INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Department of Chemical Engineering

Date of Examination: 19.11.2010 A.N. Time: 3 hours Full Marks: 60

Mid-Autumn Semester, 2010-2011 4^{th} Yr B.Tech./4^{th} Yr Dual./1^{st} Yr M.Tech.

Subject Name: Advanced Fluid Dynamics

Subject No. – CH61011 No. of Students - 104

Instructions:

1. **All** questions are compulsory.
2. Answer all the questions of each part together.
3. Feel free to assume any missing data with proper justification.
4. Be precise you're your answers. Long, redundant answers may potentially fetch zero.

PART - A

1) A set of three objects are given $A_{1,1} = x^2$, $A_{1,2} = A_{2,1} = xy$, $A_{2,2} = y^2$. Verify whether this set is a tensor or not. (4 marks)

2) Briefly and clearly explain the following: (a) Principle of material indifference (b) the parallel between rate and relaxation processes in Eyring's theory for flow behaviour of a fluid (c) Thixotropy (2+4+2 = 8 marks)

3) A rheological experiment over a characteristic length of 20 mm, is conducted on a propylene glycol – carbon tetrachloride system. The bulk shear viscosity is measured as 0.042 Pa. s at 300 K. The interfacial shear viscosity was found to be 0.003 Pa.s at the same temperature. Indicate whether the dominating flow is interfacial or bulk. Also comment on the direction of dissipation of interfacial and bulk stresses. (5 marks)

4) For a steady pipe flow described in cylindrical coordinates, assuming no helical flow, define and mathematically express the following; (a) The stress tensor. Also, indicate which components tend to zero (b) The equations of motion (c) the pipe apparent viscosity for non–Newtonian fluids. (2+2+2 = 6 marks)

5) A fluid is flowing through a narrow capillary tube of diameter 2 mm. The shear rate at the walls of the channel is estimated as 1 s^{-1}. The volumetric flow rate is 7.85 x 10^{-10} m^3/s. Estimate the pseudo shear rate and identify the flow behaviour of the fluid. (4 marks)

6) A fluid is allowed to flow between a cone and plate assembly. Draw a neat diagram to show the setup, denoting the directions of flow. What are the boundary conditions applicable for velocity profile (2+1=3 marks)

Turn over

Part B

7. (a) What is Reynolds Decomposition in Turbulent flow?
   (b) What is the difference between a homogeneous turbulence and a stationary turbulence?
   (c) Show that the continuity equation is satisfied by both the time averaged fluctuations as well as the instantaneous fluctuations in turbulence. Assume an incompressible fluid.
   (d) Discuss the origin of Renolds stresses, with the help of X- Component 3 - D Navier Stokes Equation for a Turbulent flow.
   (e) Can there be a scenario when the apparent turbulent stress is lower than the Viscous stresses? (1+2+2+4+1=10)

8. (a) What is spreading Coefficient?
   (b) How is the stability of a thin film dependant on spreading coefficient and why?
   (c) Give a simple example of "dewetting" and discuss the origin of the associated flow.
   (d) Why does a mercury drop roll on almost any surface? Can you suggest any type of a surface where a mercury drop will not roll?
   (e) What is "Equilibrium Contact Angle"? Write down the Young's Equation.
   (f) While writing the Young's equation, what happens to the vertical component of the surface and interfacial tensions?

(1+2+2+2+1+2=10)

9. (a) For the laminar flow of a viscous fluid through a circular tube of radius R, draw the location of the boundary layer with figure. How is entry length of the tube co-related to boundary layer thickness?
   (C) Starting from 2 - D Steady state Navier stokes equation, derive the Boundary Layer Equation based on an order of magnitude analysis.
   (d) Discuss how the concept of Friction Velocity emerges in Wall Co - ordinate system in a Turbulent Boundary layer.
   (e) Obtain the velocity profile in terms of Wall co-ordinates for the viscous sub layer within a turbulent boundary layer. (2+4+2+2=10)

The Expressions for Navier Stokes Eqn for X-Y-Z system:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\left(\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right)+\rho g_x$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right)+\rho g_y$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\left(\frac{\partial \tau_{zx}}{\partial x}+\frac{\partial \tau_{zy}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right)+\rho g_z$$

All the best ☺