

CHE 260F – Thermodynamics and Heat Transfer

Mid-Term Exam – 2022

You have 110 minutes to do the following five problems. You may use any type of non-communicating calculator. All questions are worth equal marks. You do not have to return the tables or question paper, so feel free to write on them.

- 1) Two flows of air are both at a pressure of 200 kPa; one has a mass flow rate of 1 kg/s at 400 K, and the other has a mass flow rate of 2 kg/s at 290 K. The two flows enter and are mixed in an insulated box from which emerges a single exit flow at 200 kPa. Find the exit temperature and the total rate of entropy generation.
- 2) Air is expanded in an adiabatic turbine with 85% isentropic efficiency from an inlet state of 2200 kPa and 300°C to an outlet pressure of 200 kPa. Calculate the outlet temperature of air and the work produced by this turbine per unit mass of air.
- 3) Air is compressed steadily by a compressor from 100 kPa and 20°C to 1200 kPa and 300°C at a rate of 0.4 kg/s. Heat is lost from the compressor at a rate of 15 kW to the surroundings at 20°C. Determine (a) the power input to the compressor and (b) the rate of entropy generation.
- 4) A steam turbine receives steam at a pressure of 1 MPa and a temperature of 300°C. The steam leaves the turbine at a pressure of 15 kPa. The work output of the turbine is measured to be 600 kJ/kg of steam flowing through the turbine. Determine (a) the isentropic efficiency of the turbine and (b) the quality of steam at the exit of the turbine.
- 5) A piston/cylinder setup shown in Fig. 1 contains 0.1 kg of saturated liquid and vapor water at 100 kPa with quality 25%. The mass of the piston is such that a pressure of 500 kPa will lift it off the stops. The water is heated to 300°C. Show the process on a P - v diagram. Find the final pressure and volume of the water, and the work done during this process.

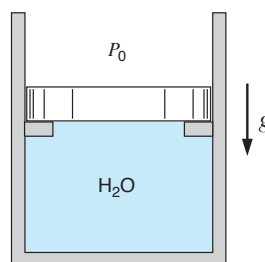


Figure 1

Ideal gas equation

$$PV = NR_u T \quad R_u = 8.314 \text{ kJ/kmol K}$$

$$PV = mRT \quad R = R_u/M$$

Boundary Work

$$W_{12} = - \int_{V_1}^{V_2} P dV$$

For a constant pressure process

$$W_{12} = P_1(V_1 - V_2) = P_1V_1 - P_2V_2$$

For a polytropic process $PV^n = C$

$$W_{12} = P_1V_1 \ln \frac{V_1}{V_2} = P_2V_2 \ln \frac{V_1}{V_2} \quad \text{for } n=1$$

$$W_{12} = \frac{P_2V_2 - P_1V_1}{n-1} \quad \text{for } n \neq 1$$

Flow work per unit mass of fluid

$$w_{\text{flow}} = Pv$$

Enthalpy $h = u + Pv$ **Specific heats**

$$c_v(T) \equiv \left(\frac{\partial u}{\partial T} \right)_v \quad \text{and} \quad c_p(T) \equiv \left(\frac{\partial h}{\partial T} \right)_p$$

For an ideal gas

$$c_p = c_v + R$$

$$\Delta u = u_2 - u_1 = c_{v, \text{avg}}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = c_{p, \text{avg}}(T_2 - T_1)$$

$$\text{Specific heat ratio } \gamma = \frac{c_p}{c_v} = \frac{\bar{c}_p}{\bar{c}_v}$$

For a control volume

$$\dot{m} = \frac{AV}{v}$$

$$\dot{Q} + \dot{W} = \dot{m} \left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \right]$$

Gibbs equation

$$ds = \frac{1}{T} du + \frac{P}{T} dv$$

For a liquid or solid

$$\Delta s = s_2 - s_1 = c_{\text{avg}} \int_{T_1}^{T_2} \frac{dT}{T} = c_{\text{avg}} \ln \frac{T_2}{T_1}$$

For an ideal gas

$$\Delta s = s_2 - s_1 = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

$$\Delta s = s_2 - s_1 = c_v \ln \frac{P_2}{P_1} + c_p \ln \frac{v_2}{v_1}$$

$$\Delta s = s_2 - s_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

Isentropic turbine efficiency

$$\eta_t = \frac{w_t}{w_{t,s}} = \frac{h_2 - h_1}{h_{2s} - h_1}.$$

Isentropic nozzle efficiency,

$$\eta_{\text{nozzle}} = \frac{V_2^2}{V_{2s}^2}.$$

Isentropic compressor or pump efficiency,

$$\eta_c = \frac{w_{c,s}}{w_c} = \frac{h_{2s} - h_1}{h_2 - h_1}.$$

For an isentropic process in an ideal gas

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{(\gamma-1)}; \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{(\gamma-1)/\gamma};$$

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2} \right)^\gamma; \quad Pv^\gamma = \text{constant}$$

For a saturated liquid-vapour mixture

$$x = \frac{\text{mass of vapour}}{\text{mass of mixture}} = \frac{m_g}{m}$$

$$u = \frac{m_g}{m} u_g + \frac{m_f}{m} u_f = x u_g + (1-x) u_f$$

$$h = \frac{m_g}{m} h_g + \frac{m_f}{m} h_f = x h_g + (1-x) h_f$$

$$s = \frac{m_g}{m} s_g + \frac{m_f}{m} s_f = x s_g + (1-x) s_f$$

Air			
Temp (K)	c_p (kJ/kgK)	c_v (kJ/kgK)	$\gamma=c_p/c_v$
250	1.003	0.716	1.401
300	1.005	0.718	1.400
350	1.008	0.721	1.398
400	1.013	0.726	1.395
450	1.020	0.733	1.391
500	1.029	0.742	1.387
550	1.040	0.753	1.381
600	1.051	0.764	1.376
650	1.063	0.776	1.370
700	1.075	0.788	1.364
750	1.087	0.800	1.359
800	1.099	0.812	1.354
900	1.121	0.834	1.344
1000	1.142	0.855	1.336

Gas	R (kJ/kgK)	c_p (kJ/kg K)	c_v (kJ/kg K)
He	2.07703	5.1926	3.1156
Ar	0.20813	0.5203	0.3122
H ₂	4.12418	14.2091	10.0849
CO	0.29683	1.0413	0.7445
N ₂	0.29680	1.0416	0.7448
O ₂	0.25983	0.9216	0.6618
H ₂ O	0.46152	1.8723	1.4108
CO ₂	0.18892	0.8418	0.6529
NH ₃	0.48819	2.1300	1.6418
Air	0.2870	1.0035	0.7165

Properties evaluated at 25°C, 100 kPa

TABLE A-4

Saturated water—Temperature table

Temp., T °C	Specific volume, m^3/kg			Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, $kJ/kg \cdot K$		
	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.7	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2566
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956	7.0771
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919	7.0265
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901	6.9773
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5	1.7392	5.1901	6.9294
145	415.68	0.001085	0.44600	610.19	1944.2	2554.4	610.64	2129.2	2739.8	1.7908	5.0919	6.8827
150	476.16	0.001091	0.39248	631.66	1927.4	2559.1	632.18	2113.8	2745.9	1.8418	4.9953	6.8371
155	543.49	0.001096	0.34648	653.19	1910.3	2563.5	653.79	2098.0	2751.8	1.8924	4.9002	6.7927
160	618.23	0.001102	0.30680	674.79	1893.0	2567.8	675.47	2082.0	2757.5	1.9426	4.8066	6.7492
165	700.93	0.001108	0.27244	696.46	1875.4	2571.9	697.24	2065.6	2762.8	1.9923	4.7143	6.7067
170	792.18	0.001114	0.24260	718.20	1857.5	2575.7	719.08	2048.8	2767.9	2.0417	4.6233	6.6650
175	892.60	0.001121	0.21659	740.02	1839.4	2579.4	741.02	2031.7	2772.7	2.0906	4.5335	6.6242
180	1002.8	0.001127	0.19384	761.92	1820.9	2582.8	763.05	2014.2	2777.2	2.1392	4.4448	6.5841
185	1123.5	0.001134	0.17390	783.91	1802.1	2586.0	785.19	1996.2	2781.4	2.1875	4.3572	6.5447
190	1255.2	0.001141	0.15636	806.00	1783.0	2589.0	807.43	1977.9	2785.3	2.2355	4.2705	6.5059
195	1398.8	0.001149	0.14089	828.18	1763.6	2591.7	829.78	1959.0	2788.8	2.2831	4.1847	6.4678
200	1554.9	0.001157	0.12721	850.46	1743.7	2594.2	852.26	1939.8	2792.0	2.3305	4.0997	6.4302

TABLE A-4

Saturated water—Temperature table (Continued)

Temp., T °C	Specific volume, m^3/kg			Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, $kJ/kg \cdot K$		
	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
205	1724.3	0.001164	0.11508	872.86	1723.5	2596.4	874.87	1920.0	2794.8	2.3776	4.0154	6.3930
210	1907.7	0.001173	0.10429	895.38	1702.9	2598.3	897.61	1899.7	2797.3	2.4245	3.9318	6.3563
215	2105.9	0.001181	0.094680	918.02	1681.9	2599.9	920.50	1878.8	2799.3	2.4712	3.8489	6.3200
220	2319.6	0.001190	0.086094	940.79	1660.5	2601.3	943.55	1857.4	2801.0	2.5176	3.7664	6.2840
225	2549.7	0.001199	0.078405	963.70	1638.6	2602.3	966.76	1835.4	2802.2	2.5639	3.6844	6.2483
230	2797.1	0.001209	0.071505	986.76	1616.1	2602.9	990.14	1812.8	2802.9	2.6100	3.6028	6.2128
235	3062.6	0.001219	0.065300	1010.0	1593.2	2603.2	1013.7	1789.5	2803.2	2.6560	3.5216	6.1775
240	3347.0	0.001229	0.059707	1033.4	1569.8	2603.1	1037.5	1765.5	2803.0	2.7018	3.4405	6.1424
245	3651.2	0.001240	0.054656	1056.9	1545.7	2602.7	1061.5	1740.8	2802.2	2.7476	3.3596	6.1072
250	3976.2	0.001252	0.050085	1080.7	1521.1	2601.8	1085.7	1715.3	2801.0	2.7933	3.2788	6.0721
255	4322.9	0.001263	0.045941	1104.7	1495.8	2600.5	1110.1	1689.0	2799.1	2.8390	3.1979	6.0369
260	4692.3	0.001276	0.042175	1128.8	1469.9	2598.7	1134.8	1661.8	2796.6	2.8847	3.1169	6.0017
265	5085.3	0.001289	0.038748	1153.3	1443.2	2596.5	1159.8	1633.7	2793.5	2.9304	3.0368	5.9662
270	5503.0	0.001303	0.035622	1177.9	1415.7	2593.7	1185.1	1604.6	2789.7	2.9762	2.9542	5.9305
275	5946.4	0.001317	0.032767	1202.9	1387.4	2590.3	1210.7	1574.5	2785.2	3.0221	2.8723	5.8944
280	6416.6	0.001333	0.030153	1228.2	1368.2	2586.4	1236.7	1543.2	2779.9	3.0681	2.7898	5.8579
285	6914.6	0.001349	0.027756	1253.7	1328.1	2581.8	1263.1	1510.7	2773.7	3.1144	2.7066	5.8210
290	7441.8	0.001366	0.025594	1279.7	1296.9	2576.5	1289.8	1476.9	2766.7	3.1608	2.6225	5.7834
295	7999.0	0.001384	0.023528	1306.0	1264.5	2570.5	1317.1	1441.6	2758.7	3.2076	2.5374	5.7450
300	8587.9	0.001404	0.021659	1332.7	1230.9	2563.6	1344.8	1404.8	2749.6	3.2548	2.4511	5.7059
305	9209.4	0.001425	0.019932	1360.0	1195.9	2555.8	1373.1	1366.3	2739.4	3.3024	2.3633	5.6657
310	9865.0	0.001447	0.018333	1387.7	1159.3	2547.1	1402.0	1325.9	2727.9	3.3506	2.2737	5.6243
315	10556	0.001472	0.016849	1416.1	1121.1	2537.2	1431.6	1283.4	2715.0	3.3994	2.1821	5.5816
320	11284	0.001499	0.015470	1445.1	1080.9	2526.0	1462.0	1238.5	2700.6	3.4491	2.0881	5.5372
325	12061	0.001528	0.014183	1475.0	1038.5	2513.4	1493.4	1191.0	2684.3	3.4998	1.9911	5.4908
330	12888	0.001560	0.012979	1505.7	993.5	2499.2	1525.8	1140.3	2666.0	3.5516	1.8906	5.4422
335	13707	0.001597	0.011848	1537.5	945.5	2483.0	1559.4	1086.0	2645.4	3.6050	1.7857	5.3907
340	14601	0.001638	0.010783	1570.7	893.8	2464.5	1594.6	1027.4	2622.0	3.6602	1.6756	5.3358
345	15541	0.001685	0.009772	1605.5	837.7	2443.2	1631.7	963.4	2595.1	3.7179	1.5585	5.2765
350	16529	0.001741	0.008806	1642.4	775.9	2418.3	1671.2	892.7	2563.9	3.7788	1.4326	5.2114
355	17570	0.001808	0.007872	1682.2	706.4	2388.6	1714.0	812.9	2526.9	3.8442	1.2942	5.1384
360	18666	0.001895	0.006950	1726.2	625.7	2351.9	1761.5	720.1	2481.6	3.9165	1.1373	5.0537
365	19822	0.002015	0.006009	1777.2	526.4	2303.6	1817.2	605.5	2422.7	4.0004	0.9489	4.9493
370	21044	0.002217	0.004953	1844.5	385.6	2230.1	1891.2	443.1	2334.3	4.1119	0.6890	4.8009
373.95	22064	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

TABLE A-5

Saturated water—Pressure table

Press., <i>P</i> kPa	Sat. temp., <i>T</i> _{sat} °C	Specific volume, <i>v</i> m ³ /kg		Internal energy, <i>u</i> kJ/kg			Enthalpy, <i>h</i> kJ/kg			Entropy, <i>s</i> kJ/kg · K	
		Sat. <i>v</i> _f	Sat. <i>v</i> _g	Sat. <i>u</i> _f	Sat. <i>u</i> _g	Evap., <i>u</i> _{fg}	Sat. <i>h</i> _f	Sat. <i>h</i> _g	Evap., <i>h</i> _{fg}	Sat. <i>s</i> _f	Sat. <i>s</i> _g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019
75	91.76	0.001037	2.1272	384.36	2111.8	2495.1	384.44	2278.0	2662.4	1.2132	6.2426
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0	1.7274	5.2128
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9	594.73	2140.4	2735.1	1.7526	5.1645
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1	604.66	2133.4	2738.1	1.7765	5.1191
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699
700	164.95	0.001108	0.27278	696.23	1875.6	2571.8	697.00	2065.8	2762.8	1.9918	4.7153
750	167.75	0.001111	0.25552	708.40	1865.6	2574.0	709.24	2056.4	2765.7	2.0195	4.6642

TABLE A-5

Saturated water—Pressure table (Continued)

Press., <i>P</i> kPa	Sat. temp., <i>T</i> _{sat} °C	Specific volume, <i>v</i> m ³ /kg		Internal energy, <i>u</i> kJ/kg			Enthalpy, <i>h</i> kJ/kg			Entropy, <i>s</i> kJ/kg · K	
		Sat. <i>v</i> _f	Sat. <i>v</i> _g	Sat. <i>u</i> _f	Sat. <i>u</i> _g	Evap., <i>u</i> _{fg}	Sat. <i>h</i> _f	Sat. <i>h</i> _g	Evap., <i>h</i> _{fg}	Sat. <i>s</i> _f	Sat. <i>s</i> _g
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	719.97	2047.5	2768.3	2.0457	4.6160
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	2.0705	4.5705
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	2.0941	4.5273
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	2.1166	4.4862
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	2.1381	4.4470
1100	184.06	0.001133	0.17745	779.78	1805.7	2585.5	781.03	1999.6	2780.7	2.1785	4.3735
1200	187.96	0.001138	0.16326	796.96	1790.9	2587.8	798.33	1985.4	2783.8	2.2159	4.3058
1300	191.60	0.001144	0.15119	813.10	1776.8	2589.9	814.59	1971.9	2786.5	2.2508	4.2428
1400	195.04	0.001149	0.14078	828.35	1763.4	2591.8	829.96	1958.9	2788.9	2.2835	4.1840
1500	198.29	0.001154	0.13171	842.82	1750.6	2593.4	844.55	1946.4	2791.0	2.3143	4.1287
1750	205.72	0.001166	0.11344	876.12	1720.6	2596.7	878.16	1917.1	2795.2	2.3844	4.0033
2000	212.38	0.001177	0.099587	906.12	1693.0	2599.1	908.47	1889.8	2798.3	2.4467	3.8923
2250	218.41	0.001187	0.088717	933.54	1667.3	2600.9	936.21	1864.3	2800.5	2.5029	3.7926
2500	223.95	0.001197	0.079952	958.87	1643.2	2602.1	961.87	1840.1	2801.9	2.5542	3.7016
3000	233.85	0.001217	0.066667	1004.6	1598.5	2603.2	1008.3	1794.9	2803.2	2.6454	3.5402
3500	242.56	0.001235	0.057061	1045.4	1557.6	2603.0	1049.7	1753.0	2802.7	2.7253	3.3991
4000	250.35	0.001252	0.049779	1082.4	1519.3	2601.7	1087.4	1713.5	2800.8	2.7966	3.2731
5000	263.94	0.001286	0.039448	1148.1	1448.9	2597.0	1154.5	1639.7	2794.2	2.9207	3.0530
6000	275.59	0.001319	0.032449	1205.8	1384.1	2589.9	1213.8	1570.9	2784.6	3.0275	2.8627
7000	285.83	0.001352	0.027378	1258.0	1323.0	2581.0	1267.5	1505.2	2772.6	3.1220	2.6927
8000	295.01	0.001384	0.023525	1306.0	1264.5	2570.5	1317.1	1441.6	2758.7	3.2077	2.5373
9000	303.35	0.001418	0.020489	1350.9	1207.6	2558.5	1363.7	1379.3	2742.9	3.2866	2.3925
10,000	311.00	0.001452	0.018028	1393.3	1151.8	2545.2	1407.8	1317.6	2725.5	3.3603	2.2556
11,000	318.08	0.001488	0.015988	1433.9	1096.6	2530.4	1450.2	1256.1	2706.3	3.4299	2.1245
12,000	324.68	0.001526	0.014264	1473.0	1041.3	2514.3	1491.3	1194.1	2685.4	3.4964	1.9975
13,000	330.85	0.001566	0.012781	1511.0	985.5	2496.6	1531.4	1131.3	2662.7	3.5606	1.8730
14,000	336.67	0.001610	0.011487	1548.4	928.7	2477.1	1571.0	1067.0	2637.9	3.6232	1.7497
15,000	342.16	0.001657	0.010341	1585.5	870.3	2455.7	1610.3	1000.5	2610.8	3.6848	1.6261
16,000	347.36	0.001710	0.009312	1622.6	809.4	2432.0	1649.9	931.1	2581.0	3.7461	1.5005
17,000	352.29	0.001770	0.008374	1660.2	745.1	2405.4	1690.3	857.4	2547.7	3.8082	1.3709
18,000	356.99	0.001840	0.007504	1699.1	675.9	2375.0	1732.2	777.8	2510.0	3.8720	1.2343
19,000	361.47	0.001926	0.006677	1740.3	598.9	2339.2	1776.8	689.2	2466.0	3.9396	1.0860
20,000	365.75	0.002038	0.005862	1785.8	509.0	2294.8	1826.6	585.5	2412.1	4.0146	0.9164
21,000	369.83	0.002207	0.004994	1841.6	391.9	2233.5	1888.0	450.4	2338.4	4.1071	0.7005
22,000	373.71	0.002703	0.003644	1951.7	140.8	2092.4	2011.1	161.5	2172.6	4.2942	0.2496
22,064	373.95	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0
22,064	373.95	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0

TABLE A-6

Superheated water

T °C	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg·K
P = 0.01 MPa (45.81°C)*												
Sat.	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741	3.4187	2511.5	2682.4	7.6953	1.6959	2506.2	2675.8	7.3611
100	17.196	2515.5	2687.5	8.4489	3.8897	2585.7	2780.2	7.9413	1.9367	2582.9	2776.6	7.6148
150	19.513	2587.9	2783.0	8.6893	4.3562	2660.0	2877.8	8.1592	2.1724	2658.2	2875.5	7.8356
200	21.826	2661.4	2879.6	8.9049	4.8206	2735.1	2976.2	8.3568	2.4062	2733.9	2974.5	8.0346
250	24.136	2736.1	2977.5	9.1015	5.2841	2811.6	3075.8	8.5387	2.6389	2810.7	3074.5	8.2172
300	26.446	2812.3	3076.7	9.2827	5.6841	2888.1	3174.6	8.6959	2.8720	2886.8	3173.2	8.3862
350	28.756	2898.3	3176.3	9.4400	6.0341	2959.6	3273.3	8.8459	3.1027	2958.3	3271.9	8.5452
400	31.063	2969.3	3280.0	9.6094	6.2944	3029.6	3372.0	8.9913	3.3355	3028.3	3370.6	8.7046
450	33.370	3039.3	3382.7	9.7700	6.5547	3099.6	3470.7	9.1362	3.5655	3102.2	3468.7	8.8592
500	35.680	3109.3	3485.4	9.9200	6.8150	3169.6	3569.2	9.2711	3.7963	3175.2	3566.7	9.0099
550	37.990	3179.3	3588.5	10.0600	7.0753	3239.6	3667.9	9.4020	4.0279	3242.2	3665.3	9.1606
600	40.296	3249.3	3691.6	10.1900	7.3356	3309.6	3766.6	9.5269	4.2599	3312.2	3763.9	9.3113
650	42.604	3319.3	3794.7	10.3200	7.5959	3379.6	3865.3	9.6468	4.4920	3385.2	3861.6	9.4620
700	44.911	3389.3	3897.8	10.4500	7.8562	3449.6	3964.0	9.7617	4.7241	3458.9	3958.3	9.6127
750	47.218	3459.3	4000.9	10.5800	8.1165	3519.6	4062.7	9.8766	4.9562	3528.6	4055.0	9.7634
800	49.525	3529.3	4104.0	10.7100	8.3768	3589.6	4161.4	9.9815	5.1883	3598.3	4152.7	9.9141
850	51.832	3599.3	4207.1	10.8400	8.6371	3659.6	4260.1	10.0864	5.4204	3668.0	4250.4	10.0648
900	54.143	3669.3	4309.2	10.9700	8.8974	3729.6	4358.8	10.1913	5.6525	3737.7	4348.1	10.2155
950	56.454	3739.3	4412.3	11.1000	9.1577	3799.6	4457.5	10.2962	5.8846	3807.7	4446.8	10.3662
1000	58.765	3809.3	4515.4	11.2300	9.4180	3869.6	4556.2	10.4011	6.1167	3876.8	4545.5	10.5169
1050	61.076	3879.3	4618.5	11.3600	9.6783	3939.6	4654.9	10.5060	6.3488	3946.8	4644.2	10.6676
1100	63.387	3949.3	4721.6	11.4900	9.9386	4009.6	4753.6	10.6109	6.5809	4015.9	4742.9	10.8183
1150	65.698	4019.3	4824.7	11.6200	10.1989	4079.6	4852.3	10.7158	6.8130	4082.1	4841.6	10.9690
1200	67.989	4089.3	4927.8	11.7500	10.4592	4149.6	4951.0	10.8207	7.0451	4148.3	4940.3	11.1197
1250	70.280	4159.3	5030.9	11.8800	10.7195	4219.6	5049.7	10.9256	7.2772	4217.0	5039.0	11.2704
1300	72.604	4229.3	5134.0	12.0100	10.9798	4289.6	5148.4	11.0305	7.5093	4286.4	5127.7	11.4211
P = 0.20 MPa (120.21°C)												
Sat.	0.88578	2529.1	2706.3	7.1270	0.60582	2543.2	2724.9	6.9917	0.46242	2553.1	2738.1	6.8955
150	0.95986	2577.1	2769.1	7.2810	0.63402	2571.0	2761.2	7.0392	0.47088	2564.4	2752.8	6.9306
200	1.08049	2654.6	2870.7	7.5081	0.71643	2651.0	2865.9	7.1723	0.53434	2647.2	2860.9	7.1723
250	1.19890	2731.4	2971.2	7.7000	0.79645	2728.9	2967.9	7.3180	0.59520	2726.4	2964.5	7.3804
300	1.31623	2808.8	3072.1	7.8941	0.87535	2807.0	3069.6	7.4637	0.65489	2805.1	3067.1	7.5677
350	1.43356	2886.2	3172.7	8.0823	0.95425	2885.0	3169.3	7.6084	0.71459	2882.1	3164.6	7.7124
400	1.55089	2963.6	3273.2	8.2705	1.03315	2962.0	3269.0	7.7531	0.77429	2959.1	3261.7	7.8571
450	1.66822	3041.0	3373.7	8.4587	1.11205	3039.6	3368.7	7.8978	0.83400	3036.7	3359.8	8.0018
500	1.78555	3118.4	3474.2	8.6479	1.19095	3117.1	3468.4	8.0425	0.89371	3114.8	3457.5	8.1465
550	1.90288	3195.8	3574.7	8.8371	1.26985	3194.8	3568.1	8.1872	0.95342	3192.5	3556.6	8.2912
600	2.02021	3273.2	3675.2	9.0263	1.34875	3272.5	3667.8	8.3319	1.01313	3270.2	3655.7	8.4359
650	2.13754	3350.6	3775.7	9.2155	1.42765	3350.2	3767.5	8.4766	1.07284	3347.8	3754.8	8.5806
700	2.25487	3428.0	3876.2	9.4047	1.50655	3427.7	3867.2	8.6213	1.13255	3425.3	3853.9	8.7253
750	2.37220	3505.4	3976.7	9.5939	1.58545	3505.3	3966.9	8.7660	1.19226	3502.9	3953.0	8.8700
800	2.48953	3582.8	4077.2	9.7831	1.66435	3583.2	4066.6	8.9107	1.25197	3580.5	4052.1	9.0147
850	2.60686	3660.2	4177.7	9.9723	1.74325	3661.1	4166.3	9.0554	1.31168	3658.0	4141.2	9.1594
900	2.72419	3737.6	4278.2	10.1615	1.82215	3739.0	4266.0	9.2001	1.37139	3735.9	4230.3	9.3041
950	2.84152	3815.0	4378.7	10.3507	1.90105	3816.4	4365.7	9.3448	1.43110	3813.3	4329.4	9.4488
1000	2.95885	3892.4	4479.2	10.5400	1.97995	3893.8	4465.4	9.4895	1.49081	3890.2	4418.5	9.5935
1050	3.07618	3969.8	4579.7	10.7292	2.05885	3971.2	4565.1	9.6342	1.55052	3966.6	4517.6	9.7382
1100	3.19351	4047.2	4680.2	10.9184	2.13775	4048.6	4664.8	9.7789	1.61023	4043.0	4616.7	9.8829
1150	3.31084	4124.6	4780.7	11.1076	2.21665	4126.0	4764.5	9.9236	1.66996	4121.4	4715.8	10.0276
1200	3.42817	4202.0	4881.2	11.2968	2.29555	4203.4	4864.2	10.0683	1.72967	4200.8	4814.9	10.1723
1250	3.54550	4279.4	4981.7	11.4860	2.37445	4280.8	4963.9	10.2130	1.78938	4278.2	4914.0	10.3170
1300	3.66283	4356.8	5082.2	11.6752	2.45335	4358.2	5063.6	10.3577	1.84909	4355.6	5013.1	10.4617

TABLE A-6

Superheated water (Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
P = 1.00 MPa (179.88°C)												
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
450	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047
500	0.40111	3297.5	3698.6	8.0311	0.33395	3296.3	3697.0	7.9456	0.28597	3295.1	3695.5	7.8730
550	0.44783	3476.3	3924.1	8.2755	0.37297	3475.3	3922.9	8.1904	0.31951	3474.4	3921.7	8.1183
600	0.49438	3661.7	4156.1	8.5024	0.41184	3661.0	4155.2	8.4176	0.35288	3660.3	4154.3	8.3455
650	0.54083	3853.9	4394.8	8.7150	0.45059	3853.3	4394.0	8.6303	0.38614	3852.7	4393.3	8.5583
700	0.58721	4052.7	4640.0	8.9155	0.48928	4052.2	4639.4	8.8310	0.41933	4051.7	4638.8	8.7595
750	0.63354	4257.9	4891.4	9.1057	0.52792	4257.5	4891.0	9.0212	0.45247	4257.0	4890.5	8.9497
800	0.67983	4469.0	5148.9	9.2866	0.56652	4468.7	5148.5	9.2022	0.48558	4468.3	5148.1	9.1308
850	0.72610	4685.8	5411.9	9.4593	0.60509	4685.5	5411.6	9.3750	0.51866	4685.1	5411.3	9.3036
P = 1.60 MPa (201.37°C)												
Sat.	0.12374	2594.8	2792.8	6.4200	0.11037	2597.3	2795.9	6.3775	0.09959	2599.1	2798.3	6.3390
225	0.13293	2645.1	2857.8	6.5537	0.11678	2637.0	2847.2	6.4825	0.10381	2628.5	2836.1	6.4160
250	0.14190	2692.9	2919.9	6.6753	0.12502	2686.7	2911.7	6.6088	0.11150	2680.3	2903.3	6.5475
300	0.15866	2781.6	3035.4	6.8864	0.14025	2777.4	3029.9	6.8246	0.12551	2773.2	3024.2	6.7684
350	0.17459	2866.6	3146.0	7.0713	0.15460	2863.6	3141.9	7.0120	0.13860	2860.5	3137.7	6.9583
400	0.19007	2950.8	3254.9	7.2394	0.16849	2948.3	3251.6	7.1814	0.15122	2945.9	3248.4	7.1292
450	0.20229	3120.1	3472.6	7.5410	0.19551	3118.5	3470.4	7.4845	0.17568	3116.9	3468.3	7.4337
500	0.24999	3293.9	3693.9	7.8101	0.22200	3292.7	3692.3	7.7543	0.19962	3291.5	3690.7	7.7043
550	0.27941	3473.5	3920.5	8.0558	0.24822	3472.6	3919.4	8.0005	0.22326	3471.7	3918.2	7.9509
600	0.30865	3659.5	4153.4	8.2834	0.27426	3658.8	4152.4	8.2284	0.24674	3658.0	4151.5	8.1791
650	0.33780	3852.1	4392.6	8.4965	0.30020	3851.5	4391.9	8.4417	0.27012	3850.9	4391.1	8.3925
700	0.36687	4051.2	4638.2	8.6974	0.32606	4050.7	4637.6	8.6427	0.29342	4050.2	4637.1	8.5936
750	0.39589	4256.6	4890.0	8.8978	0.35188	4256.2	4889.6	8.8331	0.31667	4255.7	4889.1	8.7842
800	0.42488	4467.9	5147.7	9.0689	0.37766	4467.6	5147.3	9.0143	0.33989	4467.2	5147.0	8.9654
850	0.45383	4684.8	5410.9	9.2418	0.40341	4684.5	5410.6	9.1872	0.36308	4684.2	5410.3	9.1384
P = 2.50 MPa (223.95°C)												
Sat.	0.07995	2602.1	2801.9	6.2558	0.06667	2603.2	2803.2	6.1856	0.05706	2603.0	2802.7	6.1244
225	0.08026	2604.8	2805.5	6.2629	0.07063	2644.7	2856.5	6.2893	0.05876	2624.0	2829.7	6.1764
250	0.08705	2663.3	2880.9	6.4107	0.08118	2750.8	2994.3	6.5412	0.06845	2738.8	2978.4	6.4484
300	0.09894	2762.2	3009.6	6.6459	0.09056	2844.4	3116.1	6.7450	0.07680	2836.0	3104.9	6.6601
350	0.10979	2852.5	3127.0	6.8424	0.09938	2933.6	3231.7	6.9235	0.08456	2927.2	3223.2	6.8428
400	0.12012	2939.8	3240.1	7.0170	0.10789	3021.2	3344.9	7.0856	0.09198	3016.1	3338.1	7.0074
450	0.13015	3026.2	3351.6	7.1768	0.11620	3108.6	3457.2	7.2359	0.09919	3104.5	3451.7	7.1593
500	0.13999	3112.8	3462.8	7.3254	0.12458	3195.2	3568.2	7.5103	0.11325	3282.5	3678.9	7.4357
550	0.15931	3288.5	3686.8	7.5979	0.13245	3285.5	3682.8	7.7500	0.12702	3464.7	3909.3	7.6855
600	0.17835	3469.3	3915.2	7.8455	0.14841	3467.0	3912.2	7.9590	0.14061	3652.5	4144.6	7.9156
650	0.19722	3656.2	4149.2	8.0744	0.16420	3654.3	4145.9	7.9885	0.15410	3846.4	4385.7	8.1304
700	0.21597	3849.4	4389.3	8.2882	0.17988	3847.9	4387.5	8.2028	0.16751	4046.4	4632.7	8.3324
750	0.23466	4049.0	4635.6	8.4897	0.19549	4047.7	4634.2	8.4045	0.18087	4252.5	4885.6	8.5236
800	0.25330	4254.7	4887.9	8.6804	0.21105	4253.6	4886.7	8.5955	0.19420	4464.4	5144.1	8.7053
850	0.27198	4466.3	5146.5	8.8618	0.22658	4465.3	5145.1	8.7771	0.20750	4681.8	5408.0	8.8786
900	0.29048	4683.4	5409.5	9.0349	0.24207	4682.6	5408.8	8.9502	0.21925	4907.5	5688.5	9.1250