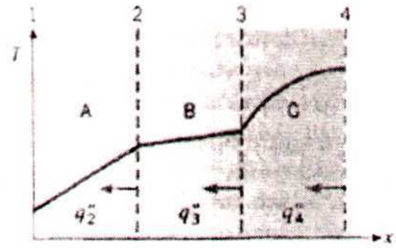
Bm '21

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR
End Semester Examination 2015
Sub. No. ME30005 Sub. Name Heat Transfer
Time: 3 Hrs, Full Marks 100
All Questions are Compulsory

Q1.

(a) The steady-state temperature distribution in a composite plane wall of three different materials, each of constant thermal conductivity, is shown in the figure below:



(i) Comment on the relative magnitudes of q_2'' and q_3'' and of q_3'' and q_4''.

(ii) Comment on the relative magnitudes of k_A and k_B and of k_B and k_C.

(iii) Sketch the heat flux as a function of x.

(b) State the assumptions under which the following expressions/formulae are valid (symbols have usual meaning):

(i) $q = \frac{kA(T_1 - T_2)}{L}$, (ii) $-k\left.\frac{\partial T}{\partial y}\right|_{wall} = h(T_{wall} - T_\infty)$, (iii) $q = \sigma\varepsilon(T^4 - T_\infty^4)$,

(iv) $\rho c_p \frac{DT}{Dt} = \nabla.(k\nabla T)$, (v) $St = \frac{C_f}{2}$

10+10=20 Marks

Q2.

(a) Derive the thermal boundary layer equation for steady flow with constant properties, assuming viscous dissipation to be important. What are the major assumptions under which this equation is valid?

(b) By order of magnitude analysis, derive a scale for the ratio of the transverse velocity components at the edges of the hydrodynamic boundary layer and the thermal boundary layer respectively, for the case of flow of oil over a heated horizontal flat plate.

(c) Consider flow of molten metal over a heated isothermal horizontal flat plate. Assuming a linear temperature profile in the thermal boundary layer, derive an expression for the Nusselt number.

4+6+10=20 Marks

Q3.

(a) Consider an incompressible flow through a rectangular channel, subjected to a constant wall temperature boundary condition. Width of the channel (z-direction) is much larger than the height (y-direction), and the velocity profile is uniform, both axially (x-direction) and in the transverse direction (y-direction). Assuming the flow to be thermally fully developed, obtain the value of the Nusselt number. State the assumptions you make.

(b) For the channel described in part (a) above, now assume that the bottom wall moves towards the right with a uniform velocity U_1, whereas the top wall is stationary. Assume that the gap between the top and the bottom plates (H) is narrow, and that there is a uniform volumetric heat generation of Q''' , due to electrical heating in the domain. Assuming that the average heat transfer coefficient is h and the inlet bulk mean temperature is T_{mi} , derive a profile of bulk mean temperature variation along the channel axis.

10+10=20 Marks

Q4.

(a) For natural convection over a vertical flat plate with constant wall heat flux (q''), derive an expression for the order of magnitude of the ratio of the thermal boundary layer thickness to the plate height, expressed in the terms of the modified Rayleigh number $Ra_{*H} = \dfrac{g\beta q'' H^4}{\upsilon\alpha k}$, symbols having their usual meaning, considering $\Pr >> 1$. Sketch the velocity and temperature profiles for this case, overlaid on the same graph.

(b) Assume that the velocity profile in the boundary layer for natural convection past a vertical flat plate is given by: $v = a_0 + a_1 x + a_2 x^2 + a_3 x^3$. Invoking suitable assumptions and approximations, obtain the expressions for a_0, a_1, a_2, a_3.

(c) Quiescent saturated vapour of a liquid at a temperature of T_v condenses over a flat surface kept at a constant temperature T_w. The surface makes an angle θ with the vertical. The condensate as a thin film of liquid flows past the plate due to gravity. The wettability characteristics of the surface result in a slip velocity u_s of the liquid at the surface. Derive an expression for the local heat transfer coefficient in terms of the liquid density (ρ_l), vapour density (ρ_v), enthalpy of condensation (h_{fg}), viscosity (μ), liquid thermal conductivity (k), temperatures T_v and T_w, and the slip velocity u_s. State clearly the assumptions needed for your derivation.

6+6+8=20 Marks

Q5.

(a) A simple shell-and-tube heat exchanger cools oil which flows at a rate of 1 kg/s with an inlet temperature of 80°C and an outlet temperature of 40°C. The cold fluid is water which flows at a rate of 0.5 kg/s, with an inlet temperature of 20°C. The overall heat transfer coefficient is 500 W/ m^2°C. The specific heats of oil and water are 2.1 kJ/kg°C and 4.2 kJ/kg°C respectively.

(i) State with reason whether the heat exchanger is of parallel flow or counterflow arrangement.

(ii) Determine the heat transfer area required for the service.

(b) Two concentric spheres of diameters 0.5 m and 1 m are separated by an air space and have surface temperatures of 400 K and 300 K respectively.

(i) What is the radiation exchange between the spheres if the surfaces are black?

(ii) What is the radiation exchange between the spheres if they are diffuse and gray with emmissivity = 0.5? Derive any formula that you use.

(iii) How much error would be incurred in the prediction of radiation heat exchange by assuming black body behaviour for the outer surface, with all other conditions remaining the same?

8+12=20 Marks