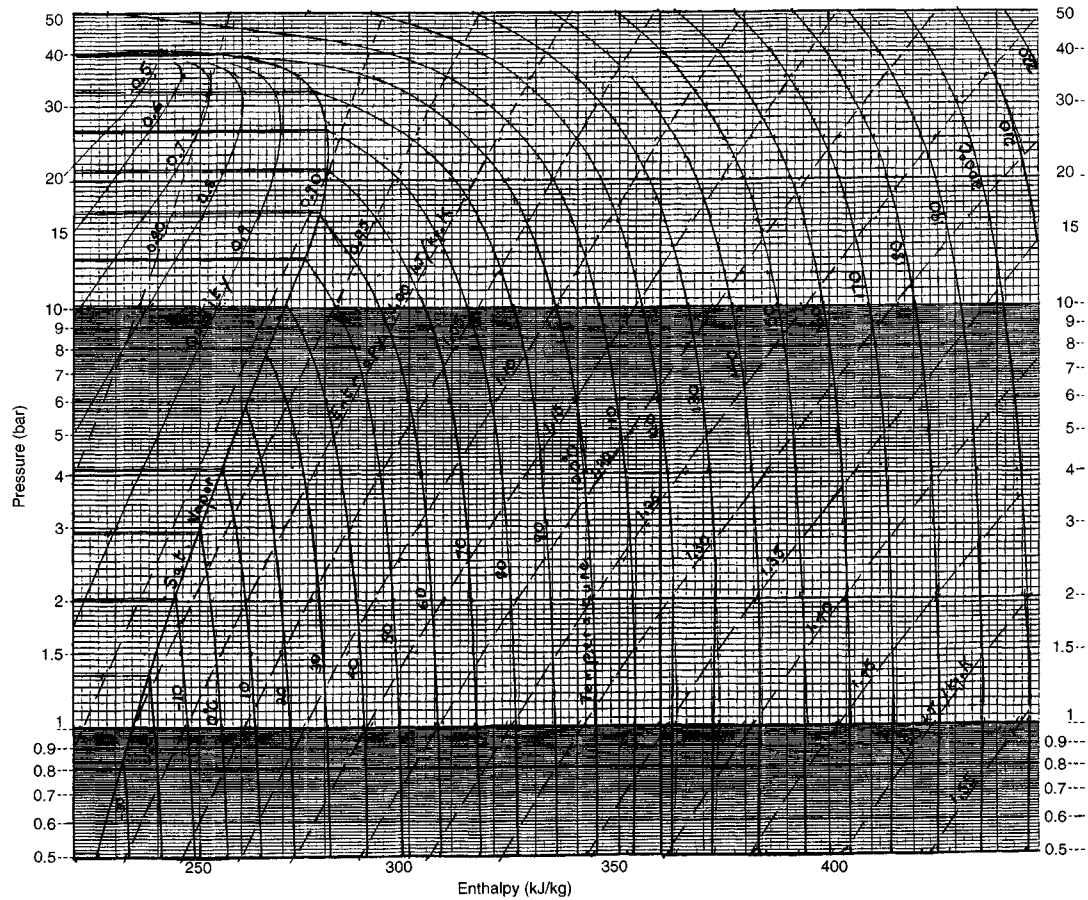


Fig. 39.5 Enthalpy-log pressure diagram for Refrigerant 134a.

Table 39.16 Thermodynamic Properties of Saturated Sodium^a

T (K)	P (bar)	v_f	v_g	h_f	h_g	s_f	s_g	c_{pf}	c_{pg}
380	2.55.-10 ^b	1.081.-3	5.277.+9	0.219	4.723	2.853	14.705	1.384	0.988
400	1.36.-9	1.086.-3	2.173.+9	0.247	4.740	2.924	14.158	1.374	1.023
420	6.16.-9	1.092.-3	2.410.+8	0.274	4.757	2.991	13.665	1.364	1.066
440	2.43.-8	1.097.-3	6.398.+7	0.301	4.773	3.054	13.219	1.355	1.117
460	8.49.-8	1.103.-3	1.912.+7	0.328	4.790	3.114	12.814	1.346	1.176
480	2.67.-7	1.109.-3	6.341.+6	0.355	4.806	3.171	12.443	1.338	1.243
500	7.64.-7	1.114.-3	2.304.+6	0.382	4.820	3.226	12.104	1.330	1.317
550	7.54.-6	1.129.-3	2.558.+5	0.448	4.856	3.352	11.367	1.313	1.523
600	5.05.-5	1.145.-3	41511	0.513	4.887	3.465	10.756	1.299	1.745
650	2.51.-4	1.160.-3	9001	0.578	4.915	3.569	10.241	1.287	1.963
700	9.87.-4	1.177.-3	2449	0.642	4.939	3.664	9.802	1.278	2.160
750	0.00322	1.194.-3	794	0.705	4.959	3.752	9.424	1.270	2.325
800	0.00904	1.211.-3	301	0.769	4.978	3.834	9.095	1.264	2.452
850	0.02241	1.229.-3	128.1	0.832	4.995	3.910	8.808	1.260	2.542
900	0.05010	1.247.-3	60.17	0.895	5.011	3.982	8.556	1.258	2.597
1000	0.1955	1.289.-3	16.84	1.021	5.043	4.115	8.137	1.259	2.624
1200	1.482	1.372.-3	2.571	1.274	5.109	4.346	7.542	1.281	2.515
1400	6.203	1.469.-3	0.688	1.535	5.175	4.546	7.146	1.330	2.391
1600	17.98	1.581.-3	0.258	1.809	5.225	4.728	6.863	1.406	2.301
1800	40.87	1.709.-3	0.120	2.102	5.255	4.898	6.649	1.516	2.261
2000	78.51	1.864.-3	0.0634	2.422	5.256	5.064	6.480	1.702	2.482
2200	133.5	2.076.-3	0.0362	2.794	5.207	5.235	6.332	2.101	3.307
2400	207.6	2.480.-3	0.0196	3.299	5.025	5.447	6.166	3.686	8.476
2500	251.9	3.323.-3	0.0100	3.850	4.633	5.666	5.980		

^a v = specific volume (m³/kg); h = specific enthalpy (MJ/kg); s = specific entropy (kJ/kg · K); c_p = specific heat at constant pressure (kJ/kg · K); f = saturated liquid; g = saturated vapor. Converted from the tables of J. K. Fink, Argonne Nat. Lab. rept. ANL-CEN-RSD-82-4, 1982.

^bThe notation 2.55.-10 signifies 2.55×10^{-10} .

Table 39.17 Thermodynamic Properties of Ice/Water^a

T (K)	P (bar)	v (m ³ /kg)	h (kJ/kg)	s (kJ/kg · K)	c_p (kJ/kg · K)
150	6.30.-11 ^b	0.001073	94.7	1.328	1.224
160	7.72.-10	0.001074	107.3	1.409	1.291
170	7.29.-9	0.001076	120.6	1.489	1.357
180	5.38.-8	0.001077	134.5	1.569	1.426
190	3.23.-7	0.001078	149.1	1.648	1.495
200	1.62.-6	0.001079	164.4	1.726	1.566
210	7.01.-6	0.001081	180.4	1.805	1.638
220	2.65.-5	0.001082	197.1	1.882	1.711
230	8.91.-5	0.001084	214.6	1.960	1.785
240	2.73.-4	0.001085	232.8	2.038	1.860
250	7.59.-4	0.001087	251.8	2.115	1.936
260	0.00196	0.001088	271.5	2.192	2.013
270	0.00469	0.001090	292.0	2.270	2.091
273.15	0.00611	0.001091	298.7	2.294	2.116
273.15	0.00611	0.001000	632.2	3.515	4.217
280	0.00990	0.001000	661.0	3.619	4.198
290	0.01917	0.001001	702.9	3.766	4.184
300	0.03531	0.001003	744.7	3.908	4.179

^a v = specific volume; h = specific enthalpy; s = specific entropy; c_p = specific heat at constant pressure. Ice values ($T \leq 273.15$ K) converted and rounded off from S. Gordon, NASA Tech. Paper 1906, 1982.

^bThe notation 6.30.-11 signifies 6.30×10^{-11} .

Table 39.18 Thermophysical Properties of Saturated Steam/Water^a

P (bar)	T (K)	v_f	v_g	h_f	h_g	η_g	λ_f	λ_g	Pr_f	Pr_g
1.0	372.78	1.0434.-3 ^b	1.6937	417.5	2675.4	0.1202	0.6805	0.0244	1.735	1.009
1.5	384.52	1.0530.-3	1.1590	467.1	2693.4	0.1247	0.6847	0.0259	1.538	1.000
2.0	393.38	1.0608.-3	0.8854	504.7	2706.3	0.1280	0.6866	0.0268	1.419	1.013
2.5	400.58	1.0676.-3	0.7184	535.3	2716.4	0.1307	0.6876	0.0275	1.335	1.027
3.0	406.69	1.0735.-3	0.6056	561.4	2724.7	0.1329	0.6879	0.0281	1.273	1.040
3.5	412.02	1.0789.-3	0.5240	584.3	2731.6	0.1349	0.6878	0.0287	1.224	1.050
4.0	416.77	1.0839.-3	0.4622	604.7	2737.6	0.1367	0.6875	0.0293	1.185	1.057
4.5	421.07	1.0885.-3	0.4138	623.2	2742.9	0.1382	0.6869	0.0298	1.152	1.066
5	424.99	1.0928.-3	0.3747	640.1	2747.5	0.1396	0.6863	0.0303	1.124	1.073
6	432.00	1.1009.-3	0.3155	670.4	2755.5	0.1421	0.6847	0.0311	1.079	1.091
7	438.11	1.1082.-3	0.2727	697.1	2762.0	0.1443	0.6828	0.0319	1.044	1.105
8	445.57	1.1150.-3	0.2403	720.9	2767.5	0.1462	0.6809	0.0327	1.016	1.115
9	448.51	1.1214.-3	0.2148	742.6	2772.1	0.1479	0.6788	0.0334	0.992	1.127
10	453.03	1.1274.-3	0.1943	762.6	2776.1	0.1495	0.6767	0.0341	0.973	1.137
12	461.11	1.1386.-3	0.1632	798.4	2782.7	0.1523	0.6723	0.0354	0.943	1.156
14	468.19	1.1489.-3	0.1407	830.1	2787.8	0.1548	0.6680	0.0366	0.920	1.175
16	474.52	1.1586.-3	0.1237	858.6	2791.8	0.1569	0.6636	0.0377	0.902	1.191
18	480.26	1.1678.-3	0.1103	884.6	2794.8	0.1589	0.6593	0.0388	0.889	1.206
20	485.53	1.1766.-3	0.0995	908.6	2797.2	0.1608	0.6550	0.0399	0.877	1.229
25	497.09	1.1972.-3	0.0799	962.0	2800.9	0.1648	0.6447	0.0424	0.859	1.251
30	506.99	1.2163.-3	0.0666	1008.4	2802.3	0.1684	0.6347	0.0449	0.849	1.278
35	515.69	1.2345.-3	0.0570	1049.8	2802.0	0.1716	0.6250	0.0472	0.845	1.306
40	523.48	1.2521.-3	0.0497	1087.4	2800.3	0.1746	0.6158	0.0496	0.845	1.331
45	530.56	1.2691.-3	0.0440	1122.1	2797.7	0.1775	0.6068	0.0519	0.849	1.358
50	537.06	1.2858.-3	0.0394	1154.5	2794.2	0.1802	0.5981	0.0542	0.855	1.386
60	548.70	1.3187.-3	0.0324	1213.7	2785.0	0.1854	0.5813	0.0589	0.874	1.442
70	558.94	1.3515.-3	0.0274	1267.4	2773.5	0.1904	0.5653	0.0638	0.901	1.503
80	568.12	1.3843.-3	0.0235	1317.1	2759.9	0.1954	0.5499	0.0688	0.936	1.573
90	576.46	1.4179.-3	0.0205	1363.7	2744.6	0.2005	0.5352	0.0741	0.978	1.651
100	584.11	1.4526.-3	0.0180	1408.0	2727.7	0.2057	0.5209	0.0798	1.029	1.737
110	591.20	1.4887.-3	0.0160	1450.6	2709.3	0.2110	0.5071	0.0859	1.090	1.837
120	597.80	1.5268.-3	0.0143	1491.8	2689.2	0.2166	0.4936	0.0925	1.163	1.963
130	603.98	1.5672.-3	0.0128	1532.0	2667.0	0.2224	0.4806	0.0998	1.252	2.126
140	609.79	1.6106.-3	0.0115	1571.6	2642.4	0.2286	0.4678	0.1080	1.362	2.343
150	615.28	1.6579.-3	0.0103	1611.0	2615.0	0.2373	0.4554	0.1172	1.502	2.571
160	620.48	1.7103.-3	0.0093	1650.5	2584.9	0.2497	0.4433	0.1280	1.688	3.041
170	625.41	1.7696.-3	0.0084	1691.7	2551.6	0.2627	0.4315	0.1404	2.098	3.344
180	630.11	1.8399.-3	0.0075	1734.8	2513.9	0.2766	0.4200	0.1557	2.360	3.807
190	634.58	1.9260.-3	0.0067	1778.7	2470.6	0.2920	0.4087	0.1749	2.951	8.021
200	638.85	2.0370.-3	0.0059	1826.5	2410.4	0.3094	0.3976	0.2007	4.202	12.16

Table 39.18 (Continued)

P (bar)	s_f	s_g	c_{pf}	c_{pg}	η_f	γ_f'	γ_g	\bar{v}_{sf}'	\bar{v}_{sg}	τ
1.0	1.3027	7.3598	4.222	2.048	2.801	1.136	1.321	438.74	472.98	0.0589
1.5	1.4336	7.2234	4.231	2.077	2.490	1.139	1.318	445.05	478.73	0.0566
2.0	1.5301	7.1268	4.245	2.121	2.295	1.141	1.316	449.51	482.78	0.0548
2.5	1.6071	7.0520	4.258	2.161	2.156	1.142	1.314	452.92	485.88	0.0534
3.0	1.6716	6.9909	4.271	2.198	2.051	1.143	1.313	455.65	488.36	0.0521
3.5	1.7273	6.9392	4.282	2.233	1.966	1.143	1.311	457.91	490.43	0.0510
4.0	1.7764	6.8943	4.294	2.266	1.897	1.144	1.310	459.82	492.18	0.0500
4.5	1.8204	6.8547	4.305	2.298	1.838	1.144	1.309	461.46	493.69	0.0491
5	1.8604	6.8192	4.315	2.329	1.787	1.144	1.308	462.88	495.01	0.0483
6	1.9308	6.7575	4.335	2.387	1.704	1.144	1.306	465.23	497.22	0.0468
7	1.9918	6.7052	4.354	2.442	1.637	1.143	1.304	467.08	498.99	0.0455
8	2.0457	6.6596	4.372	2.495	1.581	1.142	1.303	468.57	500.55	0.0444
9	2.0941	6.6192	4.390	2.546	1.534	1.142	1.302	469.78	501.64	0.0433
10	2.1382	6.5821	4.407	2.594	1.494	1.141	1.300	470.76	502.64	0.0423
12	2.2161	6.5194	4.440	2.688	1.427	1.139	1.298	472.23	504.21	0.0405
14	2.2837	6.4651	4.472	2.777	1.373	1.137	1.296	473.18	505.33	0.0389
16	2.3436	6.4175	4.504	2.862	1.329	1.134	1.294	473.78	506.12	0.0375
18	2.3976	6.3751	4.534	2.944	1.291	1.132	1.293	474.09	506.65	0.0362
20	2.4469	6.3367	4.564	3.025	1.259	1.129	1.291	474.18	506.98	0.0350
25	2.5543	6.2536	4.640	3.219	1.193	1.123	1.288	473.71	507.16	0.0323
30	2.6455	6.1837	4.716	3.407	1.143	1.117	1.284	472.51	506.65	0.0300
35	2.7253	6.1229	4.792	3.593	1.102	1.111	1.281	470.80	505.66	0.0280
40	2.7965	6.0685	4.870	3.781	1.069	1.104	1.278	468.72	504.29	0.0261
45	2.8612	6.0191	4.951	3.972	1.040	1.097	1.275	466.31	502.68	0.0244
50	2.9206	5.9735	5.034	4.168	1.016	1.091	1.272	463.67	500.73	0.0229
60	3.0273	5.8908	5.211	4.582	0.975	1.077	1.266	457.77	496.33	0.0201
70	3.1219	5.8162	5.405	5.035	0.942	1.063	1.260	451.21	491.31	0.0177
80	3.2076	5.7471	5.621	5.588	0.915	1.048	1.254	444.12	485.80	0.0156
90	3.2867	5.6820	5.865	6.100	0.892	1.033	1.249	436.50	479.90	0.0136
100	3.3606	5.6198	6.142	6.738	0.872	1.016	1.244	428.24	473.67	0.0119
110	3.4304	5.5595	6.463	7.480	0.855	0.998	1.239	419.20	467.13	0.0103
120	3.4972	5.5002	6.838	8.384	0.840	0.978	1.236	409.38	460.25	0.0089
130	3.5616	5.4408	7.286	9.539	0.826	0.956	1.234	398.90	453.00	0.0076
140	3.6243	5.3803	7.834	11.07	0.813	0.935	1.232	388.00	445.34	0.0064
150	3.6859	5.3178	8.529	13.06	0.802	0.916	1.233	377.00	437.29	0.0053
160	3.7471	5.2531	9.456	15.59	0.792	0.901	1.235	366.24	428.89	0.0043
170	3.8197	5.1855	11.30	17.87	0.782	0.867	1.240	351.19	420.07	0.0034
180	3.8765	5.1128	12.82	21.43	0.773	0.838	1.248	336.35	410.39	0.0026
190	3.9429	5.0332	15.76	27.47	0.765	0.808	1.260	320.20	399.87	0.0018
200	4.0149	4.9412	22.05	39.31	0.758	0.756	1.280	298.10	387.81	0.0011

^a v = specific volume (m^3/kg); h = specific enthalpy (kJ/kg); s = specific entropy ($\text{kJ}/\text{kg} \cdot \text{K}$); c_p = specific heat at constant pressure ($\text{kJ}/\text{kg} \cdot \text{K}$); η = viscosity ($10^{-4} \text{ Pa} \cdot \text{sec}$); λ = thermal conductivity ($\text{W}/\text{m} \cdot \text{K}$); Pr = Prandtl number; $\gamma = c_p/c_v$ ratio; \bar{v}_s = velocity of sound (m/sec); τ = surface tension (N/m); f' = wet saturated vapor; g = saturated vapor. Rounded off from values of C. M. Tseng, T. A. Hamp, and E. O. Moeck, Atomic Energy of Canada Report AECL-5910, 1977.

^bThe notation 1.0434.-3 signifies 1.0434×10^{-3} .

Table 39.19 Thermophysical Properties of Miscellaneous Substances at Atmospheric Pressure^a

	Temperature (K)					
	250	300	350	400	450	500
<i>n-Butane</i>						
<i>v</i>	0.0016	0.411	0.485	0.558	0.630	0.701
<i>h</i>	236.6	718.9	810.7	913.1	1026	1149
<i>s</i>	3.564	5.334	5.616	5.889	6.155	6.414
<i>c_p</i>	2.21	1.73	1.94	2.15	2.36	2.56
<i>Z</i>	0.005	0.969	0.982	0.988	0.992	0.993
\bar{v}_s	1161	211	229	245	259	273
λ	0.0979	0.0161	0.0220	0.0270	0.0327	0.0390
η	2.545	0.076	0.088	0.101	0.111	0.124
Pr	5.75	0.84	0.82	0.81	0.80	0.80
<i>Ethane</i>						
<i>v</i>	0.672	0.812	0.950	1.088	1.225	1.362
<i>h</i>	948.7	1068	1162	1265	1380	1505
<i>s</i>	7.330	7.634	7.854	8.198	8.467	8.730
<i>c_p</i>	1.58	1.76	1.97	2.18	2.39	2.60
<i>Z</i>	0.986	0.992	0.995	0.997	0.998	0.998
\bar{v}_s	287	312	334	355	374	392
λ	0.0103	0.0157	0.0219	0.0288	0.0361	0.0438
η	0.079	0.094	0.109	0.123	0.135	0.148
Pr	1.214	1.056	0.978	0.932	0.900	0.878
<i>Ethylene</i>						
<i>v</i>	0.734	0.884	1.034	1.183	1.332	1.482
<i>h</i>	966.8	1039	1122	1215	1316	1415
<i>s</i>	7.556	7.832	8.085	8.331	8.568	8.800
<i>c_p</i>	1.40	1.57	1.75	1.93	2.10	2.26
<i>Z</i>	0.991	0.994	0.997	0.998	0.999	1.000
\bar{v}_s	306	330	353	374	394	403
λ	0.0149	0.0206	0.0271	0.0344	0.0425	0.0506
η	0.087	0.103	0.119	0.134	0.148	0.162
Pr	0.816	0.785	0.767	0.751	0.735	0.721
<i>n-Hydrogen</i>						
<i>v</i>	10.183	12.218	14.253	16.289	18.324	20.359
<i>h</i>	3517	4227	4945	5669	6393	7118
<i>s</i>	67.98	70.58	72.79	74.72	76.43	77.96
<i>c_p</i>	14.04	14.31	14.43	14.48	14.50	14.51
<i>Z</i>	1.000	1.000	1.000	1.000	1.000	1.000
\bar{v}_s	1209	1319	1423	1520	1611	1698
λ	0.162	0.187	0.210	0.230	0.250	0.269
η	0.079	0.089	0.099	0.109	0.118	0.127
Pr	0.685	0.685	0.685	0.684	0.684	0.684
<i>Nitrogen</i>						
<i>v</i>	0.7317	0.8786	1.025	1.171	1.319	1.465
<i>h</i>	259.1	311.2	363.3	415.4	467.8	520.4
<i>s</i>	6.650	6.840	7.001	7.140	7.263	7.374
<i>c_p</i>	1.042	1.041	1.042	1.045	1.050	1.056
<i>Z</i>	0.9992	0.9998	0.9998	0.9999	1.0000	1.0002
\bar{v}_s	322	353	382	407	432	455
λ	0.0223	0.0259	0.0292	0.0324	0.0366	0.0386
η	0.155	0.178	0.200	0.220	0.240	0.258
Pr	0.724	0.715	0.713	0.710	0.708	0.706

Table 39.19 (Continued)

	Temperature (K)					
	250	300	350	400	450	500
<i>Oxygen</i>						
<i>v</i>	0.6402	0.7688	0.9790	1.025	1.154	1.282
<i>h</i>	226.9	272.7	318.9	365.7	413.1	461.3
<i>s</i>	6.247	6.414	6.557	6.682	6.793	6.895
<i>c_p</i>	0.915	0.920	0.929	0.942	0.956	0.972
<i>Z</i>	0.9987	0.9994	0.9996	0.9998	1.0000	1.0000
λ	0.0226	0.0266	0.0305	0.0343	0.0380	0.0416
η	0.179	0.207	0.234	0.258	0.281	0.303
Pr	0.725	0.716	0.713	0.710	0.708	0.707
<i>Propane</i>						
<i>v</i>	0.451	0.548	0.644	0.738	0.832	0.926
<i>h</i>	877.2	957.0	1048	1149	1261	1384
<i>s</i>	5.840	6.131	6.409	6.680	6.944	7.202
<i>c_p</i>	1.50	1.70	1.96	2.14	2.35	2.55
<i>Z</i>	0.970	0.982	0.988	0.992	0.994	0.996
\bar{v}_s	227	248	268	285	302	317
λ	0.0128	0.0182	0.0247	0.0296	0.0362	0.0423
η	0.070	0.082	0.096	0.108	0.119	0.131
Pr	0.820	0.772	0.761	0.765	0.773	0.793
<i>Propylene</i>						
<i>v</i>	0.482	0.585	0.686	0.786	0.884	0.972
<i>h</i>	891.8	957.6	1040	1131	1235	1338
<i>s</i>	6.074	6.354	6.606	6.851	7.095	7.338
<i>c_p</i>	1.44	1.55	1.73	1.91	2.09	2.27
<i>Z</i>	0.976	0.987	0.992	0.994	0.995	0.996
\bar{v}_s	247	257	278	298	315	333
λ	0.0127	0.0177	0.0233	0.0296	0.0363	0.0438
η	0.072	0.087	0.101	0.115	0.128	0.141
Pr	0.814	0.769	0.754	0.742	0.731	0.728

^a*v* = specific volume (m³/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/m²) (thus, at 250 K for *n*-butane the viscosity is 2.545×10^{-4} N · sec/m² = 0.0002545 Pa · sec); Pr = Prandtl number.

Table 39.20 Physical Properties of Numbered Refrigerants^a

Number	Formula, Composition, Synonym	Molecular Weight	<i>n.b.p.</i> (°C)	<i>crit. P</i> (bar)	<i>crit. T</i> (°C)
4	R-32/125/134a/143a (10/33/21/36)	94.50	-49.4	40.1	77.5
10	CCl ₄ (carbon tetrachloride)	153.8	76.8	45.6	283.2
CFC 11	CCl ₃ F	137.37	23.8	44.1	198.0
11B1	CBrCl ₂ F	181.82	52		
11B2	CBr ₂ ClF	226.27	80		
11B3	CBr ₃ F	270.72	107		
CFC 12	CCl ₂ F ₂	120.91	-29.8	41.1	112.0
12B1	CBrClF ₂	165.36	-2.5	42.5	153.0
12B2	CF ₂ Br ₂	209.81	24.5	40.7	204.9
CFC 13	CClF ₃	104.46	-81.4	38.7	28.8
BFC 13B1	CBrF ₃ (Halon 1301)	148.91	-57.8	39.6	67.0
FC 14	CF ₄ (carbon tetrafluoride)	88.00	-127.9	37.5	-45.7
20	CHCl ₃ (chloroform)	119.38	61.2	54.5	263.4
21	CHCl ₂ F	102.92	8.9	51.7	178.5
HCFC 22	CHClF ₂	86.47	-40.8	49.9	96.2
HFC 23	CHF ₃	70.01	-82.1	48.7	26.3
HCC 30	CH ₂ Cl ₂ (methylene chloride)	84.93	40.2	60.8	237.0
31	CH ₂ ClF	68.47	-9.1	56.2	153.8
HFC 32	CH ₂ F ₂	52.02	-51.7	58.0	78.2
33	R-22/124/152a (40/43/17)	96.62	-28.8		
40	CH ₃ Cl (methyl chloride)	50.49	-12.4	66.7	143.1
FX 40	R-32/125/143a (10/45/45)	90.70	-48.4	40.5	72.0
HFC 41	CH ₃ F (methyl fluoride)	34.03	-78.4	58.8	44.3
50	CH ₄ (methane)	16.04	-161.5	46.4	-82.5
FX 57	R-22/124/142b (65/25/10)	96.70	-35.2	47.0	105.0
110	CCl ₃ CCl ₃	236.8	185	33.4	401.8
111	CCl ₃ CCl ₂ F	220.2	137		
112	CCl ₂ FCCl ₂ F	203.8	92.8	33.4	278
CFC 113	CClF ₂ CCl ₂ F	187.38	47.6	34.4	214.1
113a	CCl ₃ CF ₃	187.36	47.5		
CFC 114	CClF ₂ CClF ₂	170.92	3.8	32.5	145.7
114a	CF ₃ CCl ₂ F	170.92	3.0	33.0	145.5
CFC 115	CClF ₂ CF ₃	154.47	-39.1	31.5	79.9
FC 116	CF ₃ CF ₃ (perfluoroethane)	138.01	-78.2	30.4	19.9
120	CHCl ₂ CCl ₃	202.3	162	34.8	373
121	CHCl ₂ CCl ₂ F	185.84	116.6		
122	CClF ₂ CHCl ₂	131.39	72.0		
HCFC 123	CHCl ₂ CF ₃	152.93	27.9	36.7	183.7
HCFC 123a	CHClFCClF ₂	152.93	28.0	44.7	188.5
HCFC 124	CHClFCF ₃	136.48	-12.0	36.4	122.5
E 125	CHF ₂ OCF ₂	136.02	-41.9	33.3	80.4
HFC 125	CHF ₂ CF ₃	120.02	-48.1	36.3	66.3
131	CHCl ₂ CHClF	151.4	102.5		
132	CHClFCHClF	134.93	58.5		
133	CHClFCHF ₂	118.5	17.0		
E 134	CHF ₂ OCHF ₂	118.03	6.2	42.3	153.5
HFC 134	CHF ₂ CHF ₂	102.03	-23.0	46.2	118.7
HFC 134a	CH ₂ FCF ₃	102.03	-26.1	40.6	101.1
141	CH ₂ ClCHClF	116.95	76		

Table 39.20 (Continued)

Number	Formula, Composition, Synonym	Molecular Weight	<i>n.b.p.</i> (°C)	<i>crit. P</i> (bar)	<i>crit. T</i> (°C)
141a	CHCl ₂ CH ₂ F	116.95			
HCFC 141b	CH ₃ CCl ₂ F	116.95	32.2	42.5	204.4
142	CHF ₂ CH ₂ Cl	100.49	35.1		
142a	CHClFCH ₂ F	100.49			
HCFC 142b	CH ₃ CClF ₂	100.50	-9.8	41.2	137.2
143	CHF ₂ CH ₂ F	84.04	5.		
E 143a	CH ₃ OCF ₃	100.04	-24.1	35.9	104.9
HFC 143a	CH ₃ CF ₃	84.04	-47.4	38.3	73.6
151	CH ₂ FCH ₂ Cl	82.50	53.2		
152	CH ₂ FCH ₂ F	66.05	10.5	43.4	171.8
HFC 152a	CH ₃ CHF ₂	66.05	-24.0	45.2	113.3
HCC 160	CH ₃ CH ₂ Cl	64.51	12.4	52.4	186.6
HFC 161	CH ₃ CH ₂ F	48.06	-37.1	47.0	102.2
E 170	CH ₃ OCH ₃ (dimethyl ether)	46.07	-24.8	53.2	128.8
HC 170	CH ₃ CH ₃ (ethane)	30.07	-88.8	48.9	32.2
216	C ₃ Cl ₂ F ₆	220.93	35.7	27.5	180.0
FC 218	CF ₃ CF ₂ CF ₃	188.02	-36.7	26.8	71.9
HFC 227ca	CHF ₂ CF ₂ CF ₃	170.03	-17.0	28.7	106.3
HFC 227ea	CF ₃ CHFCF ₃	170.03	-18.3	29.5	103.5
234da	CF ₃ CHClCHClF	114.03	70.1		
235ca	CF ₃ CF ₂ CH ₂ Cl	156.46	28.1		
HFC 236ca	CHF ₂ CF ₂ CHF ₂	152.04	5.1	34.1	153.2
HFC 236cb	CH ₂ FCF ₂ CF ₃	152.04	-1.4	31.2	130.2
HFC 236ea	CHF ₂ CHFCF ₃	152.04	6.6	35.3	141.2
HFC 235fa	CF ₃ CH ₂ CF ₃	152.04	-1.1	31.8	130.7
HFC 245ca	CH ₂ FCF ₂ CHF ₂	134.05	25.5	38.6	178.5
E 245cb	CHF ₂ OCH ₂ CF ₃	150.05	34.0		185.2
HFC 245cb	CH ₃ CF ₂ CF ₃	134.05	-18.3	32.6	108.5
E 245fa	CHF ₂ OCH ₂ CF ₃	150.05	29.2	37.3	170.9
HFC 245fa	CHF ₂ CH ₂ CF ₃	134.05	15.3	36.4	157.6
HFC 254cb	CH ₃ CF ₂ CHF ₂	116.06	-0.8	37.5	146.2
HC 290	CH ₃ CH ₂ CH ₃ (propane)	44.10	-42.1	42.5	96.8
RC 318	cyclo-CF ₂ CF ₂ CF ₂ CF ₂	200.04	-5.8	27.8	115.4
400	R-12/114				
R-401a	R-22/124/152a (53/34/13)	94.44	-33.1	46.0	108.0
R-401b	R-22/124/152a (61/28/11)	92.84	-34.7	46.8	106.1
R 401c	R 22/124/152a (33/52/15)	101.04	-28.4	43.7	112.7
R 402a	R 22/125/290 (38/60/2)	101.55	-49.2	41.3	75.5
R 402b	R 22/125/290 (60/38/2)	94.71	-47.4	44.5	82.6
R 403a	R 22/218/290 (75/20/5)	91.06	-50.0	50.8	93.3
R 403b	R 22/218/290 (56/39/5)	102.06	-49.5	50.9	90.0
R 404a	R 125/134a/143a (44/4/52)	97.60	-46.5	37.3	72.1
R 405a	R 22/142b/152a/C318 (45/5/ 7/43)	116.00	-27.3	42.6	106.1
R 406a	R 22/142b/600a (55/41/4)	89.85	-30.0	47.4	123.0
R 407a	R 32/125/134a (20/40/40)	90.10	-45.5	45.4	82.8
R 407b	R 32/125/134a (10/70/20)	102.94	-47.3	41.6	75.8
R 407c	R 32/125/134a (23/25/52)	86.20	-43.6	46.2	86.7
R 408a	R 22/125/143a (47/7/46)	87.02	-43.5	43.4	83.5
R 409a	R 22/124/142b (60/25/15)	97.45	-34.2	45.0	107.0

Table 39.20 (Continued)

Number	Formula, Composition, Synonym	Molecular Weight	<i>n.b.p.</i> (°C)	<i>crit. P</i> (bar)	<i>crit. T</i> (°C)
R 410a	R 32/125 (50/50)	72.56	-50.5	49.6	72.5
R 410b	R 32/125 (45/55)				
R 411a	R 22/152a/1270 (88/11/2)				
R 411b	R 22/152a/1270 (94/3/3)				
R 412a	R 22/142b/218 (70/25/5)				
R 500	R 12/152a (74/26)	99.31	-33.5	44.2	105.5
R 501	R 12/22 (25/75)				
R 502	R 22/115 (49/51)	111.64	-45.4	40.8	82.2
R 503	R 13/23 (60/40)	87.28	-87.8	43.6	19.5
R 504	R 32/115 (48/52)	79.2	-57.2	47.6	66.4
R 505	R 12/31 (78/22)	103.5	-30		
R 506	R 31/114 (55/45)	93.7	-12		
R 507	R 125/143a (50/50)	98.90	-46.7	37.9	70.9
R 508	R 23/116 (39/61)	100.10	-85.7		23.1
R 509	R 22/218 (44/56)	124.0	-47		
R 600	CH ₃ CH ₂ CH ₂ CH ₃ (butane)	58.13	-0.4	38.0	152.0
R 600a	CH ₃ CH ₂ CH ₃ CH (isobutane)	58.13	-11.7	36.5	135.0
R 610	C ₄ H ₁₀ O (ethyl ether)	74.12	-116.3	36.0	194.0
R 611	C ₂ H ₄ O ₂ (methyl formate)	60.05	31.8	59.9	204
630	CH ₃ NH (methyl amine)	31.06	-6.7	74.6	156.9
631	C ₂ H ₅ NH ₂ (ethyl amine)	45.08	16.6	56.2	183.0
702	H ₂ (hydrogen)	2.016	-252.8	13.2	-239.9
702p	para-hydrogen	2.016	-252.9	12.9	-240.2
704	He (helium)	4.003	-268.9	2.3	-267.9
717	NH ₃ (ammonia)	17.03	-33.3	114.2	133.0
718	H ₂ O (water)	18.02	100.0	221.0	374.2
720	Ne (neon)	20.18	-246.1	34.0	-228.7
728	N ₂ (nitrogen)	28.01	-198.8	34.0	-146.9
728a	CO (carbon monoxide)	28.01	-191.6	35.0	-140.3
729	- (air)	28.97	-194.3	37.6	-140.6
732	O ₂ (oxygen)	32.00	-182.9	50.8	-118.4
740	A (argon)	39.95	-185.9	49.0	-122.3
744	CO ₂ (carbon dioxide)	44.01	-78.4	73.7	31.1
744a	N ₂ O (nitrous oxide)	44.02	-89.5	72.2	36.5
R 764	SO ₂ (sulfur dioxide)	64.07	-10.0	78.8	157.5
1113	C ₂ ClF ₃	116.47	-27.9	40.5	106
1114	C ₂ F ₄	100.02	-76.0	39.4	33.3
1120	CHClCCl ₂	131.39	87.2	50.2	271.1
1130	CHClCHCl	96.95	47.8	54.8	243.3
1132a	C ₂ H ₂ F ₂	64.03	-85.7	44.6	29.7
1141	C ₂ H ₃ F (vinyl fluoride)	46.04	-72.2	52.4	54.7
1150	C ₂ H ₄ (ethylene)	28.05	-103.7	51.1	9.3
1270	C ₃ H ₆ (propylene)	42.09	-185	46.2	91.8
R 7146	SF ₆ (sulfur hexafluoride)	146.05	-63.8	37.6	45.6

*Refrigerant numbers in some cases are tentative and subject to revision. Compositions rounded to nearest weight percent.

Based upon data supplied by M.O. McLinden, N.I.S.T., Boulder, CO, PCR Chemicals, Gainesville, FL, G.H. Thomson, DIPPR, Bartlesville, OK, and literature sources.

Table 39.21 Specific Heat (kJ/kg · K) at Constant Pressure of Saturated Liquids

Substance	Temperature (K)															
	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400
Acetic acid	— ^a	—	—	—	2.03	2.06	2.09	2.12	2.16	2.19	2.23	2.26	2.29	2.33	2.36	2.39
Acetone	2.05	2.07	2.10	2.13	2.16	2.19	2.22	2.26	2.30	2.35	2.40					
Ammonia	4.48	4.54	4.60	4.66	4.73	4.82	4.91	5.02	5.17	5.37	5.64	6.04	6.68	7.80	10.3	21
Aniline	—	—	2.03	2.04	2.05	2.07	2.10	2.13	2.16	2.19	2.22	2.26	2.31	2.38	2.47	2.58
Benzene	—	—	—	1.69	1.71	1.73	1.75	1.78	1.81	1.84	1.87	1.91	1.94	1.98	2.03	2.09
<i>n</i> -Butane	2.19	2.23	2.27	2.32	2.37	2.43	2.50	2.58	2.67	2.76	2.86	2.97	3.08			
Butanol	2.13	2.17	2.22	2.27	2.33	2.38	2.44	2.51	2.58	2.65	2.73	2.82	2.93	3.06	3.20	3.36
Carbon tetrachloride	0.833	0.838	0.843	0.848	0.853	0.858	0.864	0.870	0.879	0.891	0.912	0.941	0.975			
Chlorobenzene	1.29	1.31	1.32	1.32	1.33	1.33	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.47	1.49	1.51
<i>m</i> -Cresol	—	—	—	—	2.04	2.07	2.11	2.14	2.18	2.21	2.24	2.27	2.30	2.32	2.35	2.38
Ethane	2.97	3.20	3.50	4.00	5.09	9.92	—	—	—	—	—	—	—	—	—	—
Ethanol	—	2.24	2.28	2.33	2.38	2.45	2.54	2.64	2.75	2.86	2.99	3.12	3.26	3.41	3.56	3.72
Ethyl acetate				1.89	1.92	1.94	1.97	2.00	2.03	2.06	2.09	2.13	2.16	2.20	2.24	2.28
Ethyl sulfide	1.96	1.97	1.97	1.98	2.00	2.01	2.02	2.03								
Ethylene	3.25	3.78	5.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Formic acid	—	—	—	—	2.15	2.16	2.17	2.18	2.20	2.22	2.24	2.26	2.28	2.30	2.33	2.36
Heptane	2.08	2.10	2.13	2.17	2.20	2.24	2.28	2.32	2.36	2.41	2.45	2.49	2.54	2.59	2.64	2.70
Hexane	2.09	2.12	2.15	2.19	2.22	2.26	2.31	2.36	2.41	2.46	2.51	2.56	2.62	2.69	2.76	2.83
Methanol	2.31	2.34	2.37	2.41	2.46	2.52	2.58	2.65	2.73	2.82	2.91	3.01	3.12	3.24	3.36	3.49
Methyl formate					2.16	2.16										
Octane	2.07	2.10	2.13	2.16	2.19	2.22	2.26	2.31	2.35	2.39	2.43	2.47	2.52	2.57	2.62	2.69
Oil, linseed	1.58	1.61	1.65	1.69	1.73	1.78	1.82	1.87	1.91	1.95	1.99	2.03	2.08	2.13	2.17	2.21
Oil, olive	1.90	1.92	1.95	1.98	2.01	2.05	2.09	2.13	2.16	2.20	2.24	2.28	2.32	2.37	2.41	2.46
Pentane	1.96	2.02	2.08	2.14	2.21	2.28	2.35	2.42	2.49	2.56	2.63	2.70	2.77	2.84	2.91	2.98
Propane	2.35	2.41	2.48	2.56	2.65	2.76	2.89	3.06	3.28	3.62	4.23	5.98	—	—	—	—
Propanol	2.04	2.10	2.16	2.24	2.32	2.41	2.51	2.62	2.74	2.86	2.99	3.12	3.26	3.40	3.55	3.71
Propylene	2.22	2.27	2.34	2.43	2.55	2.69	2.87	3.12	3.44	3.92	4.75	6.75	—	—	—	—
Sulfuric acid	—	—	—	—	1.39	1.41	1.43	1.45	1.46	1.48	1.50	1.51	1.53	1.54	1.56	1.57
Sulfur dioxide	1.31	1.32	1.33	1.34	1.36	1.39	1.42	1.46	1.50	1.55	1.61	1.68	1.76	1.85	1.99	2.14
Turpentine	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35

^aDashes indicate inaccessible states.

Table 39.23 Surface Tension (N/m) of Liquids

Substance	Temperature (K)															
	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400
Acetone	0.0291	0.0279	0.0266	0.0253	0.0240	0.0228	0.0214	0.0201	0.0187	0.0174	0.0162	0.0150	0.0139	0.0128	0.0117	0.0106
Ammonia	0.0317	0.0294	0.0271	0.0248	0.0226	0.0203	0.0181	0.0159	0.0138	0.0117	0.0099	0.0080	0.0059	0.0040	0.0021	0.0003
Benzene			0.0320	0.0306	0.0292	0.0278	0.0265	0.0252	0.0239	0.0227	0.0215	0.0203	0.0191	0.0179	0.0167	0.0155
Butane	0.0177	0.0165	0.0153	0.0141	0.0129	0.0116	0.0104	0.0092	0.0080	0.0069	0.0059	0.0049	0.0040	0.0031	0.0023	0.0016
CO ₂	0.0092	0.0071	0.0051	0.0032	0.0016	0.0003	—	—	—	—	—	—	—	—	—	—
Chlorine	0.0244	0.0228	0.0213	0.0198	0.0183	0.0168	0.0153	0.0138	0.0123	0.0108	0.0094	0.0080	0.0066	0.0052	0.0044	0.0037
Ethane	0.0059	0.0047	0.0035	0.0024	0.0013	0.0005	—	—	—	—	—	—	—	—	—	—
Ethanol	0.0271	0.0261	0.0251	0.0242	0.0232	0.0223	0.0214	0.0205	0.0196	0.0186	0.0177	0.0167	0.0158	0.0148	0.0137	0.0126
Ethylene	0.0032	0.0019	0.0009	0.0002	—	—	—	—	—	—	—	—	—	—	—	—
Heptane	0.0244	0.0234	0.0224	0.0214	0.0205	0.0195	0.0185	0.0176	0.0166	0.0156	0.0147	0.0137	0.0127	0.0118	0.0109	0.0099
Hexane	0.0229	0.0218	0.0207	0.0197	0.0186	0.0175	0.0165	0.0154	0.0145	0.0135	0.0125	0.0115	0.0106	0.0096	0.0086	0.0076
Mercury	0.474	0.472	0.470	0.468	0.466	0.464	0.462	0.460	0.458	0.456	0.454	0.452	0.450	0.448	0.446	0.444
Methanol						0.0223	0.0214	0.0205	0.0196	0.0187	0.0178	0.0168	0.0159	0.0149	0.0139	0.0128
Octane	0.0251	0.0243	0.0234	0.0225	0.0216	0.0207	0.0197	0.0188	0.0179	0.0170	0.0161	0.0152	0.0143	0.0135	0.0127	0.0120
Propane	0.0132	0.0118	0.0104	0.0091	0.0079	0.0067	0.0056	0.0046	0.0037	0.0028	0.0018	0.0009	—	—	—	—
Propylene	0.0133	0.0120	0.0106	0.0091	0.0078	0.0065	0.0053	0.0042	0.0032	0.0023	0.0014	0.0006	—	—	—	—
R12	0.0148	0.0135	0.0122	0.0109	0.0096	0.0083	0.0070	0.0058	0.0047	0.0036	0.0027	0.0018	0.0010	0.0003	—	—
R13	0.0057	0.0042	0.0029	0.0018	0.0009	0.0003	—	—	—	—	—	—	—	—	—	—
Toluene	0.0342	0.0327	0.0312	0.0298	0.0285	0.0272	0.0260	0.0249	0.0236	0.0225	0.0214	0.0203	0.0193	0.0183	0.0173	0.0163
Water	—	—	—	0.0746	0.0732	0.0716	0.0699	0.0684	0.0666	0.0650	0.0636	0.0614	0.0595	0.0575	0.0555	0.0535

Table 39.25 Viscosity (10^{-4} Pa · sec) of Saturated Liquids

Substance	Temperature (K)															
	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400
Acetic acid	—	—	—	—	13.1	11.3	9.77	8.49	7.40	6.48	5.70	5.03	4.45	3.95	3.52	3.15
Acetone	5.27	4.63	4.11	3.68	3.32	3.01	2.73	2.49	2.28	2.10	1.94					
Ammonia	2.20	1.94	1.74	1.58	1.44	1.31	1.20	1.08	0.98	0.88	0.78	0.70	0.64	0.58	0.53	0.48
Aniline	—	—	96.9	71.6	53.5	40.3	30.7	23.6	18.2	14.2	11.2	8.84	7.03	5.63	4.54	3.68
Benzene	—	—	—	8.08	6.80	5.84	5.13	4.52	4.05	3.60	3.29	2.98	2.70	2.45	2.24	2.04
Butane	2.63	2.37	2.15	1.95	1.77	1.61	1.56	1.33	1.21	1.10	1.00	0.90	0.81	0.73	0.66	0.60
Butanol	94.2	70.9	53.9	41.4	32.1	25.1	19.8	15.7	12.6	10.1	8.22	6.71	5.50	4.53	3.75	3.13
Carbon tetrachloride			14.0	11.9	10.2	8.78	7.70	6.81	6.06	5.43	4.89	4.41	4.00	3.65	3.34	3.07
Chlorobenzene	13.9	12.2	10.7	9.50	8.44	7.53	6.74	6.05	5.46	4.93	4.47	4.07	3.70	3.39	3.10	2.85
<i>m</i> -Cresol	—	—	—	—	261	136	72.0	39.0	21.5	12.1	6.90					
Ethane	0.81	0.70	0.60	0.51	0.42	0.35	—	—	—	—	—	—	—	—	—	—
Ethanol	—	23.3	18.9	15.5	12.8	10.6	8.81	7.39	6.24	5.29	4.51	3.86	3.31	2.86	2.48	2.15
Ethyl acetate	7.21	6.53	5.86	5.28	4.78	4.33	3.95	3.60	3.30	3.03	2.79	2.57	2.38	2.20	2.04	1.90
Ethyl sulfide	7.69	6.68	5.86	5.19	4.64	4.18	3.78	3.45	3.16	2.92	2.70	2.51	2.34	2.20	2.06	1.95
Ethylene	0.582	0.505	0.418	0.31	—	—	—	—	—	—	—	—	—	—	—	—
Formic acid	48.3	37.4	29.5	23.6	19.2	15.9	13.3	11.2	9.56	8.24	7.16	6.27	5.53	4.91	4.39	3.94
Heptane	7.25	6.25	5.46	4.82	4.28	3.83	3.45	3.14	2.87	2.62	2.39	2.20	2.03	1.87	1.72	1.59
Hexane	5.03	4.46	3.97	3.57	3.22	2.93	2.68	2.45	2.24	2.07	1.92	1.78	1.63	1.50	1.38	1.26
Methanol	12.3	10.1	8.43	7.15	6.14	5.32	4.60	4.09	3.60	3.19	2.84	2.53	2.28	2.06	1.85	1.65
Methyl formate	5.71	5.04	4.50	4.04	3.66	3.34	3.06	2.82	2.61	2.43	2.27	2.13	2.01	1.89	1.79	1.70
Octane	10.5	8.80	7.49	6.45	5.66	5.01	4.48	4.03	3.65	3.33	3.05	2.80	2.58	2.38	2.18	2.02
Oil, linseed	2300	1500	1000	700	490	356	263	198	152	118	93.5	74.8	60.6	49.6	41.1	34.3
Oil, olive	8350	4600	2600	1600	1000	630	410	278	193	136	98.3	72.2	54.0	40.9	31.0	24.6
Pentane	3.50	3.16	2.87	2.62	2.39	2.20	2.03	1.87	1.73	1.59	1.46	1.34	1.22	1.11	1.01	0.92
Propane	1.71	1.53	1.37	1.23	1.10	0.98	0.87	0.76	0.66	0.58	0.51	0.45	—	—	—	—
Propanol	67.8	50.0	37.7	29.0	22.7	18.0	14.6	11.9	9.87	8.27	6.99	5.97	5.14	4.46	3.90	3.44
Propylene	1.41	1.27	1.16	1.05	0.94	0.84	0.75	0.67	0.60	0.53	0.47	0.42	—	—	—	—
Sulfuric acid				363	259	189	141	107	82.6	64.7	51.4	41.4	33.7	27.7	23.1	19.4
Sulfur dioxide	5.32	4.53	3.90	3.39	2.85	2.42	2.09	1.83	1.62	1.45	1.30	1.16	1.02	0.89	0.77	0.66
Turpentine	36.3	28.8	23.3	19.1	15.9	13.4	11.4	9.80	8.50	7.44	6.56	5.83	5.21	4.68	4.23	3.85

Table 39.26 Thermochemical Properties at 1.013 bar, 298.15 K

Substance	Formula	ΔH_f° (kJ/kg · mol)	ΔG_f° (kJ/kg · mol)	S° (kJ/kg · mol · K)
Acetaldehyde	$C_2H_4O(g)$	-166,000	-132,900	265.2
Acetic acid	$C_2H_4O_2(g)$	-436,200	+315,500	282.5
Acetone	$C_3H_6O(l)$	-248,000	-155,300	200.2
Acetylene	$C_2H_2(g)$	+266,740	+209,190	200.8
Ammonia	$NH_3(g)$	-46,190	-16,590	192.6
Aniline	$C_6H_7N(l)$	+35,300	+153,200	191.6
Benzene	$C_6H_6(l)$	+49,030	+117,000	172.8
Butanol	$C_4H_{10}O(l)$	-332,400	-168,300	227.6
<i>n</i> -Butane	$C_4H_{10}(l)$	-105,900		
<i>n</i> -Butane	$C_4H_{10}(g)$	-126,200	-17,100	310.1
<i>i</i> -Butane	$C_4H_{10}(g)$	-134,500	-20,900	294.6
Carbon dioxide	$CO_2(g)$	-393,510	-394,390	213.7
Carbon disulfide	$CS_2(g)$	-109,200		237.8
Carbon monoxide	$CO(g)$	-110,520	-137,160	197.6
Carbon tetrachloride	$CCl_4(g)$	-103,000	-66,100	311.3
Carbon tetrafluoride	$CF_4(g)$	-921,300	-878,200	261.5
Chloroform	$CHCl_3(g)$	-104,000	-70,500	295.6
Cyclohexane	$C_6H_{12}(g)$	-123,100	+31,800	298.2
Cyclopropane	$C_3H_6(g)$	+53,300	+104,300	237.7
<i>n</i> -Decane	$C_{10}H_{22}(l)$	-332,600	-17,500	425.5
Diphenyl	$C_{12}H_{10}(g)$	-172,800	-283,900	348.5
Ethane	$C_2H_6(g)$	-84,670	-32,900	229.5
Ethanol	$C_2H_6O(g)$	-235,200	-168,700	282.7
Ethanol	$C_2H_6O(l)$	-277,600	-174,600	160.7
Ethyl acetate	$C_4H_8O_2(g)$	-432,700	-325,800	376.8
Ethyl chloride	$C_2H_5Cl(g)$	-107,600	-55,500	274.8
Ethyl ether	$C_4H_{10}O(g)$	-250,800	-118,400	352.5
Ethylene	$C_2H_4(g)$	+52,280	+68,130	219.4
Ethylene oxide	$C_2H_4O(g)$	-38,500	-11,600	242.9
Heptane	$C_7H_{16}(g)$	-187,800	-427,800	166.0
Hexane	$C_6H_{14}(g)$	-208,400	16,500	270.7
Hydrazine	$N_2H_4(l)$	-50,600	-149,200	121.2
Hydrazine	$N_2H_4(g)$	+95,400	+159,300	238.4
Hydrogen peroxide	$H_2O_2(l)$	-187,500	-120,400	109.6
Methane	$CH_4(g)$	-74,840	-50,790	186.2
Methanol	$CH_4O(l)$	-238,600	-126,800	81.8
Methanol	$CH_4O(g)$	-200,900	-162,100	247.9
Methyl acetate	$C_3H_6O_2(l)$	-444,300		
Methyl bromide	$CH_3Br(g)$	-36,200	-25,900	246.1
Methyl chloride	$CH_3Cl(g)$	-86,300	-63,000	234.2
Methyl formate	$C_2H_4O_2(g)$	-335,100	-301,000	292.8
Methylene chloride	$CH_2Cl_2(g)$	-94,000	-67,000	270.2
Naphthalene	$C_{10}H_8(g)$	-151,500	-224,200	336.5
Nitric oxide	$NO(g)$	+90,300	86,600	210.6
Nitrogen peroxide	$NO_2(g)$	+33,300		240.0
Nitrous oxide	$N_2O(g)$	+82,000	+104,000	219.9
Octane	$C_8H_{18}(l)$	-250,000	6,610	360.8

Table 39.26 (Continued)

Substance	Formula	ΔH_f° (kJ/kg · mol)	ΔG_f° (kJ/kg · mol)	S° (kJ/kg · mol · K)
Octane	$C_8H_{18}(g)$	-208,400	16,500	466.7
<i>i</i> -Pentane	$C_5H_{12}(g)$	-154,500	-14,600	343.6
<i>n</i> -Pentane	$C_5H_{12}(g)$	-146,400	-8,370	348.9
Propane	$C_3H_8(g)$	-103,800	-107,200	269.9
Propanol	$C_3H_8(g)$	-258,800	-164,100	322.6
Propylene	$C_3H_6(g)$	+20,400	+62,700	267.0
R11	$CFCl_3(g)$	-284,500	-238,000	309.8
R12	$CCl_2F_2(g)$	-468,600	-439,300	300.9
R13	$CClF_3(g)$	-715,500	-674,900	285.6
R13B1	$CF_3Br(g)$	-642,700	-616,300	297.6
R23	$CHF_3(g)$	-682,000	-654,900	259.6
Sulfur dioxide	$SO_2(g)$	-296,900	-300,200	248.1
Sulfur hexafluoride	$SF_6(g)$	-1,207,900	-1,105,000	291.7
Toluene	$C_7H_8(g)$	-50,000	-122,300	320.2
Water	$H_2O(l)$	-285,830	-237,210	70.0
Water	$H_2O(g)$	-241,820	-228,600	188.7

Table 39.27 Ideal Gas Sensible Enthalpies (kJ/kg · mol) of Common Products of Combustion^{a,b}

<i>T</i> (K)	Substance							
	CO	CO ₂	H ₂ O(g)	NO	NO ₂	N ₂	O ₂	SO ₂
200	-2858	-3414	-3280	-2950	-3494	-2855	-2860	-3736
220	-2276	-2757	-2613	-2345	-2803	-2270	-2279	-3008
240	-1692	-2080	-1945	-1749	-2102	-1685	-1698	-2266
260	-1110	-1384	-1277	-1148	-1390	-1105	-1113	-1508
280	-529	-667	-608	-547	-668	-525	-529	-719
300	54	67	63	54	67	55	60	75
320	638	822	736	652	813	636	650	882
340	1221	1594	1411	1248	1573	1217	1238	1702
360	1805	2383	2088	1847	2344	1800	1832	2541
380	2389	3187	2768	2444	3130	2383	2429	3387
400	2975	4008	3452	3042	3929	2967	3029	4251
420	3562	4841	4138	3641	4739	3554	3633	5123
440	4152	5689	4828	4247	5560	4147	4241	6014
460	4642	6550	5522	4849	6395	4737	4853	6923
480	5334	7424	6221	5054	7243	5329	5468	7827
500	5929	8314	6920	6058	8100	5921	6088	8749
550	7427	10580	8695	7589	10295	7401	7655	11180
600	8941	12915	10500	9146	12555	8902	9247	13545
650	10475	15310	12325	10720	14875	10415	10865	16015
700	12020	17760	14185	12310	17250	11945	12500	18550
750	13590	20270	16075	13890	19675	13490	14160	21150
800	15175	22820	17990	15550	22140	15050	15840	23720
850	16780	25410	19945	17200	24640	16630	17535	26390
900	18400	28040	21920	18860	27180	18220	19245	29020
950	20030	30700	23940	20540	29740	19835	20970	31700
1000	21690	33410	25980	22230	32340	21460	22710	34430

Table 39.27 (Continued)

T (K)	Substance							
	CO	CO ₂	H ₂ O(g)	NO	NO ₂	N ₂	O ₂	SO ₂
1050	23350	36140	28060	23940	34950	23100	24460	37180
1100	25030	38890	30170	25650	37610	24750	26180	39920
1150	26720	41680	32310	27380	40260	26430	27990	42690
1200	28430	44480	34480	29120	42950	28110	29770	45460
1250	30140	47130	36680	30870	45650	29810	31560	48270
1300	31870	50160	38900	32630	48350	31510	33350	51070
1350	33600	53030	41130	34400	51090	33220	35160	53900
1400	35340	55910	43450	36170	53810	34940	36970	56720
1450	37090	58810	45770	37950	56560	36670	38790	59560
1500	38850	61710	48100	39730	59310	38410	40610	62400
1550	40610	64800	50460	41520	62070	40160	42440	65260
1600	42380	67580	52840	43320	64850	41910	44280	68120
1650	44156	70530	55240	45120	67640	43670	46120	71000
1700	45940	73490	57680	46930	70420	45440	47970	73870
1750	47727	76460	60130	48740	73220	47210	49830	76760
1800	49520	79440	62610	50560	76010	49000	51690	79640
1850	51320	82430	65100	52380	78810	50780	53560	82540
1900	53120	85430	67610	54200	81630	52570	55440	85440
1950	54930	88440	70140	56020	84450	54370	57310	88350
2000	56740	91450	72690	57860	87260	56160	59200	91250
2100	60380	97500	77830	61530	92910	59760	62990	97080
2200	64020	103570	83040	65220	98580	63380	66800	102930
2300	67680	109670	88290	68910	104260	67010	70630	108790
2400	71350	115790	93600	72610	109950	70660	74490	114670
2500	75020	121930	98960	76320	115650	74320	78370	120560
2600	78710	128080	104370	80040	121360	77990	82270	126460
2700	82410	134260	109810	83760	127080	81660	86200	132380
2800	86120	140440	115290	87490	132800	85360	90140	138300
2900	89830	146650	120810	91230	138540	89050	94110	144240
3000	93540	152860	126360	94980	144270	92750	98100	150180

^aConverted and usually rounded off from *JANAF Thermochemical Tables*, NSRDS-NBS-37, 1971.

^bTo illustrate the term *sensible enthalpy*, which is the difference between the actual enthalpy and the enthalpy at the reference temperature, 298.15 K (= 25°C = 77°F = 537°R), the magnitude of the heat transfer, in kJ/kg · mol fuel and in kJ/kg fuel, will be calculated for the steady-state combustion of acetylene in excess oxygen, the reactants entering at 298.15 K and the products leaving at 2000 K. All substances are in the gaseous phase.

The basic equation is

$$Q + W = \sum_P n_i (\Delta h_f^o + \Delta h_s)_i - \sum_R n_i (\Delta h_f^o + \Delta h_s)_i$$

where P signifies products and R reactants, s signifies sensible enthalpy, and the Δh_s are looked up in the table for the appropriate temperatures.

If the actual reaction was



then $W = 0$ and $Q = 2(-393,510 + 91,450) + 1(-241,810 + 72,690) + 3(0 + 59,200) - (226,740 + 0) - \frac{1}{2}(0 + 0) = -604,120 + (-169,120) + 177,600 - 226,740 = -822,380$ kJ/mg mol. $\text{C}_2\text{H}_2 = -31,584$ kJ/kg C_2H_2 . Had the fuel been burnt in air one would write the equation with an additional 3.76(5.5) N_2 on each side of the equation. In the above, the enthalpy of formation of the stable elements at 298.15 K has been set equal to zero. For further information, most undergraduate engineering thermodynamics texts may be consulted.

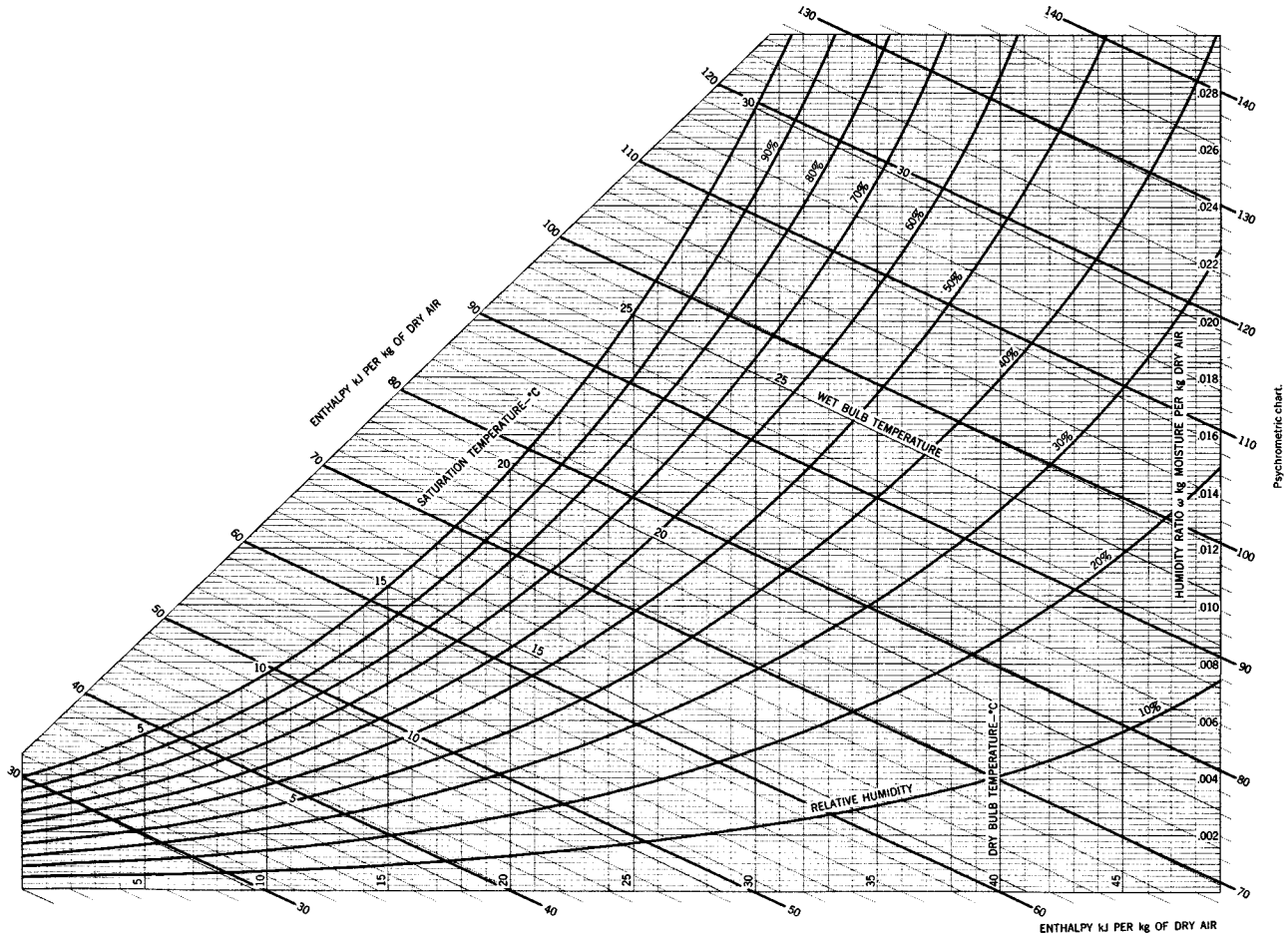


Fig. 39.6 Psychrometric chart. (ASHRAE chart No. 1, 1981. Prepared at the Center for Applied Thermodynamic Studies, University of Idaho, Moscow, ID. Copyright 1981 by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. and reproduced by permission of the copyright owner.)