CHEMICAL ENGINEERING

SECTION–A (75 Marks)

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 HB pencil. Do not use the ORS for any rough work. You can use the Answer Book for any rough work.

(Marks: 1 × 25 = 25)

1. In the complex plane, the angle between lines 1 + i and -1 + i (where i = $i = \sqrt{-1}$) is
   a. π/4
   b. π/2
   c. 3π/4
   d. π

2. The inverse of the matrix $\begin{bmatrix} 0.2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0.5 \end{bmatrix}$ is
   a. $\begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 5 \end{bmatrix}$
   b. $\begin{bmatrix} -0.2 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -0.5 \end{bmatrix}$
   c. $\begin{bmatrix} 5 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 2 \end{bmatrix}$
   d. $\begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0.2 \end{bmatrix}$

3. Which of the following conditions are satisfied at the critical point by the P-V-T relation of a real fluid
   a. $\left(\frac{\partial^2 P}{\partial V^2}\right)_T = \left(\frac{\partial P}{\partial V}\right)_T = 0$
   b. $\left(\frac{\partial^2 P}{\partial V^2}\right)_T > 0, \left(\frac{\partial P}{\partial V}\right)_T = 0$
   c. $\left(\frac{\partial^2 P}{\partial V^2}\right)_T < 0, \left(\frac{\partial P}{\partial V}\right)_T = 0$
   d. $\left(\frac{\partial^2 P}{\partial V^2}\right)_T > 0, \left(\frac{\partial P}{\partial V}\right)_T > 0$

4. Which of the following holds for any non-zero vector a
   a. $\nabla . a = 0$
   b. $\nabla \times a = 0$
   c. $\nabla . (\nabla \times a) = 0$
   d. $\nabla (\nabla \times a) = 0$

5. With increasing flow rate, the hydraulic efficiency of a centrifugal pump
   a. monotonically decreases
   b. decreases and then increases
   c. remains constant
   d. increases and then decreases

6. For flow past a flat plate. if x is the distance along the plate in the direction of flow, the boundary layer thickness is proportional to
   a. $\sqrt{x}$
   b. $\frac{1}{\sqrt{x}}$
   c. x
   d. $\frac{1}{x}$

7. For turbulent flow of an incompressible fluid through a pipe, the flow rate Q is proportional to $(\Delta P)^n$, where ΔP is the pressure drop. The value of exponent n is
   a. 1
   b. 0
   c. < 1
   d. > 1

8. For an ideal plug flow reactor the value of the Peclet number is
   a. 0
   b. ∞
   c. 1

d. 10

9. The extent of a reaction is

a. different for reactants and products
b. dimensionless
c. dependent on the stoichiometric coefficients
d. all of the above

10. An exothermic reaction takes place in an adiabatic reactor. The product temperature (choose the correct option) ... the reactor feed temperature

a. is always equal to
b. is always greater than
c. is always less than
d. may be greater or less than

11. Methane is mixed with stoichiometrie proportion of oxygen and completely combusted. The number of additional specifications required to determine the product flow rate and composition is

a. 0
b. 1
c. 2
d. 3

12. If the baffle spacing in a shell and tube heat exchanger increases, then the Reynolds number of the shell side fluid

a. Remains unchanged
b. Increases
c. Increases or decreases depending on number of shell passes
d. Decreases

13. The total investment in a project is Rs. 10 lakhs and the annual profit is Rs. 1.5 lakhs. If the project life is 10 years, then the simple rate of return on investment is

a. 15%
b. 10%
c. 1.5%
d. 150%

14. The closed loop poles of a stable second order system could be

a. both real and positive
b. complex conjugate with positive real parts
c. both real and negative
d. one real positive and the other real negative

15. A first order system with unity gain and time constant τ is subjected to a sinusoidal input of frequency $\omega = 1/\tau$. The amplitude ratio for this system is

a. 1
b. 0.5
c. $1/\sqrt{2}$
d. 0.25

16. If d_p is the equivalent diameter of a non-spherical particle, v_p its volume and s_p its surface area, then its sphericity ϕ is defined by

a. $\varphi_s = 6v_p / d_p s_p$
b. $\varphi_s = v_p / d_p s_p$
c. $\varphi_s = 6d_p s_p / v_p$
d. $\varphi_s = d_p s_p / v_p$

17. Arrange the following size reduction equipment in the decreasing order of the average particle size produced by each of them.

a. Jaw crushers, Ball mills, Fluid energy mills
b. Ball mills, Jaw crushers. Fluid energy mills
c. Fluid energy mills, Jaw crushers, Ball mills
d. Fluid energy mills, Ball mills, Jaw crushers

18. From among the following, choose one that is not an exothermic process

a. Methanol synthesis
b. Catalytic cracking
c. Ammonia synthesis
d. Oxidation of sulphur

19. The commonly used solvent in supercritical extraction is

a. Methyl-ethyl-ketone
b. Water
c. Carbon tetrachloride
d. Carbon dioxide

20. The average boiling point of aviation turbine fuel is closest to that of

a. Lubricating oils
b. LPG
c. Diesel
d. Kerosene

21. The number of degrees of freedom for an azeotropic mixture of ethanol and water in vapour-liquid equilibrium, is
   a. 3
   b. 1
   c. 2
   d. 0

22. The partial molar enthalpy of a component in an ideal binary gas mixture of composition z, at a temperature T and pressure P. is a function only of
   a. T
   b. T and P
   c. T, P and z
   d. T and z

23. Which of the following identities can be most easily used to verify steam table data for superheated steam
   a. $\left(\partial T/\partial V\right)_V = -\left(\partial P/\partial S\right)_V$
   b. $\left(\partial T/\partial P\right)_S = \left(\partial V/\partial S\right)_P$
   c. $\left(\partial P/\partial T\right)_V = \left(\partial S/\partial V\right)_T$
   d. $\left(\partial V/\partial T\right)_P = -\left(\partial S/\partial P\right)_T$

24. The dimensionless group in mass transfer that is equivalent to Prandtl number in heat transfer is
   a. Nusselt number
   b. Sherwood number
   c. Schmidt number
   d. Stanton number

25. The Reynolds analogy for momentum, heat and mass transfer is best applicable for
   a. Gases in turbulent flow
   b. Gases in laminar flow
   c. Liquids in turbulent flow
   d. Liquids and gases in laminar flow

TWO MARKS QUESTIONS (26-50)

This section 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 can use the Answer Book for any rough work.

(Marks: 2 × 25 = 50)

26. The coefficient of ^{x2} in the Taylor series of $\cos^2 x$ about 0 is
   a. 2
   b. 0
   c. 1
   d. -1

27. Three grades of paint (A, B & C, production rates: [2, 24 & 18 batches per day, respectively) are produced in independent batch production lines and stored in separate areas. The number of off-specification batches in a day is 1, 3 and 2 for grades A, B & C, respectively. The probability of picking an off-specification batch from a randomly chosen storage area is
   a. $\frac{23}{216}$
   b. $\frac{24}{216}$
   c. $\frac{19}{216}$
   d. $\frac{18}{216}$

28. The drag coefficient for a bacterium moving in water at 1 mm/s, will be of the following order of magnitude (assume size of the bacterium to be 1 micron and kinematic viscosity of water to be 10^{-6} m^2/s)
   a. 24000
   b. 24
   c. 0.24
   d. 0.44

29. A gas (density = 1.5 kg/m^3, viscosity = 2×10^{-5} kg/m s) flowing through a packed bed (particle size = 0.5 cm, porosity = 0.5) at a superficial velocity of 2 m/s causes a pressure drop of 8400 Pa/m. The pressure drop for another gas, with density of 1.5 kg/m^3 and viscosity of 3×10^{-5} kg/m s, flowing at 3 m/s will be
   a. 8400 Pa/m
   b. 18900 Pa/m
   c. 12600 Pa/m

d. 16800 Pa/m

30. A pulse tracer is introduced in an ideal CSTR (with a mean residence time τ) at time = 0. The time taken for the exit concentration of the tracer to reach half of its initial value will be

a. 2τ

b. 0.5τ

c. $\tau/0.693$

d. 0.693τ

31. A batch adiabatic reactor at an initial temperate of 373K is being used for the reaction A $\rightarrow$ B. Assume the heat of reaction is -1 kJ/mol at 373 K and the heat capacity of both A and B to be constant and equal to 50 J/mol K. The temperature rise after a conversion of 0.5 will be

a. 5°C

b. 10°C

c. 20°C

d. 100°C

32. Steam undergoes isentropic expansion in a turbine from 5000 kPa and 400°C (entropy = 6.65 kJ/kg K) to 150 kPa (entropy of saturated liquid = 1.4336 kJ/kg K, entropy of saturated vapour = 7.2234 kJ/kg K). The exit condition of steam is

a. superheated vapour

b. partially condensed vapour with quality of 0.9

c. saturated vapour

d. partially condensed vapour with quality of 0.1

33. According to the Fenske equation, what will be the minimum number of plates required in a distillation column to separate an equimolar binary mixture of components A & B into an overhead fraction containing 99 mole % A and a bottoms fraction containing 98 mole % B? [Assume that the relative volatility (α_{AB} = 2) does not change appreciably in the column]

a. 5

b. 9

c. 12

d. 28

34. A 10 cm diameter steam pipe, carrying steam at 180°C, is covered with an insulation (conductivity = 0.6 W/n°C). It loses heat to the surroundings at 30°C. Assume a heat transfer coefficient of 8.0 W/m^2 °C for heat transfer from surface to the surroundings. Neglect wall resistance of the pipe and film resistance of steam. If the insulation thickness is 2 cm, the rate of heat loss from this insulated pipe will be

a. greater than that of the un-insulated steam pipe

b. less than that of the un-insulated steam pipe

c. equal to that of the un-insulated steam pipe

d. less than the steam pipe with 5 cm insulation

35. 1000 kg of liquid at 30°C in a well-stirred vessel has to be heated to 120°C, using immersed coils carrying condensing steam at 150°C. The area of the steam coils is 1.2 m^2 and overall heat transfer coefficient to the liquid is 1500 W/m^2 °C. Assuming negligible heat loss to surrounding and specific heat capacity of the liquid to be 4 kJ/kg °C, the time taken for the liquid to reach desired temperature will be

a. 15 min

b. 22 min

c. 44 min

d. 51 min

36. Fresh orange juice contains 12% (by weight) solids and the rest water. 90% of the fresh juice is sent to an evaporator to remove water and subsequently mixed with the remaining 10 % of fresh juice. The resultant product contains 40 % solids. The kg of water removed from 1 kg fresh juice is

a. 0.4

b. 0.5

c. 0.6

d. 0.7

37. 1 kg of a saturated aqueous solution of a highly soluble component A at 60°C is cooled to 25°C. The solubility limits of A are (0.6 kg A)/(kg water) at 60°C and (0.2 kg A)/(kg water) at 25°C. The amount, in kgs, of the crystals formed is

a. 0.4

b. 0.25

c. 0.2

d. 0.175

38. In the hydrodealkylation of toluene to benzene, the following reactions occur

$$C_7H_8 + H_2 \rightarrow C_6H_6 + CH_4$$

$$2C_6H_6 \Leftrightarrow C_{12}H_{10} + H_2$$

Toluene and hydrogen are fed to a reactor in a molar ratio 1:5. 80 % of the toluene gets converted and the selectivity of benzene (defined as moles of benzene formed moles of toluene converted) is 90%. The fractional conversion of hydrogen is

a. 0.16
b. 0.144
c. 0.152
d. 0.136

39. If an amount R is paid at the end of every year for n years, then the net present value of the annuity at an interest rate of i is

a. $R\left[\frac{(1+i)^n - 1}{i}\right]$

b. $R\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$

c. $R(1+i)^n$

d. $\frac{R}{(1+i)^n}$

40. A company has a depreciable investment of Rs 36300 which is depreciated in equal installments in two years. Assume that the tax rate is 50 % and interest rate is 10 %. The net present value of tax that the company would have saved, if it had depreciated 2/3 of the investment in the first year and the rest in the second year, is

a. 0
b. 250
c. 375
d. 500

41. The frequency response of a first order system, has a phase shift with lower and upper bounds given by

a. $\left[-\infty, \frac{\pi}{2}\right]$

b. $\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$

c. $\left[-\frac{\pi}{2}, 0\right]$

d. $\left[0, \frac{\pi}{2}\right]$

42. A cylindrical pressure vessel of volume 6π m^3 has to be designed to withstand a maximum internal pressure of 10 atm. The allowable design stress of the material is 125 N/mm^2 and corrosion allowance is 2 mm. The thickness of the vessel for a length/diameter ratio of 3 will be close to

a. 5 mm
b. 6 mm
c. 8 mm
d. 10 mm

43. A composite wall consists of two plates A and B placed in series normal to the flow of heat. The thermal conductivities are k_A and k_B and the specific heat capacities are C_{pA} and C_{rB}, for plates A and B respectively. Plate B has twice the thickness of plate A. At steady state, the temperature difference across plate A is greater than that across plate B when

a. $C_{pA} > C_{pB}$
b. $C_{pA} < C_{pB}$
c. $k_A < 0.5k_B$
d. $k_A > 2k_B$

44. It takes 6 hours to dry a wet solid from 50% moisture content to the critical moisture content of 15 %. How much longer will it take to dry the solid to 10% moisture content, under the same drying conditions (the equilibrium moisture content of the solid is 5%.)

a. 15 min
b. 51 min
c. 71 min
d. 94 min

45. What is the critical rotational speed, in revolutions per second, for a ball mill of 1.2 in diameter charged with 70 mm diameter balls

a. 0.5
b. 1.0
c. 2.76
d. 0.66

46. A sand mixture was screened through a standard 10-mesh screen. The mass fraction of the oversize material in feed, overflow and underflow were found to be 0.38, 0.79 and 0.22, respectively. The screen effectiveness based on the oversize is

a. 0.50
b. 0.58
c. 0.68
d. 0.62

47. A rigid vessel, containing three moles of nitrogen gas at 30°C, is heated to 250°C Assume the average heat capacities of nitrogen to be C_p = 29.1 J/mol°C and C_v = 20.8 J/mol °C. The heat required, neglecting the heat capacity of the vessel, is

a. 13728 J
b. 19206 J
c. 4576 J
d. 12712 J

48. 1 m^3 of an ideal gas at 500 K and 1000 kPa expands reversibly to 5 times its initial volume in an insulated container. If the specific heat capacity (at constant pressure) of the gas is 21 J/mol K, the final temperature will be

a. 35 K
b. 174 K
c. 274 K
d. 154 K

49. In the manufacture of sulphuric acid from elemental sulphur, the following sequence of major operations is followed

a. furnace → converter → absorber
b. furnace → evaporator → absorber
c. furnace → convener → evaporator
d. converter → furnace → absorber

50. Consider the production of ammonia from methane and air as raw materials. The catalysts used are (a)---- for steam reforming of methane and (b)---- for ammonia synthesis

a. (a) Ni/Al_2O_3 (b) $Cu\text{-}ZnO/Al_2O_3$
b. (a) Fe/Al_2O_3 (b) $Cu\text{-}ZnO/Al_2O_3$
c. (a) Ni/Al_2O_3 (b) Fe/Al_2O_3
d. (a) Fe/Al_2O_3 (b) Ni/Al_2O_3

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 x 15 = 75)

51. Sodium hydroxide is produced in an electrolytic cell by the electrolysis of brine.

a. Write the reactions at the anode, cathode and the overall reactions in a Mercury Cell and a Diaphragm Cell.
b. Mercury cells produce more concentrated NaOH solution compared to .membrane cells. However, membrane cells are widely replacing the mercury cells in the chloralkali industry. Give two major reasons for this trend.
c. Define the decomposition efficiency of an electrolytic cell used for producing NaOH.
d. If 1.158×10^5 Coulombs is used to deposit 1 gram equivalent of NaOH, what is the current efficiency of the cell?

52. Reduce the following differential equation to linear form

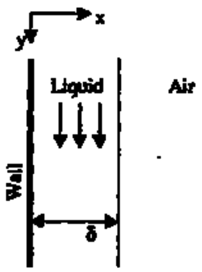
$$\frac{dz}{dt} + zt = z^{-1}t$$

a. Find a general solution to the linearised equation.
b. Determine the integration constants if z(0) = 0.

53. Matrix $A = \begin{bmatrix} 0.1 & 0.5 & 0 \\ 0.8 & 0 & 0.4 \\ 0.1 & 0.5 & 0.6 \end{bmatrix}$ has the property that it satisfies Ax = x, for any vector x.

a. Write the characteristic equation to be solved for eigenvalues of A.
b. Based on visual observation, find one of the eigenvalues of A.
c. Find the other two eigenvalues of A.

54. Consider the flow in a liquid film of constant thickness (δ) along a vertical wall as shown in the figure below.



Assuming laminar, one-dimensional, fully developed flow, the y-direction Navier Stokes equation reduces to

$$\mu \frac{d^2 v_y}{dx^2} + \rho g = 0$$

(where v_y is the velocity in y direction, μ is the viscosity and ρ is the density of the liquid.)

a. State the boundary conditions to be used for the solution of velocity profile?

b. Solve for the velocity profile.

c. If Q is the volumetric flow rate per unit width of the wall, how is it related to the film thickness δ.

55. The power required to stir water (density = 1000 kg/m^3, viscosity = 0.001 kg/m s) in a laboratory experiment with the impeller (diameter = 5 cm, blade width = 1 cm) rotating at 5 rpm is 10^{-2} W. Consider an industrial stirred vessel where a fluid (density = 900 kg/m^3, viscosity = 0.184 kg/m s) has to be stirred at 1 rpm using an impeller of 1.6 m diameter and 0.32 m blade width.

a. Show that the laboratory experiment and industrial vessel are geometrically and dynamically similar.

b. Estimate the power requirements of the industrial vessel.

56. Air flows through a smooth tube, 2.5 cm diameter and 10 m long, at 37°C. If the pressure drop through the tube is 10000 Pa, estimate

a. the air velocity through the tube and the friction factor

b. the heat transfer coefficient using Colburn Analogy $\left[j_H = (St)(\mathrm{Pr})^{0.67} \right]$, where St is the Stanton Number and Pr is the Prandtl Number.

Gas constant, R = 82.06 cm^3 atm/mol K Darcy friction factor, $f = \frac{0.184}{\mathrm{Re}^{0.2}}$. Other relevant properties of air under the given conditions: viscosity = 1.8 × 10^{-5} kg/m s, density = 1134 kg/m^3, specific heat capacity, C1, = 1.046 kJ/kg °C, thermal conductivity = 0.028 W/m °C.

57. A double pipe countercurrent heat exchanger is designed to cool 3500 kg/hr of benzene flowing in the inner pipe from 80°C to 35°C. Water enters at 20°C and exits at 37°C in the annular space. The inside pipe has an inner diameter of 3.5 cm and wall thickness of 3.56 mm. The outer pipe has an inner diameter of 5.25 cm and is insulated. Neglecting the wall resistance to heat transfer from the inner pipe, and assuming the individual film heat transfer coefficient for water to be 6600 W/m^2 °C. calculate:

a. the individual heat transfer coefficient for benzene flowing in the inner pipe.

b. the overall heat transfer coefficient based on inside diameter of inner pipe.

c. the total length required for the heat exchanger.

$\mathrm{Nu} = 0.023\,(\mathrm{Re})^{0.8}\,(\mathrm{Pr})^{0.3}$

Where Nu is the Nusselt Number and Pr is the Prandtl Number.

Average properties of benzene: viscosity = 4 × 10^{-4} kg/m s, thermal conductivity = 0.147 W/m °C, specific heat capacity = 1880 J/kg °C, density = 837 kg/m^3.

58. The Excess Gibbs free energy for cyclohexanone (1) / phenol (2) is given by

$$\left(G^E / RT\right) = -2.1 x_1 x_2$$

where, x_1 and x_2 are the mole fractions of components 1 and 2 in the liquid phase. The vapour pressures of components at 417 K are $P_1^{sat} = 75.2\,kPa$ and $P_2^{sat} = 31.66\,kPa$.

a. Derive the expressions for activity coefficients of each component as a function of composition.

b. Verify whether the expressions derived in (a) satisfy the Gibbs — Duhem equation.

c. Determine the equilibrium pressure P and vapour composition for a liquid phase composition x_1 = 0.8 and 417 K. Assume vapour phase to be ideal gas.

59. Methane gas is compressed in a steady state flow process from 101 kPa and 27°C to 500 kPa and 165°C. Assume methane to be an ideal gas under all conditions [R = 8.3 14 J/moE K; specific heat capacity, C_p/R = 1.7 + 0.009 T(K)] and surroundings to be at a constant temperature of 27°C. If the total entropy change (of the system and surroundings) during the process is 4.5 J/mol K, find

a. The specific enthalpy and specific entropy changes of methane.

b. The net shaft work done and heat exchanged with the surroundings, per mole of methane.

c. The thermodynamic efficiency of the process.

60. The mass flux from a 5 cm diameter naphthalene ball, placed in stagnant air at 40°C and atmospheric pressure, is 1.47 × 10^{-3} mol/m^2 s. Assume the vapour pressure of naphthalene to be 0.15 atm at 40°C and negligible bulk concentration of naphthalene in air. If air starts blowing across the surface of naphthalene bail at 3 m/s by what factor will the mass transfer rate increase, all other conditions remaining the same?

For spheres: $Sh = 2.0+0.6\,(Re)^{0.5}\,(Sc)^{0.33}$

where Sh is the Sherwood number and Sc is the Schmidt number. The viscosity and density of air are 1.8 × 10^{-5} kg/m sand 1.123 kg/m^3, respectively and the gas constant is 82.06 cm^3 atm/mol K

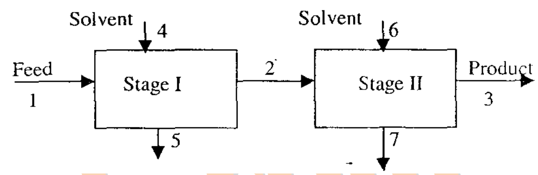
61. Ammonia is produced by the following reaction

$$N_2 + 3H_2 \Leftrightarrow 2NH_3$$

In a commercial process for ammonia production, the feed to an adiabatic reactor contains 1 kmol/s of nitrogen and stoichiometric amount of hydrogen at 700 K. What is the maximum allowable conversion in the reactor, if the adiabatic temperature rise across the reactor should not exceed 100 K.

Assume the feed and product streams to be ideal gas mixtures. The heat of reaction at 700 K for the above reaction is calculated to be -94.2 kJ/mol. Mean molar heat capacities (C_p) in the range 700 - 800 K, are 0.03, 0.0289 and 0.0492 kJ/mol K for nitrogen, hydrogen and ammonia, respectively.

62. It is desired to extract acetone from a feed containing acetone and water, using chloroform as the solvent, in two cross current extraction stages as shown below



Assume that water and chloroform are immiscible. The following data are given for the process

(i) The feed is an equimolar mixture of acetone and water.

(ii) The quantities of chloroform used in the two stages are equal.

(iii) 60 mole % of the acetone in the feed is extracted in stage 1.

(iv) The extract and raffinate phases exiting from each stage are in equilibrium. The equilibrium relation for the distribution of acetone is given by

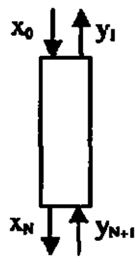
$$\frac{\text{Moles of acetone in water rich phase}}{\text{Moles of water in water rich phase}} = 2\times\frac{\text{Moles of acetone in chloroform rich phase}}{\text{Moles of chloroform in choloroform rich phase}}$$

a. Indicate (with the help of the above diagram) the components in each stream.

b. Determine the quantity of chloroform used in each stage per mol of feed.

c. Determine the mole fraction of acetone in final product stream.

63. A countercurrent multistage stripper as shown in figure below is used to remove an impurity from a cream using pure steam. 100 kg/hr of liquid cream containing 20 parts per millions (ppm) by weight of impurity is fed to the stripper. It is desired to reduce the concentration of impurity in the cream to 1 ppm. Assume that the liquid cream does not evaporate and steam does not condense. The equilibrium relation is y = 10x, where y and x are the ppm of impurity in steam and cream, respectively.

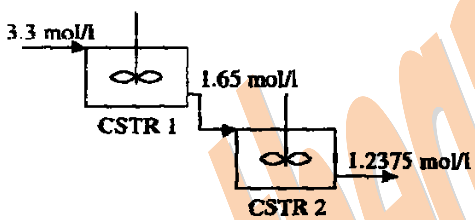


a. Indicate schematically on a x-y plot, the equilibrium line and operating line for minimum steam flow rate.

b. Determine the minimum flow rate of steam required.

c. If the rate of steam input to the stripper is 1.5 times the minimum, determine the required integral number of theoretical stages.

64. A simple chemical reaction A → B is being carried out in two CSTRs connected in series. The volume of the first reactor is 1.5 times that of the second reactor. The temperatures of the reactors are such that the rate constant in the first reactor is 1.5 times the rate constant in the second reactor.



a. Is the data given above consistent for a first order reaction kinetics? Justify.

b. Is the data given above consistent for a second order reaction kinetics? Justify.

65. An enzyme immobilized on the surface of a non-porous solid catalyzes a single-substrate reaction according to the first order rate equation given by

$$v = \frac{V_m}{K_m} S$$

Where V_m and K_m are the reaction parameters and S is the substrate (reactant) concentration at the surface of the solid.

a. If reaction rate is inhibited by liquid-film mass transfer resistance, find the overall rate expression for enzyme catalysis at steady state in terms of V_m, K_m, the bulk liquid substrate concentration S0 and the film mass transfer coefficient t.

b. If the reaction rate is of the first order even at the bulk liquid concentration, what will be the value of the effectiveness factor for the following values of the reaction parameters: V_m = 10° mol/cm^2 s, K = 2 × 10^{-3} mol/I, k_s = 5 × 10^{-5} cm/s.

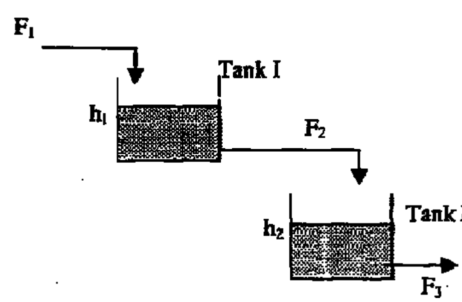
66. A mercury thermometer can be used to measure the body temperature by placing it either in the mouth or in the armpit of a patient. The true body temperature can be taken to be the temperature inside the mouth, which is usually higher than the temperature in the armpit by 0.5 K. Assume that the true body temperature of a patient is 312 K and the thermometer is initially at 300 K Also assume that the thermometer behaves like a first-order system with a time constant of 40 seconds.

a. Obtain a relation for the thermometer reading T(t) as a function of time in terms of its initial temperature T(0), and body temperature TB.

b. How long should the thermometer be placed in the patient's mouth in order to ensure that the error in the measurement is not greater than 0.05%.

c. Since the body temperature in the armpit is less, the measurement made here using the thermometer is corrected by adding 0.5 K. How long should the thermometer be placed in the armpit in order to ensure that the en-or in the corrected measurement is not greater than 0.05% of the true body temperature.

67. Consider a system of two tanks in series as shown below:



The level h_2 in Tank II is measured and has to be controlled by manipulating the flow rate F_1. It is given that $F_2 = 0.005h_1$ and $F_3 = 0.0025h_2$ m^3/s, where h is in m.

The cross- sectional areas of Tank I and 11 are both equal to 1 m^2.

a. Determine the transfer function of the process.

b. Compute the time constants of the process. Is the open loop process over damped, under damped or critically damped?

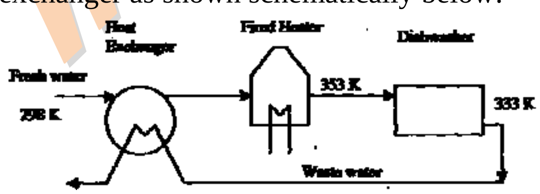
c. If proportional control is used with constant $K_c > 0$, determine the value of K_c for which the closed loop response becomes critically damped.

68. An engineer has purchased a pump for which the installed cost is Rs. 2 lakhs. If no annual maintenance is carried out on the pump, it will have a service life of 5 years, with no salvage value. On the other hand, if annual maintenance is carried out at a cost of Rs. 10,000 per year, then the pump will have a service life of 7 years, with a salvage value of Rs. 10,000.

a. Derive the formula for capitalized cost, in terms of C_I (initial purchase cost of the equipment). S (salvage value), n (lifetime), C_M (annual end-of-year maintenance cost) and i (interest rate), Assume that the cost of replacing the equipment at the end of its service life is the same as its initial cost.

b. If the interest rate is 10%, determine based on capitalized cost analysis, whether annual maintenance on the pump should be carried out or not (neglect depreciation in your analysis).

69. A canteen requires hot water for its dish-washing. For this purpose, the canteen draws 0.4 kg/s of water at 298 K and heats it to 353 K in a fired-heater. The wastewater leaving the dishwasher is at 333 K. In order to save energy, it is proposed to recover heat from the wastewaler to partially heat up the incoming water in a counter-current exchanger as shown schematically below:



Assume that there is no loss of water in the dishwasher and a minimum approach temperature of 10 K should be maintained in the exchanger.

a. Determine the maximum temperature to which the incoming Water can be heated in the exchanger.

b. If the overall heat transfer coefficient in the exchanger is 1200 W/m^2 K and the specific heat capacity of water is 4186 J/kg K, compute the area of the heat exchanger.

c. If the cost of the exchanger in 1982 was $2 \times A^{0.41}$ (in lakh rupees), where A is the exchanger area in m^2 and the Marshall and Swift cost indices in 1982 and 2000 are 315 and 400 respectively, determine the cost of the exchanger in the year 2000.

70. In a filtration process, if V is the volume of filtrate collected in time t, a general relationship can be given as

$$\frac{dt}{dV} = \frac{\mu}{A(\Delta P)}\left(\frac{\alpha c V}{A} + R_m\right)$$

where α is the specific cake resistance, R_m is the filter medium resistance, A is the filler area, c is the concentration of solids in the slurry, μ is the viscosity of the filtrate and ΔP is the overall pressure drop.

a. Filtration experiments were carried out at a constant pressure drop on slurry containing 20 kg/m^3 of $CaCO_3$ in water. The data obtained from the plots of t/V vs V at two different pressure drops are given in the table below

Pressure drop (N/m^2)	Slope (s/liter^2)	Intercept (s/liter)
5×10^4	12.5	26.5
35×10^4	3.5	6.9

If the filter area is 0.09 m^2 and the viscosity of the filtrate is 0.001 kg/m s, determine the specific cake resistance and the filter medium resistance corresponding to each pressure drop.

b. Determine from the above data whether the cake is compressible?