

MCG2130 - THERMODYNAMICS I

Final Examination
8 December 2013
Prof. W. Hallett

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

1. (7 marks total) Give brief answers to the following questions:

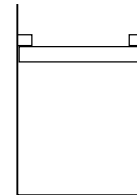
(a) (2 mark) Write two statements of the second law of thermodynamics.

(b) (2 marks) Write the first law of thermodynamics for a control volume undergoing a transient process (inflows, outflows, changes with time) including all terms.

(c) (1 marks) Name two sources of irreversibility in thermodynamics processes.

(d) (2 marks) A perfect gas passes through an adiabatic throttling process. Describe how the temperature of the gas changes. Give reasons for your answer.

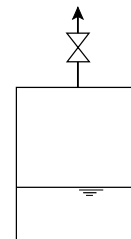
2. (7 marks) A cylinder containing air has a frictionless leaktight piston. Initially the air in the cylinder is at a pressure of $P_1 = 1.0$ MPa and a temperature $T_1 = 200^\circ\text{C}$, and the piston is prevented from moving upwards by stops, so that the initial volume is $V_1 = 10$ litres. The air is then cooled. When the pressure drops to 800 kPa, the piston moves downwards at constant pressure until a final temperature of $T_3 = 20^\circ\text{C}$ is reached.



(a) (1 mark) Sketch a P-v diagram for this process

(b) (6 marks) Calculate the work and the heat transfer in kJ.

3. (11 marks total) A rigid tank of 0.1 m^3 volume initially contains saturated water at 300 kPa with a liquid volume fraction of 0.30. A valve at the top of the tank is then opened, and 20 kg of water are allowed to flow out. The temperature remains constant during this process.



(a) (4 marks) Calculate the initial quality.

(a) (3 marks) Determine the final state (temperature or quality, whichever is appropriate).

(b) (4 marks) Calculate the heat transfer.

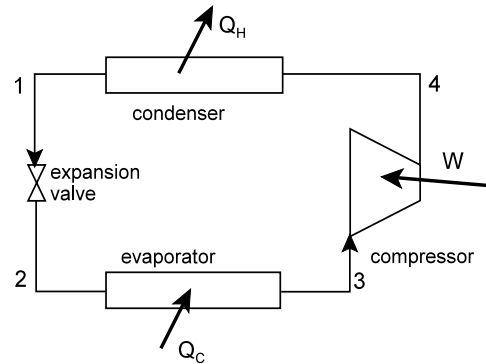
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4. (17 marks total) The sketch shows a standard refrigeration cycle using R134a as the working fluid. The valve is an adiabatic throttling process; the compressor is adiabatic and reversible. The evaporator is a heat exchanger. The following states are given:

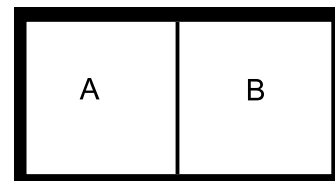
- 1: saturated liquid at $T_1 = 39.3^\circ\text{C}$
- 3: saturated vapour at $T_3 = -10^\circ\text{C}$



- (a) (2 mark) State the pressures at point 2 and 4 and sketch the processes for the valve, evaporator and compressor on a T-s diagram.
- (b) (3 marks) Calculate the state (temperature or quality, whichever is appropriate) at the outlet of the expansion valve, point 2.
- (c) (2 marks) Calculate the heat transfer in the evaporator in kJ/kg.
- (d) (5 marks) Determine the compressor work in kJ/kg and the compressor outlet temperature T_4 .
- (e) (3 marks) Calculate the coefficient of performance of the cycle and compare it to that of a Carnot cycle working between a hot reservoir at $T_H = T_1$ and a cold reservoir at $T_C = T_3$.
- (f) (2 marks) If the the refrigerant mass flow is 0.1 kg/s, determine the diameter of pipe required at point 3 if the flow velocity entering the compressor is to be $V_3 = 10$ m/s.

5. (6 marks total) Steam in a cylinder fitted with a frictionless piston expands in a reversible isothermal process from an initial state of $P_1 = 1000$ kPa with a quality $x_1 = 0.95$ to a final pressure of 300 kPa. Calculate the work done and the heat transfer in kJ/kg.

6. (12 marks total) An insulated container holds two volumes of air separated by a partition. Volume A initially contains 0.1 m^3 at $P_{A1} = 300$ kPa and $T_{A1} = 120^\circ\text{C}$, while volume B initially contains 0.1 m^3 at $P_{B1} = 100$ kPa and $T_{B1} = 150^\circ\text{C}$. The partition is then removed and the two volumes mix until a uniform state is achieved.



- (a) (6 marks) Determine the final temperature and pressure.
- (b) (6 marks) Determine the change in the entropy of the system and of the surroundings, assuming that the surroundings are at 20°C . What does this change indicate about the process?
You may assume that air is an ideal gas with constant specific heats.

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: $W_{12} = (P_2V_2 - P_1V_1)/(1 - n)$

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

Work done by ideal gas in reversible isothermal process: $W_{12} = P_1 V_1 \ln(P_1/P_2)$

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:

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

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

Steam Tables

Properties of 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	0.001	206.14	0	2375.3	0.01	2501.4	0	9.1562
5	0.8721	0.001	147.12	20.97	2382.3	20.98	2510.6	0.076	9.0257
10	1.2276	0.001	106.38	42	2389.2	42.01	2519.8	0.151	8.9008
15	1.7051	0.001	77.93	62.99	2396.1	62.99	2528.9	0.2245	8.7814
20	2.339	0.001	57.79	83.95	2402.9	83.96	2538.1	0.2966	8.6672
25	3.169	0.001	43.36	104.88	2409.8	104.89	2547.2	0.3674	8.558
30	4.246	0.001	32.89	125.78	2416.6	125.79	2556.3	0.4369	8.4533
35	5.628	0.001	25.22	146.67	2423.4	146.68	2565.3	0.5053	8.3531
40	7.384	0.001	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	0.001	12.03	209.32	2443.5	209.33	2592.1	0.7038	8.0763

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Properties of 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	0.001	14.674	191.82	2437.9	191.83	2584.7	0.6493	8.1502
20	60.06	0.001	7.6494	251.38	2456.7	251.4	2609.7	0.832	7.9085
30	69.1	0.001	5.2292	289.2	2468.4	289.23	2625.3	0.9439	7.7686
50	81.33	0.001	3.9935	340.44	2483.9	340.49	2645.9	1.091	7.5939
75	91.78	0.001	2.2171	384.31	2496.7	384.39	2663	1.213	7.4564
100	99.63	0.001	1.694	417.36	2506.1	417.46	2675.5	1.3026	7.3594
200	120.2	0.0011	0.8857	504.49	2529.5	504.7	2706.7	1.5301	7.1271
300	133.6	0.0011	0.6058	561.15	2543.6	561.47	2725.3	1.6718	6.9919
1000	179.9	0.0011	0.1944	761.68	2583.6	762.79	2778.1	2.1386	6.5864
2000	212.4	0.0012	0.1	906.42	2600.3	908.77	2799.5	2.4473	6.3408
5000	264	0.0013	0.039	1147.8	2597.1	1154.2	2794.3	2.9201	5.9733
8000	295.1	0.0014	0.024	1305.4	2569.8	1316.6	2757.9	3.2067	5.7431
10000	311.1	0.0015	0.018	1393	2544.4	1407.5	2724.7	3.3595	5.614

Properties of 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	0.1	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	6.9562
400	0.1512	2945.2	3247.6	7.127
450	0.1635	3030.4	3357.5	7.2844

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Properties of 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)	h _f (kJ/kg)	h _g (kJ/kg)	s _f (kJ/kgK)	s _g (kJ/kg K)
-26	100	0	0.1926	165.73	362.73	165.8	382.16	0.868	1.7451
-20	133.7	0	0.1465	173.65	366.5	173.74	386.08	0.9007	1.7395
-10	201.7	0	0.099	186.57	372.27	186.72	392.28	0.9507	1.7319
0	294	0	0.069	199.77	378.01	200	398.36	1	1.7262
5	350.9	0	0.058	206.48	380.85	206.75	401.32	1.0243	1.7239
10	415.8	0	0.049	213.25	383.67	213.58	404.23	1.0485	1.7218
20	572.8	0	0.036	227.03	389.15	227.49	409.84	1.0963	1.7183
30	771	0	0.027	241.14	394.48	241.79	415.08	1.1437	1.7153
40	1017	0	0.02	255.65	399.46	256.54	419.82	1.1909	1.7123
50	1318	0	0.015	270.63	403.98	271.83	423.91	1.2381	1.7088

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Properties of superheated R134a

T (°C)	300 kPa (0.56 °C)				1000kPa (39.37 °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)
sat.	0.0679	378.33	398.69	1.7259	0.02038	399.16	419.54	1.7125
10	0.0711	385.84	407.17	1.7564				
20	0.0744	393.8	416.12	1.7874				
30	0.0776	401.81	425.1	1.8175				
40	0.0808	409.9	434.12	1.8468	0.02047	399.78	420.25	1.7148
50	0.0838	418.09	443.23	1.8755	0.02185	409.39	431.24	1.7494
60	0.0868	426.39	452.44	1.9035	0.02311	418.78	441.89	1.7818
70	0.0898	434.82	461.76	1.9311	0.02429	428.05	452.34	1.8127
80	0.0928	443.37	471.21	1.9582	0.02542	437.29	462.7	1.8425
90	0.0957	452.07	480.78	1.985	0.0265	446.53	473.03	1.8713
100	0.0986	460.9	490.48	2.0113	0.02754	455.82	483.36	1.8994