THE UNIVERSITY OF MANITOBA

April 29, 1:30 p.m. 2003	Final Examination
Paper No.: 715	Page No.: Page 1 of 6
Department & Course No.: 130.112	Time: 3 Hours
Examination: Thermal Sciences	Examiner: Drs. J.T. Bartley, G.F. Naterer, and H.M. Soliman

Instructions:

1. This is a three-hour open textbook exam. Students are permitted to use the course textbook, supplementary notes on heat transfer, and a calculator. No other materials (e.g., notes, solved problems, etc.) are allowed.
2. State all assumptions and label your system with dashed lines. Write your solutions clearly and legibly in the booklets provided. Ambiguous solutions which cannot be interpreted will be considered incorrect.
3. If interpolation is required in the property tables, then use linear interpolation between table entries. Use **four** significant figures in your calculations and full precision for data from the textbook.
4. Attempt questions 1 to 4 and one only of questions 5 and 6. The values are indicated in the margin.

Values

1. A frictionless piston-cylinder and spring device, shown in the figure below, contains a mixture of three ideal gases: 3 kg Methane (**CH_4**), 2 kg Oxygen (**O_2**), and 1 kg Nitrogen (N_2). Initially the mixture exists at a pressure of 500 kPa and temperature of 250 °C and the linear spring is just touching the piston but not exerting any force on it (state 1). Also, the piston is initially resting on a set of stops, as shown in the figure. Heat is transferred to the mixture and the piston will begin to rise off the stops and compress the spring when the pressure reaches 650 kPa (state 2). Heat transfer to the mixture continues until the final volume of the mixture in the cylinder is 3 m^3 (state 3). The spring constant, k, is 250 kN/m and the cross-sectional area of the piston, A, is 0.8 m^2. Neglect changes in the kinetic and potential energies.

(6) (a) Calculate the intial volume occupied by the mixture of gases, V_1, in m^3.

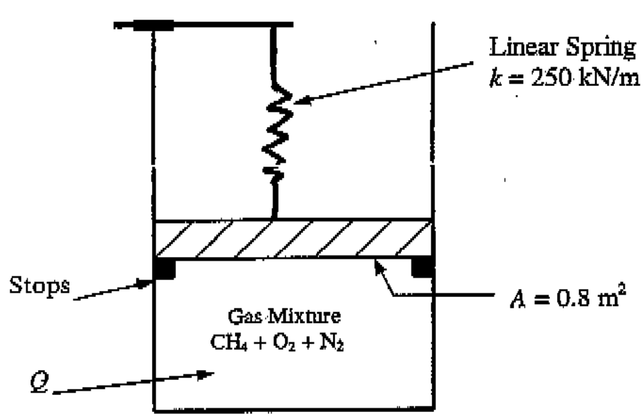
(2) (b) Determine the temperature T_2 of the mixture when the pressure reaches 650 kPa (state 2).

(4) (c) Calculate the final pressure P_3 and temperature T_3 of the mixture.

(3) (d) Calculate the work done by the system from state 1 to state 3 in processes 1–2 and 2–3, in kJ.

(6) (e) Determine the total heat transfer to the system, from state 1 to state 3, in kJ. Assume that the constant values of specific heats at 300 K are applicable.

(3) (f) Show processes 1–2 and 2–3 on a P-V diagram with respect to constant-temperature lines; identify the area representing the work.



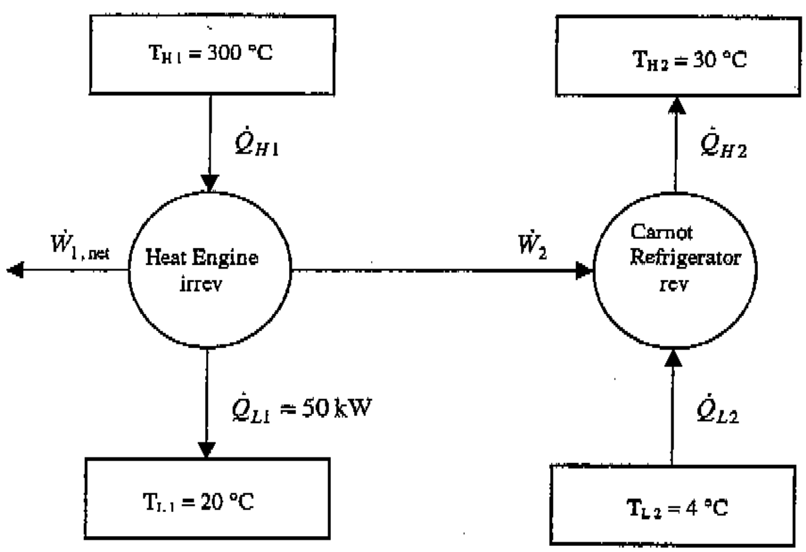
Values

2. An Irreversible Heat Engine with a thermal efficiency of 35% operates between two thermal reservoirs at $T_{H1} = 300\ ^\circ\text{C}$ and $T_{L1} = 20\ ^\circ\text{C}$. The engine is used to drive a Carnot Refrigerator (reversible) that removes heat from a low temperature reservoir at $T_{L2} = 4\ ^\circ\text{C}$ and rejects heat to a high temperature reservoir at $T_{H2} = 30\ ^\circ\text{C}$. The total power developed by the heat engine is $\dot{W}_1$. This total power is divided into two parts, an amount $\dot{W}_2$ that is used to drive the refrigerator and $\dot{W}_{1,net}$ as the remainder, *i.e.*, $\dot{W}_1 = \dot{W}_2 + \dot{W}_{1,net}$. The power input to the refrigerator, $\dot{W}_2$, is one quarter of the total power output of the heat engine $\dot{W}_1$. The Heat Engine rejects heat to a low temperature reservoir at a rate of $\dot{Q}_{L1} = 50$ kW.

(2) (a) Determine the rate of heat transfer $\dot{Q}_{H1}$ for the Heat Engine and the total output power of the Heat Engine, $\dot{W}_1$, in kW.

(4) (b) Determine the COP of the Refrigerator and the rates of heat transfer, $\dot{Q}_{L2}$ and $\dot{Q}_{H2}$, in kW.

(3) (c) Based on the Carnot Principles, confirm that the heat engine is irreversible and therefore possible.



THE UNIVERSITY OF MANITOBA

April 29, 1:30 p.m. 2003	Final Examination
Paper No.: 715	Page No.: Page 3 of 6
Department & Course No.: 130.112	Time: 3 Hours
Examination: Thermal Sciences	Examiner: Drs. J.T. Bartley, G.F. Naterer, and H.M. Soliman

Values

3. Power and heating are to be provided by the steadily operating steam plant shown in the figure below. Steam generated by the boiler at a rate of $\dot{m}_1$ =1.5 kg/s enters Turbine A, where it expands from P_1 = 1 MPa and T_1 = 400 °C down to P_2 = 300 kPa and T_2 = 250 °C. The steam that is leaving Turbine A (at state 2 and mass flow rate $\dot{m}_1$) is divided into two streams; both are at state 2. One stream with a mass flow rate $\dot{m}_2$ is directed to a heat exchanger and the other stream with a mass flow rate of $\dot{m}_3$ is directed to Turbine B, i.e., $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$. The stream $\dot{m}_2$ leaves the heat exchanger as saturated liquid at P_5 = 300 kPa and then its pressure is reduced down to P_6 = 40 kPa by a throttling valve. The stream $\dot{m}_3$ flows through Turbine B and a condenser after which the state is given by P_4 = 40 kPa and T_4 = 40 °C. The two streams are then combined in a mixing chamber. The outlet stream from the mixing chamber is at a pressure P_7 = 40 kPa. Assume that there are no pressure losses or heat losses in the lines connecting the various pieces of equipment. Also, the changes in the kinetic and potential energies throughout the cycle may be considered to be negligible.

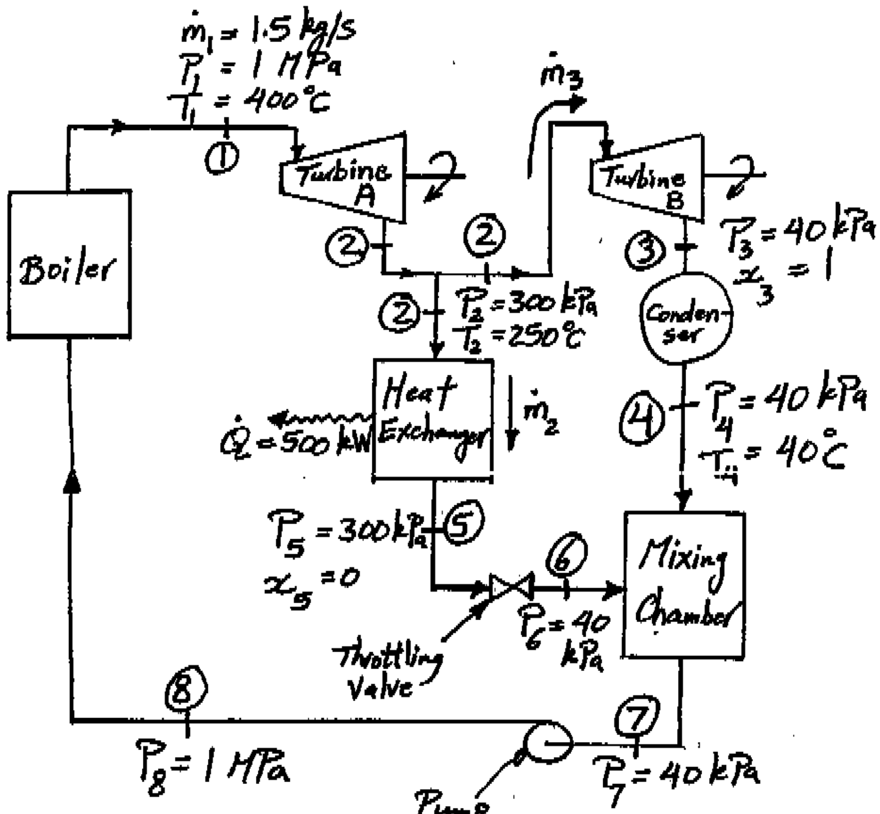
(5) (a) Determine the power output from Turbine A, in kW. Assume that the turbine is well insulated from the surroundings.

(5) (b) Determine the value of $\dot{m}_2$ if the rate of heat extraction from the steam in the heat exchanger is 500 kW.

(8) (c) Determine the temperature and quality at state 6. Assume that the throttling valve is well insulated from the surroundings.

(8) (d) Determine the enthalpy at state 7 assuming that the mixing chamber is well insulated from the surroundings. Give a phase description of state 7 (i.e., saturated liquid, superheated vapor, etc.) and justify your description.

(8) (e) Sketch a *T-V* diagram showing states 1 to 7 including the saturation lines, and the relevant pressure lines and process lines.



THE UNIVERSITY OF MANITOBA

April 29, 1:30 p.m. 2003	Final Examination
Paper No.: 715	Page No.: Page 4 of 6
Department & Course No.: 130.112	Time: 3 Hours
Examination: Thermal Sciences	Examiner: Drs. J.T. Bartley, G.F. Naterer, and H.M. Soliman

Values

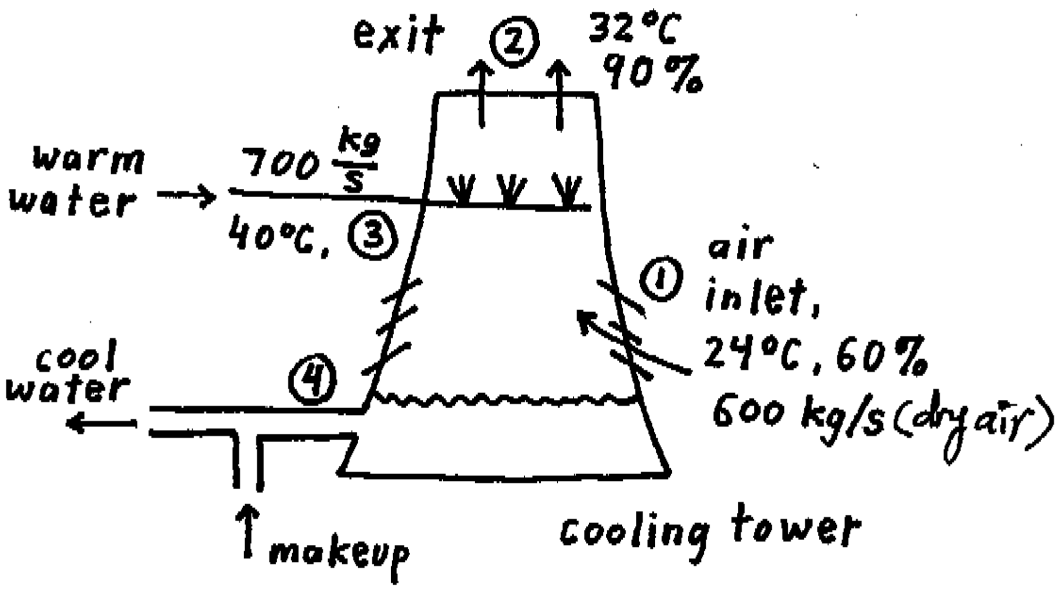
4. Cooling water enters a natural-draft cooling tower at 700 kg/s and 40 °C. Atmospheric air enters the tower at 1 atm, with a dry-bulb temperature and relative humidity of 24 °C and 60 %, respectively. The mass flow rate of dry air throughout the tower is 600 kg/s. The atmospheric air leaves the tower at 32 °C (dry-bulb temperature) with a relative humidity of 90 %.

(9) (a) Determine the temperature of the cooling water as it leaves the cooling tower (state 4), in °C.

(4) (b) Find the mass flow rate of the required makeup water, in kg/s.

(5) (C) Calculate the rate of heat removal from the cooling water, in kW. In other words, determine the rate of heat loss from the water between states 3 and 4, or the rate of heat gain by the atmospheric air between states 1 and 2.

Note: You may use the psychrometric chart (Fig. A-33), or the property relations developed in your book, in determining the properties of atmospheric air.



THE UNIVERSITY OF MANITOBA

April 29, 1:30 p.m. 2003	Final Examination
Paper No.: 715	Page No.: Page 5 of 6
Department & Course No.: 130.112	Time: 3 Hours
Examination: Thermal Sciences	Examiner: Drs. J.T. Bartley, G.F. Naterer, and H.M. Soliman

Attempt Only One of the Following Two Questions. DO NOT ATTEMPT BOTH

5. This Question Can be Solved with Knowledge from the Section on "Topics of Special Interest: Mechanisms of Heat Transfer", pp. 150-155 of Your Textbook (4th Edition).

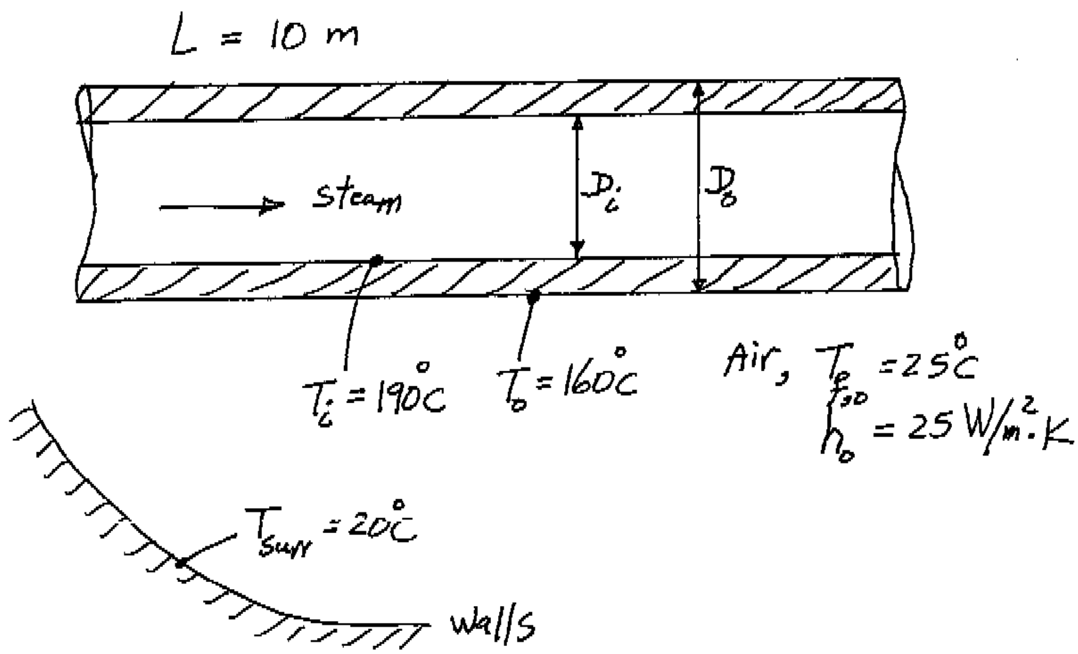
Consider a horizontal circular tube (see the figure below) with inner diameter D_i = 4.5 cm, outer diameter D_o = 5 cm, and length L = 10 m. Steam enters the tube with a mass flow rate $\dot{m}$ = 2 kg/min, a pressure P = 1.3 Mpa, and a quality x_{in} = 0.95. The steam flows inside the tube at a constant pressure and exits at a quality x_{out}. The inner and outer surfaces of the tube remain at constant temperatures T_i = 190 °C and T_o = 160 °C, respectively. Heat is transferred by convection from the steam to the inner surface of the tube. This amount of heat is then transferred by conduction through the tube wall, and finally this amount of heat is transferred from the outer surface of the tube by a mixture of convection to the surrounding air at $T_{f,o}$ = 25 °C with a heat transfer coefficient of h_o = 25 W/m²·K and radiation to surrounding walls at T_{surr} = 20 °C. The outer surface of the tube has an emissivity ε = 0.8.

Note: The surface area A of a cylinder with diameter D and length L is $A = \pi D L$.

(6) (a) Determine the total rate of heat transfer from the outer surface of the tube to the surrounding air and walls, in kW.

(3) (b) Determine the heat transfer coefficient between the steam and the inner surface of the tube, in W/m²·K.

(6) (c) Determine the outlet quality x_{out} of the steam. Neglect changes in the kinetic and potential energies.



THE UNIVERSITY OF MANITOBA

April 29, 1:30 p.m. 2003 — Final Examination
Paper No.: 715 — Page No.: Page 6 of 6
Department & Course No.: 130.112 — Time: 3 Hours
Examination: Thermal Sciences — Examiner: Drs. J.T. Bartley, G.F. Naterer, and H.M. Soliman

6. You Will Need Knowledge from the Supplementary Notes ("Heat Transfer: A Practical Approach" by Y. Cengel) in Solving this Question.

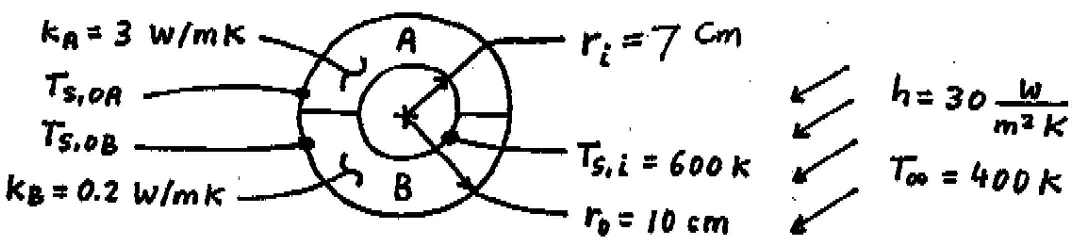
Gas flowing through a long, thin-walled pipe maintains the inner wall at a uniform temperature of 600 K. An insulation layer of two different materials, A and B, covers the wall of the pipe in halves (see figure). The entire outer surface is exposed to air at 400 K with a convection coefficient of ~~25~~ 30 W/m^{2}K. Neglect the contact resistance between the two materials.

(6) (a) Sketch the thermal circuit of this system, while labeling all pertinent nodes and resistances.

(4) (b) What is the total rate of heat loss from one-meter length of this pipe, in W/m, if the inner and outer radii of the insulation are 7 cm and 10 cm, respectively.

(5) (c) What are the surface temperatures of materials A and B on the outer wall?

Note: it may be helpful to visualize an analogous 1-D planar, composite wall problem, before solving this cylindrical problem.



1/11

1. (a) (6)

CH_4 - methane, $M = 16.043$ kg/kmol, $R = 0.5182$ kJ/kg·K
O_2 - oxygen, $M = 31.999$ kg/kmol, $R = 0.2598$ kJ/kg·K
N_2 - nitrogen, $M = 28.013$ kg/kmol, $R = 0.2968$ kJ/kg·K

$$m_m = m_{CH_4} + m_{O_2} + m_{N_2} = 3 + 2 + 1 = 6 \text{ kg}$$

$$N_i = \frac{m_i}{M_i} \qquad P_1 = 500 \text{ kPa}, \quad T_1 = 250°C$$

$$\therefore N_{CH_4} = \frac{m_{CH_4}}{M_{CH_4}} = \frac{3 \text{ kg}}{16.043 \text{ kg/kmol}} = 0.186997 \text{ kmol}$$

$$N_{O_2} = \frac{m_{O_2}}{M_{O_2}} = \frac{2 \text{ kg}}{31.999 \text{ kg/kmol}} = 0.0625020 \text{ kmol}$$

$$N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{1 \text{ kg}}{28.013 \text{ kg/kmol}} = 0.0356977 \text{ kmol}$$

$$N_m = \sum_i N_i = 0.186997 + 0.0625020 + 0.0356977$$
$$= 0.285197 \text{ kmol}$$

$$M_m = \frac{m_m}{N_m} = \frac{6 \text{ kg}}{0.285197 \text{ kmol}} = 21.0381 \text{ kg/kmol}$$

or, could use $R_m = \sum_i mf_i R_i$

$$R_m = \frac{R_u}{M_m} = \frac{8.314 \text{ kJ/kmol·K}}{21.0381 \text{ kg/kmol}} = 0.395188 \text{ kJ/kg·K}$$

$$V_1 = \frac{m_m R_m T_1}{P_1} = \frac{(6 \text{ kg})(0.395188 \text{ kJ/kg·K})(250 + 273.15 \text{ K})}{500 \text{ kPa}}$$

$$V_1 = 2.48091 \text{ m}^3$$

(b) (2)

state 2, pressure reaches 650 kPa

$$V_2 = V_1$$

$$T_2 = \frac{P_2 V_2}{m_m R_m}$$

$$T_2 = \frac{(650 \text{ kPa})(2.48091 \text{ m}^3)}{(6 \text{ kg})(0.395188 \text{ kJ/kg·K})}$$

2/11

$T_2 = 680.09\ K$ or $406.94\ °C$

(c) state 3, spring is compressed until $V = 3.0\ m^3$.
$A = 0.8\ m^2$

(2) $P_3 = P_2 + \frac{k}{A^2}(V_3 - V_2)$

$P_3 = 650\ kPa + \frac{250\ kN/m}{(0.8\ m^2)^2}(3.0 - 2.48091)\ m^3$

$P_3 = 852.77\ kPa$

(2) $T_3 = \frac{V_3 P_3}{m_m R_m}$, $T_3 = \frac{(3.0\ m^3)(852.77\ kPa)}{(6\ kg)(0.395188\ kJ/kg\cdot K)}$

$T_3 = 1078.94\ K$

(d) $W_{1-2} = 0$

$W_{2-3} = \frac{1}{2}(P_2 + P_3)(V_3 - V_2)$

(3) $= \frac{1}{2}(650 + 852.77) \times (3.0 - 2.48091)$

$= 390.036\ kJ$

(e) $Q_{1-3} - W_{out,1-3} = (U_3 - U_1) + \Delta KE + \Delta PE$

$= m_m(u_3 - u_1)$

(6)

For an ideal gas, $(u_3 - u_1) = C_{v,avg}(T_3 - T_1)$

$C_{v,m} = \sum mf_i\, C_{v,i}$ Assume values of C_v at 300 K are applicable.

$mf_{,CH_4} = 3/6 = 0.5$ $C_{v,CH_4} = 1.7354\ kJ/kg\cdot K$

$mf_{,O_2} = 2/6 = 0.3333$ $C_{v,O_2} = 0.658\ kJ/kg\cdot K$

$mf_{,N_2} = 1/6 = 0.16667$ $C_{v,N_2} = 0.743\ kJ/kg\cdot K$

$\therefore C_{v,m} = (0.5 \times 1.7354) + (0.3333 \times 0.658) + (0.16667 \times 0.743)$
$= 1.21085\ kJ/kg\cdot K$

3/11

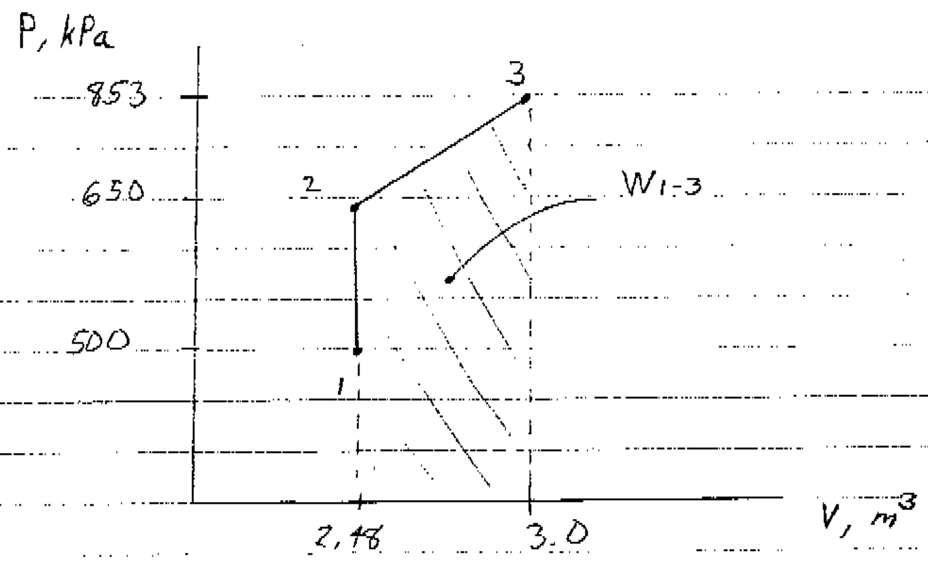
$$Q_{1-3} = m_m C_{v,m} (T_3 - T_1) + W_{out,1-3}$$

$$Q_{1-3} = (6\,kg)(1.21085\,kJ/kg \cdot K)(1078.94 - 523.15\,K) + 390.036$$

$$Q_{1-3} = 4427.91\,kJ$$

(f)

(3)



4/11

2\. (a) $\eta_{th} = \dfrac{\dot W_1}{\dot Q_{H1}} = \dfrac{\dot Q_{H1} - \dot Q_{L1}}{\dot Q_{H1}}$

(2)

$\therefore 0.35\, \dot Q_{H1} = \dot Q_{H1} - 50$

$(0.35-1)\, \dot Q_{H1} = -50 \qquad \therefore \dot Q_{H1} = 76.923 \text{ kW}$

$\dot W_1 = \eta_{th} \times \dot Q_{H1} = 0.35 \times 76.923 = 26.923 \text{ kW}$

(b) $\dot W_2 = \tfrac{1}{4}\dot W_1 = 0.25 \times 26.923 = 6.7308 \text{ kW}$

(4) $\dot W_{1,net} = \tfrac{3}{4}\dot W_1 = 0.75 \times 26.923 = \underline{20.192 \text{ kW}}$

$$COP_{R,rev} = \frac{1}{T_H/T_L - 1} = \frac{1}{\dfrac{(30+273.15)}{(4+273.15)} - 1} = 10.66$$

$$COP_R = \frac{\dot Q_{L2}}{\dot W_2}$$

$\therefore \dot Q_{L2} = COP_R \times \dot W_2 = (10.66)(6.7308) = 71.75 \text{ kW}$

$\dot W_2 = \dot Q_{H2} - \dot Q_{L2}$

$\therefore \dot Q_{H2} = \dot W_2 + \dot Q_{L2} = 6.7308 + 71.75 = 78.45 \text{ kW}$

(c) $\eta_{th} = 1 - \dfrac{\dot Q_{L1}}{\dot Q_{H1}} < 1 - \dfrac{T_{L1}}{T_{H1}}$

(3) (Irreversible) (reversible)

or, $\dfrac{\dot Q_{L1}}{\dot Q_{H1}} > \dfrac{T_{L1}}{T_{H1}} \qquad \left(\dfrac{50}{76.923} = 0.65\right) > \left(\dfrac{293}{573} = 0.511\right)$

(if irrev HE)

Since $0.65 > 0.511$ the heat engine is irreversible.

(5/11)

3. (A) $\cancel{\dot{Q}_{TA}} - \dot{W}_{TA} = \dot{m}_1 (h_2 - h_1)$ Turbine A

$$\left.\begin{array}{l} P_1 = 1\ MPa \\ T_1 = 400^\circ C \end{array}\right\} h_1 = 3263.9\ kJ/kg \qquad \left.\begin{array}{l} P_2 = 300\ kPa \\ T_2 = 250^\circ C \end{array}\right\} h_2 = 2967.6\ kJ/kg$$

$$\dot{W}_{TA} = 1.5\,(3263.9 - 2967.6) = 444.5\ kW$$

(B) $\dot{Q}_{HE} - \cancel{\dot{W}_{HE}} = \dot{m}_2 (h_5 - h_2)$ Heat Exchanger

$$\left.\begin{array}{l} P_5 = 300\ kPa \\ x_5 = 0 \end{array}\right\} h_5 = 561.47\ kJ/kg$$

$$-500 = \dot{m}_2 (561.47 - 2967.6)$$

$$\dot{m}_2 = 0.2078\ kg/s$$

(C) $\cancel{\dot{Q}_{TV}} - \cancel{\dot{W}_{TV}} = \dot{m}_2 (h_6 - h_5)$ Throttling Valve

$$h_6 = h_5 = 561.47\ kJ/kg$$

$$h_g @ 40\ kPa = 2636.8\ kJ/kg$$

$$h_f @ 40\ kPa = 317.58\ kJ/kg$$

$$h_f < h_6 < h_g \longrightarrow T_6 = 75.87^\circ C$$

(6/11)

$$x_6 = \frac{561.47 - 317.58}{2636.8 - 317.58} = 0.1052$$

(D)

$$\cancel{\dot{Q}_{MC}}^{0} - \cancel{\dot{W}_{MC}}^{0} = \dot{m}_1 h_7 - \dot{m}_2 h_6 - \dot{m}_3 h_4$$ Mixing Chamber

$$\dot{m}_3 = 1.5 - 0.2078 = 1.2922 \text{ kg/s}$$

$$h_7 = \frac{0.2078 \times 561.47 + 1.2922 \times 167.57}{1.5}$$

$$= 222.14 \text{ kJ/kg}$$

$$h_4 = h_f @ 40°C = 167.57 \text{ kJ/kg}$$

$$P_7 = 40 \text{ kPa}$$

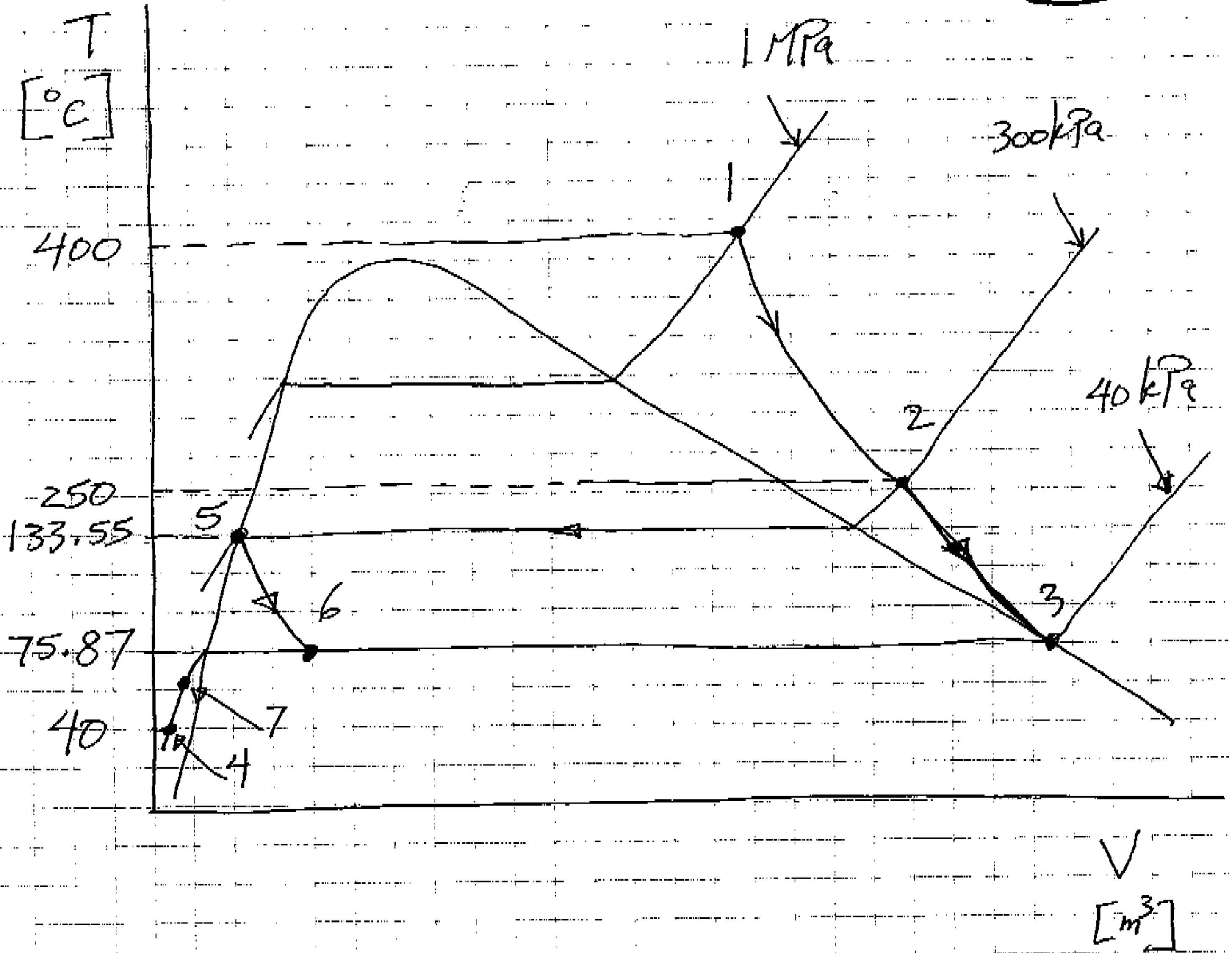
$$h_{f@P_7} = 317.58 \text{ kJ/kg}$$

$$h_7 < h_f @ P_7$$

Therefore, state 7 is compressed liquid.

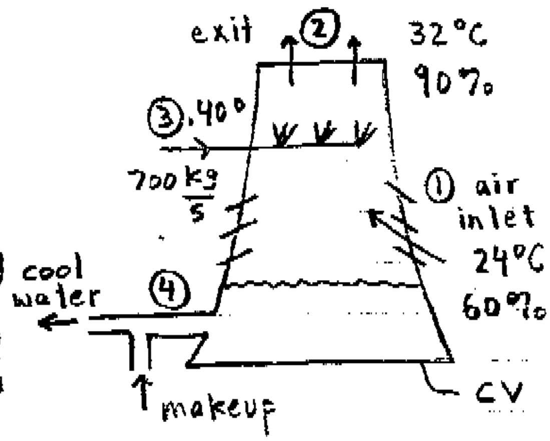
(E)

7/11



(8/11)

4. Assume: SS-SF, adiabatic cooling tower, $\Delta KE \sim 0 \sim \Delta PE$



(a) State ①: (A-33), $h_1 = 53$ kJ/kg-a, $\omega_1 = 0.0114$ kg-w/kg-a, $v_1 = 0.857$ m³/kg

State ②: $h_2 = 102.5 \frac{kJ}{kg\text{-}a}$, $\omega_2 = 0.0275 \frac{kg\text{-}w}{kg\text{-}a}$

State ③: $h_3 = h_{f@40°C} = 167.57$ kJ/kg-a

Cons. Mass (dry air): $\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a$ (1)

Cons. Mass (water): $\dot{m}_3 + \dot{m}_{a1}\omega_1 = \dot{m}_4 + \dot{m}_{a2}\omega_2$

$(1) \Rightarrow \dot{m}_3 - \dot{m}_4 = \dot{m}_a(\omega_2 - \omega_1) = \dot{m}_{makeup}$ (2)

1st Law: (cooling tower, cv) $\dot{m}_{a1}h_1 + \dot{m}_3 h_3 = \dot{m}_{a2}h_2 + \dot{m}_4 h_4$

$$(2) \Rightarrow h_4 = \frac{\dot{m}_a h_1 + \dot{m}_3 h_3 - \dot{m}_a h_2}{\dot{m}_4} = \frac{\dot{m}_a(h_1 - h_2) + \dot{m}_3 h_3}{\dot{m}_3 - \dot{m}_a(\omega_2 - \omega_1)} \quad (3)$$

$$\Rightarrow h_4 = \frac{600(53 - 102.5) + 700 \times 167.57}{700 - 600(0.0275 - 0.0114)} = 126.9 \text{ kJ/kg-a}$$

$$\text{(Table A-4)}: T_4 \sim 30 + \frac{126.9 - 125.79}{146.68 - 125.79} \sim 30.1\ °C$$

(b) $(2) \Rightarrow \dot{m}_{makeup} = \dot{m}_a(\omega_2 - \omega_1)$

$$\Rightarrow \dot{m}_{makeup} = 600(0.0275 - 0.0114) = 9.66 \text{ kg/s}$$

(c) 1st Law (cooled water): $\dot{Q} = \dot{m}_3 h_3 - \dot{m}_4 h_4$

$$\Rightarrow \dot{Q} = \dot{m}_3 h_3 - [\dot{m}_3 - \dot{m}_a(\omega_2 - \omega_1)]\, h_4$$

$$\dot{Q} = 700(167.57) - [700 - 600(0.0275 - 0.0114)] \cdot 126.9 = \underline{29{,}694.9 \frac{kJ}{s}}$$

cont

9/11

5. (a) $\dot{Q}_{total} = \dot{Q}_{conv} + \dot{Q}_{rad}$

$$\dot{Q}_{conv} = h_o A_o (T_o - T_{f,o})$$

$$= 25 \pi (0.05)(10)(160 - 25)$$

$$= 5301.4 \text{ W}$$

$$\dot{Q}_{rad} = \epsilon \sigma A_o (T_o^4 - T_{surr}^4)$$

$$= 0.8 \times 5.67 \times 10^{-8} \times \pi (0.05)(10)$$

$$[433^4 - 293^4]$$

$$= 1979.5 \text{ W}$$

$$\dot{Q}_{total} = 7280.9 \text{ W} = 7.281 \text{ kW}$$

(b) The steam temperature $T_{f,i}$ can be obtained from Table A-5 corresponding to $P = 1.3$ MPa

$$T_{f,i} = 191.64\ ^{\circ}C$$

$$\dot{Q}_{total} = h_i A_i (T_{f,i} - T_i)$$

$$7280.9 = h_i \pi (0.045)(10)(191.64 - 190)$$

10/11

$$h_i = 3140 \ W/m^2 \cdot K$$

(C) $\dot{Q}_{in} - \cancel{\dot{W}_{out}} = \dot{m}(h_{out} - h_{in}) + \cancel{\Delta KE} + \cancel{\Delta PE}$

$$h_{in} = x_{in} h_g + (1 - x_{in}) h_f$$

$$= 0.95(2787.6) + 0.05(814.93)$$

$$= 2689 \ kJ/kg$$

$$-7.281 = \frac{2}{60}(h_{out} - 2689)$$

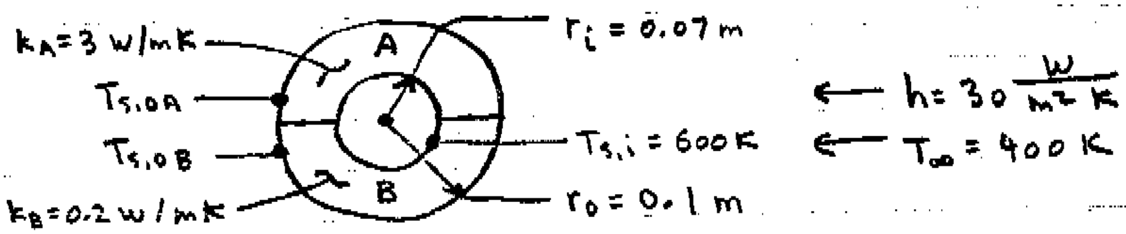
$$h_{out} = 2470.6 \ kJ/kg$$

$$h_{out} = x_{out} h_g + (1 - x_{out}) h_f$$

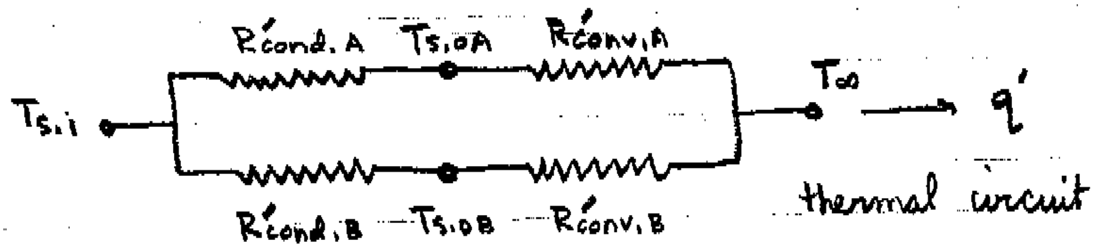
$$x_{out} = \frac{2470.6 - 814.93}{2787.6 - 814.93} = 0.8393$$

(11/11)

6 Assume: steady state, 1-D radial conduction, const. properties



(a)



thermal circuit

$$R'_{conv,A} = R'_{conv,B} = \frac{1}{\pi D h} = \frac{1}{\pi \times 0.1 \times 30} = 0.106 \ \text{m}\cdot\text{K/W}$$

$$R'_{cond,A} = \frac{\ln(0.1/r_i)}{\frac{1}{2}(2\pi k_B \cdot 1)} = 0.106 \ln\left(\frac{0.1}{0.07}\right) = 0.038 \ \text{m}\cdot\text{K/W}$$

$$R'_{cond,B} = \frac{\ln(0.1/r_i)}{\frac{1}{2}(2\pi k_A \cdot 1)} = 1.587 \ln\left(\frac{0.1}{0.07}\right) = 0.566 \ \text{m}\cdot\text{K/W}$$

(b) $$q' = \frac{T_{s,i} - T_\infty}{R'_{cond,A} + R'_{conv,A}} + \frac{T_{s,i} - T_\infty}{R'_{cond,B} + R'_{conv,B}}$$

$$\Rightarrow q' = \underbrace{\frac{600 - 400}{0.038 + 0.106}}_{q'_A} + \underbrace{\frac{600 - 400}{0.566 + 0.106}}_{q'_B}$$

So $q' = 1{,}388.9 + 297.6 = 1{,}686.5$ W/m

(c) $T_{s,oA} = T_{s,i} - q'_A R'_{cond,A} = 600 - 1388.9 \times 0.038 = 547.2$ K

$T_{s,oB} = T_{s,i} - q'_B R'_{cond,B} = 600 - 297.6 \times 0.566 = 431.6$ K

Note: It may be helpful to visualize an analogous 1-D planar, composite wall problem, before solving this cylindrical problem