INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester Examination 2022-23

Date of Examination: 22/02/2023. _ Session: (FN/AN) AN. Duration: 2 hrs. Full Marks: 30

Subject No.: CH21204 Subject: Heat Transfer

Department/~~Center/School~~: Chemical Engineering

Specific charts, graph paper, log book etc., required: NIL

Special Instructions (if any):

All questions are compulsory

Assume any missing data, if necessary, with proper justification.

Answer all questions in a part together

Please mention the part number you are answering

Also answer all parts of a question together.

Part 1

1. Assume a fluid is flowing over an isothermally flat plate. If the free-stream velocity of the fluid is doubled (flow is still laminar), then estimate the change in the drag force on the plate and the rate of heat transfer between the fluid and the plate.

(3+3 = 6)

2. Air at 20 °C is flowing at 15 m/s over an isothermally heated plate (0.5 m length X 0.5 m width, k = 0.0292 W/m K), maintained at 110 °C. What are the average heat transfer coefficient and the total amount of transferred heat? What are h, δ_t, and δ at the trailing edge? Consider, Pr = 0.7, and ν = 0.0000195 m^2/s of air at 65 °C.

(5)

3. In case of laminar flow over an isothermal flat plate, the local Nusselt number (Nu) for the entire range of Prandtl number (Pr) is given by:

$$\mathrm{Nu}_x = \frac{0.339\, \mathrm{Re}_x^{1/2}\, \mathrm{Pr}^{1/3}}{\left[1 + (0.0468/\mathrm{Pr})^{2/3}\right]^{1/4}}$$

Derive the expression for the average Nu for a laminar boundary layer over that plate for the identical condition.

(4)

Part 2

4. Heat flow @ 2 kW through a rectangular slab of 2.5 cm thickness and 0.2 m^2 cross-sectional area (normal to direction of heat flow) maintains a temperature of 100^0C at one side of the slab while the temperature at the other side is 30^0C. The temperature at the mid plane of the slab is 66^0C.
   (a) Obtain an expression for the thermal conductivity of the material assuming the thermal conductivity to vary linearly with temperature.
   (b) Mention the assumptions for the analysis.
   (c) Comment (rough sketch may be used) on the steady state temperature profile in the slab and compare the profile with the profile for constant thermal conductivity.
   (3+2+2)

5. A stainless steel [18% Cr, 8% Ni, k =20 W/m °C] sphere of diameter 4 cm is exposed to convection environment at 30^0C, h= 15W/m^2C. Heat is generated uniformly in the sphere at a rate of 1.0 MW/m^3. Calculate the steady state temperature at the centre of the sphere. **(3)**

6. Water flows through a stainless steel [18% Cr, 8% Ni, k =20 W/m.°C] tube of 25 mm ID and 2 mm wall thickness. The convection coefficient on the inside of the tube is 100W/m^2 (^0C) and on the outside is 12 W/m^2 (^0C). Estimate the overall heat transfer coefficient and comment on the main determining factor for U. Discuss the temperature profile in the tube. **(3+2)**

Given: The generalized heat conduction equation in cylindrical and spherical coordinates for constant thermal conductivity are -

$$\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{1}{r^2}\frac{\partial^2 (rT)}{\partial r^2}+\frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T}{\partial \theta}\right)+\frac{1}{r^2 \sin^2\theta}\frac{\partial^2 T}{\partial \phi^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$