EXAM 3

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.

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Problem 1: (30 points)

Given:
A pure substance is contained inside a piston-cylinder device. Initially, the substance is saturated liquid. Heat is transferred slowly to the device such that only vapor remains in the device. The reversible phase change process from saturated liquid (state 1) to saturated vapor (state 2) occurs at constant pressure of 5 bar during which temperature remains constant at 177°C.
For the given pure substance, at $P = 5$ bar:
$T_{sat} = 177°C$, $v_f = 0.05 \text{ m}^3/\text{kg}$, $v_g = 0.5 \text{ m}^3/\text{kg}$, $s_f = 1 \text{ kJ/kg-K}$, and $s_g = 5 \text{ kJ/kg-K}$

Find:
(a) Show the process from state 1 to state 2 on $P$-$v$ and $T$-$s$ diagrams in relation to the vapor dome. You must label states, show values of property (pressure, temperature, specific volume, and specific entropy), and indicate appropriate lines of constant pressure and temperature on both diagrams. (10 points)

(b) What is the change in specific internal energy (kJ/kg) of the substance during the reversible phase change process from state 1 to state 2? Write any necessary assumptions, equations, and show your solution in the spaces provided. (10 points)
Assumptions: (2 points)

Basic Equations: (8 points)

Problem 1 Solution:
Problem 2: (30 points)

Given:
Air flowing through a throttling valve and an un-insulated turbine is shown below. Air enters the throttling valve at 10 bar and 1400 K (state 1). The flow through the throttling valve is isenthalpic i.e. $h_1 = h_2$. At the exit of throttling valve, the pressure of air drops to 5 bar (state 2). Stray heat loss of 500 kJ/kg occurs from the turbine to its surrounding. The average surface temperature of the turbine at which stray heat transfer occurs is 500 K. At the exit of the turbine, the pressure of air is 1 bar (state 3). Entropy generation for the turbine is 1 kJ/kg-K.

Assume ideal gas behavior for air and that specific heats of air are constant. You must consider constant specific heats for air. No credit will be given for analysis (even though more accurate) using variable specific heats.

\[
\overline{R} = 8.314 \text{kJ/kmol-K} \quad ; \quad M_{\text{air}} = 28.97 \text{kg/kmol} \quad ; \quad C_{v,\text{air}} = 0.718 \text{kJ/kg-K} \quad ; \quad \text{and} \quad C_{p,\text{air}} = 1.005 \text{kJ/kg-K}
\]

Hint:
For an ideal gas, enthalpy depends only on temperature; entropy depends on temperature and pressure (or specific volume)

Find:
(a) Calculate the change in specific entropy (kJ/kg-K) of air from state 1 to state 2 i.e. across the throttling valve. Write any necessary assumptions, equations, and show your solution in the spaces provided. (7 points)

(b) What is the temperature (K) at the exit of the turbine? Write any necessary assumptions, equations, and show your solution in the spaces provided. (7 points)

Problem 2(c) on the next page
(c) Show the entire process for air (from state 1 to state 3) on the $T$-$s$ diagram. You must show temperature values and appropriate lines of constant of pressure. Do not show values for specific entropy. (8 points)

Assumptions: (2 points)

Basic Equations: (6 points)
Problem 2 Solution:
Problem 3: (40 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).

(a) What assumptions are required to apply the equation $Tds = dh - vdP$? Circle all that apply. (5 points)

Internally Reversible Process
Constant Volume Process
Closed System
Insulated System

Quasi-equilibrium Process
Constant Temperature Process
Open System
None of the above

(b) In a heat pump cycle, 200 kJ of heat is removed from a reservoir at a temperature of -33°C and is rejected to another reservoir at a temperature of 127°C. The heat pump requires 100 kJ of work. Indicate whether the given heat pump cycle is reversible, irreversible, or impossible by circling one answer. You must support your answer with appropriate equation(s) to receive full credit. (8 points)

(b) Reversible Irreversible Impossible
(c) A reversible process between two arbitrary states of a closed system is shown on the $P$-$v$ diagram below. Indicate the work during the process by circling one answer. You must support your answer to receive full credit. (6 points)

(c) $200 \text{ kJ/kg}$ $300 \text{ kJ/kg}$ $400 \text{ kJ/kg}$ $500 \text{ kJ/kg}$ Indeterminate

(d) An irreversible process between two arbitrary states of a closed system is shown on the $T$-$s$ diagram below. Indicate the heat transfer during the process by circling one answer. You must support your answer to receive full credit. (6 points)

(d) $30 \text{ kJ/kg}$ $50 \text{ kJ/kg}$ $84.6 \text{ kJ/kg}$ $100 \text{ kJ/kg}$ Indeterminate
(e) A system consisting of a reversible heat engine and a reversible refrigerator is shown below. The heat input to the reversible heat engine is 1000 kJ from a reservoir at 1000 K while the work input to the reversible refrigerator is 300 kJ.

Answer the following questions. You must show work with appropriate equation(s) to receive full credit.

(e1) What is the total amount of heat rejected (kJ) to the reservoir at 300 K? (10 points)

\[
\text{(e1) Total heat rejected to the 300 K reservoir} = \boxed{\text{kJ}}
\]

(e2) What is the change in entropy (kJ/K) for the reservoir at 300 K? (5 points)

\[
\text{(e2) Entropy change for the 300 K reservoir} = \boxed{\text{kJ/K}}
\]