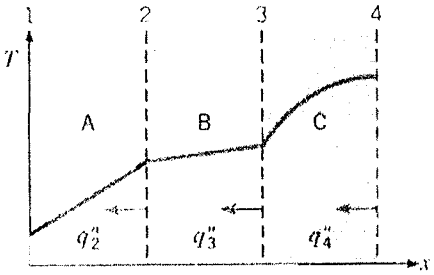
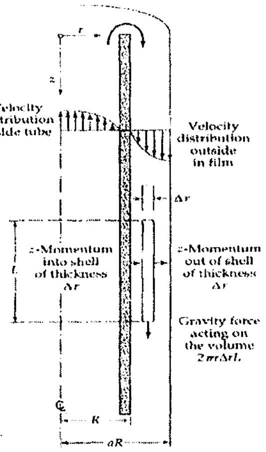
B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER - 2023
INTRODUCTION TO TRANSPORT PHENOMENA

Time: 3 Hours Full Marks: 100

Use Separate Answer Scripts for Part I and Part II

PART-I

State all the assumptions. Assume missing data (if any)

Q.No.	CO No	*Answer Question No. 1,2,3, 4(i) or 4(ii) and 5*	Marks
1(i)	1 1	 FIG 1  FIG. 2 The steady state temperature distribution in a composite plane wall of three different materials, each of constant thermal conductivity is shown in figure 1. Comment on the relative magnitude of q2'', q3'', q4''. Comment on relative magnitude of K_A, K_B, K_C. Justify your answer. Sketch the heat flux as a function of x.	(2+2+2)
1(ii)	1	Prove that for a binary gas mixture (A & B) at constant temperature and pressure $D_{AB}=D_{BA}$	4
2.	2	Consider the flow of a Newtonian fluid through a horizontal cylindrical tube of radius R and length L in presence of an oscillatory. pressure gradient ($\Delta P/L = a\cos(\omega t)$). Write the governing equation and boundary conditions. DO NOT SOLVE. Nondimensionalize the governing equation and define the Dimensionless numbers.	(4+4)
3	3	In a gas absorption experiment a viscous, Newtonian, incompressible fluid flows upward through a small circular tube and then downward in laminar flow as a thin film (Fig. 2). along the vertical outside (cylindrical) wall. (i)Derive the expression for steady state velocity profile of the falling film. (ii)Derive the expression for the average velocity.	(8+4)

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4(i)	4.	A procedure for determining the thermal conductivity of a solid material involves embedding a thermocouple in a thick slab of solid and measuring the response to a prescribed change in temperature at one surface. Consider an arrangement for which the thermocouple is embedded 10 mm from a surface that is suddenly brought and maintained at 100°C (by exposure to boiling water). If the initial temperature of the slab was 30°C and the thermocouple measures a temperature of 65°C, 2 minutes after the surface is brought to 100°C, what is the thermal conductivity of the material? The density and specific heat of the solid are known to be 2200 kg/m^3 and 700 J/kg. K, respectively. Show the necessary derivation.	(12)
4(ii)	4	You have been asked to develop a model for computing the distribution of NO_2 in the atmosphere. The molar flux of NO_2 at ground level, $N''_{A,0}$, is presumed known. This flux is attributed to automobile and smoke stack emissions. It is also known that the concentration of NO_2 at a distance well above ground level is zero and that NO_2 reacts chemically in the atmosphere. In particular, NO2 reacts with unburned hydrocarbons (in a process that is activated by sunlight) to produce PAN (peroxyacetylnitrate), the final product of photochemical smog. The reaction is first order, and the local rate at which it occurs may be expressed as $N_A = -kC_A$. (a) Assuming steady-state conditions and a stagnant atmosphere, obtain an expression for the vertical distribution $C_A(x)$ of the molar concentration of NO_2 in the atmosphere. (b) If an NO2 partial pressure of $p_A = 2\times10^{-6}$bar is sufficient to cause pulmonary damage, what is the value of the ground level molar flux for which you would issue a smog alert? You may assume an isothermal atmosphere at T =300 K, a reaction coefficient of $k1$ = 0.03 s^{-1}, and an NO2–air diffusion coefficient of D_{AB} = 0.15 × 10^{-4} m^2/s.	(12)
5.(i)	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?	(4)
5(ii)	5	A thin flat plate that is 0.2 m by 0.2 m on a side is oriented parallel to an atmospheric airstream having a velocity of 40 m/s. The air is at a temperature of T_α=20°C, while the plate is maintained at Ts=120°C. The air flows over top and bottom surfaces of the plate and measurement of the drag force reveals a value of 0.075 N. What is the rate of heat transfer from both sides of the plate to the air? Consider Reynolds analogy to be valid. Assume ρair=1 kg/m3, μair=0.01818 cP, k=29 mWm^{-1}K^{-1}	(4)

		Complementary Error Function Table											
x	**erfc(x)**	**x**	**erfc(x)**	**x**	**erfc(x)**	**x**	**erfc(x)**	**x**	**erfc(x)**	**x**	**erfc(x)**	**x**	**erfc(x)**
0	1.000000	0.5	0.479500	1	0.157299	1.5	0.033895	2	0.004678	2.5	0.000407	3	0.00002209
0.01	0.988717	0.51	0.470756	1.01	0.153190	1.51	0.032723	2.01	0.004475	2.51	0.000386	3.01	0.00002074
0.02	0.977435	0.52	0.462101	1.02	0.149162	1.52	0.031587	2.02	0.004281	2.52	0.000365	3.02	0.00001947
0.03	0.966159	0.53	0.453536	1.03	0.145216	1.53	0.030484	2.03	0.004094	2.53	0.000346	3.03	0.00001827
0.04	0.954889	0.54	0.445061	1.04	0.141350	1.54	0.029414	2.04	0.003914	2.54	0.000328	3.04	0.00001714
0.05	0.943628	0.55	0.436677	1.05	0.137564	1.55	0.028377	2.05	0.003742	2.55	0.000311	3.05	0.00001608
0.06	0.932378	0.56	0.428384	1.06	0.133856	1.56	0.027372	2.06	0.003577	2.56	0.000294	3.06	0.00001508
0.07	0.921142	0.57	0.420184	1.07	0.130227	1.57	0.026397	2.07	0.003418	2.57	0.000278	3.07	0.00001414
0.08	0.909922	0.58	0.412077	1.08	0.126674	1.58	0.025453	2.08	0.003266	2.58	0.000264	3.08	0.00001326
0.09	0.898719	0.59	0.404064	1.09	0.123197	1.59	0.024538	2.09	0.003120	2.59	0.000249	3.09	0.00001243
0.1	0.887537	0.6	0.396144	1.1	0.119795	1.6	0.023652	2.1	0.002979	2.6	0.000236	3.1	0.00001165
0.11	0.876377	0.61	0.388319	1.11	0.116467	1.61	0.022793	2.11	0.002845	2.61	0.000223	3.11	0.00001092
0.12	0.865242	0.62	0.380589	1.12	0.113212	1.62	0.021962	2.12	0.002716	2.62	0.000211	3.12	0.00001023
0.13	0.854133	0.63	0.372954	1.13	0.110029	1.63	0.021157	2.13	0.002593	2.63	0.000200	3.13	0.00000958
0.14	0.843053	0.64	0.365414	1.14	0.106918	1.64	0.020378	2.14	0.002475	2.64	0.000189	3.14	0.00000897
0.15	0.832004	0.65	0.357971	1.15	0.103876	1.65	0.019624	2.15	0.002361	2.65	0.000178	3.15	0.00000840
0.16	0.820988	0.66	0.350623	1.16	0.100904	1.66	0.018895	2.16	0.002253	2.66	0.000169	3.16	0.00000786
0.17	0.810008	0.67	0.343372	1.17	0.098000	1.67	0.018190	2.17	0.002149	2.67	0.000159	3.17	0.00000736
0.18	0.799064	0.68	0.336218	1.18	0.095163	1.68	0.017507	2.18	0.002049	2.68	0.000151	3.18	0.00000689
0.19	0.788160	0.69	0.329160	1.19	0.092392	1.69	0.016847	2.19	0.001954	2.69	0.000142	3.19	0.00000644
0.2	0.777297	0.7	0.322199	1.2	0.089686	1.7	0.016210	2.2	0.001863	2.7	0.000134	3.2	0.00000603
0.21	0.766478	0.71	0.315335	1.21	0.087045	1.71	0.015593	2.21	0.001776	2.71	0.000127	3.21	0.00000564
0.22	0.755704	0.72	0.308567	1.22	0.084466	1.72	0.014997	2.22	0.001692	2.72	0.000120	3.22	0.00000527
0.23	0.744977	0.73	0.301896	1.23	0.081950	1.73	0.014422	2.23	0.001612	2.73	0.000113	3.23	0.00000493
0.24	0.734300	0.74	0.295322	1.24	0.079495	1.74	0.013865	2.24	0.001536	2.74	0.000107	3.24	0.00000460
0.25	0.723674	0.75	0.288845	1.25	0.077100	1.75	0.013328	2.25	0.001463	2.75	0.000101	3.25	0.00000430
0.26	0.713100	0.76	0.282463	1.26	0.074764	1.76	0.012810	2.26	0.001393	2.76	0.000095	3.26	0.00000402
0.27	0.702582	0.77	0.276179	1.27	0.072486	1.77	0.012309	2.27	0.001326	2.77	0.000090	3.27	0.00000376
0.28	0.692120	0.78	0.269990	1.28	0.070266	1.78	0.011826	2.28	0.001262	2.78	0.000084	3.28	0.00000351
0.29	0.681717	0.79	0.263897	1.29	0.068101	1.79	0.011359	2.29	0.001201	2.79	0.000080	3.29	0.00000328
0.3	0.671373	0.8	0.257899	1.3	0.065992	1.8	0.010909	2.3	0.001143	2.8	0.000075	3.3	0.00000306
0.31	0.661092	0.81	0.251997	1.31	0.063937	1.81	0.010475	2.31	0.001088	2.81	0.000071	3.31	0.00000285
0.32	0.650874	0.82	0.246189	1.32	0.061935	1.82	0.010057	2.32	0.001034	2.82	0.000067	3.32	0.00000266
0.33	0.640721	0.83	0.240476	1.33	0.059985	1.83	0.009653	2.33	0.000984	2.83	0.000063	3.33	0.00000249
0.34	0.630635	0.84	0.234857	1.34	0.058086	1.84	0.009264	2.34	0.000935	2.84	0.000059	3.34	0.00000232
0.35	0.620618	0.85	0.229332	1.35	0.056238	1.85	0.008889	2.35	0.000889	2.85	0.000056	3.35	0.00000216
0.36	0.610670	0.86	0.223900	1.36	0.054439	1.86	0.008528	2.36	0.000845	2.86	0.000052	3.36	0.00000202
0.37	0.600794	0.87	0.218560	1.37	0.052688	1.87	0.008179	2.37	0.000803	2.87	0.000049	3.37	0.00000188
0.38	0.590991	0.88	0.213313	1.38	0.050984	1.88	0.007844	2.38	0.000763	2.88	0.000046	3.38	0.00000175
0.39	0.581261	0.89	0.208157	1.39	0.049327	1.89	0.007521	2.39	0.000725	2.89	0.000044	3.39	0.00000163
0.4	0.571608	0.9	0.203092	1.4	0.047715	1.9	0.007210	2.4	0.000689	2.9	0.000041	3.4	0.00000152
0.41	0.562031	0.91	0.198117	1.41	0.046148	1.91	0.006910	2.41	0.000654	2.91	0.000039	3.41	0.00000142
0.42	0.552532	0.92	0.193232	1.42	0.044624	1.92	0.006622	2.42	0.000621	2.92	0.000036	3.42	0.00000132
0.43	0.543113	0.93	0.188437	1.43	0.043143	1.93	0.006344	2.43	0.000589	2.93	0.000034	3.43	0.00000123
0.44	0.533775	0.94	0.183729	1.44	0.041703	1.94	0.006077	2.44	0.000559	2.94	0.000032	3.44	0.00000115
0.45	0.524518	0.95	0.179109	1.45	0.040305	1.95	0.005821	2.45	0.000531	2.95	0.000030	3.45	0.00000107
0.46	0.515345	0.96	0.174576	1.46	0.038946	1.96	0.005574	2.46	0.000503	2.96	0.000028	3.46	0.00000099
0.47	0.506255	0.97	0.170130	1.47	0.037627	1.97	0.005336	2.47	0.000477	2.97	0.000027	3.47	0.00000092
0.48	0.497250	0.98	0.165769	1.48	0.036346	1.98	0.005108	2.48	0.000453	2.98	0.000025	3.48	0.00000086
0.49	0.488332	0.99	0.161492	1.49	0.035102	1.99	0.004889	2.49	0.000429	2.99	0.000024	3.49	0.00000080

Ref. No.: Ex/Che/PC/B/T/224/2023

B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER EXAM 2023

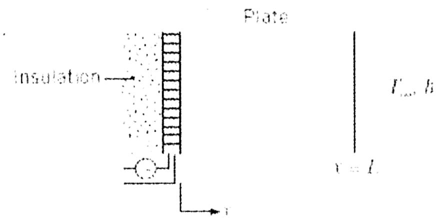
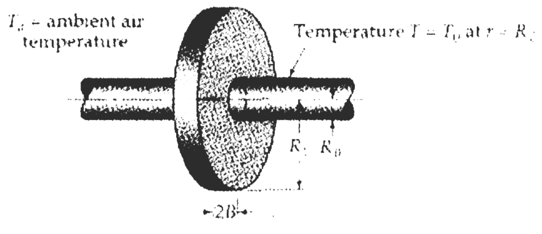
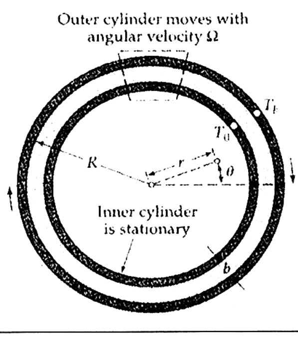
INTRODUCTION TO TRANSPORT PHENOMENA

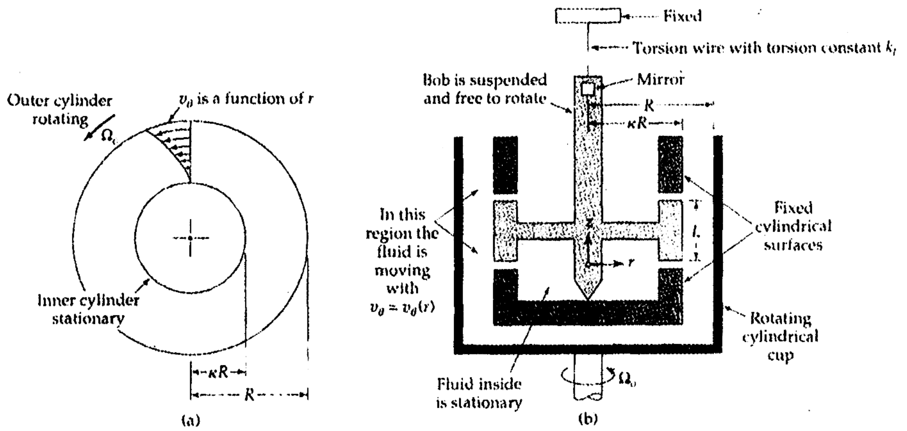
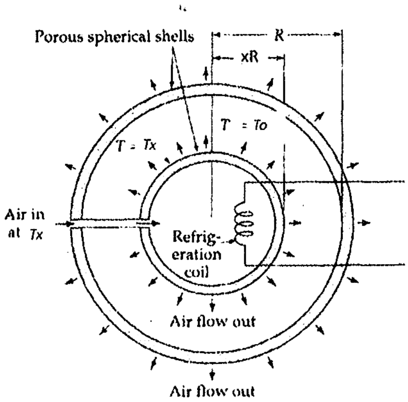
Time : 3hours **Full Marks : 50**

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.** Draw the Transient temperature distributions for different Biot numbers in a plane wall symmetrically cooled by convection. Write down significance of Biot number. **2.** Consider a thin electrical heater attached to a plate and backed by insulation. Initially, the heater and plate are at the temperature of the ambient air, T_∞. Suddenly, the power to the heater is activated, yielding a constant heat flux q''_o (W/m^2) at the inner surface of the plate.  (a) Sketch and label, on T(x,t) coordinates, the temperature distributions: initial, steady-state, and at two intermediate times. (b) Sketch the heat flux $q''_x(L,t)$ at the outer surface as a function of time.	**3** **3**
CO2	**3.** Obtain the governing equations for obtaining temperature profile $T(r)$ for a circular fin of thickness 2B on a pipe with outside wall temperature T_o. Do not solve. Clearly mention the assumptions and relevant boundary conditions. 	**7**
CO3	**4.** Obtain temperature profile of an incompressible Newtonian fluid flow between two coaxial cylinders. The surfaces of the inner and outer cylinders are maintained at $T = T_o$ and $T = T_b$, respectively. The outer cylinder rotates at an angular velocity of Ω. The volume heat source resulting from this "viscous dissipation," is S_v. Explain briefly the significance of the non-dimensional number obtained during this solution for lubricating material. 	**15**

	Or	
	5. The forerunner of all rotational viscometers is the Couette instrument, which is sketched in the Figure. The fluid is placed in the cup, and the cup is then made to rotate with a constant angular velocity Ωo, (the subscript "o" stands for outer). The rotating viscous liquid causes the suspended bob to turn until the torque produced by the momentum transfer in the fluid equals the product of the torsion constant kt and the angular displacement θb of the bob. The angular displacement can be measured by observing the deflection of a light beam reflected from a mirror mounted on the bob. The conditions of measurement are controlled so that there is a steady, tangential, laminar flow in the annular region between the two coaxial cylinders shown in the figure. Because of the arrangement used, end effects over the region including the bob height L are negligible. Analyse this measurement, apply the equations of continuity and motion for constant ρ and, μ to the tangential flow in the annular region around the bob. Derive an expression for the viscosity in terms of (the z-component of) the torque Tz, on the inner cylinder, the angular velocity Ωo, of the rotating cup, the bob height L, and the radii κR and R of the bob and cup, respectively. 	
CO4	**6.** A system with two concentric porous spherical shells of radii xR and R is shown in the Figure. The inner surface of the outer shell is at temperature T_o, and the outer surface of the inner shell is at a lower temperature T_x. Dry air at T_x is blown outward radially from the inner shell into the intervening space and then through the outer shell. Develop an expression for the required rate of heat removal from the inner sphere as a function of the mass rate of flow of the gas. Also obtain an expression for dimensionless transpiration rate. Assume steady laminar flow and low gas velocity.  **Or**	**15**

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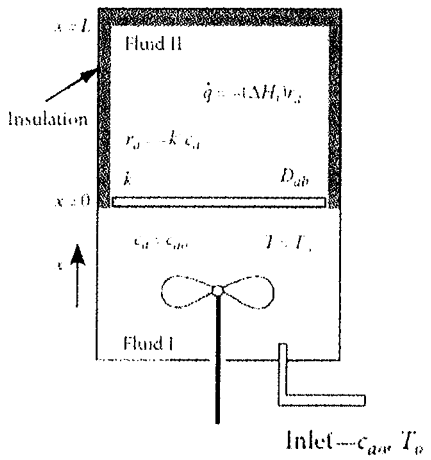
7. Two fluids are separated by a membrane permeable only to species *a*. Fluid I is well mixed. The concentration of species *a* is *Cao* everywhere within this fluid, and the temperature in fluid I is held constant at *To*. Species *a* diffuses through stagnant fluid II and undergoes a first-order reaction ($a \rightarrow b$) to form species *b* within the fluid. Fluid I is replenished with *a*, while fluid II has an outlet (not shown) to remove excess *a* and *b*. Predict both the concentration distribution and the temperature distribution in the system. Assume a is sparingly soluble in FluidII.



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<td>CO5</td>
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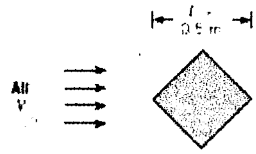
8. Experimental measurements of the convection heat transfer coefficient for a square bar in cross flow yielded the following values:

$\bar{h}_1 = 50\ \mathrm{W/m^2 \cdot K}$ when $V_1 = 20$ m/s

$\bar{h}_2 = 40\ \mathrm{W/m^2 \cdot K}$ when $V_2 = 15$ m/s



Assume that the functional form of the Nusselt number is , 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 =1 m 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?

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Continuity Equation:

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

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) = 0$$

Navier-Stokes Equation:

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

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

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

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