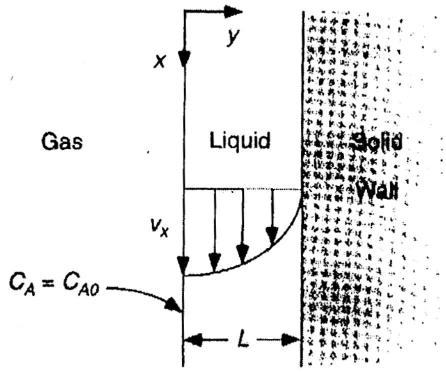
Ref. No. Ex/PG/ChE/T/113A/2024

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2024
SUBJECT: ADVENCED TRANSPORT PHENOMENA
Time: Three hours Full Marks 100

No. of Questions/ CO	**Answer Question no. 1a or 1b, 2a or 2b and any 2 of the rest** **All questions do not carry equal marks**	Marks
1 (a).	Consider flow of a Newtonian incompressible viscous fluid through a circular pipe. The wall is maintained at a temperature Tw. The fluid is heated due to viscous dissipation. Assume constant (average) properties of fluid.	
	(i) Write the continuity and momentum balance equations and deive an expression for the steady state velocity profile through the pipe.	(10)
	(ii) Write the energy balance equation and nondimensionalise the equation. Derive an expression for temperature profile. Write the significance of the nondimensional numbers.	(15)
	OR	
1(b)	OR  9i	
	Consider a liquid film of thickness L flowing down a vertical impermeable and unreactive solid wall as shown in Fig. 1. The flow is laminar and fully developed. Beginning at x=0, the liquid contacts a gas containing a species A which dissolves in the liquid and undergoes an irreversible 1st order reaction	
	(i) Derive an expression for velocity profile of the liquid for species A	(8)
	(ii) Derive an expression for concentration profile of species A in the liquid	(8)
	(iii) Derive an expression for liquid phase Sherwood number for species A valid for large x	(9)

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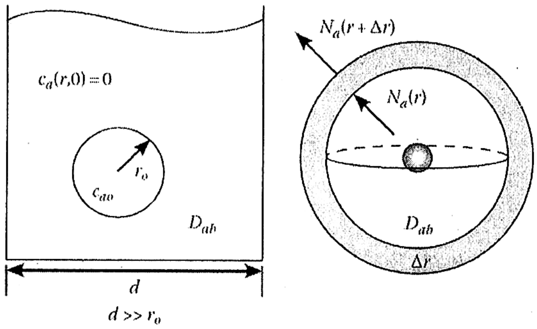
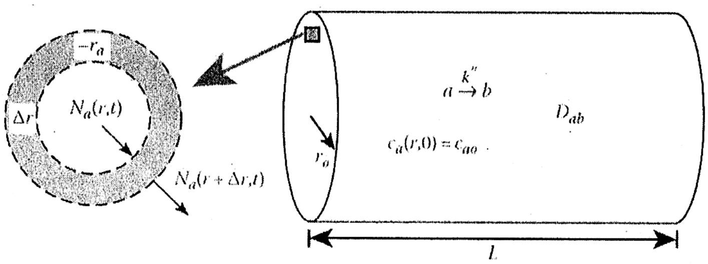
2 (a).	 FIG1 Consider the dissolution of a spherical pill in an empty stomach. Prior to t=0 the sphere has a uniform concentration Cao. At t=0 it is suspended in large tank (stomach) and is slowly leached so that at relatively short time, concentration remains Cao at r=R. Derive the expression of variation of concentration of solute (of pill) in the semi-infinite media (fluid of stomach). OR	(20)
2(b)	 Consider a long cylinder which is heated and impregnated with a substance A, at a concentration CAo at time t=0. At the outer surface of the tube flow of air across the surface effectively keeps the concentration of A zero (at the outer surface). The material A decomposes according to a first order chemical reaction. Since L>>ro, it can be assumed that diffusion takes place only along the radial direction, Considering constant properties, derive the governing equation and the boundary conditions. Derive the concentration profile.	(20)

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3.

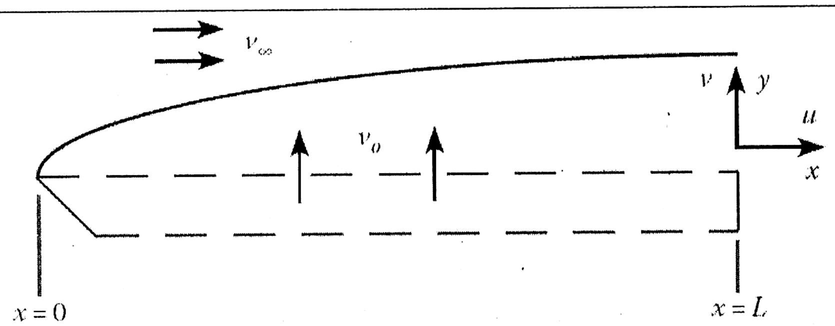

FIG.2

i) Consider a perforated flat plate (as shown in Fig. 2). A positive or negative pressure gradient is applied to induce flow through the surface at a velocity vo. Such system is employed for controlling drag force or in case of transpiration cooling.

(i) Derive the laminar hydrodynamic boundary layer equations over the above mentioned perforated flat plate considering that the temperature of free stream velocity (Tα and the temperature of the flat plate (Ts) are same. Write the boundary conditions (10) (15)

(ii) Use the integral momentum analysis. Show that the hydrodynamic boundary layer thickness is expressed by the following equations

$$v_o > 0 \qquad x = \frac{7v_\infty}{15v_0}\delta_h - \frac{7\nu}{10v_\infty v_o^2}\ln\left[1+\frac{2v_o\delta_h}{3\nu}\right]$$

$$v_o < 0 \qquad x = -\frac{7v_\infty}{15v_0}\delta_h - \frac{7\nu}{10v_\infty v_o^2}\ln\left[1-\frac{2v_o\delta_h}{3\nu}\right]$$

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No. of Questions/ CO0	**Answer Question no. 1a or 1b, 2a or 2b and any 2 of the rest All questions do not carry equal marks**	Marks
4.	(i) Consider the thermal boundary layer over a stationary flat plate of length L maintained at a temperature Ts, under forced convection; U_α and T_α are the free stream velocity and temperature. Comment on the relative magnitude (=/>/<) of thermal boundary layer thickness and hydrodynamic boundary layer thickness for different values of Prandtl numbers (Pr=1,Pr>>1, Pr<<1).	(5)
	(ii) Derive the thermal boundary layer equations and boundary 9iconditions for liquid metal (Pr <<1). Use integral balance equations. Consider that the nondimensional temperature is a function of 3rd order polynomial of (y/δ_T); derive an expression for Nusselt number.	(20)
5.	Consider laminar flow of a Newtonian fluid through a circular tube of radius *R*. The velocity profile $V_z = U_{max}\,[1-(r/R)^2]$. For $z < 0$, the fluid temperature is uniform at the inlet temperature T_1. For $z > 0$, heat is added at a uniform constant radial flux q_0 through the tube wall. The axial heat conduction and viscous dissipation effect may be neglected. The thermal conductivity k and thermal diffusivity α may be assumed constant.	
	(i) Write the governing equation and boundary condition. Define the mixing cup temperature	(6)
	(ii) Nondimensionalize the governing equations and boundary conditions. Mention the scaling used for nondimensionalization of temperature, axial distance and radial distance.	(6)
	(iii) Derive an expression for temperature profile $T(r, z)$ far downstream in the thermally fully developed region (i.e., for large z).	(6)
	(iv) Derive the limiting local Nusselt number far downstream for laminar flow in a circular tube with constant wall heat flux. What is its value?	(7)

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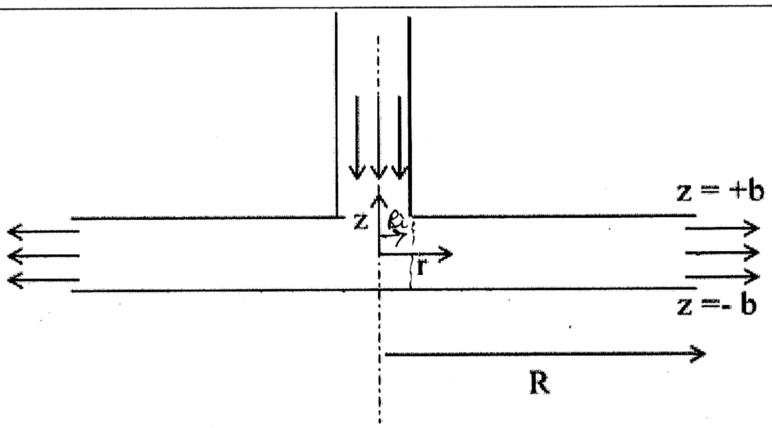
6 (a)	 A part of a lubrication system consists of two circular discs (at z=+b and z=-b) and the lubricant flows in the radial direction. The flow takes place because of modified pressure *(p_1- p_2)* between the inner and outer radii *Ri* and *R* respectively. Consider a Newtonian, constant property, incompressible fluid flow. Assume Creeping flow. Derive the velocity profile and mass flow rate.	(15)
6(b)	Consider Buoyancy driven flow (natural convection) in a vertical channel made up of two long parallel vertically mounted plates separated by a distance 2H. The temperature of the plate at y=-H is T1 and the temperature at y=H is T2. (T1>T2). The system is so constructed that the volume flow rate in the upward stream is the same as that in the downward moving stream. The temperature and velocity only vary in y direction. (i) Write the governing equations and boundary conditions. (ii) What is Boussinesq approximation? (iii)Derive the expressions for temperature profile and velocity distribution.	(15)

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	Navier Stokes equation is given below $$\rho\left[\frac{\partial \vec{V}}{\partial t}+\vec{V}.\nabla\vec{V}\right]=-\nabla p+\rho\vec{g}+\mu\nabla^2\vec{V}$$ Continuity and components of Navier Stokes equations for cylindrical coordinate are given below $$\frac{1}{r}\frac{\partial(rv_r)}{\partial r}+\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial v_z}{\partial z}=0$$ $$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r} +\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(rv_r)}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial^2 v_r}{\partial z^2}\right]+\rho g_r$$ $$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta} +\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(rv_\theta)}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]+\rho g_\theta$$ $$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z} +\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}++\frac{\partial^2 v_z}{\partial z^2}\right]+\rho g_z$$ Energy Equation **Cylindrical:** $T=T(r,\ \theta,\ z,\ t)$ $$\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+v_z\frac{\partial T}{\partial z}=\alpha\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]+\frac{H_V}{\rho C_P}$$	

Spherical: $T = T(r, 8, \phi, t)$

$$\frac{\partial T}{\partial t} + v_r \frac{\partial T}{\partial r} + \frac{v_\theta}{r} \frac{\partial T}{\partial \theta} + \frac{v_\phi}{r \sin \theta} \frac{\partial T}{\partial \phi} = \alpha \left[\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial T}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial T}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 T}{\partial \phi^2} \right] + \frac{H_V}{\rho \hat{C}_P}$$