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 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:
Saturated liquid water at 200°C (state 1) is expanded inside a piston-cylinder device via an internally reversible, isothermal (constant temperature) process. The pressure inside the cylinder at the end of expansion is 10 bar and the temperature is 200°C (state 2).

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 show the appropriate lines of constant pressure on both diagrams. Indicate the work and heat transfer during the process on $P-v$ and $T-s$ diagrams, respectively. (10 points)

(b) What is the heat transfer per unit mass (kJ/kg) during the expansion process from state 1 to state 2? (6 points)

(b) Heat transfer during the expansion process = ______________________ kJ/kg

(c) Calculate the work per unit mass (kJ/kg) during the expansion process from state 1 to state 2. (6 points)

(c) Work during the expansion process = ______________________ kJ/kg
Assumptions: (2 points)

Basic Equations: (6 points)

Solution:
Problem 2: (30 points)

Given:
Air flowing steadily at the rate of 2 kg/s expands in a turbine from 5 bar pressure and 450 K temperature at the inlet to an exit pressure of 1 bar and temperature of 300 K. Stray heat loss of 53.22 kW occurs from the turbine to its surrounding. The average surface temperature of the turbine at which the stray heat transfer occurs is 370 K.

\[ \bar{R} = 8.314 \text{kJ/kmol-K} \quad \text{and} \quad M_{\text{air}} = 28.97 \text{kg/kmol} \]

You must consider variable specific heats for air. No credit will be given for analysis using constant specific heats.

Find:
(a) Calculate the power developed (kW) by the turbine. (7 points)

(b) Calculate the rate of entropy production (kW/K) within the turbine. (5 points)

Assumptions: (4 points)

Basic Equations: (14 points)
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.

(a) A reversible heat pump receives certain quantity of heat from a thermal reservoir at -23°C and rejects 120 kJ of heat to another thermal reservoir at 27°C. You must show work with appropriate equations to receive full credit.

(a1) Calculate the coefficient of performance of the heat pump.

(5 points)

(a2) What is the work required (kJ) for the heat pump operation?

(5 points)

(b) Air executes a Carnot power cycle consisting of the following four reversible processes inside a piston-cylinder device.
Process 1-2: Isothermal compression
Process 2-3: Adiabatic compression
Process 3-4: Isothermal expansion
Process 4-1: Adiabatic expansion

Show the cycle on the T-s diagram. (5 points)
(c) An irreversible heat engine receives heat input from two thermal reservoirs: 1000 kJ from a thermal reservoir at 227°C and 500 kJ from another thermal reservoir at 727°C. The heat engine rejects 900 kJ of heat to a thermal reservoir at 27°C and produces 600 kJ of work.

Is this irreversible heat engine possible for the given heat interactions with the related thermal reservoirs? You must perform an analysis based on the second law of thermodynamics or the Clausius inequality to support your answer.

(6 points)

(d) 5 kg of water at temperature of 100°C and pressure of 5 bar is cooled at constant pressure to a temperature of 20°C. Calculate the change in entropy (kJ/K) for water.

(5 points)
(e) A monoatomic ideal gas \((k = 1.667)\) is heated from pressure of 1 bar and temperature of 300 K to a pressure of 5 bar and temperature of 600 K. The specific heat at constant volume \((C_v)\) for this ideal gas is known to be 3 kJ/kg-K. Assume constant specific heats for the gas. Calculate the change in specific entropy (kJ/kg-K) for this ideal gas. You must show work with appropriate equations to receive full credit.

(8 points)

(f) Air is compressed in an isentropic process from pressure of 100 kPa and temperature of 300 K at the inlet to a pressure of 450 kPa at the exit. Consider variable specific heats for air. Do not interpolate; use the closest values for properties of air from appropriate table.

Calculate the temperature of air at the exit.

(6 points)

(f) Temperature of air at the exit of the compressor = \(\) K

(e) Change in specific entropy for the given ideal gas = \(\) kJ/kg-K