Name: SID: Discussion Session:

Chemical Engineering Thermodynamics 141 -- Fall 2007
Tuesday, October 9, 2007
Midterm I - 70 minutes
110 Points Total
Closed Book and Notes

(20 points) 1. Consider 1 mole of an ideal gas with constant heat capacities. For each of the following processes, deduce which of the listed properties or quantities remain constant and check those boxes.

	ΔT	ΔP	ΔV	Q	W	ΔU	ΔH	ΔS
Reversible adiabatic expansion								
Reversible isothermal expansion								
Constant-pressure heating								
Constant-volume cooling								
Joule-Thomson process								

(20 points) 2. In state 1, a piston-cylinder assembly contains 3 kg of saturated steam of quality 0.1 at 45.47 kPa. Heat is added at constant pressure while the piston moves outward. This continues until it reaches state 2 where the quality is 0.3, at which point the piston becomes stuck and cannot move any further. Heat continues to be added at constant volume until the pressure reaches 133.90 kPa (state 3).

i) Sketch qualitatively the path on a PV diagram. Label each state 1, 2, and 3.
ii) Using the attached data for saturated steam:
   a. Calculate the quality of the steam at final state (state 3).
   b. Calculate the net heat added to the system.

(30 points) 3. A gas is at an initial state of 250 K and 60 bar and transitions to a final state of 1 bar. If the gas were ideal, this same transition would have resulted in an enthalpy change of 5000 J/mol. Over the considered range, the gas' equation of state is well-described by the following correlation and data:

$$\mathbf{Z = Z^0 + \omega Z^1; \qquad Z^0 = 1 + E^0 \frac{P_r}{T_r}; \qquad Z^1 = E^1 \frac{P_r}{T_r}}$$

$$\mathbf{E^0 = 1 - \frac{3}{T_r^2}; \qquad E^1 = 2 - \frac{4}{T_r^4}}$$

$$T_C = 200\,K$$

$$P_C = 50\,bar$$

$$\omega = 4.3$$

$$\mathbf{\frac{C_P^{ig}}{R} = 0.00004 * T^{2.3}}$$

Recall that: $$\mathbf{\frac{H^R}{RT_C} = -T_r^2 \int_0^{P_r} \left(\frac{\partial Z}{\partial T_r}\right)_{Pr} \frac{dP_r}{P_r}}$$

i) Using enthalpy calculations, find the final temperature of the gas.

ii) Calculate the change in enthalpy required for this transition involving the real gas.

(40 points) 4. Consider a cycle that consists of the following reversible processes:

(a) Isobaric cooling from T_1 to T_2

(b) Adiabatic compression from T_2 to T_3

(c) Isobaric heating from T_3 to T_4

(d) Adiabatic expansion from T_4 to T_1

Assuming that the working fluid is an ideal gas with constant heat capacities:

i) Sketch qualitatively the paths on a PV diagram and a TS diagram. Label each state with 1, 2, 3, and 4 according to their respective temperatures T_1, T_2, T_3, and T_4.

ii) Calculate the heat and work exchanged (using the sign convention U = Q - W), and the change in the entropy of the system for parts (a) and (b), in terms of the given temperatures.

iii) Show that: $$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

V [=] $cm^3\ g^{-1}$ U [=] $kJ\ kg^{-1}$ H [=] $kJ\ kg^{-1}$ S [=] $kJ\ kg^{-1}\ K^{-1}$

Table F.1. Saturated Steam, SI Units (Continued)

			SPECIFIC VOLUME V			INTERNAL ENERGY U			ENTHALPY H			ENTROPY S		
t °C	T K	P kPa	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.
75	348.15	38.55	1.026	4133.1	4134.1	313.9	2162.1	2476.0	313.9	2321.5	2635.4	1.0154	6.6681	7.6835
76	349.15	40.19	1.027	3974.6	3975.7	318.1	2159.2	2477.3	318.1	2318.9	2637.1	1.0275	6.6418	7.6693
77	350.15	41.89	1.027	3823.3	3824.3	322.3	2156.3	2478.5	322.3	2316.4	2638.7	1.0395	6.6156	7.6551
78	351.15	43.65	1.028	3678.6	3679.6	326.5	2153.3	2479.8	326.5	2313.9	2640.4	1.0514	6.5896	7.6410
79	352.15	45.47	1.029	3540.3	3541.3	330.7	2150.4	2481.1	330.7	2311.4	2642.1	1.0634	6.5637	7.6271
80	353.15	47.36	1.029	3408.1	3409.1	334.9	2147.4	2482.3	334.9	2308.8	2643.8	1.0753	6.5380	7.6132
81	354.15	49.31	1.030	3281.6	3282.6	339.1	2144.5	2483.5	339.1	2306.3	2645.4	1.0871	6.5123	7.5995
82	355.15	51.33	1.031	3160.6	3161.6	343.3	2141.5	2484.8	343.3	2303.8	2647.1	1.0990	6.4868	7.5858
83	356.15	53.42	1.031	3044.8	3045.8	347.5	2138.6	2486.0	347.5	2301.2	2648.7	1.1108	6.4615	7.5722
84	357.15	55.57	1.032	2933.9	2935.0	351.7	2135.6	2487.3	351.7	2298.6	2650.4	1.1225	6.4362	7.5587
85	358.15	57.80	1.033	2827.8	2828.8	355.9	2132.6	2488.5	355.9	2296.1	2652.0	1.1343	6.4111	7.5454
86	359.15	60.11	1.033	2726.1	2727.2	360.1	2129.7	2489.7	360.1	2293.5	2653.6	1.1460	6.3861	7.5321
87	360.15	62.49	1.034	2628.8	2629.8	364.3	2126.7	2490.9	364.3	2290.9	2655.3	1.1577	6.3612	7.5189
88	361.15	64.95	1.035	2535.4	2536.5	368.5	2123.7	2492.2	368.5	2288.4	2656.9	1.1693	6.3365	7.5058
89	362.15	67.49	1.035	2446.0	2447.0	372.7	2120.7	2493.4	372.7	2285.8	2658.5	1.1809	6.3119	7.4928
90	363.15	70.11	1.036	2360.3	2361.3	376.9	2117.7	2494.6	376.9	2283.2	2660.1	1.1925	6.2873	7.4799
91	364.15	72.81	1.037	2278.0	2279.1	381.1	2114.7	2495.8	381.1	2280.6	2661.7	1.2041	6.2629	7.4670
92	365.15	75.61	1.038	2199.2	2200.2	385.3	2111.7	2497.0	385.4	2278.0	2663.4	1.2156	6.2387	7.4543
93	366.15	78.49	1.038	2123.5	2124.5	389.5	2108.7	2498.2	389.6	2275.4	2665.0	1.2271	6.2145	7.4416
94	367.15	81.46	1.039	2050.9	2051.9	393.7	2105.7	2499.4	393.8	2272.8	2666.6	1.2386	6.1905	7.4291
95	368.15	84.53	1.040	1981.2	1982.2	397.9	2102.7	2500.6	398.0	2270.2	2668.1	1.2501	6.1665	7.4166
96	369.15	87.69	1.041	1914.3	1915.3	402.1	2099.7	2501.8	402.2	2267.5	2669.7	1.2615	6.1427	7.4042
97	370.15	90.94	1.041	1850.0	1851.0	406.3	2096.6	2503.0	406.4	2264.9	2671.3	1.2729	6.1190	7.3919
98	371.15	94.30	1.042	1788.3	1789.3	410.5	2093.6	2504.1	410.6	2262.2	2672.9	1.2842	6.0954	7.3796
99	372.15	97.76	1.043	1729.0	1730.0	414.7	2090.6	2505.3	414.8	2259.6	2674.4	1.2956	6.0719	7.3675
100	373.15	101.33	1.044	1672.0	1673.0	419.0	2087.5	2506.5	419.1	2256.9	2676.0	1.3069	6.0485	7.3554
102	375.15	108.78	1.045	1564.5	1565.5	427.4	2081.4	2508.8	427.5	2251.6	2679.1	1.3294	6.0021	7.3315
104	377.15	116.68	1.047	1465.1	1466.2	435.8	2075.3	2511.1	435.9	2246.3	2682.2	1.3518	5.9560	7.3078
106	379.15	125.04	1.049	1373.1	1374.2	444.3	2069.2	2513.4	444.4	2240.9	2685.3	1.3742	5.9104	7.2845
108	381.15	133.90	1.050	1287.9	1288.9	452.7	2063.0	2515.7	452.9	2235.4	2688.3	1.3964	5.8651	7.2615
110	383.15	143.27	1.052	1208.9	1209.9	461.2	2056.8	2518.0	461.3	2230.0	2691.3	1.4185	5.8203	7.2388
112	385.15	153.16	1.054	1135.6	1136.6	469.6	2050.6	2520.2	469.8	2224.5	2694.3	1.4405	5.7758	7.2164
114	387.15	163.62	1.055	1067.5	1068.5	478.1	2044.3	2522.4	478.3	2219.0	2697.2	1.4624	5.7318	7.1942
116	389.15	174.65	1.057	1004.2	1005.2	486.6	2038.1	2524.6	486.7	2213.4	2700.2	1.4842	5.6881	7.1723
118	391.15	186.28	1.059	945.3	946.3	495.0	2031.8	2526.8	495.2	2207.9	2703.1	1.5060	5.6447	7.1507
120	393.15	198.54	1.061	890.5	891.5	503.5	2025.4	2529.0	503.7	2202.2	2706.0	1.5276	5.6017	7.1293
122	395.15	211.45	1.062	839.4	840.5	512.0	2019.1	2531.1	512.2	2196.6	2708.8	1.5491	5.5590	7.1082
124	397.15	225.04	1.064	791.8	792.8	520.5	2012.7	2533.2	520.7	2190.9	2711.6	1.5706	5.5167	7.0873
126	399.15	239.33	1.066	747.3	748.4	529.0	2006.3	2535.3	529.2	2185.2	2714.4	1.5919	5.4747	7.0666
128	401.15	254.35	1.068	705.8	706.9	537.5	1999.9	2537.4	537.8	2179.4	2717.2	1.6132	5.4330	7.0462

Table A.1: Conversion Factors

Quantity	Conversion
Length	$1 \text{ m} = 100 \text{ cm}$ $= 3.28084(\text{ft}) = 39.3701(\text{in})$
Mass	$1 \text{ kg} = 10^3 \text{ g}$ $= 2.20462(\text{lb}_\text{m})$
Force	$1 \text{ N} = 1 \text{ kg m s}^{-2}$ $= 10^5(\text{dyne})$ $= 0.224809(\text{lb}_\text{f})$
Pressure	$1 \text{ bar} = 10^5 \text{ kg m}^{-1} \text{ s}^{-2} = 10^5 \text{ N m}^{-2}$ $= 10^5 \text{ Pa} = 10^2 \text{ kPa}$ $= 10^6(\text{dyne}) \text{ cm}^{-2}$ $= 0.986923(\text{atm})$ $= 14.5038(\text{psia})$ $= 750.061(\text{torr})$
Volume	$1 \text{ m}^3 = 10^6 \text{ cm}^3$ $= 35.3147(\text{ft})^3$ $= 264.172(\text{gal})$
Density	$1 \text{ g cm}^{-3} = 10^3 \text{ kg m}^{-3}$ $= 62.4278(\text{lb}_\text{m})(\text{ft})^{-3}$
Energy	$1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2} = 1 \text{ N m}$ $= 1 \text{ m}^3 \text{ Pa} = 10^{-5} \text{ m}^3 \text{ bar} = 10 \text{ cm}^3 \text{ bar}$ $= 9.86923 \text{ cm}^3(\text{atm})$ $= 10^7(\text{dyne}) \text{ cm} = 10^7(\text{erg})$ $= 0.239006(\text{cal})$ $= 5.12197 \times 10^{-3}(\text{ft})^3(\text{psia}) = 0.737562(\text{ft})(\text{lb}_\text{f})$ $= 9.47831 \times 10^{-4}(\text{Btu})$
Power	$1 \text{ kW} = 10^3 \text{ W} = 10^3 \text{ kg m}^2 \text{ s}^{-3} = 10^3 \text{ J s}^{-1}$ $= 239.006(\text{cal}) \text{ s}^{-1}$ $= 737.562(\text{ft})(\text{lb}_\text{f}) \text{ s}^{-1}$ $= 0.947831(\text{Btu}) \text{ s}^{-1}$ $= 1.34102(\text{hp})$

Table A.2: Values of the Universal Gas Constant

$$
\begin{aligned}
R &= 8.314 \text{ J mol}^{-1} \text{ K}^{-1} = 8.314 \text{ m}^3 \text{ Pa mol}^{-1} \text{ K}^{-1} \\
&= 83.14 \text{ cm}^3 \text{ bar mol}^{-1} \text{ K}^{-1} = 8{,}314 \text{ cm}^3 \text{ kPa mol}^{-1} \text{ K}^{-1} \\
&= 82.06 \text{ cm}^3(\text{atm}) \text{ mol}^{-1} \text{ K}^{-1} = 62{,}356 \text{ cm}^3(\text{torr}) \text{ mol}^{-1} \text{ K}^{-1} \\
&= 1.987(\text{cal}) \text{ mol}^{-1} \text{ K}^{-1} = 1.986(\text{Btu})(\text{lb mole})^{-1}(\text{R})^{-1} \\
&= 0.7302(\text{ft})^3(\text{atm})(\text{lb mol})^{-1}(\text{R})^{-1} = 10.73(\text{ft})^3(\text{psia})(\text{lb mol})^{-1}(\text{R})^{-1} \\
&= 1{,}545(\text{ft})(\text{lb}_\text{f})(\text{lb mol})^{-1}(\text{R})^{-1}
\end{aligned}
$$