**BIRLA INSTITUTE OF TECHNOLOGY, MESRA, RANCHI**
**(END SEMESTER EXAMINATION)**

**CLASS: BE** | | **SEMESTER :IV**
**BRANCH: CHEM ENGG** | | **SESSION : SP/19**

**SUBJECT: CL4007 TRANSPORT PHENOMENA**

**TIME: 3 Hours** | | **FULL MARKS: 60**

**INSTRUCTIONS:**
**1. The question paper contains 7 questions each of 12 marks and total 84 marks.**
**2. Candidates may attempt any 5 questions maximum of 60 marks.**
**3. The missing data, if any, may be assumed suitably.**
**4. Before attempting the question paper, be sure that you have got the correct question paper.**
**5. Tables/Data hand book/Graph paper etc. to be supplied to the candidates in the examination hall.**

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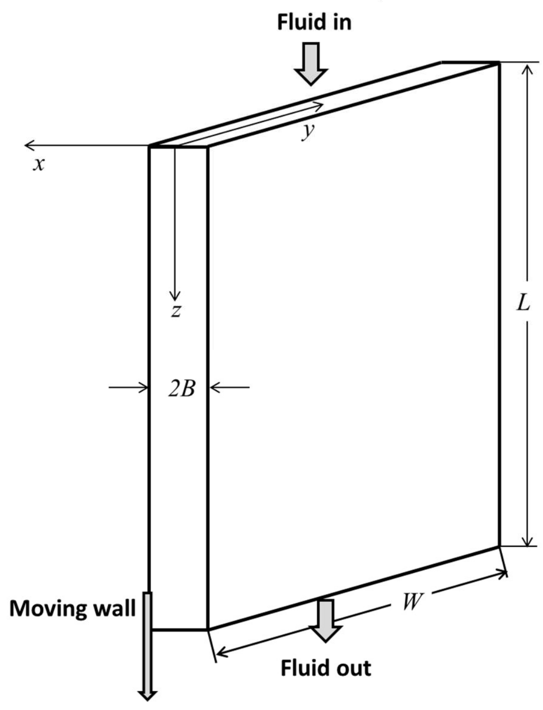
Q.1(a) Using Navier –Stoke's equation, determine the velocity distribution in steady, laminar flow of an incompressible and viscosity fluid between two parallel and vertical plates. The surface on the left is stationary and other is moving vertically at a constant velocity $v_o$. [6]

Q.1(b) A Newtonian fluid of constant density is in a vertical cylinder of radius R with the cylinder rotating about its axis at angular velocity ω. Find the shape of the free surface at steady state. [6]

Q.2 A Newtonian fluid is in laminar flow in a narrow slit formed by two parallel walls a distance *2B* apart. The flow is generated due to the motion of the wall in positive *z*- direction at $x = B$ and corresponding velocity of the wall is $U$. It is understood that *B*<<*W*, so that edge effects are unimportant. Obtain the following quantities by making a shell momentum balance when $v_x = 0, v_y = 0$ and $p = p(z)$ [12]

a. Shear-stress and velocity distribution inside the slit
b. Mean fluid velocity
c. Maximum fluid velocity




Q.3 An incompressible, isothermal Newtonian fluid is held between two vertically placed co-axial cylinders. Determine the velocity distributions for the flow of the fluid when [12]
(i) the outer cylinder is rotating at an angular velocity $\omega_2$ while the inner cylinder is stationary.
(ii) The inner and outer cylinders are rotating at angular velocities of $\omega_1$ and $\omega_2$, respectively.
Use Navier-Stoke's equation.

**PTO**

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|---|---|---|
| Q.4(a) | Briefly describe the Newtonian fluid behavior. | [3] |
| Q.4(b) | Write down the general categories of the non-Newtonian fluids. | [3] |
| Q.4(c) | Derive Rabinowitsch Equation for capillary flow | [6] |

Q.5 Consider a copper rod of circular cross-section with radius R and electrical conductivity $K_e$ $ohm^{-1}$ $cm^{-1}$ through where an electrical current with current density I amp $cm^{-2}$ is flowing. The transmission of an electrical current is an irreversible process and some electrical energy is converted to thermal energy. The rate of heat production per unit volume ($S_e$) is given by the expression $S_e=I^2/K_e$. The surface of the rod is maintained at temperature of $T_o$. Make a shell balance and obtained the temperature profile in the rod. Also find out the expression for heat flow at the surface. [12]

Q.6(a) A sphere of naphthalene having a radius of 2.0 mm is suspended in a large volume of still air at 318K and $1.01325X10^5$ Pa (1 atm). The surface temperature of the naphthalene can be assumed to be at 318K and its vapor pressure at 318K is 0.555 mm of Hg. The $D_{AB}$ of naphthalene in air at 318K is $6.92X10^{-6}$ $m^2/s$. Calculate the rate of evaporation of naphthalene from the surface. [6]

Q.6(b) A test tube, 1.5 cm in diameter and 12cm tall, is partly filled with a solution of alkaline pyrogallate. The depth of the empty space above the solution is 5 cm. The temperature is 25ºC and the total pressure is 1 atmosphere. Air may be assumed to contain 21% $O_2$ and 79% $N_2$. The diffusivity of $O_2$ in $N_2$ at the given condition is $0.21cm^2/s$. Calculate the rate of absorption of oxygen from air in solution at steady state if air flows gently over the open end of the test tube [6]

Q.7(a) Derive the concentration profile during the absorption of oxygen ($O_2$) into a falling water film. [12]

**:::::24/04/2019 E::::**

## §B.4 THE EQUATION OF CONTINUITY[a]

$$[\partial\rho/\partial t + (\nabla\cdot\rho\mathbf{v}) = 0]$$

*Cartesian coordinates $(x, y, z)$:*

$$\frac{\partial\rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0 \qquad \text{(B.4-1)}$$

*Cylindrical coordinates $(r, \theta, z)$:*

$$\frac{\partial\rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r) + \frac{1}{r}\frac{\partial}{\partial\theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) = 0 \qquad \text{(B.4-2)}$$

*Spherical coordinates $(r, \theta, \phi)$:*

$$\frac{\partial\rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}(\rho r^2 v_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\rho v_\theta \sin\theta) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\phi}(\rho v_\phi) = 0 \qquad \text{(B.4-3)}$$

[a] When the fluid is assumed to have constant mass density $\rho$, the equation simplifies to $(\nabla\cdot\mathbf{v}) = 0$.

## §B.5 THE EQUATION OF MOTION IN TERMS OF $\tau$

$$[\rho D\mathbf{v}/Dt = -\nabla p - [\nabla\cdot\boldsymbol{\tau}] + \rho\mathbf{g}]$$

*Cylindrical coordinates $(r, \theta, z)$:*[b]

$$\rho\left(\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial\theta} + v_z\frac{\partial v_r}{\partial z} - \frac{v_\theta^2}{r}\right) = -\frac{\partial p}{\partial r} - \left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr}) + \frac{1}{r}\frac{\partial}{\partial\theta}\tau_{\theta r} + \frac{\partial}{\partial z}\tau_{zr} - \frac{\tau_{\theta\theta}}{r}\right] + \rho g_r \qquad \text{(B.5-4)}$$

$$\rho\left(\frac{\partial v_\theta}{\partial t} + v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial\theta} + v_z\frac{\partial v_\theta}{\partial z} + \frac{v_r v_\theta}{r}\right) = -\frac{1}{r}\frac{\partial p}{\partial\theta} - \left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\tau_{r\theta}) + \frac{1}{r}\frac{\partial}{\partial\theta}\tau_{\theta\theta} + \frac{\partial}{\partial z}\tau_{z\theta} + \frac{\tau_{\theta r} - \tau_{r\theta}}{r}\right] + \rho g_\theta \qquad \text{(B.5-5)}$$

$$\rho\left(\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial\theta} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} - \left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz}) + \frac{1}{r}\frac{\partial}{\partial\theta}\tau_{\theta z} + \frac{\partial}{\partial z}\tau_{zz}\right] + \rho g_z \qquad \text{(B.5-6)}$$

[b] These equations have been written without making the assumption that $\boldsymbol{\tau}$ is symmetric. This means, for example, that when the usual assumption is made that the stress tensor is symmetric, $\tau_{r\theta} - \tau_{\theta r} = 0$.

## §B.6 EQUATION OF MOTION FOR A NEWTONIAN FLUID WITH CONSTANT $\rho$ AND $\mu$

$$[\rho D\mathbf{v}/Dt = -\nabla p + \mu\nabla^2\mathbf{v} + \rho\mathbf{g}]$$

*Cylindrical coordinates $(r, \theta, z)$:*

$$\rho\left(\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial\theta} + v_z\frac{\partial v_r}{\partial z} - \frac{v_\theta^2}{r}\right) = -\frac{\partial p}{\partial r} + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right) + \frac{1}{r^2}\frac{\partial^2 v_r}{\partial\theta^2} + \frac{\partial^2 v_r}{\partial z^2} - \frac{2}{r^2}\frac{\partial v_\theta}{\partial\theta}\right] + \rho g_r \qquad \text{(B.6-4)}$$

$$\rho\left(\frac{\partial v_\theta}{\partial t} + v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial\theta} + v_z\frac{\partial v_\theta}{\partial z} + \frac{v_r v_\theta}{r}\right) = -\frac{1}{r}\frac{\partial p}{\partial\theta} + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right) + \frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial\theta^2} + \frac{\partial^2 v_\theta}{\partial z^2} + \frac{2}{r^2}\frac{\partial v_r}{\partial\theta}\right] + \rho g_\theta \qquad \text{(B.6-5)}$$

$$\rho\left(\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial\theta} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial\theta^2} + \frac{\partial^2 v_z}{\partial z^2}\right] + \rho g_z \qquad \text{(B.6-6)}$$