OLLSCOIL NA hÉIREANN
The National University of Ireland

National University of Ireland, Galway.

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BE Degree (Mechanical) Examination

Heat Transfer

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Attempt FIVE Questions
Time Allowed: 3 Hrs.

The following Tables are available:
Copies of Tables A.1 to A.3.2, A.7 to A.11, 3.1, 3.2, 12.3 & 12.4 from V. Wylen & Sonntag
Copies of Tables 6.2, 7.1 to 7.7, 8.4, 9.3, 12.1, A.4 to A.6 and A.8 and Figs. 7.10, 11.10 to 11.19, 12.15, 13.4 to 13.6 from Incropera & Dewitt. Stefan-Bolzmann Constant = 5.6697 x 10^{-8} W/m^2.K^4

1(a) Heat transfer from outdoor air to a heat pump evaporator may be achieved by circulating a cold liquid through a long circular pipe. Heat transfer from the air to the pipe is assisted by wind-driven forced convection. Under certain conditions a thick layer of solid ice (with conductivity, k = 2.22 W/mK) may form on the outer surface of the pipe. Show that heat transfer from the outdoor air to the pipe is maximised when :

$$\frac{h r_o}{k} = 1$$

where h is the outer surface convection coefficient, and
r_o is the ice outer radius.
As a starting point, you may use the expression in part (c) of this question. **(7)**

(b) For a 20 mm outside diameter pipe with surface temperature of -10°C, an air temperature of 0°C and h = 100 W/m^{2}K, calculate the maximum heat transfer per unit length and the ice thickness at which this maximum occurs. Draw a sketch of the process. **(4)**

(c) From first principles, show that the radial conduction through a thick pipe wall is given by:

$$q = \frac{T_i - T_o}{R}$$

where
R = $\ln(r_o/r_i)/2\pi kl$,
T_i and T_o(°C) = inner & outer surface temperatures,
r_i and r_o(m) = inner & outer radii,
k = the material conductivity (W/m°C), and
l = the pipe length (m). **(9)**

2. Finned passages are frequently formed between parallel plates to enhance convection heat transfer in compact heat exhanger cores. An important application is in electronic equipment cooling, where one or more air-cooled stacks are placed between heat dissipating electrical components. Consider a single stack of rectangular fins of length L and thickness t, with convection conditions corresponding to h and $T\infty$.

(a) Obtain expressions for the fin heat transfer rates, $q_{f,0}$ and $q_{f,L}$, in terms of the base temperatures, T_0 and T_L.

(12)

(b) In a specific application, a stack which is 200 mm wide and 100 mm deep contains 50 fins, each of length L = 12 mm. The entire stack is made from aluminium which is everywhere 1.0 mm thick. If temperature limitation associated with electrical components joined to opposite plates dictate maximum allowable plate temperatures of $T_0 = 400$ K and $T_L = 350$ K, what are the corresponding maximum power dissipations along the total 50 fins if h = 150 W/m^2.K, $T\infty = 300$ K and k = 240 W/mK ?

(8)

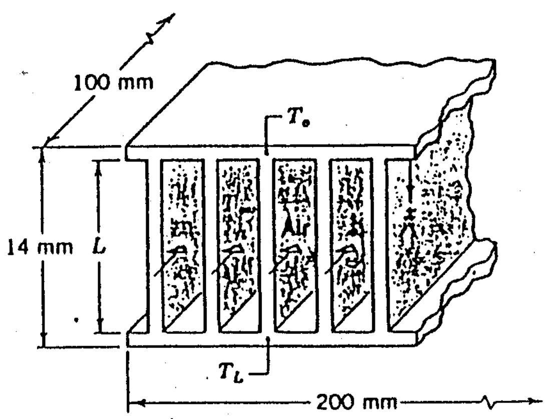

FIGURE 2

3. A conservatory placed along the south wall of a building may be used for passive solar energy collection. The energy performance partly depends on the transient heat transfer behaviour of the back wall of the conservatory as shown in Figure 3. The wall is at a uniform temperature of T_∞ when the insulated shutters of the conservatory are opened and the front surface is suddenly exposed to a net radiation flux of q''_r. There is convection heat transfer from the front surface and the back surface may be regarded as perfectly insulated.

Using an implicit finite difference approach, and basing your calculations on $1m^2$ of wall surface area, carry out the following :

(i) Derive a finite difference model for the surface node. **(8)**

(ii) Derive the finite difference equations for the four other nodes and place all equations in a form suitable for Gauss-Seidel iteration. **(7)**

(iii) In a few sentences, describe how you would compute the temperature distribution in the wall over time. **(3)**

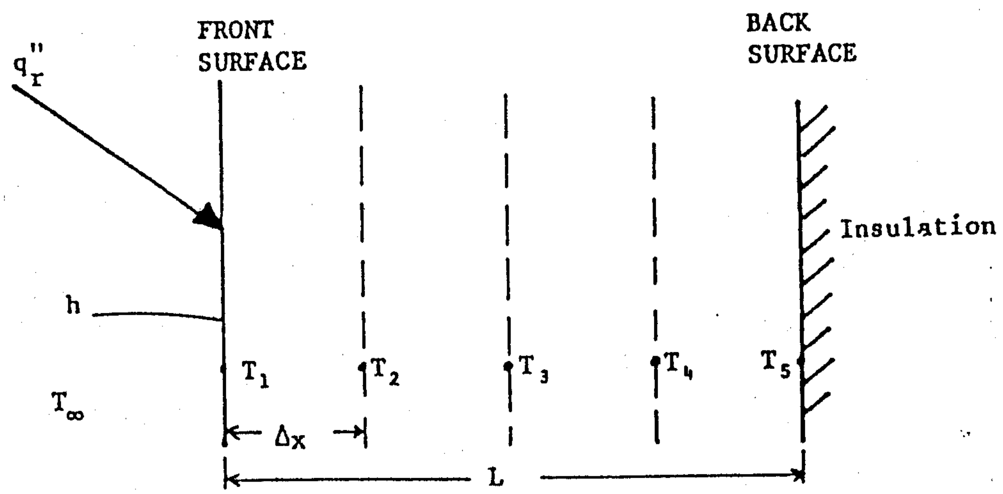

FIGURE 3

4. Figure 4 shows an array of 10 square silicon chips, each of length L = 10 mm on each side. The array is insulated on one surface and cooled on the opposite surface by atmospheric air in parallel flow with $T_\infty = 24°C$ and $U_\infty = 40$ m/s. When in use, the same electrical power is dissipated in each chip, maintaining a uniform heat flux over the entire cooled surface.

(a) If the temperature of each chip may not exceed 80°C, what is the maximum allowable power per chip ? **(14)**

(b) What is the maximum allowable power if a turbulence promoter is used to trip the boundary layer at the leading edge ? (In the latter case, the entire boundary layer may be treated as being turbulent). **(6)**

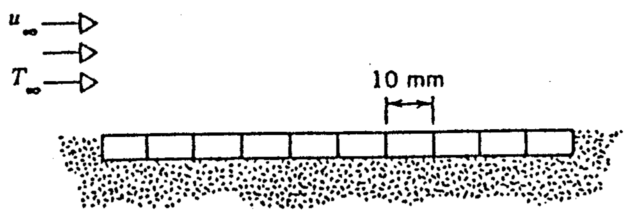

FIGURE 4

5. Tubes placed outdoors may be used as a heat source for a heat pump evaporator by transferring sensible heat from outdoor air and latent heat by condensation of water vapour contained in outdoor air. One design is based on vertical tubes of 0.02 m outer diameter. At a particular operating condition, the wind speed is 5 m/s, the air has a temperature of 10°C and a relative humidity of 80 %, and the tube outer surface is at 1°C.

Assuming that each tube may be treated as an individual tube in cross flow, calculate (per m^2) the following :

(i) the sensible heat transfer, **(8)**

(ii) the mass rate of condensation of water vapour, **(10)**

(iii) the latent heat transfer, and **(1)**

(iv) the total heat transfer. **(1)**

6(a) An evaporator for an ocean thermal energy conversion system has a heat transfer rate of 66.67 MW. The evaporator is a heat exchanger consisting of a single shell with many tubes executing two passes. If the working fluid is evaporated at its phase change temperature of 290 K, with ocean water entering at 300 K and leaving at 292 K :

(i) What is the heat exchanger area required for the evaporator ? **(8)**

(ii) What flow rate must be maintained for the water passing through the evaporator ? **(2)**

The overall heat transfer coefficient may be approximated as 1200 $W/m^2.K$.

(b) Consider a concentric tube heat exchanger characterised by a uniform overall heat transfer coefficient and operating under the following conditions :

	m (kg/s)	c_p (J/kg.K)	T_i (°C)	T_0 (°C)
Cold fluid	0.125	4200	40	95
Hot fluid	0.125	2100	210	

(i) What is the maximum possible heat transfer rate ? **(3)**

(ii) What is the heat exchanger effectiveness ? **(4)**

(iii) What is the ratio of the required areas for the two key flow conditions (parallel flow versus counterflow) ? **(3)**

7. Radiation leaves a furnace of inside surface temperature 1500 K through an aperture 20 mm in diameter. A portion of the radiation is intercepted by a detector that is 1 m from the aperture, has a surface area of $10^{-5} m^2$, and is oriented as shown in Figure 7.

(a) If the aperture is open, what is the rate at which radiation leaving the furnace is intercepted by the detector ? **(13)**

(b) If the aperture is covered with a diffuse, semi-transparent material of spectral transmissivity $\tau_\lambda = 0.8$ for $\lambda \leq 2$ µm and $\tau_\lambda = 0$ for $\lambda > 2$ µm, what is the rate at which radiation leaving the furnace is intercepted by the detector ? **(7)**

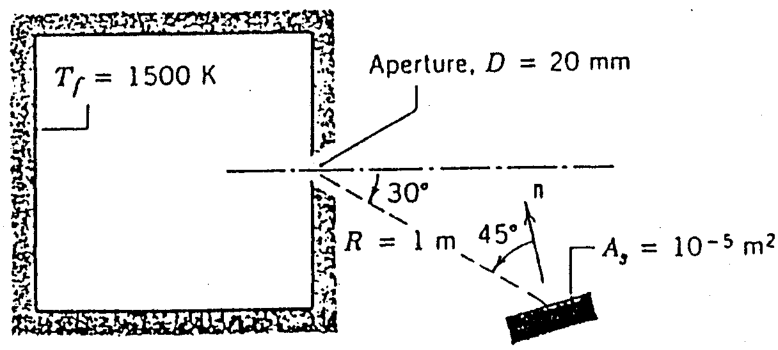

FIGURE 7