ME 200 Exam 3
November 17, 2014
8:00 p.m. to 9:00 p.m.

INSTRUCTIONS

1. This is a closed book and closed notes examination. You are provided with an equation sheet and all the needed property tables.
2. Start each problem on the same page as the problem statement. Write on only one side of the page. Materials on the back side of the page will not be graded.
3. Put only one problem on a page. Another problem on the same page will not be graded.
4. Show your system and list relevant assumptions and basic equations as applicable.
5. If you give multiple solutions, you will receive only a partial or no credit although one of the solutions might be correct. Delete the solution you do not want graded.
6. For your own benefit, please write clearly and legibly. Maximum credit for each problem is indicated below.
7. After you have completed the exam, at your seat put your papers in order. This may mean that you have to remove the staple and re-staple. Do not turn in loose pages.
8. Once time is called you must stop writing.
9. Talking during the exam will be considered as cheating.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
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<tr>
<td>2</td>
<td>25</td>
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<td>3</td>
<td>15</td>
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<td><strong>Total</strong></td>
<td><strong>100</strong></td>
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Problem 1: (a) Show the Carnot power cycle on a T-s diagram and indicate the areas that represent the heat rejected $Q_C$, and the net work output $W_{\text{net}}$ on the diagram. [5]

(b) In a steady flow irreversible process, the entropy of a system (circle the correct answer) [5]

(i) Always increases.  
(ii) Always decreases.  
(iii) Always remains constant.  
(iv) Can increase, decrease, or remain constant.
(c) In a reversible heat interaction, 54 kJ of energy is transferred to a thermodynamic system. The process occurs isothermally at 425 K. Determine the entropy change of the system (kJ/K).

\[
S_2 - S_1 = \frac{54 \text{ kJ}}{425 \text{ K}}
\]

\[
= 0.1271 \text{ kJ/K}
\]

No partial credit.

(d) Is the adiabatic expansion of air from 175 kPa (abs) and 60°C to 101 kPa (abs) and 5°C possible? Justify your answer. Assume air to be an ideal gas with a constant specific heat \( c_p \) of 1.005 kJ/kg.K. The molecular weight (molar mass) of air is 28.97 kg/kmol. [10]

For air (ideal gas),

\[
S_2 - S_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}
\]

\[
= 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \ln \frac{278.15 \text{ K}}{383.15 \text{ K}} - 8.3143 \frac{\text{kJ}}{\text{kmol} \cdot \text{K}} \ln \frac{101 \text{ kPa}}{28.97 \text{ kg/kmol}}
\]

\[
= -0.1813 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} + 0.1578 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}
\]

\[
= -0.0235 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}
\]
\[ \delta = m (\delta_2 - \delta_1) \]

Must be \( \geq 0 \)

\( \delta \) cannot be negative. The expansion is not possible

No partial credit will be given if the student does not recognize that the solution objective is to find the sign of \( \delta \)

(e) Are the following interpretations of the 2\textsuperscript{nd} Law True or False (circle correct answer): [10]

(i) Heat cannot be transferred from a cold body to a hot body without work interaction
   \( \text{TRUE} / \text{FALSE} \)

(ii) A heat engine cannot convert 100\% of heat input into work
     \( \text{TRUE} / \text{FALSE} \)

(iii) All heat pump cycles operating between the same two thermal reservoirs have the same COP
     \( \text{TRUE} / \text{FALSE} \)

(iv) Entropy generated for a non-adiabatic process with irreversibilities is negative
     \( \text{TRUE} / \text{FALSE} \)

(v) The Carnot efficiency places an upper limit on the efficiency of a power cycle
    \( \text{TRUE} / \text{FALSE} \)
(f) It is proposed to heat a home using a heat pump. Due to poor insulation, the house loses energy to the environment via heat transfer at the rate of 15 kW. The home is to be maintained at 20°C. The outside air is -20°C. Determine the minimum power (kW) required to drive the heat pump. [10]

\[
W_{\text{min}} = \frac{15 \text{ kW}}{7.329} = 2.047 \text{ kW}
\]

\[
\text{COP}_{\text{HP}} = \frac{T_H}{T_H - T_C} = \frac{293.15 \text{ K}}{40 \text{ K}} = 7.329
\]

15 kW of power needs to be provided to the house to keep it at 20°C.
(g) A 50-kg piece of iron at 500 K is thrown into a large lake (a reservoir) that is at 285 K. If the average specific heat of the iron is 0.45 kJ/kg.K and of the water is 4.18 kJ/kg.K, determine (a) the heat transferred from the iron to the water in kJ, and (b) the total entropy generated (kJ/K) when the iron and water are in thermodynamic equilibrium.

(a) By definition, the temperature of the reservoir does not change. For the iron as the system,

\[
(U_f - U_i)_{\text{iron}} = Q_{\text{iron}}
\]

\[
U_f - U_i = m \cdot c \cdot (T_f - T_i)
\]

\[
= 50 \text{kg} \times 0.45 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot (285 \text{K} - 500 \text{K})
\]

\[
= -4837.5 \text{ kJ}
\]

\[
Q_{\text{iron}} = -4837.5 \text{ kJ}
\]

The iron loses 4837.5 kJ, which the reservoir gains.

(b) \( S_f - S_i = \frac{Q}{T} + \delta \) 

Considering the lake and iron as an adiabatic system, \( Q = 0 \)

\[
\delta = (S_f - S_i)_{\text{iron}} + (S_f - S_i)_{\text{water}}
\]

\[
= m \cdot c \cdot \ln \frac{T_f}{T_i}
\]

\[
= 50 \text{kg} \times 0.45 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot \ln \frac{285 \text{K}}{500 \text{K}}
\]

\[
= +4837.5 \text{ kJ}
\]
\[ = 4.32 \frac{k \cdot J}{k} \]
Problem 2: A sealed, rigid container whose volume is 1 m$^3$ contains saturated water vapor at 100$^\circ$C. The container is heated until the temperature inside reaches 278$^\circ$C. Properties at the two states are given in the Table below. Determine the entropy generation (kJ/K) that occurs if the boundary of the container is maintained at a temperature of 278$^\circ$C during the heating process.

<table>
<thead>
<tr>
<th></th>
<th>(v) (m$^3$/kg)</th>
<th>(u) (kJ/kg)</th>
<th>(h) (kJ/kg)</th>
<th>(s) (kJ/kg.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sat. vapor at 100$^\circ$C</td>
<td>1.673</td>
<td>2506.5</td>
<td>2676.1</td>
<td>7.3549</td>
</tr>
<tr>
<td>Superheated vapor at 278$^\circ$C</td>
<td>1.673</td>
<td>2774.3</td>
<td>3030.0</td>
<td>7.9501</td>
</tr>
</tbody>
</table>

\[
T_1 = 100^\circ C \quad T_2 = 278^\circ C
\]

System has to be identified to get 2 pts.

Assumptions:
1. Rigid container - no work interaction
2. \( \Delta KE, \Delta PE = 0 \) in system

\[
Q = m (u_2 - u_1)
\]

\[
Q_2 = m (u_2 - u_1) = 0.5977 \text{ kg}
\]

\[
m = \frac{V_i}{v_1} = \frac{1 \text{ m}^3}{1.673 \text{ m}^3/\text{kg}} = 0.5977 \text{ kg}
\]

\[
Q_1 = 0.5977 \text{ kg} \left( \frac{2774.3 \text{ kJ}}{\text{kg}} - \frac{2506.5 \text{ kJ}}{\text{kg}} \right) = 160.1 \text{ kJ}
\]
2. \[ S_2 - S_1 = \frac{Q_{12}}{T_b} + z_{12} \]

3. \[ z_{12} = m(S_2 - S_1) - \frac{Q_{12}}{T_b} \]

recognizing that \[ z_{12} \neq 0 \]

\[
= 0.5977 \text{kg} \left( 7.9501 \frac{\text{kJ}}{\text{kg} \cdot \text{k}} - 7.3549 \frac{\text{kJ}}{\text{kg} \cdot \text{k}} \right) - \frac{160.1 \text{kJ}}{551.15 \text{k}}
\]

\[
= 0.3558 \frac{\text{kJ}}{\text{k}} - 0.2905 \frac{\text{kJ}}{\text{k}}
\]

\[
= 0.0653 \frac{\text{kJ}}{\text{k}}
\]
Problem 3: Determine the entropy generation rate when Refrigerant-134a flowing at a steady rate of 1 kg/s is throttled adiabatically from the saturated liquid state at 700 kPa (abs) to a pressure of 160 kPa (abs) (kW/K).

**Assumption:**
Adiabatic
\[ \Delta q = 0 \]

\[ \Delta u = 0 \]

**Steady state**

**Governing equation:**
\[ \dot{h}_1 = \dot{h}_2 \]

\[ \frac{d\Delta s}{dt} = \frac{\dot{Q}}{T} + m(\Delta h_1 - \Delta h_2) + \Delta \]

\[ \Delta h = m(\Delta h_2 - \Delta h_1) \]

**Solution:**

From Table A-11

At 700 kPa, Sat. liquid
\[ s_1 = 0.3242 \text{ kJ/kg.K} \]
\[ h_1 = 86.78 \text{ kJ/kg} \]

At 160 kPa
\[ h_2 = 86.78 \text{ kJ/kg} \]

\[ \text{lies in SLVM region} \]
Quality

\[ \chi = \frac{h_2 - h_{fg}}{h_{fg}} \]

\[ = \frac{86.78 \text{ kJ/kg} - 29.78 \text{ kJ/kg}}{208.19 \text{ kJ/kg}} \]

\[ = 0.2738 \]

\[ S_2 = S_{fg} + \chi (S_{fg} - S_{fg}) \]

\[ = 0.1211 \text{ kJ/kg.k} + 0.2738 (0.9295 \text{ kJ/kg.k} - 0.1211 \text{ kJ/kg.k}) \]

\[ = 0.3424 \text{ kJ/kg.k} \]

\[ = \frac{1}{5} \left( 0.3424 \text{ kJ/kg.k} - 0.3242 \text{ kJ/kg.k} \right) \]

\[ = 0.0182 \text{ kW/k} \]