TRANSPORT PHENOMENA
(CHEN 2202)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

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

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) If 'u' is a vector then $\nabla \times (\nabla \times u)$ is given by ________
(a) $\nabla \times (\nabla \cdot u) - \nabla^2 u$ (b) $\nabla \cdot (\nabla \times u) - \nabla^2 u$
(c) $\nabla \cdot (\nabla \cdot u) - \nabla^2 u$ (d) $\nabla \cdot (\nabla \cdot u) - \nabla u$.

(ii) The molecular stress at the core of a pipeline is given by ________, when the hydrodynamic boundary layer thickness is much lesser than the radius of the pipe.
(a) zero (b) normal stress (c) viscous stress (d) both (b) and (c)

(iii) Hagen-Poiseuille equation relates the mass flow rate of fluid with ________
(a) the pressure drop inside the pipeline (b) density of the fluid
(c) viscosity of the fluid (d) (a), (b) and (c).

(iv) For irrotational flow ________
(a) $\nabla \times u = 0$ (b) $\nabla \bullet u = 0$ (c) $\nabla \times (\nabla \bullet u) = 0$ (d) $\nabla \times (\nabla \times u) = 0$

(v) Example of Dirichlet boundary condition is ________
(a) Constant surface heat flux (b) Newton's law of cooling
(c) Constant surface temperature (d) Insulated surface.

(vi) Example of Neumann boundary condition is
(a) Constant surface temperature (b) Finite heat flux at the surface
(c) Newton's law of cooling (d) Both (a) and (b).

(vii) The dimensionless temperature profile during electrical heating of a wire with conduction-convection boundary condition is a function of ________
(a) Biot number (b) Nusselt number (c) Reynolds number (d) Prandtl number.

(viii) Schmidt number is given by ________ (symbols have their usual meaning).
(a) $\frac{\mu}{\rho D_{AB}}$ (b) $\frac{\dot{m}}{\rho L_c D_{AB}}$ (c) $\frac{\rho D_{AB}}{\mu}$ (d) $\frac{\rho L_c D_{AB}}{\dot{m}}$

(ix) The correlation between the momentum (δ) and mass boundary layer (δ_m) is given by ________.
(a) $\frac{\delta}{\delta_m} = Sc^{0.33}$ (b) $\frac{\delta}{\delta_m} = St_m^{0.33}$ (c) $\frac{\delta}{\delta_m} = (Re.Sc)^{0.33}$ (d) $\frac{\delta}{\delta_m} = (Re.St_m)^{0.33}$

(x) High value effectiveness factor during pore diffusion reaction modelindicates ________
(a) exothermic catalytic reaction (b) catalyst needs to be regenerated
(c) catalyst suits the reaction (d) endothermic catalytic reaction.

Group – B

2. (a) A symmetric stress tensor component is given by $\tau = \begin{bmatrix} 3 & 2 & -1 \\ 2 & 2 & 1 \\ -1 & 1 & 4 \end{bmatrix}$ and the velocity vector (v) is given by $v = 5\hat{i} + 3\hat{j} - 2\hat{k}$. Evaluate $v.[\tau.v]$. [(CO2)(Apply/IOCQ)]

(b) "$\nabla\times(\nabla.p)$ yields zero, when $\nabla.p$ represents a pressure gradient within a fluid flow domain" – Justify the appropriateness of the statement. [(CO2)(Understand/LOCQ)]

9 + 3 = 12

3. (a) "Euler equation is only valid with the inviscid flow." – Justify the statement in light of the Navier-Stokes' equation. [(CO2)(Evaluate/HOCQ)]

(b) 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. [(CO2)(Apply/IOCQ)]

Species	Mole fraction	Molecular weight	Viscosity (Pa.s)
CO_2	0.133	44	14.62×10^{-6}
O_2	0.039	32	20.31×10^{-6}
N_2	0.828	28	17.54×10^{-6}

5 + 7 = 12

Group - C

4. (a) In a falling cylinder viscometer of radius 'R' capped at both ends a concentric cylindrical slug of radius 'κR' and height 'H' is descending slowly within the cylinder filled with a fluid of viscosity 'μ' and density 'ρ_f' (Fig.1). Slug density is 'ρ_s' and falls with a terminal velocity 'u_0'. Show that the velocity profile can be given by $\frac{u}{u_0}=-\frac{(1-\xi^2)-(1+\kappa^2)\ln\left(1/\xi\right)}{(1-\kappa^2)-(1+\kappa^2)\ln\left(1/\kappa\right)};\xi=\frac{r}{R}$

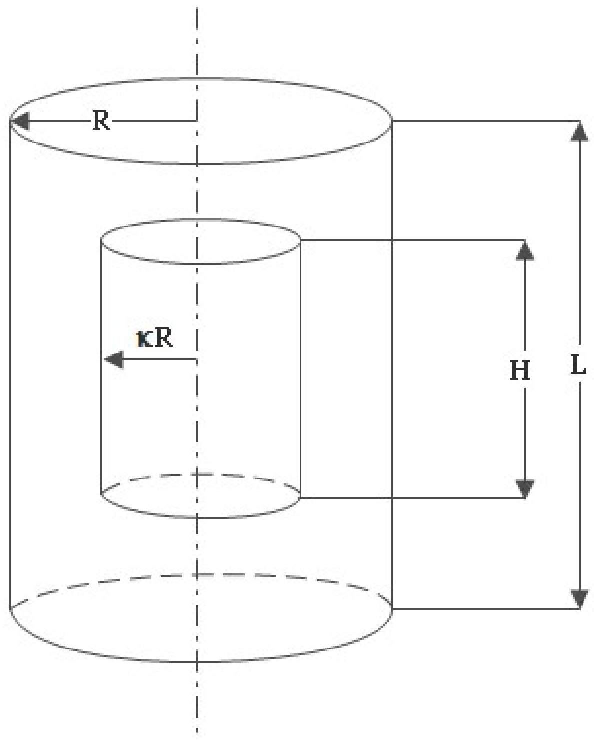

Fig.1

Given: [(CO2)(Create/HOCQ)]

$$\rho_f\left[\frac{\partial u_z}{\partial t}+u_r\frac{\partial u_z}{\partial r}+\frac{u_\theta}{r}\frac{\partial u_z}{\partial \theta}+u_z\frac{\partial u_z}{\partial z}\right]$$
$$=-\nabla p+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 u_z}{\partial \theta^2}+\frac{\partial^2 u_z}{\partial z^2}\right]+\rho_f g_z$$

(b) "Leaching is a process happens when the mass transfer direction is from solid to liquid. To have an effective leaching process from a solid surface for sparingly soluble component, the cross flow velocity of the solvent must ensure higher Peclect number." – Justify the appropriateness of the statement. [(CO2)(Create/HOCQ)]

8 + 4 = 12

5. (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. 2). There is no pressure gradient or gravity force in the 'x' direction, and the flow is presumed to be laminar. Show that

$$\frac{u_x(y,t)}{u_0} = 1 - \text{erf}\left(\frac{y}{\sqrt{4\nu t}}\right)$$

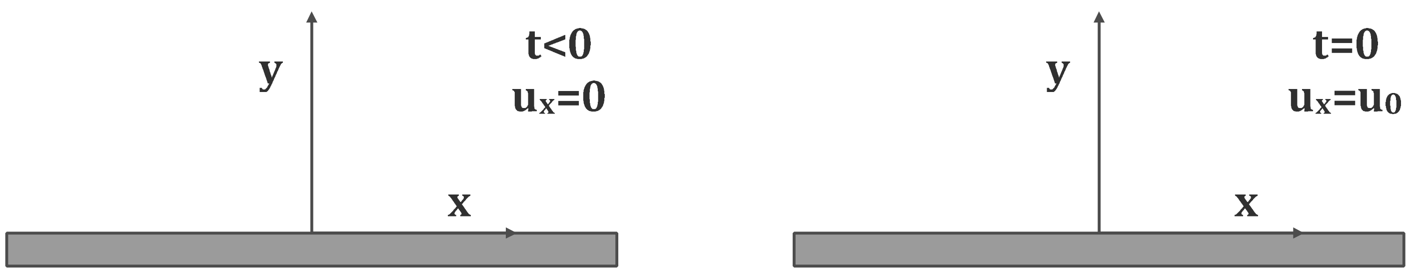

Fig.2

[(CO2)(Create/HOCQ)]
4 + 8 = 12

Group - D

6. (a) Consider an incompressible fluid flowing in the annular space between two coaxial cylinders where the outer cylinder is rotating. "For values of Brinkman number greater than 2, the maximum temperature due to viscous heating is attained in some intermediate point between the two cylinders".
   (i) Justify the above claim by deriving the temperature profile due to viscous dissipation during flow of an incompressible fluid in the space between the two cylinders.
   (ii) State the necessary assumptions.
   (iii) Sketch the velocity profile and the temperature profile in the annular space for different values of Brinkman number.
   (iv) State some applications where viscous heating is significant. [(CO4)(Analyze/HOCQ)]

   (b) For heat transfer through a plane composite wall made of three different material, when the wall is in contact with a hot fluid at one end and cold fluid at the other end,
   (i) Derive the expression for heat flux, temperature distribution and the overall heat transfer coefficient
   (ii) State the necessary boundary conditions and sketch the temperature profile.

[(CO4)(Evaluate/IOCQ)]
(4 + 2 + 1 + 1) + 4 = 12

7. (a) For free convection laminar flow of a fluid between two vertical plates maintained at two different temperatures,
   (i) obtain the expression for the velocity distribution as a function of Grashof number and the distance between the plates
   (ii) derive the expression for temperature distribution between the plates
   (iii) sketch the velocity and temperature profiles. [(CO4)(Evaluate/HOCQ)]

   (b) Using the von Karman method, show that the ratio of thermal to momentum boundary layer thickness is a $Pr^{-1/3}$. [(CO6)(Understand/LOCQ)]

(4 + 1 + 2) + 5 = 12

Group - E

8. (a) In case with the mass transport explain the utility of representing average velocity on the basis of both mass and moles. [(CO3)(Analyse/IOCQ)]

   (b) "For a catalytic reaction if Damkohler number II is much higher, the steady state mass transfer can be approximated near the surface of the catalyst." – Justify the appropriateness of the statement.

[(CO3)(Analyse/IOCQ)]

   (c) "Mass transfer of a volatile liquid placed within the capillary tube through a stagnant fluid is an example of quasi-steady state approximation." – Explain. [(CO3)(Analyse/IOCQ)]

4 + 4 + 4 = 12

9. (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}) is second 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 diffusion can be treated as pseudobinary. Assume that the air is

essentially insoluble in the C_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 $\frac{c_{A0}}{c_A} = \left[1 + z\sqrt{\frac{k_2''' c_A^2}{6D_{AB}}}\right]^2$

[(CO3)(Create/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. [(CO5)(Analyze/IOCQ)

6 + (3 + 1 + 2) = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	8.33	43.75	47.92

Course Outcome (CO):

After the completion of the course students will be able to

1. The students will be able to identify the inherent analogy between different property transport processes.
2. The students will be able to describe the concept of momentum transport for different flow geometry.
3. The students will be able to describe the concept of mass transport for different flow geometry.
4. The students will be able to describe the concept of energy transport for different flow geometry.
5. The students will be able to solve the flow problems relating all three different transport processes.
6. The students will be able to describe the concept of boundary layer and analyze the flow problem based on the comparative survey on the boundary layer thickness.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question