EXAM 2

INSTRUCTIONS

- This is a closed book and closed notes exam. Answer as many questions as you can in the allotted time. Do not hesitate to ask questions if you do not understand a problem statement. For your own benefit, please write clearly and legibly. Maximum credit for each problem is indicated below. To receive full credit for a problem, you must follow instructions, show all work, and write the answers in the appropriate boxes.

- For Problems 1 and 2, significant partial credit will be given if you start with the basic equation(s), list all assumption(s), and illustrate the method by which you propose to solve the problem correctly. Some parts of Problem 3 will be given no partial credit.

- Do not write on the back of any page. Material on the back of a page may not be graded. If additional pages are needed, ask for additional pages. Insert the extra pages in their proper order and staple them to the exam.

- The use of PDAs, Blackberry-type devices, cell phones, laptop computers, or any other sources of communication (wireless or otherwise) are strictly prohibited during examinations. Doing so is cheating. If you bring a cell phone or other communication devices to the examination, they must be turned off prior to the start of the exam, placed in your backpack, and the backpack stored below your seat, and only picked up as you leave the examination room for the final time. They are not to be turned on again until after you have exited the examination room. Otherwise it will be considered a form of cheating and treated as such.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td></td>
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<tr>
<td>2</td>
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<td></td>
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<tr>
<td>3</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
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</table>
Problem 1: (25 points)

Given:
Two identical tanks, both insulated and both having a volume of 1 m³, are connected by a valve. Tank A initially contains air at a pressure of 10 bar and a temperature of 500 K; tank B initially contains air at a pressure of 1 bar and a temperature of 300 K. The valve is opened and the entire system proceeds to thermodynamic equilibrium.
Assume that specific heats of air are constant at $C_v = 0.718$ kJ/kg-K and $C_p = 1.005$ kJ/kg-K. You must consider constant specific heats for air. No credit will be given for analysis (even though more accurate) using variable specific heats.

Find:
What is the final temperature (°C) of air? Write any necessary assumptions, equations, and show your solution in the spaces provided. (13 points)

**Assumptions:** (6 points)
Basic Equations: (6 points)

Problem 1 Solution:
Problem 1 Solution (continued):
Problem 2: (45 points)

Given:
A sub-system of a certain chemical processing industry consisting of a heat exchanger, a steam turbine, and an air compressor operating at steady state is shown below.

- There is no stray heat transfer from the heat exchanger to its surroundings.
- Air at a pressure of 1 bar and a temperature of 450 K (state 1) enters the heat exchanger and is cooled to a pressure of 1 bar and a temperature of 400 K (state 2) at the exit of the heat exchanger.
- The air is then compressed using an insulated compressor and exits at a pressure of 3 bar and a temperature of 630 K (state 3).
- The mass flow rate of air through the heat exchanger and compressor is 2 kg/s.
- The heat lost by air in the heat exchanger is used to heat saturated water vapor entering the heat exchanger at a pressure of 3 bar (state 4). At the exit of the heat exchanger, the pressure and temperature of water are 3 bar and 200°C, respectively (state 5).
- After expansion through an insulated turbine, water exits at a pressure of 1 bar (state 6).
- All the power output of the turbine is used as power input for the air compressor.

Assume ideal gas behavior for air. You must consider variable specific heats for air.
Find:
(a) Complete the following tables for air and water. (10 points)

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure (bar)</th>
<th>Temperature (K)</th>
<th>Specific Enthalpy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>630</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure (bar)</th>
<th>Temperature (°C)</th>
<th>Specific Volume (m³/kg)</th>
<th>Specific Enthalpy (kJ/kg)</th>
<th>Phase</th>
<th>Quality (%) (If Applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>sat. vapor</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) Calculate the mass flow rate (kg/s) of water by performing energy balance for the heat exchanger. Write any necessary assumptions, equations, and show your solution in the spaces provided. (7 points)

(b) Mass flow rate of water = kg/s

(c) After finding the mass flow rate of water, now complete the following table for state 6 of water at the exit of the turbine. Write any necessary assumptions, equations, and show your solution in the spaces provided. (11 points)

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure (bar)</th>
<th>Temperature (°C)</th>
<th>Specific Volume (m³/kg)</th>
<th>Specific Enthalpy (kJ/kg)</th>
<th>Phase</th>
<th>Quality (%) (If Applicable)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(d) Show the entire process for water (from state 4 to state 6) on the P-v diagram. You must show pressure values and appropriate lines of constant of temperature. (5 points)
Name: __________________________________   Thermo No: _____________________

(Last)                          (First)

Assumptions: (4 points)

Basic Equations: (8 points)

Problem 2 Solution:
Problem 2 Solution (continued):
Problem 3: (30 points)

Write your answers in the boxes provided for each question. Only the answers written in the boxes will be graded. For Problem 3 only, you do not have to list assumptions; however, you must show work (basic equations and calculations to support your answers) to receive full credit. There is no partial credit for 3(a) and 3(b).

(a) The variation of specific heat, $C_p$, of an ideal gas as function of temperature is shown below for two different pressures. State whether the shown $C_p$ variation for the ideal gas is true or false. You must provide justification with no more than two sentences to receive any credit.

(b) Propane has a molar mass of 44.09, a critical pressure of 42.7 bar, and a critical temperature of 370 K. Indicate by circling one of the answers the combination of pressure and temperature for which propane will show the most ideal gas behavior. You must provide justification with no more than two sentences to receive any credit.

Hint: It is not necessary to find the actual values of compressibility factor.
(c) Liquid water flows through a constant diameter, perfectly insulated pipe at steady state. The temperature of water at locations 1 and 2 is 20°C. What is difference between pressures \( (P_1 - P_2) \) (kPa) at locations 1 and 2? You must show work with appropriate equation(s) to receive full credit.

(8 points)

\[
\]
(d) An ideal gas has a molar mass of 8.314 kg/kmol. At a temperature of $T_1$ (in K), the specific internal energy and specific enthalpy values of this ideal gas are 3,000 kJ/kg and 5,000 kJ/kg, respectively. At another temperature of $T_2$ (in K), the specific internal energy and specific enthalpy values of the same ideal gas are 6,000 kJ/kg and 10,000 kJ/kg, respectively.

The value of universal gas constant is: $R = 8.314 \frac{\text{kJ}}{\text{kmol-K}}$

(d1) What is the ratio of specific heats, $k = C_p/C_v$, for this ideal gas? You must show work with appropriate equation(s) to receive full credit.

(5 points)

(d1) Ratio of specific heats ($k$) for the given ideal gas =

(d2) Calculate the two unknown temperatures, $T_1$ and $T_2$. You must show work with appropriate equation(s) to receive full credit.

(7 points)

(d2) $T_1 =$ K

$T_2 =$ K