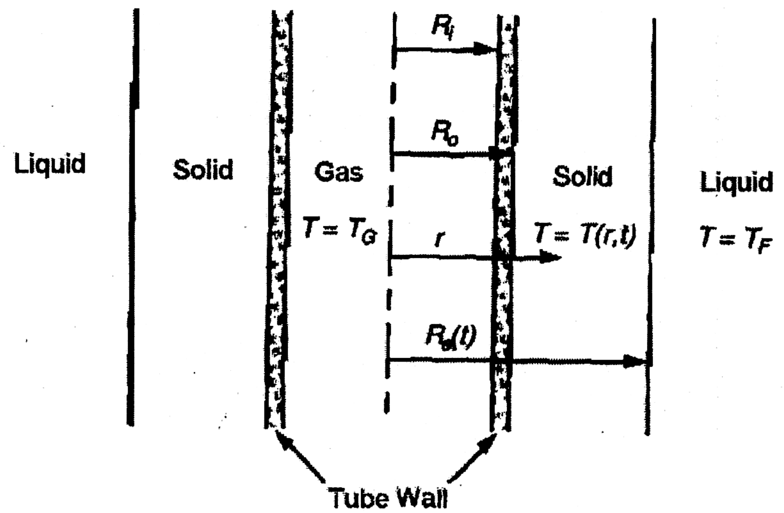
Ref. No. Ex/PG/ChE/T/111/2025

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025

SUBJECT: ADVENCED TRANSPORT PHENOMENA

Time: Three hours Full Marks 100

No. of Q/CO		Marks
1 (a)./ CO1	Consider Fluid flow in porous media which is modelled by Darcy's law $$\mathbf{v} = -\frac{\kappa}{\mu}(\nabla P - \rho \mathbf{g}) \equiv -\frac{\kappa}{\mu}\nabla \mathcal{P},$$ Where κ is Dacrcy permeability (unit m^2) which is constant for a specific material. The microstructural details are not considered, Pore structure enters only through the value of κ, which is usually determined through experiments. (i) For a material of average porosity ε (pore volume fraction), derive the integral and differential form of conservation of mass (ii) Show that for an incompressible fluid : $\nabla^2 \mathcal{P} = 0.$	(2+2)
1(b)/ CO2	 FIG. 1 A pure liquid is being frozen outside a refrigerated tube, as shown in Figure 1. The bulk liquid is at its freezing temperature (T_F) and the inner wall of the tube is cooled by convective heat transfer to a gas at bulk temperature T_G. The internal heat transfer coefficient is h and the heat of fusion is λ. Assume that freezing occurs slowly enough that the time derivative in the energy equation is negligible (pseudo steady state approximation) and T_G is independent of axial position. Assume that the tube wall is thin and has negligible thermal resistance.	

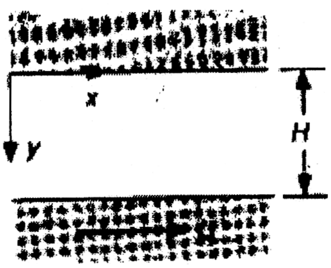
[Turn over

-*Ref. No. Ex/PG/ChE/T/111/2025*

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025

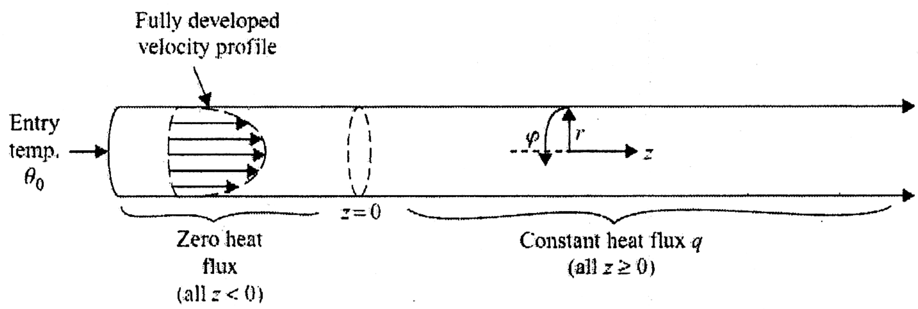
SUBJECT: ADVENCED TRANSPORT PHENOMENA

Time: Three hours Full Marks 100

No. of Questions/ CO		Marks
	(i)Determine the pseudo-steady state temperature profile in the solid at a given instant.(ii) Determine the rate of freezing at a given instant, expressed as dRs/dt.	(5+5)
3(a). /CO2	Pyrethrin is an insecticide derived from the pyrethrum plant. Polymeric supports are impregnated with pyrethrin and the insecticide slowly diffuses through the polymer and into a room. The lethal concentration of most insects is about $CL=5x\ 10^{-4}$ mg/m_3. A spherical pyrethrin delivery device is suspended from the ceiling of a room. The concentration of pyrethrin in the polymer is Cf= 1 weight % and may be assumed constant over time. The density (ρ) of the delivery device is 0.96 g/cm3 and its radius is 6 mm. The diffusivity of pyrethrin in air, Dp-a is 0.03 cm2/s and its molecular weight is 328 g/mol. Write the governing balance equation and solve for the concentration profile. How long will it take for the lethal concentration to be reached at a point 3 m from the delivery device? Assume no interfacial resistance in getting the pyrethrin from the polymer and in to the air. OR	(16)
3 (b). CO2	Consider the start-up of Couette flow (confined between two plates with zero pressure gradient). Assume that initially the fluid was at rest and suddenly at time t=0 the bottom plate is set in motion at a constant velocity U (refer to Fig. 2). Derive the expression of velocity profile Vx(y,t). Derive an expression for the time required to approach to within 5% of the steady state. FIG. 2 	(16)

Ref. No. Ex/PG/ChE/T/111/2025

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025
SUBJECT: ADVENCED TRANSPORT PHENOMENA
Time: Three hours Full Marks 100

No. of Questions/ CO		Marks
4. CO3	(i) Derive the laminar hydrodynamic boundary layer equations over a stationary flat plate of length L, considering U_α as the free stream velocity.	(6)
*	(iii) Derive the integral momentum equations.	(4)
	(iv) Assuming that the nondimensional axial velocity is a fourth order polynomial of (y/δ), derive the expressions for boundary layer thickness δ(x) and friction factor.	(12)
	(v) Using Reynolds averaging rules derive the Turbulent boundary layer equations over a stationary flat plate of length L. Define Eddy viscosity.	(8)
5. CO3,CO4	 FIG 3 Consider that an incompressible Newtonian fluid at a uniform temperature θ_0 enters a circular tube of radius R. For z>0 its wall receives a uniform heat flux q (refer to FIG.3). The bulk temperature T_b of the fluid increases as the fluid moves through the tube. Beyond a definite thermal entry length the shape of temperature profile does not change. This is called fully developed temperature profile.	
	(i) Considering average fluid properties derive an expression of steady state fully developed laminar velocity profile through the tube.	(8)
	(ii) Write the governing equation and boundary conditions for energy transport. Define the mixing cup temperature and derive the steady state fully developed temperature profile at far downstream. Prove that the value of Nusselt number is 4.364 (48/11).	(12)

Ref. No. Ex/PG/ChE/T/111/2025

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025
SUBJECT: ADVENCED TRANSPORT PHENOMENA
Time: Three hours Full Marks 100

<table>
<tr><td>No. of Questions/ CO0</td><td></td><td>Marks</td></tr>
<tr><td>6. CO4</td><td>

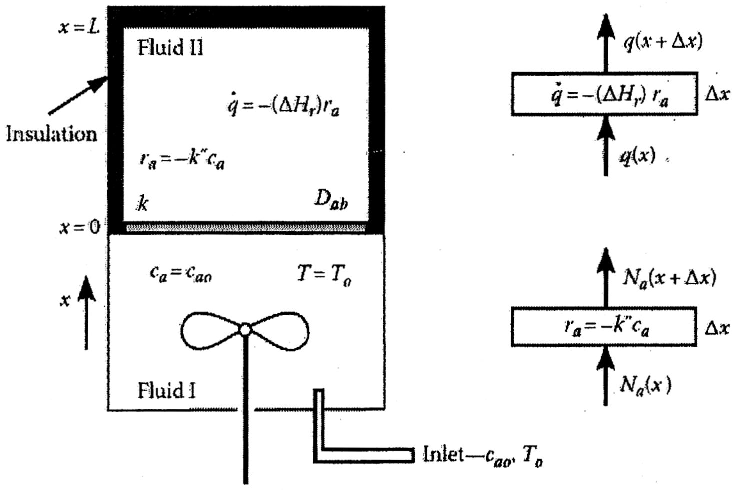


FIG. 4

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 ⟶ 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'. The reaction is exothermic, yielding -ΔHr joules per mole of 'a' reacted. The whole system is insulated from the surroundings, and all sides of the vessel are impermeable to both fluids. Write the governing balance equations and boundary conditions. Nondimensionalize the equations and name the dimensionless numbers. Derive the concentration distribution and temperature distribution in the system. Assume constant properties, dilute solutions (solute 'a' is sparingly soluble in fluid II) and the volume of fluid II remains constant.

</td><td>(20)</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Ref. No. Ex/PG/ChE/T/111/2025

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025

SUBJECT: ADVENCED TRANSPORT PHENOMENA

Time: Three hours Full Marks 100

TABLE 2-1
General Conservation Equations for Interior Points and Interfaces

Interior points		Points at interfaces
$\frac{\partial b}{\partial t} = -\nabla \cdot \mathbf{F} + B_V$	(A)	$[(\mathbf{F} - b\mathbf{v}_I)_B - (\mathbf{F} - b\mathbf{v}_I)_A] \cdot \mathbf{n}_I = B_S$
$\frac{\partial b}{\partial t} + \nabla \cdot (b\mathbf{v}) = -\nabla \cdot \mathbf{f} + B_V$	(C)	$[(\mathbf{f} + b(\mathbf{v} - \mathbf{v}_I))_B - (\mathbf{f} + b(\mathbf{v} - \mathbf{v}_I))_A] \cdot \mathbf{n}_I = B_S$

Navier Stokes equation is given below

$$\rho\left[\frac{\partial \vec{V}}{\partial t} + \vec{V}.\nabla\vec{V}\right] = -\nabla p + \rho\vec{g} + \mu\nabla^2\vec{V}$$

Continuity and components of Navier Stokes equations for cylindrical coordinate are given below

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

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

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

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

Ref. No. Ex/PG/ChE/T/111/2025

M. E. CHEMICAL ENGINEERING 1st YEAR 1ST SEMESTER EXAMINATION 2025
SUBJECT: ADVENCED TRANSPORT PHENOMENA
Time: Three hours Full Marks 100

Energy Equation

Cylindrical: $T = T(r, \theta, z, t)$

$$\frac{\partial T}{\partial t} + v_r \frac{\partial T}{\partial r} + \frac{v_\theta}{r} \frac{\partial T}{\partial \theta} + v_z \frac{\partial T}{\partial z} = \alpha \left[\frac{1}{r} \frac{\partial}{\partial r}\left(r \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} \right] + \frac{H_V}{\rho C_P}$$

Species-balance-equation

Spherical: $C_i = C_i(r, \theta, \phi, t)$

$$\frac{\partial C_i}{\partial t} + v_r \frac{\partial C_i}{\partial r} + \frac{v_\theta}{r} \frac{\partial C_i}{\partial \theta} + \frac{v_\phi}{r \sin\theta} \frac{\partial C_i}{\partial \phi} = D_i \left[\frac{1}{r^2} \frac{\partial}{\partial r}\left(r^2 \frac{\partial C_i}{\partial r} \right) + \frac{1}{r^2 \sin\theta} \frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial C_i}{\partial \theta} \right) + \frac{1}{r^2 \sin^2\theta} \frac{\partial^2 C_i}{\partial \phi^2} \right] + R_{Vi}$$

Error Function Table

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt$$

	Hundredths digit of x									
x	0	1	2	3	4	5	6	7	8	9
0.0	0.00000	0.01128	0.02256	0.03384	0.04511	0.05637	0.06762	0.07886	0.09008	0.10128
0.1	0.11246	0.12362	0.13476	0.14587	0.15695	0.16800	0.17901	0.18999	0.20094	0.21184
0.2	0.22270	0.23352	0.24430	0.25502	0.26570	0.27633	0.28690	0.29742	0.30788	0.31828
0.3	0.32863	0.33891	0.34913	0.35928	0.36936	0.37938	0.38933	0.39921	0.40901	0.41874
0.4	0.42839	0.43797	0.44747	0.45689	0.46623	0.47548	0.48466	0.49375	0.50275	0.51167
0.5	0.52050	0.52924	0.53790	0.54646	0.55494	0.56332	0.57162	0.57982	0.58792	0.59594
0.6	0.60386	0.61168	0.61941	0.62705	0.63459	0.64203	0.64938	0.65663	0.66378	0.67084
0.7	0.67780	0.68467	0.69143	0.69810	0.70468	0.71116	0.71754	0.72382	0.73001	0.73610
0.8	0.74210	0.74800	0.75381	0.75952	0.76514	0.77067	0.77610	0.78144	0.78669	0.79184
0.9	0.79691	0.80188	0.80677	0.81156	0.81627	0.82089	0.82542	0.82987	0.83423	0.83851
1.0	0.84270	0.84681	0.85084	0.85478	0.85865	0.86244	0.86614	0.86977	0.87333	0.87680
1.1	0.88021	0.88353	0.88679	0.88997	0.89308	0.89612	0.89910	0.90200	0.90484	0.90761
1.2	0.91031	0.91296	0.91553	0.91805	0.92051	0.92290	0.92524	0.92751	0.92973	0.93190
1.3	0.93401	0.93606	0.93807	0.94002	0.94191	0.94376	0.94556	0.94731	0.94902	0.95067
1.4	0.95229	0.95385	0.95538	0.95686	0.95830	0.95970	0.96105	0.96237	0.96365	0.96490
1.5	0.96611	0.96728	0.96841	0.96952	0.97059	0.97162	0.97263	0.97360	0.97455	0.97546
1.6	0.97635	0.97721	0.97804	0.97884	0.97962	0.98038	0.98110	0.98181	0.98249	0.98315
1.7	0.98379	0.98441	0.98500	0.98558	0.98613	0.98667	0.98719	0.98769	0.98817	0.98864
1.8	0.98909	0.98952	0.98994	0.99035	0.99074	0.99111	0.99147	0.99182	0.99216	0.99248
1.9	0.99279	0.99309	0.99338	0.99366	0.99392	0.99418	0.99443	0.99466	0.99489	0.99511
2.0	0.99532	0.99552	0.99572	0.99591	0.99609	0.99626	0.99642	0.99658	0.99673	0.99688
2.1	0.99702	0.99715	0.99728	0.99741	0.99753	0.99764	0.99775	0.99785	0.99795	0.99805
2.2	0.99814	0.99822	0.99831	0.99839	0.99846	0.99854	0.99861	0.99867	0.99874	0.99880
2.3	0.99886	0.99891	0.99897	0.99902	0.99906	0.99911	0.99915	0.99920	0.99924	0.99928
2.4	0.99931	0.99935	0.99938	0.99941	0.99944	0.99947	0.99950	0.99952	0.99955	0.99957
2.5	0.99959	0.99961	0.99963	0.99965	0.99967	0.99969	0.99971	0.99972	0.99974	0.99975
2.6	0.99976	0.99978	0.99979	0.99980	0.99981	0.99982	0.99983	0.99984	0.99985	0.99986
2.7	0.99987	0.99987	0.99988	0.99989	0.99989	0.99990	0.99991	0.99991	0.99992	0.99992
2.8	0.99992	0.99993	0.99993	0.99994	0.99994	0.99994	0.99995	0.99995	0.99995	0.99996
2.9	0.99996	0.99996	0.99996	0.99997	0.99997	0.99997	0.99997	0.99997	0.99997	0.99998
3.0	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99999	0.99999	0.99999
3.1	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
3.2	0.99999	0.99999	0.99999	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

Complementary Error Function Table

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2}\, dt$$

	Hundredths digit of x									
x	0	1	2	3	4	5	6	7	8	9
0.0	1.00000	0.98872	0.97744	0.96616	0.95489	0.94363	0.93238	0.92114	0.90992	0.89872
0.1	0.88754	0.87638	0.86524	0.85413	0.84305	0.83200	0.82099	0.81001	0.79906	0.78816
0.2	0.77730	0.76648	0.75570	0.74498	0.73430	0.72367	0.71310	0.70258	0.69212	0.68172
0.3	0.67137	0.66109	0.65087	0.64072	0.63064	0.62062	0.61067	0.60079	0.59099	0.58126
0.4	0.57161	0.56203	0.55253	0.54311	0.53377	0.52452	0.51534	0.50625	0.49725	0.48833
0.5	0.47950	0.47076	0.46210	0.45354	0.44506	0.43668	0.42838	0.42018	0.41208	0.40406
0.6	0.39614	0.38832	0.38059	0.37295	0.36541	0.35797	0.35062	0.34337	0.33622	0.32916
0.7	0.32220	0.31533	0.30857	0.30190	0.29532	0.28884	0.28246	0.27618	0.26999	0.26390
0.8	0.25790	0.25200	0.24619	0.24048	0.23486	0.22933	0.22390	0.21856	0.21331	0.20816
0.9	0.20309	0.19812	0.19323	0.18844	0.18373	0.17911	0.17458	0.17013	0.16577	0.16149
1.0	0.15730	0.15319	0.14916	0.14522	0.14135	0.13756	0.13386	0.13023	0.12667	0.12320
1.1	0.11979	0.11647	0.11321	0.11003	0.10692	0.10388	0.10090	0.09800	0.09516	0.09239
1.2	0.08969	0.08704	0.08447	0.08195	0.07949	0.07710	0.07476	0.07249	0.07027	0.06810
1.3	0.06599	0.06394	0.06193	0.05998	0.05809	0.05624	0.05444	0.05269	0.05098	0.04933
1.4	0.04771	0.04615	0.04462	0.04314	0.04170	0.04030	0.03895	0.03763	0.03635	0.03510
1.5	0.03389	0.03272	0.03159	0.03048	0.02941	0.02838	0.02737	0.02640	0.02545	0.02454
1.6	0.02365	0.02279	0.02196	0.02116	0.02038	0.01962	0.01890	0.01819	0.01751	0.01685
1.7	0.01621	0.01559	0.01500	0.01442	0.01387	0.01333	0.01281	0.01231	0.01183	0.01136
1.8	0.01091	0.01048	0.01006	0.00965	0.00926	0.00889	0.00853	0.00818	0.00784	0.00752
1.9	0.00721	0.00691	0.00662	0.00634	0.00608	0.00582	0.00557	0.00534	0.00511	0.00489
2.0	0.00468	0.00448	0.00428	0.00409	0.00391	0.00374	0.00358	0.00342	0.00327	0.00312
2.1	0.00298	0.00285	0.00272	0.00259	0.00247	0.00236	0.00225	0.00215	0.00205	0.00195
2.2	0.00186	0.00178	0.00169	0.00161	0.00154	0.00146	0.00139	0.00133	0.00126	0.00120
2.3	0.00114	0.00109	0.00103	0.00098	0.00094	0.00089	0.00085	0.00080	0.00076	0.00072
2.4	0.00069	0.00065	0.00062	0.00059	0.00056	0.00053	0.00050	0.00048	0.00045	0.00043
2.5	0.00041	0.00039	0.00037	0.00035	0.00033	0.00031	0.00029	0.00028	0.00026	0.00025
2.6	0.00024	0.00022	0.00021	0.00020	0.00019	0.00018	0.00017	0.00016	0.00015	0.00014
2.7	0.00013	0.00013	0.00012	0.00011	0.00011	0.00010	0.00009	0.00009	0.00008	0.00008
2.8	0.00008	0.00007	0.00007	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005	0.00004
2.9	0.00004	0.00004	0.00004	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00002
3.0	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00001	0.00001	0.00001
3.1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
3.2	0.00001	0.00001	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000