Ref. No. Ex/PE/PC/B/T/223/2023

B.E. POWER ENGINEERING SECOND YEAR SECOND SEMESTER - 2023

SUBJECT: HEAT TRANSFER

Time: Three Hours (Full Marks 100)

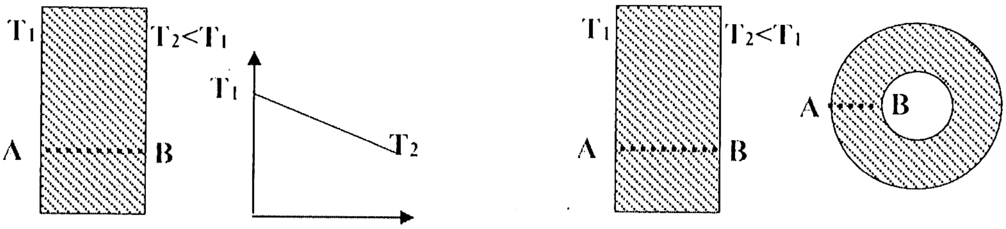
Assume the following properties of air and water unless otherwise specified:

AIR: $\rho = 1.16$ kg m^{-3}, $\nu = 1.8\times10^{-5}$ m^2 s^{-1}, $C_p = 1.014$ kJ kg^{-1} K^{-1}, $Pr = 0.7$

WATER: $\rho = 1000$ kg m^{-3}, $\nu = 1.0\times10^{-6}$ m^2 s^{-1}, $C_p = 4.186$ kJ kg^{-1} K^{-1}, $Pr = 7.0$

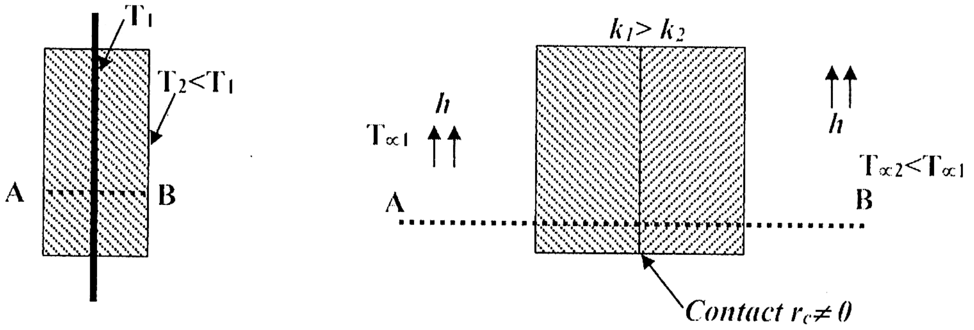
Part I (CO1) (25 marks)

1. Figure 1 shows six heat transfer scenarios under steady state. The temperature profile under scenario (a) along the line AB is shown as example. Plot the temperature profiles for the other five cases along line AB likewise. 15



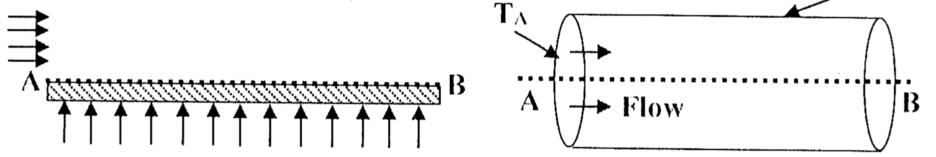
(a) A plane wall with no volumetric heat generation, i.e., $q_{gen} = 0$

(b) A cylindrical shell with $q_{gen} = 0$, $r_A > r_B$



(c) An infinite cylindrical wire with $q_{gen} = 0$, but having a current carrying wire passing through the axis, generating $q_l = C$ per unit length of the conductor.

(d) A plane composite wall with $q_{gen} = 0$, convective heat transfer coefficients h on both sides, and a finite contact thermal resistance r_c. Left block has larger thermal conductivity than the tight one.



(e) Flow of a cold fluid over a flat plate receiving constant wall heat flux q″

(f) Thermally fully developed flow of a hot fluid through a long pipe with wall temperature $T_w < T_1$

Fig 1

[Turn over

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Time: Three Hours **(Full Marks 100)**

2. Figure 2 shows four sets of radiating surfaces that are infinitely spread along the direction perpendicular to the plane of the paper. Find the view factors asked in the respective sub-figures. **$2^1/_2 \times 4 = 10$**

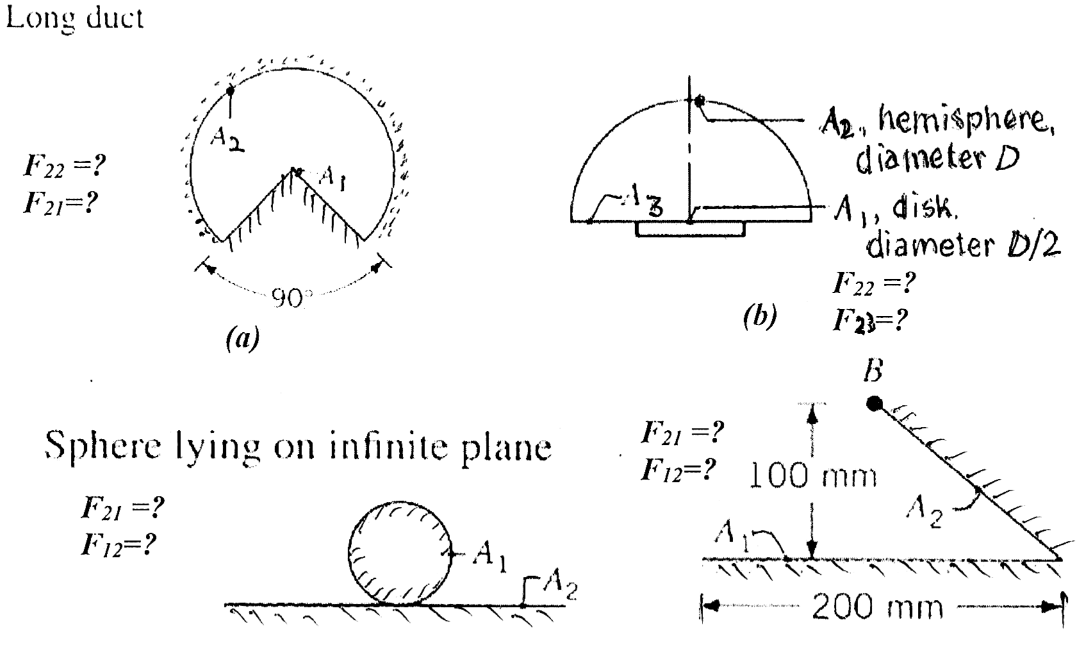

Fig 2

Part II (CO2) (25 marks)

3. A hot (T_m) metal cube of side a and material properties k, ρ and C_p (each having their conventional meaning) is suddenly immersed in a cold bath (at T_0) where the average heat transfer coefficient is h. (a) State the criteria for which the temperature within the cube at each instant of time may be assumed spatially uniform. (b) Deduce an expression of temporal variation of the cube temperature under the aforementioned assumption. (c) Also express the time needed for the cube to cool down to a temperature difference that is 10% of the initial temperature difference between the cube and the cold bath.

3+15+7 = 25

OR

Starting from the governing differential equation of steady-state one-dimensional heat conduction through a spherical shell, deduce the expression of thermal resistance offered by a cylindrical shell of inner radius a, outer radius b and thermal conductivity k. If the outer side of the shell is exposed to a convective heat transfer coefficient of h, for what value of b the overall thermal resistance will be the least? Express this minimum thermal resistance in terms of a, b, k and h. **20+5 = 25**

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Part III (CO3) (25 Marks)

4. A thermocouple having a bead diameter of 500 micron is inserted in a hot air stream, when it reads 600 K. The air stream has a flow velocity of 5 m/s. The emissivity of the thermocouple bead is 0.9. While it is expected that the thermocouple shows the actual temperature of the air stream, it actually does not do so! Under steady state, the bead loses heat by radiation to the enclosure of the flow, which is at 227 °C. What is the actual temperature of the air stream. Air properties may be taken from the header in page 1 of the question paper. For cross-flow over spheres, you may assume

$$Nu_D = 2 + (0.4Re_D^{0.5} + 0.06Re_D^{2/3})Pr^{0.4}$$

OR

A furnace is of cylindrical shape with $R = H = 2$ m. The base, top, and side surfaces of the furnace are all black and are maintained at uniform temperatures of 500, 700, and 1200 K, respectively. Determine the net rate of radiation heat transfer to or from the curved surface during steady operation. Use the view factor chart provided at the end of the question paper.

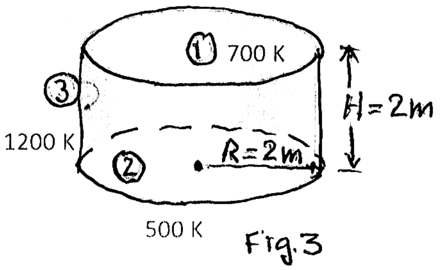

Fig.3

Part IV (CO4) (25 Marks)

5. It is desired to use a double-pipe counter-current heat exchanger to cool 3 kg/s of oil (C_p=2.1 kJ/kg.K) from 120 °C. Cooling water at 20 °C enters the outer tube of the heat exchanger at a rate of 10 kg/s. Heat transfer coefficient at the water and the oil sides of the inner tube are 900 and 1800 W/m^{2}K, respectively. The heat transfer surface area is 6 m^2. Neglecting any heat transfer between the heat exchanger and the surrounding, and thermal resistance offered by the tube metal, estimate the exit temperatures of oil and water.

OR

An aluminum (k=204 W/mK) rod of 2 cm diameter and 20 cm length protrudes from a wall that is maintained at 300 °C. The rod is exposed to a stream of air at 30 °C in a cross-flow velocity of 15.5 cm/s. The average Nusselt number correlation for cross flow over cylinder may be taken as $Nu_D = 0.683\ Re^{0.466}\ Pr^{1/3}$. You may assume the air properties mentioned in the header of page 1 of this question paper. Calculate the heat lost by the rod and the temperature of the rod at a distance of 10 cm from the wall.

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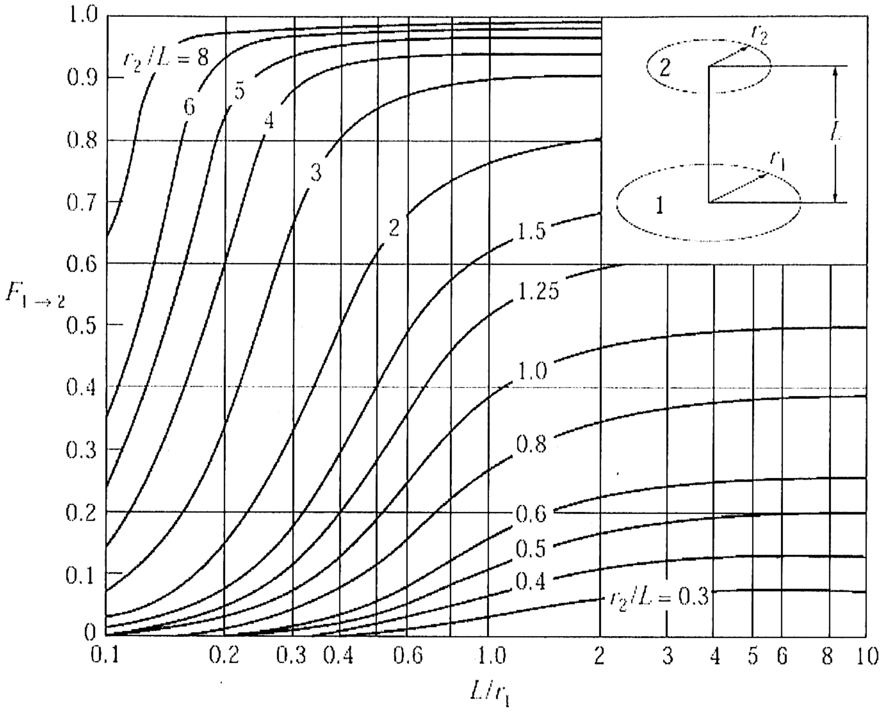
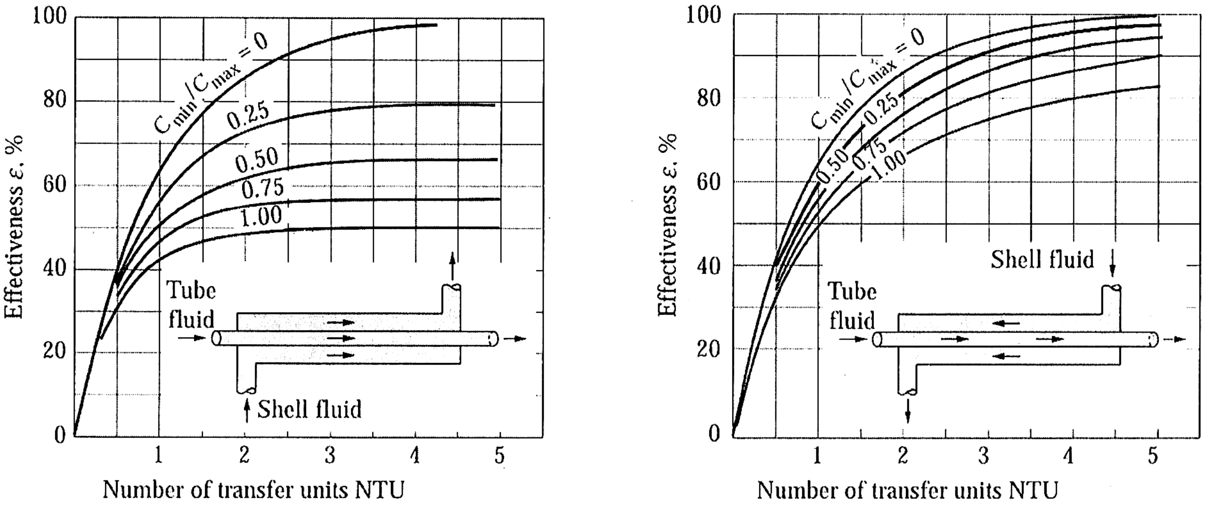
ADDITIONAL INFORMATION



View Factor Chart



ε-NTU plots for concentric tube heat exchangers

$$\varepsilon_{PARALLEL} = \frac{1-exp\left[-NTU\left(1+C_r\right)\right]}{1+C_r};\qquad \varepsilon_{COUNTER} = \frac{1-exp\left[-NTU\left(1-C_r\right)\right]}{1-C_r\,exp\left[-NTU\left(1-C_r\right)\right]}\quad \left(for\ C_r<1\right)$$

$$= \frac{NTU}{1+NTU}\qquad \left(for\ C_r=1\right)$$