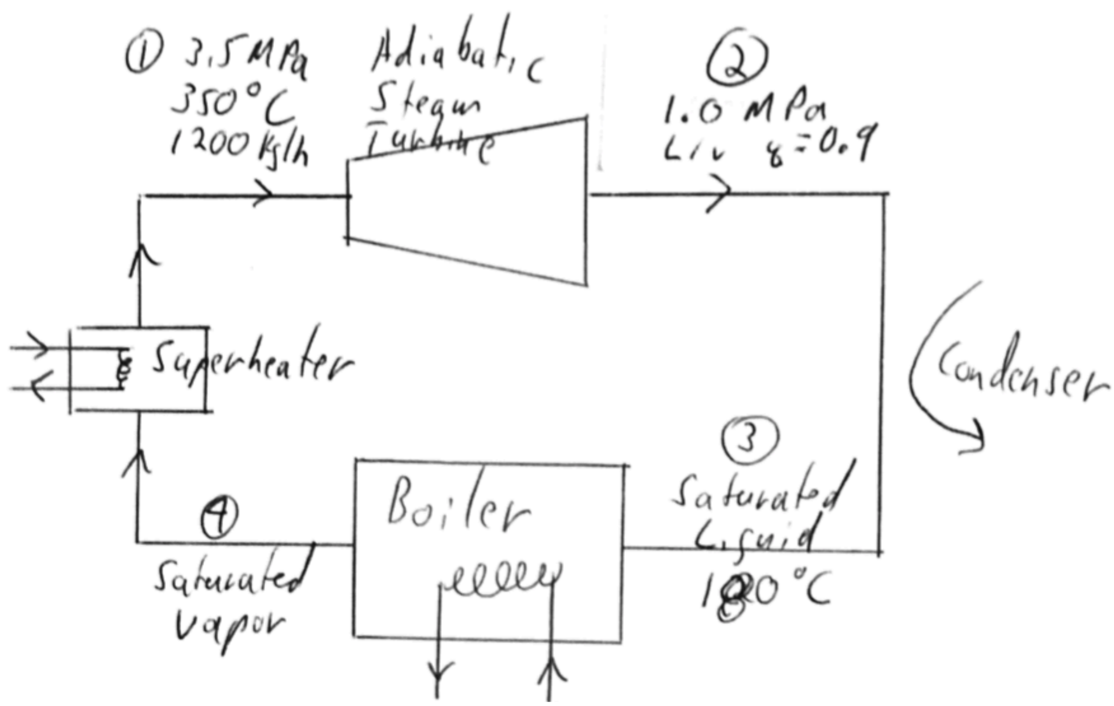
Chemical Engineering Thermodynamics
Quiz 1
January 16, 2020

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

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 1200 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 with a turbine at 100% efficiency. Why is this efficiency less than 100%?
d) The maximum possible efficiency for a heat engine can be shown to be $(T_H - T_C)/T_H$. Compare this best possible efficiency to your efficiency. (Carefully choose the units of temperature.)
e) On the log-log P vs V plot, below, approximately show the points 1, 2 and 3. Explain why the lever rule will not work on this plot.

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



T (°C)	P (MPa)	V^L m^3/kg	V^V m^3/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 = 2.50MPa (224.0)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
224.0	0.0799	2602.1	2801.9	6.2558
250	0.0871	2663.3	2880.9	6.4107
300	0.0989	2762.2	3009.6	6.6459
350	0.1098	2852.5	3127.0	6.8424
400	0.1201	2939.8	3240.1	7.0170
450	0.1302	3026.2	3351.6	7.1767
500	0.1400	3112.8	3462.7	7.3254
550	0.1497	3200.1	3574.3	7.4653
600	0.1593	3288.5	3686.8	7.5979
650	0.1689	3378.2	3800.4	7.7243
700	0.1783	3469.3	3915.2	7.8455
750	0.1878	3562.0	4031.5	7.9620
800	0.1972	3656.2	4149.2	8.0743
850	0.2066	3752.0	4268.5	8.1830
900	0.2160	3849.4	4389.3	8.2882
950	0.2253	3948.4	4511.7	8.3904
1000	0.2347	4048.9	4635.6	8.4896
1050	0.2440	4151.0	4761.0	8.5863
1100	0.2533	4254.7	4887.9	8.6804
1150	0.2626	4359.7	5016.2	8.7722
1200	0.2719	4466.2	5146.0	8.8618
1250	0.2812	4574.1	5277.1	8.9493
1300	0.2905	4683.3	5409.5	9.0349

P = 3.00MPa (233.9)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
233.9	0.0667	2603.2	2803.2	6.1856
250	0.0706	2644.7	2856.5	6.2893
300	0.0812	2750.8	2994.3	6.5412
350	0.0906	2844.4	3116.1	6.7449
400	0.0994	2933.5	3231.7	6.9234
450	0.1079	3021.2	3344.8	7.0856
500	0.1162	3108.6	3457.2	7.2359
550	0.1244	3196.6	3569.7	7.3768
600	0.1324	3285.5	3682.8	7.5103
650	0.1405	3375.6	3796.9	7.6373
700	0.1484	3467.0	3912.2	7.7590
750	0.1563	3559.9	4028.9	7.8758
800	0.1642	3654.3	4146.9	7.9885
850	0.1720	3750.3	4266.5	8.0973
900	0.1799	3847.9	4387.5	8.2028
950	0.1877	3947.0	4510.1	8.3051
1000	0.1955	4047.7	4634.1	8.4045
1050	0.2033	4149.9	4759.7	8.5012
1100	0.2111	4253.6	4886.7	8.5955
1150	0.2188	4358.7	5015.2	8.6874
1200	0.2266	4465.3	5145.0	8.7770
1250	0.2343	4573.3	5276.2	8.8646
1300	0.2421	4682.5	5408.8	8.9502

P = 3.50MPa (242.6)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
242.6	0.0571	2602.9	2802.6	6.1243
250	0.0588	2624.0	2829.7	6.1764
300	0.0685	2738.8	2978.4	6.4484
350	0.0768	2836.0	3104.8	6.6601
400	0.0846	2927.2	3223.2	6.8427
450	0.0920	3016.1	3338.0	7.0074
500	0.0992	3104.5	3451.6	7.1593
550	0.1063	3193.1	3565.0	7.3014
600	0.1133	3282.5	3678.9	7.4356
650	0.1202	3372.9	3793.5	7.5633
700	0.1270	3464.7	3909.3	7.6854
750	0.1338	3557.8	4026.3	7.8027
800	0.1406	3652.5	4144.6	7.9156
850	0.1474	3748.6	4264.4	8.0247
900	0.1541	3846.4	4385.7	8.1303
950	0.1608	3945.6	4508.4	8.2328
1000	0.1675	4046.4	4632.7	8.3324
1050	0.1742	4148.7	4758.4	8.4292
1100	0.1809	4252.5	4885.6	8.5235
1150	0.1875	4357.7	5014.1	8.6155
1200	0.1942	4464.4	5144.1	8.7053
1250	0.2009	4572.4	5275.4	8.7929
1300	0.2075	4681.7	5408.0	8.8785

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 (m3/kg)	V V (m3/kg)
1	3.5	350	superheated steam							
2	1		V/L	0.9						
3		180	Sat. Liq.	0						
4										

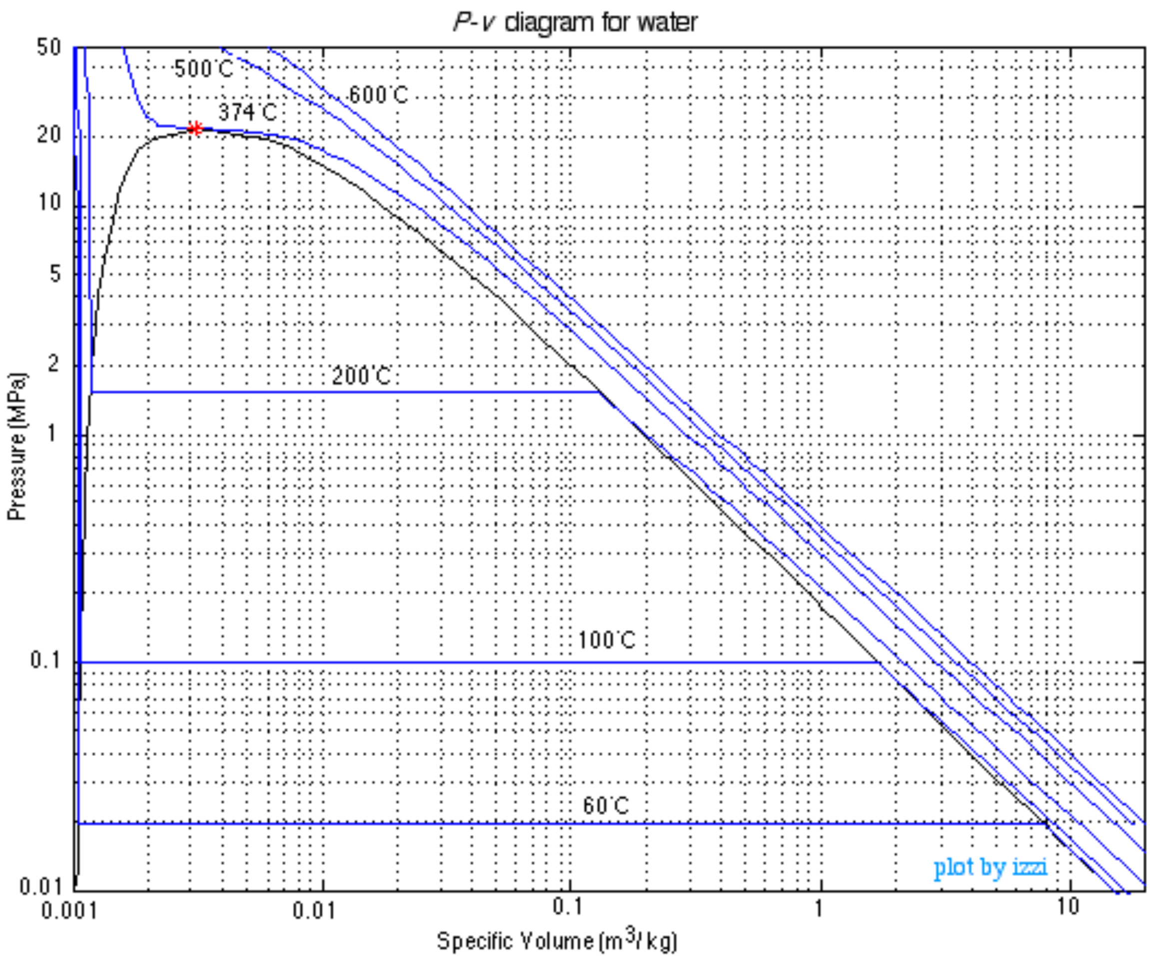
a) Shaft Work =

b) Combined Heat =

c) Efficiency = (Give comments/calculations on separate sheet)

d) Ideal Efficiency = (Give comments/calculations on separate sheet)

e)



ANSWERS: **Chemical Engineering Thermodynamics**
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<u>Turn this sheet in with your answer</u>

Stream	P (Mpa)	T (°C)	State	q	H (kJ/kg)	HL (kJ/kg)	HV (kJ/kg)	V (m3/kg)	VL (m3/kg)	VV (m3/kg)
1	3.5	350	superheated steam		3100			0.077		
2	1	180	V/L	0.9	2580	763	2780	0.175	0.00113	0.194
3	1	180	Sat. Liq.	0	763	763		0.00113	0.00113	
4										

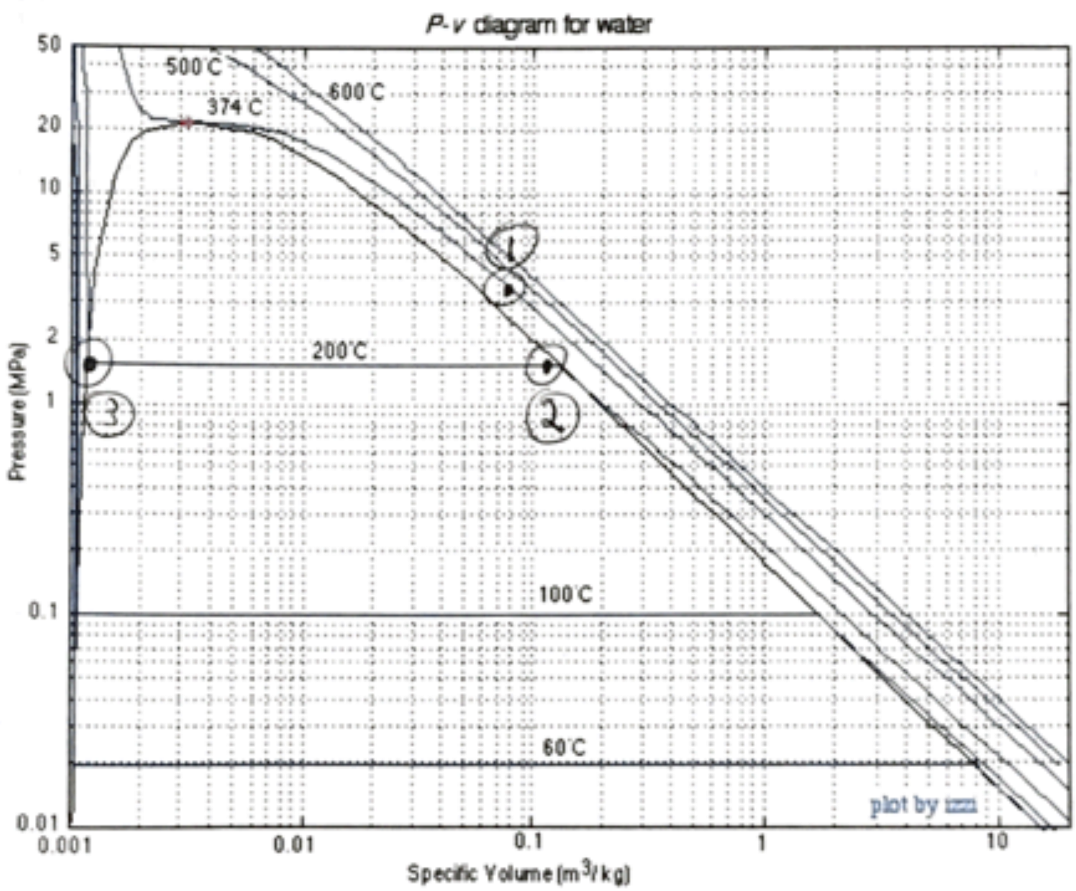
a) Shaft Work = -173 kW

b) Combined Heat = 779 kW

c) Efficiency = 0.222 (Give comments/calculations on separate sheet)

d) Ideal Efficiency = 0.273 (Give comments/calculations on separate sheet)

e)



a) Find H_2-H_1
W_s = (2580-3100)kJ/kg (1200 kg/h) (1/(3600 s/h)) = -173 kW

b) Find H1-H3
Q = (3100-763)kJ/kg (1200 kg/h) (1/(3600 s/h)) = 779 kW

c) η = 173 kW/779 kW = 0.222 or 22.2% efficiency.
There is loss at the condenser. Also, there is a maximum efficiency associated with the necessary production of entropy limiting the process to about 27% efficiency, see part d.

d) $\eta_{Carnot} = (T_H - T_C)/T_H$ = (350°C-180°C)/(350°C + 273°C) = 0.273
The Carnot efficiency is higher than the observed efficiency since this is a real process.

e) The lever rule won't work on a log-scale.