मोतीलाल नेहरू राष्ट्रीय प्रौद्योगिकी संस्थान इलाहाबाद
प्रयागराज-211004 [भारत]

Motilal Nehru National Institute of Technology Allahabad
Prayagraj-211004 [India]

Department of Chemical Engineering
Mid Semester (Even) Examination 2024-25

Programme Name: B.Tech	**Semester:** VIth
Course Code: CHN-16113	**Course Name:** Transport Phenomenon
Branch: Chemical Engineering	**Student Reg. No.:** 20222068
Duration: 90 Minutes	**Max. Marks:** 25

Instructions: (Related to Questions)

1. *Figures to the right indicate the full marks.*
2. *All questions are compulsory. Be precise in your answers*

Marks

Q 1 a What are the advantages of studying heat, momentum, and mass transport together? (2)

b Define molecular and convective momentum fluxes. Express in terms of their components. Why are they called second-order tensors? (3)

Q 2 In a gas absorption experiment an incompressible viscous Newtonian fluid flow upward through a small circular tube and then downward in laminar flow on the outside. Set up a momentum balance over a shell of thickness Δr in the film, as shown in figure 1. Note that the "momentum in" and "momentum out" arrows are always taken in the positive coordinate direction, even though in this problem the momentum is flowing through the cylindrical surfaces in the negative r direction. Show that the velocity distribution in the falling film (neglecting end effects) is (10)

$$v_z = \frac{\rho g R^2}{4\mu}\left[1-\left(\frac{r}{R}\right)^2 + 2a^2 \ln\left(\frac{r}{R}\right)\right]$$

Q 3 An incompressible Newtonian fluid is in laminar flow in a narrow slit by two parallel walls a distance 2B apart as shown in figure 2. It is understood that B<<W, so that "edge effects" are unimportant. The fluid is flowing under pressure and gravity forces. The wall at $x = -B$ is stationary while the wall at $x = B$ is moving in the positive z direction at a steady speed v_0. Show with the help of governing equations given in Appendix I, the momentum flux and velocity distribution in the narrow slit is given by Eq. (1) and (2) respectively. State the assumptions clearly. (10)

$$\tau_{xz} = \left(\frac{P_0 - P_L}{L}\right)x - \frac{\mu v_0}{2B} \qquad (1)$$

$$v_z = \frac{(P_0 - P_L)B^2}{2\mu L}\left[1-\left(\frac{x}{B}\right)^2\right] + \frac{v_0}{2}\left(1+\frac{x}{B}\right) \qquad (2)$$

In these expressions $P = p + \rho g h = p - \rho g z$.

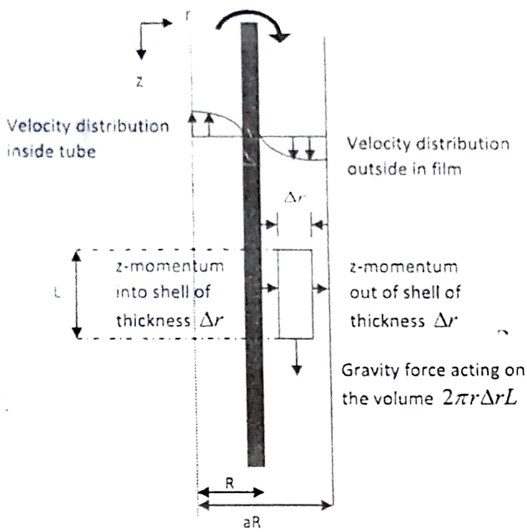

Figure 1

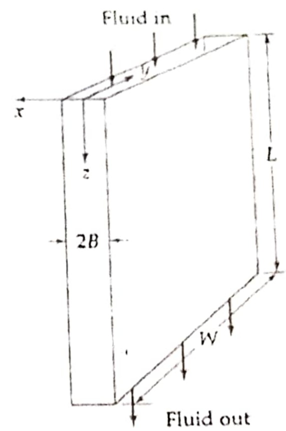

Figure 2

Appendix-I

<u>Equation of Continuity and Navier's Stoke Equation</u>

Cartesian coordinates (x, y, z):

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0$$

Cartesian coordinates (x, y, z):

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

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

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

****End****

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Department of Chemical Engineering
End Semester (Even) Examination 2024-25

Programme Name: B.Tech	**Semester:** VIth
Course Code: CHN-16113	**Course Name:** Transport Phenomenon
Branch: Chemical Engineering	**Student Reg. No.:**
Duration: 2.5 hours	**Max. Marks:** 50

Instructions: (Related to Questions)

1. *Figures to the right indicate the full marks.*
2. *All questions are compulsory. Be precise in your answers*

		Marks	CO
Q 1	What are second order tensors? Determine which among the following are second order tensors and why: velocity gradient, momentum flux, temperature gradient, heat flux, concentration gradient, mass flux.	(04)	CO.1
Q 2	Consider a Bingham plastic fluid flowing over an inclined flat plate inclined at an angle β from the vertical direction. The length of the plate is L, and the liquid flows in the form of a thin film of thickness δ. The coordinates are so selected that the flow is along the z-direction and $x=0$ and $x=\delta$ represent the surface of the free liquid and the surface of the wall, respectively. Find the momentum flux and velocity distributions inside the thin film in the plug flow and non-plug flow regions. State the assumptions clearly.	(12)	CO.1
Q 3	Derive the equation of motion in both Euler's and Lagrangian forms using the Cartesian coordinate system.	(10)	CO.2
Q 4	Consider the flow of an incompressible molten polymer between two coaxial cylinders as shown in Fig. 1a, whose viscosity can be adequately described by the power law model given by Eq. (1).	(12)	CO.3

$$\tau_{rz} = -m\left(\frac{dv_z}{dr}\right)^n \qquad (1)$$

Where, m and n are constants characterizing the fluid. The surfaces of the inner and outer cylinders are maintained at $T=T_0$ and $T=T_b$, respectively. We can expect T will be a function of r alone. As the outer cylinder rotates, each cylindrical shell of fluid "rubs" against an adjacent shell of the fluid. This friction between adjacent layers of the fluid produces heat that is mechanical energy is degraded into thermal energy. If the slit width b is small w.r.t. the radius R of the outer cylinder one can ignore the curvature effects of the boundary surfaces as shown in Fig. 1b. Under this condition assume a linear velocity profile given by Eq. (2).

$$V_z = \frac{V_b}{b}x \qquad (2)$$

Find the volume heat source resulting from this viscous heat dissipation and show that the temperature profile in this thin slit is given by Eq. (3)

$$\left(\frac{T-T_0}{T_b-T_0}\right) = \frac{1}{2}Br_n\frac{x}{b}\left(1-\frac{x}{b}\right)+\frac{x}{b} \qquad (3)$$

Where, $Br_n = \left[\frac{mv_b^{n+1}}{b^{n-1}k(T_b-T_0)}\right]$ is the dimensionless Brinkman number, which is a measure of the importance of the viscous heat dissipation term.

Q 5 In a catalytic reactor, imagine that each catalyst particle is surrounded by a stagnant gas film through which A has to diffuse in order to arrive at the catalytic surface. At the catalyst surface, we presume that the reaction $nA \rightarrow A_n$ occurs instantaneously and that product A_n then diffuses back out through the gas film to the main turbulent gas stream composed of A and A_n. If the effective gas-film thickness is δ and the main gas stream compositions are x_{A_0} and x_{An_0}. Show that the local rate of polymerization per unit area of catalytic surface is given by **(12)** **CO.4**

$$N_{Az} = \frac{ncD_{AA_n}}{(n-1)\delta}\ln\left(\frac{1}{1-(1-n^{-1})x_{Ao}}\right)$$

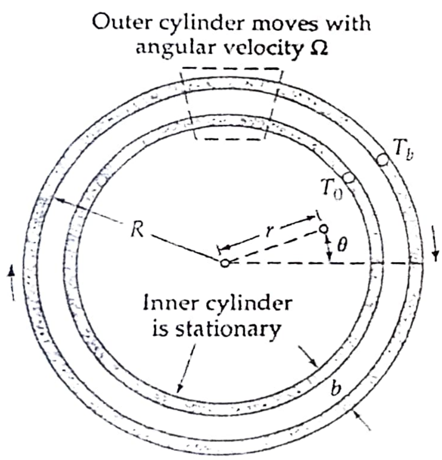

Fig. 1(a). Flow between cylinders with viscous heat generation. The part of the system enclosed with the dotted lines is shown in modified form in Fig. 1 (b).

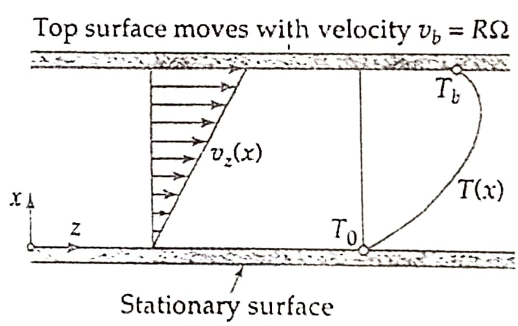

Fig. 1(b). Modification of a portion of the flow system in Fig. 1(a), in which the curvature of the bounding surfaces is neglected.

End