BACHELOR OF ENGINEERING IN CHEMICAL ENGINEERING EXAMINATION, 2019

(2nd Year, 2nd Semester)

INTRODUCTION TO TRANSPORT PHENOMENA

Time : Three hours Full Marks : 100

(50 marks for each Part)

Use a separate Answer-Script for each Part

PART - I

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

No. of Questions	*CO1 : Identify the transport properties and describe the different mechanism of momentum, energy and mass transport*	Marks
1.	Answer any three (i)Compare the molar flux of component A with respect to a stationary coordinate (N_A) with diffusive molar flux (J_A) of A. How are they related? (ii)Prove that for a binary gas mixture of A and B, at constant temperature, $D_{AB} = D_{BA}$ (iii)Define effectiveness of a porous catalyst and state the role of diffusion through pore on it. (iv)Compare forced convection with natural convection (v) For absorption of a highly soluble solute A in a liquid B, define overall gas phase mass transfer coefficient (Ky) and its relation with the individual mass transfer coefficient (kx, ky) and equilibrium constant (m). Assume Henry's law is applicable.	(3x4=12)
2.	*CO5:Non-dimensionalzethe transport equations, identify the dimensionless numbers and to apply analogies between momentum, heat and mass transport to scale up.*	
	(i)For a liquid metal, the ratio (value) of momentum and thermal diffusivity is much smaller than 1. What is the ratio of thermal and velocity boundary layer thickness (>1/<1/1)? (ii) A thin flat plate of 0.2m by 0.2m on one side is oriented parallel to an atmospheric airstream having a velocity of 40 m/s. The air is at a temperature of 20°C (T_∞), while the plate is maintained at Ts=120°C.The air flows over the top and bottom surfaces of the plate and the measurement of drag force reveals a value of 0.075 N. What is the rate of heat transfer from both sides of the plate to air? At 70°C the density and viscosity of air ρ=0.9950 kgm^{-3} and μ=200x10^{-7} N s m^{-2}. Assume Reynold's analogy is valid.	(2+4)

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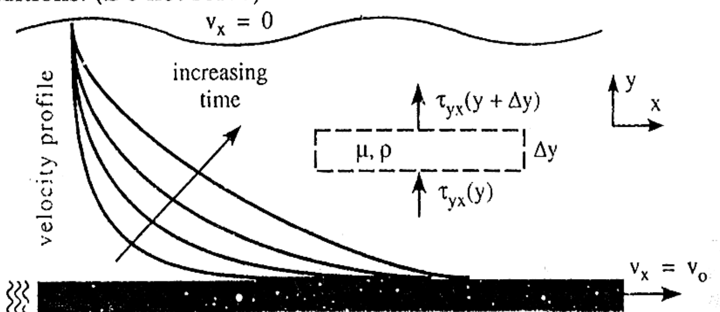
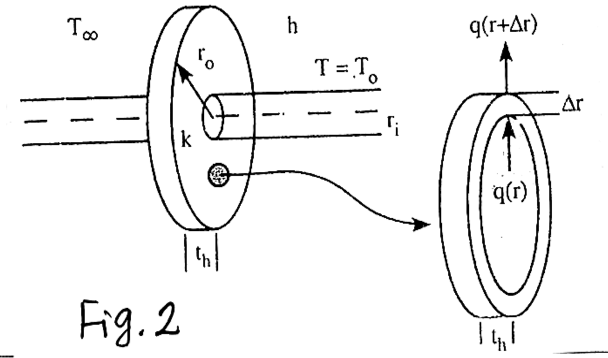
No. of Questions/CO	*CO2: Develop the governing conservation equations for steady state and transient momentum, heat and mass transport* *Answer either 3a or 3b*	Marks
3.(a)	A flat plate is immersed in an infinite pool of incompressible Newtonian fluid. The plate and fluid were initially at rest. At time t=0, the plate is suddenly set into motion and it begins to move with a steady velocity V_o (refer to Fig. 1). It is desired to determine the velocity of the fluid for a short time after the initial starting motion of the plate but before bulk convection of fluid becomes important. Develop the governing conservation equations and state the initial and boundary conditions. (Do not solve)  Fig.1	(8)
3.(b)	Consider circumferential fin surrounding a tube (refer to Fig. 2). This type of fin is used in many heating and cooling applications. We are interested in the amount of heat removed per fin. Develop the governing conservation equation and state the boundary conditions in order to obtain the temperature profile along the circumferential fin. (Do not solve)  Fig.2	(8)

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No. of Questions/ CO	*CO3 Analytically solve and analyze a variety of steady state and transient momentum, heat and mass transport problems with appropriate assumptions and approximation* Answer either 4(a) or 4(b)	Marks
4 (a)	Wetted wall tower is often used in laboratory experiment for determination of mass transfer coefficient. Consider a vertical wetted wall tower (refer to Fig.3), which is being used for absorption of solute (chlorine) in a Newtonian incompressible liquid (water). Water (ρ=1000kg/m^3, μ=1 cP) is flowing as a thin film along the vertical inside (cylindrical) wall of the wetted wall tower of length H=12cm and diameter R=1.5cm. The average velocity of water is 20cm/s. (i) Derive the expression for steady state velocity profile of the falling film of water. (ii) Derive the expression for the average velocity of water. (iii)Calculate the value of δ	(6+3+3)

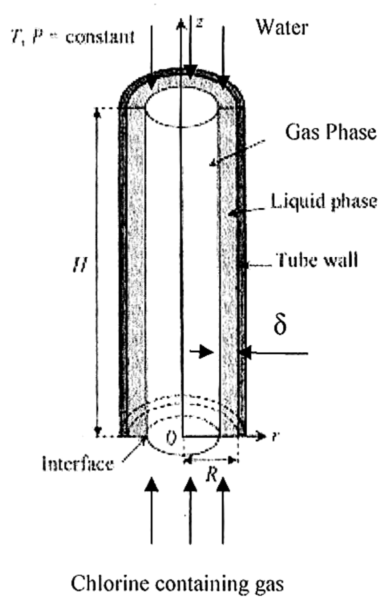

Fig. 3

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PART - I

No. of Questions/ CO	*CO3 Analytically solve and analyze a variety of steady state and transient momentum, heat and mass transport problems with appropriate assumptions and approximation*	Marks
4 (b)	Consider the wetted wall tower shown in Fig. 3. A thin film of thickness δ of a Newtonian liquid B (water) flows along (z) a vertical wall while in contact with a gas mixture containing the solute A (chlorine). The solute A diffuses and absorbed in to the liquid B. The length of contact between the two phases is relatively short during normal operation. The concentration of the solute at the liquid gas interface is constant (C_{As}) at the value of solubility of A. (i) Derive the governing equation of transport of solute neglecting the curvature effect (δ<<R, the cylindrical wall may be assumed to be a rectangular wall of width ~2πR, R is the inner radius of the tower). (ii) Considering that solute A penetrates only a short distance in to the liquid film (before it is carried by the flow) due to slow rate of diffusion or a short time of exposure, derive the solute (A) concentration profile under steady state. (iii)Derive the expression for the total rate of mass transferred from gas phase to the liquid film.	(4+4+4)

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No. of Questions/ CO	*CO4 Analyze and solve a practical real life problem applying momentum, heat and mass transport equations and appropriate solution technique* *Answer either 5(a) or 5(b)*	Marks
5(a)	Consider a bio-film that is associated with a skin infection. Bio-films, which are colonies of bacteria that can cling to living and inert surfaces, can cause wide array of human infections. Infections caused by bacteria living within bio-films are often chronic, because antibiotics that are applied to the surface of the bio-films have difficulty penetrating through the film thickness. An antibiotic (species A) is applied at the top layer of a bio-film (species B) so that a fixed concentration of medication $C_{Ao}=4\times10^{-3}$ kmol/m^3 exists at the upper surface of the bio-film. The diffusion coefficient of the antibiotic within the biofilm, $D_{AB}=2\times10^{-12}$ m^2/s. The antibiotic is consumed by biochemical reactions within the film and the consumption rate depends on the local concentration of A: $R_A= k_1\ C_A$; $k_1 =0.1\ s^{-1}$. To eradicate the bacteria the antibiotic must be consumed at least at the rate of (R_A=) 0.2×10^{-4} kmolm^{-3}s^{-1}, since at smaller absolute consumption rates, the bacteria will be able to grow back faster than it is destroyed. What is the maximum thickness of the biofilm that can be successfully treated by the antibiotic mentioned above? Show the necessary derivation.	(12)
5(b)	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 15 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 60°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)

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No. of Questions/CO		
	Navier Stokes equation is given below $\rho\left[\frac{\partial\vec{V}}{\partial t}+\vec{V}\cdot\nabla\vec{V}\right]=-\nabla p+\mu\nabla^2\vec{V}+\rho\vec{g}$ Continuity and components of Navier Stokes equations for cylindrical coordinate are given below $\frac{1}{r}\frac{\partial(rv_r)}{\partial r}+\frac{1}{r}\frac{\partial v_\theta}{\partial\theta}+\frac{\partial v_z}{\partial z}=0$ $\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial\theta}-\frac{v_\theta{}^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r}$ $+\mu\left[\frac{\partial}{\partial r}(\frac{1}{r}\frac{\partial(rv_r)}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial\theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial\theta}+\frac{\partial^2 v_r}{\partial z^2}\right]+\rho g_r$ $\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial\theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial\theta}$ $+\mu\left[\frac{\partial}{\partial r}(\frac{1}{r}\frac{\partial(rv_\theta)}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial\theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial\theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]+\rho g_\theta$ $\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial\theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}$ $+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial v_z}{\partial r})+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial\theta^2}++\frac{\partial^2 v_z}{\partial z^2}\right]+\rho g_z$	

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	0.014987	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

B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER - 2019

INTRODUCTION TO TRANSPORT PHENOMENA

Part II

Answer any five questions, taking at least one (1) from each of the COs
All the questions carry equal marks.

CO1. *Identify the transport properties and describe the different mechanisms of momentum, energy and mass transport*

1.
   a. Explain 'kinematic viscosity' in the light of diffusive transport of momentum.
   b. Write down the continuity equation in cylindrical coordinate system.
   c. Is the 'No-Slip' condition at the Solid-Liquid boundary a hypothetical concept?
   d. Explain two Liquid-Liquid boundary conditions. Are they valid for all types of fluids?

(2.5 x 4 =10)

2.
   a. Explain 'Lumped Capacitance' in the light of unsteady-state conduction of heat.
   b. Define efficiency of a fin.
   c. Explain 'thermal diffusivity' in the light of diffusive transport of heat.
   d. What is the physical significance of Lewis number in heat transfer in a flowing fluid.

(2.5 x 4 =10)

3.
   a. Define molar average velocity.
   b. Consider the adsorption of a species A from a gas stream to a liquid solution. The partial pressure of A in the bulk gas phase is p_{Att}, and the concentration of the A in the bulk liquid phase is c_{AL}. Draw and explain the typical concentration profiles for $H=1.0$ and $H<1.0$, where H is the Henry's law constant. Assuming a suitable driving force, model the adsorption of A from the gas phase considering a two-step process. Explain the two steps qualitatively.
   c. Explain diffusion controlled chemical reaction. **(2+6+2)**

CO2. *Develop the governing conservation equations and boundary conditions for the steady state and transient momentum, heat and mass transport.*

4. Consider a hot body of an arbitrary shape, with a surface area A_s and an initial temperature T_0 at time $t=0$, placed in an infinite pool of fluid of temperature T_∞ and convective heat transfer coefficient h. Considering a lumped capacitance system, derive an equation for the total heat

transfer rate $Q(t)$ from time $t=0$ till time $t=t$ in terms of Biot number, Fourier number, h, A_s, T_0 and T_∞.

5. Consider a steady, laminar, two dimensional flow over a flat plate at zero angle of approach to the flow. If the local skin friction coefficient can be expressed as $C_f = \{(0.664)/\sqrt{(Re_x)}\}$, derive an expression for the average skin friction coefficient defined by: $\underline{C}_f = [(\tau_{av}) / \{(1/2)\rho V^2\}]$, where τ_{av} = the average shear stress.

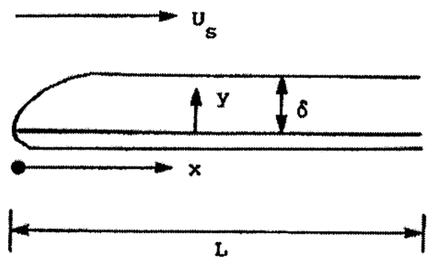
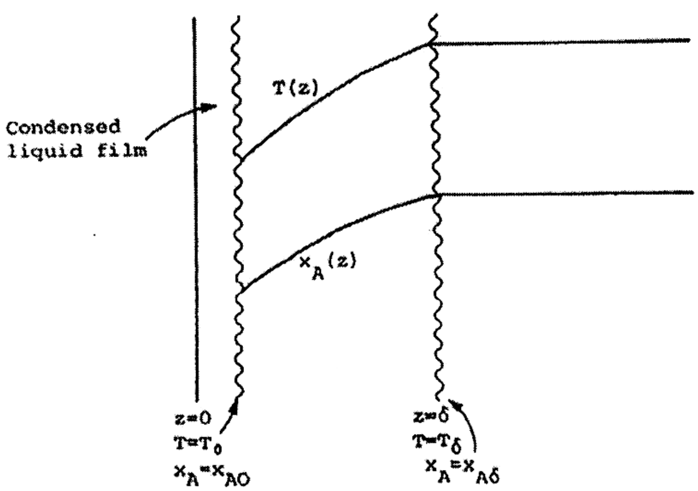


Fig. Hydrodynamic boundary layer development on a flat plate.

CO3. *Analytically solve and analyze a variety of steady state and transient momentum, heat and mass transport problems with appropriate assumptions and approximation.*

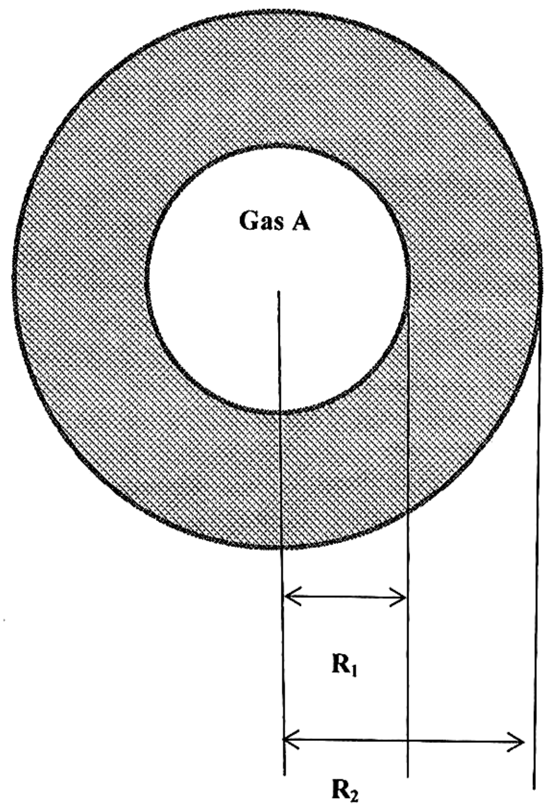
6. Consider a fluid with constant viscosity μ and density ρ, flowing between two fixed parallel plates. The velocity profile is given by $u = c\,(bz - z^2)$, where b is the distance between the plates and c is a constant. If the pressure at the point $(0, 0, 0)$ is p_0, show that the pressure distribution at any point in the flow region is given by $p(x, z) = p_0 - 2\mu cx - \rho gz$. Assume that $v = w = 0$. Down-stream flow is in the direction x and cross-flow is in the direction z.

7. A hot condensable vapor A diffuses through a stationary film of a non-condensable gas B towards a cold surface at $z = 0$ where it condenses. Develop the temperature profile for the gas A. Assume (i) The gas A behaves as an ideal gas and (ii) The pressure and physical properties of the mixture are constant.



CO4. *Analyze and solve a practical real life problem applying the momentum, heat and mass transport equations and appropriate solution techniques.*

8. A gas diffuses through the walls of a pyrex tube whose cross-section is shown in the figure. Derive a relation for the rate of diffusion of the gas through the tube as a function of the diffusivity of the gas in pyrex, its interfacial concentration in the pyrex and the dimensions of the tube.



9. Two infinite bodies of thermal conductivities k_1 and k_2, thermal diffusivities α_1 and α_2 are initially at temperatures T_1 and T_2 respectively. Each body has single plane surface and these surfaces are placed in contact with each other. Show that the condition under which the contact surface remains at constant temperature T_S where $T_1 > T_S > T_2$ is given by the following expression:

$$T_S = \frac{(k_1 T_1/\sqrt{\alpha_1}) + (k_2 T_2/\sqrt{\alpha_2})}{(k_1/\sqrt{\alpha_1}) + (k_2/\sqrt{\alpha_2})}$$

CO5. *Non-dimensionalize the transport equations, identify the dimensionless numbers and to apply analogies between momentum, heat and mass transport to scale up.*

10.

a. What do you mean by Normalization and Non-dimensionalization.
b. Consider the unsteady-state flow of an incompressible Newtonian fluid with uniform-viscosity, *with* body forces. Non-dimensionalize the governing equations for momentum balance in such a way that the non-dimensional form contains all of the following dimensionless numbers: *Strouhal Number, Euler Number, Reynolds Number and Froude Number.*

11.

a. Compare diffusive transport of momentum and heat transport analogically.
b. Starting with Reynolds analogy, develop an equation demonstrating Chilton-Colburn analogy expressing the relation between fluid friction and heat transfer for laminar flow on a flat plate in terms of Stanton number, Prandtl number and friction coefficient.

Continuity Equation

Cylindrical

$$\frac{\partial \rho}{\partial t} + \left\{\frac{1}{r}\frac{\partial}{\partial r}(r\rho V_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho V_\theta) + \frac{\partial(\rho V_z)}{\partial z}\right\} = 0$$

Navier Stokes Equations

Cartesian

$$x: \quad \rho\left\{\frac{\partial V_x}{\partial t} + V_x\frac{\partial V_x}{\partial x} + V_y\frac{\partial V_x}{\partial y} + V_z\frac{\partial V_x}{\partial z}\right\} = \rho g_x - \frac{\partial p}{\partial x} + \mu\left\{\frac{\partial^2 V_x}{\partial x^2} + \frac{\partial^2 V_x}{\partial y^2} + \frac{\partial^2 V_x}{\partial z^2}\right\}$$

$$y: \quad \rho\left\{\frac{\partial V_y}{\partial t} + V_x\frac{\partial V_y}{\partial x} + V_y\frac{\partial V_y}{\partial y} + V_z\frac{\partial V_y}{\partial z}\right\} = \rho g_y - \frac{\partial p}{\partial y} + \mu\left\{\frac{\partial^2 V_y}{\partial x^2} + \frac{\partial^2 V_y}{\partial y^2} + \frac{\partial^2 V_y}{\partial z^2}\right\}$$

$$z: \quad \rho\left\{\frac{\partial V_z}{\partial t} + V_x\frac{\partial V_z}{\partial x} + V_y\frac{\partial V_z}{\partial y} + V_z\frac{\partial V_z}{\partial z}\right\} = \rho g_z - \frac{\partial p}{\partial z} + \mu\left\{\frac{\partial^2 V_z}{\partial x^2} + \frac{\partial^2 V_z}{\partial y^2} + \frac{\partial^2 V_z}{\partial z^2}\right\}$$

Mass Diffusion Equation

Cylindrical Coordinates

$$\frac{1}{r}\frac{\partial}{\partial r}\left(D_{AB} r\frac{\partial C_A}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \theta}\left(D_{AB}\frac{\partial C_A}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(D_{AB}\frac{\partial C_A}{\partial z}\right) + \dot{N_A} = \frac{\partial C_A}{\partial t}$$