DEPARTMENT OF CHEMICAL ENGINEERING IIT KHARAGPUR

MID SEMESTER EXAMINATION 2012 – 2013, SPRING SEMESTER

Subject: Advanced Heat Transfer **Subject No: CH 61014**

No of Students: 85

FULL MARKS: 30 **Closed Book/ Closed Notes**

General Instructions:

1. *All Questions are compulsory*
2. *Fell free to assume any missing data with proper justifications.*
3. *Answer all the questions of each part together.*

PART A

1. Consider one-dimensional heat conduction in a plane wall with its surfaces being kept at constant temperatures. There is no heat generation in the wall and the wall has constant thermal conductivity. We know that the steady state temperature varies linearly in the wall in this case. Will this still be the case when the wall loses heat from surfaces by radiation? [1]

2. Write the boundary conditions of third kind for an anisotropic slab at the boundary surfaces $x = 0$ and $x = L$. [2]

3. Let us consider the problem of unsteady heat conduction in a stationary homogeneous solid with prescribed initial and surface temperatures. There is no heat generation in the solid and the thermo-physical properties may be assumed to be constant. Show that the heat conduction problem has unique solution. [5]

4. A steel slab has thickness 0.05 m and length and width both of 2 m. The slab is initially at a uniform temperature of 900°C and is then cooled by force convection of cold air (heat transfer coefficient, $h = 1000\ W/m^2{}^\circ C$, temperature of air = 0°C) from both broad sides. Assume constant thermo-physical properties.
   (a) Write down the mathematical formulation for this problem, including boundary and initial conditions. List all your assumptions and their justification. [2]
   (b) Use the method of separation of variables to obtain a solution of the problem in terms of series. [5]

PART B

5. (a) For similarity solution of the momentum and thermal boundary layer, how do you select the similarity parameter (η)? What is the corresponding expression for $f(\eta)$? [2]
   (b) Show that $\delta_T/L \sim Pr^{-1/3}.\ Re_x^{-1/2}$ for a situation where $\delta_T << \delta$ [2]
   (c) Comment on the geometry of the boundary layer at the leading edge of plate, kept parallel to the direction of the flow. The functionality between boundary layer thickness (δ) and the distance in the direction of the flow is given as (x): $\delta \sim x^n$. [1]

6. (a) Starting from the 2 – D Navier stokes equation for steady state, derive the Boussinesq approximated momentum balance equation for a Natural Convection Boundary Layer. You can use the expression $\frac{\partial p}{\partial y} = \frac{dp}{dy} = \frac{dp_\infty}{dy}$ for necessary simplifications. Perform an order of magnitude analysis to this equation and derive the expression for δ_T (thickness of thermal boundary layer) for the case where $Pr >> 1$. [3]
   (b) For this scenario, comment on the qualitative shape of the thermal and velocity boundary layer with justification. [2]

7. It is known that for a 2 – D convective flow field, the thermal energy transport equation is

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial x^2}\right] + \frac{1}{\rho C_p}\Phi$$

, where Φ is viscous dissipation [4+1]

Derive and expression for Φ. and comment under what condition it can be neglected?