Name: **Enrolment No:**	UPES UNIVERSITY WITH A PURPOSE

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
End Semester Examination, December 2019
Course: Transport Phenomena **Semester: I**
Program: M Tech CE-PDE, M Tech PLE **Time: 03 hrs.**
Course Code: CHPD 7001 **Max. Marks: 100**
Instructions: 1. Solve all questions. 2. Tie QP to answer-sheet. 3. Make assumptions if needed. 5 pg

Section A: 4 Q x 5 Marks = 20 Marks [Q1-Q4]

Q.1 Water is contained between two plates with area = 5 m^2, at the temperature of 33 °C. Compute the steady-state momentum flux, τ_{yx} in MKS units, when the lower plate is set into motion with velocity V equalling 1 m/s in the positive x direction. Plates' separation=1 mm. List all assumptions. **[CO1, 5 Marks]**

Q.2 Repeat the calculations for 5 °C, and comment on results. **[CO1, 5 Marks]**

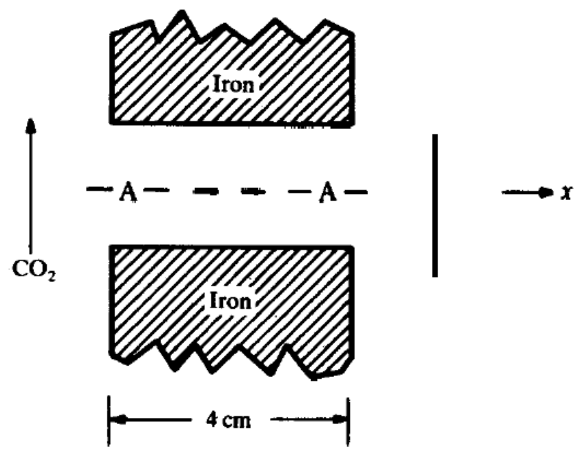
Temp.	Dyn. Viscosity	Kin. Viscosity	Density
[°C]	[mPa.s]	[mm^2/s]	[g/cm^3]
5	1.5182	1.5182	1
33	0.7488	0.7528	0.9947

Q.3 Explain the concept of boundary layer in relation to transport phenomena and elucidate important properties of boundary layer. In particular, describe the relation between thermal and momentum boundary layer, and give your detailed comments, about each. **[CO2, 5 Marks]**

Q.4 Write a short note on diffusivity of gases, and liquids. **[CO3, 5 Marks]**

Section B: 5 Q x 10 Marks = 50 Marks [Q5-Q9]

Q.5 Two gas streams, CO_2, and air, are flowing in the same direction in a channel. The channel is divided into equal volumes by a piece of iron 4 cm thick. At the plane A-A, there is a hole 1.2 cm in diameter drilled in the iron so that CO_2, diffuses from left to right and air from right to left. At the plane A-A, both gases are at a pressure of 2 atm and a temperature of 20 °C. Upstream of the hole both gases are pure. Under the conditions given, the concentration of CO_2 equals 0.083 kmol/mm^3, i.e., the concentration of CO_2, on the left at the point A. At the right-hand side of the hole, the concentration of CO, in air may be assumed to be zero because air is flowing rapidly past the hole. The diffusion coefficient of CO_2 in air is 1.56 x 10^{-3} m^2/s. Find the molar flux of CO_2. **[CO3, 10 Marks]**



Q.6 Explain difference between Newtonian and non-Newtonian fluids. What is the effect of non-Newtonian behaviour on the velocity profile of flow of liquid through pipe? Explain clearly with help of equations and diagram. **[CO1, 10 Marks]**

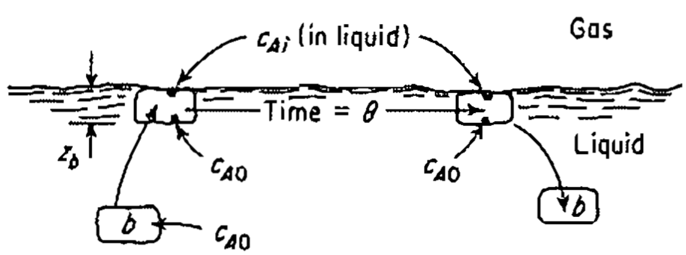
Q.7 What is the instantaneous velocity in turbulent flow. What is Reynolds stress Tensor. Explain the contribution of eddy diffusivity in turbulence. **[CO2, 10 Marks]**

Q.8 Prove $D_{AB} = D_{BA}$ in binary diffusion, give method for evaluation of diffusivity in multi-component mixture. **[CO3, 10 Marks]**

Q.9 Three rectangular slabs, Slab-I, Slab-II, and Slab-III of thickness, L_1, L_2 and L_3, with thermal conductivities equal to k_1, k_2 and k_3 are in intimate contact of each other. The heights of all the slabs is $\boldsymbol{H}$, and width is $\boldsymbol{W}$. The surface temperature of Slab-I, is $\boldsymbol{T_1}$, and it is in contact with fluid of temperature $\boldsymbol{T_a}$, which has a heat transfer coefficient of $\boldsymbol{h_0}$. The surface temperature of Slab-III, is $\boldsymbol{T_3}$, and it is in contact with fluid of temperature $\boldsymbol{T_b}$, which has a heat transfer coefficient of $\boldsymbol{h_3}$. Draw a neat diagram of the problem, and develop equations for temperature profile and heat flux. Determine the value of overall heat transfer coefficient. [**CO2, 10 Marks]**

Section C: 2 Q x 15 Marks = 30 Marks [Q10-Q11]

Q.10 Higbie developed his theory of Mass Transfer to describe contact of two fluids, more specifically, gas absorption into a liquid. According to penetration theory of mass transfer, given by Higbie and emphasized that in many situations, the time of exposure of liquid to the mass transfer is short and the concentration gradients typical of film theory in steady state will not have time to develop. In the shown figure, an eddy ***b*** is rising from the turbulent depths of liquid, and remaining exposed to time theta for the action of the gas. In this theory, time of exposure is taken to be same for all eddies of liquid. **[CO3, 15 Marks]**



Initially, concentration of the dissolved gas in the eddy is uniformly $\boldsymbol{C_{A,0}}$ and internally the eddy is considered to be stagnant. When the eddy is exposed to the gas at the surface, the concentration of gas in the liquid at the G-L interface is equal to $\boldsymbol{C_{A,i}}$ which may be taken as the equilibrium solubility of gas in the liquid. During the time theta, the liquid eddy is subject to unsteady state diffusion, or unsteady state diffusion of gas and solute in $\boldsymbol{z}$-direction. The mass balance for unsteady state diffusion in this case will be given by following equation, designated here as Equation (A) :

$$\frac{\partial c_A}{\partial \theta} = D_{AB} \frac{\partial^2 c_A}{\partial z^2}$$

Also, for short exposure times, and with the slow diffusion in the liquid, the molecules of solute are never able to reach the full depth of Z_b corresponding to thickness of eddy. In other words, for the solute point of view, the conditions of semi-infinite slab would prevail.

a) Derive the above differential equation, i.e., Equation (A) by using the component balance for A, given below. Give full reasoning. **[5]**

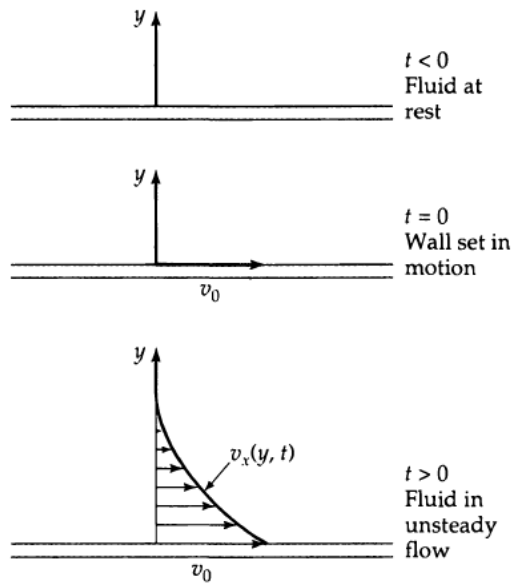
$$u_x \frac{\partial c_A}{\partial x} + u_y \frac{\partial c_A}{\partial y} + u_z \frac{\partial c_A}{\partial z} + \frac{\partial c_A}{\partial \theta} = D_{AB}\left(\frac{\partial^2 c_A}{\partial x^2} + \frac{\partial^2 c_A}{\partial y^2} + \frac{\partial^2 c_A}{\partial z^2} \right) + R_A$$

b) Give the appropriate initial conditions and boundary conditions and explain the reasons in detail. **[5]**

c) Describe steps to solve PDE Equation (A) to get the solution in form of **[5]**

$$N_{A,\,av} = 2(c_{A,\,i} - c_{A0})\sqrt{\frac{D_{AB}}{\pi\theta}}$$

Q.11 A semi-infinite body of liquid with constant density and viscosity is bounded below by a horizontal surface (the ***xz***-plane). Initially the fluid and the solid are at rest. Then at time $t = 0$, the solid surface is set in motion in the $+x$ direction with velocity V_0 as shown in Fig. below. Find the velocity V_x as a function of y and t, *i.e.* $V_x = V_x(y,t)$. There is no pressure gradient or gravity force in the ***x*** direction, and the flow is presumed to be laminar. You may use appropriate Boundary conditions, and use combination of variables technique to generate a new variable $\eta = y/\sqrt{(4.\nu.t)}$. **[CO1, 15 Marks]**



Cartesian coordinates (x, y, z):

$$\rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right] + \rho g_x$$

$$\rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right] + \rho g_y$$

$$\rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right] + \rho g_z$$

The error function is defined as

$$\operatorname{erf} x = \frac{\int_0^x \exp(-\bar{x}^2)\, d\bar{x}}{\int_0^\infty \exp(-\bar{x}^2)\, d\bar{x}} = \frac{2}{\sqrt{\pi}}\int_0^x \exp(-\bar{x}^2)\, d\bar{x}$$

$$\frac{d}{dx}\operatorname{erf} u = \frac{2}{\sqrt{\pi}}\exp(-u^2)\frac{du}{dx}$$