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 $\nu = 0.0000195$ 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 -

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

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

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester Examination 2022-23

Date of Examination: 25-04-2023 Session: (FN/AN) AN. Duration: 3 hrs.

Full Marks: 50

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 each part in one place.*
- *Mention the part number you are answering.*
- *No queries will be entertained during the examination.*

PART – I

1. For fully developed laminar flow in a circular tube subjected to constant surface heat flux, derive the expression for fluid temperature profile in the tube and the Nusselt number.

(6+4 = 10)

2. Water, flowing at a rate of 0.5 kg/s through a 10 m long pipe with an inside diameter of 2 cm, is being heated with uniform wall heat flux at a rate of 5×10^4 W/m^2. Assuming fully developed flow, calculate:
   a. the pressure drop per unit pipe length in kPa/m
   b. the heat transfer coefficient based on the Colburn analogy in W/m^{2}K
   c. the heat transfer coefficient based on the Dittus–Boelter correlation in W/m^{2}K
   d. the difference between the wall temperature and the local mean water temperature
   e. the temperature enhancement experienced by the mean water temperature in the longitudinal direction from the inlet to the outlet

   Data given: Water properties at 20°C

   $k = 0.59$ W/(m.K), Pr = 7.07, $c_p = 4.2$ kJ/(kg.K), $\rho = 0.998$ g/cm^3, $\nu = 1$ cSt

(2+2+2+2+2 = 10)

3. Draw the boiling curve and identify the burnout point on the curve. Explain how burnout is caused. Why is the burnout point avoided in the design of boilers?

(2+2+1 = 5)

PART – II

1. It is required to calculate the heat flux through the composite wall shown in Fig. 1. Discuss if the assumption of one-dimensional heat flow is justified for the calculation. (2)

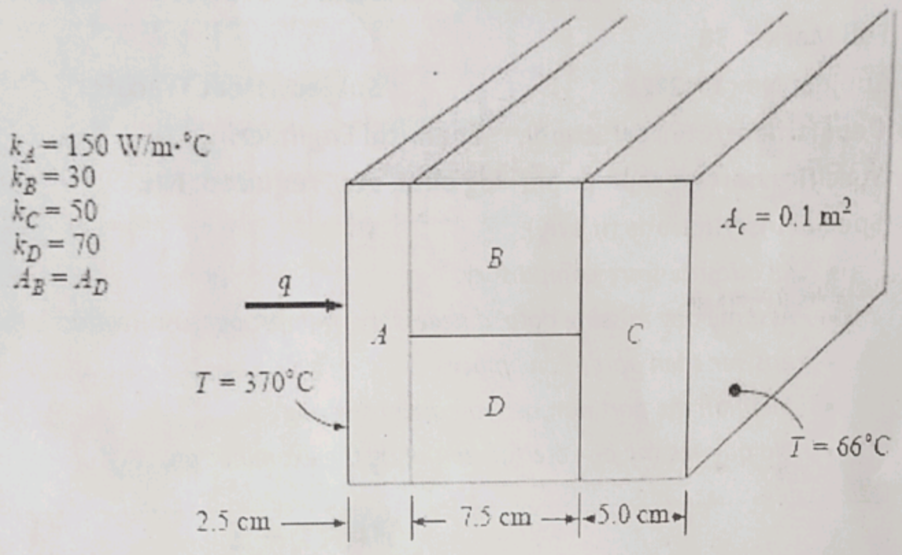


Fig. 1

2. Consider a shielding wall of thickness L for a nuclear reactor. The wall receives gamma ray flux such that heat is generated within the wall according to the relation - $\dot{q} = \dot{q}_0 e^{-ax}$ where $\dot{q}_0$ is the heat generation at the inner face of wall exposed to the gamma -ray flux and a is a constant. The constant heat generation maintains the inner surface at a constant temperature Ti while the outer surface is adiabatic

   (i) Represent the problem with a proper sketch containing all details and nomenclatures. (2)

   (ii) Starting from the generalized heat conduction equation for constant thermal conductivity in rectangular coordinates

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

   (a) derive an expression (using the specified nomenclatures in (i)) to obtain the temperature profile in the wall

   (b) Mathematically state the boundary conditions for obtaining the temperature profile. (The complete solution of the profile is not required). (3)

3. It is required to cool a 3.0 cm (side) steel cube (specific heat capacity = 460 J/kg (^{0}C), thermal conductivity= 40 W/m ^{0}C, density = 7800kg/m^3) from a temperature of 450^{0}C to 150 ^{0}C. The cooling can be either by (i) exposing the cube to air at room temperature of 40^{0}C (h= 7 W/m^2 ^{0}C) or (ii) submerging into boiling water where h= 10000 W/m^2 ^{0}C.

(i) With proper justification, state under which condition we can use lumped capacity method for estimating the rate of cooling (4)

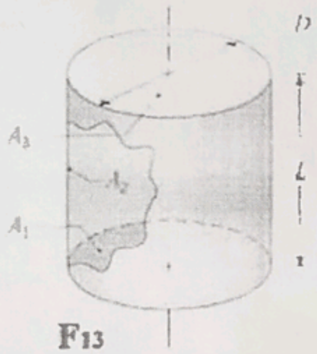
(ii) Sketch the transient temperature profile for the two cases (2)

(iii) Calculate the time required for cooling under the condition where lumped capacity method is applicable. (4)

4. Iron plate appears grey when cold and bright yellow when hot. Why? (2)

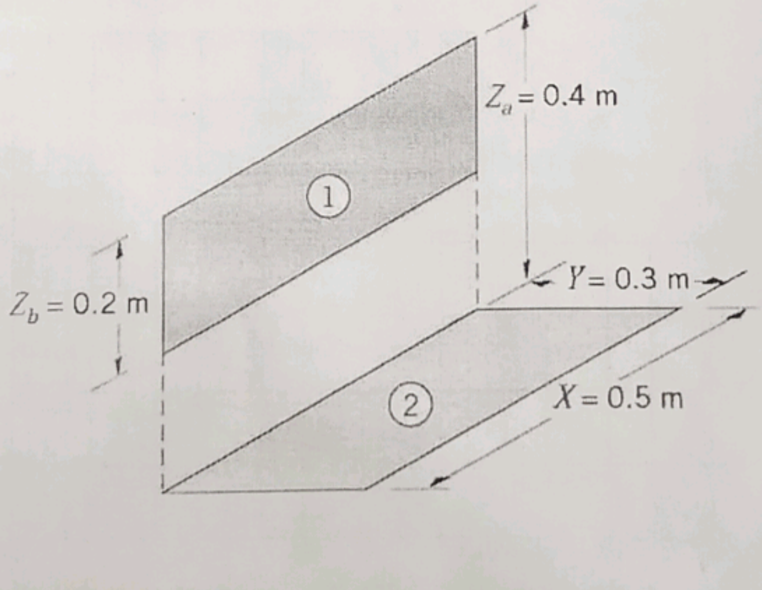
5. Calculate the view factors specified in each problem for the following geometries. The graphs below may be referred for calcualtions. (3+3)

(a) F_{13} for right circular cylinder of diameter D and length L where L=1.5D



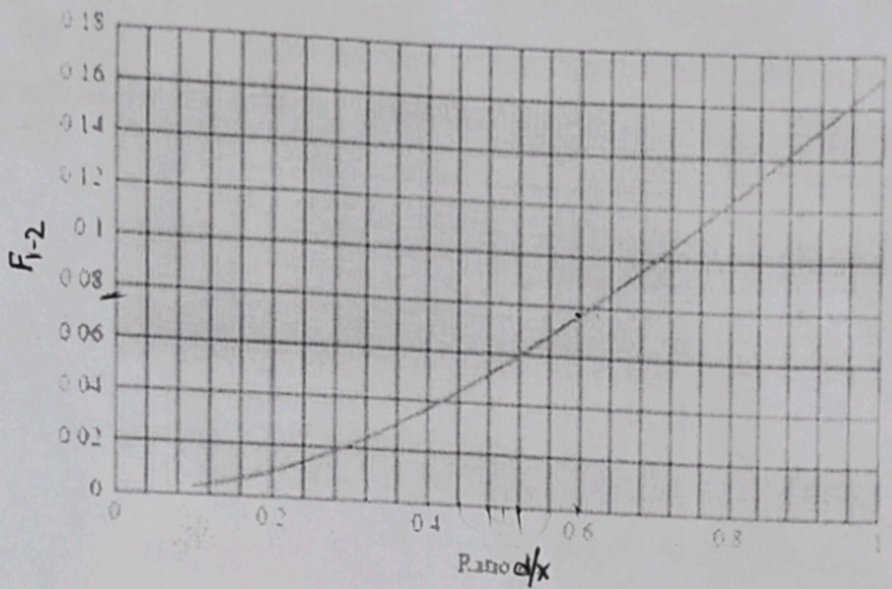
F_{13}

(c) F_{12} for surfaces 1 and 2 which are perpendicular but do not share a common edge



Radiation Shape Factor for radiation between

(a) parallel equal coaxial disks



(b) perpendicular rectangles with a common base