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Department of Mechanical Engineering

MCG 2131 Thermodynamics II — **Instructor: Nabel Sadek**
Final Exam — **Time Allowed: 3 Hours**
Date: July 31/2018 — **Closed Book Exam.**
Non-Programmable Calculators Allowed

NOTE: Every student is allowed to use a one page, size A4, double sided formula sheet. The formula sheet has to be submitted with the answer booklet. Students should write their name on the formula sheet.

1. **Concept questions, Use brief description only to answer them. (2 marks for each part).**
   (a) Humid air A has the same moisture content as humid air B ($\omega_A=\omega_B$) but the dry-bulb temperature of B is higher than that of A. What would you say about the relative humidity and dew point temperature of A compared to those of B (higher, lower, or the same).
   (b) What is the importance of identifying the dew point temperature of the combustion products?
   (c) State three reasons that make the air-standard refrigeration cycle more suitable than vapor compression cycles for airplane cooling applications.
   (d) Explain why is the typical compression ratio of the compression-ignition engine much higher than that of the spark-ignition engine. What is the limiting factor in each case?
   (e) State two advantages of the open feed water heaters.

2. A gas turbine plant consists of one turbine for compressor drive and another for output power. Both turbines are served by one compressor and one combustion chamber (burner) as shown in figure 1. Air enters the compressor at 100 kPa and 15°C and is compressed with isentropic efficiency of 0.76. Gas inlet temperature and pressure in both turbines are 680°C and 500 kPa, respectively. Gas expands to 100 kPa in both turbines. The isentropic efficiency of each turbine is 0.86. Assuming c_p=1.005 kJ/kg.K and k=1.4 for air and c_p=1.128 kJ/kg.K and k=1.34 for gases,
   (a) Find T_2 and T_4 **3 marks**
   (b) For each kg of compressed air entering the burner, mf kg of fuel is added. The heat added in the combustion process 2-3 is 42000 kJ/kg of fuel. Use the energy balance over the combustion chamber to find mf and the air to fuel ratio. **4 marks**
   (c) Find the fraction of flue gases that passes through the turbine driving the compressor, (shown as x in figure 1). **4 marks**

(d) If the mass flow rate of air through the compressor is 23 kg/s, find the power output of the plant (shown as $\dot{w}_{net}$ in figure 1). **4 marks**

(e) State all your assumptions **1 mark**

3. A steam power plant equipped with regenerative as well as reheat arrangement, as shown in figure 2, is supplied with steam to the H.P. turbine at 80 bar 470°C. For open feed water heating, a part of steam is extracted at 7 bar and the remainder of the steam is reheated to 350°C in a reheater and then expanded in L.P. turbine down to 0.03 bar.

(a) Draw a T-S diagram of the cycle assuming isentropic processes throughout. **2 marks**

(b) Find h_1, h_2, h_3, h_4, and h_5, using steam tables. **3 marks**

(c) If the isentropic efficiency of the pump is 0.8, find the specific work of each pump. **3 marks**

(d) Find the amount of steam bled-off for feed water heating (m) per kilogram of steam flow such that saturated liquid comes out of the regenerator. Assume adiabatic mixing in the regenerator. **3 marks**

(e) Find the cycle efficiency. **2 marks**

4. Saturated air at 3ºC is required to be supplied to a room at 22ºC with a relative humidity of 55%. The air is heated and then water at 10ºC is adiabatically sprayed to give the required humidity. Neglect the fan power. Assume that the total pressure is constant at 1.0132 bar and for dry air consider c_p=1.005 kJ/kg.K. Determine :

(a) The mass of spray water required per kg of dry air. **3 marks**

(b) The mass of spray water required per m^3 of dry air. **2 marks**

(c) The temperature to which the air must be heated. **3 marks**

5. A four-cylinder petrol engine has a bore of 57 mm and a stroke of 90 mm. Its rated speed is 2800 rpm and it is tested at this speed against a brake which has a torque arm of 0.356 m. the net brake load is 155 N and the fuel consumption is 6.74 l/hr. the specific gravity of the fuel used is 0.735 and its lower heat value is 44200 kJ/kg. The mechanical efficiency at this speed is measured to be 82.3%. Calculate for this speed:

(a) The brake mean effective pressure, **2 marks**

(b) The brake thermal efficiency, **2 marks**

(c) The brake specific fuel consumption in kg/kWh, **2 marks**

(d) The indicated mean effective pressure, **2 marks**

(e) If the engine is idling at this speed (brake load is removed), what would be its mechanical efficiency? **1 mark**

(f) The analysis of dry exhaust from this engine is as follows:

Carbon dioxide (CO_2) = 15 per cent Carbon monoxide (CO) = 3 per cent

Methane (CH_4) = 3 per cent, Hydrogen (H_2) = 1 per cent

Oxygen (O_2) = 2 per cent Nitrogen (N_2) = 76 per cent

The molecular weight in kg/kmol is C=12, H=1, N=14, O=16

Calculate the proportions by mass of carbon to hydrogen in the fuel, assuming it to be a pure hydrocarbon. **4 marks**

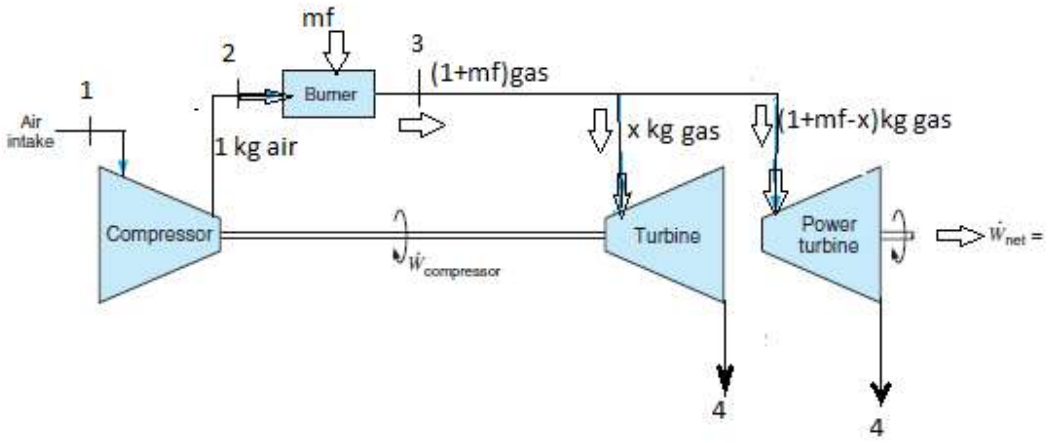

Fig.1

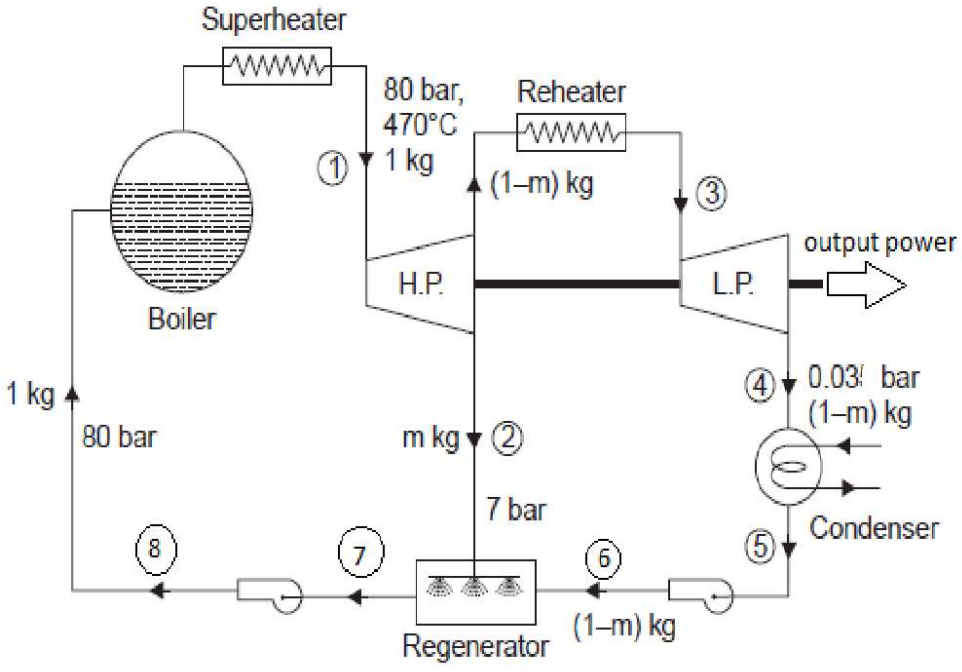

Fig.2

Saturated Water Pressure Entry

		Specific Volume, m^3/kg			Internal Energy, kJ/kg		
Press. (kPa)	**Temp. (°C)**	**Sat. Liquid v_f**	**Evap. v_{fg}**	**Sat. Vapor v_g**	**Sat. Liquid u_f**	**Evap. u_{fg}**	**Sat. Vapor u_g**
0.6113	0.01	0.001000	206.131	206.132	0	2375.3	2375.3
1	6.98	0.001000	129.20702	129.20802	29.29	2355.69	2384.98
1.5	13.03	0.001001	87.97913	87.98013	54.70	2338.63	2393.32
2	17.50	0.001001	67.00285	67.00385	73.47	2326.02	2399.48
2.5	21.08	0.001002	54.25285	54.25385	88.47	2315.93	2404.40
3	24.08	0.001003	45.66402	45.66502	101.03	2307.48	2408.51
4	28.96	0.001004	34.79915	34.80015	121.44	2293.73	2415.17
5	32.88	0.001005	28.19150	28.19251	137.79	2282.70	2420.49
7.5	40.29	0.001008	19.23674	19.23775	168.76	2261.74	2430.50
10	45.81	0.001010	14.67254	14.67355	191.79	2246.10	2437.89
15	53.97	0.001014	10.02117	10.02218	225.90	2222.83	2448.73
20	60.06	0.001017	7.64835	7.64937	251.35	2205.36	2456.71
25	64.97	0.001020	6.20322	6.20424	271.88	2191.21	2463.08
30	69.10	0.001022	5.22816	5.22918	289.18	2179.22	2468.40
40	75.87	0.001026	3.99243	3.99345	317.51	2159.49	2477.00
50	81.33	0.001030	3.23931	3.24034	340.42	2143.43	2483.85
75	91.77	0.001037	2.21607	2.21711	394.29	2112.39	2496.67
100	99.62	0.001043	1.69296	1.69400	417.33	2088.72	2506.06
125	105.99	0.001048	1.37385	1.37490	444.16	2069.32	2513.48
150	111.37	0.001053	1.15828	1.15933	466.92	2052.72	2519.64
175	116.06	0.001057	1.00257	1.00363	486.78	2038.12	2524.90
200	120.23	0.001061	0.88467	0.88573	504.47	2025.02	2529.49
225	124.00	0.001064	0.79219	0.79325	520.45	2013.10	2533.56
250	127.43	0.001067	0.71765	0.71871	535.08	2002.14	2537.21
275	130.60	0.001070	0.65624	0.65731	548.57	1991.95	2540.53
300	133.55	0.001073	0.60475	0.60582	561.13	1982.43	2543.55
325	136.30	0.001076	0.56093	0.56201	572.88	1973.46	2546.34
350	138.88	0.001079	0.52317	0.52425	583.93	1964.98	2548.92
375	141.32	0.001081	0.49029	0.49137	594.38	1956.93	2551.31
400	143.63	0.001084	0.46138	0.46246	604.29	1949.26	2553.55
450	147.93	0.001088	0.41289	0.41398	622.75	1934.87	2557.62
500	151.86	0.001093	0.37380	0.37489	639.66	1921.57	2561.23
550	155.48	0.001097	0.34159	0.34268	655.30	1909.17	2564.47
600	158.85	0.001101	0.31457	0.31567	669.88	1897.52	2567.40
650	162.01	0.001104	0.29158	0.29268	683.55	1886.51	2570.06
700	164.97	0.001108	0.27176	0.27286	696.43	1876.07	2572.49
750	167.77	0.001111	0.25449	0.25560	708.62	1866.11	2574.73
800	170.43	0.001115	0.23931	0.24043	720.20	1856.58	2576.79

Saturated Water Pressure Entry

		Enthalpy, kJ/kg			Entropy, kJ/kg-K		
Press. (kPa)	**Temp. (°C)**	**Sat. Liquid h_f**	**Evap. h_{fg}**	**Sat. Vapor h_g**	**Sat. Liquid s_f**	**Evap. s_{fg}**	**Sat. Vapor s_g**
0.6113	0.01	0.00	2501.3	2501.3	0	9.1562	9.1562
1.0	6.98	29.29	2484.89	2514.18	0.1059	8.8697	8.9756
1.5	13.03	54.70	2470.59	2525.30	0.1956	8.6322	8.8278
2.0	17.50	73.47	2460.02	2533.49	0.2607	8.4629	8.7236
2.5	21.08	88.47	2451.56	2540.03	0.3120	8.3311	8.6431
3.0	24.08	101.03	2444.47	2545.50	0.3545	8.2231	8.5775
4.0	28.96	121.44	2432.93	2554.37	0.4226	8.0520	8.4746
5.0	32.88	137.79	2423.66	2561.45	0.4763	7.9187	8.3950
7.5	40.29	168.77	2406.02	2574.79	0.5763	7.6751	8.2514
10	45.81	191.81	2392.82	2584.63	0.6492	7.5010	8.1501
15	53.97	225.91	2373.14	2599.06	0.7548	7.2536	8.0084
20	60.06	251.38	2358.33	2609.70	0.8319	7.0766	7.9085
25	64.97	271.90	2346.29	2618.19	0.8930	6.9383	7.8313
30	69.10	289.21	2336.07	2625.28	0.9439	6.8247	7.7686
40	75.87	317.55	2319.19	2636.74	1.0258	6.6441	7.6700
50	81.33	340.47	2305.40	2645.87	1.0910	6.5029	7.5939
75	91.77	384.36	2278.59	2662.96	1.2129	6.2434	7.4563
100	99.62	417.44	2258.02	2675.46	1.3025	6.0568	7.3593
125	105.99	444.30	2241.05	2685.35	1.3739	5.9104	7.2843
150	111.37	467.08	2226.46	2693.54	1.4335	5.7897	7.2232
175	116.06	486.97	2213.57	2700.53	1.4848	5.6868	7.1717
200	120.23	504.68	2201.96	2706.63	1.5300	5.5970	7.1271
225	124.00	520.69	2191.35	2712.04	1.5705	5.5173	7.0878
250	127.43	535.34	2181.55	2716.89	1.6072	5.4455	7.0526
275	130.60	548.87	2172.42	2721.29	1.6407	5.3801	7.0208
300	133.55	561.45	2163.85	2725.30	1.6717	5.3201	6.9918
325	136.30	573.23	2155.76	2728.99	1.7005	5.2646	6.9651
350	138.88	584.31	2148.10	2732.40	1.7274	5.2130	6.9404
375	141.32	594.79	2140.79	2735.58	1.7527	5.1647	6.9174
400	143.63	604.73	2133.81	2738.53	1.7766	5.1193	6.8958
450	147.93	623.24	2120.67	2743.91	1.8206	5.0359	6.8565
500	151.86	640.21	2108.47	2748.67	1.8606	4.9606	6.8212
550	155.48	655.91	2097.04	2752.94	1.8972	4.8920	6.7892
600	158.85	670.54	2086.26	2756.80	1.9311	4.8289	6.7600
650	162.01	684.26	2076.04	2760.30	1.9627	4.7704	6.7330
700	164.97	697.20	2066.30	2763.50	1.9922	4.7158	6.7080
750	167.77	709.45	2056.98	2766.43	2.0199	4.6647	6.6846
800	170.43	721.10	2048.04	2769.13	2.0461	4.6166	6.6627

Superheated Vapor Water

Temp. (°C)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
	8000 kPa (295.06°C)			
Sat.	0.02352	2569.79	2757.94	5.7431
300	0.02426	2590.93	2784.98	5.7905
350	0.02995	2747.67	2987.30	6.1300
400	0.03432	2863.75	3138.28	6.3633
450	0.03817	2966.66	3271.99	6.5550
500	0.04175	3064.30	3398.27	6.7239
550	0.04516	3159.76	3521.01	6.8778
600	0.04845	3254.43	3642.03	7.0205
700	0.05481	3444.00	3882.47	7.2812
800	0.06097	3636.08	4123.84	7.5173
900	0.06702	3832.08	4368.26	7.7350
1000	0.07301	4032.81	4616.87	7.9384
1100	0.07896	4238.60	4870.25	8.1299
1200	0.08489	4449.45	5128.54	8.3115
1300	0.09080	4665.02	5391.46	8.4842

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
	P = 0.60 MPa (158.83°C)				P = 0.80 MPa (170.41°C)			
Sat.	0.31560	2566.8	2756.2	6.7593	0.24035	2576.0	2768.3	6.6616
200	0.35212	2639.4	2850.6	6.9683	0.26088	2631.1	2839.8	6.8177
250	0.39390	2721.2	2957.6	7.1833	0.29321	2715.9	2950.4	7.0402
300	0.43442	2801.4	3062.0	7.3740	0.32416	2797.5	3056.9	7.2345
350	0.47428	2881.6	3166.1	7.5481	0.35442	2878.6	3162.2	7.4107
400	0.51374	2962.5	3270.8	7.7097	0.38429	2960.2	3267.7	7.5735
500	0.59200	3128.2	3483.4	8.0041	0.44332	3126.6	3481.3	7.8692
600	0.66976	3299.8	3701.7	8.2695	0.50186	3298.7	3700.1	8.1354
700	0.74725	3478.1	3926.4	8.5132	0.56011	3477.2	3925.3	8.3794
800	0.82457	3663.2	4157.9	8.7395	0.61820	3662.5	4157.0	8.6061
900	0.90179	3855.1	4396.2	8.9518	0.67619	3854.5	4395.5	8.8185
1000	0.97893	4053.8	4641.1	9.1521	0.73411	4053.3	4640.5	9.0189
1100	1.05603	4258.8	4892.4	9.3420	0.79197	4258.3	4891.9	9.2090
1200	1.13309	4469.8	5149.6	9.5229	0.84980	4469.4	5149.3	9.3898
1300	1.21012	4686.4	5412.5	9.6955	0.90761	4686.1	5412.2	9.5625

Psychrometric chart