B. CHEMICAL ENGINEERING 2[ND] YEAR 2[nd] SEMESTER EXAMINATION, 2024

SUBJECT: INTRODUCTION TO TRANSPORT PHENOMENA

Time: Three hours — Part I — Full marks 100

Use separate answer scripts for each part. State the assumptions and assume missing data

| Q No. | CO | Answer question 1,2,3,5 and either 4(a) or 4(b) | Marks |
|---|---|---|---|
| 1/1 | | a) Define Biot Number and explain its significance in transient heat conduction<br>b) Define diffusive flux and Ficks 1[st] law of diffusion.<br>c) Define Strouhal number and explain its significance in fluid flow | (4x3)=(12) |
| 2/2 | | Consider the composite pin fin; half of the fin is formed of a material with thermal conductivity k1 and the other half is formed of material with thermal conductivity k2. The base (x=0) is held at a constant temperature Tb and the tip (x=L) is insulated. 'h' is the convective heat transfer coefficient and Tα is the external temperature. Derive the governing equations and write the boundary Conditions. DO NOT SOLVE | |
| 3/3 | | The space between two coaxial cylinders is filled with an incompressible fluid at constant temperature. The radii of the inner and outer wetted surfaces are ***KR*** and *R*, respectively.<br>The angular velocities of rotation of the inner and outer cylinders are ***ωi*** and ω***o***, *respectively.* Determine the velocity distribution in the fluid and the torques on the two cylinders needed to maintain the motion.Continuity and Navier Stokes equations are given below<br>$\frac{1}{r}\frac{\partial(rv_r)}{\partial r}+\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial v_z}{\partial z}=0$<br>$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r}+\mu\left[\frac{\partial}{\partial r}(\frac{1}{r}\frac{\partial(rv_r)}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial^2 v_r}{\partial z^2}\right]+\rho g_r$<br>$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left[\frac{\partial}{\partial r}(\frac{1}{r}\frac{\partial(rv_\theta)}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]+\rho g_\theta$<br>$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial v_z}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}++\frac{\partial^2 v_z}{\partial z^2}\right]+\rho g_z$<br>$\tau_{r\theta}=\tau_{\theta r}=-\mu\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right)+\frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]$ | (8)<br>(10) |

[ Turn over

**Ref. No. : Ex/Che/PC/B/T/224/2024**

B. CHEMICAL ENGINEERING 2ND YEAR 2nd SEMESTER EXAMINATION, 2024
SUBJECT: INTRODUCTION TO TRANSPORT PHENOMENA

Time: Three hours | Part I | Full marks 100

| Q No. | CO | Answer question 1,2,3,5 and either 4(a) or 4(b) | Marks |
|---|---|---|---|
| 4(a)/4 | | Asphalt pavement may achieve temperatures as high as 50°C on a hot summer day. Assume that such a temperature exists throughout the pavement, when suddenly rainstorm reduces the surface temperature to 20°C. Considering asphalt to be a semi-infinite media, derive the governing equations for heat conduction. Derive an expression for the temperature distribution over time and space. Calculate the total amount of energy (J/m2) that will be transferred from the asphalt over a 30 min period (while surface temperature is maintained at 20°C). | (14) |
| | | OR | |
| 4(b)/4 | | Consider the (pseudo)steady state, radial diffusion of oxygen from air to the surface of a spherical particle of coal having initial radius $r_i$. At the surface of the particle, oxygen gas reacts instantaneously with solid carbon (C) in the coal to form carbon monoxide gas (CO) and carbon dioxide ($CO_2$) gas according to the heterogeneous gas reaction equation<br>$3C(s) + 2.5\ O_2(g) \rightarrow 2CO_2(g) + CO(g)$<br>The product gases back diffuse through the gas film adjacent to the coal. As the coal particle is oxidized the particle shrinks with time. Assuming that far away from the surface of the coal particle the mole fraction of oxygen is 0.21, derive expressions for radial distribution of oxygen concentration and rate of transfer of oxygen per unit time at steady state. The diffusion coefficient of oxygen through the gas mixture at the reaction temperature is $1.5\times10^{-4}$ m²/s.<br>How long will it take to reduce the size of the particle from initial radius of $r_i$=1cm to final radius $r_f$=0.2 cm? The density of carbon, ρ=2000 kg/m³ | |

B. CHEMICAL ENGINEERING 2ND YEAR 2nd SEMESTER EXAMINATION, 2024
SUBJECT: INTRODUCTION TO TRANSPORT

Time: Three hours | Part I | Full marks 100

| Q No. | CO | Answer question 1,2,3,5 and either 4(a) or 4(b) | Marks |
|---|---|---|---|
| 5/5 | | a) State the conditions of Reynolds analogy | (2) |
| | | b) Experimental tests on a portion of turbine blade having characteristic length scale (chord length) 40 mm, indicate a heat flux to the blade of $q''$=95,000 W/m$^2$. The blade operates in an airflow at $T\alpha$=1150°C and V=160 m/s. Steady state surface temperature of 800°C,is maintained by circulating a coolant inside the blade. (a) Calculate the heat transfer coefficient. (b) Determine the heat flux at the same dimensionless location of a geometrically similar turbine blade having a chord length of L=80 mm, when the blade operates in an airflow at $T\alpha$=1150°C and V=80 m/s, with Ts=800°C. | (4) |

| x | erf x | x | erf x | x | erf x | x | erf x |
|---|---|---|---|---|---|---|---|
| 0.05 | 0.01994 | 0.80 | 0.28814 | 1.55 | 0.43943 | 2.30 | 0.48928 |
| 0.10 | 0.03983 | 0.85 | 0.30234 | 1.60 | 0.44520 | 2.35 | 0.49061 |
| 0.15 | 0.05962 | 0.90 | 0.31594 | 1.65 | 0.45053 | 2.40 | 0.49180 |
| 0.20 | 0.07926 | 0.95 | 0.32894 | 1.70 | 0.45543 | 2.45 | 0.49286 |
| 0.25 | 0.09871 | 1.00 | 0.34134 | 1.75 | 0.45994 | 2.50 | 0.49379 |
| 0.30 | 0.11791 | 1.05 | 0.35314 | 1.80 | 0.46407 | 2.55 | 0.49461 |
| 0.35 | 0.13683 | 1.10 | 0.36433 | 1.85 | 0.46784 | 2.60 | 0.49534 |
| 0.40 | 0.15542 | 1.15 | 0.37493 | 1.90 | 0.47128 | 2.65 | 0.49597 |
| 0.45 | 0.17365 | 1.20 | 0.38493 | 1.95 | 0.47441 | 2.70 | 0.49653 |
| 0.50 | 0.19146 | 1.25 | 0.39435 | 2.00 | 0.47726 | 2.75 | 0.49702 |
| 0.55 | 0.20884 | 1.30 | 0.40320 | 2.05 | 0.47982 | 2.80 | 0.49744 |
| 0.60 | 0.22575 | 1.35 | 0.41149 | 2.10 | 0.48214 | 2.85 | 0.49781 |
| 0.65 | 0.24215 | 1.40 | 0.41924 | 2.15 | 0.48422 | 2.90 | 0.49813 |
| 0.70 | 0.25804 | 1.45 | 0.42647 | 2.20 | 0.48610 | 2.95 | 0.49841 |
| 0.75 | 0.27337 | 1.50 | 0.43319 | 2.25 | 0.48778 | 3.00 | 0.49865 |

Table 1.1: erf - Error function

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**B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER EXAM 2024**

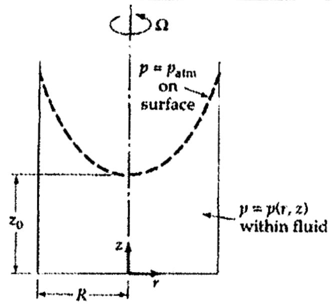
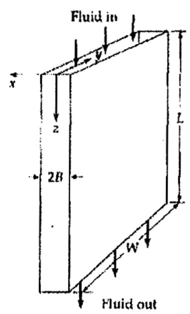
**INTRODUCTION TO TRANSPORT PHENOMENA**

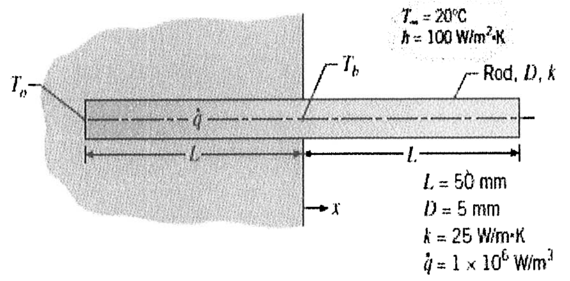
**Time : 3hours** **Full Marks : 100**

**Part -II ( 50 Marks)**

**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 heat transfer from a thick wall.<br>2. State the difference between natural and forced convection? | 3<br>2 |
| CO2 | 3. Set-up the governing equation for the shape of a rotating fluid, write relevant boundary conditions (do not solve).   | 7 |
| CO3 | 4. A Newtonian fluid is in laminar flow in a narrow slit formed by two parallel walls a distance 2B apart. It is understood that B << W, so that "edge effects" are unimportant. The wall at x = B moves in the positive z direction at a steady speed vo. Obtain (a) the shear-stress distribution and (b) the velocity distribution. Draw carefully labelled sketches of these functions.  <br>**Or**<br>5. A heated sphere of radius R is suspended in a large, motionless body of fluid. It is desired to study the heat conduction in the fluid surrounding the sphere in the absence of convection.<br>(a) Set up the differential equation describing the temperature Tin the surrounding fluid as a function of r, the distance from the center of the sphere. The thermal conductivity k of the fluid is considered constant.<br>(b) Integrate the differential equation and use these boundary conditions to determine the integration constants:<br>at r = R, T = TR; and at r = ∞, T = T∞.<br>(c) From the temperature profile, obtain an expression for the heat flux at the surface. Equate this result to the heat flux given by "Newton's law of cooling" and show that a dimensionless heat transfer coefficient (known as the Nusselt number) is given by<br>Nu=hD/k=2<br>in which D is the sphere diameter. | 15 |

| | | |
|---|---|---|
| **CO4** | **6.** A metal rod of length 2L, diameter D, and thermal conductivity k is inserted into a perfectly insulating wall, exposing one-half of its length to an airstream that is of temperature T∞ and provides a convection coefficient h at the surface of the rod. An electromagnetic field induces volumetric energy generation at a uniform rate q within the embedded portion of the rod.<br><br><br>(a) Derive an expression for the steady-state temperature $T_b$ at the base of the exposed half of the rod. The exposed region may be approximated as a very long fin.<br>(b) Derive an expression for the steady-state temperature $T_o$ at the end of the embedded half of the rod.<br>(c) Using numerical values provided in the schematic, plot the temperature distribution in the rod.<br>**Or**<br>**7.** A salt slab and a pool of water intitially separated by an impervious membrane suddenly brought in contact. The water does not contain any salt at time t=0, The concentration of salt at the interface, $\rho_{As}$ at this point is equal to 400 kg/m$^3$, the solubility of salt in water. And the density of solid salt slab, the $\rho_A$ (s )=2150 kg/m$^3$, the diffusion coefficient of salt in water $D_{AB}$ is, $1.2 \times 10^{-9}$ m$^2$/s. Find out<br>a) how the salt concentration changes in the liquid and<br>b) what is the recession rate (thickness of the slab changes with time) | **15** |
| **CO5** | **8.** Nondimensionalize the N-S equation and write down physical significance of each term. | **8** |

Continuity Equation: $\frac{D\rho}{Dt} = -\rho(\nabla \cdot \mathbf{v})$

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

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

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

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

Heat Equation:

Cylindrical coordinate

$$\rho C_p\frac{\partial T}{\partial t} = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right]$$

Spherical coordinate

$$\rho C_p\frac{\partial T}{\partial t} = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \phi}\left(r\frac{\partial T}{\partial \phi}\right) + \frac{\partial^2 T}{\partial z^2}\right]$$