B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER - 2025
INTRODUCTION TO TRANSPORT PHENOMENA

Time: 3 Hours Full Marks: 100

Use Separate Answer Scripts for Part I and Part II

(50 marks for each Part)

PART I

Q.	CO	*State all assumptions. Assume missing data (if any)*	Marks
1.	1	Identify whether the statement is TRUE or FALSE. Give reasons and show the derivation. Answer any two of the following (i)For a spherical container of radius R having liquid nitrogen, the heat transfer from ambient to the liquid nitrogen will be minimized at the critical insulation thickness [(2k/h)-R] (ii)The flow of a tooth paste (Bingham plastic) through a tube of length L and radius R under the influence of finger pressure (gauge, Pf) of a normal human being is only possible if $P_f R/2L > \tau_o$ (iii) For a binary gas mixture of A and B at constant pressure and temperature $D_{AB}=D_{BA}$	(3+3)
2	2	A Newtonian, incompressible, constant property fluid is confined between two parallel plates. The upper plate is moving at a velocity $U\cos(\omega t)$. No pressure gradient is applied.	
		(i)Set up the governing equation and boundary conditions in order to derive the velocity distribution. Do not solve	(4)
		(ii)Non-dimensionalize the governing equations and calculate the nondimensional numbers. Data Given h=5mm, Uo=1m/s, ρ =1000 kg/m3, μ=10 cP, ω=1 s^{-1}	(5)
3	3	(i)Consider the laminar flow of a Newtonian incompressible fluid (water) like a film of thickness δ along a vertical wall of length L and width W. Derive the shear stress profile and velocity profile.	(8)
		(ii)A solute 'A' (chlorine) is being absorbed in the liquid film (refer to FIG 1). Write the solute A balance equation and derive the concentration profile of the solute in the films. Derive an expression for rate of absorption of the solute by the liquid across surface x=0. Write all assumption.	(12)

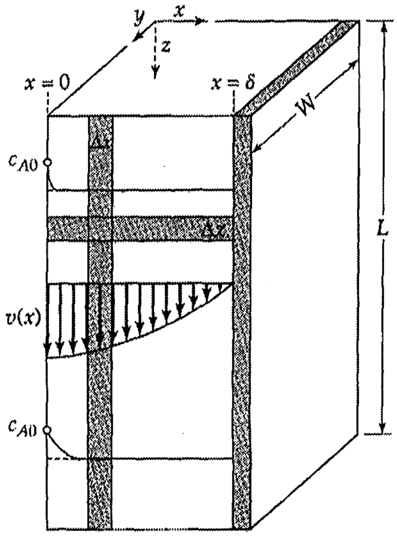

FIG1

4	4	(i)A microprocessor has an aluminum heat sink attached that consists of a series of parallel rectangular fins. Each fin is 2 mm thick, 25 mm long, 25 mm high and spaced on 6 mm centers. When the microprocessor is turned on it begins producing heat at a rate of 5W/cm2 of surface area. A fan within the computer circulates air at $T\infty$=25°C through the machine providing a heat transfer coefficient of 15W/m^2K. Write the governing equation and boundary conditions and derive the steady state temperature profile in a single fin. Calculate the temperature at the base.	(12)
		Or	
	4	(ii)An important step in purification of Uranium isotopes involves the conversion of Uranium to Uranium-hexafluoride, UF_6. In the present process UF_6 is prepared by exposing uranium pellets, spherical in shape, to fluorine gas at 1000K and 1 atm pressure. The molecular diffusion of fluorine gas to the pellet surface is thought to be the controlling step. If the reaction : $U(s) + 3F_2(g) \rightarrow UF_6(g)$ occurs irreversibly and instantaneously on the pellet surface and the diffusivity of fluorine gas through uranium hexafluoride gas is 0.273 cm^2 /s at 1000K and 1 atm, determine the production rate of UF_6 when the pellet diameter is 0.4 cm.	
5.	5	Consider the hydrodynamic (velocity), thermal and concentration boundary layers over a flat plate. State the conditions of Reynolds analogy. Under what conditions the thickness of all three boundary layers (δ_h,δ_t and δ_c) are same? Navier Stokes equation is given below $$\rho\left[\frac{\partial \vec{V}}{\partial t}+\vec{V}.\nabla\vec{V}\right]=-\nabla p+\rho\vec{g}+\mu\nabla^2\vec{V}$$	(2+1)

Ref. No.: Ex/Che/PC/B/T/224/2025

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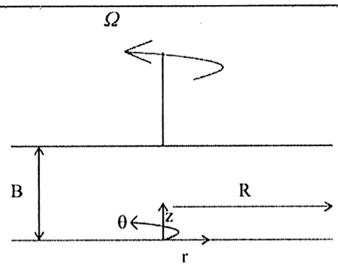
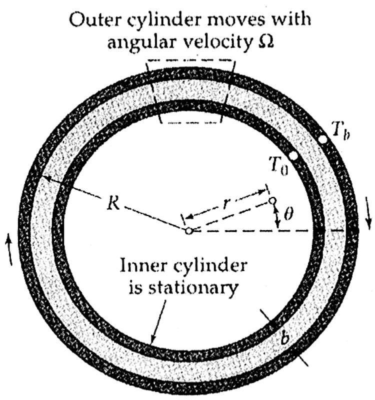
INTRODUCTION TO TRANSPORT PHENOMENA

Time : 3hours **Full Marks : 100**

Part -II

Use Separate Answer scripts for each Part

Clearly mention all the assumptions
Assume any missing data and mention it clearly

CO	Question statement	Marks
CO1	**1.** Write down different boundary conditions for conductive heat transfer in a thick wall. **2.** State the difference between natural and forced convection?	3 2
CO2	**3.** Parallel plate viscometer. A fluid is placed in a gap (of thickness B) between two parallel discs of radius R. The lower disc is kept stationary while the upper disc is made to rotate at a constant angular velocity Ω. Obtain the governing equation and write down the relevant boundary conditions for solving the problem. **Do not solve.** 	7
CO3	**4.** Derive the temperature profile for heat conduction with viscous heat dissipation for the following arrangement. State all the assumptions carefully. Write the physical significance of the nondimensional number that appears in the temperature profile.  **Or** **5.** Derive an expression for the 1-D concentration profile for a homogeneous first-order chemical reaction in a stationary medium. Also obtain an expression for the average concentration of A and the flux of A across the gas-liquid interface. State all the assumptions carefully.	15

<table>
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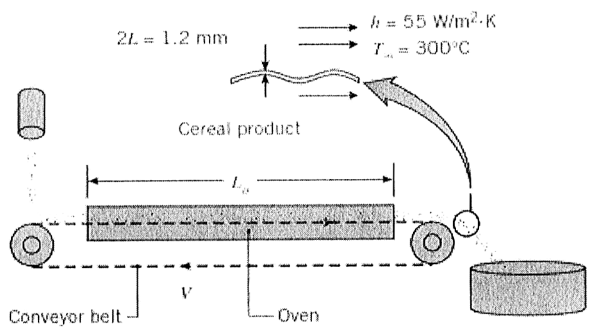
<td>CO4</td>
<td>6. A flaked cereal is of thickness 2L = 1.2 mm. The density, specific heat, and thermal conductivity of the flake are ρ = 700 kg/m^3, cp = 2400 J/kg.K, and k = 0.34 W/m.K, respectively. The product is to be baked by increasing its temperature from Ti = 20 °C to T_f = 220°C in a convection oven, through which the product is carried on a conveyor. If the oven is Lo = 3 m long and the convection heat transfer coefficient at the product surface and oven air temperature are h = 55 W/m. K and T∞ = 300°C, respectively, determine the required conveyor velocity, V. An engineer suggests that if the flake thickness is reduced to 2L = 1.0 mm the conveyor velocity can be increased, resulting in higher productivity. Determine the required conveyor velocity for the thinner flake.



Or

A thick steel slab (ρ= 7800 kg/m^3, c = 480 J/kg / K, k = 50 W/m. K) is initially at 300°C and is cooled by water jets impinging on one of its surfaces. The temperature of the water is 25°C, and the jets maintain an extremely large, approximately uniform convection coefficient at the surface. Assuming that the surface is maintained at the temperature of the water throughout the cooling, how long will it take for the temperature to reach 50°C at a distance of 25 mm from the surface?</td>
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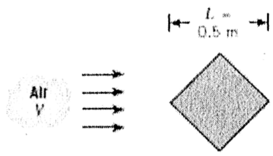
<tr>
<td>CO5</td>
<td>7. Experimental measurements of the convection heat transfer coefficient for a square bar in cross flow yielded the following values:

$\bar{h}_1 = 50\ \text{W/m}^2\cdot\text{K}$ when $V_1 = 20$ m/s
$\bar{h}_2 = 40\ \text{W/m}^2\cdot\text{K}$ when $V_2 = 15$ m/s



Assume that the functional form of the Nusselt number is Nu = C Re^m Pr^n , where C, m, and n are constants.
(a) What will be the convection heat transfer coefficient for a similar bar with L= 1 m when V = 20 m/s?
(b) What will be the convection heat transfer coefficient for a similar bar with L =1m when V = 30 m/s?
(c) Would your results be the same if the side of the bar, rather than its diagonal, were used as the characteristic length?

8. State physical significance of Euler number, Reynolds Number and Strouhal number.</td>
<td>10

3</td>
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Continuity Equation: $\frac{D\rho}{Dt} = -\rho(\nabla \cdot \mathbf{v})$

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

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

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

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

Heat Equation:

Cartesian coordinates (x, y, z):

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_x\frac{\partial T}{\partial x} + v_y\frac{\partial T}{\partial y} + v_z\frac{\partial T}{\partial z}\right) = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \mu\Phi_v$$

Cylindrical coordinates (r, θ, z):

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_r\frac{\partial T}{\partial r} + \frac{v_\theta}{r}\frac{\partial T}{\partial \theta} + v_z\frac{\partial T}{\partial z}\right) = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right] + \mu\Phi_v$$

Spherical coordinates (r, θ, φ):

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

Error function Table:

w	erf w	w	erf w	w	erf w
0.00	0.00000	0.36	0.38933	1.04	0.85865
0.02	0.02256	0.38	0.40901	1.08	0.87333
0.04	0.04511	0.40	0.42839	1.12	0.88679
0.06	0.06762	0.44	0.46622	1.16	0.89910
0.08	0.09008	0.48	0.50275	1.20	0.91031
0.10	0.11246	0.52	0.53790	1.30	0.93401
0.12	0.13476	0.56	0.57162	1.40	0.95228
0.14	0.15695	0.60	0.60386	1.50	0.96611
0.16	0.17901	0.64	0.63459	1.60	0.97635
0.18	0.20094	0.68	0.66378	1.70	0.98379
0.20	0.22270	0.72	0.69143	1.80	0.98909
0.22	0.24430	0.76	0.71754	1.90	0.99279
0.24	0.26570	0.80	0.74210	2.00	0.99532
0.26	0.28690	0.84	0.76514	2.20	0.99814
0.28	0.30788	0.88	0.78669	2.40	0.99931
0.30	0.32863	0.92	0.80677	2.60	0.99976
0.32	0.34913	0.96	0.82542	2.80	0.99992
0.34	0.36936	1.00	0.84270	3.00	0.99998

[1]The Gaussian error function is defined as

$$\operatorname{erf} w = \frac{2}{\sqrt{\pi}}\int_0^w e^{-v^2}\,dv$$

The complementary error function is defined as

$$\operatorname{erfc} w = 1 - \operatorname{erf} w$$