TRANSPORT PHENOMENA
(CHE2205)

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) If 'u' is a vector and 's' is a scalar function then ∇.(su) is given by ___________.
(a) $s(\nabla.u)$ (b) $(\nabla s).u - s(\nabla.u)$
(c) $(\nabla s).u + s(\nabla.u)$ (d) $u.(\nabla s) + s(\nabla.u)$

(ii) In case with the non-dimensional differential mass balance equation the dimensionless number______________ appears along with Reynold's number
(a) Le (b) Sh
(c) Sc (d) Pr

(iii) The shear stress at a point in a liquid is found to be 0.03 N/m^2. The velocity gradient at the point is 0.15 s^{-1}. The value of viscosity is equal to ___________.
(a) 0.15 (b) 0.25
(c) 0.10 (d) 0.20

(iv) Two pipes of diameters d1 and d2 converge to form a pipe of diameter 2d. If the liquid flows with a velocity of u1 and u2 in the two pipes, the flow velocity within the third pipe is __________________.
(a) u1+u2 (b) u1+0.5u2
(c) u1+0.25u2 (d) 2(u1+u2)

(v) If the film thickness of flowing fluid over a flat plate is δ, then the velocity profile is given by _______________ for a Newtonian fluid.
(a) $u = u_{max}\left[1+\left(\frac{x}{\delta}\right)^2\right]$ (b) $u = u_{max}\left[1-\left(\frac{x}{\delta}\right)^2\right]$
(c) $u = u_{max}\left(\frac{x}{\delta}\right)^2$ (d) $u = u_{max}\Big/\left(\frac{x}{\delta}\right)^2$

(vi) 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

(vii) In free convection heat transfer, density is approximated to be a ________________ function of temperature
(a) parabolic (b) linear
(c) quadratic (d) none of these

(viii) Thiele modulus is a parameter saying about the relative influence of _____________ over pore diffusion within the porous catalyst.
(a) reaction rate (b) surface reaction rate
(c) volume reaction rate (d) bulk diffusion

(ix) Damkoher II number is valid __________________.
(a) within the mass transfer boundary layer (b) within the momentum boundary layer
(c) within the thermal boundary layer (d) both (a) and (b)

(x) Reynolds' Analogy is defined as _____________.
(a) St = f/2 (b) St = Re.Pr
(c) St .Pr = f/3 (d) Sc = Pr$^{0.33}$

Fill in the blanks with the correct word

(xi) If 'u' is a vector then ∇ × (∇× u) is given by ______________.

(xii) For falling film average velocity is ________________ at steady condition with fully developed boundary layer.

(xiii) The effectiveness of a heat exchanger fin (Biot number, N) is mathematically expressed as ___________.

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

(xv) For air-water system Lewis number is equal to ____________.

Group - B

2. (a) For steady state inviscid flow using control volume within the flow domain, show that the momentum balance equation in x-direction for a cartesian coordinate system is given by $u_x \nabla.(\rho U) = -\nabla p_x$, Where $U = u_x\hat{\imath} + u_y\hat{\jmath} + u_z\hat{k}$ and $p = p_x\hat{i} + p_y\hat{j} + p_z\hat{k}$.
[(CO2)(Analyse/HOCQ)]

(b) For an incompressible fluid, the velocity vector is given by $6xy\hat{\imath} + Cy^2\hat{\jmath} + 7yz\hat{k}$, where 'C' is a constant. Find out the value of 'C'.
[(CO2)(Apply/IOCQ)]

(c) "There is practically no difference between ∇.u and ∇×u, when 'u' is a scalar quantity." – Justify the appropriateness of the statement.
[(CO2)(Remember/LOCQ)]

6 + 3 + 3 = 12

3. (a) For $v_x = -\frac{1}{2}bx, v_y = -\frac{1}{2}by$ and $v_z = 0$ velocity distributions, draw a meaningful sketch showing the flow pattern. Then find all the components of τ and ρvv for the Newtonian fluid. The parameter b is a constant.
[(CO2)(Analyse/HOCQ)]

(b) Shear stress is given by $\tau_{ij} = -\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$. Explain, both the force and momentum flux directions are included in τij to calculate velocity gradient.
[(CO2)(Apply/IOCQ)]

(c) What is momentum transfer direction in case with the hindered settling during sedimentation of a particle? Show the answer through a proper schematic of the boundary layer.
[(CO2)(Remember/LOCQ)]

6 + 4 + 2 = 12

Group - C

4. (a) Derive continuity equation in Cartesian system for a compressible steady state Newtonian fluid.
[(CO2)(Apply/IOCQ)]

(b) A semi-infinite body of liquid (momentum diffusivity 'ν') with constant density and viscosity is bounded below by a horizontal surface (the xz-plane). Initially the fluid and the solid are at rest. Then at time t = 0,the solid surface is set in motion in the positive x direction with velocity u_0 (Fig. 1). There is no pressure gradient or gravity force in the 'x' direction, and the flow is presumed to be laminar. Show that $\frac{u_x(y,t)}{u_0} = 1 - \mathrm{erf}\left(\frac{y}{\sqrt{4\nu t}}\right)$

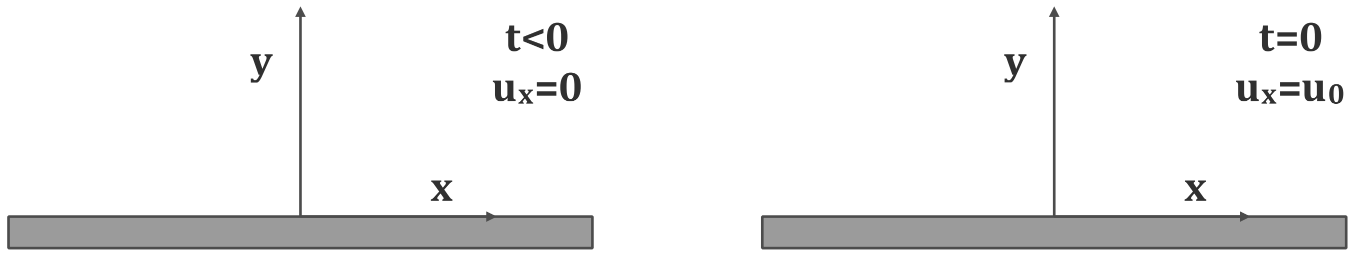

Fig. 1

[(CO2)(Analyse/HOCQ)]

4 + 8 = 12

5. (a) "No-slip assumption's validity during the formulation of any transport model for a fluid flow inside a conduit depends on the geometry of the conduit." – Justify the appropriateness of the statement.
[(CO2)(Apply/IOCQ)]

(b) A Newtonian fluid is in laminar flow in a narrow slit (Fig. 2) formed by two parallel walls a distance 2B apart. It is understood that B<<W, so that "edge effects" are unimportant. Make a differential momentum balance, and show that the velocity distribution is given by $v_z = \frac{(P_0 - P_L)}{2\mu L}B^2\left[1 - \left(\frac{x}{B}\right)^2\right]$

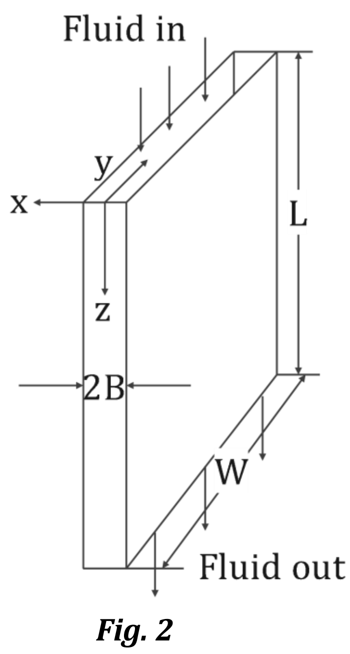

Fig. 2

[(CO2)(Analyse/LOCQ)]

3 + 9 = 12

Group - D

6. (a) For fluid flowing across a submerged object as shown in Fig. 3, where the x and y directions are as shown in figure, if the bulk velocity is V_b and the approach velocity is V_∞, the linear dimension of the body being, L and the boundary layer thickness is δ, what order of estimate assumptions are used in deriving the Prandtl boundary layer equation starting from the Navier-Stokes and the continuity equation.

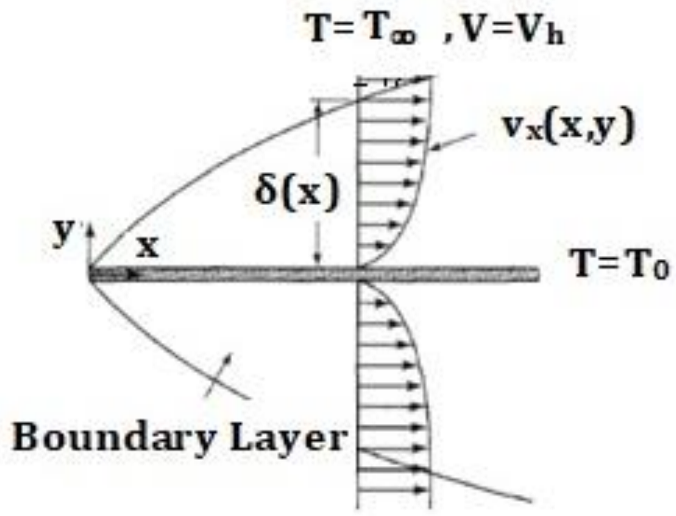

Fig. 3 [(CO3)(Remember/LOCQ)]

(b) In non-isothermal flow shown in **Fig. 3** [Q. 6 (a)], where the temperature of the solid is T_0 and that in the bulk is T_∞, derive the approximate boundary layer equations. [(CO3)(Remember/LOCQ)]

(c) Write out the mathematical expression for the convective energy flux vector. How is it physically different from the molecular work flux vector? [(CO3)(Apply/IOCQ)]

4 + 4 + 4 = 12

7. (a) 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 $V_x = V_{max}\left[1-\left(\frac{r}{R}\right)^2\right]$. Derive the differential equation relating the combined flux vector, e_r and e_x in the radial and axial direction.

x<0
T = T_L

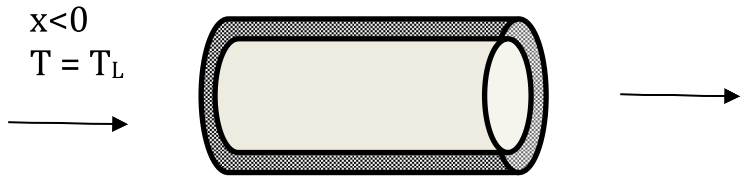

Fig. 4 [(CO3)(Analyse/HOCQ)]

(b) With appropriate justification, state the full expression for the components, $e_r$and e_x evaluated in [Q. 7 (a)]. [(CO3)(Remember/LOCQ)]

(c) State the assumptions and boundary condition used in the final analytical derivation of expression for T(r,x) in [Q. 7 (a)]. [(CO3)(Apply/IOCQ)]

4 + 4 + 4 = 12

Group - E

8. (a) Chlorine can be absorbed from Cl_2-air mixtures byolefins dissolved in CCl_4. It was found that the reaction of Cl_2, with cyclohexene (C_6H_{10})issecond order with respect to Cl_2, and zero order with respect to C_6H_{10}. Hence the rate of disappearance of Cl_2, per unit volume is $k_2^{'''}c_A^2$ (where A designates Cl_2).B is C_6H_{10}- CCl_4, mixture, assuming that the diffusioncan be treated as pseudobinary. Assume that the air is essentially insoluble in theC_6H_{10}- CCl_4, mixture. Let the liquid phase be sufficiently deep that L can be taken to be infinite.c_{A0} is the concentration of 'A' at the liquid surface. Show that $\frac{c_{A0}}{c_A} = \left[1 + z\sqrt{\frac{k_2^{'''}c_A^2}{6D_{AB}}}\right]^2$. [(CO4)(Analyse/HOCQ)]

(b) Discuss the concept of Reynolds analogy in fully developed turbulent flow with heat and mass transfer. State the significance of this analogy in transport phenomena. Explain the concept of Prandtl mixing length and state its importance in deriving this analogy. [(CO1)(Apply/IOCQ)]

6 + (3 + 1 + 2) = 12

9. (a) Consider porous catalyst particles in the shape of a disc (Fig. 5), such that the surface area of the edge of the disc is small in compare to that of the two circular faces. Show that the mass transfer at the surface z=±b is $|w_A| = 2\pi R^2 C_{As} D_A \lambda \tan(\lambda b)\,, where\ \lambda = \sqrt{\frac{k_1 a}{D_A}}$ (a is the specific surface area, k_1 is the reaction rate constant, D_A is the diffusivity of A and C_{As} is the surface concentration of A)

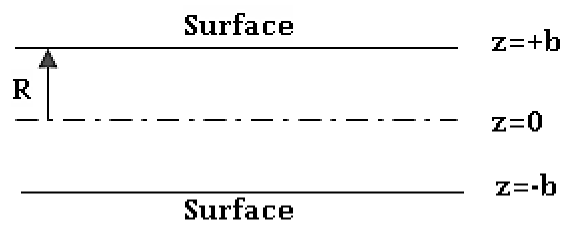

Fig. 5 [(CO4)(Analyse/HOCQ)]

(b) In case with component flux determination during mass transfer, why one requires to understand the advective mass transfer along with the molecular mass transfer? Explain mathematically. *[(CO4)(Apply/IOCQ)]*

8 + 4 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	27	33.3	39.7