THE UNIVERSITY OF MANITOBA

6.00pm, April 13 2004	Final Examination
Paper No: 151	Page No: Page 1 of 6
Dept. and Course No.: 130.112	Time: 3 Hours
Examination.: Thermal Science	Examiners: Drs. D. Fraser, E. Bibeau, R. Xu, O.Adeyinka

Instructions:

- Answer 5 out of the 6 questions in this exam. Each problem is worth 20 points.
- Follow the "Problem-Solving Technique" discussed in class.
- The exam is 3 hours long, open book, and use of a calculator is permitted.
- You are allowed only one double-sided crib sheet and copies of Section 3-1 from the heat transfer text book.
- When you are finished, take time to review your work and double check units and formulas; make sure you have assumptions in every problem solution, have made a sketch, have shown the units and inputs, and have drawn a T-V or P-V diagram if applicable.
- Ask for clarification if any problem statement is unclear to you.
- Retain all the significant figures of properties and molecular weights taken from tables, in your calculations. Final results require at least 3 significant digits.
- Assume constant specific heats.

Values **Problem #1 (20 points):** A rigid tank contains 3 ideal gases: methane (CH_4), oxygen (O_2), and carbon monoxide (CO). At the start of the process (**State 1**), each gas is separated using adiabatic and impermeable membranes and the temperature of each gas is 87.10°C (CH_4), 200.00°C (O_2), and 19.87°C (CO). The three gases are then mixed together by removing the membrane as shown in the figure. A paddle is used to keep the fluid mixture homogenous and requires 100.00 kJ/kg of work during the process. Heat transfer also occurs across the tank boundary. The final temperature of the mixture is 200.00°C (**State 2**). The mixture mole fraction composition is 0.500 CH_4, 0.300 O_2, and 0.200 CO. Assume the mixture to be an ideal gas and that no chemical reaction occurs. Neglect changes in kinetic and potential energies.

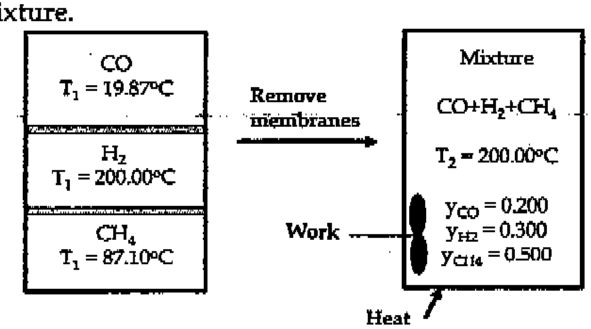
(4) (a) Calculate the mass fractions of each component.

(4) (b) Calculate the gas constant for the mixture in kJ/kg K.

(4) (c) Calculate the mixture C_v in kJ/kg K.

(4) (d) Calculate the change in internal energy of the system per unit mass of mixture.

(4) (e) Determine the magnitude and direction of the heat transfer across the tank wall per unit mass of mixture.



Values **Problem #2 (20 points):** A person is replacing his oil furnace with a heat pump that has a COP of 2.00 to heat his house during winter. The average outside winter temperature is -5.0°C. The heat pump will supply the required energy to the house which is maintained at a constant temperature of 24.8°C during winter. The heat load can be estimated by the oil consumed during winter by the furnace which is 1.00 kg per hour. Assume the heating value of oil is 42,000 kJ/kg and that the furnace has an efficiency of 85.7%. (Hint: The energy from the furnace going to heat the house is the furnace efficiency multiplied by the heating value of the oil).

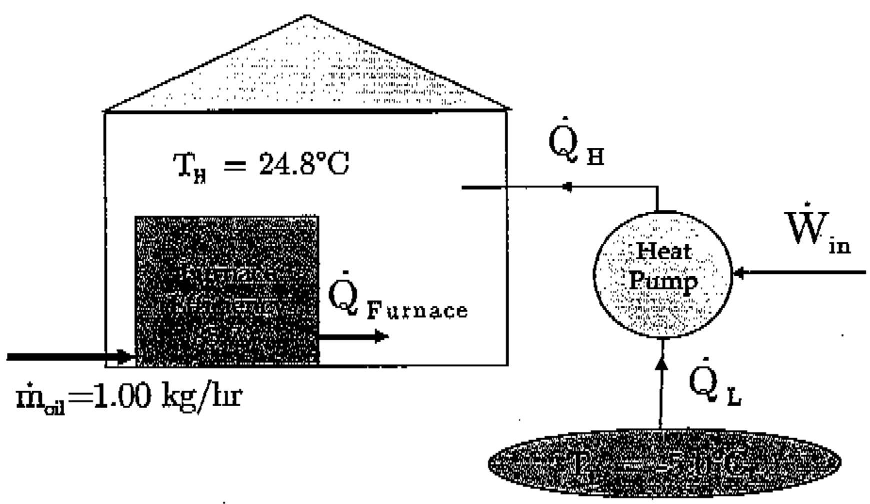
(4) (a) Estimate the average heat requirements of the house during winter in kW.

(5) (b) Calculate the heat pump power and the heat transferred from the outside air in kW.

(5) (c) What is the minimum power required to drive the heat pump and the maximum heat that can be transferred from the outside air to maintain the house at 24.8°C during winter?

(3) (d) How much power would be consumed if electrical heaters were use instead of a heat pump in kW?

(3) (e) Which requires less work: the heat pump or the electrical resistive heating? Explain.



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Values **Problem #3 (20 Points):**

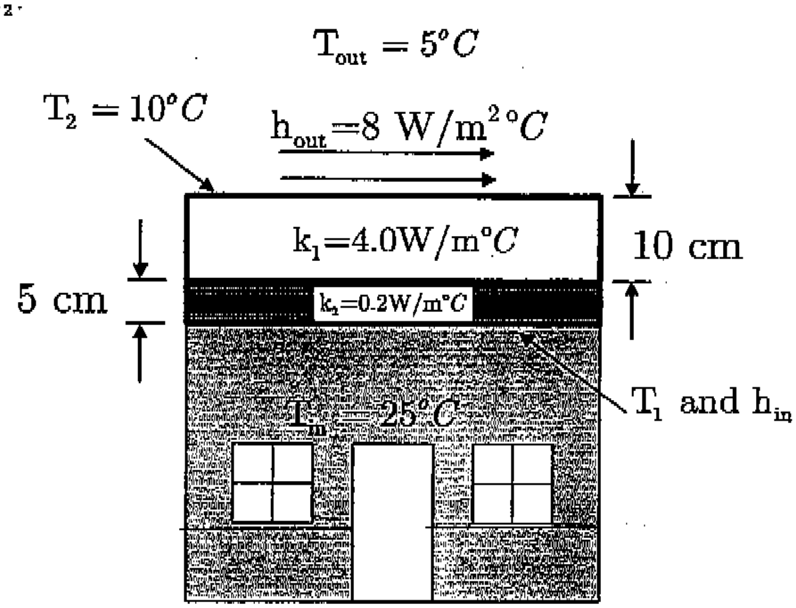
The roof of a house consists of a 10 cm thick concrete slab ($k_1 = 4.0\ W/m°C$) and 5 cm thick of insulation ($k_2 = 0.2\ W/m°C$), as shown in the figure. The roof is 20 m wide and 25 m long. The inside surface of the roof at T_1 is exposed to convection with room air. The room air temperature, T_{in}, is $25°C$. On a beautiful spring morning, the temperature of the ambient air is $5°C$ (no wind chill!) and the heat transfer coefficient at the outer surface of the roof, $h_{out}=8\ W/m^2 °C$. The outer surface of the roof is at $T_2=10°C$ and it dissipates heat by convection to the ambient air. Assume the heat transfer through the sides of the concrete slap is negligible. Neglect radiative heat transfer.

(4) (a) Determine the total rate of heat loss from the roof to the surrounding air, Q_{tot} in kW.

(5) (b) Determine the inner surface temperature of the roof, T_1 in $°C$.

(4) (c) Determine the convection heat transfer coefficient between the air in the house and the inner surface of the roof, h_{in} in $W/m^2 °C$.

(7) (d) At night, the ambient air temperature drops to $-5°C$ so that additional heat is required from the furnace to keep the room warm with $T_{in} = 25°C$. If h_{out} and h_{in} remains the same, determine the new rate of heat loss, Q'_{tot} and the outer surface temperature of the roof, T_2.



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Values **Problem #4 (20 Points):** A steam power plant that also provides heating for industrial purposes is shown in the Figure below. Steam generated by the boiler at a rate of $\dot{m}_b$=4 kg/s enters the turbine where it expands from P_1=3 MPa and T_1=400°C down to P_2= 100 kPa and a quality of 95%. Part of the mass flow, $\dot{m}_{he}$ leaving the steam turbine goes through a heat exchanger, where it exits as a saturated liquid at P_4= 100 kPa, before it flows into a mixing chamber. Heat is extracted in the heat exchanger for industrial heating. The rest of the turbine exhaust flow passes through a condenser where it exits as a compressed liquid at T_3=60°C. The two streams are combined in a mixing chamber. The outlet stream from the mixing chamber is at a pressure P_5=100 kPa and T_5=75°C. The exit flow from the pump is at a pressure of 3 MPa. Assume that the turbine, valve, mixing chamber and pump are adiabatic and the kinetic and potential energies throughout the cycle are negligible. The pressure drop across the condenser and the heat exchangers are also negligible.

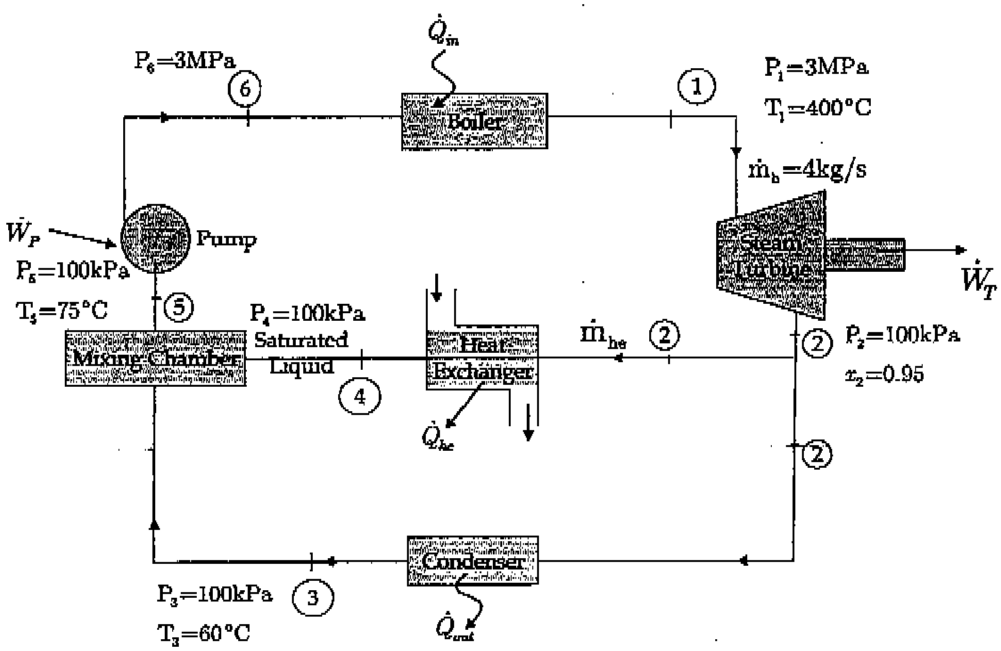
(5) (a) Determine the rate of heat transfer to the boiler, $\dot{Q}_{in}$ in kW.

(3) (b) Determine the power output of the steam turbine, $\dot{W}_T$ in kW.

(6) (c) Determine the mass flow rate of steam through the heat exchanger, $\dot{m}_v$ in kg/s.

(3) (d) Determine the rate of heat extraction from the heat exchanger, $\dot{Q}_{he}$ in kW.

(3) (e) Determine the **NET** power output of the steam cycle in kW.



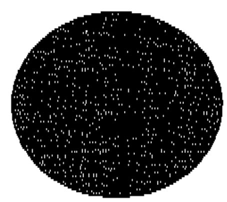
Values **Problem #5 (20 Points):** Consider a helium gas balloon that has the following characteristics as shown in the figure. The balloon has an initial volume of $15\ m^3$, is at a temperature of $20°C$, and at an absolute pressure that is equal to the surrounding atmosphere which is 100 kPa **(State 1)**. The balloon is heated. As the balloon expands the pressure remains constant at 100 kPa until the volume reaches $20\ m^3$ **(State 2)**. The balloon is then further heated until the temperature of the helium reaches $400°C$ at which point the absolute pressure is 150 kPa **(State 3)**. During the expansion from state 2 to state 3, the pressure in the balloon is given by (due to the elastic nature of the balloon fabric):

$$P = 100 + C\,(V - 20)^2 \qquad \text{where P is in kPa; V is in m}^3$$

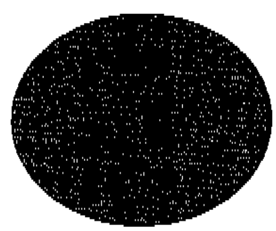
(4) (a) Calculate the value of constant "C" in the above equation.
(6) (b) Calculate the work done by the helium during the process.
(5) (c) Calculate the change in internal energy of the balloon during this process.
(5) (d) Calculate the heat transfer to the balloon during this process.

State 1: $P_1 = 100\ kPa\ ;\ V_1 = 15\ m^3$
$T_1 = 20°C$

State 2: $P_2 = 100\ kPa\ ;\ V_2 = 20\ m^3$



State 3: $P_3 = 150\ kPa\ ;\ T_3 = 400°C$



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Problem #6 (20 Points): A fire-hose-injector in a plant is designed to use steam to pump fluid rather that using pressurized water. Cold water at 25.0°C and 100.0 kPa pressure is drawn from a water tank (inlet 1). Superheated steam enters the injector at a pressure of 1000.0 kPa, at a temperature of 250°C, and a velocity of 300.0 m/s (inlet 2). All the steam is condensed in the injector. Compressed water exits the injector at a pressure of 800.0 kPa, temperature of 100.0°C, and at a velocity of 30.0 m/s (outlet 1). The flow rate of the steam entering the injector is 0.20 kg/s and the flow rate of the water entering the injector is 2.00 kg/s. The mixing of the steam and water occurs slowly without producing oscillations, the process is steady, all potential energies can be neglected, and the kinetic energy of the water entering the injector can be assumed negligible.

(5) (a) On a $P - v$ diagram show the state of the inlet steam, the inlet water, and the exit nozzle (you do not have to draw the process, just show the 3 state points with proper labels). What is the specific enthalpy of all three states in kJ/kg, and the exit mass flow rate from the nozzle outlet in kg/s?

(4) (b) What is the change in the kinetic energies between the two inlets and the exit of the injector?

(6) (c) What is the heat transfer from the surroundings to the injector in kW. Describe the direction of the actual heat transfer.

(5) (d) How much heat in kW is absorbed from the fire to change the nozzle exit water from 30°C and 100 kPa to saturated steam conditions at 100 kPa (ignore kinetic energy and potential energy changes).