

## CH : CHEMICAL ENGINEERING

Duration : Three Hours

Maximum Marks :150

Read the following instructions carefully

1. This question paper contains **24** printed pages including pages for rough work. Please check all pages and report discrepancy, if any.
2. Write your registration number, your name and name of the examination centre at the specified locations on the right half of the ORS.
3. Using HB pencil, darken the appropriate bubble under each digit of your registration number and the letters corresponding to your paper code.
4. All the questions in this question paper are of objective type.
5. Questions must be answered on **Objective Response Sheet (ORS)** by darkening the appropriate bubble (marked A, B, C, D) using HB pencil against the question number on the left hand side of the ORS. **Each question has only one correct answer.** In case you wish to change an answer, erase the old answer completely. More than one answer bubbled against a question will be treated as a wrong answer.
6. Questions 1 through 20 are 1-mark questions and questions 21 through 85 are 2-mark questions.
7. Questions 71 through 73 is one set of common data questions, questions 74 and 75 is another pair of common data questions. The question pairs (76, 77), (78, 79), (80, 81), (82, 83) and (84, 85) are questions with linked answers. The answer to the second question of the above pairs will depend on the answer to the first question of the pair. If the first question in the linked pair is wrongly answered or is un-attempted, then the answer to the second question in the pair will not be evaluated.
8. Un-attempted questions will carry zero marks.
9. **NEGATIVE MARKING:** For Q.1 to Q.20, **0.25** mark will be deducted for each wrong answer. For Q.21 to Q.75, **0.5** mark will be deducted for each wrong answer. For the pairs of questions with linked answers, there will be negative marks only for wrong answer to the first question, i.e. for Q.76, Q.78, Q.80, Q.82 and Q.84, **0.5** mark will be deducted for each wrong answer. There is no negative marking for Q.77, Q.79, Q.81, Q.83 and Q.85.
10. Calculator **without data connectivity** is allowed in the examination hall.
11. Charts, graph sheets and tables are NOT allowed in the examination hall.
12. Rough work can be done on the question paper itself. Additional blank pages are given at the end of the question paper for rough work.

Q. 1 – Q. 20 carry one mark each.

Q.1 Which **ONE** of the following is **NOT** an integrating factor for the differential equation  $x dy - y dx = 0$ ?

- (A)  $\frac{1}{x^2}$                       (B)  $\frac{1}{y^2}$                       (C)  $\frac{1}{xy}$                       (D)  $\frac{1}{(x+y)}$

Q.2 Which **ONE** of the following is **NOT** a solution of the differential equation  $\frac{d^2 y}{dx^2} + y = 1$ ?

- (A)  $y = 1$                       (B)  $y = 1 + \cos x$                       (C)  $y = 1 + \sin x$                       (D)  $y = 2 + \sin x + \cos x$

Q.3 The limit of  $\frac{\sin x}{x}$  as  $x \rightarrow \infty$  is

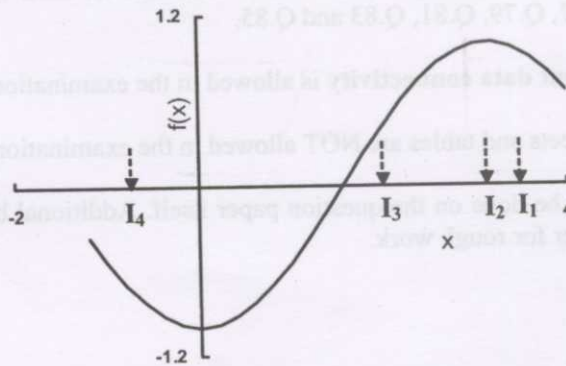
- (A) -1                      (B) 0                      (C) 1                      (D)  $\infty$

Q.4 The unit normal vector to the surface of the sphere  $x^2 + y^2 + z^2 = 1$  at the point

$\left(\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}}\right)$  is  $(\hat{i}, \hat{j}, \hat{k})$  are unit normal vectors in the cartesian coordinate system)

- (A)  $\frac{1}{\sqrt{2}}\hat{i} + \frac{1}{\sqrt{2}}\hat{j}$                       (B)  $\frac{1}{\sqrt{2}}\hat{i} + \frac{1}{\sqrt{2}}\hat{k}$                       (C)  $\frac{1}{\sqrt{2}}\hat{j} + \frac{1}{\sqrt{2}}\hat{k}$                       (D)  $\frac{1}{\sqrt{3}}\hat{i} + \frac{1}{\sqrt{3}}\hat{j} + \frac{1}{\sqrt{3}}\hat{k}$

Q.5 A nonlinear function  $f(x)$  is defined in the interval  $-1.2 < x < 4$  as illustrated in the figure below. The equation  $f(x) = 0$  is solved for  $x$  within this interval by using the Newton-Raphson iterative scheme. Among the initial guesses ( $I_1, I_2, I_3$  and  $I_4$ ), the guess that is likely to lead to the root most rapidly is



- (A)  $I_1$                       (B)  $I_2$                       (C)  $I_3$                       (D)  $I_4$

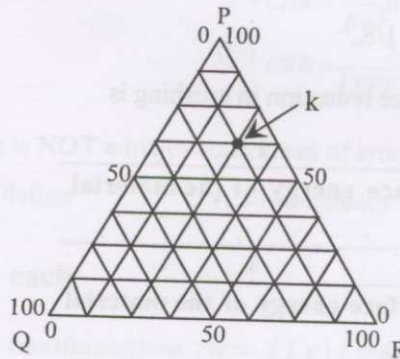


- Q.6 For a Carnot refrigerator operating between  $40^{\circ}\text{C}$  and  $25^{\circ}\text{C}$ , the coefficient of performance is  
 (A) 1 (B) 1.67 (C) 19.88 (D) 39.74

- Q.7 The work done by one mole of a van der Waals fluid undergoing reversible isothermal expansion from initial volume  $V_i$  to final volume  $V_f$  is

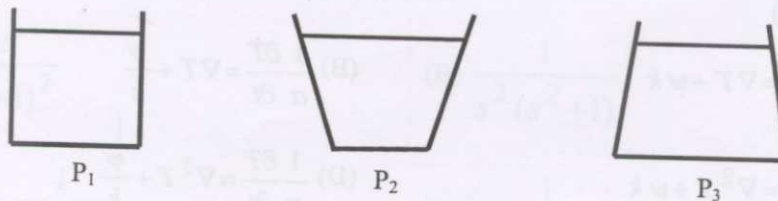
(A)  $RT \ln\left(\frac{V_f}{V_i}\right)$  (B)  $RT \ln\left(\frac{V_f - b}{V_i - b}\right)$   
 (C)  $RT \ln\left(\frac{V_f - b}{V_i - b}\right) - a\left(\frac{1}{V_f} - \frac{1}{V_i}\right)$  (D)  $RT \ln\left(\frac{V_f - b}{V_i - b}\right) + a\left(\frac{1}{V_f} - \frac{1}{V_i}\right)$

- Q.8 For a system containing species P, Q and R, composition at point k on the ternary plot is



- (A) 62.5% P, 12.5% Q, 25% R (B) 25% P, 62.5% Q, 12.5% R  
 (C) 12.5% P, 62.5% Q, 25% R (D) 12.5% P, 25% Q, 62.5% R

- Q.9 Three containers are filled with water up to the same height as shown. The pressures at the bottom of the containers are denoted as  $P_1$ ,  $P_2$  and  $P_3$ . Which ONE of the following relationships is true?



- (A)  $P_3 > P_1 > P_2$  (B)  $P_2 > P_1 > P_3$  (C)  $P_1 > P_2 = P_3$  (D)  $P_1 = P_2 = P_3$

- Q.10 Losses for flow through valves and fittings are expressed in terms of

- (A) drag coefficient (B) equivalent length of a straight pipe  
 (C) shape factor (D) roughness factor

Q.11 To determine the performance of a compressor, a standardized test is performed. In the testing process, when the compressor is under operation, "shut off" term signifies

- (A) maximum flow (B) zero flow  
(C) steady flow (D) intermittent flow

Q.12 Given a pipe of diameter  $D$ , the entrance length necessary to achieve fully developed laminar flow is proportional to ( $N_{Re}$  is Reynolds number)

- (A)  $DN_{Re}$  (B)  $\frac{D}{N_{Re}}$  (C)  $DN_{Re}^2$  (D)  $\frac{D}{N_{Re}^2}$

Q.13 For laminar flow conditions, the relationship between the pressure drop ( $\Delta P_c$ ) across an incompressible filter cake and the specific surface area ( $S_o$ ) of the particles being filtered is given by **ONE** of the following

- (A)  $\Delta P_c$  is proportional to  $S_o$   
(B)  $\Delta P_c$  is proportional to  $1/S_o$   
(C)  $\Delta P_c$  is proportional to  $S_o^2$   
(D)  $\Delta P_c$  is proportional to  $1/S_o^2$

Q.14 The power required for size reduction in crushing is

- (A) proportional to  $\frac{1}{\text{Surface energy of the material}}$   
(B) proportional to  $\sqrt{\frac{1}{\text{Surface energy of the material}}}$   
(C) proportional to **Surface energy of the material**  
(D) independent of the **Surface energy of the material**

Q.15 Transient three-dimensional heat conduction is governed by **ONE** of the following differential equations ( $\alpha$  - thermal diffusivity,  $k$  - thermal conductivity and  $\psi$  - volumetric rate of heat generation)

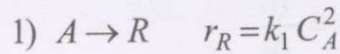
- (A)  $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla T + \psi k$  (B)  $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla T + \frac{\psi}{k}$   
(C)  $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla^2 T + \psi k$  (D)  $\frac{1}{\alpha} \frac{\partial T}{\partial t} = \nabla^2 T + \frac{\psi}{k}$

Q.16 In a countercurrent gas absorber, both the operating and equilibrium relations are linear. The inlet liquid composition and the exit gas composition are maintained constant. In order to increase the absorption factor

- (A) the liquid flow rate should decrease  
(B) the gas flow rate should increase  
(C) the slope of the equilibrium line should increase  
(D) the slope of the equilibrium line should decrease



Q.17 A species ( $A$ ) reacts on a solid catalyst to produce  $R$  and  $S$  as follows:



Assume film resistance to mass transfer is negligible. The ratio of instantaneous fractional yield of  $R$  in the presence of pore diffusion to that in the absence of pore diffusion is

- (A) 1                      (B)  $>1$                       (C)  $<1$                       (D) Zero

Q.18 For the case of single lump-sum capital expenditure of Rs. 10 crores which generates a constant annual cash flow of Rs. 2 crores in each subsequent year, the payback period (in years), if the scrap value of the capital outlay is zero is

- (A) 10                      (B) 20                      (C) 1                      (D) 5

Q.19 The relation between capital rate of return ratio (CRR), net present value (NPV) and maximum cumulative expenditure (MCE) is

(A)  $CRR = \frac{NPV}{MCE}$

(B)  $CRR = \frac{MCE}{NPV}$

(C)  $CRR = NPV \times MCE$

(D)  $CRR = \frac{MCE}{(NPV + MCE)}$

Q.20 Which **ONE** of the following is **NOT** a major constituent of crude oil?

- (A) Paraffins                      (B) Olefins                      (C) Naphthenes                      (D) Aromatics

**Q. 21 to Q.75 carry two marks each**

Q.21 Which **ONE** of the following transformations  $\{u = f(y)\}$  reduces

$$\frac{dy}{dx} + Ay^3 + By = 0 \text{ to a linear differential equation? (A and B are positive constants)}$$

- (A)  $u = y^{-3}$                       (B)  $u = y^{-2}$                       (C)  $u = y^{-1}$                       (D)  $u = y^2$

Q.22 The Laplace transform of the function  $f(t) = t \sin t$  is

(A)  $\frac{2s}{(s^2 + 1)^2}$

(B)  $\frac{1}{s^2 (s^2 + 1)}$

(C)  $\frac{1}{s^2} + \frac{1}{(s^2 + 1)}$

(D)  $\frac{1}{(s-1)^2 + 1}$

Q.23 The value of the surface integral  $\oiint_S (x \hat{i} + y \hat{j}) \cdot \hat{n} \, dA$  evaluated over the surface of a cube

having sides of length  $a$  is ( $\hat{n}$  is unit normal vector)

- (A) 0                      (B)  $a^3$                       (C)  $2a^3$                       (D)  $3a^3$

Q.24 The first four terms of the Taylor series expansion of  $\cos x$  about the point  $x = 0$  are

(A)  $1 + x + \frac{x^2}{2!} + \frac{x^3}{3!}$

(B)  $1 - x + \frac{x^2}{2!} - \frac{x^3}{3!}$

(C)  $1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!}$

(D)  $x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!}$

Q.25 If  $A = \begin{bmatrix} 1 & 2 \\ 2 & 1 \end{bmatrix}$ , then the eigenvalues of  $A^3$  are

(A) 5, 4

(B) 3, -1

(C) 9, -1

(D) 27, -1

Q.26 An analytic function  $w(z)$  is defined as  $w = u + iv$ , where  $i = \sqrt{-1}$  and  $z = x + iy$ . If the real part is given by  $u = \frac{y}{x^2 + y^2}$ ,  $w(z)$  is

(A)  $\frac{1}{z}$

(B)  $\frac{1}{z^2}$

(C)  $\frac{i}{z}$

(D)  $\frac{1}{iz}$

Q.27 The normal distribution is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right), \quad -\infty < x < \infty$$

The points of inflexion to the normal curve are

(A)  $x = -\sigma, +\sigma$

(B)  $x = \mu + \sigma, \mu - \sigma$

(C)  $x = \mu + 2\sigma, \mu - 2\sigma$

(D)  $x = \mu + 3\sigma, \mu - 3\sigma$

Q.28 Using Simpson's 1/3 rule and FOUR equally spaced intervals ( $n = 4$ ), estimate the value of the

integral  $\int_0^{\frac{\pi}{4}} \frac{\sin x}{\cos^3 x} dx$

(A) 0.3887

(B) 0.4384

(C) 0.5016

(D) 0.5527

Q.29 The following differential equation is to be solved numerically by the Euler's explicit method.

$$\frac{dy}{dx} = x^2 y - 1.2 y \quad \text{with } y(0) = 1$$

A step size of 0.1 is used. The solution for  $y$  at  $x = 0.1$  is

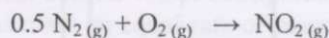
- (A) 0.880                      (B) 0.905                      (C) 1.000                      (D) 1.100

Q.30

The Poisson distribution is given by  $P(r) = \frac{m^r}{r!} \exp(-m)$ . The first moment about the origin for this distribution is

- (A) 0                      (B)  $m$                       (C)  $1/m$                       (D)  $m^2$

Q.31 Air (79 mole % nitrogen and 21 mole % oxygen) is passed over a catalyst at high temperature. Oxygen completely reacts with nitrogen as shown below



The molar ratio of NO to NO<sub>2</sub> in the product stream is 2:1. The fractional conversion of nitrogen is

- (A) 0.13                      (B) 0.20                      (C) 0.27                      (D) 0.40

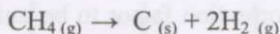
Q.32 A 35 wt% Na<sub>2</sub>SO<sub>4</sub> solution in water, initially at 50°C, is fed to a crystallizer at 20°C. The product stream contains hydrated crystals Na<sub>2</sub>SO<sub>4</sub>·10H<sub>2</sub>O in equilibrium with a 20 wt% Na<sub>2</sub>SO<sub>4</sub> solution. The molecular weights of Na<sub>2</sub>SO<sub>4</sub> and Na<sub>2</sub>SO<sub>4</sub>·10H<sub>2</sub>O are 142 and 322, respectively. The feed rate of the 35% solution required to produce 500 kg/hr of hydrated crystals is

- (A) 403 kg/hr                      (B) 603 kg/hr                      (C) 803 kg/hr                      (D) 1103 kg/hr

Q.33 600 kg/hr of saturated steam at 1 bar (enthalpy 2675.4 kJ/kg) is mixed adiabatically with superheated steam at 450°C and 1 bar (enthalpy 3382.4 kJ/kg). The product is superheated steam at 350°C and 1 bar (enthalpy 3175.6 kJ/kg). The flow rate of the product is

- (A) 711 kg/hr                      (B) 1111 kg/hr                      (C) 1451 kg/hr                      (D) 2051 kg/hr

Q.34 Carbon black is produced by decomposition of methane:



The single pass conversion of methane is 60%. If fresh feed is pure methane and 25% of the methane exiting the reactor is recycled, then the molar ratio of fresh feed stream to recycle stream is

- (A) 0.9                      (B) 9                      (C) 10                      (D) 90

Q.35 The molar volume ( $v$ ) of a binary mixture, of species 1 and 2 having mole fractions  $x_1$  and  $x_2$  respectively is given by

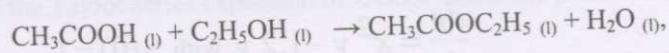
$$v = 220 x_1 + 180 x_2 + x_1 x_2 (90 x_1 + 50 x_2)$$

The partial molar volume of species 2 at  $x_2 = 0.3$  is

- (A) 183.06                      (B) 212.34                      (C) 229.54                      (D) 256.26



Q.36 The standard Gibbs free energy change and enthalpy change at 25°C for the liquid phase reaction



are given as  $\Delta G^\circ_{298} = -4650 \text{ J/mol}$  and  $\Delta H^\circ_{298} = -3640 \text{ J/mol}$ . If the solution is ideal and enthalpy change is assumed to be constant, the equilibrium constant at 95°C is

- (A) 0.65 (B) 4.94 (C) 6.54 (D) 8.65

Q.37 A cylindrical vessel with hemispherical ends is filled with water as shown in the figure. The head space is pressurized to a gauge pressure of  $40 \text{ kN/m}^2$ . The vertical force  $F$  (in kN) tending to lift the top dome and the absolute pressure  $P$  (in  $\text{kN/m}^2$ ) at the bottom of the vessel are ( $g = 9.8 \text{ m/s}^2$ , density of water =  $1000 \text{ kg/m}^3$ )

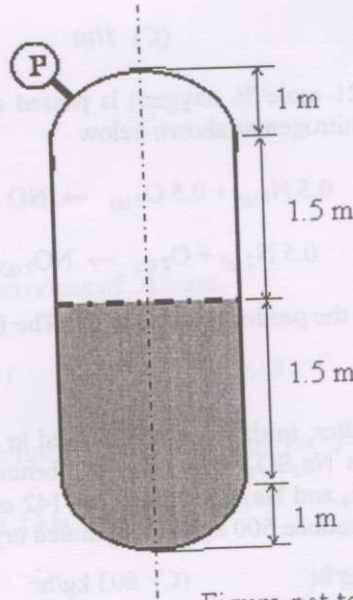


Figure not to scale

- (A)  $F = 83.6$  ;  $P = 64.5$  (B)  $F = 83.6$  ;  $P = 165.8$   
 (C)  $F = 125.7$  ;  $P = 64.5$  (D)  $F = 125.7$  ;  $P = 165.8$

Q.38 A pump draws oil (specific gravity 0.8) from a storage tank and discharges it to an overhead tank. The mechanical energy delivered by the pump to the fluid is  $50 \text{ J/kg}$ . The velocities at the suction and the discharge points of the pump are  $1 \text{ m/s}$  and  $7 \text{ m/s}$ , respectively. Neglecting friction losses and assuming kinetic energy correction factor to be unity, the pressure developed by the pump (in  $\text{kN/m}^2$ ) is

- (A) 19.2 (B) 20.8 (C) 40 (D) 80

Q.39 Match the following

**GROUP 1**

- (P) Euler number  
 (Q) Froude number  
 (R) Weber number

**GROUP 2**

- (1) Viscous force / Inertial force  
 (2) Pressure force / Inertial force  
 (3) Inertial force / Gravitational force  
 (4) Inertial force / Surface tension force

- (A) P-1, Q-2, R-3 (B) P-2, Q-3, R-4 (C) P-3, Q-2, R-1 (D) P-4, Q-3, R-2



Q.40

A steady flow field of an incompressible fluid is given by  $\vec{V} = (Ax + By)\hat{i} - Ay\hat{j}$ , where  $A = 1 \text{ s}^{-1}$ ,  $B = 1 \text{ s}^{-1}$ , and  $x, y$  are in meters. The magnitude of the acceleration (in  $\text{m/s}^2$ ) of a fluid particle at (1, 2) is

- (A) 1 (B)  $\sqrt{2}$  (C)  $\sqrt{5}$  (D)  $\sqrt{10}$

Q.41 Two identically sized spherical particles  $A$  and  $B$  having densities  $\rho_A$  and  $\rho_B$ , respectively, are settling in a fluid of density  $\rho$ . Assuming free settling under turbulent flow conditions, the ratio of the terminal settling velocity of particle  $A$  to that of particle  $B$  is given by

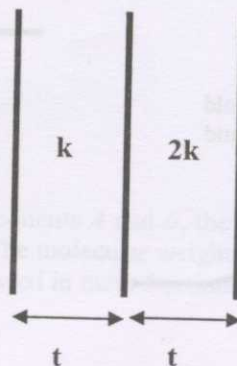
- (A)  $\sqrt{\frac{(\rho_A - \rho)}{(\rho_B - \rho)}}$  (B)  $\sqrt{\frac{(\rho_B - \rho)}{(\rho_A - \rho)}}$   
 (C)  $\frac{(\rho_A - \rho)}{(\rho_B - \rho)}$  (D)  $\frac{(\rho_B - \rho)}{(\rho_A - \rho)}$

Q.42 Consider the scale-up of a cylindrical baffled vessel configured to have the standard geometry (i.e. Height = Diameter). In order to maintain an equal rate of mass transfer under turbulent conditions for a Newtonian fluid, the ratio of the agitator speeds should be

(Given  $N_1, D_1$  are agitator speed and vessel diameter before scale-up;  $N_2, D_2$  are agitator speed and vessel diameter after scale-up)

- (A)  $\frac{N_1}{N_2} = \frac{D_1}{D_2}$  (B)  $\frac{N_1}{N_2} = \frac{D_2}{D_1}$   
 (C)  $\frac{N_1}{N_2} = \left(\frac{D_1}{D_2}\right)^{\frac{2}{3}}$  (D)  $\frac{N_1}{N_2} = \left(\frac{D_2}{D_1}\right)^{\frac{2}{3}}$

Q.43 Two plates of equal thickness ( $t$ ) and cross-sectional area, are joined together to form a composite as shown in the figure. If the thermal conductivities of the plates are  $k$  and  $2k$  then, the effective thermal conductivity of the composite is



- (A)  $3k/2$  (B)  $4k/3$  (C)  $3k/4$  (D)  $2k/3$

- Q.44 A metallic ball ( $\rho = 2700 \text{ kg/m}^3$  and  $C_p = 0.9 \text{ kJ/kg } ^\circ\text{C}$ ) of diameter 7.5 cm is allowed to cool in air at  $25^\circ\text{C}$ . When the temperature of the ball is  $125^\circ\text{C}$ , it is found to cool at the rate of  $4^\circ\text{C}$  per minute. If thermal gradients inside the ball are neglected, the heat transfer coefficient (in  $\text{W/m}^2 \text{ } ^\circ\text{C}$ ) is
- (A) 2.034 (B) 20.34 (C) 81.36 (D) 203.4

- Q.45 Hot liquid is flowing at a velocity of 2 m/s through a metallic pipe having an inner diameter of 3.5 cm and length 20 m. The temperature at the inlet of the pipe is  $90^\circ\text{C}$ . Following data is given for liquid at  $90^\circ\text{C}$

Density =  $950 \text{ kg/m}^3$ ;

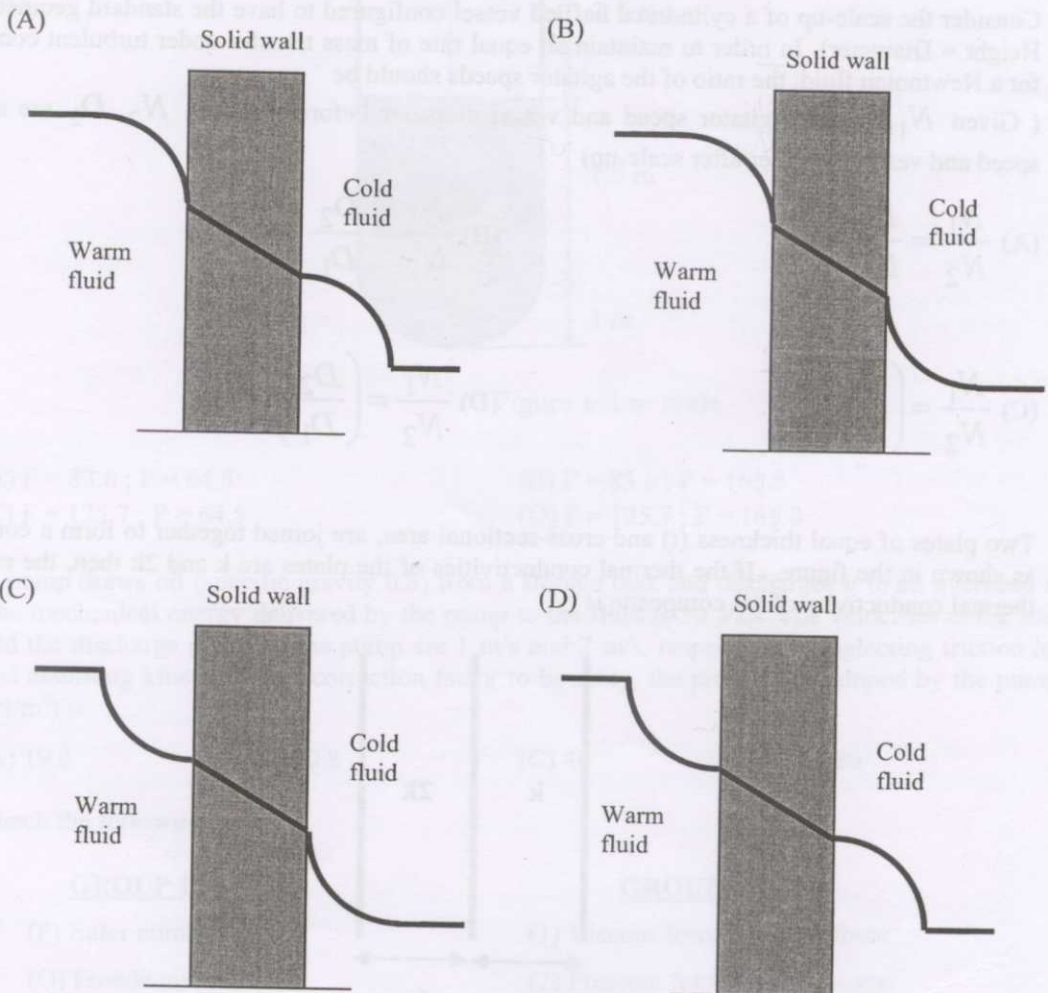
Specific heat =  $4.23 \text{ kJ/kg } ^\circ\text{C}$ ;

Viscosity =  $2.55 \times 10^{-4} \text{ kg/m.s}$ ;

Thermal conductivity =  $0.685 \text{ W/m } ^\circ\text{C}$

The heat transfer coefficient (in  $\text{W/m}^2 \text{ } ^\circ\text{C}$ ) inside the tube is

- (A) 222.22 (B) 111.11 (C) 22.22 (D) 11.11
- Q.46 The temperature profile for heat transfer from one fluid to another separated by a solid wall is



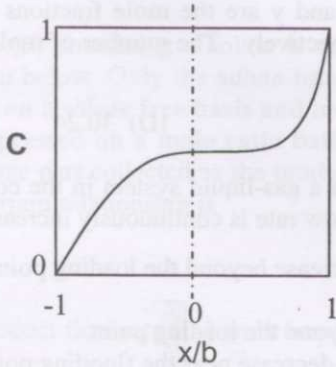


Q.47 A rectangular slab of thickness  $2b$  along the  $x$  axis and extending to infinity along the other directions is initially at concentration  $c_{AO}$ . At time  $t=0$ , both surfaces of the slab ( $x = \pm b$ ) have their concentrations increased to  $c_{AW}$  and maintained at that value. Solute A diffuses into the solid. The dimensionless concentration  $C$  is defined as

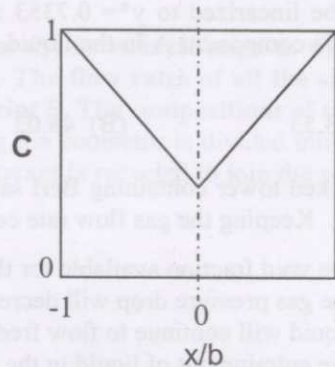
$$C = \frac{c_A - c_{AO}}{c_{AW} - c_{AO}}$$

The diffusivity of  $A$  inside the solid is assumed constant. At a certain time instant, which ONE of the following is the correct representation of the concentration profile?

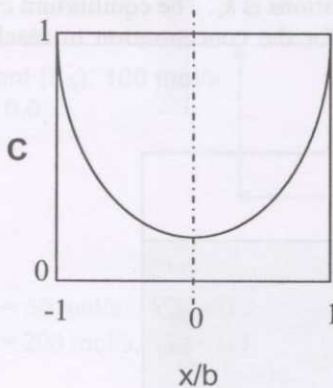
(A)



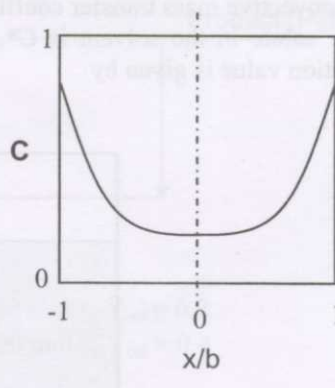
(B)



(C)



(D)



Q.48 In a binary mixture containing components  $A$  and  $B$ , the relative volatility of  $A$  with respect to  $B$  is 2.5 when mole fractions are used. The molecular weights of  $A$  and  $B$  are 78 and 92 respectively. If the compositions are however expressed in mass fractions the relative volatility will then be

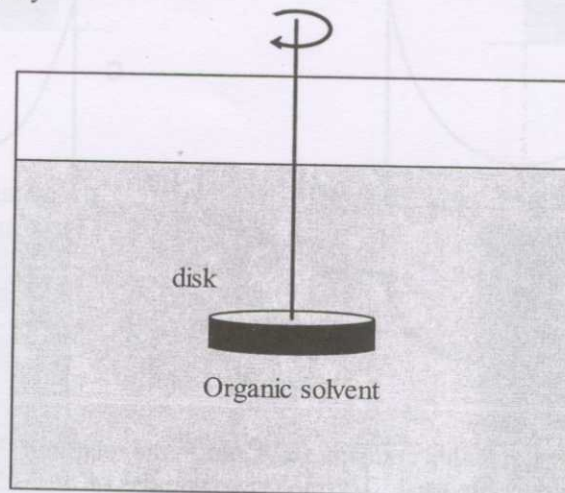
(A) 1.18

(B) 2.12

(C) 2.5

(D) 2.95

- Q.49 An ideal flash vaporization is carried out with a binary mixture at constant temperature and pressure. A process upset leads to an increase in the mole fraction of the heavy component in the feed. The flash vessel continues to operate at the previous temperature and pressure and still produces liquid and vapor. After steady state is re-established,
- (A) the amount of vapor produced will increase  
 (B) the amount of liquid produced will decrease  
 (C) the new equilibrium compositions of the vapor and liquid products will be different  
 (D) the new equilibrium compositions of the vapor and liquid products will remain as they were before the upset occurred
- Q.50 A batch distillation operation is carried out to separate a feed containing 100 moles of a binary mixture of A and B. The mole fraction of A in the feed is 0.7. The distillation progresses until the mole fraction of A in the residue decreases to 0.6. The equilibrium curve in this composition range may be linearized to  $y^* = 0.7353x + 0.3088$ . Here  $x$  and  $y$  are the mole fractions of the more volatile component A in the liquid and vapor phases respectively. The number of moles of residue is
- (A) 73.53                      (B) 48.02                      (C) 40                      (D) 30.24
- Q.51 A packed tower containing Berl saddles is operated with a gas-liquid system in the countercurrent mode. Keeping the gas flow rate constant, if the liquid flow rate is continuously increased,
- (A) the void fraction available for the gas to flow will decrease beyond the loading point  
 (B) the gas pressure drop will decrease  
 (C) liquid will continue to flow freely down the tower beyond the loading point  
 (D) the entrainment of liquid in the gas will considerably decrease near the flooding point
- Q.52 A sparingly soluble solute in the form of a circular disk is dissolved in an organic solvent as shown in the figure. The area available for mass transfer from the disk is  $A$  and the volume of the initially pure organic solvent is  $V$ . The disk is rotated along the horizontal plane at a fixed  $rpm$  to produce a uniform concentration of the dissolving solute in the liquid. The convective mass transfer coefficient under these conditions is  $k_c$ . The equilibrium concentration of the solute in the solvent is  $C^*$ . The time required for the concentration to reach 1% of the saturation value is given by



(A)  $\exp\left(-\frac{k_c A}{V} t\right) = 0.99$

(B)  $\exp\left(-\frac{k_c A}{V} t\right) = 0.01$

(C)  $\frac{V}{A k_c} \exp(-0.99) = t$

(D)  $\frac{V}{A k_c} \exp(0.01) = t$



- Q.53 Air concentrated with solute P is brought in contact with water. At steady state, the bulk concentrations of P in air and water are 0.3 and 0.02 respectively. The equilibrium equation relating the interface compositions is

$$y_{P,i} = 0.25 x_{P,i}$$

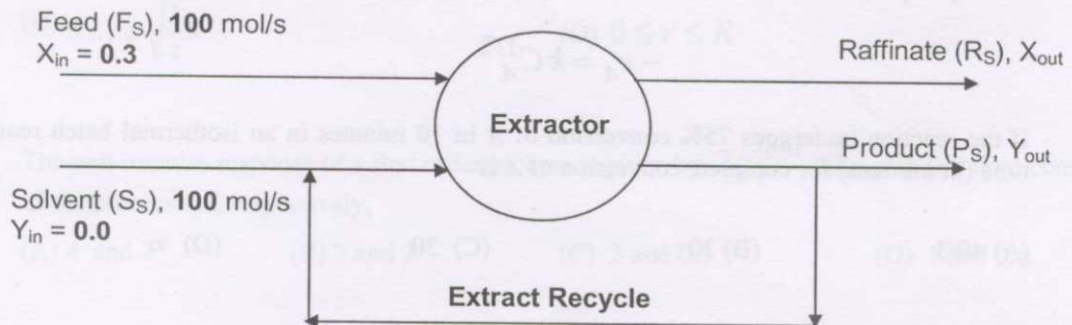
Assume that the mass transfer coefficients  $F_G$  and  $F_L$  are identical. The gas phase mole fraction of P at the interface ( $y_{P,i}$ ) is

- (A) 0.0663                      (B) 0.075                      (C) 0.16                      (D) 0.3

- Q.54 A feed (F) containing a solute is contacted with a solvent (S) in an ideal stage as shown in the diagram below. Only the solute transfers into the solvent. **The flow rates of all the streams are shown on a solute free basis and indicated by the subscript S. The compositions of the streams are expressed on a mole ratio basis.** The extract leaving the contactor is divided into two equal parts, one part collected as the product (P) and the other stream is recycled to join the solvent. The equilibrium relationship is

$$Y^* = 2X$$

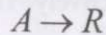
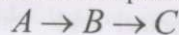
The product flow rate ( $P_S$ ) and composition ( $Y_{out}$ ) are



- (A)  $P_S = 50 \text{ mol/s}$ ,  $Y_{out} = 0.3$                       (B)  $P_S = 100 \text{ mol/s}$ ,  $Y_{out} = 0.2$   
 (C)  $P_S = 200 \text{ mol/s}$ ,  $Y_{out} = 0.1$                       (D)  $P_S = 100 \text{ mol/s}$ ,  $Y_{out} = 0.4$
- Q.55 The gas phase reaction  $A + 3 B \rightarrow 2 C$  is conducted in a PFR at constant temperature and pressure. The PFR achieves a conversion of 20% of A. The feed is a mixture of A, B and an inert I. It is found that the concentration of A remains the same throughout the reactor. Which **ONE** of the following ratios of inlet molar rates ( $F_{A,in}$ :  $F_{B,in}$ :  $F_{I,in}$ ) is consistent with this observation? Assume the reaction mixture is an ideal gas mixture.

- (A) 2 : 3 : 0  
 (B) 2 : 2 : 1  
 (C) 3 : 2 : 1  
 (D) 1 : 2 : 1

Q.56 The elementary liquid phase series-parallel reaction scheme



is to be carried out in an isothermal CSTR. The rate laws are given by

$$r_R = k' C_A$$

$$r_B = k C_A - k C_B$$

Feed is pure A. The space time of the CSTR which results in the maximum exit concentration of B is given by

(A)  $\frac{1}{\sqrt{k k'}}$

(B)  $\frac{1}{\sqrt{k'(k+k')}}$

(C)  $\frac{1}{(k+k')}$

(D)  $\frac{1}{\sqrt{k(k+k')}}$

Q.57 The liquid phase reaction  $A \rightarrow$  Products is governed by the kinetics

$$-r_A = k C_A^{1/2}$$

If the reaction undergoes 75% conversion of A in 10 minutes in an isothermal batch reactor, the time (in minutes) for complete conversion of A is

(A) 40/3

(B) 20

(C) 30

(D)  $\infty$

Q.58 The homogeneous reaction  $A + B \rightarrow C$  is conducted in an adiabatic CSTR at 800 K so as to achieve a 30% conversion of A. The relevant specific heats and enthalpy change of reaction are given by

$$C_{P,A} = 100 \text{ J/(mol K)}, C_{P,C} = 150 \text{ J/(mol K)}$$

$$C_{P,B} = 50 \text{ J/(mol K)}, \Delta h^{rxn} = -100 \text{ kJ/mol}$$

If the feed, a mixture of A and B, is available at 550 K, the mole fraction of A in the feed that is consistent with the above data is

(A) 5/7

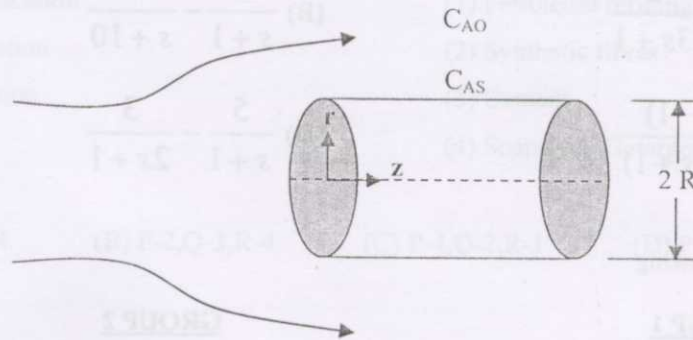
(B) 1/4

(C) 1/2

(D) 2/7



- Q.59 The irreversible zero order reaction  $A \rightarrow B$  takes place in a porous cylindrical catalyst that is sealed at both ends as shown in the figure. Assume dilute concentrations and neglect any variations in the axial direction.



The steady state concentration profile is

$$\frac{C_A}{C_{AS}} = 1 + \frac{\phi_0^2}{4} \left[ \left( \frac{r}{R} \right)^2 - 1 \right]$$

where  $\phi_0$  is the Thiele modulus. For  $\phi_0 = 4$ , the range of  $r$  where  $C_A = 0$  is

- (A)  $0 < r < \frac{R}{4}$  (B)  $0 < r < \frac{R}{2}$   
 (C)  $0 \leq r \leq \sqrt{\frac{3}{4}}R$  (D)  $0 \leq r \leq R$
- Q.60 The unit impulse response of a first order process is given by  $2e^{-0.5t}$ . The gain and time constant of the process are, respectively,
- (A) 4 and 2 (B) 2 and 2 (C) 2 and 0.5 (D) 1 and 0.5
- Q.61 A unit step input is given to a process that is represented by the transfer function  $\frac{(s+2)}{(s+5)}$ . The initial value ( $t = 0^+$ ) of the response of the process to the step input is

- (A) 0 (B) 2/5 (C) 1 (D)  $\infty$

- Q.62 A tank of volume  $0.25 \text{ m}^3$  and height 1 m has water flowing in at  $0.05 \text{ m}^3/\text{min}$ . The outlet flow rate is governed by the relation

$$F_{out} = 0.1h$$

where  $h$  is the height of the water in the tank in m and  $F_{out}$  is the outlet flow rate in  $\text{m}^3/\text{min}$ .

The inlet flow rate changes suddenly from its nominal value of  $0.05 \text{ m}^3/\text{min}$  to  $0.15 \text{ m}^3/\text{min}$  and remains there. The time (in minutes) at which the tank will begin to overflow is given by

- (A) 0.28 (B) 1.01 (C) 1.73 (D)  $\infty$

Q.63 Which ONE of the following transfer functions corresponds to an inverse response process with a positive gain?

(A)  $\frac{1}{2s+1} - \frac{2}{3s+1}$

(B)  $\frac{2}{s+1} - \frac{5}{s+10}$

(C)  $\frac{3(0.5s-1)}{(2s+1)(s+1)}$

(D)  $\frac{5}{s+1} - \frac{3}{2s+1}$

Q.64 Match the following

**GROUP 1**

(P) Temperature

(Q) Pressure

(R) Flow

**GROUP 2**

(1) Hot wire anemometry

(2) Strain Gauge

(3) Chromatographic analyzer

(4) Pyrometer

(A) P-1, Q-2, R-3

(B) P-4, Q-1, R-3

(C) P-1, Q-2, R-4

(D) P-4, Q-2, R-1

Q.65 Match the following

**GROUP 1**

(P) Ziegler Nichols

(Q) Under damped response

(R) Feed-forward Control

**GROUP 2**

(1) Process Reaction Curve

(2) Decay ratio

(3) Frequency Response

(4) Disturbance measurement

(A) P-3, Q-2, R-4

(B) P-1, Q-2, R-3

(C) P-3, Q-4, R-2

(D) P-1, Q-4, R-2

Q.66 A reactor has been installed at a cost of Rs. 50,000 and is expected to have a working life of 10 years with a scrap value of Rs. 10,000. The capitalized cost (in Rs.) of the reactor based on an annual compound interest rate of 5% is

(A) 1,13,600

(B) 42,000

(C) 52,500

(D) 10,500

Q.67 In a shell and tube heat exchanger, if the shell length is  $L_s$ , the baffle spacing is  $L_B$  and the thickness of baffle is  $t_b$ , the number of baffles on the shell side,  $N_B$ , is

(A)  $\frac{L_s}{L_B + t_b}$

(B)  $\frac{L_s}{L_B + t_b} - 1$

(C)  $\frac{L_s}{L_B + t_b} + 1$

(D)  $\frac{L_s}{L_B + t_b} + 2$



Q.68 Match the unit processes in **Group 1** with the industries in **Group 2**

**GROUP 1**

- (P) Saponification  
(Q) Calcination  
(R) Alkylation

**GROUP 2**

- (1) Petroleum refining  
(2) Synthetic fibres  
(3) Cement  
(4) Soaps and Detergents

- (A) P-1,Q-3,R-4      (B) P-2,Q-3,R-4      (C) P-4,Q-2,R-1      (D) P-4,Q-3,R-1

Q.69 Which **ONE** of the following process sequences is used in the production of synthesis gas?

- (A) Desulphurization → Steam reforming → Hot  $K_2CO_3$  cycle  
(B) Steam reforming → Desulphurization → Hot  $K_2CO_3$  cycle  
(C) Hot  $K_2CO_3$  cycle → Steam reforming → Desulphurization  
(D) Hot  $K_2CO_3$  cycle → Desulphurization → Steam reforming

Q.70 Which **ONE** of the following process sequences is used in the sugar industry?

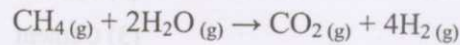
- (A)  $Ca_2HPO_4$ / Lime Treatment → Crystallization → Crushing  
(B)  $Ca_2HPO_4$ / Lime Treatment → Multiple stage evaporation → Crystallization  
(C) Crushing → Crystallization →  $Ca_2HPO_4$ / Lime Treatment  
(D) Multiple stage evaporation → Crystallization →  $Ca_2HPO_4$ / Lime Treatment



## Common Data Questions

## Common Data for Questions 71,72 and 73:

Methane and steam are fed to a reactor in molar ratio 1: 2. The following reactions take place,



where  $\text{CO}_2$  is the desired product,  $\text{CO}$  is the undesired product and  $\text{H}_2$  is a byproduct. The exit stream has the following composition

Species	$\text{CH}_4$	$\text{H}_2\text{O}$	$\text{CO}_2$	$\text{H}_2$	$\text{CO}$
Mole %	4.35	10.88	15.21	67.39	2.17

Q.71 The selectivity for desired product relative to undesired product is

- (A) 2.3                      (B) 3.5                      (C) 7                      (D) 8

Q.72 The fractional yield of  $\text{CO}_2$  is

(where fractional yield is defined as the ratio of moles of the desired product formed to the moles that would have been formed if there were no side reactions and the limiting reactant had reacted completely)

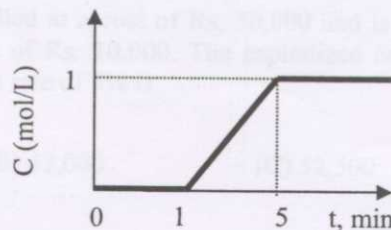
- (A) 0.7                      (B) 0.88                      (C) 1                      (D) 3.5

Q.73 The fractional conversion of methane is

- (A) 0.4                      (B) 0.5                      (C) 0.7                      (D) 0.8

## Common Data for Questions 74 and 75:

A liquid is flowing through a reactor at a constant flow rate. A step input of tracer at a molar flow rate of 1 mol/min is given to the reactor at time  $t = 0$ . The time variation of the concentration ( $C$ ) of the tracer at the exit of the reactor is as shown in the figure:



Q.74 The volumetric flow rate of the liquid through the reactor (in L/min) is

- (A) 1                      (B) 2                      (C) 1.5                      (D) 4

Q.75 The mean residence time of the fluid in the reactor (in minutes) is

- (A) 1                      (B) 2                      (C) 3                      (D) 4

**Linked Answer Questions: Q.76 to Q.85 carry two marks each**

**Statement for Linked Answer Questions 76 and 77:**

A binary mixture containing species 1 and 2 forms an azeotrope at 105.4°C and 1.013 bar. The liquid phase mole fraction of component 1 ( $x_1$ ) of this azeotrope is 0.62. At 105.4°C, the pure component vapor pressures for species 1 and 2 are 0.878 bar and 0.665 bar, respectively. Assume that the vapour phase is an ideal gas mixture. The van Laar constants,  $A$  and  $B$ , are given by the expressions:

$$A = \left[ 1 + \frac{x_2 \ln \gamma_2}{x_1 \ln \gamma_1} \right]^2 \ln \gamma_1, \quad B = \left[ 1 + \frac{x_1 \ln \gamma_1}{x_2 \ln \gamma_2} \right]^2 \ln \gamma_2$$

Q.76 The activity coefficients ( $\gamma_1, \gamma_2$ ) under these conditions are

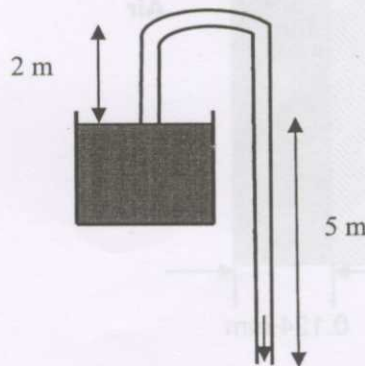
- (A) (0.88, 0.66)      (B) (1.15, 1.52),      (C) (1.52, 1.15)      (D) (1.52, 0.88)

Q.77 The van Laar constants ( $A, B$ ) are

- (A) (0.92, 0.87)      (B) (1.00, 1.21)      (C) (1.12, 1.00)      (D) (1.52, 1.15)

**Statement for Linked Answer Questions 78 and 79:**

A siphon tube having a diameter of 2 cm draws water from a large open reservoir and discharges into the open atmosphere as shown in the figure. Assume incompressible fluid and neglect frictional losses. ( $g = 9.8 \text{ m/s}^2$ )



Q.78 The velocity (in m/s) at the discharge point is

- (A) 9.9      (B) 11.7      (C) 98      (D) 136.9

Q.79 The volumetric flow rate (in L/s) of water at the discharge is

- (A) 3.11      (B) 3.67      (C) 30.77      (D) 42.99



**Statement for Linked Answer Questions 80 & 81:**

The liquid phase reaction  $A \rightarrow \text{Products}$  is to be carried out at constant temperature in a CSTR followed by a PFR in series. The overall conversion of  $A$  achieved by the reactor system (CSTR + PFR) is 95%. The CSTR has a volume of 75 liters. Pure  $A$  is fed to the CSTR at a concentration  $C_{A0} = 2 \text{ mol/liter}$  and a volumetric flow rate of 4 liters/min. The kinetics of the reaction is given by

$$-r_A = 0.1 C_A^2 \frac{\text{mol}}{\text{liter} \cdot \text{min}}$$

Q.80 The conversion achieved by the CSTR is

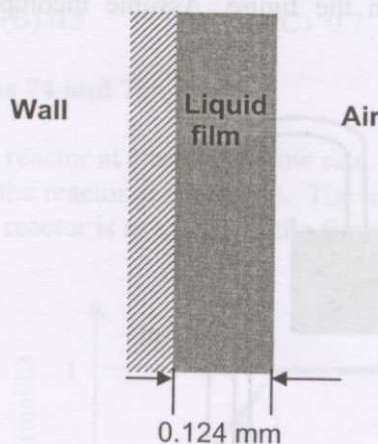
- (A) 40%                      (B) 50%                      (C) 60%                      (D) 80%

Q.81 The volume of the PFR required (in liters) is

- (A) 380                      (B) 350                      (C) 75                      (D) 35

**Statement for Linked Answer Questions 82 and 83:**

A thin liquid film flows at steady state along a vertical surface as shown in the figure. The average velocity of the liquid film is 0.05 m/s. The viscosity of the liquid is 1 cP and its density is  $1000 \text{ kg/m}^3$ . The initially pure liquid absorbs a sparingly soluble gas from air as it flows down. The length of the wall is 2 m and its width is 0.5 m. The solubility of the gas in the liquid is  $3.4 \times 10^{-2} \text{ kmol/m}^3$  and isothermal conditions may be assumed.



Q.82 If the exit average concentration in the liquid is measured to be  $1.4 \times 10^{-2} \text{ kmol/m}^3$ , the total mass transfer rate (in kmol/s) of the sparingly soluble gas into the liquid is

- (A)  $0.133 \times 10^{-4}$       (B)  $0.434 \times 10^{-7}$       (C)  $3.4 \times 10^{-2}$       (D)  $17 \times 10^{-2}$

Q.83 The mass transfer coefficient  $k_{c,avg}$  (in m/s), averaged along the length of the vertical surface is

- (A)  $2.94 \times 10^{-6}$       (B)  $2.27 \times 10^{-6}$       (C)  $1.94 \times 10^{-6}$       (D)  $1.65 \times 10^{-6}$

**Statement for Linked Answer Questions 84 and 85:**

The cross-over frequency associated with a feedback loop employing a proportional controller to control the process represented by the transfer function

$$G_p(s) = \frac{2e^{-s}}{(\tau s + 1)^2}, \text{ (units of time is minutes)}$$

is found to be 0.6 rad/min. Assume that the measurement and valve transfer functions are unity.

Q.84 The time constant,  $\tau$  (in minutes) is

- (A) 1.14                      (B) 1.92                      (C) 3.23                      (D) 5.39

Q.85 If the control loop is to operate at a gain margin of 2.0, the gain of the proportional controller must equal

- (A) 0.85                      (B) 2.87                      (C) 3.39                      (D) 11.50

**END OF THE QUESTION PAPER**