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)

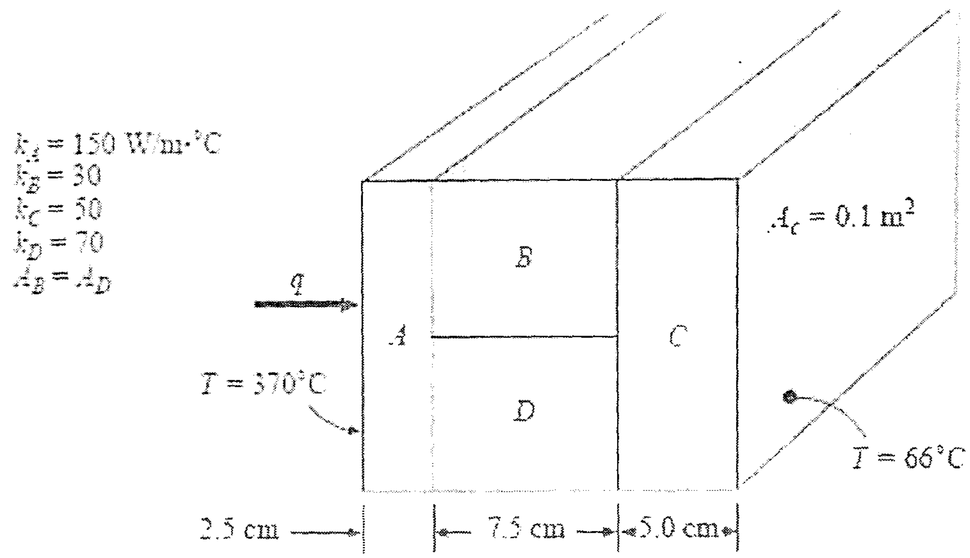


Fig. 1

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)

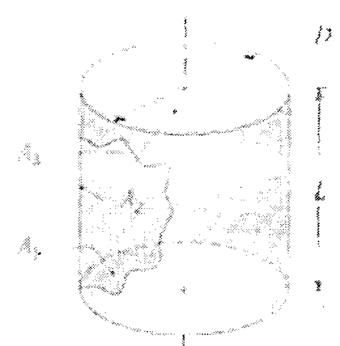
(ii) Sketch the transient temperature profile for the two cases (2)

(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)

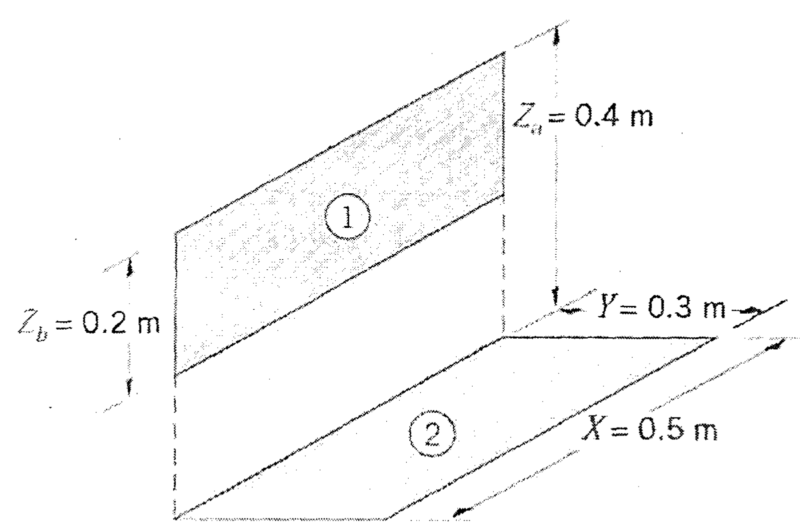
5. Calculate the view factors specified in each problem for the following geometries. The graphs below may be referred for calcualtions. (3+3)

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



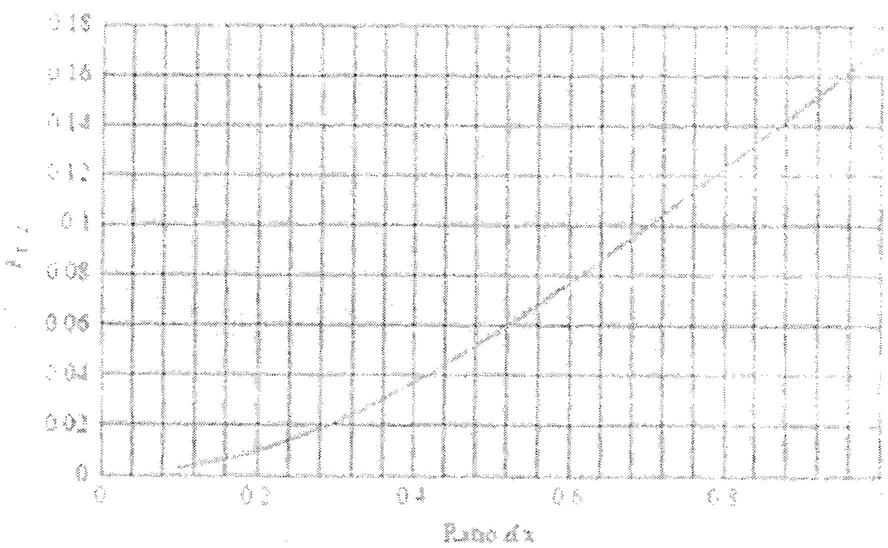
F_{13}

(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