THE UNIVERSITY OF MANITOBA

9:00 a.m. 20 April 20 06 FINAL EXAMINATION

PAPER NO.: 580

DEPARTMENT & COURSE NO.: 130.112 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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18 **1.** A 14.4 mm thick mirror mounted on a 22.5 mm thick plaster wall in a hotel bathroom is shown schematically in Figure 1. The mirror has a surface area of 0.8 m^2 and is mounted with a very thin electrically powered heating strip between it and the wall. When the heating strip is operating, it produces energy at a rate denoted by $\dot{Q}_{\mathrm{HS}}$. The heating strip produces uniform heating over the mirror surface area. The thermal conductivities of the mirror and the plaster can be taken to be k_G=1.20 W/m · K and k_P=0.750 W/m · K, respectively. In your analysis, neglect any heat loss from the edges of the mirror (i.e., treat the problem as one-dimensional heat transfer). For the purposes of this analysis, the temperature on the back side of the plaster wall, T_3, is taken to be 19.5°C, and the convection heat transfer coefficient between the mirror and the bathroom ambient air temperature is taken as 10.0 $\mathrm{W/m^2 \cdot K}$. For the conditions of interest, the bathroom ambient temperature is 25.0°C.

2 (a) Draw a thermal resistance network for the heat transfer analysis of this problem. Label with symbols all the thermal resistances and heat flows in the system.

3 (b) Compute the values of all the thermal resistances in the system.

6 (c) For the case when the heating strip is **not** operating, determine the temperature of the outside surface of the mirror, T_1, in °C. If the relative humidity in the bathroom is 98%, will the mirror fog up in this case? Support your answer with the appropriate calculations.

7 (d) Determine the rate of energy that must be produced by the heating strip, $\dot{Q}_{\mathrm{HS}}$, to keep T_1 at 27.0°C.

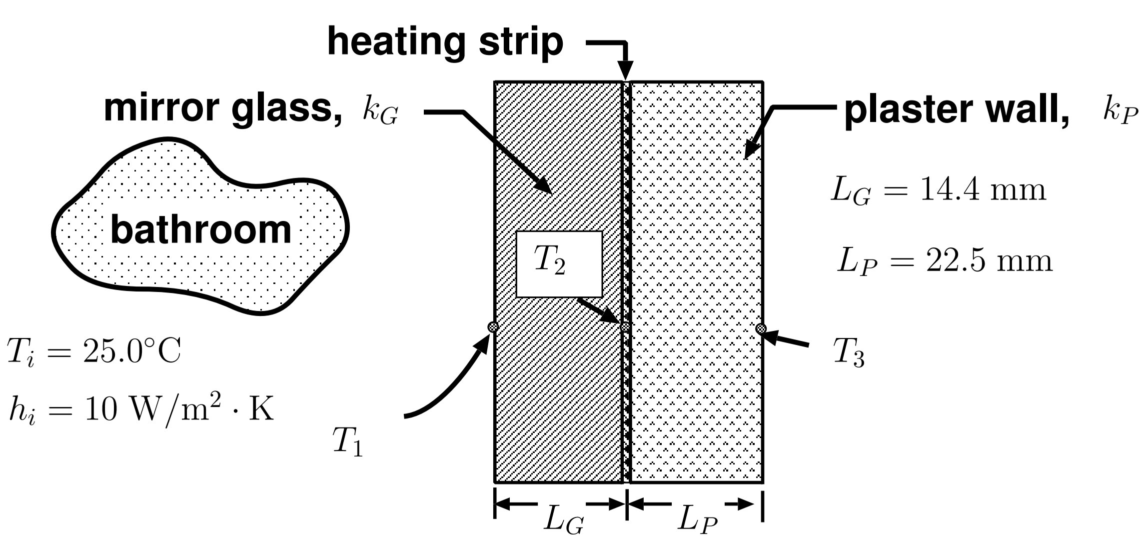

Figure 1: Figure for problem **1**

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2. Consider the piston-cylinder arrangement in Figure 2. Initially, two ideal gases, Argon and Oxygen, are separated by a thin insulating membrane and the piston-cylinder environment is such that each gas is held at its own State 1. There are $n_{\mathrm{Ar}} = 0.09$ kmol of Argon gas occupying a volume $V_{\mathrm{Ar},1} = 0.6\ \mathrm{m}^3$ at a temperature of $T_{\mathrm{Ar},1} = 300$ K. Below the membrane there are $n_{\mathrm{O}_2} = 0.18$ kmol of Oxygen gas occupying a volume $V_{\mathrm{O}_2,1} = 0.8\ \mathrm{m}^3$ at a temperature of $T_{\mathrm{O}_2,1} = 500$ K. With the piston held stationary, the membrane separating the two gases is ruptured, allowing the gases to mix completely and establish a new state of equilibrium (State 2) with temperature $T_2 = 400$ K. The piston is then raised in a controlled manner such that the gas mixture expands polytropically according to the relation, $PV^{0.25} = C$. The polytropic process continues until the mixture temperature is $T_3 = 600$ K (State 3).

29

2 (a) Determine the mass, m, of each gas.

8 (b) Calculate the heat transfer that occurred during the first process (the gases mixing). Was this heat transfer to or from the system?

2 (c) Calculate the pressure of the mixture at State 2, P_2.

5 (d) For the gas mixture, determine the total number of moles, n_{tot}, the total mass, m_{tot}, the mass fractions, c_i, the molecular mass, M_{mix}, and the gas constant, R_{mix}.

6 (e) For the polytropic process (State 2 to State 3) determine the work done by the system, ${}_2W_3$, and the heat transferred to the system, ${}_2Q_3$.

6 (f) Calculate the final volume, V_3, and the final pressure, P_3, of the gas mixture.

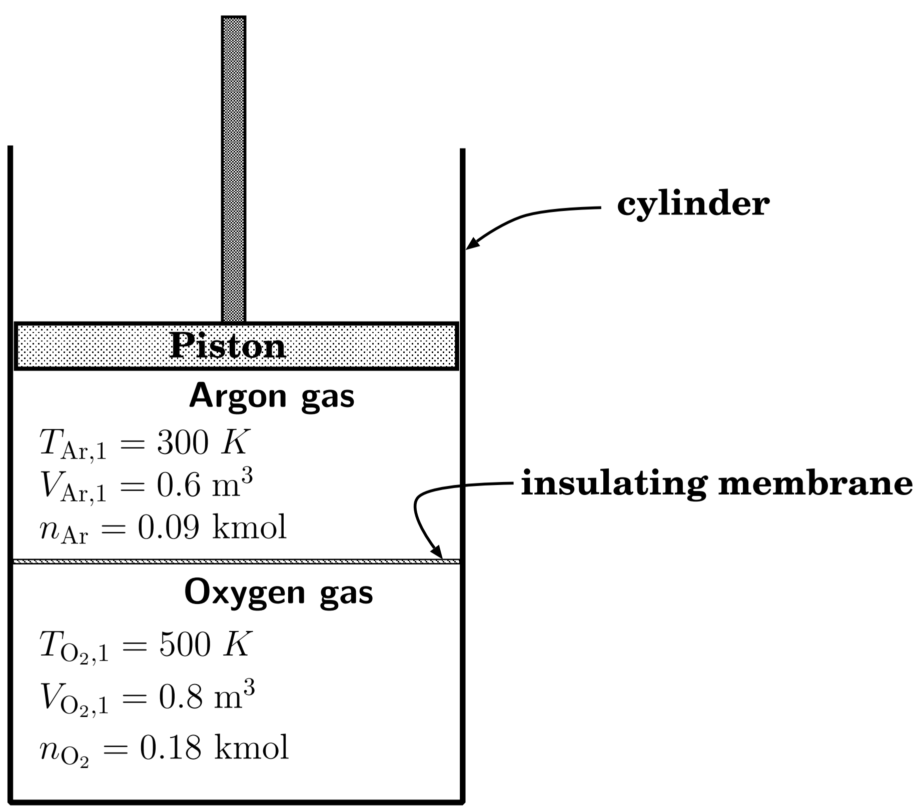

Figure 2: Figure for problem **2**

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22 **3**. Figure 3 shows a schematic of a vapour-compression refrigeration system that uses Refrigerant 22 (R-22) as the working fluid. The insulated heat exchanger subcools a portion of the saturated liquid refrigerant flow leaving the condenser. This stream exits the heat exchanger at 5°C and 1.2 MPa. The remainder of the flow from the condenser is diverted through an expansion valve (to State 6) before going through the other side of the heat exchanger (i.e., it is the other, separated stream). This stream exits the heat exchanger as saturated vapour at −10°C, and is then compressed up to a pressure of 1.2 MPa by Compressor 2 (to State 8). The rate of heat removal from the cold space ($\dot{Q}_{\text{in}}$) is 162.9 kW. The fluid leaving the evaporator is a saturated vapour at −30°C. The flow leaving Compressor 1 is at a pressure of 1.2 MPa and a temperature of 70°C. The flow leaving Compressor 2 is at a temperature of 50°C. The mixing of the streams leaving the two compressors occurs within the condenser. The two compressors are also insulated (i.e. adiabatic). Neglect changes in potential and kinetic energies.

7 (a) Determine the mass flow rate at the inlet to each compressor, in kg/s.

4 (b) Determine the power input to each compressor, in kW.

1 (c) Determine the coefficient of performance of the overall system.

2 (d) What is the maximum possible coefficient of performance for this system?

8 (e) On a T-v (temperature–specific volume) diagram, draw process representations for this system with respect to the saturation lines. On the diagram, 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. On the diagram, indicate state temperature values and saturation temperature values for reference as appropriate. Do any additional work necessary to locate states 5 and 6 correctly. Labelling v values is optional.

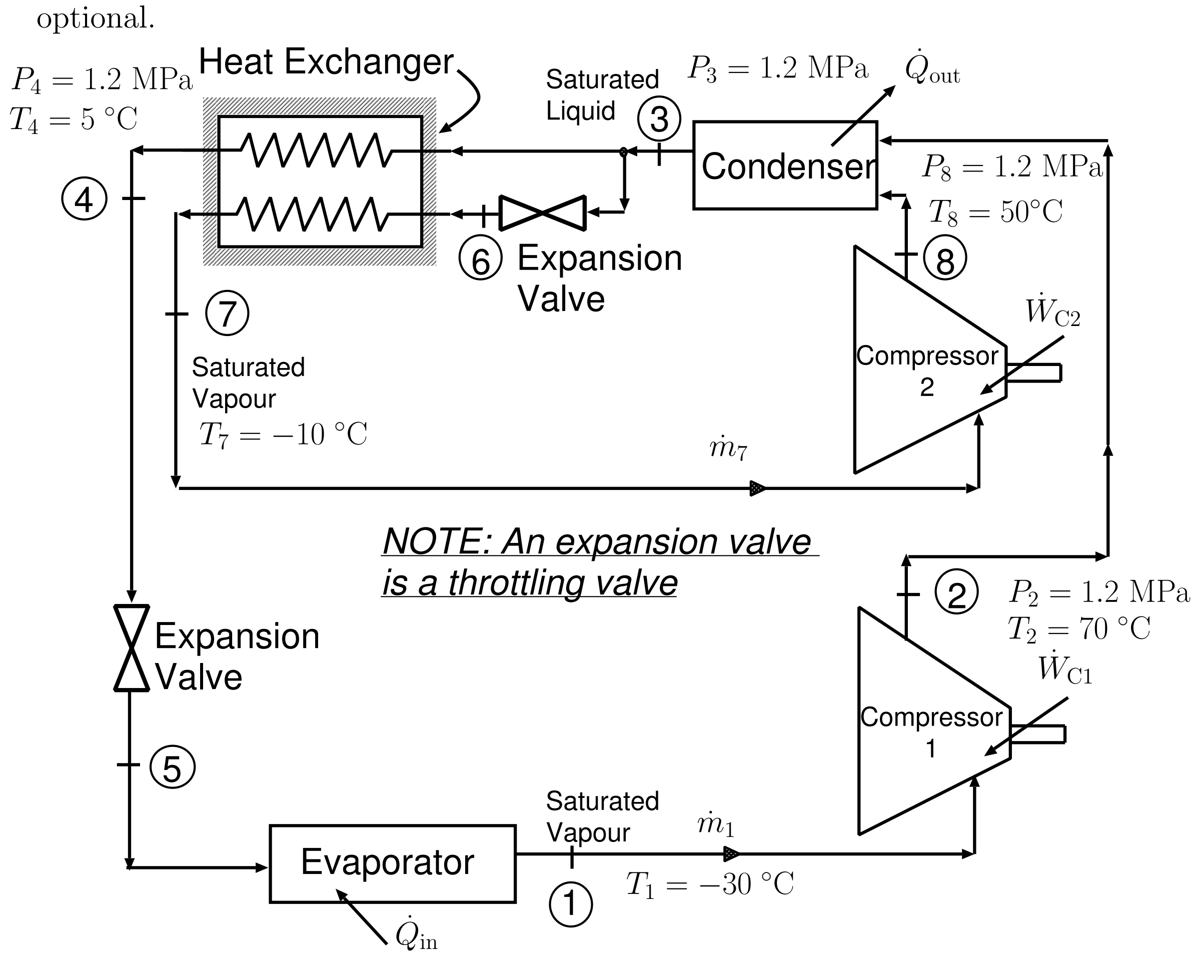

Figure 3: Figure for problem **3**

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10 **4**. A Carnot heat engine is used to drive a Carnot heat pump as shown in Figure 4. The heat engine takes $\dot{Q}_{W1}$ from a waste energy heat source at 60°C, produces just enough work, $\dot{W}$, to drive the heat pump, and rejects energy $\dot{Q}_{L1}$ at 20°C. The waste energy heat source also supplies $\dot{Q}_{W2}$ to the heat pump that delivers $\dot{Q}_{H2}$ at 145°C. If the total waste energy supplied ($\dot{Q}_{W1} + \dot{Q}_{W2}$) is 5.00 MW, determine $\dot{Q}_{H2}$ in MW.

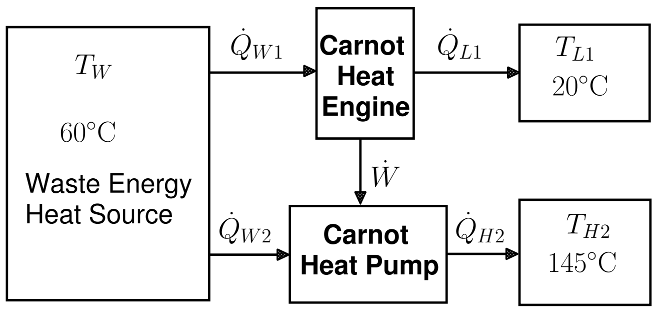

Figure 4: Figure for problem **4**

5. As a first stage of an overall dehumidification system, two air streams (State 1 and State 2) are mixed adiabatically at constant pressure, $P = 100$ kPa, and the combined flow passes through a cooling/dehumidifying section. As shown in Figure 5, stream 1 enters the mixing section with mass flow rate $\dot{m}_{a,1} = 0.2$ kg/s (dry air), temperature $T_1 = 40$°C and relative humidity $\phi_1 = 60\%$. Stream 2 enters the mixing section with mass flow rate $\dot{m}_{a,2} = 0.3$ kg/s (dry air), temperature $T_2 = 25$°C and humidity ratio $\omega_2 = 0.018$ (kg water vapour per kg dry air). Assume the two inlet streams are fully mixed by the time they reach the cooling/dehumidifying section, and also assume the total pressure remains constant at $P = 100$ kPa. The air stream exiting at State 4 has a temperature of $T_4 = 15$°C and relative humidity $\phi_4 = 100\%$. Below the cooling coils, condensate (liquid water) is allowed to flow out of the duct (State 3) and has mass flow rate $\dot{m}_{\text{liq}}$ and a temperature equal to that of T_4 (i.e., $T_3 = T_4$). For the combined mixing and cooling/dehumidifying sections, assume steady-state steady-flow conditions, and neglect changes in kinetic and potential energies.

21 **NOTE:** Use the formulas in your calculations. **Do not use the psychrometric chart.**

3 (a) Determine the humidity ratio ω_1 for inlet stream 1, (State 1).

3 (b) Determine the humidity ratio ω_4 for the exiting stream, and the mass flow rate of dry air $\dot{m}_{a,4}$ at State 4.

4 (c) Calculate the mass flow rate of the liquid leaving at State 3, $\dot{m}_{\text{liq}}$, in kg/s.

11 (d) Determine the rate of cooling, $\dot{Q}_{\text{cooling}}$, in kW.

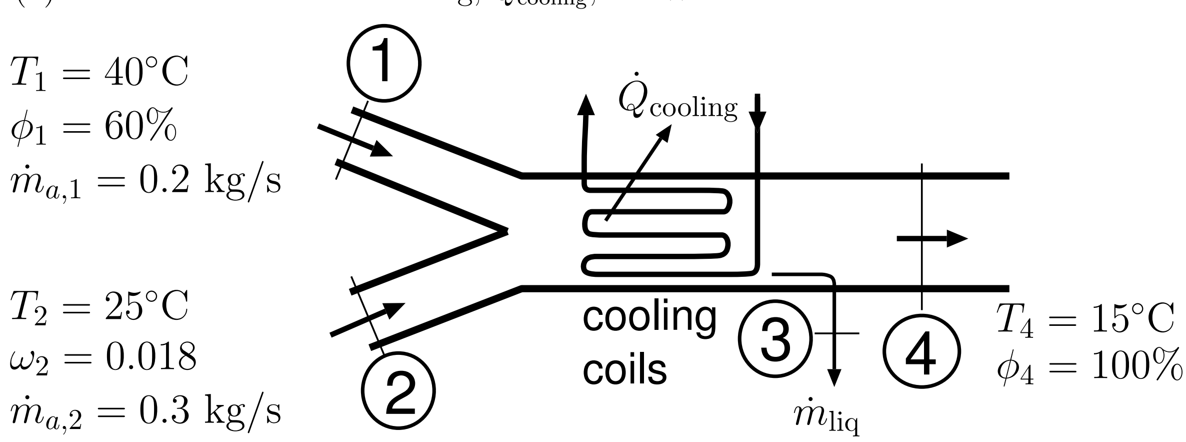

Figure 5: Figure for problem **5**