TRANSPORT PHENOMENA
(CHEN 3104)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) The dimension of momentum diffusivity is
(a) LT^{-1} (b) L^2T^{-1} (c) L^2T^{-2} (d) LT^{-2}.

(ii) The expression for Schmidt number is
(a) $\rho D_{AB}/\mu$ (b) D_{AB}/μ (c) $\mu/\rho D_{AB}$ (d) μ/ρ.

(iii) Lewis number is the ratio of
(a) thermal diffusivity to mass diffusivity (b) momentum diffusivity to mass diffusivity
(c) thermal diffusivity to momentum diffusivity (d) mass diffusivity to thermal conductivity.

(iv) The analogue of Nusselt number in mass transport is
(a) Lewis number (b) Schmidt number
(c) Graetz number (d) Sherwood number.

(v) Navier Stokes equation is a balance equation for
(a) Mass (b) Momentum (c) Energy (d) Force.

(vi) Outside the boundary layer, what type of flow occurs?
(a) Steady (b) Uniform (c) Potential (d) Irrotational.

(vii) The Grashoff number for air flowing between parallel plates __________ when air is replaced by oil
(a) decreases (b) increases
(c) first increases then decreases (d) remains the same

(viii) Brinkmann number measures the ratio of
(a) heat generated due to viscous dissipation to that of conduction
(b) viscous forces to gravity forces
(c) convective heat transfer to conductive heat transfer
(d) none of above.

(ix) The relative importance of reaction rate to diffusion rate inside a porous catalyst is given by
(a) Hatta number (b) Damkohler number
(c) Thiele Modulus (d) None of the above.

(x) Stanton number for mass transfer is defined as
(a) Nu/(Re.Sc) (b) Sh/(Re.Pr) (c) Nu/(Re.Pr) (d) Sh/(Re.Sc).

Fill in the blanks with the correct word

(xi) The principal mechanism of momentum transfer in laminar boundary layers is _______ transport.

(xii) A Prandtl number of 0.8 implies that the thickness of the momentum boundary layer is __________ than the thermal boundary layer.

(xiii) Fick's 2nd law of diffusion describes ______ diffusion.

(xiv) For momentum transfer, the transport parameter which is obtained from analogy expressions is ______.

(xv) An empirical correlation for estimating the diffusivity of gases is ________.

Group - B

2. (a) What is the utility of non-dimensionalizing an equation? *[(CO1)(Analyse/IOCQ)]*
(b) Differentiate between diffusive and convective transport with examples. *[(CO1)(Analyse/IOCQ)]*
(c) Heat is flowing radially through a cylindrical pipe of radius 2 inch and length 3 m. The rate of heat flow is 3×10^3 J/s. Calculate the heat flux. *[(CO1,3)(Apply/IOCQ)]*

4 + 4 + 4 = 12

3. (a) Estimate the viscosity of the following gas mixture at 1 atm and 293 K from the given data on the pure components at the same pressure and temperature:

Species α	Mole fraction, x_α	Molecular weight, M_α	Viscosity, μ_α (g/cm · s)
1. CO_2	0.133	44.01	1462×10^{-7}
2. O_2	0.039	32.00	2031×10^{-7}
3. N_2	0.828	28.02	1754×10^{-7}

The following equations can be used:

$$\mu_{\text{mix}} = \sum_{\alpha=1}^{N} \frac{x_\alpha \mu_\alpha}{\sum_\beta x_\beta \Phi_{\alpha\beta}} \qquad \Phi_{\alpha\beta} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_\alpha}{M_\beta}\right)^{-1/2}\left[1 + \left(\frac{\mu_\alpha}{\mu_\beta}\right)^{1/2}\left(\frac{M_\beta}{M_\alpha}\right)^{1/4}\right]^2$$

[(CO1,2)(Evaluate/HOCQ)]

(b) The molecular theory of the viscosity of gases is better described by the Chapman-Enskog model than the rigid sphere model. Justify. *[(CO1.2)(Evaluate/HOCQ)]*

8 + 4 = 12

Group - C

4. (a) Solving problems by making shell momentum balances involves the use of several boundary conditions. What are the possible boundary conditions that may arise? *[(CO2)(Analyse/IOCQ)]*
(b) A Newtonian fluid is flowing in laminar flow through a slit formed by two parallel walls at a distance 2B apart, shown in Fig. 1. The width W of the walls is much larger than B. Obtain the expressions for the shear stress and velocity

distributions by performing a shell momentum balance. State all relevant assumptions. *[(CO2)(Apply/IOCQ)]*

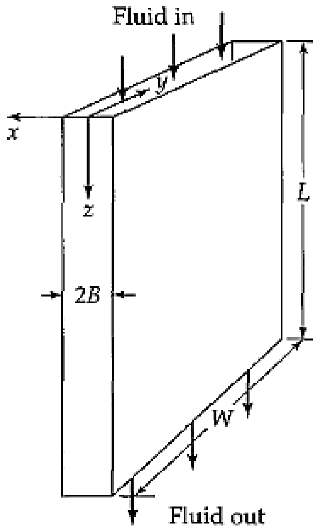

Fig. 1

4 + 8 = 12

5. (a) A fluid flows in the positive x direction through a long, flat duct of length L, width W and thickness B, where L>>W., as shown in Fig. 2. The duct has porous walls at y = 0 and y = B, so that a constant cross flow can be maintained with $v_y = v_0$ (constant everywhere). Show that the velocity profile of the system is given by:

$$v_x = \frac{(P_0 - P_L)B^2}{\mu L}\frac{1}{A}\left(\frac{y}{B} - \frac{e^{Ay/B} - 1}{e^A - 1}\right)$$

Where $A = Bv_0\rho/\mu$.

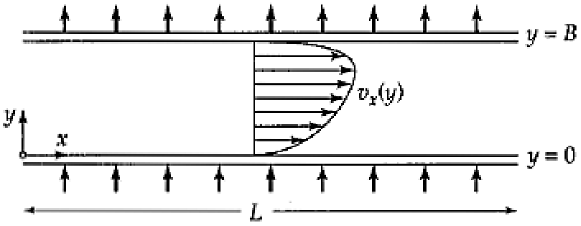

Fig. 2 *[(CO2)(Evaluate/HOCQ)]*

(b) Define creeping flow. *[(CO2)(Remember/LOCQ)]*

10 + 2 = 12

Group - D

6. (a) Write out the expression for the combined energy flux vector and explain each term. Write out the expression for the total molecular stress tensor explaining each term. *[(CO3)(Remember/LOCQ)]*

(b) An exothermic heterogeneous reaction is taking place in the central zone of a plug flow reactor with insulated walls. The central zone of the reactor is of length, *L* is filled with catalytic pellets. Gaseous reactants enter the reactor with superficial velocity, *V*. The heat generated due to reactions is S_c. The beginning and end of the reactor zone each of length, *L/2* is filled with inert particles. Considering that the direction of gas flow in the z direction, derive the differential equation relating temperature, *T* with distance, *z*. *[(CO3)(Remember/LOCQ)]*

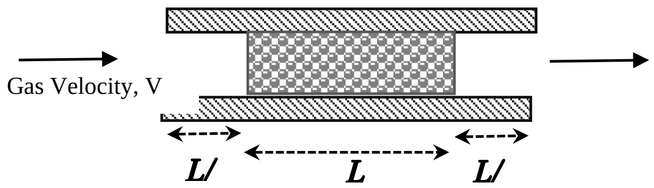

Fig. 3

(c) State the boundary conditions required to solve for *T vs. z* profile. Why would you want to make the equation in (b) dimensionless? Write out the expression for dimensionless temperature. *[(CO3)(Analyse/IOCQ)]*

4 + 4 + 4 = 12

7. A viscous fluid with physical properties (μ, κ, ρ, C_p) assumed constant is in laminar flow in a circular heated tube of radius *R*. For x < 0 the fluid temperature is uniform at the inlet temperature T_I. For x > 0 there is a constant radial heat flux $q_r = -q_0$ at the wall as shown in Fig. 4. Assume the velocity profile in x-direction is parabolic ($v_x = v_{max}\left[1 - \left(\frac{r}{R}\right)^2\right]$).

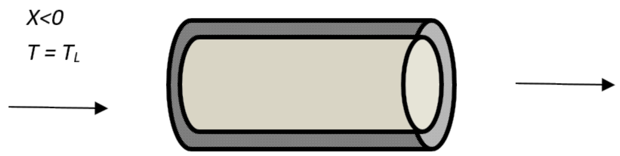

Fig. 4

(i) Derive the differential equation relating the combined flux vector, e_r and e_x in the radial and axial direction. *[(CO3)(Analyse/IOCQ)]*

(ii) With appropriate justification, state the full expression for the components, e_r and e_x. *[(CO3)(Remember/LOCQ)]*

(iii) State the assumptions and boundary condition used in the final analytical derivation of expression for *T(r,x)*. *[(CO3)(Apply/IOCQ)]*

(4 + 4 + 4) = 12

Group - E

8. (a) In a catalytic reactor, a heterogeneous reaction 2A→B is being carried out. Each catalyst particle is surrounded by a stagnant gas film through which A diffuses onto the catalyst surface. The reaction is instantaneous, and the product B diffuses back outwards through the film. The gas film is assumed to be isothermal, with a thickness δ. Derive an expression of the concentration profile of A in the film, assuming the concentration of A and B in the main stream outside the film to be X_{A0} and X_{B0}. *[(CO4)(Evaluate/HOCQ)]*

(b) What will be the change in the result if the reaction is slow? *[(CO4)(Evaluate/HOCQ)]*

6 + 6 = 12

9. (a) A flat plate consists of species A at concentration c_{A0}. A fluid B, in which A is slightly soluble, flows past the plate with approach velocity V_∞ the solubility of A in B is C_∞. A reacts with B via an nth order homogeneous reaction. Determine the ratio of the hydrodynamic boundary layer to concentration boundary layer thickness. *[(CO5)(Evaluate/HOCQ)]*

(b) What is the significance of the Damkohler number? *[(CO5)(Analyse/IOCQ)]*

10 + 2 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	12.5	41.67	45.8