(*Continued*)

Temp. °C	Abs. Press. MPa p	Specific Volume, m³/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapour v_g	Enthalpy, kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapour h_g	Entropy, kJ/kg K Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapour s_g
50	1.3180	0.000908	0.014217	0.015124	271.830	152.085	423.915	1.2381	0.4706	1.7088
55	1.4915	0.000928	0.012237	0.013166	279.718	145.933	425.650	1.2619	0.4447	1.7066
60	1.6818	0.000951	0.010511	0.011462	287.794	139.336	427.130	1.2857	0.4182	1.7040
65	1.8898	0.000976	0.008995	0.009970	296.088	132.216	428.305	1.3099	0.3910	1.7009
70	2.1169	0.001005	0.007653	0.008657	304.642	124.468	429.110	1.3343	0.3627	1.6970
75	2.3644	0.001038	0.006453	0.007491	313.513	115.939	429.451	1.3592	0.3330	1.6923
80	2.6337	0.001078	0.005368	0.006446	322.794	106.395	429.189	1.3849	0.3013	1.6862
85	2.9265	0.001128	0.004367	0.005495	332.644	95.440	428.084	1.4117	0.2665	1.6782
90	3.2448	0.001995	0.003412	0.004606	343.380	82.295	425.676	1.4404	0.2266	1.6670
95	3.5914	0.001297	0.002432	0.003729	355.834	64.984	420.818	1.4733	0.1765	1.6498
101.15	4.0640	0.001969	0	0.001969	390.977	0	390.977	1.5658	0	1.5658

Table A.4.2

Superheated R-134a

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	0.10 MPa			*0.15 MPa*			*0.20 MPa*		
−25	0.19400	383.212	1.75058	—	—	—	—	—	—
−20	0.19860	387.215	1.76655	—	—	—	—	—	—
−10	0.20765	395.270	1.79775	0.13603	393.839	1.76058	0.10013	392.338	1.73276
0	0.21652	403.413	1.82813	0.14222	402.187	1.79171	0.10501	400.911	1.76474
10	0.22527	411.668	1.85780	0.14828	410.602	1.82197	0.10974	409.500	1.79562
20	0.23393	420.048	1.88689	0.15424	419.111	1.85150	0.11436	418.145	1.82563
30	0.24250	428.364	1.91545	0.16011	427.730	1.88041	0.11889	426.875	1.85491
40	0.25102	437.223	1.94355	0.16592	436.473	1.90879	0.12335	435.708	1.88357
50	0.25948	446.029	1.97123	0.17168	445.350	1.93669	0.12776	444.658	1.91171
60	0.26791	454.986	1.99853	0.17740	454.366	1.96416	0.13213	453.735	1.93937
70	0.27631	464.096	2.02547	0.18308	463.525	1.99125	0.13646	462.946	1.96661
80	0.28468	473.359	2.05208	0.18874	472.831	2.01798	0.14076	472.296	1.99346
90	0.29303	482.777	2.07837	0.19437	482.285	2.04438	0.14504	481.788	2.01997
100	0.30136	492.349	2.10437	0.19999	491.888	2.07046	0.14930	491.424	2.04614

(Continued)

Table A.4.2
(Continued)

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
		0.25 MPa			0.30 MPa			0.40 MPa	
0	0.082637	399.579	1.74284	—	—	—	—	—	—
10	0.086584	408.357	1.77440	0.071110	407.171	1.75637	0.051681	404.651	1.72611
20	0.090408	417.151	1.80492	0.074415	416.124	1.78744	0.054362	413.965	1.75844
30	0.090139	425.997	1.83460	0.077620	425.096	1.81754	0.056926	423.216	1.78947
40	0.097798	434.925	1.86357	0.080748	434.124	1.84684	0.059402	432.465	1.81949
50	0.101401	443.953	1.89195	0.083816	443.234	1.87547	0.061812	441.751	1.84868
60	0.104958	453.094	1.91980	0.086838	452.442	1.90354	0.064169	451.104	1.87718
70	0.108480	462.359	1.94720	0.089821	461.763	1.93110	0.066484	460.545	1.90510
80	0.111972	471.754	1.97419	0.092774	471.206	1.95823	0.068767	470.088	1.93252
90	0.115440	481.285	2.00080	0.095702	480.777	1.98495	0.071022	479.745	1.95948
100	0.118888	490.955	2.02707	0.098609	490.482	2.01131	0.073254	489.523	1.98604
110	0.122318	500.766	2.05302	0.101498	500.324	2.03734	0.075468	499.428	2.01223
120	0.125734	510.720	2.07866	0.104371	510.304	2.06305	0.077665	509.464	2.03809
		0.50 MPa			0.60 MPa			0.70 MPa	
20	0.042256	411.645	1.73420	—	—	—	—	—	—
30	0.044457	421.221	1.76632	0.036094	419.093	1.74610	0.030069	416.809	1.72770
40	0.046557	430.720	1.79715	0.037958	428.881	1.77786	0.031781	426.933	1.76056
50	0.048581	440.205	1.82696	0.039735	438.589	1.80838	0.033392	436.895	1.79187
60	0.050547	449.718	1.85596	0.041447	448.279	1.83791	0.034929	446.782	1.82201

70	0.052467	459.290	1.88426	0.043108	457.994	1.86664	0.036410	456.555	1.85121
80	0.054351	468.942	1.91199	0.044730	467.764	1.89471	0.037848	466.554	1.87964
90	0.056205	478.690	1.93921	0.046319	477.611	1.92220	0.039251	476.507	1.90743
100	0.058035	488.546	1.96598	0.047883	487.550	1.94920	0.040627	486.535	1.93467
110	0.059845	498.518	1.99235	0.049426	497.594	1.97576	0.041980	496.654	1.96143
120	0.061639	508.613	2.01836	0.050951	507.750	2.00193	0.043314	506.875	1.98777
130	0.063418	518.835	2.04403	0.052461	518.026	2.02774	0.044633	517.207	2.01372
140	0.065184	529.187	2.06940	0.053958	528.425	2.05322	0.045938	527.656	2.03932
		0.80 MPa			*0.90 MPa*			*1.00 MPa*	
40	0.027113	424.860	1.74457	0.023446	422.642	1.72943	0.020473	420.249	1.71479
50	0.028611	435.114	1.77680	0.024868	433.235	1.76273	0.021849	431.243	1.74936
60	0.030024	445.223	1.80761	0.026192	443.595	1.79431	0.023110	441.890	1.78181
70	0.031375	455.270	1.83732	0.027447	453.835	1.82459	0.024293	452.345	1.81273
80	0.032678	465.308	1.86616	0.028649	464.025	1.85387	0.025417	462.703	1.84248
90	0.033944	475.375	1.89427	0.029810	474.216	1.88232	0.026497	473.027	1.87131
100	0.035180	485.499	1.92177	0.030940	484.441	1.91010	0.027543	483.361	1.89938
110	0.036392	495.698	1.94874	0.032043	494.726	1.93730	0.028561	493.736	1.92682
120	0.037584	505.988	1.97525	0.033126	505.088	1.96399	0.029556	504.175	1.95371
130	0.038760	516.379	2.00135	0.034190	515.542	1.99025	0.030533	514.694	1.98013
140	0.039921	526.880	2.02708	0.035241	526.096	2.01611	0.031495	525.305	2.00613
150	0.041071	537.496	2.05247	0.036278	536.760	2.04161	0.032444	536.017	2.03175

(Continued)

Table A.4.2
(Continued)

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
		1.20 MPa			*1.40 MPa*			*1.60 MPa*	
50	0.017243	426.485	1.72373	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	0.018439	438.210	1.75837	0.015032	434.079	1.73597	0.012392	429.322	1.71349
70	0.019530	449.179	1.79081	0.016083	445.720	1.77040	0.013449	441.888	1.75066
80	0.020548	459.925	1.82168	0.017040	456.944	1.80265	0.014378	453.722	1.78466
90	0.021512	470.551	1.85135	0.017931	467.931	1.83333	0.015225	465.145	1.81656
100	0.022436	481.128	1.88009	0.018775	478.790	1.86282	0.016015	476.333	1.84695
110	0.023329	491.702	1.90805	0.019583	489.589	1.89139	0.016763	487.390	1.87619
120	0.024197	502.307	1.93537	0.020362	500.379	1.91918	0.017479	498.387	1.90452
130	0.025044	512.965	1.96214	0.021118	511.192	1.94634	0.018169	509.371	1.93211
140	0.025874	523.697	1.98844	0.021856	522.054	1.97296	0.018840	520.376	1.95908
150	0.026691	534.514	2.01431	0.022579	532.984	1.99910	0.019493	531.427	1.98551
160	0.027495	545.426	2.03980	0.023289	543.994	2.02481	0.020133	542.542	2.01147
170	0.028289	556.443	2.06494	0.023988	555.097	2.05015	0.020761	553.735	2.03702
		1.80 MPa			*2.0 MPa*			*2.50 MPa*	
70	0.011341	437.562	1.73085	0.009581	432.531	1.71011	[illegible]	[illegible]	[illegible]
80	0.012273	450.202	1.76717	0.010550	446.304	1.74968	0.007221	433.797	1.70180
90	0.013099	462.164	1.80057	0.011374	458.951	1.78500	0.008157	449.499	1.74567
100	0.013854	473.741	1.83202	0.012111	470.996	1.81772	0.008907	463.279	1.78311
110	0.014560	485.095	1.86205	0.012789	482.693	1.84866	0.009558	476.129	1.81709

120	0.015230	496.325	1.89098	0.013424	494.187	1.87827	0.010148	488.457	1.84886
130	0.015871	507.498	1.91905	0.014028	505.569	1.90686	0.010694	500.474	1.87904
140	0.016490	518.659	1.94639	0.014608	516.900	1.93463	0.011208	512.307	1.90804
150	0.017091	529.841	1.97314	0.015168	528.224	1.96171	0.011698	524.037	1.93609
160	0.017677	541.068	1.99936	0.015712	539.571	1.98821	0.012169	535.722	1.96338
170	0.018251	552.357	2.02513	0.016242	550.963	2.01421	0.012624	547.399	1.99004
180	0.018814	563.724	2.05049	0.016762	562.418	2.03977	0.013066	559.098	2.01614
190	0.019369	575.177	2.07549	0.017272	573,950	2.06494	0.013498	570,841	2.04177
		3.0 MPa			*3.50 MPa*			*4.0 MPa*	
90	0.005755	436.193	1.69950	—	—	—	—	—	—
100	0.006653	453.731	1.74717	0.004839	440.433	1.70386	—	—	—
110	0.007339	468.500	1.78623	0.005667	459.211	1.75355	0.004277	446.844	1.71840
120	0.007924	482.043	1.82113	0.006289	474.697	1.79346	0.005005	465.987	1.76415
130	0.008446	494.915	1.85347	0.006813	488.771	1.82881	0.005559	481.865	1.80404
140	0.008926	507.388	1.88403	0.007279	502.079	1.86142	0.006027	496.295	1.83940
150	0.009375	519.618	1.91328	0.007706	514.928	1.89216	0.006444	509.925	1.87200
160	0.009801	531.704	1.94151	0.008103	527.496	1.92151	0.006825	523.072	1.90271
170	0.010208	543.713	1.96892	0.008480	539.890	1.94980	0.007181	535.917	1.93203
180	0.010601	555.690	1.99565	0.008839	552.185	1.97724	0.007517	548.573	1.96028
190	0.010982	567.670	2.02180	0.009185	564.430	2.00397	0.007837	561.117	1.98766
200	0.011353	579.678	2.04745	0.009519	576.665	2.03010	0.008145	573.601	2.01432

TABLE A.5 THERMODYNAMIC PROPERTIES OF AMMONIA

Table A.3.1

Saturated Ammonia Table

T (°C)	P (kPa)	Specific volume (m³/kg)			Enthalpy (kJ/kg)			Entropy (kJ/kg K)	
		Sat. liquid v_f	t	Sat. vapour, v_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapour, h_g	Sat. liquid, s_f	Sat. vapour s_g
− 50	40.88	0.001424		2.6254	− 44.3	1416.7	1372.4	− 0.1942	6.1561
− 48	45.96	0.001429		2.3533	− 35.5	1411.3	1375.8	− 0.1547	6.1149
− 46	51.55	0.001434		2.1140	− 26.6	1405.8	1379.2	− 0.1156	6.0746
− 44	57.69	0.001439		1.9032	− 17.8	1400.3	1382.5	− 0.0768	6.0352
− 42	64.42	0.001444		1.7170	− 8.9	1394.7	1385.8	− 0.0382	5.9967
− 40	71.77	0.001449		1.5521	0.0	1389.0	1389.0	0.0000	5.9589
− 38	79.80	0.001454		1.4058	8.9	1383.3	1392.2	0.0380	5.9220
− 36	88.54	0.001460		1.2757	17.8	1377.6	1395.4	0.0757	5.8858
− 34	98.05	0.001465		1.1597	26.8	1371.8	1398.5	0.1132	5.8504
− 32	108.37	0.001470		1.0562	35.7	1365.9	1401.6	0.1504	5.8156
− 30	119.55	0.001476		0.9635	44.7	1360.0	1404.6	0.1873	5.7815
− 28	131.64	0.001481		0.8805	53.6	1354.0	1407.6	0.2240	5.7481
− 26	144.70	0.001487		0.8059	62.6	1347.9	1410.5	0.2605	5.7153
− 24	158.78	0.001492		0.7388	71.6	1341.8	1413.4	0.2967	5.6831
− 22	173.93	0.001498		0.6783	80.7	1335.6	1416.2	0.3327	5.6515
− 20	190.22	0.001504		0.6237	89.7	1329.3	1419.0	0.3684	5.6205
− 18	207.71	0.001510		0.5743	98.8	1322.9	1421.7	0.4040	5.5900
− 16	226.45	0.001515		0.5296	107.8	1316.5	1424.4	0.4393	5.5600
− 14	246.51	0.001521		0.4889	116.9	1310.0	1427.0	0.4744	5.5305
− 12	267.95	0.001528		0.4520	126.0	1303.5	1429.5	0.5093	5.5015

− 10	290.95	0.001534	0.4185	135.2	1296.8	1432.0	0.5440	5.4730
− 8	315.25	0.001540	0.3878	144.3	1290.1	1434.4	0.5785	5.4449
− 6	341.25	0.001546	0.3599	153.5	1283.3	1436.8	0.6128	5.4173
− 4	368.90	0.001553	0.3343	162.7	1276.4	1439.1	0.6469	5.3901
− 2	398.27	0.001559	0.3109	171.9	1269.4	1441.3	0.6808	5.3633
0	429.44	0.001566	0.2895	181.1	1262.4	1443.5	0.7145	5.3369
2	462.49	0.001573	0.2698	190.4	1255.2	1445.6	0.7481	5.3108
4	497.49	0.001580	0.2517	199.6	1243.0	1447.6	0.7815	5.2852
6	531.51	0.001587	0.2351	208.9	1240.6	1449.6	0.8148	5.2599
8	573.64	0.001594	0.2198	218.3	1233.2	1451.5	0.8479	5.2350
10	614.95	0.001601	0.2056	227.6	1225.7	1453.3	0.8808	5.2104
12	658.52	0.001608	0.1926	237.0	1218.1	1455.1	0.9136	5.1861
14	704.44	0.001616	0.1805	246.4	1210.4	1456.8	0.9463	5.1621
16	752.79	0.001623	0.1693	255.9	1202.6	1458.5	0.9788	5.1385
18	803.66	0.001631	0.1590	265.4	1194.7	1460.0	1.0112	5.1151
20	857.12	0.001639	0.1494	274.9	1186.7	1461.5	1.0434	5.0920
22	913.27	0.001647	0.1405	284.4	1178.5	1462.9	1.0755	5.0692
24	972.19	0.001655	0.1322	294.0	1170.3	1464.3	1.1075	5.0467
26	1033.97	0.001663	0.1245	303.6	1162.0	1465.6	1.1394	5.0244
28	1098.71	0.001671	0.1173	313.2	1153.6	1466.8	1.1711	5.0023
30	1166.49	0.001680	0.1106	322.9	1145.0	1467.9	1.2028	4.9805
32	1237.41	0.001689	0.1044	332.6	1136.4	1469.0	1.2343	4.9589
34	1311.55	0.001698	0.0986	342.3	1127.6	1469.9	1.2656	4.9374
36	1369.03	0.001707	0.0931	352.1	1118.7	1470.8	1.2969	4.9161

(Continued)

Table A.5.1
(Continued)

T (°C)	P (kPa)	Specific volume (m³/kg) Sat. liquid vt	t	Sat. vapour, vg	Enthalpy (kJ/kg) Sat. liquid, ht	Evap., htg	Sat. vapour, hg	Entropy (kJ/kg K) Sat. liquid, st	Sat. vapour sg
38	1469.92	0.001716		0.0880	361.9	1109.7	1471.5	1.3281	4.8950
40	1554.33	0.001726		0.0833	371.7	1100.5	1472.2	1.3591	4.8740
42	1642.35	0.001735		0.0788	381.6	1091.2	1472.8	1.3901	4.8530
44	1734.09	0.001745		0.0746	391.5	1081.7	1473.2	1.4209	4.8322
46	1829.65	0.001756		0.0707	401.5	1072.0	1473.5	1.4518	4.8113
48	1929.13	0.001766		0.0669	411.5	1062.2	1473.7	1.4826	4.7905
50	2032.62	0.001777		0.0635	421.7	1052.0	1473.7	1.5135	4.7696

Table A.5.2
Superheated Ammonia Table

Abs. Press. (kPa) (Sat. temp., °C)		Temperature (°C) −20	−10	0	10	20	30	40	50	60	70	80	100
	v	2.4474	2.5481	2.6482	2.7479	2.8479	2.9464	3.0453	3.1441	3.2427	3.3413	3.4397	
50	h	1435.8	1457.0	1478.1	1499.2	1520.4	1541.7	1563.0	1584.5	1606.1	1627.8	1649.7	
(−46.54)	s	6.3256	6.4077	6.4865	6.5625	6.6360	6.7073	6.7766	6.8441	6.9099	6.9743	7.0372	
	v	1.6233	1.6915	1.7591	1.8263	1.8932	1.9597	2.0261	2.0933	2.1584	2.2244	2.2903	
75	h	1433.0	1454.7	1476.1	1497.5	1518.9	1540.3	1561.8	1583.4	1605.1	1626.9	1648.9	
(−39.18)	s	6.1190	6.2028	6.2828	6.3597	6.4339	6.5058	6.5756	6.6434	6.7096	6.7742	6.8373	
	v	1.2110	1.2631	1.3145	1.3654	1.4160	1.4664	1.5165	1.5664	1.6163	1.6659	1.7155	1.8145
100	h	1430.1	1452.2	1474.1	1495.7	1517.3	1538.9	1560.5	1582.2	1604.1	1626.0	1648.0	1692.6
(−33.01)	s	5.9695	6.0552	6.1366	6.2144	6.2894	6.3618	6.4321	6.5003	0.5668	6.6316	6.6950	6.8177
	v	0.9635	1.0059	1.0476	1.0889	1.1297	1.1703	1.2107	1.2509	1.2909	1.3309	1.3707	1.4501

125	h	1427.2	1449.8	1472.0	1493.9	1515.7	1537.5	1559.3	1581.1	1603.0	1625.0	1647.2	1691.8
(−29.08)	**s**	**5.8512**	**5.9389**	**6.0217**	**6.1006**	**6.1763**	**6.2494**	**6.3201**	**6.3887**	**6.4555**	**6.5206**	**6.5842**	**6.7072**
	v	0.7984	0.8344	0.8697	0.9045	6.9388	0.9729	1.0068	1.0405	1.0740	1.1074	1.1408	1.2072
150	**h**	**1424.1**	**1447.3**	**1469.8**	**1492.1**	**1514.1**	**1536.1**	**1558.0**	**1580.0**	**1602.0**	**1624.1**	**1646.3**	**1691.1**
(−25.23)	s	5.7526	5.8424	5.9266	6.0066	6.0831	6.1568	6.2280	6.2970	6.3641	6.4295	6.4933	6.6167
	v		**0.6199**	**0.6471**	**0.6738**	**0.7001**	**0.7261**	**0.7519**	**0.7774**	**0.8029**	**0.8282**	**0.8533**	**0.9035**
200	h		1442.0	1465.5	1448.1	1510.9	1533.2	1555.5	1577.7	1599.9	1622.2	1644.6	1689.6
(−18.86)	**s**		**5.6863**	**5.7737**	**5.8559**	**5.9342**	**6.0091**	**6.0813**	**6.1512**	**6.2189**	**6.2849**	**6.3491**	**6.4732**
	v		0.4910	0.5135	0.5354	0.5568	0.5780	0.5989	0.6196	0.6401	0.6605	0.6809	0.7212
250	**h**		**1436.6**	**1461.0**	**1484.5**	**1507.6**	**1530.3**	**1552.9**	**1575.4**	**1597.8**	**1620.3**	**1642.8**	**1688.2**
(−13.67)	s		5.5609	5.6517	5.7465	5.8165	5.8928	5.9661	6.0368	6.1052	6.1717	6.2365	6.3613
	v			**0.4243**	**0.4430**	**0.4613**	**0.4792**	**0.4968**	**0.5113**	**0.5316**	**0.5488**	**0.5658**	**0.5997**
300	h			1456.3	1480.6	1504.2	1527.4	1550.3	1573.0	1595.7	1618.4	1641.1	1686.7
(−9.23)	**s**			**5.5193**	**5.6366**	**5.7186**	**5.7963**	**5.8707**	**5.9423**	**6.0114**	**6.0785**	**6.1437**	**6.2693**
	v			0.3605	0.3770	0.3929	0.4086	0.4239	0.4391	0.4541	0.4689	0.4837	0.5129
350	**h**			**1451.5**	**1478.5**	**1590.7**	**1521.4**	**1547.6**	**1570.7**	**1593.6**	**1616.5**	**1639.3**	**1685.2**
(−5.35)	s			5.4600	5.5502	5.6312	5.7135	5.7800	5.8615	5.9314	5.9990	6.0647	6.1910
	v			**0.3125**	**0.3274**	**0.3417**	**0.3556**	**0.3692**	**0.3826**	**0.3959**	**0.4090**	**0.4220**	**0.4478**
400	h			1446.5	1472.4	1497.2	1521.3	1544.9	1568.3	1591.5	1614.5	1637.6	1683.7
(−1.89)	**s**			**5.3803**	**5.4735**	**5.5597**	**5.6405**	**5.7173**	**5.7907**	**5.8613**	**5.9296**	**5.9957**	**6.1228**
	v			0.2752	0.2887	0.3017	0.3143	0.3266	0.3387	0.3506	0.3624	0.3740	0.3971
450	**h**			**1441.3**	**1468.1**	**1493.6**	**1518.2**	**1542.2**	**1565.9**	**1589.3**	**1612.6**	**1635.8**	**1682.2**
(1.26)	s			5.3078	5.4042	5492.6	5.5752	5.6532	5.7275	5.7989	5.8678	5.9345	6.0623
	v	**0.2698**	**0.2813**	**0.2926**	**0.3036**	**0.3144**	**0.3251**	**0.3357**	**0.3565**	**0.3771**	**0.3975**		
500	h	1489.9	1515.0	1539.5	1563.4	1587.1	1610.6	1634.0	1680.7	1727.5	1774.7		
(4.14)	**s**	**5.4314**	**5.5157**	**5.5950**	**5.6704**	**5.7425**	**5.8120**	**5.8793**	**6.0079**	**6.1301**	**6.2472**		
	v	0.2217	0.2317	0.2414	0.2508	0.2600	0.2691	0.2781	0.2957	0.3130	0.3302		
600	**h**	**1482.4**	**1508.6**	**1533.8**	**1558.5**	**1582.7**	**1606.6**	**1630.4**	**1677.7**	**1724.9**	**1772.4**		

(Continued)

(Continued)

Abs. Press. (kPa) (Sat. temp., °C)		Temperature (°C) 20	30	40	50	60	70	80	100	120	140	160	180
(9.29)	s	5.3222	5.4102	5.4923	5.5697	5.6436	5.7144	5.7826	5.9129	6.0363	6.1541		
	v	0.1874	0.1963	0.2048	0.2131	0.2212	0.2291	0.2369	0.2522	0.2672	0.2821		
700	h	1474.5	1501.9	1528.1	1553.4	1578.2	1602.6	1626.8	1674.6	1722.4	1770.2		
(13.81)	s	5.2259	5.3179	5.4029	5.4826	5.5582	5.6303	5.6997	5.8316	5.9562	6.0749		
	v	0.1615	0.1696	0.1773	0.1848	0.1920	0.1991	0.2060	0.2196	0.2329	0.2459	0.2589	
800	h	1466.3	1495.0	1522.2	1548.3	1573.7	1598.6	1623.1	1671.6	1719.8	1768.0	1816.4	
(17.86)	s	5.1387	5.2351	5.3232	5.4053	5.4827	5.5562	5.6268	5.7603	5.8861	6.0057	6.1202	
	v		0.1488	0.1559	0.1627	0.1693	0.1757	0.1820	0.1942	0.2061	0.2178	0.2294	
900	h		1488.0	1516.2	1543.0	1569.1	1594.4	1619.4	1668.5	1717.1	1765.7	1814.4	
(21.54)	s		5.1593	5.2508	5.3354	5.4147	5.4897	5.5614	5.6968	5.8237	5.9442	6.0594	
	v		0.1321	0.1388	0.1450	0.1511	0.1570	0.1627	0.1739	0.1847	0.1954	0.2058	0.2162
1000	h		1480.6	1510.0	1537.7	1564.4	1590.3	1615.6	1665.4	1714.5	1763.4	1812.4	1861.7
(24.91)	s		5.0889	5.1840	5.2713	5.3525	5.4292	5.5021	5.6392	5.7674	5.8888	6.0047	6.1159
	v			0.1129	0.1185	0.1238	0.1289	0.1338	0.1434	0.1526	0.1616	0.1705	0.1792
1200	h			1497.1	1526.6	1554.7	1581.7	1608.0	1659.2	1709.2	1758.9	1808.5	1858.2
(30.96)	s			5.0629	5.1560	5.2416	5.3215	5.3970	5.5379	5.6687	5.7919	5.9091	6.0214
	v			0.0944	0.0995	0.1042	0.1088	0.1132	0.1216	0.1297	0.1376	0.1452	0.1528
1400	h			1483.4	1515.1	1544.7	1573.0	1600.2	1652.8	1703.9	1754.3	1804.5	1854.7
(36.28)	s			4.9534	5.0530	5.1434	5.2270	5.3053	5.4501	5.5836	5.7087	5.8273	5.9406
	v				0.0851	0.0895	0.0937	0.0977	0.1053	0.1125	0.1195	0.1263	0.1330
1600	h				1502.9	1534.4	1564.0	1592.3	1646.4	1698.5	1749.7	1800.5	1851.2
(14.05)	s				4.9584	5.0543	5.1419	5.2232	5.3722	5.5084	5.6355	5.7555	5.8699

Table A.6

Variation of $\bar{c}_p$ with Temperature for Various Ideal Gases

$$\frac{\bar{c}_p}{\bar{R}} = \alpha + \beta T + \gamma T2 + \delta T3 + \epsilon T4$$

T is in K, equations valid from 300 to 1000 K

Gas	α	$\beta \times 10w^3$	$\gamma \times 10^6$	$\delta \times 10^9$	$\varepsilon \times 10^{12}$
CO	3.710	– 1.619	3.692	– 2.032	0.240
CO_2	**2.401**	**8.735**	**– 6.607**	**2.002**	**0**
H_2	3.057	2.677	– 5.180	5.521	– 1.812
H_2O	**4.070**	**– 1.108**	**4.152**	**– 2.964**	**0.807**
O_2	3.626	– 1.878	7.056	– 6.764	2.156
N_2	**3.675**	**– 1.208**	**2.324**	**– 0.632**	**– 0.226**
Air	3.653	– 1.337	3.294	– 1.913	0.2763
SO_2	**3.267**	**5.324**	**0.684**	**– 5.281**	**2.559**
CH_4	3.826	– 3.979	24.558	– 22.733	6.963
C_2H_2	**1.410**	**19.057**	**24.501**	**16.391**	**– 4.135**
C_2H_4	1.426	11.383	7.989	– 16.254	6.749
Monatomic gases*	2.5	0	0	0	0

* For monatomic gases, such as He, Ne, and Ar, $\bar{c}_p$ is constant over a wide temperature range and is very nearly equal to 5/2 $\bar{R}$.

Source: Adapted from K. Wark, *Thermodynamics, 4th ed. McGraw-Hill,* New York, 1983, as based on NASA SP-273, U.S. Government Printing Office, Washington, DC, 1971.

Table A.7

Ideal Gas Specific Heats of Some Common Gases (kJ/kg.K)

Temp. K	Air			*Nitrogen, N_2*			*Oxygen, O_2*			*Temp. K*
	c_p	c_v	k	c_p	c_v	k	c_p	c_v	k	
250	1.003	0.716	1.401	1.039	0.742	1.400	0.913	0.653	1.398	250
300	**1.005**	**0.718**	**1.400**	**1.039**	**0.743**	**1.400**	**0.918**	**0.658**	**1.395**	**300**
350	1.008	0.721	1.398	1.041	0.744	1.399	0.928	0.668	1.389	350
400	**1.013**	**0.726**	**1.395**	**1.044**	**0.747**	**1.397**	**0.941**	**0.681**	**1.382**	**400**
450	1.020	0.733	1.391	1.049	0.752	1.395	0.956	0.696	1.373	450
500	**1.029**	**0.742**	**1.387**	**1.056**	**0.759**	**1.391**	**0.972**	**0.712**	**1.365**	**500**

(*Continued*)

Table A.7
(Continued)

	c_p	c_v	k	c_p	c_v	k	c_p	c_v	k	
Temp. K		**Air**			**Nitrogen, N_2**			Oxygen, O_2		Temp. K
550	1.040	0.753	1.381	1.065	0.768	1.387	0.988	0.728	1.358	550
600	1.051	0.764	1.376	1.075	0.778	1.382	1.003	0.743	1.350	600
650	1.063	0.776	1.370	1.086	0.789	1.376	1.017	0.758	1.343	650
700	1.075	0.788	1.364	1.098	0.801	1.371	1.031	0.771	1.337	700
750	1.087	0.800	1.359	1.110	0.813	1.365	1.043	0.783	1.332	750
800	1.099	0.812	1.354	1.121	0.825	1.360	1.054	0.794	1.327	800
900	1.121	0.834	1.344	1.145	0.849	1.349	1.074	0.814	1.319	900
1000	1.142	0.855	1.336	1.167	0.870	1.341	1.090	0.830	1.313	1000
Temp. K		Carbon Dioxide, CO_2			Carbon Monoxide, CO			Hydrogen, H_2 Temp. K		
250	0.791	0.602	1.314	1.039	0.743	1.400	14.051	9.927	1.416	250
300	0.846	0.657	1.288	1.040	0.744	1.399	14.307	10.183	1.045	300
350	0.895	0.706	1.268	1.043	0.746	1.398	14.427	10.302	1.400	350
400	0.939	0.750	1.252	1.047	0.751	1.395	14.476	10.352	1.398	400
450	0.978	0.790	1.239	1.054	0.757	1.392	14.501	10.377	1.398	450
500	1.014	0.825	1.229	1.063	0.767	1.387	14.513	10.389	1.397	500
550	1.046	0.857	1.220	1.075	0.778	1.382	14.530	10.405	1.396	550
600	1.075	0.886	1.213	1.087	0.790	1.376	14.546	10.422	1.396	600
650	1.102	0.913	1.207	1.100	0.803	1.370	14.571	10.447	1.395	650
700	1.126	0.937	1.202	1.113	0.816	1.364	14.604	10.480	1.394	700
750	1.148	0.959	1.197	1.126	0.829	1.358	14.645	10.521	1.392	750
800	1.169	0.980	1.193	1.139	0.842	1.353	14.695	10.570	1.390	800
900	1.204	1.015	1.186	1.163	0.866	1.343	14.822	10.698	1.385	900
1000	1.234	1.045	1.181	1.185	0.888	1.335	14.983	10.859	1.380	1000

Source: Adapted from K. Wark, *Thermodynamics*, *4th ed.*, McGraw-Hill, New York, 1983, as based on "Tables of Thermal Properties of Gases," NBS Circular 564, 1955.

TABLE A.8 LOGARITHM TO THE BASE 10 OF THE EQUILIBRIUM CONSTANT K

	log 10 K								
Temp. K	$H_2 \rightleftharpoons 2H$	$O_2 \rightleftharpoons 2O$	$N_2 \rightleftharpoons 2N$	$\frac{1}{2}O_2 + \frac{1}{2}N_2 \rightleftharpoons NO$	$H_2O \rightleftharpoons H_2 + \frac{1}{2}O_2$	$H_2O \rightleftharpoons OH + \frac{1}{2}H_2$	$CO_2 \rightleftharpoons CO + \frac{1}{2}O_2$	$CO_2 + H_2 \rightleftharpoons CO + H_2O$	Temp. °R
298	− 71.224	− 81.208	− 159.600	− 15.171	− 40.048	− 46.054	− 45.066	− 5.018	537
500	**− 40.316**	**− 45.880**	**− 92.672**	**− 8.783**	**− 22.886**	**− 26.130**	**− 25.025**	**− 2.139**	**900**
1000	− 17.292	− 19.614	− 43.056	− 4.062	− 10.062	− 11.280	− 10.221	− 0.159	1800
1200	**− 13.414**	**− 15.208**	**− 34.754**	**− 3.275**	**− 7.899**	**− 8.811**	**− 7.764**	**+ 0.135**	**2160**
1400	− 10.630	− 12.054	− 28.812	− 2.712	− 6.347	− 7.021	− 6.014	+ 0.333	2520
1600	**− 8.532**	**− 9.684**	**− 24.350**	**− 2.290**	**− 5.180**	**− 5.677**	**− 4.706**	**+ 0.474**	**2880**
1700	− 7.666	− 8.706	− 22.512	− 2.116	− 4.699	− 5.124	− 4.169	+ 0.530	3060
1800	**− 6.896**	**− 7.836**	**− 20.874**	**− 1.962**	**− 4.270**	**− 4.613**	**− 3.693**	**+ 0.577**	**3240**
1900	− 6.204	− 7.058	− 19.410	− 1.823	− 3.886	− 4.190	− 3.267	+ 0.619	3420
2000	**− 5.580**	**− 6.356**	**− 18.092**	**− 1.699**	**− 3.540**	**− 3.776**	**− 2.884**	**+ 0.656**	**3600**
2100	− 5.016	− 5.720	− 16.898	− 1.586	− 3.227	− 3.434	− 2.539	+ 0.688	3780

(Continued)

Table A.8
(Continued)

Temp. K	log 10 K $H_2 \rightleftharpoons 2H$	$O_2 \rightleftharpoons 2O$	$N_2 \rightleftharpoons 2N$	$\frac{1}{2}O_2 + \frac{1}{2}N_2 \rightleftharpoons NO$	$H_2O \rightleftharpoons H_2 + \frac{1}{2}O_2$	$H_2O \rightleftharpoons OH + \frac{1}{2}H_2$	$CO_2 \rightleftharpoons CO + \frac{1}{2}O_2$	$CO_2 + H_2 \rightleftharpoons CO + H_2O$	Temp. °R
2200	−4.502	−5.142	−15.810	−1.484	−2.942	−3.091	−2.226	+0.716	3960
2300	−4.032	−4.614	−14.818	−1.391	−2.682	−2.809	−1.940	+0.742	4140
2400	−3.600	−4.130	−13.908	−1.305	−2.443	−2.520	−1.679	+0.764	4320
2500	−3.202	−3.684	−13.070	−1.227	−2.224	−2.270	−1.440	+0.784	4500
2600	−2.836	−3.272	−12.298	−1.154	−2.021	−2.038	−1.219	+0.802	4680
2700	−2.494	−2.892	−11.580	−1.087	−1.833	−1.823	−1.015	+0.818	4860
2800	−2.178	−2.536	−10.914	−1.025	−1.658	−1.624	−0.825	+0.833	5040
2900	−1.882	−2.206	−10.294	−0.967	−1.495	−1.438	−0.649	+0.846	5220
3000	−1.606	−1.898	−9.716	−0.913	−1.343	−1.265	−0.485	+0.858	5400
3100	−1.348	−1.610	−9.174	−0.863	−1.201	−1.103	−0.322	+0.869	5580
3200	−1.106	−1.340	−8.664	−0.815	−1.067	−0.951	−0.189	+0.878	5760
3300	−0.878	−1.086	−8.186	−0.771	−0.942	−0.809	−0.054	+0.888	5940
3400	−0.664	−0.846	−7.736	−0.729	−0.824	−0.674	+0.071	+0.895	6120
3500	−0.462	−0.620	−7.312	−0.690	−0.712	−0.547	+0.190	+0.902	6300

Source: Based on data from the JANAF Thermochemical Tables, NSRDS–NBS–37, 1971.

Table A.9a

*Enthalpy of formation at 25°C, ideal gas enthalpy, and Absolute Entropy at 0.1 MPa (1 bar) Pressure**

Temp. K	Nitrogen, Diatomic (N_2) $(h^\circ_f)_{298} = 0$ kJ/kmol $M = 28.013$ $(\bar{h}^\circ - \bar{h}^\circ_{298})$ kJ/kmol	s° kJ/kmol K	Oxygen, Diatomic (O_2) $(h^\circ_f)_{298} = 0$ kJ/kmol $M = 31.999$ $(\bar{h}^\circ - \bar{h}^\circ_{298})$ kJ/kmol K	$\bar{s}^\circ$ kJ/kmol K
0	– 8669	0	– 8682	0
100	– 5770	159.813	– 5778	173.306
200	– 2858	179.988	– 2866	193.486
298	0	191.611	0	205.142
300	54	191.791	54	205.322
400	2971	200.180	3029	213.874
500	5912	206.740	6088	220.698
600	8891	212.175	9247	226.455
700	11937	216.866	12502	231.272
800	15046	221.016	15841	235.924
900	18221	224.757	19246	239.936
1000	21406	288.167	22707	243.585
1100	24757	231.309	26217	246.928
1200	28108	234.225	29765	250.016
1300	31501	236.941	33351	252.886
1400	34936	239.484	36966	255.564
1500	38405	241.878	40610	258.078
1600	41903	244.137	44279	260.446
1700	45430	246.275	47970	262.685
1800	48982	248.304	51689	264.810
1900	52551	250.237	55434	266.835
2000	56141	252.078	59199	268.764

* Adapted from Tables A. 11 (Pages 687 to 696) in *Fundamentals of Classical Thermodynamics* by G.J. Van Wylen and R. Sonntag, John Wiley, New York, 1976 (with the kind permission of the publishers, John Wiley & Sons, Inc., New York).

Table A.9b

(Continued)

Temp. K	Carbon Dioxide (CO_2) $(h^\circ_f)_{288} = -393522$ kJ/kmol $M = 44.01$		Carbon Monoxide (CO) $(h^\circ_f)_{298} = -110529$ kJ/kmol $M = 28.01$	
	$(\bar{h}^\circ - \bar{h}^\circ_{298})$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol K	$(\bar{h}^\circ - \bar{h}^\circ_{298})$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol K
0	−9364	0	−8669	0
100	−6456	179.109	−5770	165.850
200	−3414	199.975	−2858	186.025
298	0	213.795	0	197.653
300	67	214.025	54	197.833
400	4008	225.334	2975	206.234
500	8314	234.924	5929	212.828
600	12916	243.309	8941	218.313
700	17765	250.773	12021	223.062
800	22815	257.517	15175	227.271
900	28041	263.668	18397	231.006
1000	33405	269.325	21686	234.531
1100	38894	274.555	25033	237.719
1200	44484	279.417	28426	240.673
1300	50158	283.956	31865	243.426
1400	55907	288.216	35338	245.999
1500	61714	292.224	38848	248.421
1600	67580	296.010	42384	250.702
1700	73492	299.592	45940	252.861
1800	79442	302.993	49522	254.907
1900	85429	306.232	53124	256.852
2000	91450	309.320	56739	258.710

Table A.9

(Continued)

Temp. K	**Water (H_2O)** $(\bar{h}_f^\circ)_{298} = -241827$ kJ/kmol, $M = 18.015$ $(\bar{h}^\circ - \bar{h}_{298}^\circ)$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol K	**Hydrogen, Diatomic (H_2)** $(\bar{h}_f^\circ)_{298} = 0$ kJ/kmol, $M = 2.016$ $(\bar{h}^\circ - \bar{h}_{298}^\circ)$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol K
0	−9904	0	−8468	0
100	−6615	152.390	−5293	102.145
200	−3280	175.486	−2770	119.437
298	0	188.833	0	130.684
300	63	189.038	54	130.864
400	3452	198.783	2958	139.215
500	6920	206.523	5883	145.738
600	10498	213.037	8812	151.077
700	14184	218.719	11749	155.608
800	17991	223.803	14703	159.549
900	21924	228.430	17682	163.060
1000	25978	232.706	20686	166.223
1100	30167	236.694	23723	169.118
1200	34476	240.443	26794	171.792
1300	38903	243.986	29907	174.281
1400	43447	247.350	33062	176.620
1500	48095	250.560	36267	178.833
1600	52844	253.622	39522	180.929
1700	57685	256.559	42815	182.929
1800	62609	259.372	46150	184.833
1900	67613	262.078	49522	186.657
2000	72689	264.681	52932	188.406

TABLE A.10 GAS TABLES

Table A.10.1

Sentropic Flow

M	M^*	$\frac{A}{A^*}$	$\frac{p}{p_0}$	$\frac{\rho}{\rho_0}$	$\frac{T}{T_0}$
0	0	∞	1.00000	1.00000	1.00000
0.10	**0.10943**	**5.8218**	**0.99303**	**0.99502**	**0.99800**
0.20	0.21822	2.9635	0.97250	0.98027	0.99206
0.30	**0.32572**	**2.0351**	**0.93947**	**0.95638**	**098232**
0.40	0.43133	1.5901	0.89562	0.92428	0.96899
0.50	**0.53452**	**1.3398**	**0.84302**	**0.88517**	**0.95238**
0.60	0.63480	1.1882	0.78400	0.84045	0.93284
0.70	**0.73179**	**1.09437**	**0.72092**	**0.79158**	**0.91075**
0.80	0.82514	1.03823	0.65602	0.74000	0.88652
0.90	**0.91460**	**1.00886**	**0.59126**	**0.68704**	**0.86058**
1.00	1.00000	1.00000	0.52828	0.63394	0.83333
1.10	**1.08124**	**1.00793**	**0.46835**	**0.58169**	**0.80515**
1.20	1.1583	1.03044	0.41238	0.53114	0.77640
1.30	**1.2311**	**1.06631**	**0.36092**	**0.48291**	**0.74738**
1.40	1.2999	1.1149	0.31424	0.43742	0.71839
1.50	**1.3646**	**1.1762**	**0.27240**	**0.39498**	**0.68965**
1.60	1.4254	1.2502	0.23527	0.35573	0.66138
1.70	**1.4825**	**1.3376**	**0.20259**	**0.31969**	**0.63372**
1.80	1.5360	1.4390	0.17404	0.28682	0.60680
1.90	**1.5861**	**1.5552**	**0.14924**	**0.25699**	**0.58072**
2.00	1.6330	1.6875	0.12780	0.23005	0.55556
2.10	**1.6769**	**1.8369**	**0.10935**	**0.20580**	**0.53135**
2.20	1.7179	2.0050	0.09352	0.18405	0.50813
2.30	**1.7563**	**2.1931**	**0.07997**	**0.16458**	**0.48591**
2.40	1.7922	2.4031	0.06840	0.14720	0.46468
2.50	**1.8258**	**2.6367**	**0.05853**	**0.13169**	**0.44444**
2.60	1.8572	2.8960	0.05012	0.11787	0.42517
2.70	**1.8865**	**3.1830**	**0.04295**	**0.10557**	**0.40684**
2.80	1.9140	3.5001	0.03685	0.09462	0.38941
2.90	**1.9398**	**3.8498**	**0.03165**	**0.08489**	**0.37286**

(*Continued*)

Table A.10.1
(Continued)

M	M^*	$\frac{A}{A^*}$	$\frac{p}{p_0}$	$\frac{\rho}{\rho_0}$	$\frac{T}{T_0}$
3.00	1.9640	4.2346	0.02722	0.07623	0.35714
3.50	2.0642	6.7896	0.01311	0.04523	0.28986
4.00	2.1381	10.719	0.00658	0.02766	0.23810
4.50	2.1936	16.562	0.00346	0.01745	0.19802
5.00	2.2361	25.000	$189(10)^{-5}$	0.01134	0.16667
6.00	2.2953	53.180	$633(10)^{-6}$	0.00519	0.12195
7.00	2.3333	104.143	$242(10)^{-6}$	0.00261	0.09259
9.00	2.3772	327.189	$474(10)^{-7}$	0.000815	0.05814
10.00	2.3904	535.938	$236(10)^{-7}$	0.000495	0.04762
∞	2.4495	∞	0	0	0

Table A.10.2
Normal Shocks

M_x	M_y	$\frac{p_y}{p_x}$	$\frac{\rho_y}{\rho_x}$	$\frac{T_y}{T_x}$	$\frac{p_{oy}}{p_{ox}}$	$\frac{p_{oy}}{p_x}$
1.00	1.00000	1.00000	1.0000	1.0000	1.00000	1.8929
1.10	0.91177	1.2450	1.1691	1.0649	0.99892	2.1328
1.20	0.84217	1.5133	1.3416	1.1280	0.99280	2.4075
1.30	0.78596	1.8050	1.5157	1.1909	0.97935	2.7135
1.40	0.73971	2.1200	1.6896	1.2547	0.95819	3.0493
1.50	0.70109	2.4583	1.8621	1.3202	0.92978	3.4133
1.60	0.66844	2.8201	2.0317	1.3880	0.89520	3.8049
1.70	0.64055	3.2050	2.1977	0.4583	0.85573	4.2238
1.80	0.61650	3.6133	2.3592	1.5316	0.81268	4.6695
1.90	0.58562	4.0450	2.5157	1.6079	0.76635	5.1417
2.00	0.57735	4.5000	2.6666	1.6875	0.72088	5.6405
2.10	0.56128	4.9784	2.8119	1.7704	0.67422	6.1655
2.20	0.54706	5.4800	2.9512	1.8569	0.62812	6.7163
2.30	0.53441	6.0050	3.0846	1.9968	0.58331	7.2937
2.40	0.52312	6.5533	3.2119	2.0403	0.54015	7.8969
2.50	0.51299	7.1250	3.3333	2.1375	0.49902	8.5262

(Continued)

Table A.10.2

(Continued)

M_x	M_y	$\frac{p_y}{p_x}$	$\frac{\rho_y}{\rho_x}$	$\frac{T_y}{T_x}$	$\frac{p_{0y}}{p_{0x}}$	$\frac{p_{0y}}{p_x}$
2.60	0.50387	7.7200	3.4489	2.2383	0.46012	9.1813
2.70	**0.49563**	**8.3383**	**3.5590**	**2.3429**	**0.42359**	**9.8625**
2.80	0.48817	8.9800	3.6635	2.4512	0.38946	10.569
2.90	**0.48138**	**9.6450**	**3.7629**	**2.5632**	**0.35773**	**11.302**
3.00	0.47519	10.333	3.8571	2.6790	0.32834	12.061
4.00	**0.43496**	**18.500**	**4.5714**	**4.0469**	**0.13876**	**21.068**
5.00	0.41523	29.000	5.0000	5.8000	0.06172	32.654
10.00	**0.38757**	**116.50**	**5.7143**	**20.388**	**0.00304**	**129.217**
∞	0.37796	∞	6.000	∞	0	∞

Table A.11

*Critical point data**

Substance	***Formula***	***Molecular Weight***	***Temperature K***	***Pressure MPa***	***Volume m³/kmol***
Ammonia	NH_3	17.03	405.5	11.28	.0724
Argon	**Ar**	**30.948**	**151**	**4.86**	**.0749**
Bromine	Br_2	159.808	584	10.34	.1355
Carbon Dioxide	CO_3	**44.01**	**304.2**	**7.39**	**.0943**
Carbon Monoxide	CO	28.001	133	3.50	.0930
Chlorine	CL_2	**70.906**	**417**	**7.71**	**.1242**
Deuterium (Normal)	D_2	4.00	38.4	1.66	—
Helium	**He**	**4.003**	**5.3**	**0.23**	**.0578**
Helium^3	He	3.00	3.3	0.12	—
Hydrogen (Normal)	H_2	**2.106**	**33.3**	**1.30**	**.0649**
Krypton	Kr	83.80	209.4	5.50	.0924
Neon	**Ne**	**20.183**	**44.5**	**2.73**	**.0417**
Nitrogen	N_2	28.013	126.2	3.39	.0899
Nitrous Oxide	N_2O	**44.013**	**309.7**	**7.27**	**.0961**

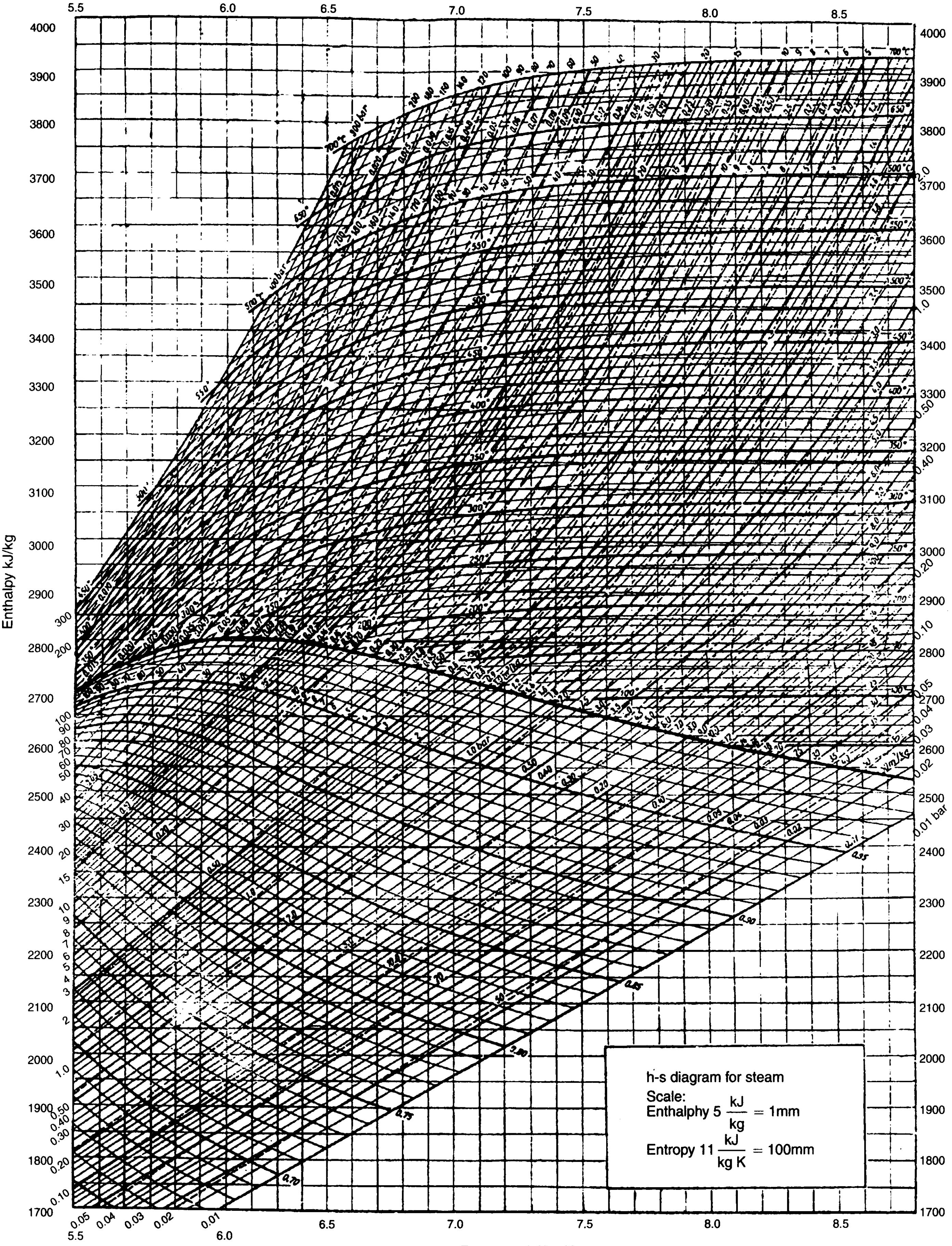
(Continued)

Table A.11
(Continued)

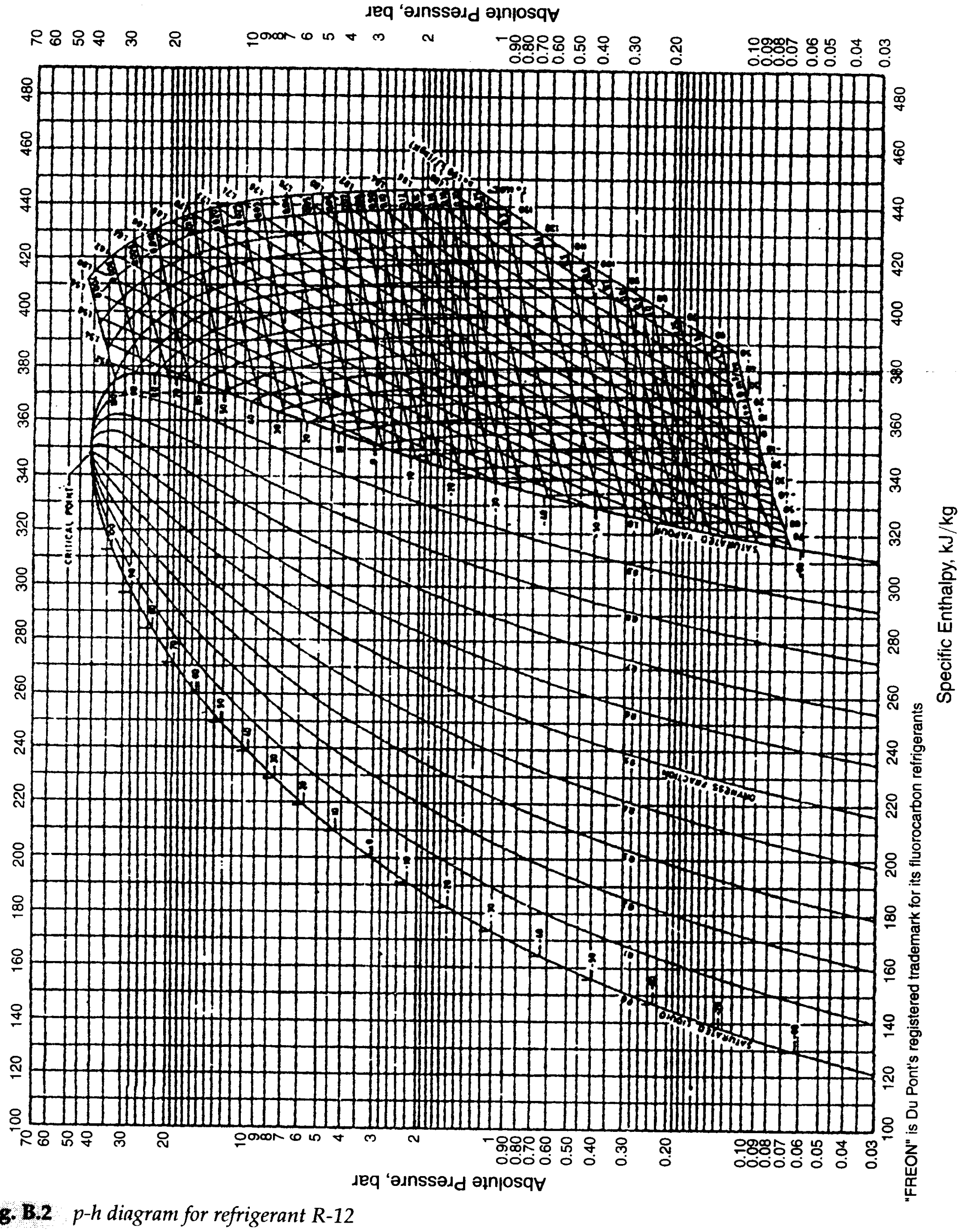
Substance	***Formula***	***Molecular Weight***	***Temperature K***	***Pressure MPa***	***Volume m³/kmol***
Oxygen	O_2	31.999	154.8	5.08	.0780
Sulfur Dioxide	SO_2	64.063	430.7	7.88	.1217
Water	H_2O	18.015	647.3	22.09	.0568
Xenon	Xe	131.30	289.8	5.88	.1186
Benzene	X_2H_6	78.115	562	4.92	.2603
n-Butane	C_4H_{10}	58.124	425.5	3.80	.2547
Carbon Tetra-chloride	CCL_4	153.82	556.4	4.56	.2759
Chloroform	$CHCL_3$	119.38	536.6	5.47	.2403
Dhichlorodi-fluoromethane	CCL_2F_2	120.91	384.7	4.01	.2179
Dichloro-fluoromethane	$CHCL_2F$	102.92	451.7	5.17	.1973
Ethane	C_2H_6	30.070	305.5	4.88	.1480
Ethyl Alcohol	C_2H_5OH	46.07	516	6.38	.1673
Ethylene	C_2H_{14}	28.054	282.4	5.12	.1242
n-Hexane	C_6H_4	86.178	507.9	3.03	.3677
Methane	CH_4	16.043	191.1	4.64	0.993
Methyl Alcohol	CH_3OH	32.042	513.2	7.95	.1180
Methyl Chloride	CH_3Cl	50.488	416.3	6.68	.1430
Propane	C_3H_8	44.097	370	4.26	.1998
Propene	C_3H_6	42.081	365	4.62	.1810
Propyne	C_3H_4	40.065	401	5.35	
Trichloro-fluoromethane	CCL_3F	137.37	471.2	4.38	.2478

* K.A. Kobe and R.E. Lynn, Jr., *Chem. Rev.*, 52: 117–236 (1953).

Appendix B

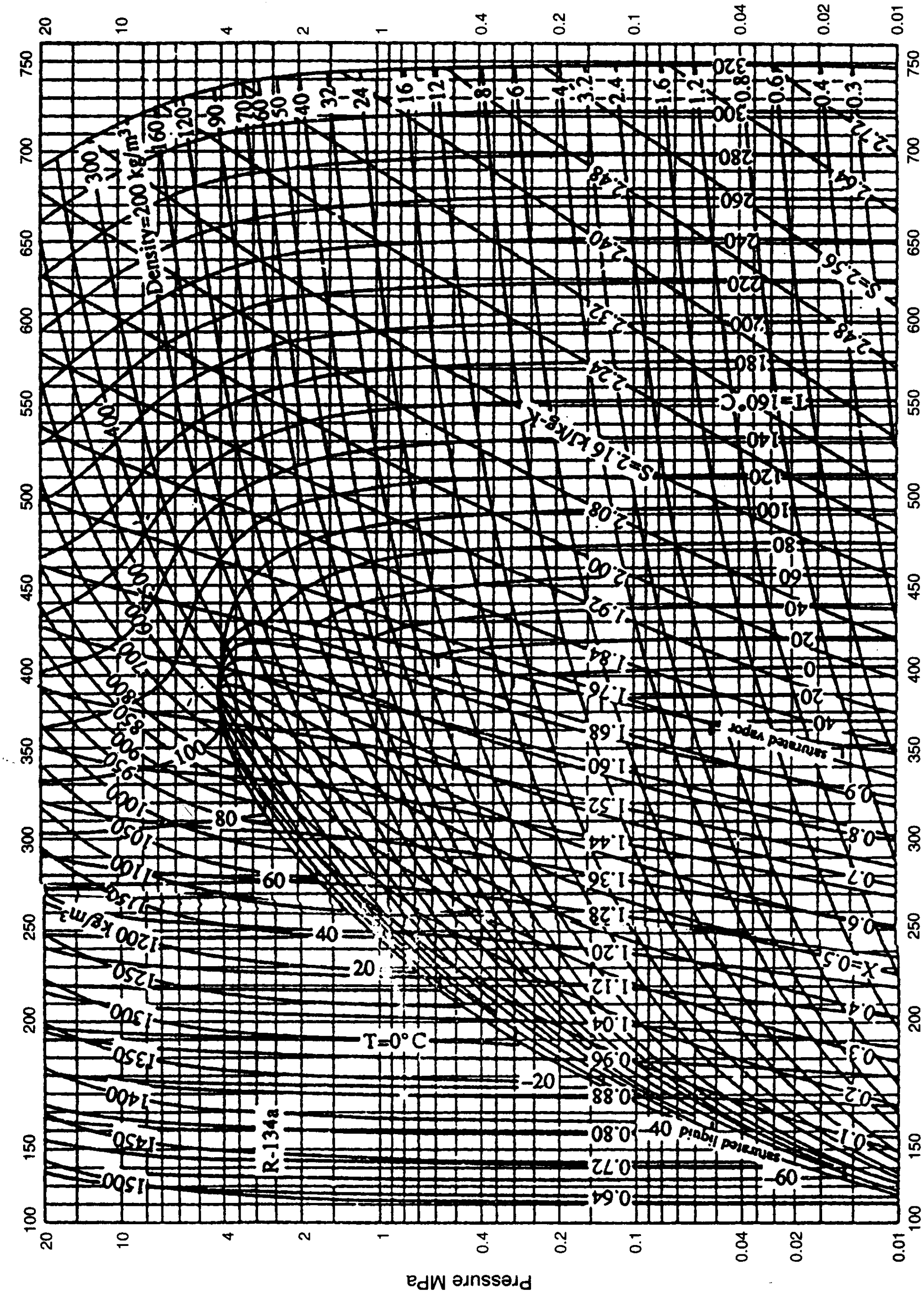


[redacted] *Mollier diagram for steam*



"FREON" is Du Pont's registered trademark for its fluorocarbon refrigerants

Fig. B.2 *p-h diagram for refrigerant R-12*



[illegible] *p-h diagram for refrigerant R-134a*

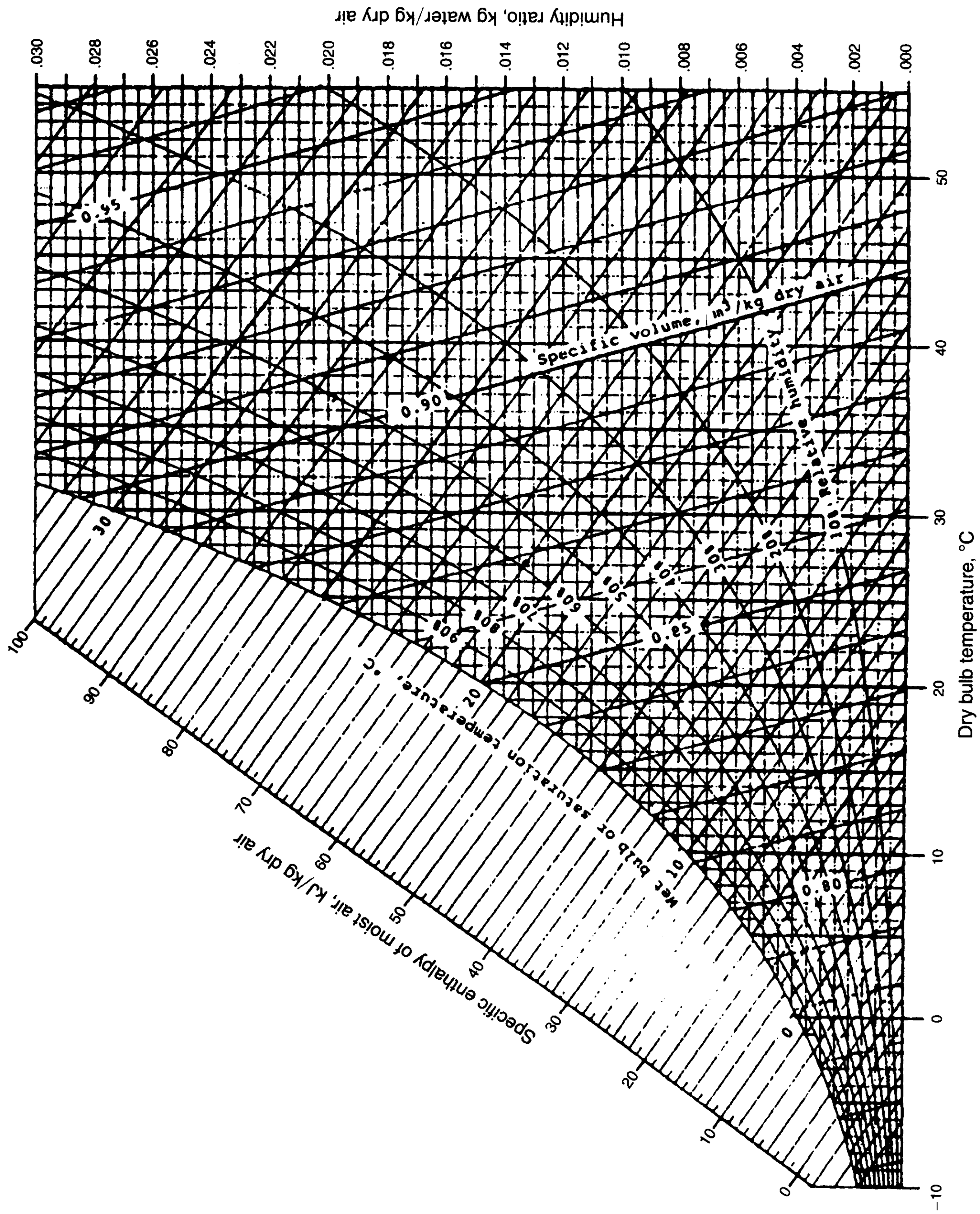


Fig. B.4 *Psychrometric chart for 1 atm (SI units)*

Source: Zhang, Z, and Pate, M.B., "A Methodology for Implementing a Psychrometric Chart in a Camputer Graphics System," ASHRAE Transactions, Vol. 94,Pt. 1,1988

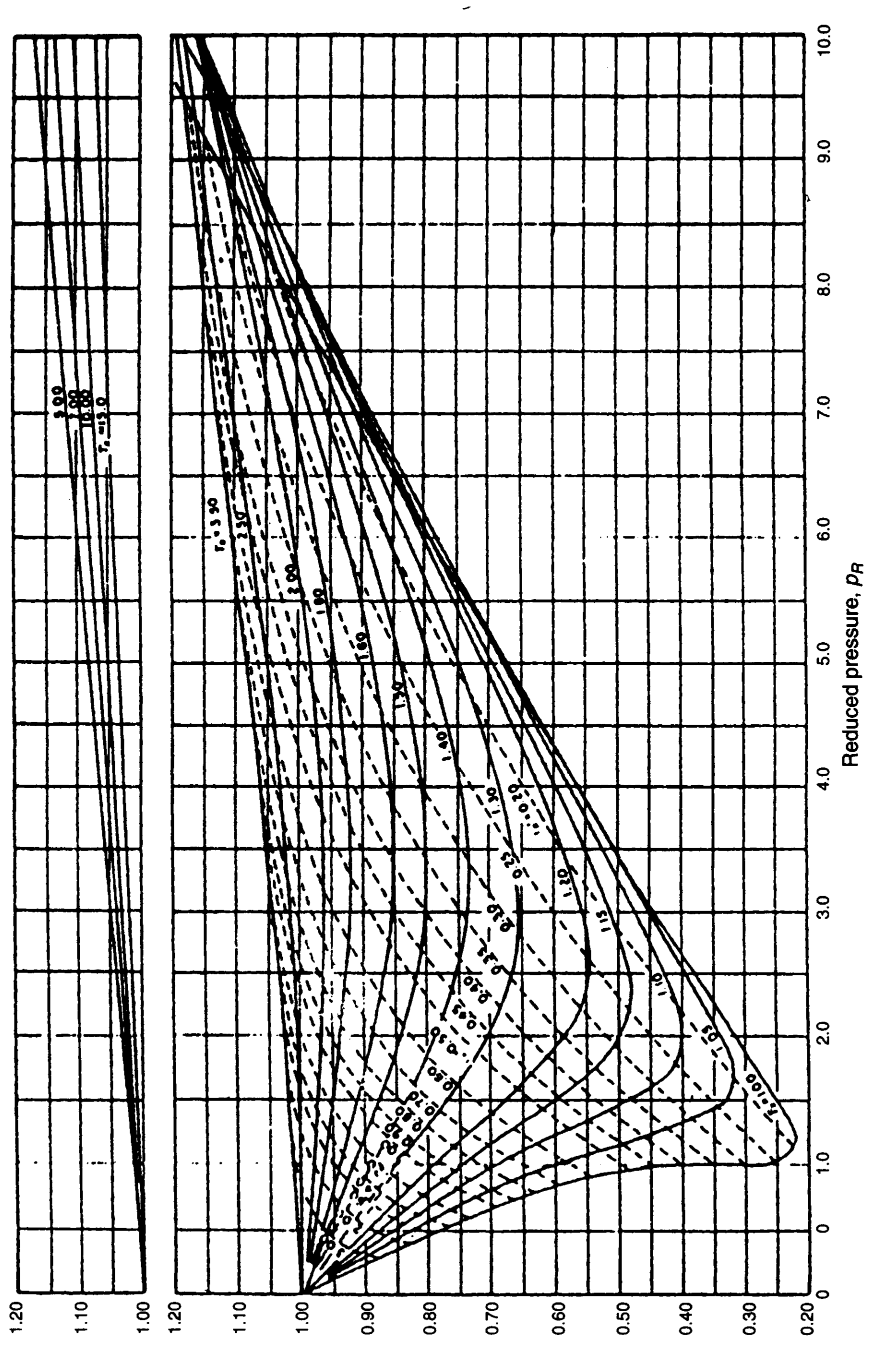


Fig. B.5 *Generalized compressibility chart,* $p_R \le 10.0$
Source: E.F. Obert, "Concepts of Thermodynamics, "McGraw-Hill, New York, 1960

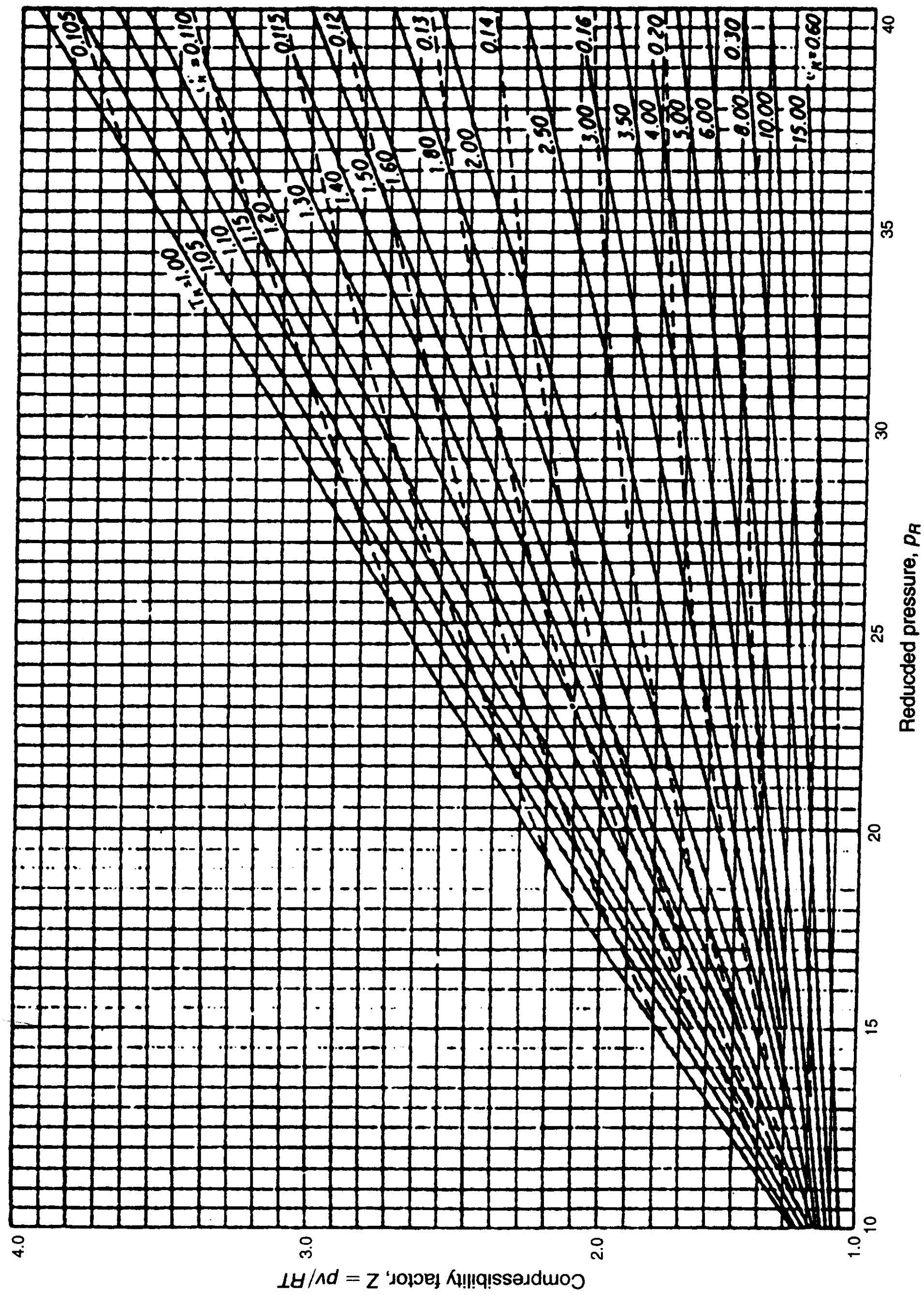


Fig. B.6 *Generalized compressibility chart,10 ≤ p_R ≤ 40*
Source: E.F. Obert, "Concepts of Thermodynamics, "McGraw-Hill, New York, 1960

Multiple-Choice Questions

1. Lead compounds were earlier used to be added to gasoline in S.I. engines so as to

   (a) reduce hydrocarbon emissions (b) reduce knocking
   (c) reduce exhaust gas temperature (d) increase power output

2. Decrease of air–fuel ratio in SI engines results in

   (a) an increase NO_x (b) a decrease of CO and unburnt hydrocarbon
   (c) an increase of CO and unburnt hydrocarbon (d) none of the above

3. If N is the rpm, the number of power strokes per minute in a four-stroke engine is

   (a) $2N$ (b) $N/2$ (c) N (d) $4N$

4. Volumetric efficiency is a measure of

   (a) speed of the engine (b) power of the engine
   (c) breathing capacity of the engine (d) pressure rise in the cylinder

5. If N is the rpm, the number of power strokes per minute in a two-stroke engine is

   (a) N (b) $N/2$ (c) $2N$ (d) $4N$

6. The volumetric efficiency of a well-designed engine is in the range of

   (a) 30 to 40% (b) 40 to 60% (c) 60 to 70% (d) 75 to 90%

7. If L is the stroke and N is the rpm, the mean piston speed of a two-stroke engine is

   (a) LN (b) $LN/2$ (c) $2LN$ (d) none of the above

8. Equivalence ratio is

   (a) $\dfrac{\text{actual fuel–air ratio}}{\text{stoichiometric fuel–air ratio}}$ (b) $\dfrac{\text{stoichiometric fuel–air ratio}}{\text{actual fuel–air ratio}}$

   (c) $\dfrac{\text{stoichiometric fuel–air ratio}}{\text{actual air–fuel ratio}}$ (d) $\dfrac{\text{stoichiometric air–fuel ratio}}{\text{actual air–fuel ratio}}$

9. The compression ratio in diesel engines is of the order of

   (a) 5–7 (b) 7–10 (c) 10–12 (d) 14–20

10. The compression ratio of an SI engine is in the range of

    (a) 4 to 6 (b) 6 to 8 (c) 6 to 10 (d) 10 to 14

11. The octane number of iso-octane is

    (a) 0 (b) 30 (c) 60 (d) 100

12. The ignition quality of diesel fuel is indicated by its
    (a) octane number (b) cetane number (c) flash point (d) fire point
13. A simple carburetor supplies rich mixture during
    (a) starting (b) idling (c) cruising (d) accelerating
14. Modern carburetors provide the correct quality of air–fuel mixture during
    (a) starting (b) idling (c) cruising (d) all conditions
15. Fuel is injected in a four-stroke CI engine
    (a) at the end of the suction stroke (b) at the end of the expansion stroke
    (c) at the end of the compression stoke (d) at the end of the exhaust stroke
16. The advantage of fuel injection in SI engine is
    (a) low initial cost (b) low maintenance requirement
    (c) increased volumetric efficiency (d) none of the above
17. For engines operating with rich mixtures, the optimum spark timing
    (a) must be advanced (b) must be retarded (c) must be at TDC (d) none of the above
18. By decreasing the cooling water temperature in SI engines, the knocking tendency
    (a) increases (b) decreases (c) is not affected (d) none of the above
19. In CI engines knocking tendency increases with
    (a) increase in compression ratio (b) increase in inlet temperature of air
    (c) decrease in compression ratio (d) increasing coolant water temperature
20. In turbocharging, the supercharger is driven by
    (a) a gas turbine using the exhaust gases (b) the engine itself
    (c) a separate electric motor (d) none of the above
21. For a multi-stage compressor, the polytropic efficiency is
    (a) the efficiency of all stages combined together (b) the isentropic efficiency of one stage
    (c) constant throughout for all stages (d) a direct consequence of pressure ratio
22. When the flow of air through the compressor is parallel to the axis of the compressor, it is a
    (a) rotary compressor (b) reciprocating compressor
    (c) centrifugal compressor (d) axial flow compressor
23. The stip in a centrifugal compressor will
    (a) increase with increasing number of vanes (b) decrease with increasing number of vanes
    (c) remain the same with increasing number of vanes (d) have none of the above
24. **Assertion (A):** The polytropic efficiency of a compressor decreases with increasing pressure ratio.
    Reasoning (R): Because more energy is required to compress air at higher pressures and temperatures.
    (a) Both A and R are true, but R is not the correct answer of A
    (b) both A and R are true and R is the correct answer of A
    (c) A is true, R is false
    (d) A is false, R is true
25. The maximum pressure ratio in an actual sing-stage axial flow compressor will be approximately
    (a) 1:15 (b) 1:10 (c) 1:4 (d) 1: 1.2

26. The degree of reaction in a turbo compressor is defined as
    (a) enthalpy drop in rotor/enthalpy drop in stage (b) enthalpy increase in the stage/enthalpy drop in rotor
    (c) enthalpy drop in stage/enthalpy drop in rotor (d) enthalpy rise in rotor/enthalpy increase in stage

27. The volumetric efficiency of a reciprocating compressor having a given pressure ratio decreases if the index compression
    (a) increases (b) decreases (c) remains constant (d) is equal to 1

28. For the same compression ratio, the efficiency of the Brayton cycle is
    (a) equal to the Diesel cycle (b) equal to the Otto cycle
    (c) equal to the dual cycle (d) greater than the Diesel cycle

29. If the temperature at the turbine inlet is kept constant, the net output of a simple gas turbine plant would
    (a) increase with increasing pressure ratio
    (b) decrease with increasing pressure ratio
    (c) first increase and then decrease with increasing pressure ratio
    (d) remain unaffected with changes in pressure ratio

30. The specific output of a gas turbine plant can be increased by water injection. The water should be injected between the
    (a) regenerator and the combustion chamber (b) combustion chamber and the turbine
    (c) compressor and the regenerator (d) turbine and compressor

31. The thermal efficiency of a gas turbine cycle can be increased by
    (a) reheating (b) regeneration (c) intercooling (d) all the above

32. The maximum temperature in a gas turbine is approximately
    (a) 300°C (b) 600°C (c) 900°C (d) 1200°C

33. **Assertion A:** A regenerator always increases the efficiency of a gas turbine unit.
    Reasoning (R): Because it recovers the energy which was going as a waste and saves fuel consumption.
    (a) Both A and R are false (b) A is false, R is true
    (c) A is true, R is false (d) Both A and R are true

34. For an axial-flow gas turbine, the polytropic efficiency is equal to the
    (a) isentropic efficiency (b) overall efficiency
    (c) isentropic efficiency of an infinitely small stage (d) stage efficiency

35. In a gas turbine unit with a regenerator, perfect regeneration means
    (a) $T_3 < T_4$ (b) $T_3 > T_4$ (c) $T_3 = T_4$ (d) none of the above

    where T_3 is the temperature of air coming out of the regenerator and T_4 is the temperature of gases leaving the turbine.

36. **Assertion (A):** The output and thermal efficiency of a closed-cycle gas turbine can be greater than that of an open cycle gas turbine.
    Reasoning (R): Because a closed cycle gas turbine can use helium as a working fluid.
    (a) Both A and R are true and R is the correct explanation of A
    (b) Both A and R are false
    (c) A is false and R is true
    (d) Both A and R are true and R is not the correct explanation of A

37. For a gas turbine unit, the pressure ratio for maximum output is given by

(a) $(T_3/T_1)^{\frac{\gamma}{2(\gamma+1)}}$ (b) $(T_3/T_1)^{\frac{2(\gamma-1)}{\gamma}}$ (c) $(T_3/T_1)^{\frac{\gamma}{2(\gamma-1)}}$ (d) $(T_3/T_1)^{\frac{2\gamma}{\gamma-1}}$

where T_1 is the temperature of air at the compressor inlet and T_3 is the temperature at the turbine inlet.

38. In a gas turbine, reheating is done mainly to

(a) increase the outlet temperature (b) reduce the size of the turbine
(c) increase the power output (d) reduce the peak temperature

39. Higher air–fuel ratio in a gas turbine would

(a) increase thermal efficiency (b) increase power output
(c) decrease the outlet temperature (d) make all of the above

40. The maximum thrust power is obtained in a turbojet engine when

(a) aircraft velocity is equal to the jet velocity (b) aircraft velocity is twice the jet velocity
(c) aircraft velocity is half the jet velocity (d) aircraft velocity is the square root of the jet velocity

41. Restricted burning in a solid propellant rocket is adopted when

(a) a large thrust is required for a small period of time (b) a small thrust is required for a small period of time
(c) a small thrust is required for a large period of time (d) a large thrust is required for a large period of time

42. **Assertion (A):** It is hot possible to attain 100% propulsive efficiency of a turbojet.
Reasoning (R): Because that would require the thrust and thrust power equal to zero.

(a) Both A and R are false (b) Both A and R are true
(c) A is true, but R is false (d) A is false and R is true

43. Propulsive efficiency is defined as

(a) thrust power/propulsive power (b) propulsive power/thrust power
(c) propulsive power × thrust power (d) none of the above

44. The maximum propulsive efficiency for maximum thrust power of a turbojet engine is

(a) 50% (b) 66.7% (c) 75% (d) 100%

45. The thrust of a jet-propulsion power input can be increased by

(a) burning fuel after gas turnbine (b) injecting water into the compressor
(c) injecting ammonia into the combustion chamber (d) none of the above

46. The propeller of a turboprop engine is driven by

(a) compressor (b) turbine (c) both 'a' and 'b' (d) none of the above

47. **Assertion (A):** A turbojet employs a smaller gas turbine unit
Reasoning (R): Because aircrafts fly at comparatively lower speeds.

(a) Both A and R are false (b) Both A and R are true
(c) A is false, R is true (d) A is true, R is false

48. The efficiency of a jet engine is higher at

(a) high altitudes (b) low altitudes (c) low speeds (d) high speeds

49. In a refrigeration plant, if the condenser temperature increases, the power input to the compressor will

(a) decrease (b) increase (c) remain the same (d) be unpredictable

50. At a place where there is no electricity, we can use the following system to obtain refrigeration.

(a) Vapour compression (b) Vapour absorption (c) Steam jet refrigeration (d) Air cycle refrigeration

51. In an aircraft-refrigeration system, the pressure at the cooling turbine outlet is equal to

(a) ambient pressure
(b) cabin pressure
(c) pressure at inlet to compressor
(d) none of the above

52. Match list I and list II and select the answer from the code given below:

List I	*List II*
Equipment in a refrigeration system	Variation of properties
A. Compressor	1. Enthalpy remains constant
B. Evaporator	2. Enthalpy increases
C. Throttle valve	3. Enthalpy increases but pressure remains constant
D. Condenser	4. Enthalpy decreases but pressure remains constant

Code:

	A	*B*	*C*	*D*
(a)	3	2	1	4
(b)	2	3	4	1
(c)	2	3	1	4
(d)	4	2	3	1

53. In a 2-stage vapour compression system, a flash intercooler is installed between the

(a) HP compressor and condenser
(b) LP and HP compressor
(c) Evaporator and LP compressors
(d) none of the above

54. In a water-vapour refrigeration system, a steam ejector maintains a very low pressure in the

(a) condenser
(b) absorber
(c) flash chamber
(d) none of the above

55. In a vapour compression system, the working fluid is a superheated vapour at inlet to

(a) evaporator
(b) condenser
(c) compressor
(d) throttle valve

56. A good refrigerant should have a

(a) large latent heat at condensing pressure
(b) large latent heat at evaporator pressure
(c) condensing pressure close to critical pressure
(d) high critical pressure

57. The effects of superheating the vapour in the evaporator and subcooling in the condenser

(a) decrease of COP
(b) increase the COP
(c) superheating increases COP, but undercooling decreases COP
(d) superheating decreases COP, but subcooling increases COP

58. A humidification process means

(a) a decrease in relative humidity
(b) a decrease in specific humidity
(c) an increase in specific humidity
(d) an increase in temperature

59. In an adiabatic saturation process

(a) the enthalpy remains constant
(b) the temperature remains constant
(c) the absolute humidity remains constant
(d) the relative humidity remains constant

60. When air is adiabatically saturated, the temperature attained is

(a) dew point temperature
(b) dry bulb temperature
(c) wet bulb temperature
(d) triple point temperature

61. The saturation temperature at the partial pressure of water vapour in an air–water mixture is the

(a) dew point temperature
(b) wet bulb temperature
(c) dry bulb temperature
(d) adiabatic saturation temperature

62. The use of reheating of steam in a steam-power plant

(a) permits the use of higher boiler steam pressure to increase the net power output
(b) reduces the steam rate and the heat rate
(c) limits the permissible quality of steam at turbine exhaust
(d) accomplishes all the above

63. The ideal regenerative steam cycle which yields an efficiency equal to that of Carnot cycle is not practicable because

(a) reversible heat transfer cannot be obtained in finite time
(b) heat exchanger in the turbine is mechanically not practicable
(c) the moisture content of the steam in the turbine will be high
(d) of all the above reasons

64. If the number of feedwater heaters used in a steam power plant are seven, the maximum gain in cycle efficiency occurs when the overall temperature rise of feedwater is about x times the difference between the condenser and boiler saturation temperature (with dry saturated steam at turbine inlet),

Where

(a) $x = \frac{1}{2,}$
(b) $x = \frac{3}{4}$
(c) $x = \frac{7}{8}$
(d) $x = \frac{8}{9}$

65. In a steam power plant while the energy loss in the condenser is about 60%, the energy loss is nearly.

(a) zero
(b) 4%
(c) 60%
(d) 100%

66. The overall efficiency of a steam power plant is expressed as the product of efficiencies of its components. If the boiler efficiency takes care of the energy loss in the boiler, the cycle efficiency takes care of the energy loss in the

(a) turbine
(b) condenser
(c) electric generator
(d) the auxiliaries

67. Two Thermodynamic cycles are coupled in series where heat lost by one is absorbed by the other. If the topping cycle has an efficiency of 30% and the bottoming cycle has an efficiency of 20%, the overall efficiency of the combined cycle is

(a) 50%
(b) 60%
(c) 44%
(d) 54%

68. This cycle is applicable to a pulse jet engine:

(a) Brayton cycle
(b) Lenoir cycle
(c) Atkinson cycle
(d) Ericsson cycle

69. A gas turbine plant operates on an ideal Brayton cycle. If the minimum temperature is 300 K and the maximum temperature is 1200 K, the cycle efficiency corresponding to maximum net work is

(a) 0.30
(b) 0.40
(c) 0.50
(d) 0.75

70. In the expansion of steam is a turbine with friction and heat loss, the entropy decrease of steam due to heat loss happens to be equal to the entropy increase of steam due to friction. Then, the entropy of steam at the turbine exit minus that at turbine inlet is

(a) zero
(b) positive
(c) negative
(d) more or less than zero

ANSWERS

1. (b)
2. (c)
3. (b)
4. (c)
5. (a)
6. (d)
7. (c)
8. (b)
9. (d)
10. (c)
11. (d)
12. (b)
13. (d)
14. (d)
15. (c)
16. (c)
17. (a)
18. (b)
19. (c)
20. (a)
21. (a)
22. (d)
23. (a)
24. (b)
25. (d)
26. (d)
27. (b)
28. (b)
29. (c)
30. (c)
31. (d)
32. (d)
33. (d)
34. (c)
35. (c)
36. (a)
37. (c)
38. (c)
39. (d)
40. (c)
41. (c)
42. (b)
43. (a)
44. (b)
45. (a)
46. (b)
47. (d)
48. (a)
49. (b)
50. (b)
51. (b)
52. (c)
53. (b)
54. (c)
55. (b)
56. (b)
57. (b)
58. (c)
59. (a)
60. (c)
61. (a)
62. (d)
63. (d)
64. (c)
65. (b)
66. (b)
67. (c)
68. (b)
69. (c)
70. (a)

Bibliography

1. Adrian Bejan, *Advanced Engineering Thermodynamics*, John Wiley, New York, 1988.
2. Adrian Bejan, *Entropy Generation through Heat and Fluid Flow*, Wiley Int. Science, New York, 1982.
3. R.W. Benson, *Advanced Engineering Thermodynamics*, Pergamon Press, London, 1977.
4. H.B. Callen, *Thermodynamics*, John Wiley, New York, 1960.
5. Y.A. Cengel and M.A. Boles, *Thermodynamics: An Engineering Approach*, McGraw-Hill, New York, 1988.
6. G.N. Hatsopoulos and J.H. Keenan, *Principles of General Thermodynamics*, John Wiley, New York, 1965.
7. Jack P. Holman, *Heat Transfer*, McGraw-Hill, New York, 1978.
8. J.R. Howell and R.O. Buckius, *Fundamentals of Engineering Thermodynamics,* McGraw-Hill, New York, 1992.
9. J.S. Hsieh, *Principles of Thermodynamics*, McGraw-Hill, 1975.
10. J.B. Jones and R.E. Dugan, *Engineering Thermodynamics*, Prentice-Hall, India, 1998.
11. J.H. Keenan, *Thermodynamics*, John Wiley, New York, 1941.
12. J.F. Lay, *Thermodynamics*, Merril Books, 1963.
13. J.F. Lee and F.W. Sears, *Thermodynamics*, Addison-Wesely, Cambridge, Mass, 1962.
14. David A. Mooney, *Mechanical Engineering Thermodynamics*, Prentice-Hall, New Jersey, 1953.
15. M.J. Moran and H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, John Wiley, New York, 1988.
16. P.K. Nag, *Heat and Mass Transfer*, 2e, Tata McGraw-Hill, New Delhi, 2007.
17. E.F. Obert, *Concepts of Thermodynamics*, McGraw-Hill, New York, 1960.
18. W.C. Reynolds and H.C. Perkins, *Engineering Thermodynamics*, McGraw-Hill, New York, 1977.
19. Michel A. Saad, *Thermodynamics for Engineers*, Prentice-Hall, New Delhi, 1969.
20. A.H. Shapiro, *The Dynamics and Thermodynamics of Compressible Fluid Flow*, The Ronald Press, New York, 1953.
21. G.J. Van Wylen, R.E. Sonntag and C. Borgnakke, *Fundamentals of Classical Thermodynamics*, John Wiley, New York, 1994.
22. D.B. Spalding and E.H. Cole, *Engineering Thermodynamics*, Edward Arnold, London, 1967.
23. Kenneth Wark, *Thermodynamics*, Fourth edition, McGraw-Hill, New York, 1985.
24. M.W. Zemansky, *Heat and Thermodynamics*, McGraw-Hill, New York, 1957.
25. M.W. Zemansky and H.C. Van Ness, *Basic Engineering Thermodynamics*, McGraw-Hill, New York, 1966.
26. ML Macheve and R.P. Sharma, A course in *Internal Combustion Engines,* Dhanpat Rai and Sons, Delhi, 1960.
27. P.W. Gill, J.H. Smith, E. J. Ziurys, Fundamentals of Internal Combustion Engines Fourth Edition, Oxford & IBH Publishing Co., Delhi, 1959.

28. T.D. Eastop and A. McKonkey *Applied Thermodynamics for Engineering* Technologists, Fifth Edition, Addison-Wesley Longman Ltd., UK, 1993.
29. H. Cohen, G.F.C. Rogers and H.L.H Saravanamutto, Gas Turbine Theory, Third Edition, Longman, UK, 1987.
30. G. M. Dusinberre and J.C. Lester Gas Turbine Power, International Textbook, 1958.

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