# CHE 260F – Thermodynamics and Heat Transfer
Mid-Term Exam – 2023

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) A cylinder with a piston restrained by a linear spring contains 2 kg of carbon dioxide at 500 kPa, 400°C. It is cooled to 40°C, at which point the pressure is 300 kPa. Show the process on a *P-V* diagram, with the pressure and volume values indicated at the start and end. Calculate the heat transfer for the process.
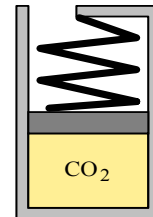
2) An insulated piston–cylinder device contains 5 L of saturated liquid water at a constant pressure of 175 kPa. The water is stirred by a paddle wheel while a current of 8 A flows for 45 min through a resistor placed in the water. If one-half of the liquid is evaporated during this constant- pressure process and the paddle-wheel work amounts to 400 kJ, determine the voltage applied across the resistor. Show the process on a *P-v* diagram with respect to the vapour dome.
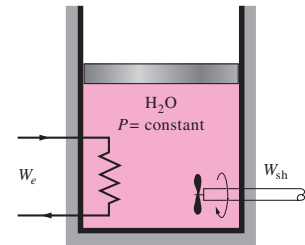
3) Carbon dioxide enters an adiabatic compressor at 100 kPa, 300 K and exits at 1000 kPa, 520 K. Find the isentropic efficiency of the compressor and the entropy generated in it per unit mass of gas flowing through it.

4) Steam enters an adiabatic turbine at 3 MPa, 600°C, and 80 m/s and leaves at 50 kPa, 150°C, and 140 m/s. If the power output of the turbine is 6 MW determine (*a*) the mass flow rate of the steam flowing through the turbine and (*b*) the isentropic efficiency of the turbine.

5) Two flow streams of water, one of saturated vapor at 0.6 MPa and the other at 0.6 MPa and 600°C, mix adiabatically in a steady flow to produce a single flow out at 0.6 MPa, 400°C. Find the total entropy generation for this process per kg of fluid leaving the mixer.

Ideal gas equation

$$PV = NR_u T \qquad R_u = 8.314 \text{ kJ/kmol K}$$
$$PV = mRT \qquad R = R_u/M$$

Boundary Work

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

For a constant pressure process

$$W_{12} = P_1(V_1 - V_2) = P_1 V_1 - P_2 V_2$$

For a polytropic process $PV^n = C$

$$W_{12} = P_1 V_1 \ln\frac{V_1}{V_2} = P_2 V_2 \ln\frac{V_1}{V_2} \quad \text{for } n=1$$

$$W_{12} = \frac{P_2 V_2 - P_1 V_1}{n-1} \qquad \text{for } n \neq 1$$

Flow work per unit mass of fluid

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

Enthalpy $h = u + Pv$

Specific heats

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

For an ideal gas

$$c_p = c_v + R$$
$$\Delta u = u_2 - u_1 = c_{v,avg}(T_2 - T_1)$$
$$\Delta h = h_2 - h_1 = c_{p,avg}(T_2 - T_1)$$

Specific heat ratio $\gamma = \dfrac{c_p}{c_v} = \dfrac{\overline{c_p}}{\overline{c_v}}$

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

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

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,

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

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

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

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

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

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

	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_2O	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	Sat. press., P_{sat} kPa	Specific volume m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy kJ/kg·K 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	2346.6	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	8.2556
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	Sat. press., P_{sat} kPa	Specific volume m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy kJ/kg·K 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	1153.0	1443.2	2596.5	1159.8	1633.7	2793.5	2.9304	3.0358	5.9662
270	5503.0	0.001303	0.035622	1177.0	1415.7	2593.7	1185.1	1604.6	2789.7	2.9762	2.9542	5.9305
275	5946.4	0.001317	0.032767	1202.0	1387.4	2590.3	1210.7	1574.5	2785.2	3.0221	2.8723	5.8944
280	6416.6	0.001333	0.030153	1228.0	1358.2	2586.6	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	0.025554	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	10,556	0.001472	0.016849	1416.1	1121.1	2537.2	1431.6	1283.4	2715.0	3.3994	2.1821	5.5816
320	11,284	0.001499	0.015470	1445.1	1080.9	2526.0	1462.0	1238.5	2700.6	3.4491	2.0881	5.5372
325	12,051	0.001528	0.014183	1475.0	1038.5	2513.4	1493.4	1191.0	2684.3	3.4998	1.9911	5.4908
330	12,858	0.001560	0.012979	1505.7	993.5	2499.2	1525.8	1140.3	2666.0	3.5516	1.8906	5.4422
335	13,707	0.001597	0.011848	1537.5	945.5	2483.0	1559.4	1086.0	2645.4	3.6050	1.7857	5.3907
340	14,601	0.001638	0.010783	1570.7	893.8	2464.5	1594.6	1027.4	2622.0	3.6602	1.6756	5.3358
345	15,541	0.001685	0.009772	1605.5	837.7	2443.2	1631.7	963.4	2595.1	3.7179	1.5585	5.2765
350	16,529	0.001741	0.008806	1642.4	775.9	2418.3	1671.2	892.7	2563.9	3.7788	1.4326	5.2114
355	17,570	0.001808	0.007872	1682.2	706.4	2388.6	1714.0	812.9	2526.9	3.8442	1.2942	5.1384
360	18,666	0.001895	0.006950	1726.2	625.7	2351.9	1761.5	720.1	2481.6	3.9165	1.1373	5.0537
365	19,822	0.002015	0.006009	1777.2	526.4	2303.6	1817.2	605.5	2422.7	4.0004	0.9489	4.9493
370	21,044	0.002217	0.004953	1844.5	385.6	2230.1	1891.2	443.1	2334.3	4.1119	0.6890	4.8009
373.95	22,064	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., P kPa	Sat. temp., T_{sat} °C	Specific volume m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy kJ/kg·K Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_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	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476	7.3545
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100	7.2841
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894	7.2231
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200	6.9917
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645	6.9650
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0	1.7274	5.2128	6.9402
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9	594.73	2140.4	2735.1	1.7526	5.1645	6.9171
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1	604.66	2133.4	2738.1	1.7765	5.1191	6.8955
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356	6.8561
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603	6.8207
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916	6.7886
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285	6.7593
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322
700	164.95	0.001108	0.27278	696.23	1875.6	2571.8	697.00	2065.8	2762.8	1.9918	4.7153	6.7071
750	167.75	0.001111	0.25552	708.40	1865.6	2574.0	709.24	2056.4	2765.7	2.0195	4.6642	6.6837

TABLE A–5

Saturated water—Pressure table (Continued)

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy kJ/kg·K Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3	2.0457	4.6160	6.6616
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	2.0705	4.5705	6.6409
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	2.0941	4.5273	6.6213
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	2.1166	4.4862	6.6027
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	2.1381	4.4470	6.5850
1100	184.06	0.001133	0.17745	779.78	1805.7	2585.5	781.03	1999.6	2780.7	2.1785	4.3735	6.5520
1200	187.96	0.001138	0.16326	796.96	1790.9	2587.8	798.33	1985.4	2783.8	2.2159	4.3058	6.5217
1300	191.60	0.001144	0.15119	813.10	1776.8	2589.9	814.59	1971.9	2786.5	2.2508	4.2428	6.4936
1400	195.04	0.001149	0.14078	828.35	1763.4	2591.8	829.96	1958.9	2788.9	2.2835	4.1840	6.4675
1500	198.29	0.001154	0.13171	842.82	1750.6	2593.4	844.55	1946.4	2791.0	2.3143	4.1287	6.4430
1750	205.72	0.001166	0.11344	876.12	1720.6	2596.7	878.16	1917.1	2795.2	2.3844	4.0033	6.3877
2000	212.38	0.001177	0.099587	906.12	1693.0	2599.1	908.47	1889.8	2798.3	2.4467	3.8923	6.3390
2250	218.41	0.001187	0.088717	933.54	1667.3	2600.9	936.21	1864.5	2800.5	2.5029	3.7926	6.2954
2500	223.95	0.001197	0.079952	958.87	1643.2	2602.1	961.87	1840.1	2801.9	2.5542	3.7016	6.2558
3000	233.85	0.001217	0.066667	1004.6	1598.5	2603.2	1008.3	1794.9	2803.2	2.6454	3.5402	6.1856
3500	242.56	0.001235	0.057061	1045.4	1557.6	2603.0	1049.7	1753.0	2802.7	2.7253	3.3991	6.1244
4000	250.35	0.001252	0.049779	1082.4	1519.3	2601.7	1087.4	1713.5	2800.8	2.7966	3.2731	6.0696
5000	263.94	0.001286	0.039448	1148.1	1448.9	2597.0	1154.5	1639.7	2794.2	2.9207	3.0530	5.9737
6000	275.59	0.001319	0.032449	1205.8	1384.1	2589.9	1213.8	1570.9	2784.6	3.0275	2.8627	5.8902
7000	285.83	0.001352	0.027378	1258.0	1323.0	2581.0	1267.5	1505.2	2772.6	3.1220	2.6927	5.8148
8000	295.01	0.001384	0.023525	1306.0	1264.5	2570.5	1317.1	1441.6	2758.7	3.2077	2.5373	5.7450
9000	303.35	0.001418	0.020489	1350.9	1207.6	2558.5	1363.7	1379.3	2742.9	3.2866	2.3925	5.6791
10,000	311.00	0.001452	0.018028	1393.3	1151.8	2545.2	1407.8	1317.6	2725.5	3.3603	2.2556	5.6159
11,000	318.08	0.001488	0.015988	1433.9	1096.6	2530.4	1450.2	1256.1	2706.3	3.4299	2.1245	5.5544
12,000	324.68	0.001526	0.014264	1473.0	1041.3	2514.3	1491.3	1194.1	2685.4	3.4964	1.9975	5.4939
13,000	330.85	0.001566	0.012781	1511.0	985.5	2496.6	1531.4	1131.3	2662.7	3.5606	1.8730	5.4336
14,000	336.67	0.001610	0.011487	1548.4	928.7	2477.1	1571.0	1067.0	2637.9	3.6232	1.7497	5.3728
15,000	342.16	0.001657	0.010341	1585.5	870.3	2455.7	1610.3	1000.5	2610.8	3.6848	1.6261	5.3108
16,000	347.36	0.001710	0.009312	1622.6	809.4	2432.0	1649.9	931.1	2581.0	3.7461	1.5005	5.2466
17,000	352.29	0.001770	0.008374	1660.2	745.1	2405.4	1690.3	857.4	2547.7	3.8082	1.3709	5.1791
18,000	356.99	0.001840	0.007504	1699.1	675.9	2375.0	1732.2	777.8	2510.0	3.8720	1.2343	5.1064
19,000	361.47	0.001926	0.006677	1740.3	598.9	2339.2	1776.8	689.2	2466.0	3.9396	1.0860	5.0256
20,000	365.75	0.002038	0.005862	1785.8	509.0	2294.8	1826.6	585.5	2412.1	4.0146	0.9164	4.9310
21,000	369.83	0.002207	0.004994	1841.6	391.9	2233.5	1888.0	450.4	2338.4	4.1071	0.7005	4.8076
22,000	373.71	0.002703	0.003644	1951.7	140.8	2092.4	2011.1	161.5	2172.6	4.2942	0.2496	4.5439
22,064	373.95	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

TABLE A-6

Superheated water

P = 0.01 MPa (45.81°C)*

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.†	14.670	2437.2	2583.9	8.1488
50	14.867	2443.3	2592.0	8.1741
100	17.196	2515.5	2687.5	8.4489
150	19.513	2587.9	2783.0	8.6893
200	21.826	2661.4	2879.6	8.9049
250	24.136	2736.1	2977.5	9.1015
300	26.446	2812.3	3076.7	9.2827
400	31.063	2969.3	3280.0	9.6094
500	35.680	3132.9	3489.7	9.8998
600	40.296	3303.3	3706.3	10.1631
700	44.911	3480.8	3929.9	10.4056
800	49.527	3665.4	4160.6	10.6312
900	54.143	3856.9	4398.3	10.8429
1000	58.758	4055.3	4642.8	11.0429
1100	63.373	4260.0	4893.8	11.2326
1200	67.989	4470.9	5150.8	11.4132
1300	72.604	4687.4	5413.4	11.5857

P = 0.05 MPa (81.32°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	3.2403	2483.2	2645.2	7.5931
100	3.4187	2511.5	2682.4	7.6953
150	3.8897	2585.7	2780.2	7.9413
200	4.3562	2660.0	2877.8	8.1592
250	4.8206	2735.1	2976.2	8.3568
300	5.2841	2811.6	3075.8	8.5387
400	6.2094	2968.9	3279.3	8.8659
500	7.1338	3132.6	3489.3	9.1566
600	8.0577	3303.1	3706.0	9.4201
700	8.9813	3480.6	3929.7	9.6626
800	9.9047	3665.2	4160.4	9.8883
900	10.8280	3856.8	4398.2	10.1000
1000	11.7513	4055.2	4642.7	10.3000
1100	12.6745	4259.9	4893.7	10.4897
1200	13.5977	4470.8	5150.7	10.6704
1300	14.5209	4687.3	5413.3	10.8429

P = 0.10 MPa (99.61°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	1.6941	2505.6	2675.0	7.3589
100	1.6959	2506.2	2675.8	7.3611
150	1.9367	2582.9	2776.6	7.6148
200	2.1724	2658.2	2875.5	7.8356
250	2.4062	2733.9	2974.5	8.0346
300	2.6389	2810.7	3074.5	8.2172
400	3.1027	2968.3	3278.6	8.5452
500	3.5655	3132.2	3488.7	8.8362
600	4.0279	3302.8	3705.6	9.0999
700	4.4900	3480.4	3929.4	9.3424
800	4.9519	3665.0	4160.2	9.5682
900	5.4137	3856.7	4398.0	9.7800
1000	5.8755	4055.0	4642.6	9.9800
1100	6.3372	4259.8	4893.6	10.1698
1200	6.7988	4470.7	5150.6	10.3504
1300	7.2605	4687.2	5413.3	10.5229

P = 0.20 MPa (120.21°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.88578	2529.1	2706.3	7.1270
150	0.95986	2577.1	2769.1	7.2810
200	1.08049	2654.6	2870.7	7.5081
250	1.19890	2731.4	2971.2	7.7100
300	1.31623	2808.8	3072.1	7.8941
400	1.54934	2967.2	3277.0	8.2236
500	1.78142	3131.4	3487.7	8.5153
600	2.01302	3302.2	3704.8	8.7793
700	2.24434	3479.9	3928.8	9.0221
800	2.47550	3664.7	4159.8	9.2479
900	2.70656	3856.3	4397.7	9.4598
1000	2.93755	4054.8	4642.3	9.6599
1100	3.16848	4259.6	4893.3	9.8497
1200	3.39938	4470.5	5150.4	10.0304
1300	3.63026	4687.1	5413.1	10.2029

P = 0.30 MPa (133.52°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.60582	2543.2	2724.9	6.9917
150	0.63402	2571.0	2761.2	7.0792
200	0.71643	2651.0	2865.9	7.3132
250	0.79645	2728.9	2967.9	7.5180
300	0.87535	2807.0	3069.6	7.7037
400	1.03155	2966.0	3275.5	8.0347
500	1.18672	3130.6	3486.6	8.3271
600	1.34139	3301.6	3704.0	8.5915
700	1.49580	3479.5	3928.2	8.8345
800	1.65004	3664.3	4159.3	9.0605
900	1.80417	3856.0	4397.3	9.2725
1000	1.95824	4054.5	4642.0	9.4726
1100	2.11226	4259.4	4893.1	9.6624
1200	2.26624	4470.3	5150.2	9.8431
1300	2.42019	4686.9	5413.0	10.0157

P = 0.40 MPa (143.61°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.46242	2553.1	2738.1	6.8955
150	0.47088	2564.4	2752.8	6.9306
200	0.53434	2647.2	2860.9	7.1723
250	0.59520	2726.4	2964.5	7.3804
300	0.65489	2805.1	3067.1	7.5677
400	0.77265	2964.9	3273.9	7.9003
500	0.88936	3129.8	3485.5	8.1933
600	1.00558	3301.0	3703.3	8.4580
700	1.12152	3479.0	3927.6	8.7012
800	1.23730	3663.9	4158.9	8.9274
900	1.35298	3855.7	4396.9	9.1394
1000	1.46859	4054.3	4641.7	9.3396
1100	1.58414	4259.2	4892.9	9.5295
1200	1.69966	4470.2	5150.0	9.7102
1300	1.81516	4686.7	5412.8	9.8828

P = 0.50 MPa (151.83°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.37483	2560.7	2748.1	6.8207
200	0.42503	2643.3	2855.8	7.0610
250	0.47443	2723.8	2961.0	7.2725
300	0.52261	2803.3	3064.6	7.4614
350	0.57015	2883.0	3168.1	7.6346
400	0.61731	2963.7	3272.4	7.7956
500	0.71095	3129.0	3484.5	8.0893
600	0.80409	3300.4	3702.5	8.3544
700	0.89696	3478.6	3927.0	8.5978
800	0.98966	3663.6	4158.4	8.8240
900	1.08227	3855.4	4396.6	9.0362
1000	1.17480	4054.0	4641.4	9.2364
1100	1.26728	4259.0	4892.6	9.4263
1200	1.35972	4470.0	5149.8	9.6071
1300	1.45214	4686.6	5412.6	9.7797

P = 0.60 MPa (158.83°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.31560	2566.8	2756.2	6.7593
200	0.35212	2639.4	2850.6	6.9683
250	0.39390	2721.2	2957.6	7.1833
300	0.43442	2801.4	3062.0	7.3740
350	0.47428	2881.6	3166.1	7.5481
400	0.51374	2962.5	3270.8	7.7097
500	0.59200	3128.2	3483.4	8.0041
600	0.66976	3299.8	3701.7	8.2695
700	0.74725	3478.1	3926.4	8.5132
800	0.82457	3663.2	4157.9	8.7395
900	0.90179	3855.1	4396.2	8.9518
1000	0.97893	4053.8	4641.1	9.1521
1100	1.05603	4258.8	4892.4	9.3420
1200	1.13309	4469.8	5149.6	9.5229
1300	1.21012	4686.4	5412.5	9.6955

P = 0.80 MPa (170.41°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.24035	2576.0	2768.3	6.6616
200	0.26088	2631.1	2839.8	6.8177
250	0.29321	2715.9	2950.4	7.0402
300	0.32416	2797.5	3056.9	7.2345
350	0.35442	2878.6	3162.2	7.4107
400	0.38429	2960.2	3267.7	7.5735
500	0.44332	3126.6	3481.3	7.8692
600	0.50186	3298.7	3700.1	8.1354
700	0.56011	3477.2	3925.3	8.3794
800	0.61803	3662.5	4157.0	8.6061
900	0.67619	3854.5	4395.5	8.8185
1000	0.73411	4053.3	4640.5	9.0189
1100	0.79197	4258.3	4891.9	9.2090
1200	0.84980	4469.4	5149.3	9.3898
1300	0.90761	4686.1	5412.2	9.5625

TABLE A-6

Superheated water (Continued)

P = 1.00 MPa (179.88°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.19437	2582.8	2777.1	6.5850
200	0.20602	2622.3	2828.3	6.6956
250	0.23275	2710.4	2943.1	6.9265
300	0.25799	2793.7	3051.6	7.1246
350	0.28250	2875.7	3158.2	7.3029
400	0.30661	2957.9	3264.5	7.4670
500	0.35411	3125.0	3479.1	7.7642
600	0.40111	3297.5	3698.6	8.0311
700	0.44783	3476.3	3924.1	8.2755
800	0.49438	3661.7	4156.1	8.5024
900	0.54083	3853.3	4394.8	8.7150
1000	0.58721	4052.2	4640.0	8.9155
1100	0.63354	4257.9	4891.4	9.1057
1200	0.67983	4469.0	5148.9	9.2866
1300	0.72610	4685.8	5411.9	9.4593

P = 1.20 MPa (187.96°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.16326	2587.8	2783.8	6.5217
200	0.16934	2612.9	2816.1	6.5909
250	0.19241	2704.7	2935.6	6.8313
300	0.21386	2789.7	3046.3	7.0335
350	0.23455	2872.7	3154.2	7.2139
400	0.25482	2955.5	3261.3	7.3793
500	0.29464	3123.4	3477.0	7.6779
600	0.33395	3296.3	3697.0	7.9456
700	0.37297	3475.3	3922.9	8.1904
800	0.41184	3661.0	4155.2	8.4176
900	0.45059	3853.3	4394.0	8.6303
1000	0.48928	4052.2	4639.4	8.8310
1100	0.52792	4257.5	4891.0	9.0212
1200	0.56652	4468.7	5148.5	9.2022
1300	0.60509	4685.5	5411.6	9.3750

P = 1.40 MPa (195.04°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.14078	2591.8	2788.9	6.4675
200	0.14303	2602.7	2803.0	6.4975
250	0.16356	2698.9	2927.9	6.7488
300	0.18233	2785.7	3040.9	6.9553
350	0.20029	2869.7	3150.1	7.1379
400	0.21782	2953.1	3258.1	7.3046
500	0.25216	3121.8	3474.8	7.6047
600	0.28597	3295.1	3695.5	7.8730
700	0.31951	3474.4	3921.7	8.1183
800	0.35288	3660.3	4154.3	8.3458
900	0.38614	3852.7	4393.3	8.5587
1000	0.41933	4051.2	4638.8	8.7595
1100	0.45247	4257.0	4890.5	8.9497
1200	0.48558	4468.3	5148.1	9.1308
1300	0.51866	4685.1	5411.3	9.3036

P = 1.60 MPa (201.37°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.12374	2594.8	2792.8	6.4200
225	0.13293	2645.1	2857.8	6.5537
250	0.14190	2692.9	2919.9	6.6753
300	0.15866	2781.6	3035.4	6.8864
350	0.17459	2866.6	3146.0	7.0713
400	0.19007	2950.8	3254.9	7.2394
500	0.22029	3120.1	3472.6	7.5410
600	0.24999	3293.9	3693.9	7.8101
700	0.27941	3473.5	3920.5	8.0558
800	0.30865	3659.5	4153.4	8.2834
900	0.33780	3852.1	4392.6	8.4965
1000	0.36687	4051.2	4638.2	8.6974
1100	0.39589	4256.6	4890.0	8.8878
1200	0.42488	4467.9	5147.7	9.0689
1300	0.45383	4684.8	5410.9	9.2418

P = 1.80 MPa (207.11°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.11037	2597.3	2795.9	6.3775
225	0.11678	2637.0	2847.2	6.4825
250	0.12502	2686.7	2911.7	6.6088
300	0.14025	2777.4	3029.9	6.8246
350	0.15460	2863.6	3141.9	7.0120
400	0.16849	2948.3	3251.6	7.1814
500	0.19551	3118.5	3470.4	7.4845
600	0.22200	3292.7	3692.3	7.7543
700	0.24822	3472.6	3919.4	8.0005
800	0.27426	3658.8	4152.4	8.2284
900	0.30020	3851.5	4391.9	8.4417
1000	0.32606	4050.7	4637.6	8.6427
1100	0.35188	4256.2	4889.6	8.8331
1200	0.37766	4467.6	5147.3	9.0143
1300	0.40341	4684.5	5410.6	9.1872

P = 2.00 MPa (212.38°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.09959	2599.1	2798.3	6.3390
225	0.10381	2628.5	2836.1	6.4160
250	0.11150	2680.3	2903.3	6.5475
300	0.12551	2773.2	3024.2	6.7684
350	0.13860	2860.5	3137.7	6.9583
400	0.15122	2945.9	3248.4	7.1292
500	0.17568	3116.9	3468.3	7.4337
600	0.19962	3291.5	3690.7	7.7043
700	0.22326	3471.7	3918.2	7.9509
800	0.24674	3658.0	4151.5	8.1791
900	0.27012	3850.9	4391.1	8.3925
1000	0.29342	4050.2	4637.1	8.5936
1100	0.31667	4255.7	4889.1	8.7842
1200	0.33989	4467.2	5147.0	8.9654
1300	0.36308	4684.2	5410.3	9.1384

P = 2.50 MPa (223.95°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.07995	2602.1	2801.9	6.2558
225	0.08026	2604.8	2805.5	6.2629
250	0.08705	2663.3	2880.9	6.4107
300	0.09894	2762.2	3009.6	6.6459
350	0.10979	2852.5	3127.0	6.8424
400	0.12012	2939.8	3240.1	7.0170
450	0.13015	3026.2	3351.6	7.1768
500	0.13999	3112.8	3462.8	7.3254
600	0.15931	3288.5	3686.8	7.5979
700	0.17835	3469.3	3915.2	7.8455
800	0.19722	3656.2	4149.2	8.0744
900	0.21597	3849.4	4389.3	8.2882
1000	0.23466	4049.0	4635.6	8.4897
1100	0.25330	4254.7	4887.9	8.6804
1200	0.27190	4466.3	5146.0	8.8618
1300	0.29048	4683.4	5409.5	9.0349

P = 3.00 MPa (233.85°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.06667	2603.2	2803.2	6.1856
250	0.07063	2644.7	2856.5	6.2893
300	0.08118	2750.8	2994.3	6.5412
350	0.09056	2844.4	3116.1	6.7450
400	0.09938	2933.6	3231.7	6.9235
450	0.10789	3021.2	3344.9	7.0856
500	0.11620	3108.6	3457.2	7.2359
600	0.13245	3285.5	3682.8	7.5103
700	0.14841	3467.0	3912.2	7.7590
800	0.16420	3654.3	4146.9	7.9885
900	0.17988	3847.9	4387.5	8.2028
1000	0.19549	4047.7	4634.2	8.4045
1100	0.21105	4254.2	4886.7	8.5955
1200	0.22658	4465.3	5145.1	8.7771
1300	0.24207	4682.6	5408.8	8.9502

P = 3.50 MPa (242.56°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
Sat.	0.05706	2603.0	2802.7	6.1244
250	0.05876	2624.0	2829.7	6.1764
300	0.06845	2738.8	2978.4	6.4484
350	0.07680	2836.0	3104.9	6.6601
400	0.08456	2927.2	3223.2	6.8428
450	0.09198	3016.1	3338.1	7.0074
500	0.09919	3104.5	3451.7	7.1593
600	0.11325	3282.5	3678.9	7.4357
700	0.12702	3464.7	3909.3	7.6855
800	0.14061	3652.5	4144.6	7.9156
900	0.15410	3846.4	4385.7	8.1304
1000	0.16751	4046.4	4632.7	8.3324
1100	0.18087	4252.5	4885.6	8.5236
1200	0.19420	4464.4	5144.1	8.7053
1300	0.20750	4681.8	5408.0	8.8786