# CHEMICAL ENGINEERING

## SECTION A

**(100 Marks)**

Write in your answer book the correct or the most appropriate answer to the following multiple choice questions by writing the corresponding letter A, B, C or D against the subquestion number.

(25 × 1 = 25)

1. The energy balance equation over a tubular reactor under transient conditions is
   a. an ordinary nonlinear differential equation
   b. an algebraic equation
   c. a linear partial differential equation
   d. a nonlinear partial differential equation
2. The number of degrees of freedom for a mixture of ice-and water (liquid) are
   a. 2
   b. 3
   c. 1
   d. 0
3. From collision theory, the reaction rate constant is proportional to
   a. $\exp\left(-\frac{E}{RT}\right)$
   b. $\exp\left(-\frac{E}{2RT}\right)$
   c. $\sqrt{T}$
   d. $T^m \exp\left(-\frac{E}{RT}\right)$
4. Toothpaste is a
   a. Bingham plastic
   b. Pseudoplastic
   c. Newtonian liquid
   d. Dilatant
5. Fluidized beds are formed when
   a. fluid friction is zero
   b. gravity force is less than fluid friction
   c. pressure forces equal gravity forces
   d. sum of fluid friction and pressure faces is equal and opposite to gravity forces
6. The distribution given by microscopic-analysis of powder is
   a. Number
   b. Length
   c. Area
   d. Volume
7. Stokes equation valid in the Reynolds number range
   a. 0.01 to 0.1
   b. 01 to 2
   c. 2 to 10
   d. 10 to 100
8. To produce talcum powder use
   a. Ball mill
   b. Hammer mill
   c. Jet-mill
   d. Pin-mill
9. In natural convection heat transfer the correlating parameter is
   a. Graetz number
   b. Eckert number
   c. Grashof number
   d. Bond number
10. The critical radius r of insulation on a-pipe is given by
    a. $r = \frac{2k}{h}$
    b. $r = \frac{k}{h}$
    c. $r = \frac{k}{2h}$
    d. $r = \frac{h}{k}$

    (where k is the thermal conductivity of the insulation and h the heat transfer coefficient with the ambient)
11. The & non-dimensional temperature gradient in a liquid at the wall of a pipe is
    a. the heat flux
    b. the Nusselt number
    c. the Prandtl number
    d. the Schmidt-number
12. The reason for preferring packed towers over plate towers in distillation practice is that the packed tower operation gives
    a. low pressure drop and high hold up
    b. high pressure drop and low hold up
    c. low pressure drop and low hold up
    d. high pressure drop and high hold up
13. When a multistage tray tower uses a minimum reflux ratio it implies
    a. infinite trays and maximum reboiler heat load

b. infinite trays and minimum reboiler heat load
c. minimum trays and minimum reboiler heat load
d. minimum trays and maximum reboiler heat load

14. The sequence in which three C.S.T.R.'s of volumes 5, 10 and 15 cu.m. will be connected in series to obtain the maximum production in a second order irreversible reaction is
a. 15 10 5
b. 5 10 15
c. 10 5 15
d. 10 15 5

15. For a mixed flow reactor operating at steady state, the rate of reaction is given by
a. $\frac{F_{A0}}{V} - \frac{dC_A}{dt}$
b. $\frac{F_{A0}}{V} + \frac{dC_A}{dt}$
c. $\frac{F_{A0}X_A}{V}$
d. $-\frac{dC_A}{dt}$

16. For a tubular reactor with space time τ and residence time θ, the following statement holds
a. τ and θ are always equal
b. τ = θ when the fluid density changes in the reactor
c. τ = θ for an isothermal tubular reactor in which the density of the process fluid is constant
d. τ = θ for a non-isothermal reactor

17. The Knudsen diffusivity is dependent on
a. the molecular velocity only
b. the pore radius of the catalyst only
c. the molecular mean free path only
d. the molecular velocity and pore radius of the catalyst

18. If the pore diffusion controls in a catalytic reaction, the apparent activation energy $E_a$ is equal to
a. the intrinsic activation energy E
b. $(E + E_D)$ where $E_D$ is activation energy due to diffusion
c. $\frac{(E+E_D)}{2}$
d. $\frac{E_D}{2}$

19. The reaction A (ℓ) = R(g) + S(g) is allowed to reach equilibrium conditions in an autoclave. At equilibrium there are two phases, one a pure liquid phase of A and the other a vapour phase of A, R and S. Initially A alone is present. The number of degrees of freedom are
a. 1
b. 2
c. 3
d. 0

20. The equation dU = TdS − PdV is applicable to infinitesimal changes occurring in
a. an open system of constant composition
b. a closed system of constant composition
c. an open system with changes in composition
d. a closed system with changes in composition

21. For a first order chemical reaction in a porous catalyst, the Thiele modulus is 10. The effectiveness factor is approximately equal to
a. 1
b. 0.5
c. 0.1
d. 0

22. Styrene-Butadiene rubber is commercially manufactured by
a. Bulk polymerisation
b. Suspension polymerisation
c. Solution polymerisation
d. Emulsion polymerisation

23. In a feed-back control system G and H denote open loop and closed loop transfer functions respectively The output-input relationship is
a. $\frac{G}{1+H}$
b. $\frac{H}{1+G}$
c. $\frac{G}{H}$
d. $\frac{H}{G}$

24. The open loop transfer function of a control system is $\frac{KR}{(1+Ts)}$. This represents
a. A first order system
b. dead time system

c. a first order time lag
d. a second order system

25. The Laplace transform of a stair-case function s (b, t) formed by successive addition of unit, step functions at 0, b, 2 b 3 b, etc. is
a. $\frac{1}{s}$
b. $\frac{1}{bs}$
c. $s\left(1-e^{-bs}\right)$
d. $\frac{1}{s\left(1-e^{-bs}\right)}$

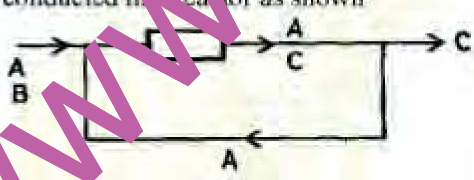
## TWO MARKS QUESTIONS (26-50)

Write in your answer book the correct or the most appropriate answer to the following multiple choice questions by writing the corresponding letter A, B, C or D against the subquestion number.

(17 × 2 = 34)

26. The ratio $\frac{\int_{x_1}^{x_2} \frac{dx}{y}}{(x_2-x_1)/y \text{ at } x=x_2}\,(x_2>x_1)$ where is $\frac{1}{y}$ a monotonically increasing function of x, is
a. Less than unity
b. Equal to unity
c. Greater than unity
d. Less than zero

27. The reaction A + B → C has been conducted in a reactor as shown




27.1 The number of boundaries around which material balances can be written are
a. 1
b. 6
c. 3
d. 4

27.2 The number of independent balances (material) that can be made around the reactor are
a. 1
b. 2
c. 3
d. 4

28. For an isothermal variable volume batch reactor, the following relation is applicable for a first order irreversible reaction
a. $X_A = kt$
b. $\frac{C_{A0}}{1+\varepsilon_A X_A}\left(\frac{dX_A}{dt}\right)=k$
c. $-\ln(1-X_A)=kt$
d. $\varepsilon_A \ln(1-X_A)=kt$

where $X_A$ is conversion, $\varepsilon_A$ is fractional change in volume on complete conversion, k is the rate constant, and t is time.

29. A rotameter through which air at room temperature and atmospheric pressure is flowing gives a certain reading for a flow rate of 100 cc/s. If helium (molecular weight 4) is used and the rotameter shows the same reading, the flow rate is
a. 2[illegible] cc/s
b. 42 cc/s
c. 269 cc/s
d. 325 cc/s

30. A bed consists of particles of density 2000 $kg/m^3$. If the height of the bed is 1.5 m and its porosity 0.4, the pressure drop required to fluidize the bed is
a. 25.61 kPa
b. 11.77 kPa
c. 14.86 kPa
d. 21.13 kPa

31. The sphericity of a cylinder of 1 mm diameter and length 3 mm is
a. 0.9
b. 0.78
c. 0.6
d. 0.5

32. The hydrodynamic and thermal boundary layers will merge when
a. Prandtl number is one
b. Schmidt number tends to infinity
c. Nusselt number tends to infinity
d. Archimedes number is greater than 10,000

33. When the ratio of the Grashof number to the square of the Reynolds number is one, the dominant mechanism of heat transfer is
a. free convection

b. entry length problem in laminar forced convection (developing thermal boundary layer)
c. mixed convection (both free and forced)
d. forced convection

34. The theoretical minimum work required to separate one mole of a liquid mixture at 1 atm, containing 50 mole % each of n-heptane and n-octane into pure compounds each at 1 atm is
a. –2RT ln 0.5
b. –RT ln 0.5
c. 0.5 RT
d. 2 RT

35. Given $3H_2 + CO = CH_4 + H_2O$ $K_p = 10^{1.84}$ and $4H_2 + CO_2 = CH_4 + 2H_2O$ $K_p = 10^{1.17}$ the $K_p$ for the reaction $CO + H_2O = CO_2 + H_2$ is
a. $10^{3.01}$
b. $10^{-0.67}$
c. $10^{-3.01}$
d. $10^{0.67}$

36. The rate expression for a heterogeneous catalytic reaction is given by

$$-r_A = k k_A P_A / (1 + k_A P_A + k_R P_R)$$

where k is surface reaction rate constant and $k_A$ and $k_R$ are adsorption equilibrium constants of A and K respectively. If $k_R P_R >> (1 + k_A P_A)$ the apparent activation energy- EA is equal to (given E is the activation energy for the reaction, and $\Delta H_R$ and $\Delta H_A$ are the activation energies of adsorption of R and A)
a. E
b. $E + \Delta H_A$
c. $E + \Delta H_A - \Delta H_R$
d. $\Delta H_A + \Delta H_R$

37. For a heterogeneous catalytic reaction $A + B \rightarrow C$, with equimolal feed of A and B, the initial rate $-r_{A0}$ is invariant with total pressure. The rate controlling step is
a. surface reaction between adsorbed A and B in the gas phase
b. surface reaction between adsorbed A and adsorbed B
c. surface reaction between A in the gas phase and adsorbed B
d. desorption of C

38. When an exothermic reversible reaction is conducted adiabatically the rate of reaction
a. continuously increases
b. continuously decreases
c. passes through a maximum
d. passes through a minimum

39. A typical example of an exothermic reversible reaction conducted at high pressures in industry is
a. dehydration of ethanol
b. methanol synthesis
c. reformation of methane
d. polymerisation of ethylene

40. The transfer function for an ideal proportional plus reset controller (Reset time T) is
a. $K_c\left[1+\frac{1}{Ts}\right]$
b. $K_c\left[1+Ts\right]$
c. $\frac{K_c}{1+Ts}$
d. $\frac{K_c}{1+\frac{s}{T}}$

41. An example of autothermal reactor operation is
a. sulfurdioxide oxidation
b. ethylene oxidation
c. benzene oxidation
d. ammonia synthesis

42. In a mixture of benzene vapour and nitrogen gas at a total pressure, of 900 mm Hg, if the absolute humidity of benzene is 0.2 Kg benzene / Kg nitrogen, the partial pressure of benzene in mm Hg is
a. 180
b. 60.3
c. 720
d. 200

43. Match the items in the left column with the appropriate items in the right column
(I) Gear pump
(II) Air lift pump
(A) Suspension
(B) Concentrated sulphuric acid
(C) Viscous oil
(D) Toluene

44. Match the items in the left column with the appropriate items in the right column

| | Jacket side | Vessel |
|---|---|---|
| (I) | Steam | Water |
| (II) | Water | Polymer-monomer-mixture |

Overall Heat Transfer coefficient($W/m^2\,^\circ C$)
(A) 30 - 75
(B) 5000 - 6000
(C) 285 - 800
(D) 850 - 1700

45. Match the items in the left column with the appropriate items in the right column
(I) 1/7 th power law
(II) Hagen-Poiseuille eqn
(A) irrotational flow
(B) turbulent flow
(C) inviscid flow
(D) laminar flow in pipes

46. Match the items in the left column with the appropriate items in the right column
(I) Graetz number
(II) Rayleigh number
(A) heat transfer in creeping flow
(B) thermally developing flow
(C) product of Grashof and Prandtl numbers
(D) product of Reynolds and Prandtl numbers

47. Match the items in the left column with the appropriate items in the right column
(I) RTD for laminar flow
(II) RTD for a CSTR
(A) $\delta(t-\tau)$
(B) $\exp\left(-\frac{t}{\tau}\right)$
(C) $\tau^2/2^3$ for $\frac{\tau}{2} \le t \le \infty$
(D) $\exp\left(-\frac{t}{\tau}\right)/\tau$

48. Match the items in the left column with the appropriate items in the right column
(I) Trickle bed reactors
(II) Batch reactors
(A) pharmaceuticals
(B) hydrodesulfurization of petroleum fractions
(C) dehydrogenation of butan-2-ol
(D) chlorination of benzene

49. Match the items in the left column with the appropriate items in the right column
(I) Flow factor
(II) Grade efficiency
(A) Comminution
(B) Storage silo
(C) Hydrocyclone
(D) Mixing

50. Match the items in the left column with the appropriate items in the right column
(I) Saltation velocity
(II) Compressible cake
(A) Filtration
(B) Fluidization
(C) Pneumatic conveying
(D) Screw conveyor

## FIVE MARKS QUESTIONS (51 & 55)

51. Solve $\frac{d^2y}{dx^2} - m^2 y = 0$ subject to y = 1 at x = 0 and $\frac{dy}{dx} = 0$ at $x = 1$.

52. At a given space time τ, a mixed reactor is operated at a temperature which maximizes the concentration $c_R$ of the desired product for the elementary reactions
$A \xrightarrow{k_1} R \xrightarrow{k_2} S$
$k_1 = 0.0333\ s^{-1}$, τ = [illegible] s, $E_1/E_2 = 3$, where $E_1$ and $E_2$ are the activation energies of the two reactions. Find the value of $k_2$ at this temperature. The feed to the reactor consists of [illegible].

53. A tank full of water is open at the top with a hole near the bottom, the area of which is [illegible] $m^2$ and the cross-sectional area of the tank is 1 $m^2$. If the height of the water above the hole is maintained at 10 m, what is the volumetric flow rate out of the hole?

54. 160 kg of wet solid is to be dried from an initial moisture content of 25% to a final value of 6%. Drying test shows that the rate of drying is constant at $3 \times 10^{-4}$ kg $H_2O/m^2.s$ in the region 0.2 - 0.4 kg $H_2O$ /kg solid. The drying rate falls linearly in the range 0.01 - 0.2 kg $H_2O$ / kg solid. If the equilibrium moisture content is 0.01 kg $H_2O$ / kg solid, calculate the time of drying. The drying surface is 1 $m^2$ / 30 kg dry weight.

55. The constant density isothermal elementary reaction A + B → C + D is conducted in a set-up consisting of a plug flow reactor followed by a mixed reactor. A is in excess and hence the reaction may be considered first order in B. Does reversing the order of the two units increase the production? Justify your answer.

# SECTION B

## FIVE MARKS QUESTIOSN (55 & 75)

Answer any TEN questions in this section. All questions carry equal marks.

56. Given the matrix $\underline{\underline{A}} = \begin{bmatrix} -1 & -2 \\ 3 & 4 \end{bmatrix}$

a. Write down the characteristic equation.

b. Compute $\left(\overline{A}\right)^{4}$ without direct multiplication.

57. Solve $\frac{dy}{dx}+0.6y=6e^{-0.5x}$ using the integrating factor method, given y = 1 at x = 0.

58. A hydrocarbon is burnt with excess air. The Orsat analysis of the flue gas shows 10.81% $CO_2$ , 3.78% $O_2$ and 85.40% $N_2$. Calculate the atomic ratio of C:H in the hydrocarbon and the % excess air. (5)

59. Methanol vapour can be converted into formaldehyde by the following reaction scheme:

$$CH_3OH+\frac{1}{2}O_2\rightarrow HCHO+H_2O$$

$$CH_3OH\rightarrow HCHO+H_2$$

The fresh feed to the process was 0.5 Kg mol / h of $O_2$ and an excess methanol. All of the $O_2$ reacts in the reactor. Formaldehyde and water are removed from the product stream first, after which $H_2$ is removed from the recycled methanol. The recycle flow rate of methanol was 1 Kg mol / h. The ratio of methanol reacting by decomposition to that by oxidation was 3. Draw the flow diagram and then calculate the per pass conversion of methanol in the reactor and the fresh feed rate of methanol.

60. Water trickles by gravity over a bed of particles, each 1 mm dia in a bed of dia 6 cm and height 2 m. The water is fed from a reservoir whose diameter is much larger than that of the packed bed, with water maintained at a height of 0.1 m above the top of the bed. The bed has a porosity 0.31. Calculate the volumetric flow rate of water if its viscosity is 1.0 cp.

61. Ammonia at atmospheric pressure and 300 K with a bulk stream velocity of 10 m/s flows through a pipe of i.d. 25 cm. Calculate the pressure drop per 100m length of the pipe and the power consumed. Friction factor $f = 0.079\ Re^{-0.25}$ in the turbulent regime. Viscosity of ammonia may be taken as $10.2\times10^{-6}$ kg/(m.s).

62. The rate of grinding of uniform sized particles is assumed to follow first order breakage of particles. 50 gm of powder of average diameter 215 microns was ground in a laboratory batch-mill. The amount of unground material (215 microns) was measured at various times of grinding and the results are given in Table 1. Estimate the specific rate of grinding.

Table 1

| Wt (gm) | 50 | 17 | 12 | 8 | 6 | 2 |
|---|---|---|---|---|---|---|
| Time(s) | 0 | 60 | 90 | 120 | 150 | [illegible] |

63. The surface area of spherical catalyst particles is 30,000 $m^2$. The catalyst particles follow a normal distribution with mean diameter of 100 microns and standard deviation of 2.5 microns. The density of particles 2000 kg/$m^3$. Calculate the weight, in kg, of catalyst particles.

64. A mixture of ore (density = 2000 kg / $m^3$) and waste material (density = 7000 kg / $m^3$) of size distribution given in Table 2 has to be separated in a hydraulic free settling elutriator. The drag force is related as $f_D = 18.5 / Re_p^{0.6}$ . What is the velocity of water (viscosity = 1 cp) to get ore free from waste material? What is the percentage loss of ore particles going with waste material?

Table 2

| Size (µm) | -1.5+1.1 | -1.1+0.7 | -0.7+0.52 | -0.52+0.40 | -0.40+0.4 | -0.4+0.36 |
|---|---|---|---|---|---|---|
| Mass fraction (-) | 0.08 | 0.26 | 0.1 | 0.22 | 0.17 | 0.17 |

65. Give five advantages of cement production by Dry Method compared with Wet Method.

66. What are the catalysts employed in the following commercial reactor operations?

a. oxidation of $SO_2$

b. oxidation of $NH_3$

c. oxidation of $C_2H_4$

d. hydrogenation of vegetable oil

e. dehydrogenation of propan-2-ol.

67. A thermocouple junction may be approximated as a sphere of diameter 2 mm with, thermal conductivity 30 W / (m. deg C), density 8600 kg / $m^3$ and specific heat 0.4 kJ / (kg. deg C). The heat transfer coefficient between the gas stream and the junction is 280 W / ($m^2$ . deg C). How long will it take for the thermocouple to record 98 percent of the applied temperature difference?

68. A shell and tube steam condenser is to be constructed of 2.5 cm OD., 2.2 cm ID, single pass horizontal tubes with steam condensing at 54°C on the outside of the

tubes. The cooling water enters at 20° C and leaves at 36° C at a flow rate of 1 kg/s. The heat transfer coefficient for the condensation of steam is 7900 W/($m^2$. deg C). Calculate the tube length. If the latent heat of condensation is 2454 kJ/kg, calculate the condensation rate per tube. The properties of water are as follows: specific heat 4180 J/(kg. deg C) viscosity $0.86 \times 10^{-3}$ kg/(m.s), thermal conductivity 0.61 W/(m. deg C). The heat transfer coefficient for turbulent flow in a pipe may be determined by

$Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$

69. 990 kg/h of an aqueous solution has a solute at a concentration of 0.1 kg solute / kg water. It is treated with 600 kg / h of a pure immiscible organic solvent in a 2-stage mixer-settler system. If the organic and aqueous streams leaving each stage are in equilibrium such that

$$\left(\frac{\text{kg solute in organic phase}}{\text{kg solvent}}\right) = 2\left(\frac{\text{kg solute in aqueous phase}}{\text{kg water}}\right)$$

calculate the kg solute extracted per kg solvent if countercurrent operation is employed.

70. A liquid mixture containing 50 mole % each of benzene and toluene at 40° C is to be continuously flash vaporized to vaporize 60 mole % of the feed. The residual liquid product contains 35 mole % benzene. If the enthalpies per mole of feed, the liquid product and the vapour product are respectively 5. 2 and [illegible] kJ / mole,
   a. Calculate the heat added in kJ per mole of vapour product.
   b. Represent the process on a H-x-y diagram.

71. Acetaldehyde (A) decomposes to methane (B) and CO (C) according to the irreversible gas phase reaction $A \longrightarrow B + C$ 1 kg mol/s of A is to be decomposed at 527°C and 1 atmosphere in a-plug flow reactor. The first order rate constant K was 0.5 /s.
Calculate the volume of the reactor for 40% decomposition of A.

72. Cis-2-butene (A) isomerizes to trans-2-butene (B) on a o1zd catalyst under isothermal conditions according to the reaction A⇌ B. Assuming desorption of B from the surface of the catalyst to be rate controlling, derive an expression for the intrinsic rate of reaction per unit mass of catalyst. Sketch rate of reaction vs total pressure (at constant composition) for the above mechanism.

73. The activity coefficients of benzene (A) – cyclohexane (B) mixture at 40°C are given by RT ln $\gamma_A = bx_B^2$ and RT ln $\gamma_B = bx_A^2$. At 40° C, A and B from an azeotrope containing [illegible].4 mol % A at a total pressure of [illegible] mm Hg. If the vapour pressures of pure A and pure B are 182.6 and [illegible]3.5 mmHg respectively, calculate the total pressure of the vapour at temperature 40° C in equilibrium with a liquid mixture containing 12.6 mol% A.

74. Calculate the change in internal energy of 25 k mol of $CO_2$ gas when it is isothermally expanded from 10132 kPa to 101.32 kPa at 373 K, the corresponding molar volumes being 0.215 $m^3$/kmol and 30.53 $m^3$/k mol. Assume $CO_2$ to obey

$$\left(P + \frac{365}{v^2}\right)(v - 0.043) = RT$$

75. Identify the extensive and intensive properties from the given list:
   a. chemical potential
   b. entropy
   c. fugacity
   d. enthalpy
   e. activity coefficient