THE UNIVERSITY OF MANITOBA

1:30 p.m. 14 December 20 06 FINAL EXAMINATION

PAPER NO.: 397

DEPARTMENT & COURSE NO.: ENG 1460 TIME: 3 HOURS

EXAMINATION: Thermal Sciences EXAMINER: Dr. J. Bartley, Dr. S. Ormiston

Values

Instructions:

1. You are permitted to use the textbooks for the course and a calculator.
2. Clear, systematic solutions are required. **Show your work.** Marks will not be assigned for problems that require unreasonable (in the opinion of the instructor) effort to decipher.
3. Ask for clarification if any problem statement is unclear to you.
4. Use linear interpolation between table entries as necessary. Use constant specific heat.
5. Retain all the significant figures and units of property values from tables. Keep 4 or 5 significant figures in your intermediate results. Final answers must have 3 to 5 significant figures and units.
6. There are **five** questions on this exam. The weight of each problem is indicated. The exam will be marked out of 100.

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25 **1.** A saturated mixture of water is contained in a piston-cylinder assembly as shown in Figure 1. The water has an initial quality of 25%. The mass of the piston is $m_P = 80.09$ [kg] and it has a diameter $D_P = 10$ [cm]. Take the atmospheric pressure to be 100 [kPa]. The piston is initially motionless at a distance of 40.0 [cm] from the bottom of the cylinder. The maximum height the piston can rise to, where it hits a set of stops, is 181.0 [cm] from the bottom of the cylinder, as shown in the figure. Heat is transferred to the water in the cylinder until a final pressure of 400 [kPa] is reached. Use a gravity constant $g = 9.80665$ [m/s^2].

7 (a) Determine the initial pressure, P_1, and specific volume, v_1, of the water in the cylinder. Also determine the mass, m, of the water.

6 (b) Determine if the piston hits the stops before the final pressure is reached. If so, describe the state and determine the pressure, P, temperature, T, and specific volume, v, for this state.

1 (c) Describe the final state, with $P = 400$ [kPa], and determine the final temperature and specific volume.

1 (d) Calculate the work done during the heating process, in [kJ].

5 (e) Determine the amount of heat transferred to the water, Q, in [kJ], for the overall process.

5 (f) Show the state points and process path(s) on a P-v diagram relative to the saturation lines. Also indicate on the sketch constant temperature lines, saturation pressures, and the region that represents work done.

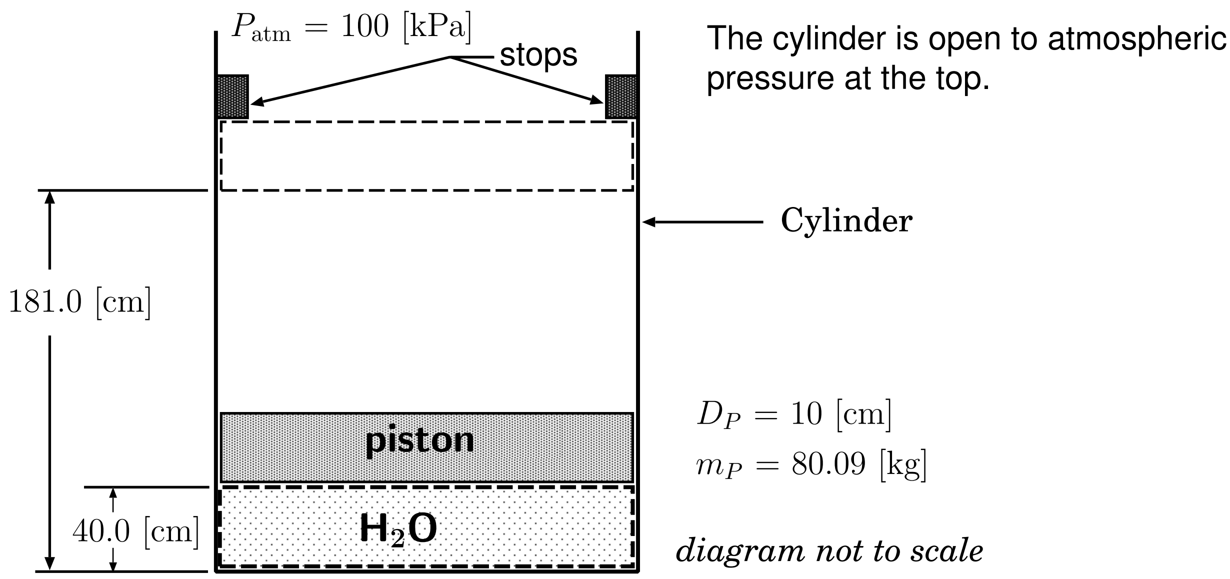

Figure 1: Figure for problem **1**

Values

41 **2**. Figure 2 shows a schematic of a combined cycle power plant in which a simple closed loop cycle using helium is added to a vapour power cycle using water. The energy source for heating the helium is a nuclear reactor. The two cycles are connected via an insulated heat exchanger. The steady-state operating conditions are shown in the figure. The water leaves the heat exchanger as saturated vapour at 10 [MPa]. The water is passed through a superheater so that it is at 550 [°C] and 10 [MPa] before entering the steam turbine. The turbine exhaust has a quality of 90% at 10 [kPa]. Saturated liquid leaves the insulated condenser and enters the pump, where it exits at 47.5 [°C] and 10 [MPa]. In the condenser, the energy from the water in the power loop is transferred to cooling water drawn from a lake. The temperature of the cooling water rises from 15 [°C] to 35 [°C] as it passes through the condenser and its mass flow rate is 1750 [kg/s]. The helium exits the heat exchanger at 1.38 [MPa] and 80 [°C]. After passing through the compressor, the helium is at 5.50 [MPa] and 407 [°C]. The helium passes through the reactor and is heated to 760 [°C] with negligible pressure change. After expanding through the gas turbine, the helium is at 1.38 [MPa] and 395 [°C]. The gas turbine shaft work output is used to drive the compressor and to produce a net power output. The compressor, turbines, and pump are also insulated (*i.e.*, adiabatic). Neglect changes in potential and kinetic energies.

11 (a) Determine the mass flow rate in the steam power cycle, $\dot{m}_W$, in [kg/s].

2 (b) Determine the power output of the steam turbine, $\dot{W}_{T1}$, in [kW].

12 (c) Determine the net power output of the gas turbine, $\dot{W}_{T2,\mathrm{net}}$, in [kW].

9 (d) Determine the thermal efficiency of the combined cycle.

7 (e) On two separate T-v (temperature–specific volume) diagrams, draw process representations for the steam cycle and the helium cycle. On the diagrams, clearly indicate the labelled state points, the process paths (use a dashed line if the path is unknown), and the constant pressure lines that pass through the state points. Indicate state temperature values and saturation temperature values for reference as appropriate. Do any additional work necessary to label the diagram. Labelling v values is optional.

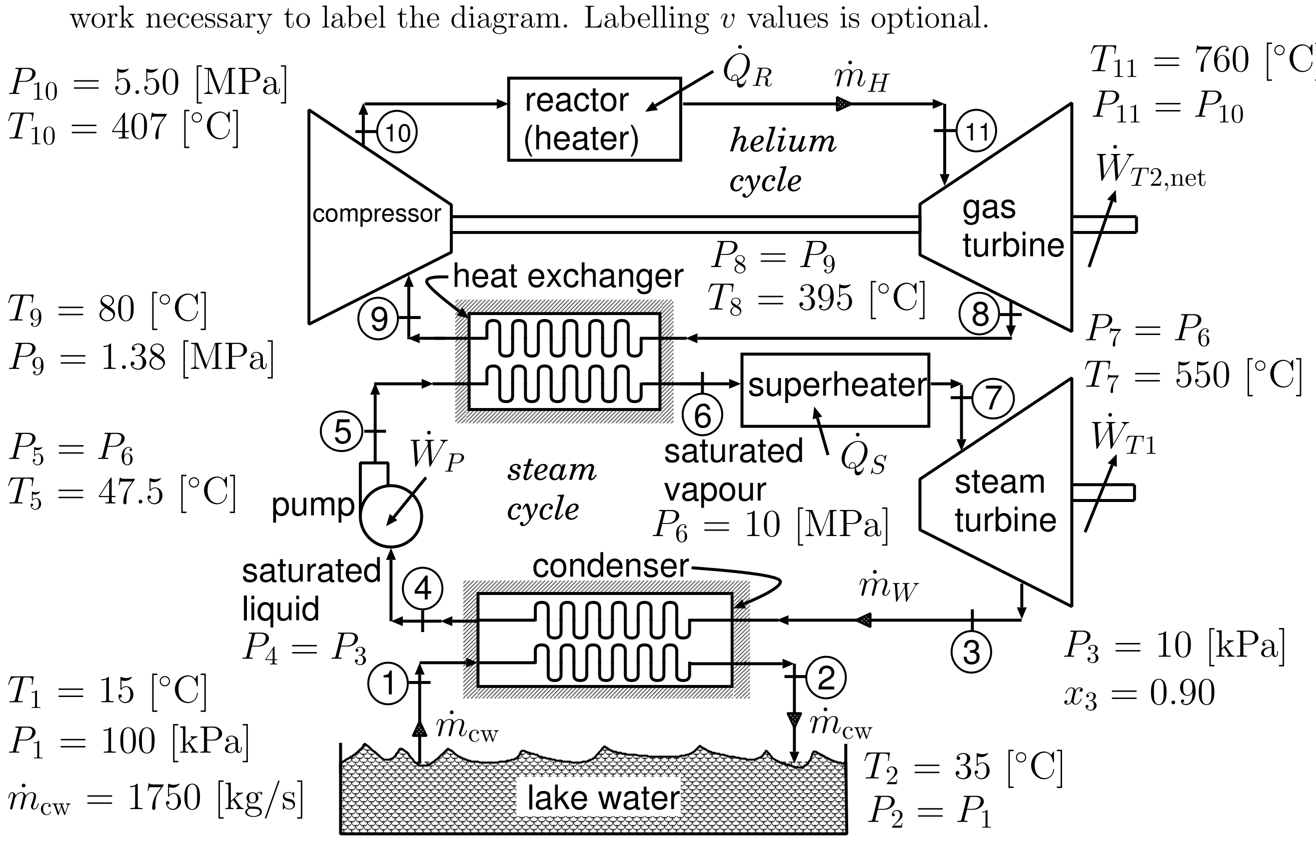

Figure 2: Figure for problem **2**

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3. A rigid and well-insulated chamber is divided by a partition that is initially pinned in place at the position shown in Figure 3. The partition separates two gases, air and CO_2 gas, and the partition is free to move without friction once the pin is pulled. The partition allows for the transfer of heat between both sides of the chamber. There is 1.5 [kg] of air which is at an initial pressure and temperature of 500 [kPa] and 350 [K], respectively. On the other side of the partition is 4 [kg] of CO_2 gas at an initial pressure and temperature of 200 [kPa] and 478 [K], respectively. Assume the air and CO_2 are ideal gases with constant specific heats. A process occurs whereby the pin is pulled out and the gases in the chamber are allowed to reach a new state of equilibrium in a quasi-equilibrium manner (assume the partition moves very slowly as the states change).

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11 (a) Determine the final temperature, T_2, corresponding to the final state of the gases.

11 (b) Determine the final pressure, P_2.

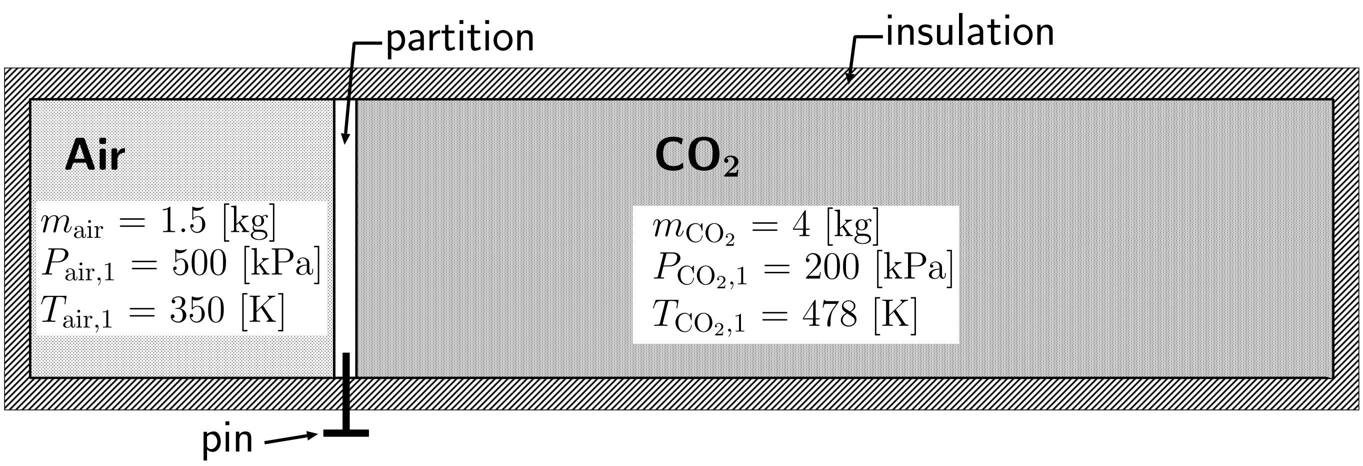

Figure 3: Figure for problem **3**

4. The performance of a heat pump degrades (*i.e.*, its coefficient of performance decreases) as the temperature of the heat source decreases. Consider a house that is maintained at 22 [°C] by a heat pump during winter. Determine the maximum coefficient of performance for this heat pump if the heat is extracted from outdoor air at (a) 0 [°C] and (b) −20 [°C].

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5. A common sense recommendation is that, in order to save energy, hot foods should be first left to cool to room temperature before they are put into the refrigerator. Despite this recommendation, three times per week (156 times per year) a person you know puts a large casserole into the refrigerator while it is still hot, thinking that the money to be saved is probably small. He says that he can be convinced otherwise, however, if you can show him that the money to be saved is significant.

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The average mass of the casserole and its contents is 4 [kg]. The average temperature of the kitchen is 21 [°C], and the average temperature of the casserole is 101 [°C] when it is currently being put away in the refrigerator. The average specific heat of the casserole dish and its contents can be taken to be 3.5 [kJ/kg · K], and the refrigerated space is maintained at 3 [°C]. If the refrigerator has a coefficient of performance of 1.2 and the cost of electricity is 10 cents per kWh, determine how much money this person would save in a year by waiting for the food to cool to room temperature before putting it into the refrigerator.