INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Chemical Engineering

Mid-Spring Semester Examination, 2016-2017

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

Time: **2 Hrs** **Closed Book/Closed Notes** *Full Marks*: **30**

Instructions:

1. Use a SINGLE answer script for both the parts.
2. All questions are compulsory.
3. Clearly write your Name, Roll Number, Subject Name, and Subject Number on the Answer Book.
4. Feel free to assume any missing data with proper justifications.
5. Please try to answer all the questions of each part together. Also, all sub parts of each question MUST be answered together.

PART - A

1. (a) While proceeding along the solution of a thermal boundary layer by the momentum integral method, we obtain the following equation.

$$\theta_\infty U_\infty \frac{d}{dx}\left[\partial\left(\frac{3}{20}\zeta^2 - \frac{3}{280}\zeta^4\right)\right] = \frac{3 \propto \theta_\infty}{2\zeta\partial}$$

Where $\zeta = \frac{\partial_T}{\partial}$, $\partial \gg \partial_T$. θ_∞, U_∞ and α have their usual meaning.

Starting from the above equation, find an expression of ζ in terms of Pr.

Assume ζ **= f(x).** You may want to use the following expressions $\partial \frac{d\partial}{dx} = \frac{140\gamma}{13U_\infty}$

(b) Show that $\delta_T/L \sim Pr^{-1/3}.\ Re_x^{-1/2}$ when $\delta_T << \delta$ in **Forced Convection.** δ_T and δ refer to the thermal and momentum boundary layer thicknesses respectively and are both functions of **x**. You may want to use the following functionality for your analysis: $\delta \sim LRe_X^{-1/2}$. The symbols have their usual meaning. Assume constant free stream velocity U_∞ and temperatures T_∞ respectively. **(Marks: 6+3=9)**

2. (a) In a convective Heat Transfer Problem, ***Nu*** is Proportional to Re_x^n. Which of the following two cases will contribute to more effective enhancement in the rate of heat transfer?
   I. A fluid with higher thermal conductivity
   II. An increase in flow velocity of a given fluid.

(b) It is known that for a 2 – D convective flow field, the thermal energy transport equation is

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

, where Φ is viscous dissipation.

Derive and expression for Φ, and comment under what condition it can be neglected? **(Marks: 2+4=6)**

PART – B

3. Consider that a one-dimensional solid slab of length l with thermal conductivity k, specific heat c_p, and mass density ρ is initially at uniform temperature T_0. There is no heat generation in the slab. If the slab comes in contact with another body with a different temperature, estimate the approximate time required for the slab to cool down to a temperature, say T_1 using dimensional analysis. How will the cooling time change if we double the size of the slab ($2l$) keeping everything else constant? [3]

4. Consider a rectangular fin made of copper. The width of the fin is very large and the fin has thickness of 1 cm. The thermal conductivity of copper is about 400 W/(m K) and the heat transfer coefficient on the fin surface is about 10 W/(m^2 K). Justify the one-dimensional assumption made in the analysis of such a fin. [2]

5. Consider the problem of unsteady-state heat conduction in a stationary opaque solid with prescribed initial and surface temperatures. There is no internal heat generation in the body. Thermo-physical properties of the solid may be considered as constant. Prove that the solution of this heat conduction problem is unique. [5]

6. Consider a nuclear fuel element in the form of a hollow cylinder with inner and outer radii as 5 cm and 10 cm, respectively. The inner surface of the element is insulated and the outer surface is exposed to a fluid at 50 °C where the heat transfer coefficient is 100 W/(m^2 K). The thermal conductivity for nuclear element is given as 50 W/(m K). Find the rate of uniform heat generation if outer surface temperature in the system should not exceed 200 °C at steady state. [5]

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