

MCG2130 - THERMODYNAMICS I

Final Examination
22 December 2011
Prof. W. Hallett

Time: 3 hours
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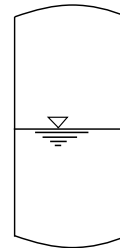
Closed book. All calculators allowed. In each problem, state any assumptions you need to make. Properties tables and equations are given at the end of the paper.

1. (6 marks total) Give brief answers to the following questions:

- (a) (1 mark) Give the Clausius statement of the second law of thermodynamics.
- (b) (2 marks) Describe how the efficiency of a reversible heat engine cycle changes with (i) the temperature of the hot heat source T_H ; (ii) the temperature of the cold heat sink T_C .
- (c) (1 marks) Under what conditions can the specific heat of a gas be assumed constant?
- (d) (2 marks) Name three sources of irreversibility in thermodynamic processes.

2. (10 marks) A rigid vessel of 10 m^3 volume is initially filled with saturated water at 8MPa. The initial liquid volume fraction in the vessel is 0.50.

- (a) (4 marks) Determine the initial quality x_1 of the water in the vessel.
- (b) (4 marks) The water is now heated until a final pressure of 10 MPa is reached. Determine the final quality x_2 and the amount of heat input in kJ.



- (c) (2 marks) Sketch a T-v diagram and a T-s diagram for this process, showing the vapour dome and lines of constant pressure for the initial and final states. (This is similar to the device used to control the pressure in Canadian nuclear reactors.)

3. (9 marks total) The cylinder of a refrigeration compressor initially contains 0.1 L of saturated vapour R134a at -20°C . The R134a is then compressed in a polytropic process (PV^n , with $n = 1.1$) to a final pressure of 1 MPa.

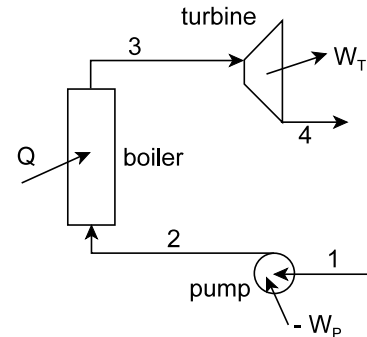
- (a) (4 marks) Determine the final temperature T_2 .
- (b) (4 marks) Calculate the total work and the heat transfer in kJ.
- (b) (1 mark) Sketch this process on a P-v diagram, showing its relation to the saturation region.

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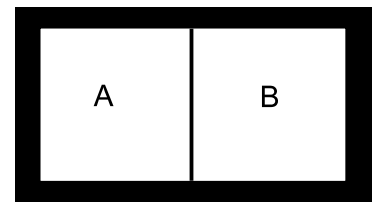
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4. (13 marks total) The sketch shows a simple steam power plant. Water enters at point 1 as saturated liquid at $T_1 = 20^\circ\text{C}$ and is raised to a pressure of $P_2 = 2\text{ MPa}$ by the pump. It is then turned to steam and raised to a temperature of $T_3 = 400^\circ\text{C}$ in the boiler, and finally expands in the turbine to a final pressure of $P_4 = 100\text{ kPa}$. The turbine and the pump are well insulated and may be assumed to be reversible.



- (4 marks) Determine the exit state from the turbine (quality or temperature, whichever is appropriate), and the specific work of the turbine in kJ/kg.
- (4 marks) Calculate the specific work required for the pump in kJ/kg, and the exit temperature from the pump T_2 .
- (3 marks) Find the mass flow of water required in kg/s for a turbine work output of 1 MW. If the diameter of the pipe leaving the turbine at 4 is 0.1 m, determine the velocity of the steam at 4.
- (2 mark) Sketch a T-s diagram for these processes, showing the vapour dome.

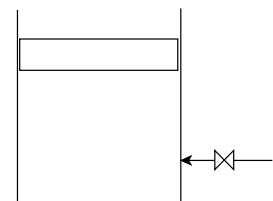
5. (11 marks total) A well-insulated rigid container is subdivided by a partition into two parts A and B, each of volume $V_A = V_B = 0.2\text{ m}^3$, and each filled with air. The initial temperatures and pressures are $P_{A1} = 200\text{ kPa}$, $T_{A1} = 100^\circ\text{C}$, $P_{B1} = 100\text{ kPa}$, and $T_{B1} = 20^\circ\text{C}$. The partition is then removed, and the system comes to equilibrium.



- (7 marks) Determine the final temperature and pressure in the container.
- (4 marks) Calculate the total entropy change for the air in the container in kJ/K.

You may assume that air is a perfect gas with constant specific heats.

6. (11 marks total) A well-insulated cylinder is fitted with a piston which maintains a constant pressure of $P = 300\text{ kPa}$ in the cylinder. The cylinder is initially filled with 0.2 kg of steam at a temperature of $T_1 = 170^\circ\text{C}$. A mass of 0.5 kg of liquid water at $T_i = 20^\circ\text{C}$ is then injected into the cylinder.



- (3 marks) Write an expression for the work done in the process.
- (2 marks) Write the first law for this process, stating any assumptions.
- (6 marks) The final state is a saturated mixture. Determine the final quality x_2 and the work done.

Total marks for this paper: 60

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Equations and Other Data

Work done in a polytropic process $Pv^n = \text{constant}$, control mass:

$$W_{12} = (P_2 V_2 - P_1 V_1) / (1 - n)$$

Work done in reversible steady flow: $w = - \int_1^2 v dP$

Entropy change for an ideal gas with constant specific heats:

$$s_2 - s_1 = c_p \ln(T_2 / T_1) - R \ln(P_2 / P_1)$$

Properties for air:

$R = 0.287 \text{ kJ/kg K}$; specific heats at 300K: $c_{p0} = 1.004 \text{ kJ/kg K}$, $c_{v0} = 0.717 \text{ kJ/kg K}$

Universal gas constant: $\bar{R} = 8.314 \text{ kJ/kmol K}$

Steam Tables

Saturated Steam - Temperature Table

T (°C)	P (kPa)	v_f (m ³ /kg)	v_g (m ³ /kg)	u_f (kJ/kg)	u_g (kJ/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kgK)	s_g (kJ/kg K)
0.01	0.6113	0.001000	206.14	0.00	2375.3	0.01	2501.4	0	9.1562
5	0.8721	0.001000	147.12	20.97	2382.3	20.98	2510.6	0.0761	9.0257
10	1.2276	0.001000	106.38	42.00	2389.2	42.01	2519.8	0.151	8.9008
15	1.7051	0.001001	77.93	62.99	2396.1	62.99	2528.9	0.2245	8.7814
20	2.339	0.001002	57.79	83.95	2402.9	83.96	2538.1	0.2966	8.6672
25	3.169	0.001003	43.36	104.88	2409.8	104.89	2547.2	0.3674	8.558
30	4.246	0.001004	32.89	125.78	2416.6	125.79	2556.3	0.4369	8.4533
35	5.628	0.001006	25.22	146.67	2423.4	146.68	2565.3	0.5053	8.3531
40	7.384	0.001008	19.52	167.56	2430.1	167.57	2574.3	0.5725	8.257
45	9.593	0.001010	15.26	188.44	2436.8	188.45	2583.2	0.6387	8.1648
50	12.349	0.001012	12.03	209.32	2443.5	209.33	2592.1	0.7038	8.0763

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Saturated Steam - Pressure Table

P (kPa)	T (°C)	v_f (m ³ /kg)	v_g (m ³ /kg)	u_f (kJ/kg)	u_g (kJ/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kgK)	s_g (kJ/kg K)
10	45.81	0.00101	14.674	191.82	2437.9	191.83	2584.7	0.6493	8.1502
20	60.06	0.00102	7.6494	251.38	2456.7	251.4	2609.7	0.832	7.9085
30	69.1	0.00102	5.2292	289.20	2468.4	289.23	2625.3	0.9439	7.7686
50	81.33	0.00103	3.9935	340.44	2483.9	340.49	2645.9	1.091	7.5939
75	91.78	0.00104	2.2171	384.31	2496.7	384.39	2663.0	1.213	7.4564
100	99.63	0.00104	1.6940	417.36	2506.1	417.46	2675.5	1.3026	7.3594
200	120.2	0.00106	0.88573	504.49	2529.5	504.7	2706.7	1.5301	7.1271
300	133.6	0.00107	0.60582	561.15	2543.6	561.47	2725.3	1.6718	6.9919
1000	179.9	0.00113	0.19444	761.68	2583.6	762.79	2778.1	2.1386	6.5864
2000	212.4	0.00119	0.09963	906.42	2600.3	908.77	2799.5	2.4473	6.3408
5000	264.0	0.00128	0.03944	1147.8	2597.1	1154.2	2794.3	2.9201	5.9733
8000	295.1	0.00138	0.02352	1305.4	2569.8	1316.6	2757.9	3.2067	5.7431
10000	311.1	0.00145	0.01803	1393.0	2544.4	1407.5	2724.7	3.3595	5.6140

Superheated Water Vapour

P = 5.0 MPa ($T_{SAT} = 263.99$)

T (°C)	v (m ³ /kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg K)
Sat	0.039	2597.1	2794.3	5.9733
300	0.045	2698	2924.5	6.2083
350	0.052	2808.7	3068.4	6.4492
400	0.058	2906.6	3195.6	6.6458
450	0.063	2999.7	3316.2	6.8185
500	0.069	3091	3433.8	6.9758

P = 2.0 MPa ($T_{SAT} = 212.42$)

T (°C)	v (m ³ /kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg K)
Sat	0.0996	2600.3	2799.5	6.3408
250	0.1114	2679.6	2902.5	6.5452
300	0.1255	2772.6	3023.5	6.7663
350	0.1386	2859.8	3137.0	6.9562
400	0.1512	2945.2	3247.6	7.1270
450	0.1635	3030.4	3357.5	7.2844

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Superheated Water Vapour

P = 1.0 MPa ($T_{SAT} = 179.9$)

T (°C)	v (m ³ /kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg K)
Sat	0.1944	2583.6	2778.1	6.5865
200	0.206	2621.9	2827.9	6.694
250	0.2327	2709.9	2942.6	6.9247
300	0.2579	2793.2	3051.2	7.1229
350	0.2825	2875.2	3157.7	7.3011
400	0.3066	2957.3	3263.9	7.4651

P = 0.3 MPa ($T_{SAT} = 133.55$)

T (°C)	v (m ³ /kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg K)
Sat	0.6058	2543.6	2725.3	6.9919
150	0.6339	2570.8	2761	7.0778
200	0.7163	2650.7	2865.6	7.3115
250	0.7964	2728.7	2967.6	7.5166
300	0.8753	2806.7	3069.3	7.7022
400	1.0315	2965.6	3275	8.033

Tables for Refrigerant R134a

Properties of saturated refrigerant R134a

T (°C)	P (kPa)	v_f (m ³ /kg)	v_g (m ³ /kg)	u_f (kJ/kg)	u_g (kJ/kg)	s_f (kJ/kg K)	s_g (kJ/kg K)
-26.5	100.0	0.000728	0.19257	165.73	362.73	0.8680	1.7451
-20	133.7	0.000738	0.14649	173.65	366.50	0.9007	1.7395
-10	201.7	0.000755	0.09921	186.57	372.27	0.9507	1.7319
0	294.0	0.000773	0.06919	199.77	378.01	1.0000	1.7262
5	350.9	0.000783	0.05833	206.48	380.85	1.0243	1.7239
10	415.8	0.000794	0.04945	213.25	383.67	1.0485	1.7218
20	572.8	0.000817	0.03606	227.03	389.15	1.0963	1.7183
30	771.0	0.000843	0.02671	241.14	394.48	1.1437	1.7153
40	1017.0	0.000873	0.02002	255.65	399.46	1.1909	1.7123
50	1318.1	0.000908	0.01512	270.63	403.98	1.2381	1.7088

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Properties of superheated R134a

T (°C)	100 kPa (-26.5°C)			300 kPa (0.56°C)			1000kPa (39.37°C)		
	v (m ³ /kg)	u (kJ/kg)	s (kJ/kg K)	v (m ³ /kg)	u (kJ/kg)	s (kJ/kg K)	v (m ³ /kg)	u (kJ/kg)	s (kJ/kg K)
sat.	0.19257	362.73	1.7456	0.06787	378.33	1.7259	0.02038	399.16	1.7125
- 20	0.19860	367.36	1.7665						
- 10	0.20765	374.51	1.7978						
0	0.21652	381.76	1.8281						
10	0.22527	389.14	1.8578	0.07111	385.84	1.7564			
20	0.23392	396.66	1.8869	0.07441	393.80	1.7874			
30	0.24250	404.31	1.9155	0.07762	401.81	1.8175			
40	0.25101	412.12	1.9436	0.08075	409.90	1.8468	0.02047	399.78	1.7148
50	0.25948	420.08	1.9712	0.08382	418.09	1.8755	0.02185	409.39	1.7494
60	0.26791	428.20	1.9985	0.08684	426.39	1.9035	0.02311	418.78	1.7818
70	0.27631	436.47	2.0255	0.08982	434.82	1.9311	0.02429	428.05	1.8127
80	0.28468	444.89	2.0521	0.09277	443.37	1.9582	0.02542	437.29	1.8425
90	0.29302	453.47	2.0784	0.09570	452.07	1.9850	0.02650	446.53	1.8713
100	0.30135	462.21	2.1044	0.09861	460.90	2.0113	0.02754	455.82	1.8994