National Program on Technology Enhanced Learning

CONDUCTION AND RADIATION

Final Examination

Max. Marks: 100 Duration: 3 hours

1. Make suitable assumptions wherever required with justification
2. Assume any missing data

(1) The steady state temperature distribution in a one dimensional wall of constant thermal conductivity of 50 W/mK and thickness 45 mm is observed to be $T = 200 - 2100\,x^2$ where T is in $^\circ$C and x is in metres (measured from the left end of the wall).

(a) What is the volumetric heat generation, q_v in W/m^3.
(b) Determine the heat flux at the two walls.
(c)What is the relationship between the wall heat fluxes and the heat generation rate? (6)

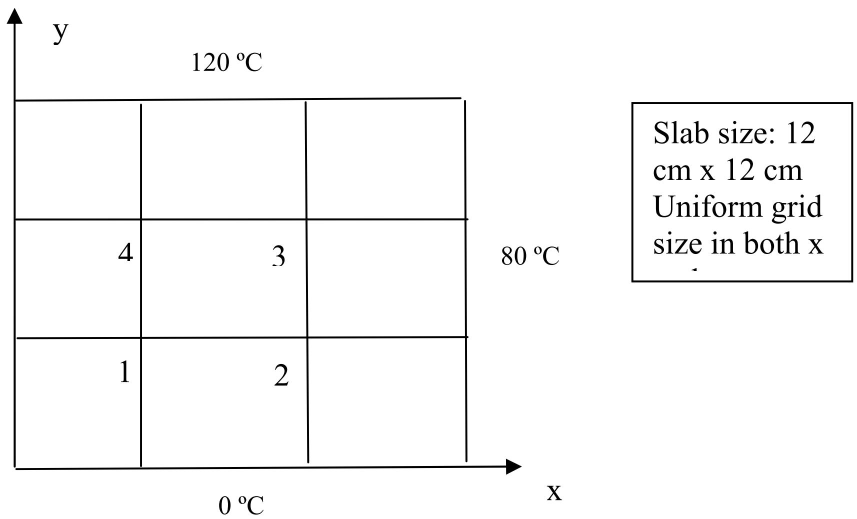
(2) A Bakelite coating is to be used with a 10 mm diameter conducting rod, whose surface is maintained at 240 $^\circ$C by passage of an electrical current. The rod is in contact with a fluid at 30 $^\circ$C and the convection heat transfer coefficient is 150 W/m^{2}K. How much Bakelite should be added to reduce the heat transfer rate associated with the bare rod by 30% (thermal conductivity of Bakelite is 1.4 W/mK) (8)

(3) A composite spherical shell of inner radius r_1= 0.25 m is constructed from lead of outer radius r_2=0.30 m and stainless steel of outer radius r_3=0.31 m. The cavity is filled with radioactive wastes that generate heat at the rate of q_v= 5 x 10^5 W/m^3. It is proposed to submerge the container in sea waters at a temperature of T_∞=15 $^\circ$C. The heat transfer coefficient provided by the sea water is 550 W/m^{2}K at the outer surface of the container. Given that the melting point of lead is 600 K, determine if the proposal is safe (k_{Pb}= 35 W/mK, k_{SS}= 15.1 W/mK). (8)

(4) A thin metallic wire of thermal conductivity k, diameter D and length 2L is annealed by passing an electric current through the wire in order to induce a uniform volumetric heat generation q_v. The heat transfer coefficient between the ambient and the wire is given by h. The ambient temperature and the temperature at the two ends of the wire (i.e. at $x = \pm L$) is T_∞.

(a) Derive the governing equation for the one dimensional temperature distribution in the wire (T=f(x) only) treating it as a fin that also has heat generation for steady state conditions in the fin.

(b) Obtain an expression for the steady state temperature distribution in the wire by solving the equation derived in part (a) (6+6)



(5) Two dimensional, steady state conduction in a square slab with k = 40 W/mK and an internal heat generation of $q_v = 6 \times 10^5$ W/m^3 is to be numerically simulated. The details are given in the figure. For simplicity the number of grid points is intentionally kept small for this problem.

(a) Identify the governing equation for the problem. (1)

(b) Using the central difference finite difference scheme in conjunction with the Gauss-Seidel method, estimate T_1,T_2, T_3 and T_4. Start with an initial guess of 50 ºC for all the four temperatures. ***Do at least 6 iterations***. (8)

(c) What is the center temperature? (1)

(6) Radiation is the only mode of heat transfer possible in space radiators used in space stations. As the sizes of the space stations keep increasing, cooling technologies have also to keep pace. One novel idea is to use what is now known as a Liquid Droplet Radiator (LDR). Here, the heat is first transferred to a high vacuum oil, which is then injected into outer space as a stream of small droplets. The stream travels over a distance "L" over which it cools by radiating heat to

outer space at a temperature T_∞. The droplets are returned and collected to the space station.

(a) Derive the governing equation for the transient temperature response of a spherical droplet of mass m, specific heat capacity C_p and emissivity ε. The droplet is at an initial temperature of T_i. You may assume the droplet to be spatially isothermal.

(b) Solve the governing equation and obtain an expression for the transient temperature response of the droplet.

(c) Consider droplets that have an emissivity of 0.95 and diameter of 0.6 mm. These are injected at an initial temperature of T_i = 520 K and a velocity of 0.11 m/s. Properties of the oil are ρ=890 kg/m^3, C_p= 1900 J/kgK and k=0.15 W/mK. Assume each droplet to radiate to deep space at T_∞ = 0 K. Determine the distance L for the droplets to reach the collector at a final temperature of 303 K. What is the enthalpy rejected by each droplet in the process?

(d) Is the lumped capacitance formulation justified? (4+6+7+1)

(7) Consider a thin opaque, horizontal plate with an electrical heater on its bottom side. The top side is exposed to ambient air at 25 $^\circ$C with a convection heat transfer coefficient of 12 W/m^{2}K, solar irradiation of 650 W/m^2 and an effective sky temperature of -40 $^\circ$C. Determine the electrical power required to maintain the temperature of the surface at 65 $^\circ$C if the plate is diffuse and has the following spectral, hemispherical reflectivity

$0 \le \lambda \le 2$ μm, ρ_λ= 0.2

$2 \le \lambda \le \infty$ μm, ρ_λ= 0.75

(10)

(8) A two dimensional evacuated, gray diffuse enclosure is in the shape of a triangle ABC. The sides of the enclosure are infinitely deep in the direction perpendicular to the plane of the paper.

Surface	Length, m	Emissivity, ε	Temperature, K
AB	8	0.65	1050
BC	6	0.45	450
CA	9	0.75	800

Compute the net radiation heat transfer from the three surfaces using the radiosity-irradiation method. (14)

(9) A gas turbine combustion chamber may be approximated as a long tube 40 cm in diameter. The combustion gases (**a participating medium)** are at a pressure of 2 atm and 1150° C, while the surface temperature of the chamber is 550° C. If the combustion gases are composed of CO_2 with a mole fraction of 0.2, water vapour with a mole fraction of 0.15 and the remainder Nitrogen, what is the net radiation heat transfer between the gas and the surface of the combustion chamber? The emissivity of the combustion chamber surface may be taken to be 0.90. (14)