INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Mid-Spring Semester Examination, 2013-2014

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

Time: **2 Hrs** *Full Marks*: **30**

Instructions:

1. All Questions are compulsory.
2. Clearly write your name, Roll No., Subject Name, Subject Number on the Answer Book.
3. Fell free to assume any missing data with proper justifications.
4. Please try to answer all the questions of each part together. **Also, all sub parts of each questions MUST be together.**
5. Be Precise with your answers. Long, redundant answers can potentially fetch zero!

PART A

1. Obtain the Boussinesq Approximated Governing Equation for Natural Convection. Based on Scaling Analysis, comment (and justify, with sketches) on the qualitative shapes of the boundary layers for different range of values of **Pr**. Please start from the general form of Navier stokes equation, simplified only for 2-D statedy state flow. (3+4=7)

2. (a) How is Thermal conductivity and electrical conductivity of a material correlated with temperature? Write the corresponding equation and explain. (1)

   (b) What is Wind Chill? (1)

   (c) Is it possible to have Natural convection & forced convection together? Discuss/ give example. (1)

   (d) 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: $\delta \sim L Re_x^{-1/2}$**.** The symbols have their usual meaning. Assume constant free stream velocity U_∞ and temperatures T_∞ respectively. (3)

   (e) 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

   Further, $$\Phi = 2\mu\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right]$$ for a Newtonian Fluid

   Discuss, based on a proper scaling analysis under what condition it is appropriate to neglect viscous dissipation. [2]

[Total marks in question 2: **08**]

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PART B

3. Consider a large body of liquid initially at a uniform temperature T_i which is higher than fusion temperature T_f (Fig. 1). A line heat sink, of strength per unit length q'_{line} (W/m) and located at $r = 0$, is suddenly activated at $t = 0$ to remove heat continuously for times $t > 0$. Consequently, the liquid starts to solidify at $r = 0$ and the cylindrical solid-liquid interface moves in the r direction with a velocity $V_i = ds(t)/dt$, where $s(t)$ denotes the instantaneous interface location at time t. Assume constant thermo-physical properties in each phase and neglect the effect of any convective motion in the liquid phase. Set up the complete mathematical formulation for the two-region heat conduction problem. **Note:** Only complete formulation of the problem is required. **[3]**

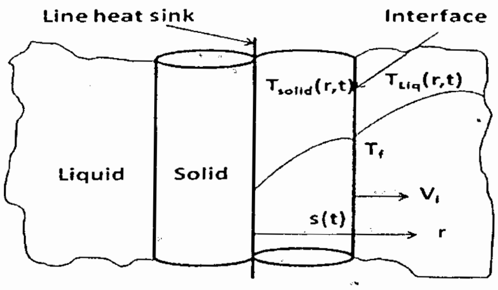

Figure 1

4. Consider the problem of heat conduction in a finite closed region with prescribed initial and surface temperatures. There is no internal heat generation in the body. Prove that the solution of this heat conduction problem is unique. **[5]**

5. The Kirchhoff transformation is a classical method of solution to the nonlinear heat conduction problem with temperature dependent thermal conductivity. Show that the Kirchhoff transformation is a particular consequence of more general Cole-Hopf transformation. **[4]**

6. A plane wall of 60 cm thickness is made from a material whose thermal conductivity (k) varies with temperature (T) as $k = 1+0.0025T$. Here T is in °C and k is in W/mK. Calculate the rate of heat transfer through this wall per unit area if one side of the wall is maintained at 1000°C and the other side at 0°C. Assume steady-state conditions. **[3]**

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