CHEMICAL ENGINEERING

SECTION A

(75 Marks)

ONE MARKS QUESTIONS (1 – 35)

For each of the following questions (1 to 35), four alternatives – A, B, C and D are provided. Indicate the correct answer by writing A, B, C or D, as appropriate, against the corresponding question number in the block in the answer book.

(Marks : $1 \times 35 = 35$)

1. The system of equations,

$$2x + 4y = 10$$
$$5x + 10y = 25$$

a. has no unique solution
b. has only one solution
c. has only two solutions
d. has infinite solutions

2. Four fair coins are tossed simultaneously. The probability that at least one head turn up is
a. 1/16
b. 15/16
c. 7/8
d. 1/8

3. The rank of the matrix $\begin{pmatrix} 3 & 0 & 1 & 2 \\ [illegible] & 3 & 3 \\ 1 & 7 & 2 & 1 \end{pmatrix}$ is
a. 0
b. 1
c. [illegible]
d. [illegible]

4. The harmonic series $\sum_{n=1}^{\infty} \frac{1}{n^p}$
a. converges for $p > 1$
b. diverges for $p > 1$
c. converges for $p < 1$
d. diverges for $p < 1$

5. A solution of specific gravity 1.0 consists of 35% A by weight and the remaining B. If the specific gravity of A is 0.7, the specific gravity of B is
a. 1.25
b. 1.3
c. 1.35
d. 1.2

6. Pure A in gas phase enters a reactor. 50% of this A is converted to B through the reaction $A \rightarrow 3\ B$. Mole fraction of A in the exit stream is
a. 1/2
b. 1/3
c. 1/4
d. 1/5

7. Which of the following is true for Virial equation of state
a. Virial coefficients are universal constants
b. Virial coefficient B represents three body interactions
c. Virial coefficients are functions of temperature only
d. For some gases, Virial equations and ideal gas equations are the same

8. A gas mixture of three components is brought in contact with a dispersion of an organic phase in water. The degrees of freedom of the system are
a. 4
b. 3
c. 5
d. 6

9. A pipe of I.D. 4 m is bifurcated into two pipes of I.D. 2 m each. If the average velocity of water flowing through the main pipe is 5 m/s, the average velocity through the bifurcated pipes is
a. 20 m/s
b. 10 m/s
c. $5\sqrt{2}$ m/s
d. 5 m/s

10. In centrifugal pumps, cavitation occurs when pressure of the impeller eye or vane becomes
a. less than atmospheric pressure
b. more than liquid vapour pressure

c. less than liquid vapour pressure
d. more than atmospheric pressure

11. For laminar flow through a packed bed, the pressure drop is proportional to (V_s is the superficial liquid velocity and D_p is the particle diameter)
a. V_s / D_p^2
b. V_s^2 / D_p^2
c. V_s^2 / D_p^3
d. V_s / D_p^3

12. For a turbine-agitated and baffled tank, operating at low Reynolds number (based on impeller diameter), the power number (N_p) varies with N_{Re}, as
a. $N_p \propto N_{Re}$
b. $N_p \propto \sqrt{N_{Re}}$
c. $N_p \rightarrow$ costant
d. $N_p \propto 1/N_{Re}$

13. Gibbs phase rule finds application when heat transfer occurs by
a. conduction
b. convection
c. radiation
d. condensation

14. As the difference between the wall temperature and the bulk temperature increases, the boiling heat transfer coefficient
a. continues to increase
b. continues to decrease
c. goes through a minimum
d. goes through a maximum

15. In pipe flow, heat is transferred from hot wall to the liquid by
a. conduction only
b. forced convection only
c. forced convection and conduction
d. free and forced convection

16. Heat transfer occurs by natural convection because change in temperature causes differences in
a. viscosity
b. density
c. thermal conductivity
d. heat capacity

17. Solvent used in extractive distillation
a. is of low volatility
b. forms a low-boiling azeotrope
c. forms a high-boiling azeotrope
d. does not alter the relative volatility of the original components

18. The recovery of penicillin from the acidified fermentation broth is done by
a. distillation
b. evaporation
c. absorption
d. liquid extraction

19. Penetration theory states that the mass transfer coefficient is equal to (where D_e is diffusivity and t is time)
a. $(D_e t)^{1/2}$
b. $(D_e/t)^{1/2}$
c. $(4D_e/\pi)^{1/2}$
d. $(4D_e/t)^{1/2}$

20. An alkaline solution is used to reduce the concentration of carbon dioxide in a stream from 10% to 0.1% by absorption with irreversible chemical reaction. The overall number of transfer units based on gas phase is
a. 9.21
b. 4.605
c. 100
d. 0.001

21. Overall order of reaction for which rate constant has units of $(mol/L)^{-(3/2)} sec^{-1}$ is
a. –3/2
b. 1/2
c. 3/2
d. 5/2

22. For the reaction $A + B \rightarrow 2B + C$,
a. $r_A = r_B$
b. $r_A = -r_B$
c. $r_A = 2 r_B$
d. $r_A = r_B / 2$

23. The exit age distribution curve E(0) for an ideal CSTR with the average residence time τ, is given by
a. $e^{-t/\tau}$
b. $(1/\tau)e^{-t/\tau}$
c. $1-e^{-t/\tau}$
d. $1-(1/\tau)e^{-t/\tau}$

24. An endothermic second-order reaction is carried out in an adiabatic plug flow reactor. The rate of heat generation is
    a. maximum at the inlet of the reactor
    b. maximum at the exit of the reactor
    c. maximum at the center of the reactor
    d. constant throughout the reactor

25. The Laplace transform of exp(at), where a > 0, is defined only for the Laplace parameter, S > a, since
    a. the function is exponential
    b. the Laplace-transform integral of exp(at) has finite values only for s > a
    c. the Laplace-transform integral of exp(at) has initial values only for s > a
    d. the function exp(at) is piece-wise continuous only for s > a

26. A system with a double pole at the origin is unstable since the corresponding term in the time domain
    a. is a constant
    b. grows exponentially with time
    c. grows linearly with time
    d. decays linearly with time

27. A sinusoidal variation in the input passing through a linear first-order system
    a. becomes more oscillatory (frequency increases)
    b. becomes less oscillatory (frequency decreases)
    c. gets amplified (magnitude increases)
    d. gets attenuated (magnitude decreases)

28. A typical example of a physical system with under-damped characteristics is a
    a. U-tube manometer
    b. spring-loaded diaphragm valve
    c. CSTR with first-order reaction
    d. thermocouple kept immersed in a liquid-filled thermowell

29. In a manufacturing industry, break-even point occurs when
    a. the total annual rate of production equals the assigned value
    b. the total annual product cost equals the total annual sales
    c. the annual profit equals the expected value
    d. the annual sales equals the fixed costs

30. Hastelloy C is a good material of construction in chemical process industry since it is
    a. highly corrosion-resistant and is readily fabricated
    b. relatively inexpensive although it can be fabricated with some difficulty
    c. corrosion-resistant to most alkalis, particularly because of its Cu content
    d. light and resists attack by acids

31. In a heat exchanger, floating head is provided to
    a. facilitate cleaning of the exchanger
    b. increase the heat transfer area
    c. relieve stresses caused by thermal expansion
    d. increase the log mean temperature gradient

32. Sucrose is a disaccharide consisting of
    a. glucose and glucose
    b. glucose and fructose
    c. glucose and galactose
    d. fructose and galactose

33. The organic acid monomer in Nylon 66 is
    a. sebacic acid
    b. terephthallic acid
    c. adipic acid
    d. benzoic acid

34. Which one of the following is not likely to be a constituent of vegetable oils?
    a. citric acid
    b. oleic acid
    c. stearic acid
    d. glycerol

35. The gas which contributes the maximum to the heating value of natural gas is
    a. CO
    b. CO_2
    c. H_2
    d. CH_4

TWO MARKS QUESTIONS (36-65)

For each of the following questions (36 to 52), four alternatives – A, B, C and D are provided. Indicate the correct answer by writing A, B, C or D, as appropriate, against the corresponding question number in the answer book. For

questions 53 to 55 two items are indicated in the left-hand column and six items in the right-hand column. Each item in the left-hand column is closely associated with one of the items in the right-hand column. For each question, write the appropriate match in the corresponding box in the answer book

(Marks: 2 × 20 = 40)

36. A box contains 8 balls, 2 of which are defective. The probability that none of the balls drawn are defective when two are drawn at random without replacement is
    a. 15/28
    b. 9/16
    c. 7/16
    d. 1/8

37. The gradient of $xy^2 + yz^3$ at the point (–1,2,1) is
    a. $3\hat{i}-3\hat{j}+3\hat{k}$
    b. $3\hat{i}-3\hat{j}+6\hat{k}$
    c. $4\hat{i}-\hat{j}+3\hat{k}$
    d. $4\hat{i}-3\hat{j}+6\hat{k}$

38. Saturated solution of benzene in water is in equilibrium with a mixture of air and vapours of benzene and water at room temperature and pressure. Mole fraction of benzene in liquid is x_B and the vapour pressures of benzene and water at these conditions are p_v^B and p_v respectively. The partial pressure of benzene in air-vapour mixture is
    a. p_v^B
    b. $x_B p_v^B$
    c. $(p_{atm} - p_v$
    d. $x_B p_$

39. For the reversible reaction A ⇌ 2B, if the equilibrium constant K is 0.05 mol/lit, starting from initially 2 moles of A and zero moles of B, how many moles will be formed at equilibrium?
    a. 0.253
    b. 0.338
    c. 0.152
    d. 0.637

40. Maxwell's relation corresponding to the identity, $dH = T\,dS + V\,dP + \Sigma\mu_i dn_i$ is
    a. $\left(\frac{\partial T}{\partial V}\right)_{S,n_i} = -\left(\frac{\partial P}{\partial S}\right)_{V,n_i}$
    b. $\left(\frac{\partial S}{\partial P}\right)_{T,n_i} = \left(\frac{\partial V}{\partial T}\right)_{P,n_i}$
    c. $\left(\frac{\partial S}{\partial V}\right)_{T,n_i} = \left(\frac{\partial P}{\partial T}\right)_{V,n_i}$
    d. $\left(\frac{\partial T}{\partial P}\right)_{S,n_i} = \left(\frac{\partial V}{\partial S}\right)_{P,n_i}$

41. Velocity of a small particle of diameter D_p at a distance r from the rotational axis of a cyclone rotating at an angular speed ω is given by (the other symbols are as per standard notation)
    a. $\left(\frac{D_p}{18}\frac{\rho_p - \rho}{\mu}\right)\omega^2 r$
    b. $\left(\frac{D_p^2}{18}\frac{\rho_p - \rho}{\mu}\right)\omega r^2$
    c. $\left(\frac{D_p}{18}\frac{\rho_p - \rho}{\mu}\right)\omega^2 r^2$
    d. $\left(\frac{D_p^2}{18}\frac{\rho_p - \rho}{\mu}\right)\omega^2 r$

42. Water is flowing at 1 m/s through a pipe (of 10 cm I.D.) with a right angle bend. The force in Newtons exerted on the bend by the water is
    a. $10\sqrt{2}\pi$
    b. $5\pi/2$
    c. $5\sqrt{2}\pi$
    d. $5\pi/\sqrt{2}$

43. Rate of heat transfer through a pipe wall is given by

$$q = \frac{2\pi k(T_i - T_0)}{\ln\left(\frac{r_i}{r_0}\right)}$$

For cylinders of very thin wall, q can be approximated by
    a. $q = \frac{2\pi k\left[(T_i + T_0)/2\right]}{\ln\left(\frac{r_0}{r_i}\right)}$
    b. $q = \frac{2\pi r_i k(T_i - T_0)}{(r_0 - r_i)}$

c. $q = \frac{2\pi k(T_i - T_0)}{(r_0 - r_i)}$

d. $q = \frac{2\pi k(T_i - T_0)}{[(r_i + r_0)/2]}$

44. For a counter-current heat exchanger with $T^i_h = 80$ C, $T^o_c = 60$ C, $T^o_h = 50$ C, and $T^i_c = 30$ C, and the temperature difference between the two streams being the same everywhere along z, the direction of flow of the hot fluid, the temperature profile should satisfy

a. $\frac{d^2T}{dz^2} > 0$

b. $\frac{d^2T}{dz^2} = 0$

c. $\frac{d^2T}{dz^2} < 0$

d. $\frac{dT}{dz} = 0$

45. Walls of a cubical oven are of thickness L, and they are made of material of thermal conductivity, k. The temperature inside the oven is 100 C and the inside heat transfer coefficient is $\frac{3k}{L}$. If the wall temperature on the outside is held at 25 C, what is the inside wall temperature in degrees C?

a. 35.5

b. 43.75

c. 81.25

d. 48.25

46. If the specific heats of a gas and a vapour are 0.2 kJ/kg K and 1.5 kJ/kg K respectively, and the humidity is 0.01, the humid heat in kJ/kg K is

a. 0.31

b. 0.47

c. 0.017

d. 0.215

47. The Vapour pressures of benzene and toluene are 3 and 4/3 atmospheres respectively. A liquid feed of 0.4 moles of benzene and 0.6 moles of toluene is vaporized. Assuming that the products are in equilibrium, the vapour phase mole fraction of benzene is

a. 0.4

b. 0.6

c. 0.8

d. 0.2

48. For the liquid phase zero-order irreversible reaction A → B, the conversion of A in a CSTR is found to be 0.3 at a space velocity of 0.1 min^{-1}. What will be the conversion for a PFR with a space velocity of 0.2 mm^{-1} ? Assume that the all the other operating conditions are the same for CSTR and PFR.

a. 0.15

b. 0.3

c. 0.6

d. 0.9

49. Consider the nth order irreversible liquid phase reaction A → B. Which one of the following plots involving half-life of the reaction ($t_{1/2}$) and the initial reactant concentration (C_{A0}) gives a straight line plot?

a. C_{A0} vs. $t_{1/2}$

b. In C_{A0} vs. $t_{1/2}$

c. C_{A0} vs. In $t_{1/2}$

d. In C_{A0} vs. In $t_{1/2}$

50. At a given value of E/R (ratio of activation energy and gas constant), the ratio of the rate constants at 500 K and 400 K is 2 if Arrhenius law is used. What will be this ratio if transition-state theory is used with the same value of E/R?

a. 1.6

b. 2

c. 2.24

d. 2.5

51. A control system has the following transfer function,

a. 1

b. 1/8

c. 7/8

d. –1

52. Which of the systems having the following transfer functions is stable?

a. $\frac{1}{s^2 + 2}$

b. $\frac{1}{s^2 - 2s + 3}$

c. $\frac{1}{s^2+2s+2}$

d. $\frac{\exp(-20s)}{s^2+2s-1}$

53. Each item given in the left-hand column is closely associated with a specific characteristic listed in the right-hand column. Match each of the items with the corresponding characteristic.

[Write both answers in Box No. 53]

A. Transportation lag
B. Control valve

1. Increase in gain margin
2. Phase lag is proportional to frequency
3. Hyperbolic
4. Unstable response
5. Increase in phase margin
6. Phase angle is –90°

54. Each of the methods given in the left-hand column is closely linked to one of the items listed in the right-hand column Match each method with the corresponding item.

[Write both answers in Box No. 54]

A. Discounted cash flow
B. Declining balance

1. Depreciation
2. Payout period
3. Profitability analysis
4. Solvage value
5. Annuity
6. Working capital

55. Match each polymer mentioned in the left-hand column with the corresponding chemical name listed in the right-hand column.

[Write both answers in Box No. 55]

A. Perspex
B. Rayon

1. Polysaccharide
2. Polyamide
3. Polyacrylate
4. Polyester
5. Polyether
6. Polyolefin

SECTION B

Five Marks Questions (56 & 78)

Answer any fifteen questions

(Marks: 5 × 15 = 75)

56. Evaluate $\int_0^1 (4x^2 + x)\,dx$ by trapezoidal rule. Use a step size of 0.2. Obtain the error bounds for this solution. Compute the absolute error of the numerical solution by evaluating the integral analytically.

57. Solve $\frac{dy}{dx} - 6xy = -6x$ by the following methods:

a. variation of parameters
b. separation of variables

58.

a. At what points are the Cauchy-Reiman equations satisfied for the function, $F(z) = xy^2 + i\,x^2y$? Where is F(z) analytic?

b. Compute the distinct cube roots of (1+i).

59. It is proposed to produce acetaldehyde by oxidation of ethanol in gas phase

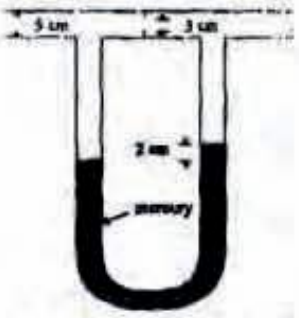
$C_2H_5OH\,(g) + 1/2\,O_2(g) \rightarrow CH_3CHO\,(g) + H_2O\,(g)$

The ratio of air to ethanol in the fresh feed (before it is mixed with recycle stream) is 10 to 1. The conversion of ethanol on a single pass through the reactor is 25%. The unreacted ethanol is completely separated from the reaction products and recycled. What is the ratio of recycle stream to the fresh feed stream? What is the composition of the outlet stream from the rector in mass fraction and mole fraction?

60. $CaCO_3$ slurry has to be dried. The drier is designed to remove 100 kg moisture per hour. Air at 20 C and 40% relative humidity, enters the drier and leaves at 65 °C and 65% relative humidity. What is the weight (in kg) of bone-dry air required per hour? The atmospheric pressure is 103 kPa. If the humidity of the air entering the drier can be varied, what is the minimum amount of dry air required? The constants for Antoine equation for vapour pressure of water iii mm Hg may be taken as A = 18.306, B = 3816.44, and C = –46.13.

61. For the binary system methanol (1) and benzene (2), the recommended values of the Wilson parameters at 68 C are A_{12} = 0.1751 and A_{21} = 0.3456. The vapour pressure of pure species at 68 C are p_1^{sat} = 68.75 kPa and p_2^{sat} = 115.89 kPa. Show that the given system can form an azeotrope at 68 C. Assume that the vapour behaves like an ideal gas.

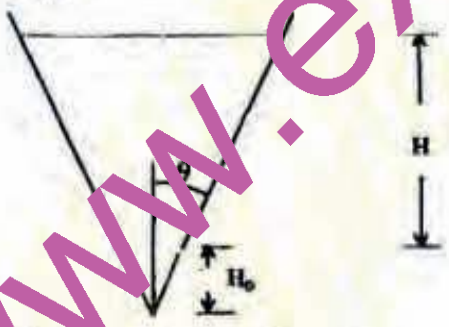
62. Flow rate of water flowing through a pipe is being measured by using an orifice meter as shown in the following figure.



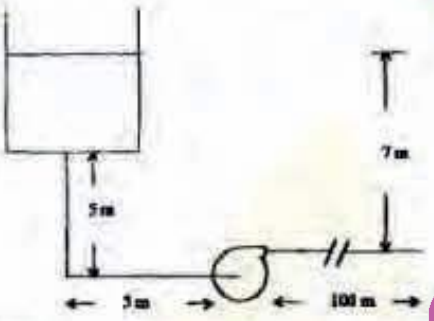
a. What is the direction of flow in the pipe?

b. Derive an expression for velocity through the orifice. Determine the flow rate for an orifice coefficient of 0.8.

63. Derive an expression to obtain the time required to empty the vessel containing water as shown in the following figure. The cross sectional area of the opening at the bottom of the tank is a. Assume that $H_0 \ll H$.



64. Oil of viscosity 100 cP is to be pumped as shown in the following figure. The pipe used every where is of 7 cm I.D. If the efficiency of the pump is 80 %, find the energy required for pumping the oil at 20 m^3/hr. Density of the oil is 800 kg/m^3.



65. Obtain expressions for steady state temperature profile and heat transfer rate for a hollow spherical container. The inner surface (at $r = r_i$) is maintained at $T = T_i$, and the outer surface (at $r = r_0$) is maintained at $T = T_0$.

66. 150 kg of water is to be heated in a steam-jacketed vessel from 25 C to 80 C. Steam is condensing at 120 C and the heat transfer area is 0.25 m^2. The heat transfer coefficient for condensation of steam and heating of water by convection are 1000 W/m^2 C and 500 W/m^2 C respectively. Write appropriate unsteady balance equations and find the time required for heating the water. Assume that the specific heat of water in the temperature range of interest is 4.18×10^3 J/kg C.

67. Stripping of ammonia is carried out at a pressure of 1.1 atms. One m^3 of water enters the system and the ratio of the molar flow rate of air and that of the water is 4. The inlet air and the inlet water have 0.1 and 1.0 mole percent of ammonia respectively. The Murphree vapour plate efficiency for ammonia removal is 50% and the Henry's law constant for ammonia in water is 2.574 × 10 atm m^3/mol. determine the exit water composition and the exit air composition.

68. Determination of efficiency is critical in plate column design. The gas and liquid rates are 0.1 and 0.25 kmol/s respectively. The interfacial area for mass transfer is 35 m^2/m^3 froth on the plate. The residence time of both the liquid and gas in the froth zone is 3seconds. The liquid phase and gas phase mass transfer coefficients are 1×10^{-2} m/s and 2×10^{-3} m/s respectively. Calculate

a. liquid phase transfer units

b. gas phase transfer units

c. stripping factor, given that the slope of the equilibrium curve is 5

d. overall transfer units

e. Murphree point efficiency

69. Two parallel first-order reactions A → B and A → C are taking place in liquid phase in a well-mixed batch reactor. After 60 mm. of operation, 80 % of A has reacted awhile 2 moles of B per mole of C was detected in the reactor. Calculate the rate constants k_1 and k_2 for the two reactions. Assume that no B and C were initially present in the reactor.

70. An isothermal plug flow reactor is designed to give 80 % conversion of A for a second-order liquid phase reaction A → B. Pure A at concentration 1 kmol/m^3 is fed to the reactor at a flow rate of 5 m^3/hr The rate constant for the reaction at a specified operating temperature is 0.5 m^3/kmol h. When the reactor is actually operated based on this design, it was found that 30 % of the initial reactor behaved as a well-mixed reactor while the remaining behaved as a plug flow reactor. Calculate the conversion obtained in such a reactor.

71. For an exothermic reaction A → B, [illegible] kmol of B are to be produced while achieving 90 % conversion of [illegible] isothermal batch reactor operated at 500 K. The reaction is to be started with pure A at the concentration of 10 kmol/m^3. Determine the volume of the reactor, duration of the batch operation and the total heat removed during the isothermal operation. The heat of the reaction at 500 K is – 40 kJ/mol of A reacted. Following additional information is available to determine the order and rate constant of the reaction. Laboratory experiments conducted at 500 K with 1 kmol/m^3 initial concentration of pure A showed that 20% conversion is obtained in 20 min. while 50 % conversion is obtained in 80 min. The reaction is suspected to be either first or second order.

72. A proportional controller is used for the control of a first-order system. If the dynamics of all the other units in the control loop are negligible and their steady-state gains are all equal to unity, show that

a. the response of the controlled process is faster than that of the uncontrolled process, and

b. the offset, both for changes in the set point and in the load variable, decreases as the parameter of the controller is increased.

73. A second-order process with the transfer function

$$K_p G_p = \frac{1}{s^2 + 2s + 3}$$

is controlled with a proportional-integral controller, if all the other lags in the control loop are negligible and their steady-state gains are all equal to unity, find the relation between the parameters of the controller, that should be satisfied for the control system to be stable.

74. A piece equipment made of material A costs, post installation, Rs. 3 lakhs and is expected to have a scrap value of 10% of this cost at the end of a useful life of 10 years. Similar equipment made of material B costs Rs. 1.5 lakhs, but is likely to have no scrap value. Assume that both types of the equipment could be replaced at a cost that is 20 % more than the original value. On the basis of equal capitalized costs for both types of the equipment, estimate what should be the useful life for equipment made of material B. The company has to pay an annual interest on the investment at a rate of 15 %.

75. Write the overall chemical reaction (stoichiometrically balanced) for the manufacture of each of the following chemicals

a. vinyl acetate from ethylene

b. urea from ammonia

c. styrene from ethyl benzene

d. caustic soda from brine

e. triple super phosphate from phosphate rock