Mer231 - Thermodynamics
Exam 1
January 26, 2010

Part A  40 points

Closed Notes/Book

Name: ___________________________________
Problem 1 (15 points)

The following P-T diagram is for a simple compressible substance.

a) What does curve A-B represent? What is it called?
   Phase line between solid/vapor, Sublimation Line

b) What does curve B-C represent? What is it called?
   Phase line between solid/liquid, Melting Line

c) What does curve B-D represent? What is it called?
   Phase line between liquid/vapor, Vaporization Line

d) What is Point B called?
   TRIPLE POINT

e) Identify the SOLID, LIQUID and VAPOR Phases on the above diagram

f) Identify the Critical Point on the above diagram.
   POINT C

g) Identify the liquid-vapor mixture phase on the above diagram
   LINE BD.
Problem 2 (12 points)

For the following conditions of water, determine the phase at which that water will exist at equilibrium. Use the table below (Thermodynamic Properties of Water) and justify (explain) your answer for full credit.

2 (a) $P = 20 \text{kPa}$, $v = 7.0 \text{ m}^3/\text{kg}$

\[ P = 20 \text{kPa}, \quad v_f = .001017, \quad v_g = 7.645 \text{m}^3/\text{kg} \]

\[ v_f < v < v_g \text{ MIXTURE} \]

2 (b) $P = 10 \text{kPa}$, $T = 20 \degree C$

\[ P = 10 \text{kPa}, \quad T_{sat} = 45.8 \degree C \text{ SINCE } T < T_{sat} \text{ COMPRESSED LIQ} \]

2 (c) $P = 75 \text{kPa}$, $T = 91.77 \degree C$

\[ P = 75 \text{kPa}, \quad T_{sat} = 91.77 \degree C \text{ SINCE } T = T_{sat} \text{ MELT} \]

2 (d) $P = 75 \text{kPa}$, $v = 0.0008 \text{ m}^3/\text{kg}$

\[ P = 75 \text{kPa}, \quad v_f = .001037, \quad v_g = 2.2171 \text{m}^3/\text{kg} \]

\[ v < v_f \text{ COMPRESSED LIQ} \]

2 (e) $P = 125 \text{kPa}$, $v = 3.2 \text{ m}^3/\text{kg}$

\[ P = 125 \text{kPa}, \quad v_f = .001048, \quad v_g = 1.37 \text{m}^3/\text{kg} \]

\[ v > v_f \text{ SUPERHEATED LIQUID} \]

(f) For which conditions (a) through (e) can the state be identified? Why?

\[ a, b, d, e \text{ because we know independent properties} \]

<table>
<thead>
<tr>
<th>Press. (kPa)</th>
<th>Temp. (°C)</th>
<th>Sat. Liquid $v_f$</th>
<th>Evap. $v_f$</th>
<th>Sat. Vapor $v_g$</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.0011000</td>
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<td>206.132</td>
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<td>87.98013</td>
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<td>67.00285</td>
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<td>0.001048</td>
<td>1.37385</td>
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</tbody>
</table>
Problem 3 (6 points)
Illustrate the possible process for each physical situation shown below on a PV diagram.

Problem 4 (5 points)
Is it reasonable to assume that Ammonia at 100 kPa and 600 K behaves as an ideal gas? Why or why not. (Note for ammonia the critical pressure is 11.35 MPa and the critical temperature is 405.5 K)

\[ \frac{p_r}{p_c} = \frac{100}{11,350} = 0.009 < 1 \quad \text{YES} \]
Mer231 - Thermodynamics
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Part B  60 points

Open Book

Name:_____________________________________
Problem 5 (20 points)

A 0.2 m³ rigid tank with air at 1 MPa, 400 K is connected to an air line. The valve is opened and the air flows into the tank until the pressure reaches 10 MPa, at which point the valve is closed and the temperature inside is 700 K.

3 (a) State any assumptions used to solve this problem.
- Air behaves like ideal gas
- The tank is rigid
- Mass is constant (no leaks)

\[ c = 0.287 \text{ kJ/kgK} \]

(b) What is the mass of the air in the tank before and after the process?

**State 1** \( P_1 = 1 \text{ MPa}; \quad T_1 = 400 \text{ K} \)

Solve for \( V_1 = \frac{m_1}{p_1} = \frac{0.2}{1000} = 0.1148 \text{ m}^3/\text{kg} \)

\[ m_1 = \frac{V_1}{\frac{0.2}{1000}} = 1.74 \text{ kg} \]

**State 2** \( P_2 = 10 \text{ MPa}; \quad T_2 = 700 \text{ K} \)

\[ V_2 = \frac{m_2}{p_2} = \frac{0.2}{10000} = 0.02 \text{ m}^3/\text{kg} \]

\[ m_2 = \frac{V_2}{0.02} = 10.0 \text{ kg} \]

(c) The tank eventually cools to room temperature, 300 K. What is the pressure inside the tank then?

**State 3** \( V_3 = V_2 = 0.02 \quad T_3 = 300 \text{ K} \)

\[ P_3 = \frac{RT_3}{V_3} = \frac{(0.287)(300)}{0.02} = 4.3 \text{ MPa} \]

(d) Show this process on a P-v diagram
Problem 6 (40 points).

Consider the piston/cylinder arrangement shown to the right. 5 kg of water at 400 °C, 300 kPa are contained in the cylinder (state 1). The water is cooled until the volume is 1.0 m³ at which point the piston just rests on the stops (state 2). The water is then further cooled until the pressure in the cylinder is 100 kPa (state 3). At this point the weights are removed and the stops are removed and the system is cooled to a saturated liquid state (state 4).

Saturated Water Data (from table B.1.2):

<table>
<thead>
<tr>
<th>( P ) (kPa)</th>
<th>( T ) (°C)</th>
<th>( v_f (m^3/kg) )</th>
<th>( v_{fl} (m^3/kg) )</th>
<th>( v_r (m^3/kg) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>99.62</td>
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<td>1.69296</td>
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<tr>
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<td>0.60475</td>
<td>0.60582</td>
</tr>
</tbody>
</table>

(a) List any assumptions used in the solution of this problem.

- \( Q \), \( E \), \( p \)
- no friction
- no leaks (constant mass)

(b) Draw the process on a P-V diagram.

(c) Calculate the volume at state 1 and the pressure and temperature at state 2.

\[ \text{State 1: } m = 5 \text{ kg} \]
\[ T = 400 \text{ °C} \]
\[ P_1 = 300 \text{ kPa} \]
\[ v_f = 1.03151 \text{ m}^3/\text{kg} \]
\[ V_1 = \frac{m}{\rho_f} = \frac{5}{1000} = 0.005 \text{ m}^3 \]
\[ \text{State 2: } P_2 = 100 \text{ kPa} \]
\[ v_2 = \frac{V_2}{m} = \frac{0.2}{5} = 0.04 \text{ m}^3/\text{kg} \]
\[ T = 133.6 \text{ °C} \]
(d) Calculate the final pressure, temperature and volume of the system.

At state (3): \( P_3 = 100 \text{kPa} \)
\[ V_3 = 5 \text{m}^3 \]

State (4a): \( P_4 = P_3 = 100 \text{kPa} \)
\[ V_4 = V_f = 0.001043 \text{m}^3 \]
\[ T = 75 + 99.6^\circ C = 179.6^\circ C \]
\[ V_4 = 5(V_f) = 0.0052 \text{m}^3 \]

(e) Calculate the amount of work done during this process.

\[
W = \int P \, dV = \int P_1 (V_1-V_2) + P_3 (V_2-V_4) \, dV
\]
\[ = 300(5.158-1) + 100(1-0.0052) \]
\[ = 135 \text{kJ} \]

(f) Without performing any further calculations, explain how your answers to parts (d) and (e) would change if there was significant friction in the system.

\[ PA = P_o A + u \, \vec{f} \]
Friction works to oppose motion.

\[ P_o \text{decrease/decrease} \]

\[ PA \text{decrease/increase} \]

As system cools, \( P_o \) would decrease due to the effects of friction. Since \( P \) decrease, \( T \) decreases as does \( V_f \).

Work would decrease.

Bonus: What place is the Union College Men's Hockey team in the ECAC Hockey League?

1st!