7. (a) Compute the thermal conductivity of Air-chlorine mixture where chlorine has a mole fraction of 0.25. At 297 K and 1 atm pressure the following data is provided:

Substance	μ (Pa.s)	κ(W/(m.K))	C_p (J/kg.K)	M_w
Air	1.854×10^{-5}	2.614×10^{-2}	1001	29
Chlorine	1.351×10^{-5}	8.960×10^{-3}	479.8	35

(b) Estimate the rate of heat loss by free convection from a unit length of a long horizontal pipe, 6 cm. in outside diameter, if the outer surface temperature is 100°C and the surrounding air is at 1 atm and 23°C.

6 + 6= 12

Group - E

8. (a) A polymer solid is saturated with a salt solution such that the initial concentration of salt is constant and equal to 0.1 kmol/m³. The solid is in the shape of a cube, 10 cm on a side. The diffusion coefficient of salt in the polymer is equal to 2×10^{-10} m²/s. At zero time, four sides of the cube are washed with pure water of sufficient velocity such that the mass transfer coefficient may be assumed infinite. The two sides not in contact with water are kept dry; these sides are located at the planes z=0 and z=10. Find the time in hours for the concentration in the middle of the solid to drop to 10% of the original concentration.

(b) What is the purpose of calculating mass transfer average velocity in two different ways – one is the mass average velocity and the other one is the molar average velocity?

9 + 3 = 12

9. (a) In the case of component flux determination during mass transfer, why does one require to understand the advective mass transfer along with the molecular mass transfer? Explain mathematically.

(b) A droplet of liquid A, of radius r_1 is suspended in a stream of gas B. We postulate that there is a spherical stagnant gas film of radius r_2 surrounding the droplet. The concentration of A in the gas phase is x_{A1} at r = r_1 and X_{A2} at the outer edge of the film, r = r_2. By a shell balance, show that for steady-state diffusion r^2N_{Ar} is a constant within the gas film, and setting the constant equal to $r_1^2N_{Ar1}$ at the droplet surface also show that the result leads to the following equation for x_A.

$$r_1^2N_{Ar1} = -\frac{cD_{AB}}{1-x_A}r^2\frac{dx_A}{dr}.$$

12

TRANSPORT PHENOMENA
(CHEN 4101)

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) The divergence theorem is
(a) converting volume integral to a surface integral
(b) converting volume integral to a line integral
(c) saying about the property change of a system normally outward across the control surface
(d) (a) and (c).

(ii) In order to find the Kronecker delta value, the identity matrix is given by

(a) $\begin{bmatrix}0&1&0\\0&1&0\\0&1&0\end{bmatrix}$ (b) $\begin{bmatrix}0&0&1\\0&1&0\\1&0&0\end{bmatrix}$ (c) $\begin{bmatrix}0&0&0\\1&1&1\\0&0&0\end{bmatrix}$ (d) $\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}$.

(iii) According to Chapman-Enskog theory, the diffusivity of gas molecules is proportional to ______________, where 'T' is the temperature of the gas.
(a) $T^{1.5}$ (b) T (c) $T^{0.5}$ (d) T^2.

(iv) $\vec{\nabla}\times\left(c\vec{U}\right)=$___________, where 'c' is the constant
(a) $c\vec{\nabla}\times\vec{U}$ (b) $c\vec{\nabla}\bullet\vec{U}$ (c) $c\times\left(\vec{\nabla}\times\vec{U}\right)$ (d) $c\times\left(\vec{\nabla}\bullet\vec{U}\right)$.

(v) Flow behavior index (n) of pseudoplastic fluid is
(a) 0 (b) <1 (c) >1 (d) infinity.

(vi) 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) $\frac{\delta}{\delta_m} = (Re.St_m)^{0.33}$.

(vii) For falling film average velocity is
(a) 2/3 of maximum velocity
(b) 3/4 of maximum velocity
(c) 1/2 of maximum velocity
(d) 3/5 of maximum velocity.

(viii) Creeping flow around a sphere is defined, when particle Reynold's no. is
(a) <2100 (b) <0.1
(c) 2 (d) 500.

(ix) The product of two tensors is
(a) called a 'dyad'
(b) same as one obtained from dot product of two vectors
(c) same as one obtained from cross product of two vectors
(d) equal to a "null vector".

(x) The term $[\boldsymbol{\pi}.\mathbf{v}]$ is the combined energy flux vector and it
(a) denotes molecular heat flux vector
(b) denotes molecular work flux vector
(c) denotes convective energy flux vector
(d) denotes work done due to energy change.

Group - B

2. (a) Using definition of divergence, show that div $\vec{A} = \nabla \bullet \vec{A}$, where A is a vector.

(b) Applying Reynold's transport theorem, derive x-component Navier-Stokes form for a flowing fluid of density ρ and viscosity μ, where the flow velocity vector is given as $\vec{v} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$.

5 + 7 = 12

3. Using Von-Karman integral method show that the local Sherwood number (Sh_x) for a flowing fluid over a flat plate can be given as $Sh_x=0.332Re^{0.5}Sc^{0.33}$.

12

Group - C

4. (a) In case of laminar flow of a falling film along a vertical flat surface, obtain an expression of average velocity and volumetric flowrate in terms of width of the plate, viscosity, density of the fluid and film thickness.

(b) Oil having a kinematic viscosity of 2.1×10^{-4} m²/s and a density of 0.8×10^{3} kg/m³ is flowing down a vertical wall. Find the mass rate of flow per unit width of the wall if the film thickness is 2.6 mm.

8 + 4 = 12

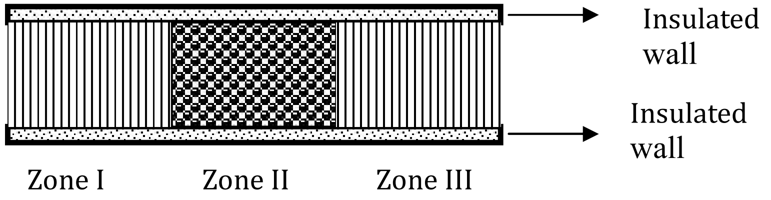
5. (a) An incompressible, viscous fluid (density ρ, viscosity μ) is flowing upward at steady state in the annular region between two vertical coaxial circular cylinders of radii κR and R. Obtain expression of shear stress distribution and velocity profile in the annulus if P_0 and P_L are the inlet and outlet pressure respectively.

(b) Also obtain expression of maximum velocity.

10 + 2 = 12

Group - D

6. (a)



The above figure shows a cylindrical packed bed reactor. Zone I is the preheater where S_H is constant heat source applied per unit volume. Zone II contains catalyst packing where the heterogeneous reaction occurs and exothermic heat generation p.u. volume, S_C is a function of the dimensionless temperature, $\Theta = (T - T_0)/(T_1 - T_0)$. T_1 is the temperature of inlet gas. Zone III is the exit length. Use the standard boundary conditions of temperature and and heat flux continuity. Evaluate an expression for Θ as a function of z along the length, L of the packing in the reactor.

(b) If Zone III (figure in Q. 6(a)) is also of length L and this section has a cooling jacket so that the product gas temperature decreased as a linear function of z, evaluate the expression for Θ in Zone III.

9 + 3 = 12