BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)
SECOND YEAR FIRST SEMESTER EXAMINATION 2025

HEAT TRANSFER

Time: Three hours Full marks: 100

Answer **any** ***five*** questions.
All questions carry equal marks.
Assume any unfurnished data relevant to the solutions.

1. a) State the conditions under which the concept of electrical analogy for thermal resistances in heat conduction can be applied.

   b) Consider a composite plane wall of a furnace made up of layers of fire clay and red brick with the space between them filled with crushed brick. The thicknesses of the fire clay layer, crushed brick and red brick are 0.120 m, 0.050 m and 0.250 m, respectively and their thermal conductivities are 0.93 W/m^oC, 0.13 W/m^oC and 0.7 W/m^oC, respectively. If the inside and outside temperatures of the furnace wall are 1050 ^oC and 50 ^oC, respectively, find the heat transfer rate from the wall having a surface area of 2 m^2. Find also the temperature at the interface between the fire clay and the crushed brick and that between the crushed brick and the red brick interface. **(4+16)**

2. a) A plane wall separates two fluids at different temperatures T_{fi} and T_{fo} ($T_{fi} > T_{fo}$). The wall has a thickness L, surface area A and thermal conductivity k. The hot fluid convects heat to the wall with a heat transfer coefficient h_i and the cold fluid receives heat from the wall with a heat transfer coefficient h_o. Find the total thermal resistance R_{total} to heat flow, the overall heat transfer coefficient U and the rate of heat transfer. Assume steady one-dimensional heat transfer.

   b) Consider steady one-dimensional heat conduction through the thickness of a plane slab having thickness L and thermal conductivity k. The two faces of the slab are maintained at constant temperatures T_1 and T_2. The two faces of the slab have surface area A. There is uniform volumetric heat generation inside the wall at a constant rate of q_{gen}. Starting from an appropriate governing differential equation and stating the boundary conditions, find an expression for the temperature variation through the thickness of the slab. Also, find the rate of heat transfer through the two faces of the slab. **(6+14)**

3. (a) Consider a hot metal body having a volume V, surface area A, density ρ, specific heat c. The body is initially at a uniform temperature T_i and it is suddenly quenched by immersing it in a liquid reservoir at temperature T_∞. h is the heat transfer coefficient of convection from the body to the quenching bath. Treating the body as a lumped system, derive an expression for the temperature transient.

   (b) Consider a straight fin of length L, uniform cross sectional area A and perimeter P with its base maintained at a temperature T_b. The fin loses heat by

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convection to an ambient at a temperature T_∞ with heat transfer coefficient h. The thermal conductivity of the fin material is k.

Assume the differential equation that governs the temperature distribution in the fin stating the assumptions. Write the boundary conditions. Hence solve for the temperature distribution for a very long fin. Also find the fin heat transfer rate from the fin. **(6+14)**

4. Consider Couette flow between two infinitely large parallel plates, separated by a distance L. The upper plate is moving with a velocity U. The temperatures of the lower and the upper plates are maintained at constant temperatures T_L and T_0 respectively ($T_L > T_0$). Obtain the velocity and temperature distributions for the flow having significant viscous dissipation. Consider zero pressure gradient in the axial direction. Draw the velocity and temperature variations in the fluid between the parallel plates. **(20)**

5. Consider steady, laminar boundary flow and heat transfer of a molten metal having a low Prandtl number ($Pr<<1$) over a flat plate. The free stream velocity and temperature are $U\infty$ and $T\infty$ respectively. The plate is maintained at a uniform temperature of Tw. Draw the velocity and thermal boundary layers highlighting all the relevant details. Show the following by the method of scale analysis:

$$\delta_T / L \sim Re_L^{-1/2}\,\mathrm{Pr}^{-1/2}$$

$$\delta_T / \delta \sim \mathrm{Pr}^{-1/2}$$

$$Nu_L \sim Re_L^{1/2}\,\mathrm{Pr}^{1/2}$$

(20)

6. (a) Derive an expression for LMTD of a counter flow heat exchanger in terms of its terminal temperature differences.

(b) In a double pipe heat exchanger, hot oil (c_p = 2200 J/kg^0C) flows at a rate of 2 kg/s and gets cooled from 150 ^0C to 40 ^0C. Cooling is achieved by circulating 2 kg/s of water (c_p = 4180 J/kg^0C) which enters the heat exchanger at 20 ^0C. Assuming an overall heat transfer coefficient U = 3000 W/m^2 ^0C, calculate the heat transfer area required for a counter flow heat exchanger. Can the job be accomplished by a parallel flow heat exchanger? **(10+10)**

7. (a) Explain the terms '*Sizing*' and '*Rating*' of a heat exchanger.

(b) Derive an expression for effectiveness (ε) of a parallel flow heat exchanger in terms of Number of Transfer Unit (NTU) and ratio of heat capacity rates (C_r) of the two fluids. **(6+14)**