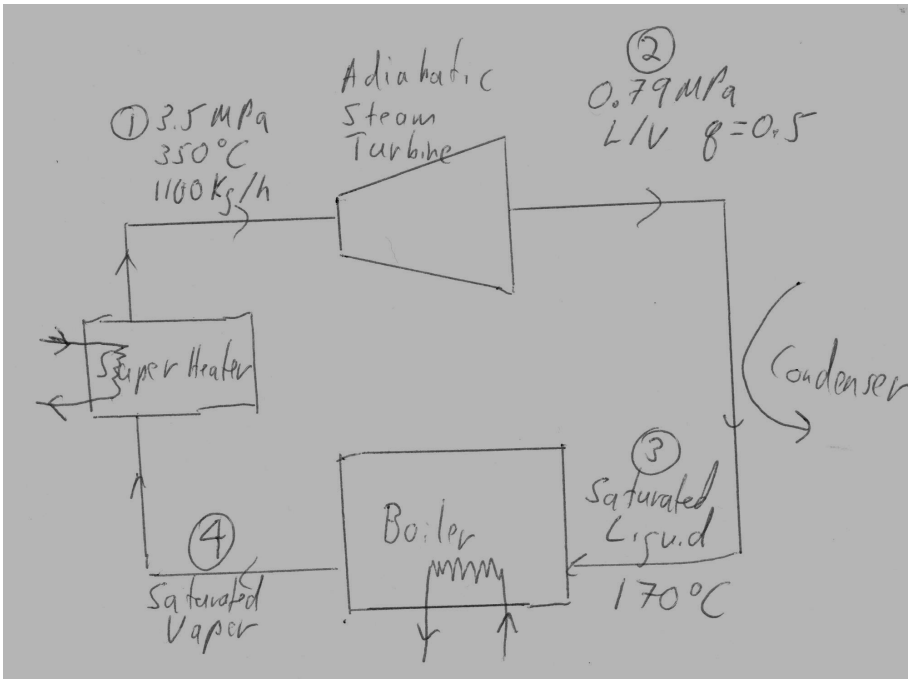
Chemical Engineering Thermodynamics
Quiz 1
January 17, 2019

Consider a simplified steam turbine/condenser/boiler/superheater for production of electricity shown in the schematic below. Fill in the table below the diagram to answer the questions using the steam table attached.

a) Use the steam tables to determine the shaft work, W_s, for the turbine **in kW** (which is kJ/s). Under and adiabatic assumption (no heat loss) the shaft work equals the difference in enthalpy, H, between the exiting and entering streams at 100% efficiency. (The flow rate is 1100 kg/h for all streams.)
b) Calculate the combined heat needed for the boiler and superheater (boiler converts from liquid to vapor and superheater further heats the steam) **in kW** (which is kJ/s). (This is the enthalpy (H) difference between the streams.)
c) Take the ratio of the shaft work recovered from the steam turbine to the heat needed for the boiler to get an idea of how efficient this system is at 100% efficiency.
d) On the log-log P vs V plot below approximately show the points 1, 2 and 3. Do the same for the P vs $\log_{10}V$ plot from the book (the scale isn't optimal for this). *Note that on a log V x-axis the lever rule doesn't work.*
e) If PV is a measure of energy or work what do you think is the meaning of the area under the line connecting points 1 and 2 and the area under the line connecting points 3 and 1 on the P vs V plot. Why do the two areas seem to be different?

Water Molecular Weight 18.0 g/mol
1 m^3 = 10^6 cm^3
Watt = J/s



T (°C)	P (MPa)	V^L m³/kg	V^V m³/kg	U^L kJ/kg	ΔU^{vap} kJ/kg	U^V kJ/kg	H^L kJ/kg	ΔH^{vap} kJ/kg	H^V kJ/kg	S^L kJ/kg-K	ΔS^{vap} kJ/kg-K	S^V kJ/kg-K
6.97	0.001	0.001000	129.1780	29.30	2355.19	2384.49	29.30	2484.37	2513.67	0.1059	8.8690	8.9749
17.50	0.002	0.001001	66.9869	73.43	2325.47	2398.90	73.43	2459.45	2532.88	0.2606	8.4620	8.7226
24.08	0.003	0.001003	45.6532	100.98	2306.90	2407.88	100.98	2443.86	2544.84	0.3543	8.2221	8.5764
28.96	0.004	0.001004	34.7911	121.38	2293.12	2414.50	121.39	2432.28	2553.67	0.4224	8.0510	8.4734
32.87	0.005	0.001005	28.1853	137.74	2282.06	2419.80	137.75	2422.98	2560.73	0.4762	7.9176	8.3938
36.16	0.006	0.001006	23.7334	151.47	2272.76	2424.23	151.48	2415.15	2566.63	0.5208	7.8082	8.3290
39.00	0.007	0.001008	20.5245	163.34	2264.71	2428.05	163.35	2408.37	2571.72	0.5590	7.7155	8.2745
41.51	0.008	0.001008	18.0989	173.83	2257.58	2431.41	173.84	2402.37	2576.21	0.5925	7.6348	8.2273
43.76	0.009	0.001009	16.1992	183.24	2251.19	2434.43	183.25	2396.97	2580.22	0.6223	7.5635	8.1858
45.81	0.01	0.001010	14.6701	191.80	2245.36	2437.16	191.81	2392.05	2583.86	0.6492	7.4996	8.1488
60.06	0.02	0.001017	7.6480	251.40	2204.58	2455.98	251.42	2357.52	2608.94	0.8320	7.0752	7.9072
69.10	0.03	0.001022	5.2284	289.24	2178.46	2467.70	289.27	2335.28	2624.55	0.9441	6.8234	7.7675
75.86	0.04	0.001026	3.9930	317.58	2158.75	2476.33	317.62	2318.43	2636.05	1.0261	6.6429	7.6690
81.32	0.05	0.001030	3.2400	340.49	2142.72	2483.21	340.54	2304.68	2645.22	1.0912	6.5018	7.5930
85.93	0.06	0.001033	2.7317	359.85	2129.10	2488.95	359.91	2292.95	2652.86	1.1455	6.3856	7.5311
89.93	0.07	0.001036	2.3648	376.68	2117.20	2493.88	376.75	2282.67	2659.42	1.1921	6.2869	7.4790
93.49	0.08	0.001039	2.0871	391.63	2106.58	2498.21	391.71	2273.47	2665.18	1.2330	6.2009	7.4339
96.69	0.09	0.001041	1.8694	405.10	2096.97	2502.07	405.20	2265.11	2670.31	1.2696	6.1247	7.3943
99.61	0.1	0.001043	1.6939	417.40	2088.15	2505.55	417.50	2257.45	2674.95	1.3028	6.0561	7.3589
120.21	0.2	0.001061	0.8857	504.49	2024.60	2529.09	504.70	2201.53	2706.23	1.5302	5.5967	7.1269
133.52	0.3	0.001073	0.6058	561.11	1982.04	2543.15	561.43	2163.45	2724.88	1.6717	5.3199	6.9916
143.61	0.4	0.001084	0.4624	604.22	1948.88	2553.10	604.66	2133.39	2738.05	1.7765	5.1190	6.8955
151.83	0.5	0.001093	0.3748	639.54	1921.17	2560.71	640.09	2108.02	2748.11	1.8604	4.9603	6.8207
158.83	0.6	0.001101	0.3156	669.72	1897.07	2566.79	670.38	2085.76	2756.14	1.9308	4.8285	6.7593
164.95	0.7	0.001108	0.2728	696.23	1875.58	2571.81	697.00	2065.75	2762.75	1.9918	4.7153	6.7071
170.41	0.8	0.001115	0.2403	719.97	1856.06	2576.03	720.86	2047.44	2768.30	2.0457	4.6159	6.6616
175.35	0.9	0.001121	0.2149	741.55	1838.09	2579.64	742.56	2030.47	2773.03	2.0941	4.5272	6.6213
179.88	1	0.001127	0.1944	761.39	1821.36	2582.75	762.52	2014.59	2777.11	2.1381	4.4469	6.5850
187.96	1.2	0.001139	0.1633	796.96	1790.87	2587.83	798.33	1985.41	2783.74	2.2159	4.3058	6.5217
195.04	1.4	0.001149	0.1408	828.36	1763.40	2591.76	829.97	1958.88	2788.85	2.2835	4.1840	6.4675
201.37	1.6	0.001159	0.1237	856.60	1738.23	2594.83	858.46	1934.36	2792.82	2.3435	4.0764	6.4199
207.11	1.8	0.001168	0.1104	882.37	1714.87	2597.24	884.47	1911.44	2795.91	2.3975	3.9800	6.3775
212.38	2	0.001177	0.0996	906.15	1692.97	2599.12	908.50	1889.79	2798.29	2.4468	3.8922	6.3390
223.95	2.5	0.001197	0.0799	958.91	1643.15	2602.06	961.91	1840.02	2801.93	2.5543	3.7015	6.2558
233.85	3	0.001217	0.0667	1004.69	1598.47	2603.16	1008.34	1794.81	2803.15	2.6456	3.5400	6.1856
242.56	3.5	0.001235	0.0571	1045.47	1557.47	2602.94	1049.80	1752.84	2802.64	2.7254	3.3989	6.1243

P = 0.20MPa (120.3)

T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
120.3	0.8857	2529.1	2706.2	7.1269
150	0.9599	2577.1	2769.1	7.2810
200	1.0805	2654.6	2870.7	7.5081
250	1.1989	2731.4	2971.2	7.7100
300	1.3162	2808.8	3072.1	7.8941
350	1.4330	2887.3	3173.9	8.0644
400	1.5493	2967.1	3277.0	8.2236
450	1.6655	3048.5	3381.6	8.3734
500	1.7814	3131.4	3487.7	8.5152
550	1.8973	3215.9	3595.4	8.6502
600	2.0130	3302.2	3704.8	8.7792
650	2.1287	3390.2	3815.9	8.9030
700	2.2443	3479.9	3928.8	9.0220
750	2.3599	3571.4	4043.4	9.1369
800	2.4755	3664.7	4159.8	9.2479
850	2.5910	3759.6	4277.8	9.3555
900	2.7066	3856.3	4397.6	9.4598
950	2.8221	3954.7	4519.1	9.5612
1000	2.9375	4054.8	4642.3	9.6599
1050	3.0530	4156.4	4767.0	9.7560
1100	3.1685	4259.6	4893.3	9.8497
1150	3.2839	4364.3	5021.1	9.9411
1200	3.3994	4470.5	5150.4	10.0304
1250	3.5148	4578.1	5281.1	10.1176
1300	3.6302	4687.0	5413.1	10.2029

P = 0.30MPa (133.5)

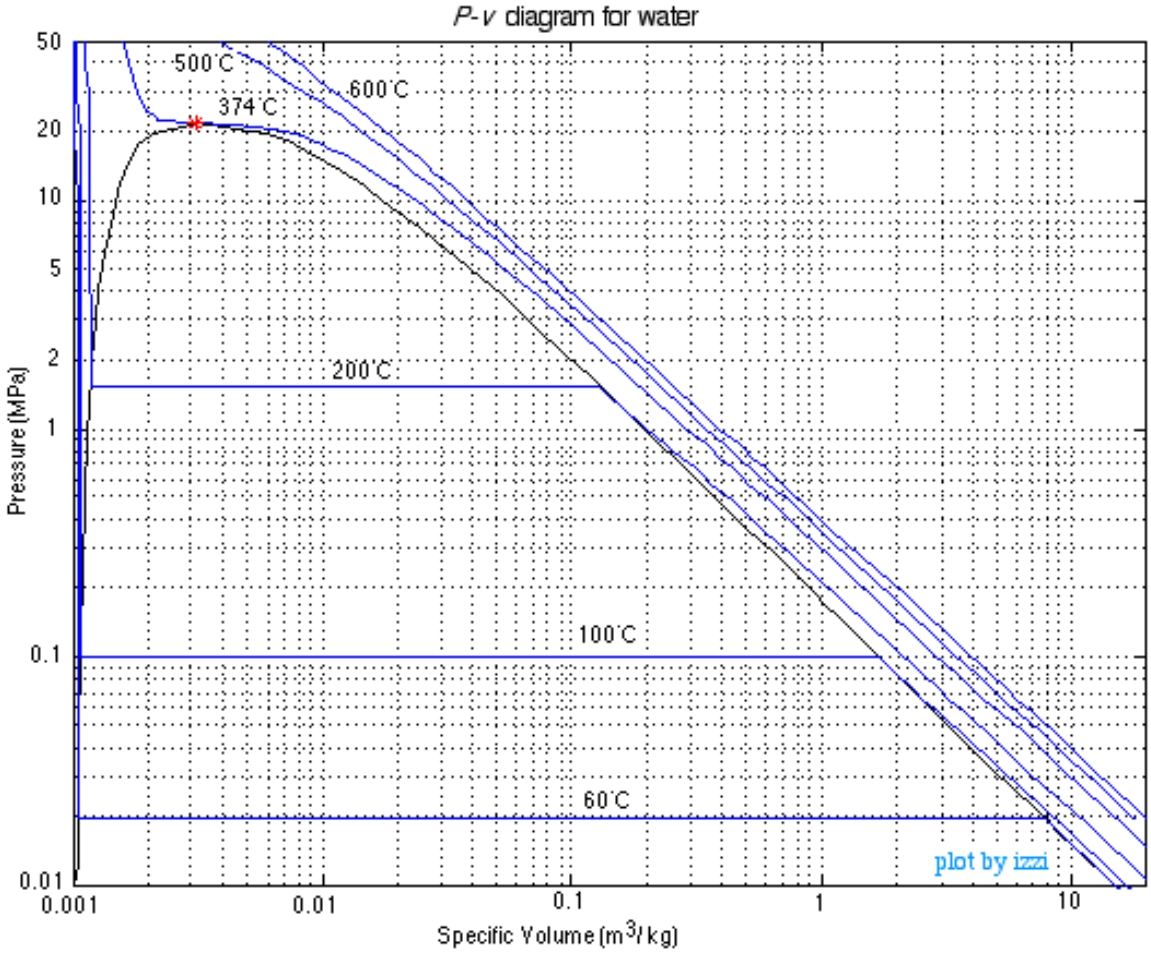
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
133.5	0.6058	2543.2	2724.9	6.9916
150	0.6340	2571.0	2761.2	7.0791
200	0.7164	2651.0	2865.9	7.3131
250	0.7964	2728.9	2967.9	7.5180
300	0.8753	2807.0	3069.6	7.7037
350	0.9536	2885.9	3172.0	7.8750
400	1.0315	2966.0	3275.5	8.0347
450	1.1092	3047.5	3380.3	8.1849
500	1.1867	3130.6	3486.6	8.3271
550	1.2641	3215.3	3594.5	8.4623
600	1.3414	3301.6	3704.0	8.5914
650	1.4186	3389.7	3815.3	8.7153
700	1.4958	3479.5	3928.2	8.8344
750	1.5729	3571.0	4042.9	8.9494
800	1.6500	3664.3	4159.3	9.0604
850	1.7271	3759.3	4277.4	9.1680
900	1.8042	3856.0	4397.3	9.2724
950	1.8812	3954.4	4518.8	9.3739
1000	1.9582	4054.5	4642.0	9.4726
1050	2.0352	4156.2	4766.7	9.5687
1100	2.1122	4259.4	4893.1	9.6624
1150	2.1892	4364.1	5020.9	9.7538
1200	2.2662	4470.3	5150.2	9.8431
1250	2.3432	4577.9	5280.9	9.9303
1300	2.4202	4686.9	5412.9	10.0156

P = 0.40MPa (143.6)

T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
143.6	0.4624	2553.1	2738.1	6.8955
150	0.4709	2564.4	2752.8	6.9306
200	0.5343	2647.2	2860.9	7.1723
250	0.5952	2726.4	2964.5	7.3804
300	0.6549	2805.1	3067.1	7.5677
350	0.7140	2884.4	3170.0	7.7399
400	0.7726	2964.9	3273.9	7.9002
450	0.8311	3046.6	3379.0	8.0508
500	0.8894	3129.8	3485.5	8.1933
550	0.9475	3214.6	3593.6	8.3287
600	1.0056	3301.0	3703.2	8.4580
650	1.0636	3389.1	3814.6	8.5820
700	1.1215	3479.0	3927.6	8.7012
750	1.1794	3570.6	4042.4	8.8162
800	1.2373	3663.9	4158.8	8.9273
850	1.2951	3759.0	4277.0	9.0350
900	1.3530	3855.7	4396.9	9.1394
950	1.4108	3954.2	4518.5	9.2409
1000	1.4686	4054.3	4641.7	9.3396
1050	1.5264	4155.9	4766.5	9.4357
1100	1.5841	4259.2	4892.8	9.5295
1150	1.6419	4363.9	5020.7	9.6209
1200	1.6997	4470.1	5150.0	9.7102
1250	1.7574	4577.8	5280.7	9.7975
1300	1.8152	4686.7	5412.8	9.8828

Turn this sheet in with your answer

Stream	*P* (Mpa)	*T* (°C)	State	*q*	*H* (kJ/kg)	*H* L (kJ/kg)	*H* V (kJ/kg)	*V* (m3/kg)	*V* L (cm3/kg)	*V* V (cm3/kg)	V (cm3/mol)	log10 *V*
1	3.5	350	superheated steam									
2	0.79		V/L	0.5								
3		170	Sat. Liq.	0								
4												



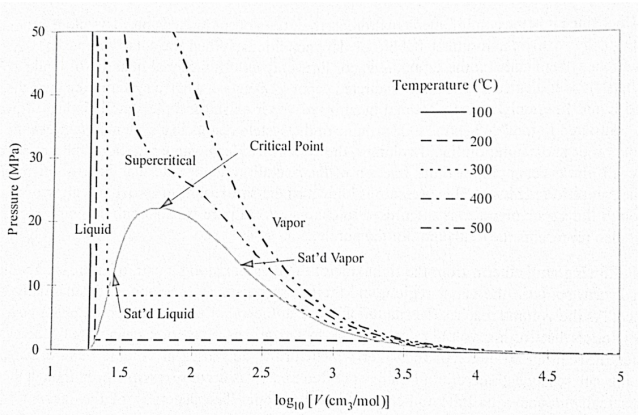


Figure 1.4 *P-V-T behavior of water at the same temperatures used in Fig. 1.3. The plot is prepared from the steam tables in Appendix E.*

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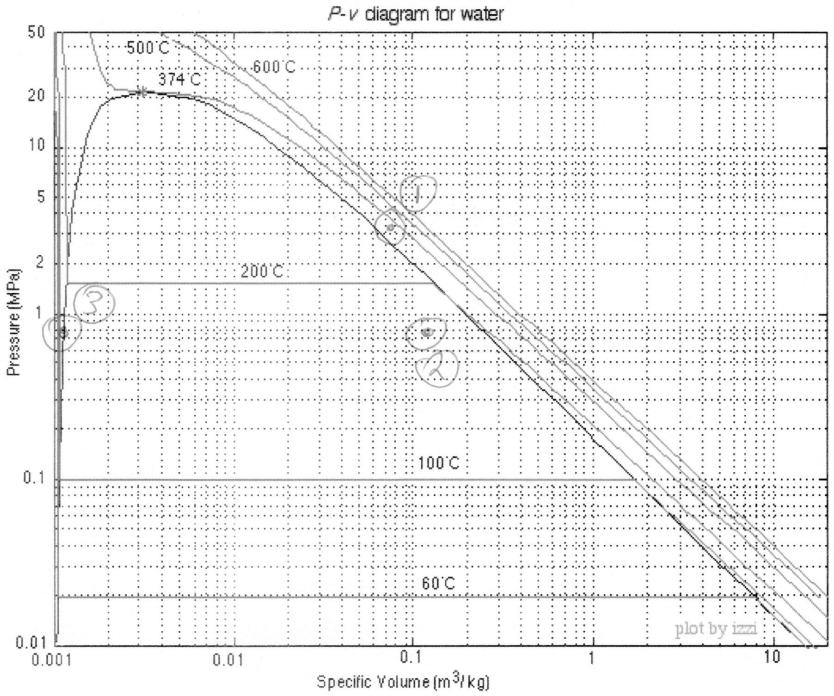
Stream	P (Mpa)	T (°C)	State	q	H (kj/kg)	H L (kj/kg)	H V (kj/kg)	V (m3/kg)	V L (cm3/kg)	V V (cm3/kg)	V (cm3/mol)	log10 V
1	3.5	350	superheated steam		3170			0.0769			1390	3.14
2	0.79	170	V/L	0.5	1390	721	2050	0.120	0.00112	0.240	2200	3.38
3	0.8	170	Sat. Liq.	0	721	721		0.00112	0.00112		20.2	1.30
4												



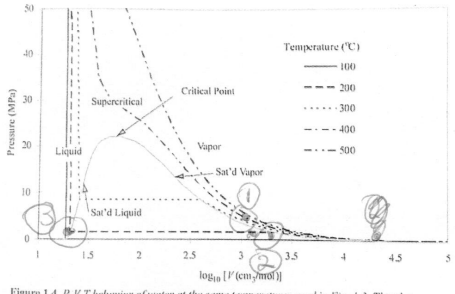


Figure 1.4 *P-V-T behavior of water at the same temperatures used in Fig. 1.3. The plot is prepared from the steam tables in Appendix E.*

a) Find H1-H2

W_s = (3170-1390)kJ/kg (1100 kg/h) (1/(3600 s/h)) = 545 kW

b) Find H1-H3

Q = (3170-721)kJ/kg (1100 kg/h) (1/(3600 s/h)) = 748 kW

c) 545 kW/748 kW = 0.729 or 72.9% efficiency.

d) See plot

e) The area under 1-2 is the work from the turbine, the area under 3-1 is the heat for the boiler. This is approximate since the connecting curve is not a line. The two areas disproportionate since this is plotted on a log-log scale.