B.E. (Mech) Part-III 5th Semester Final Examination, 2011

SUBJECT: HEAT TRANSFER (ME-503)

Branch: Mechanical Engineering.

Time: 3 Hrs. Full Marks: 70

FIRST HALF

Answer any three questions. All questions are of equal value.

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1. (a) Explain Buckingham π-Theorem. Apply this to show that Nusselt number is function of Reynolds number and Prandtl number in case of forced convection heat transfer.

(b) A horizontal pipe laid in the ground is 75 mm in diameter and 2 m in length. It is kept at constant temperature of 110°C. The pipe is surrounded by atmospheric air at a temperature of 30°C. Calculate the heat loss by natural convection from this pipe. The fluid properties at the relevant temperature are

$\nu = 20.02\times10^{-6}$ m²/s, k = 0.256 kcal/hr-m-°C and Pr = 0.694

The heat transfer correlation that can be used is given by $Nu = C\,[Gr.Pr]^m$

where C = 0.525 and m = 0.25 if $10^4 < Gr.Pr < 10^9$

and C = 0.129 and m = 1/3 if $10^9 < Gr.Pr < 10^{12}$

2. (a) Define radiosity and irradiation in connection with radiation heat transfer. Prove that the radiant heat interchange between two gray bodies is given by

$$Q_{net} = \frac{A_1\sigma_b\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2}\times\frac{A_1}{A_2}}$$, where the symbols have their usual meanings.

(b) Calculate the view factor F_{12} and F_{21} for the following cases:

(i) sphere of diameter D inside a cubical box of length D (Fig.1)

(ii) a hemisphere closed by a plane surface (Fig. 2). Also calculate F11 in this case.

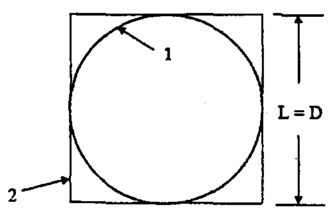


Figure 1

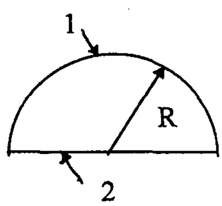


Figure 2

3. (a) What do you mean by spectral and total emissive power? State and deduce Kirchoff's law in radiation.

(b) A cryogenic fluid flows through a long tube of 20 mm diameter, the outer surface of which is diffuse and gray ($\varepsilon_1 = 0.02$) at 77 K. This tube is concentric with a larger tube of 50 mm diameter, the inner surface of which is diffuse and gray ($\varepsilon_2 = 0.05$) and at 300 K. The space between the surfaces is evacuated. Calculate the heat gain by cryogenic fluid per unit length of tubes. If a thin radiation shield of 35 mm diameter ($\varepsilon_3 = 0.02$ on both sides) is inserted midway between the inner and outer surfaces, calculate the percentage change in heat gain.

4. (a) What do you mean by effectiveness of a heat exchanger? Derive the expression for effectiveness of a parallel flow heat exchanger as given below:

$$\varepsilon = \frac{1-\exp[-NTU(1+C)]}{1+C}$$ where the symbols have their usual meaning. Also show that for evaporator and condenser the expression reduces to $\varepsilon = 1-\exp(-NTU)$.

(b) Water at 25°C and 1.5 m/s enters a long brass (k = 110 W/m-K) condenser tube with inner diameter of 1.34 cm and outer diameter of 1.58 cm. The heat transfer co-efficient for condenser at outer surface of the tube is 12000 W/m^2 K. Calculate the overall heat transfer co-efficient based on outer surface of the tube. The properties of water at 25°C may be taken as given below:

$\rho = 996$ kg/m^3, $\mu = 8.6\times10^{-4}$ N-s/m^2 k = 0.614 W/mK and Pr = 5.85

5. Write short notes (any three):

(i) LMTD method of heat exchanger analysis

(ii) Radiation shield

(iii) Wien's displacement law

(iv) Nusselt number

Second Half

Answer Q 6 or Q 7; also answer Q 8 and Q 9.

6. (a) Derive the general heat conduction equation

$$\nabla^2 T + \frac{q_G}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

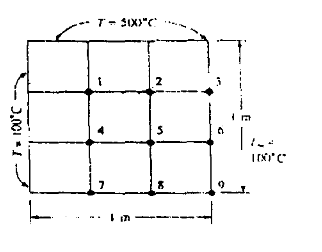
by considering a volume element in Cartesian coordinate system.

(b) Determine the maximum current that a 1 mm diameter bare aluminium (k = 204 W/mK) wire can carry without exceeding a temperature of 200°C. The wire is suspended in air at temperature 25°C and h = 10 W/m^{2}K. The electrical resistance of this wire per unit length is 0.037 Ω/m.

7. (a) Consider a composite hollow cylinder made up of two cylinders, the inner cylinder having radii r_1 and r_2, and the outer cylinder having radii r_2 and r_3. The thermal conductivities of the materials of the two cylinders are k_1 and k_2, respectively. Let the temperatures of the two fluids inside and outside the composite cylinder be T_i and T_o and let the corresponding heat transfer coefficients be h_i and h_o. Draw the thermal resistance circuit. Find out the expressions for total thermal resistance, the heat transfer rate and overall heat transfer coefficients based on inner area and outer area.

(b) A hot gas at 300°C flows through a long metal pipe 10 cm OD and 3 mm thick. From the standpoint of safety and energy conservation, mineral wool insulation (k = 0.052 W/mK) is wrapped around it so that the exposed surface of the insulation is at a temperature of 50°C. Calculate the thickness of insulation required to achieve this temperature if h_i = 29 W/m^{2}K, h_o = 12 W/m^{2}K and the surrounding air temperature is 25°C. Also calculate the corresponding heat loss rate per unit length.

8. Consider the adjacent square. The left face is maintained at 100°C and the top face at 500°C, while the other two faces are exposed to an environment at 100°C. Given h = 10 W/m^{2}K and k = 10 W/mK. The block is 1 m square. Compute the temperature of the various nodes as indicated in the figure and the heat flows at the boundaries.



$T_\infty = 100°C$

9. A solid steel ball 5 cm in diameter and initially at a temperature of 450°C is quenched in a controlled environment whose temperature is maintained at a steady value of 90°C. Given: h = 115 W/m^{2}K, ρ = 8000 kg/m^3, C_p=0.42kJ/kgK, k = 46 W/mK. Determine the time taken by the centre of the ball to reach a temperature of 150°C if (a) internal temperature gradients are neglected, and (b) internal temperature gradients are not neglected. Compare your results in (a) and (b) with respect to the value of Bi. Take $\lambda_1 R = 0.430$ and

$$\frac{2(\sin\lambda_1 R - \lambda_1 R\cos\lambda_1 R)}{\lambda_1 R - \sin\lambda_1 R\cos\lambda_1 R} = 1.01865$$