CHEMICAL ENGINEERING

SECTION - A

ONE MARKS QUESTIONS (1-25)

This question consists of TWENTY FIVE sub-questions (1 - 25) of ONE mark each. For each of these sub-questions, four possible answers (A, B, C and D) are given, out of which only one is correct. Answer each sub-question by darkening the appropriate bubble on the OBJECTIVE RESPONSE SHEET (ORS) using a soft MB pencil. Do not use the ORS for any rough work. You may like to use the Answer Book for any rough work, if needed.

(Marks: 1 × 25 = 25)

1. The value of the following determinant

$$\begin{vmatrix} 1 & 0 & 0 & 0 & 0 \\ -2 & 2 & 0 & 0 & 0 \\ 3 & 5 & 3 & 0 & 0 \\ -1 & 4 & 7 & 4 & 0 \\ -5 & -6 & 2 & 1 & 1 \end{vmatrix} \text{ is}$$

a. 24
b. 32
c. -112
d. 0

2. The value of $(1 + i)^8$, where $i = \sqrt{-1}$, is
a. 8 + 4i
b. 8 – 4i
c. 16
d. 8

3. A reasonably general expression for vapour-liquid phase equilibrium at low to moderate pressures is

$$\phi_i y_i P = \gamma_i x_i f_i^0$$

where ϕ_i is a vapour fugacity coefficient, γ_i is the liquid activity coefficient, and f_i^0 is the fugacity of pure component i. The K_i value ($y_i = K_i x_i$) is therefore, in general, a function of
a. temperature only
b. temperature and pressure only
c. temperature, pressure, and liquid composition x_i only
d. temperature, pressure, liquid composition x_i, and vapour composition y_i.

4. High pressure steam is expanded adiabatically and reversibly through a well insulated turbine which produces some shaft work. If the enthalpy change and entropy change across the turbine are represented by ΔH and ΔS, respectively, for this process:
a. ΔH = 0 and ΔS = 0
b. ΔH ≠ 0 and ΔS = 0
c. ΔH ≠ 0 and ΔS ≠ 0
d. ΔH = 0 and ΔS ≠ 0

5. For the case of a fuel gas undergoing combustion with air, if the air/fuel ratio is increased, the adiabatic flame temperature will
a. increase
b. decrease
c. increase or decrease depending on the fuel type
d. not change

6. The Power number for a stirred tank becomes constant at high Reynolds number. In this limit, the variation of power input with impeller rotational speed (N) is proportional to
a. N_0
b. N^1
c. N^2
d. N^3

7. The operation of a Rota meter is based on
a. variable flow area
b. rotation of a turbine
c. pressure drop across a nozzle
d. pressure at a stagnation point

8. Applying a pressure drop across capillary results in a volumetric flow rate Q under laminar flow conditions. The flow rate, for

the same pressure drop, in a capillary of the same length but half the radius is

a. Q/2
b. Q/4
c. Q/8
d. Q/16

9. The heat transfer by radiation from a mild steel surface is to be reduced by reducing the emissivity of the surface. This can be best achieved by

a. painting the surface black
b. painting the surface white
c. giving the surface a mirror finish
d. roughening the surface

10. Heat transfer by natural convection is enhanced in systems with

a. high viscosity
b. high coefficient of thermal expansion
c. low temperature gradients
d. low density change with temperature

11. The surface renewal frequency in Danckwerts' model of mass transfer is given by (k_L: mass transfer coefficient, m/s)

a. $\sqrt{k_L^2 D_A}$
b. $k_L^2 D_A$
c. k_L^2 / D_A
d. k_L / D_A^2

12. For gas absorption the height of a transfer unit, based on the gas phase, is given by (G: superficial molar gas velocity; L: superficial molar liquid velocity; F_G: mass transfer coefficient, mol/m^{2}s; a: interfacial area per unit volume of tower)

a. $\dfrac{G}{F_G a}$
b. $\dfrac{F_G}{Ga}$
c. $\dfrac{Ga}{F_G}$
d. $\dfrac{L}{F_G G}$

13. The Lewis relation for air-water humidification is given by (k_Y: mass transfer coefficient of moisture in air; h_G: heat transfer coefficient; C_S: heat capacity of vapour- gas mixture)

a. $\dfrac{h_G^2}{k_Y C_S} = 1$
b. $\dfrac{k_Y C_S^2}{h_G} = 1$
c. $\dfrac{h_G}{k_Y C_S} = 1$
d. $\dfrac{k_Y^2 h_G}{C_S} = 1$

14. The conversion for a second order, irreversible reaction (constant volume), $A \xrightarrow{k_2} B$, in batch mode is given by

a. $\dfrac{1}{1 + k_2 C_{A0} t}$
b. $\dfrac{k_2 C_{A0} t}{1 + k_2 C_{A0} t}$
c. $\dfrac{(k_2 C_{A0} t)^2}{1 + k_2 C_{A0} t}$
d. $\dfrac{k_2 C_{A0} t}{(1 + k_2 C_{A0} t)^2}$

15. The reaction rate constants at two different temperatures T_1 and T_2 are related by

a. $\ln\left(\dfrac{k_2}{k_1}\right) = \dfrac{E}{R}\left(\dfrac{1}{T_2} - \dfrac{1}{T_1}\right)$
b. $\ln\left(\dfrac{k_2}{k_1}\right) = \dfrac{E}{R}\left(\dfrac{1}{T_1} - \dfrac{1}{T_2}\right)$
c. $\exp\left(\dfrac{k_2}{k_1}\right) = \dfrac{E}{R}\left(\dfrac{1}{T_1} - \dfrac{1}{T_2}\right)$
d. $\exp\left(\dfrac{k_2}{k_1}\right) = \dfrac{E}{R}\left(\dfrac{1}{T_2} - \dfrac{1}{T_1}\right)$

16. The E-curve for a non-ideal reactor defines the fraction of fluid having age between t and t + dt

a. at the inlet
b. at the outlet
c. in the reactor
d. averaged over the inlet and outlet

17. The calibration data of a thermocouple with its cold junction at 0°C are given below

Hot junction temperature (°C)	0	20	40	60	80	100
Thermo emf (mV)	0.00	0.80	1.61	2.43	3.26	4.10

The hot junction of the thermocouple is placed in a bath at 80°C while its cold junction is at 20°C. What is the emf of the thermocouple?

a. 3.26 mV
b. 0.80 mV
c. 2.46 mV
d. 2.43 mV

18. A process is initially at steady state with its output y = I for an input u = 1. The input is suddenly changed to 2 at time r = 0. The output response is y(t) = 1 + 2r . The transfer function of the process is

a. $\frac{2}{s}$
b. $1+\frac{2}{s^2}$
c. $1+\frac{2}{s}$
d. $\frac{1}{s}\left(1+\frac{2}{s}\right)$

19. The inherent characteristics of an equal percentage valve relating flow rate q with valve stem movement x are described by the equation

a. $\frac{dq}{dx}=k$
b. $\frac{dq}{dx}=kq$
c. $\frac{dq}{dx}=\frac{k}{q}$
d. $\frac{dq}{dx}=kq^2$

20. A perforated plate has holes of diameter d_h arranged in a pitch, p_h. Each hole has a tube of i.d., d_t, passing through it. The ligament efficiency is given by

a. $\frac{p_h-d_h}{p_h}$
b. $\frac{p_h-d_h d_t/2}{p_h}$
c. $\frac{p_h-d_t}{p_h}$
d. $\frac{p_h-d_h}{p_h}$

21. The ends of a cylindrical vessel can be closed by a head, which can be one of the four shapes. For the same thickness, choose the one which can withstand the highest pressure.

a. flat plate
b. hemispherical
c. torispherical
d. ellipsoidal

22. An investment of Rs. 100 lakhs is to be made for construction of a plant which will take two years to start production. The annual profit from operation of the plant is Rs. 20 lakhs. What will be the payback time?

a. 5 years
b. 7 years
c. 12 years
d. 10 years

23. One of the steps during refining of cane sugar consists of addition of hydrated lime to the sugar syrup followed by carbonation of the resulting solution. The purpose of this step is to

a. Adjust the pH of the syrup.
b. Remove the coloring matter from the syrup.
c. Reduce the viscosity of the syrup.
d. Improve the rate of crystallization of sugar.

24. Styrene is produced from ethylbenzene by the process of

a. Dehydrogenation
b. Oxidation
c. Alkylation
d. Dehydration

25. In the fluid catalytic cracker (FCC), the cracking reaction is ---(a)--- and the regeneration is ---(b)--

a. (a) Exothermic (b) Endothermic.
b. (a) Exothermic (b) Exothermic.
c. (a) Endothermic (b) Endothermic.
d. (a) Endothermic (b) Exothermic.

TWO MARKS QUESTIONS (26-50)

This question consists of TWENTY FIVE sub-questions (26 - 50) of TWO marks each. For each of these sub-questions, four possible answers (A, B, C and D) are given, out of which only one is correct. Answer each sub-question by darkening the appropriate bubble on the OBJECTIVE RESPONSE SHEET (ORS) using a soft HB pencil. Do not use the ORS for any rough work. You may like to use the Answer Book for any rough work, if needed.

(Marks: 2 × 25 = 50)

26. The function $f(x,y) = x^2 + y^2 - xy - x - y + 5$ has the
   a. Maximum at (1, 1)
   b. Saddle point at (1, 1)
   c. Minimum at (1, 1)
   d. None of the above at (1, 1).

27. A fair die is rolled four times. Find the probability those six shows up twice.
   a. $\frac{1}{2}$
   b. $\frac{16}{325}$
   c. $\frac{1}{36}$
   d. $\frac{25}{216}$

28. A butane isomerization process produces 70 kmol/h of pure isobutane. A purge stream, removed continuously, contains 85% n-butane and 15% impurity (mole %). The feed stream is n-butane containing 1% impurity (mole %). The flow rate of the purge stream will be:
   a. 3 kmol/h
   b. 4 kmol/h
   c. 5 kmol/h
   d. 6 kmol/h

29. The Maxwell relation derived from the differential expression for the Helmholtz free energy (dA) is:
   a. $(\partial T/\partial V)_S = -(\partial P/\partial S)_V$
   b. $(\partial S/\partial P)_T = -(\partial V/\partial T)_P$
   c. $(\partial V/\partial S)_P = (\partial T/\partial P)_S$
   d. $(\partial S/\partial V)_T = (\partial P/\partial T)_V$

30. At 100°C, water and methylcyclohexane both have vapour pressures of 1.0 atm. Also at 100°C, the latent heats of vapourization of these compounds are 40.63 kJ/mol for water and 31.55 kJ/mol for methylcyclohexane. The vapour pressure of water at 150°C is 4.69 atm. At 150°C, the vapour pressure of methylcyclohexane would be expected to be:
   a. significantly less than 4.69 atm
   b. nearly equal to 4.69 atm
   c. significantly more than 4.69 atm
   d. indeterminate due to a lack of data

31. A Bingham fluid of viscosity μ = 10 Pa s, and yield stress τ_0 = 10 kPa, is sheared between flat parallel plates separated by a distance 10^{-3} m. The top plate is moving with a velocity of 1 m/s. The shear stress on the plate is
   a. 10 kPa
   b. 20 kPa
   c. 30 kPa
   d. 40 kPa

32. Air enters an adiabatic compressor at 300 K. The exit temperature for a compression ratio of 3, assuming air to be an ideal gas ($\gamma = C_p/C_v = 7/5$) and the process to be reversible, is
   a. $300(3^{2/7})$
   b. $3O0(3^{3/5})$
   c. $300(3^{3/7})$
   d. $300(3^{5/7})$

33. The energy required per unit mass to grind limestone particles of very large size to 100 μm is 12.7 kWh/ton. An estimate (using Bond's Law) of the energy to grind the particles from a very large size to 50 μm is
   a. 6.35 kWh/ton
   b. 9.0 kWh/ton
   c. 18 kWh/ton
   d. 25.4 kWh/ton

34. The Sieder-Tate correlation for heat transfer in turbulent flow in a pipe gives $Nu \infty \mathrm{Re}^{0.8}$, where Nit is the Nusselt number and Re is the Reynolds number for the flow. Assuming that this relation is valid, the heat transfer coefficient varies with pipe diameter (D) as

a. $D^{-1.8}$
b. $D^{-0.2}$
c. $D^{0.2}$
d. $D^{1.8}$

35. The overall heat transfer coefficient for a shell and tube heat exchanger for clean surfaces is U_0 = 400 W/m^{2}K. The fouling factor after one year of operation is found to be h_{do} = 2000 W/m^{2}K. The overall heat transfer coefficient at this time is

a. 1200 W/m^{2}K
b. 894 W/m^{2}K
c. 333 W/m^{2}K
d. 287 W/m^{2}K

36. The heat flux (from outside 10 inside) across an insulating wall with thermal conductivity k = 0.04 W/m K and thickness 0.16 m is 10W/m^2. The temperature of the inside wall is -5°C. The outside wall temperature is

a. 25°C
b. 30°C
c. 35°C
d. 40°C

37. The interfacial area per unit volume of dispersion, in a gas-liquid contactor, for fractional hold-up of gas = 0.1 and gas bubble diameter = 0.5 mm is given by (in m^2/m^3)

a. 500
b. 1200
c. 900
d. 800

38. 200 kg of solid (on dry basis) is subjected to a drying process for a period of 5000s. The drying occurs in the constant rate period with the drying rate as N_C = 0.5 × 10 kg/m^{2}s. The initial moisture content of the solid is 0.2 kg moisture/kg dry solid. The interfacial area available for drying is 4 m^2/100 kg of dry solid. The moisture content at the end of the drying period is (in kg moisture/kg thy solid)

a. 0.5
b. 0.05
c. 0.1
d. 0.15

39. In a single stage extraction process, 10 kg of pure solvent S (containing no solute A) is mixed with 30 kg of feed F containing A at a mass fraction x_f = 0.2. The mixture splits into an extract phase E and a raffinate phase R, containing A at x_E = 0.5 and x_R = 0.05, respectively. The total mass of the extract phase is (in kg)

a. 6.89
b. 8.89
c. 10
d. 8.25

40. The mean conversion in the exit stream, for a second-order, liquid phase reaction in a non-ideal flow reactor is given by

a. $\int_0^\infty \frac{k_2 C_{A0} t}{1+k_2 C_{A0} t} E(t)\,dt$

b. $\int_0^\infty \frac{1}{1+k_2 C_{A0} t} E(t)\,dt$

c. $\int_0^\infty \frac{1}{1+k_2 C_{A0} t} \left(1-E(t)\tau\right)dt$

d. $\int_0^\infty \frac{\exp(-k_2 C_{A0} t)}{1+k_2 C_{A0} t} E(t)\,dt$

41. For a vapor phase catalytic reaction (A + B → F) which follows the Rideal mechanism and the reaction step is rate controlling, the rate of reaction is given by (reaction step is irreversible, product also adsorbs)

a. $-r_A = \frac{k p_A p_B}{1+K_A p_A + K_p p_p}$

b. $-r_A = \frac{k p_A^2 - p_p}{1+K_A p_A + K_p p_p}$

c. $-r_A = \frac{k p_A p_B}{1+K_A p_A + K_B p_B + K_p p_p}$

d. $-r_A = \frac{k p_A p_B}{1+K_A p_A}$

42. The first-order, gas phase reaction $A \xrightarrow{k_1} 2B$ is conducted isothermally in

batch mode. The rate of change of conversion with time is given by

a. $\frac{dX_A}{dt} = k_1(1-X_A)^2(1+2X_A)$

b. $\frac{dX_A}{dt} = k_1(1-X_A)(1+0.5X_A)$

c. $\frac{dX_A}{dt} = k_1(1-X_A)$

d. $\frac{dX_A}{dt} = k_1(1-X_A)/(1+X_A)$

43. An ideal PID controller has the transfer function $[1+1/(0.5s)+0.2s]$. The frequency at which the Magnitude Ratio of the controller is 1, is

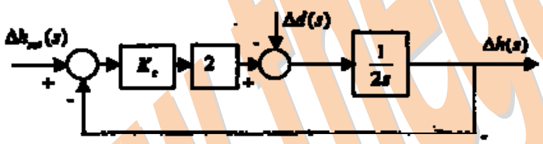
a. $\frac{0.5}{0.2}$

b. $\frac{0.2}{0.5}$

c. 0.2×0.5

d. $\frac{1}{\sqrt{0.2\times 0.5}}$

44. The block diagram of an integrating level process is given below. For unit step change in the set point $\Delta h_{set}=1$ with $\Delta d=0$, the offset exhibited by the system is



a. $\frac{K_c}{1+K_c}$

b. $\frac{1}{1+K_c}$

c. 0

d. $\frac{2K_c}{1+2K_c}$

45. A second order system can be obtained by connecting two first order systems $1/(\tau_1 s+1)$ and $1/(\tau_2 s+1)$ in series. The damping ratio of the resultant second order system for the case $\tau_1 \neq \tau_2$ will be

a. > 1

b. = 1

c. < 1

d. $= \tau_2/\tau_1$

46. An investment of Rs. 1000 is carrying an interest of 10% compounded quarterly. The value of the investment at the end of five years will be

a. $1000\left(1+\frac{0.1}{4}\right)^{20}$

b. $1000(1+0.10)^{20}$

c. $1000\left(1+\frac{0.1}{4}\right)^{5}$

d. $1000\left(1+\frac{0.1}{2}\right)^{5}$

47. P is the investment made on an equipment, S is its salvage value and ii is the life of the equipment in years. The depreciation for the mth year by the Sum-of-Years-Digits method will be

a. $\frac{P-S}{n}$

b. $1-\left(\frac{P}{S}\right)^{\frac{1}{m}}$

c. $\frac{m}{n}(P-S)$

d. $\frac{2(n-m+1)}{n(n+1)}(P-S)$

48. In a cylindrical vessel subjected to internal pressure, the longitudinal stress σ_L, and the circumferential stress, σ_h, are related by

a. $\sigma_h = 2\sigma_L$

b. $\sigma_h = \sigma_L$

c. $\sigma_h = \frac{\sigma_L}{2}$

d. No relation exists

49. In the converter of the contact process for the manufacture of H_2SO_4, the equilibrium conversion of SO_2 ---(a)--- with increase in the temperature and ---(b)--- with increase in the mole ratio of SO_2 to air.

a. (a) increases (b) decreases.

b. (a) decreases (b) increases.

c. (a) increases (b) increases.

d. (a) decreases (b) decreases.

50. For the hydrogenation of oils, ---(a)--- is commonly used as catalyst, arid ---(b)--- is a catalyst poison.

a. (a) Platinum (b) Sulfur.
b. (a) Palladium (b) Oxygen.
c. (a) Nickel (b) Sulfur.
d. (a) Nickel (b) Oxygen.

SECTION - B

FIVE MARKS QUESTIONS (51-70)

This section consists of TWENTY questions of FIVE marks each. ANY FIFTEEN out of these questions have to be answered on the Answer Book provided.

(Marks: 5 × 15 = 75)

51. The parametric equation of a curve is: $\bar{r}(t) = r\bar{i} + \frac{2}{t}\bar{j}$ where t is the parameter.

a. What type of conic (parabola, circle, ellipse, and hyperbola) does the curve represent?
b. Find the unit tangent to the curve at t = 1.
c. Find the unit normal to the curve at r = 1.

52. Laplace transforms:

a. Show that the Laplace transform of $e^{\omega t}$ is

$$\mathcal{L}[e^{\omega t}] = \frac{1}{s-\omega}$$

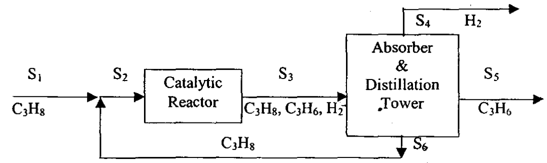
b. Show <u>from (a)</u> that:

$$\mathcal{L}[\sinh(\omega t)] = \frac{\omega}{s^2 - \omega^2}$$

c. Show <u>from (b)</u> that:

$$\mathcal{L}[\sin(\omega t)] = \frac{\omega}{s^2 + \omega^2}$$

53. The process schematic of a propane dehydrogenation plant is shown below. It is desired to set up a simplified version of the material balance for this plant. Assume that the only reaction is the dehydrogenation of propane to propylene; there are no side reactions. The yield of propylene per pass is 30% (i.e., 30% of the propane entering the reactor is converted to propylene). Assume that the amount of carbon formed on the catalyst is negligible. The product flow rate (stream S_5) is 50 kmol/h. Calculate the flow rates of all the other streams. Notice that all streams except stream S_3 are pure.



54. 100 m^3 of carbon dioxide initially at 423 K and 50 bar (50×10^5 Pa) is to be isothermally compressed in a frictionless piston and cylinder device to a final pressure of 300 bar (300×10^5Pa). Assuming ideal gas behaviour (R = 8.314 × 102 bar m^3/kmol K),

a. Write a general expression for the energy balance for the gas within the piston and cylinder device as the system, and define all the terms.
b. Calculate the volume of the compressed carbon dioxide gas at 300 bar.
c. Calculate the work done to compress the carbon dioxide gas.
d. Calculate the heat flow on compression.

55. Normal pentane is isomerized to isopentane and neopentane at 500 K and atmospheric pressure. Determine the equilibrium composition (mole %) of the three components. State any assumptions made. Consider the reactions to be:

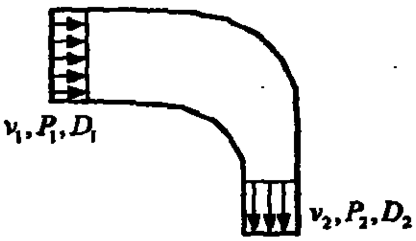
a. $n-C_5H_{12}(g) \Leftrightarrow iso-C_5H_{12}(g)$

b. $n-C_5H_{12}(g) \Leftrightarrow neo-C_5H_{12}(g)$

Equilibrium constant for reaction (a) at 500K, K_1 = 3,519

Equilibrium constant for reaction (b) at 500 K, K_2 = 0.682

56. The inlet velocity of water (ρ = 1000 kg/m^3) in a right angled bend-reducer is v_1 = 1m/s, as shown below. The inlet diameter is D_1 = 0.8 m and the outlet diameter is D_2 = 0.4 m. The flow is turbulent and the velocity profiles at the inlet and outlet are flat (plug flow). Gravitational forces are negligible.



a. Find the pressure drop ($P_1 - P_2$) across the bend assuming negligible friction losses.

b. If the actual pressure drop is ($P_1 - P_2$) = 8.25 kPa, find the friction loss factor (K_f) based on the velocity v_1.

57. The volumetric flow rate during constant pressure filtration is

$$\frac{dV}{dt} = \frac{1}{K_c V + 1q_0}$$

where V is the total volume of filtrate collected in time t, and K_c and q_0 are constants.

a. Integrate the above equation to obtain a relation between V and t.

b. Make a sketch of t/V versus V from your results.

c. Given V = 1.0 litre at t = 41.3 sand V = 2.0 liter at t = 108.3 s, find K_c.

58. A 200 W heater has a spherical casing of diameter .0.2 m. The heat transfer coefficient for conduction and convection from the casing to the ambient air is obtained from $Nu = 2 + 0.6\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}$ with $\mathrm{Re} = 10^4$ and Pr = 0.69. The temperature of the ambient air is 30°C and the thermal conductivity of air is k = 0.02 W/m K.

a. Find the heat flux from the surface at steady state.

b. Find the steady state surface temperature of the casing.

c. Find the temperature of the casing at steady state for stagnant air. Why is this situation physically infeasible?

59. A 1-2 shell and tube heat exchanger has liquid (specific heat C_p) flowing at a mass flow rate $\dot{m}$ in the tubes and saturated steam (temperature T_s) condensing on the shell side.

a. Carry out a differential energy balance on a single tube to show that

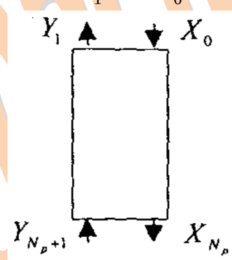
$$\frac{\dot{m}}{N} C_p \frac{dT}{dz} = \pi D U \left(T_s - T\right)$$

where T is the temperature of the liquid, N is the number of tubes in a pass, z is the distance along the tube, D is the inner diameter of the tubes and U is the overall heat transfer coefficient based on the inside surface area.

b. Obtain an expression for the temperature of the liquid at the exit of the heat exchanger, T_2. The length of the tubes is L and liquid enters the heat exchanger at temperature T_0.

60. For a counter-current, multistage contact, show that if the driving force for solute transfer is constant for all trays, then the number of stages is given by

$$N_p = \frac{Y_{N_{p+1}} - Y_1}{Y_1 - mX_0}$$



61. A sugary substance A is added to a pot of milk (initially containing no A) and stirred vigorously by a spoon so that the concentration of A, C_A, is uniform everywhere. The mass transfer coefficient for the transfer of A into the liquid is k_{sl} = 1 × 10^{-4} m/s. Solid A is added in great excess compared to the saturation capacity of milk to dissolve A. Assume that the solid-liquid interfacial area stays constant throughout the dissolution process and is given by a = 1000 cm^2. Derive the expression for. C_A versus time, t. Find the time taken for $C_A / C_A^* = 0.95$. $C_A^* = 5 \times 10^{-2}$ kmil/m^3; V_L = 1000 cm^3.

62. The concentration versus batch time data for a constant volume, isothermal batch reactor is given in the Table below. Assuming the reaction to be first order in A. find the best value of k_1 by least squares regression.

t (s)	0	30	60	90	120	150	180
C_A (kmol/m^3)	1.00	0.92	0.89	0.81	0.76	0.72	0.70

63. A CSTR and a PFR of equal volume V (each) are given for the conduct of a

second-order, isothermal, liquid phase reaction. The reactors are to be arranged sequentially (in series). Find the values of the conversionr for the two possible reactor arrangements. $A \xrightarrow{k_2} B, k_2 = 1m^3/\text{kmol}$ s, $C_{A0} = 0.1$ kmol/m^{3}s and τ = 5 s (for volume V).

64. Find the expression for the effectiveness factor of a catalyst pellet in the form of a thin slab such that the area of two opposite faces is much larger than the area of the other four faces. Material A can diffuse from both the large faces. Assume a first order reaction and isothermal, irreversible conditions. The two large faces are separated by a distance 2w, the effective diffusivity of A in the slab is D_{Ae} and the rate constant is denoted by k_1.

65. The hot junction of a thermocouple having time constant r mm. is initially at room temperature of 30°C. At time t = 0 min., it is placed in a bath held at 100°C. The thermocouple is connected to a recorder which has fast dynamics. At t = 2 min., the hot junction is withdrawn from the bath and held in the air which is at 30°C. From the recorded data, the value of dT/dt at t = 2^+ min. is given to you. dT/dt = -2.5°C/min. at t = 2^+ min. Is this data sufficient to calculate the time constant of the thermocouple? If so, suggest a procedure for calculation of the time constant τ.

66. The transfer function of a system consisting of a thermal process, valve and measuring system is given by

$$\frac{\Delta T(s)}{\Delta I(s)} = \frac{5}{(5s+1)(0.5s+1)(0.1s+1)}$$

Initially a proportional controller with proportional sensitivity K_c is used. The controller equation is $\Delta I(s) = K_c\left(\Delta T_{set}(s) - \Delta T(s)\right)$ where T_{set} is the set point. Find the value of $K_c = K_{c,max}$ above which the closed loop will be unstable. Can you use the results of the closed loop response at $K_c = K_{c,max}$ to tune a PID controller to be used in place of the proportional controller? If so, calculate the tuning parameters of the controller.

67. A packed gas liquid contactor employs ceramic Intalox saddles (38 mm). The gas flow rate, G = 1.5 kg/s and gas density, ρ_G = 1.5 kg/m^3. The liquid flow rate, L = 30 kg/s and liquid density ρ_L = 1000 kgm^3. The column is to be designed for a pressure drop of 42 mm H_2O. Norton's correlation for this pressure drop is

$$K = \frac{1331 G_W^2 \left(\frac{\mu_L}{\rho_L}\right)^{0.1}}{\rho_G\left(\rho_L - \rho_G\right)}$$

where K = flow coefficient, μ_L, liquid viscosity = 10^{-3} Ns/m^2, G_w = gas flow rate per unit cross sectional area, kg/(m^{2}s), F_p = packing factor = 170 m^{-1}. K is given by the equation: K = 0.62 - 0,5(m - 0.5) for 0.5 ≤ m ≤ 1.0 where

$$m = \frac{L}{G}\sqrt{\frac{\rho_C}{\rho_L}}$$

Calculate the diameter of the contactor.

68. A plant designer has to choose between equipment 1 and equipment 2. Equipment 1 is made of special material and requires no maintenance, The cost of the equipment is Rs. 3,00,000. Equipment 2 is of a lower cost material and costs Rs. 1,50,000. For maintenance of equipment 2, a maintenance cost of Rs 10,000 has to be paid at the end of each year. Life of equipment 2 is four years while that of equipment I is 8 years. Interest rate is 15% compounded annually. Calculate the present worth of investment to be made for each equipment and choose the option which has the lower present worth. Equipment 1 has a salvage value of Rs 30,000 while equipment 2 has no salvage value.

69. Using appropriate structural formulae, write the equations representing the following reactions in the stoichiometricatly balanced form.

a. Dehydrogenation of isopropanol to acetone.
b. Hydroformylation of propylene to butyraldehyde.
c. Nitration of toluene to o-nitrotoluene.
d. Oxidation of cumene to cumene hydroperoxide using oxygen.
e. Isomerisation of n-butane to isobutane.

70. Answer each of the following questions in one sentence.

a. What function does the membrane perform in the membrane cell for the manufacture of NaOH?
b. What is the generic chemical name for the class of polymers which are commercially known as nylons?
c. Name the commonly used process for the manufacture of synthesis gas from the natural gas.
d. What change in the design of the synthesis gas compressors has revolutionized the ammonia manufacture during the recent years?
e. State the major advantage of the Kraft process over the other processes for the manufacture of paper pulp?