DEPARTMENT OF MECHANICAL ENGINEERING, IIT Bombay

Ph.D. Comprehensive Examination – May/June 2015

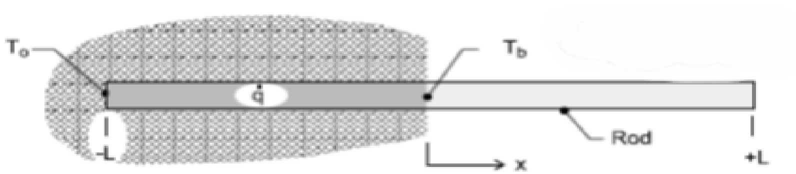
Heat Transfer

Maximum marks: 60 **Passing Marks: 30**

Instructions:

1. All questions are compulsory. This is an **open-notes** examination. Only **own handwritten** noted are permitted.
2. Please start each new question on a new page and keep all subparts of a question together.
3. Maximum marks per question are given in parenthesis.
4. Use of calculator is permitted.
5. Make suitable assumptions where necessary and state them clearly.
6. Make sure to cancel any unwanted work clearly, so that it is not graded.

Problem 1:A metal rod of length *2L*, diameter *D* and thermal conductivity, *k* is inserted into a perfectly insulating wall, exposing one half of the rod to an air stream at temperature T_∞ and providing a uniform heat transfer coefficient, h at the surface of the rod. Within the embedded portion of the rod, an electromagnetic field induces volumetric heat generation at a uniform rate $\dot{q}$.



a. Obtain an expression for the steady state temperature T_b at the base of the exposed half of the rod. The exposed portion may be treated as an infinitely long fin.
b. Derive an expression for the steady state temperature distribution for each half of the rod.

Problem 2:A cylinder of diameter 30 mm and length 150 mm is heated in cross flow in a large furnace having walls maintained at 1000 K. Air at 400 K circulates around the cylinder with a velocity of 3 m/s.

a. Starting with a control volume around the cylinder, obtain an expression for the initial rate of change of temperature of the cylinder.**[3 marks]**
b. Calculate the steady state surface temperature if the surface is selective with $\alpha_\lambda = 0.1 \, for \, \lambda \leq 3\mu m$, and $\alpha_\lambda = 0.5 \, for \, \lambda > 3\mu m$. You may assume a value of total hemispherical emissivity to be 0.5.**[7 marks]**

Problem 3:

A rod 2 cm in diameter and 20 cm long is at Temperature T_1 = 1200 K and has a hemispherical total emissivity of ε_1 = 0.3. it is within a thin-walled concentric cylinder of the same length having a diameter of 8 cm. The emissivity on the inside of the cylinder is ε_2 = 0.45, and on the outside is ε_o = 0.15. all surfaces are diffuse-gray. The entire assembly is suspended in a large vacuum chamber at T_e = 300 K. what is the temperature T_2 of the cylindrical shell? For simplicity, do not subdivide the surface areas. Given $F_{2\text{-}1}$ = 0.225, $F_{2\text{-}2}$ = 0.617.

[10 marks]

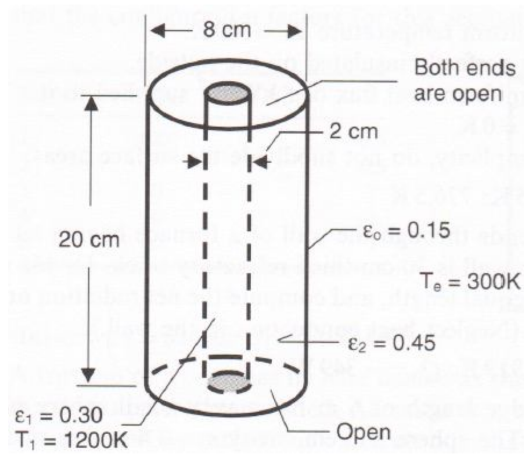
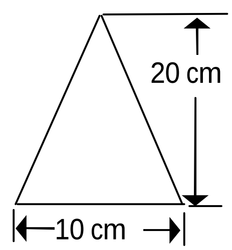


Figure for Problem 3.

Problem 4: Consider the case of a student who was in a hurry to reach the department for giving his qualifier. He forgot to turn off the electric iron he was using to iron his clothes just before leaving. The base of the electric iron may be assumed as an isosceles triangle as shown in the figure. The iron was left in its vertical position with the base (10 cm) at the bottom and the tip at the top. The iron had a thermostat whose setting was such that it cut off the power at 140°C and turned it on at 120°C. Assuming that the student returns to his room after 4 hours, compute the increase in the electricity bill of the hostel due to his negligence. You may assume that:



a) Natural Convection heat transfer occurs only from one side of the iron.
b) The wall temperature may be taken to be a constant at the mean of the cut off temperatures.
c) Radiation effects can be neglected
d) Ambient Temperature: 30°C
e) Cost per kW-hr of electricity is Rs. 10/-
f) The correlation to be used for the estimation of local heat transfer coefficient is

$$h_x = 0.508\,\mathrm{Pr}^{0.5}\frac{\left(\dfrac{g\beta\Delta T x^3}{\nu^2}\right)^{0.25}}{(0.952+\mathrm{Pr})^{0.25}}\frac{k}{x}$$, where x is the distance from the base

f) The properties of air may be taken as constant in the range 120°C -140°C:

$\rho = 0.968\ kg/m^3, \beta = 2.8X10^{\ 3}\ K^{-1}, k = 0.03\ W/m\text{-}K, \mu = 20.8\times10^{\ 6}\,Ns/m^2, \mathrm{Pr} = 0.71$

Proceed systematically. **[10 marks]**

Problem 5: Integral method is used to get approximate analytical expressions for heat transfer coefficients in boundary layer flows. In this method, the governing equations are integrated in across the boundary layer to get an ordinary differential equation for the variation of boundary layer thickness. From your study of heat transfer, answer the following questions.

a. Consider forced convection heat transfer from a horizontal flat plate held at a constant wall temperature to a fluid flowing with a uniform free stream velocity. If the Prandtl number of the fluid is very small (say 0.01), sketch the thermal and velocity boundary layers. What assumption can be made on the velocity profile across the thermal boundary layer?

[2 marks]

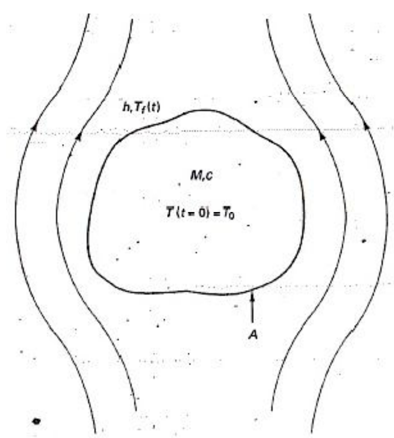
b. Now develop an integral method starting from the integral form of the energy equation for the boundary layer. You may assume a cubic profile for the temperature distribution and get the following:
   i. The variation of thermal boundary layer thickness as a function local Reynolds number.
   ii. The variation of local Nusselt number as a function of local Reynolds number and Prandtl number.**[8 marks]**

Problem 6:A body of mass *M*, specific heat *c*, surface area *A*, and initial condition T_o is immersed in a fluid of temperature $T_f(t)$ that varies with time as follows:

$$T_f(t) = \begin{cases} T_0 & for\ t \le 0 \\ T_0 + C_1 t & for\ t > 0 \end{cases}$$

where C_1 is a constant. The heat transfer coefficient *h* at the body-fluid interface is assumed to constant.

(a) Find the temperature profile for $Bi \ll O(1)$.
(b) Plot the variation of *T* with *t* for different (*hA/Mc*) and comment on the nature of curves.



[10 marks]

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