CHEMICAL ENGINEERING

SECTION A

ONE MARKS QUESTIONS (1-25)

Write, in the boxes provided in your answer (boxes 1 to 25) the most appropriate answer to the following multiple choice questions by writing the letters – A, B, C or D – against the subquestion number. (25 × 1 = 25 marks)

1. The Laplace transform of the function e^{-at} has the form:
   a. $\frac{1}{s+a}$
   b. $\frac{1}{s(s+a)}$
   c. $\frac{a}{s}$
   d. $s+a$

2. The unit normal to the plane $2x + y + 2z = 6$ can be expressed in the vector form :
   a. $i3+j2+k2$
   b. $i\frac{2}{3}+j\frac{1}{3}+k\frac{2}{3}$
   c. $i\frac{1}{3}+j\frac{1}{2}+k\frac{1}{2}$
   d. $-i\frac{2}{3}+j\frac{1}{3}-k\frac{2}{3}$

3. $\lim_{x\to\infty}\frac{x-\sin 2x}{x+\sin 3x}$ has the value :
   a. 1
   b. –1/4
   c. 0
   d. ∞

4. The preferred material of construction for storage tanks for 98% sulphuric acid is
   a. Aluminium
   b. Lead
   c. Stainless steel 316
   d. Mild steel

5. In the context of the chemical process industries, the term BOD is normally associated with
   a. Characterization of solid wastes
   b. The organics concentration in gaseous effluents
   c. Characterization of liquid effluents

6. The variation of thermal conductivity of a metal with temperature is often correlated using an expression of the form
   $k = k_0 + aT$
   Where k is the thermal conductivity and T is the temperature (in K). The units of a in the SI system will be
   a. W/m K
   b. W/m
   c. W/m K^2
   d. None; a is just a number

7. A liquid mixture contains 30% o-xylene, 60% p-xylene and 10% m-xylene (all percentages are w/w). Which of the following statements would be true in respect of the mixture ?
   a. The mixture exhibits an azeotrope at 10[illegible] kPa.
   b. The composition of the mixture, in percent by volume is : o-xylene 30, p-xylene 60 and m-xylene 10.
   c. The composition of the mixture in mole percent is o-xylene 30, p-xylene 60 and m-xylene 10.
   d. The mixture contains optical isomers.

8. Pure ethanol vapour is fed to a reactor packed with Alumina catalyst, at the rate of 100 kmol/h. The reactor products comprise Ethylene 95 kmol/h, water vapour : 97.5 kmol/h and diethyl ether : 2.5 kmol/h.
   The reactions occurring can be represented by :
   $C_2H_5OH \rightarrow C_2H_4 + H_2O$
   $2C_2H_5\text{–}OH \rightarrow C_2H_5\text{–}O\text{–}C_2H_5 + H_2O$
   The percent conversion of ethanol in the reactor is:
   a. 100.0
   b. 97.5
   c. 5.0
   d. 2.5

9. Boundary layer separation is characterised by one of the conditions given below, where Re is the Reynold's number for the flow. Select the appropriate conditions.
   a. Re << 1, accelerating flow
   b. Re >> 1, accelerating flow
   c. Re << 1, decelerating flow

10. A globe valve is most suitable for applications in which
    a. the valve is required to be either fully open or fully closed.
    b. flow control is required.
    c. the fluid contains dispersed particles.
    d. one-way flow is required.

11. The hydraulic radius for flow in a rectangular duct of cross-sectional dimensions H, W is
    a. $\sqrt{\frac{HW}{\pi}}$
    b. $\frac{HW}{2(H+W)}$
    c. $\frac{(HW)^2}{4(H+W)^2}$
    d. $\frac{2HW}{(H+W)}$

12. The work index in Bond's law for crushing of solids has the following dimensions
    a. No units (dimensionless)
    b. kWh / ton
    c. kW / ton
    d. kWh $m^{1/2}$ / ton

13. The advantage of using a 1-2 shell and tube heat exchanger over a 1-1 shell and tube heat exchanger is
    a. Lower tube side pressure drop
    b. Lower shell side pressure drop
    c. Higher tube side heat transfer coefficient
    d. Higher shell side heat transfer coefficient

14. A multiple effect evaporator as compared to a single effect evaporator of the same capacity has
    a. Lower heat transfer area
    b. Lower steam economy
    c. Higher Steam economy:
    d. Higher solute concentrations in the product.

15. For a fixed number of ideal stages in a distillation column, as the reflux ratio is increased, the difference in composition between the top and bottom product streams
    a. increases
    b. decreases
    c. remains unaffected
    d. passes through a maximum

volume of quiescent liqui… is the diffusivity of the solute,
    a. D/a
    b. $D/2a$
    c. proportional to $\sqrt{D}$
    d. dependent on the Reynold's number

17. In a interphase mass transfer process, the lesser the solubility of a given solute in a liquid, the higher are the chances that the transfer process will be
    a. liquid phase resistance-controlled
    b. gas phase resistance controlled
    c. impossible
    d. driven by a nonlinear driving force

18. In distillation column design, the McCabe-Thiele procedure is inadequate and a Ponchon-Savarit procedure is needed when
    a. saturated feeds is not used
    b. azeotropes forms
    c. the latent heats of vapourisation of the more and less volatile components are greatly different
    d. a total condenser is used

19. For reaction P + Q → R + S, molar rate of consumption of P is
    a. double of that of Q
    b. same as that of Q
    c. half of that of Q
    d. 2/3 of that of Q

20. Molecularity of an elementary reaction P + Q → R + S is
    a. 1
    b. 2
    c. 3
    d. 4

21. A change in state involving a decrease in entropy can be spontaneous only if
    a. it is exothermic
    b. it is isenthalpic
    c. it takes place isothermally
    d. it takes place at constant volume

22. A Carnot cycle consists of the following steps :
    a. two isothermals and two isentropics
    b. two isobarics and two isothermals
    c. two isochorics and two isobarics
    d. two isothermals and two isochorics

23. Locus plot of the roots of the characteristic equation of a closed loop having the open loop transfer function

$\frac{K(s+1)}{S(2s+1)(3s+1)}$ will have a define number variation of K from 0 to ∞. The number of loci is

a. 1
b. 3
c. 4
d. 2

24. der system with a time constant of 1 min is subjected to frequency analysis. At an input frequency of 1 radian/min, the phase shift is

a. -50^0
b. -90^0
c. -180^0
d. -45^0

25. For a cylindrical internally pressurized vessel, which of the following closure types would withstand highest pressure if each closure is of the same material and thickness ?

a. Hemispherical
b. Ellipsoidal (2 : 1)
c. Conical
d. Flat plate

TWO MARKS QUESTIONS (26-50)

26.

27. The differential equation $\frac{d^3x}{dt^3} + 3\frac{dx}{dt} + 2x = 0$ will have a ...tion of the form

a. $C_1e^{3t} + C_2e^{2t}$
b. $C_1e^{-2t} + C_2e^{-}$
c. $C_1e^{-3t} + C_2e^{-}$
d. C_1e^{-5t}

where ... are constant.

28. The ...l $\int_0^1 \frac{dx}{x^p}$ is convergent for

a. ...lue of p
b. $p > 1$
c. $p < 1$
d. all values of p

29. Each of the chemicals mentioned in the left hind column is very closely linked with one specific industry mentioned in the right hand column. Match each chemical with the corresponding industry. [Write both answers in the box provided –

(II) Purified Terephthalic ...
(A) Detergents
(B) Soaps
(C) Paints and Pigments
(D) Synthetic fibres
(B) Nuclear Fuels
(F) Synthetic Rubber

30. Each of the byproducts / coproducts mentioned in the left hand colu...n is linked to one of the main ...ducts mentioned in the right han... colu...n. Match the byproducts / co...odu...s with the corresponding main pr...ducts. [Write both answers in th... box p...ovided – Box No. 30]

(I) Glycerine
(II) Ammonium Chlori...
(A) Rocket ...llant
(B) Soda ...sh
(C) B...tery ...ad ... MnO_2
(D) ...ntibi...ics
(E) S...p
(F) ...ugar

31. ...ach of the techniques / processes / ...erations mentioned in the left hand column is closely related to a specific industry mentioned in the right hand column. Match each technique / process / operation with the appropriate industry. [Write both answers in the box provided – Box No. 2.6]

(I) Granulation
(II) Fluid Catalytic Cracking
(A) Cement
(B) Petroleum Refining
(C) Ammonium Phosphates
(D) Urea
(F) Phosphoric Acid
(F) Glass

32. A sample of well water contains 140 g/m^3 Ca^{2+} ions and 345 g/m^3 Na^+ ions. The hardness of the sample of water, expressed in terms of equivalent $CaCO_3$ in g/m^3 [assuming atomic masses of Ca : 40, Na : 23, C : 12 and O : 16] is

a. 350
b. 485
c. 140
d. 345

33. Air, initially at 101.3 kPa and 40°C, and with a Relative Humidity of 50%, is cooled at constant pressure to 30°C. The

b. A higher absolute (specific) humidity
c. A higher relative humidity
d. A higher wet bulb temperature

34. At low Reynold's numbers the power (P) required for agitating a fluid in a stirred tank becomes independent of inertial forces. In this limit, indicate which of the following relations is satisfied :
a. $P_0 \alpha Re^{-1.0}$
b. $P_0 \alpha Re^{0.0}$
c. $P_0 \alpha Re^{0.5}$
d. $P_0 \alpha Re^{1.0}$

$P_0 = P / \rho N^3 D^5$: Power number
$Re = \rho N D^2 / \mu$: Reynold's number
N is the impeller rotational speed, and D is the impeller diameter.

35. The dependence of the volumetric flow rate (Q) on the pressure drop is given by

$$\Delta P \alpha Q^n,$$

for different flow regimes. Match the exponent n to each of the flow regimes given below
[Write both answers in the box provided; Box No. 2.10]
(I) Laminar flow
(II) Turbulent flow
(A) $n < 0.5$
(B) $n = 0.5$
(C) $n = 1.0$
(D) $n > 1.0$

36. A long iron rod initially at a temperature of 20°C has one end clipped in boiling water (100°C) at time t = 0. The curved surface of the rod is insulated so that heat conduction is one-dimensional in the axial direction. The temperature at a distance 100 mm from the dipped end becomes 40°C at t = 2[illegible]. The same temperature is achieved at a distance 200 mm from the dipped end at time
a. [illegible]
b. t = 350s
c. t = 400s
d. t = 800s

37. The radiation heat flux from a heating element at a temperature of 800°C, in a furnace maintained at 300°C is 8 kW/m^2. The flux when the element temperature is increased to 1000°C for the same furnace temperature is
a. 11.2 kW/m^2
b. 12.0 kW/m^2

38. For the Air–Water system[illegible]ent conditions, the adiabatic temperature and the wet-bulb-[illegible] are nearly equal, because
a. water ha a high latent hea[illegible] evaporation
b. Lewis number is close to unity
c. they are always equal under all circumstances
d. solubility of the components [illegible]ir in water is very small.

39. If the Prandtl number is greater than the Schmidt number,
a. the thermal boundary layer lies inside the concentration boundary layer.
b. the concentration boundary layer lies inside the thermal boundary layer.
c. the thermal and concentration boundary layers are of equal thickness.
d. the hydrodynamic (i.e., momentum) boundary layer is thicker than the other two

40. Second order consecutive irreversible reactions

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

were carried out in a constant volume isothermal batch reactor with different initial feed compositions. Reactor temperature was same in all the cases. In experiments where the ratio of concentration of B to that of A in initial feed was less than 0.5, the concentration of B increased first, reached a maximum and then declined with time. However, for all experiments where this concentration ratio was 0.5 or above, concentration of B decreased monotonically with time right from the beginning. What is the ratio of the two rate constants (k_1 / k_2) ?
a. 1/4
b. 1/2
c. 2
d. 4

41. A spherical porous catalyst particle of radius R is subjected to reactant A which reacts to form B by a zero order surface reaction A → B. Film mass transfer resistance is negligible and pore diffusion of A is rate controlling. The effectiveness factor of the catalyst is reported as 7/8. Which of the following statements is true ?
a. Inner catalyst core of radius R/8 does

b. Inner catalyst core of radius R/2 does not participate in reaction
c. Inner catalyst core of radius 7R/8 does not participate in reaction.
d. Effectiveness factor for a zero order reaction cannot be 7/8 as it must always be 1.

42. It is desired to bring about a certain change in the state of a system by performing work on the system under adiabatic conditions.
a. The amount of work needed is path-dependent.
b. Work alone cannot bring about such a change of state.
c. The amount of work needed is independent of path.
d. More information is needed to conclude anything about the path dependence or otherwise of the work needed.

43. If the heat of solution of an ideal gas in a liquid is negative, then its solubility at a given partial pressure varies with the temperature as
a. solubility increases as temperature increases.
b. solubility decreases as temperature increases.
c. solubility is independent of temperature.
d. solubility increases or decreases with temperature depending on the Gibb's free energy change of solution

44. In an interphase heat transfer process, the equilibrium state corresponds to equality of temperatures in the two phases, while the condition for equilibrium in an interphase mass transfer process is
a. equality of concentrations
b. equality of chemical potentials
c. equality of activity coefficients
d. equality of mass transfer coefficients

45. A proportional plus integral controller with proportional sensitivity $K_c = 1$ mA/mA and integral time $T_1 = 1$ min is initially at steady state with error signal $e = 0$ and controller output I at 10 mA. At time $t = 0$, a step change of 1 mA is given in the error signal. The controller output will show one of the following responses. Identify the correct one.
a. I jumps instantaneously to 11 mA and
b. I increases at a [illegible] of 1 mA/min.
c. I jumps to 18 mA and [illegible] exponentially at the rate $e^{-t/1}$
d. I jumps instantaneously to 11 mA, then increases linearly at the rate of [illegible] mA/min.

46. The frequency response of a dynamic element shows a constant magnitude ratio at all frequencies. The element exhibits a negative phase shift at all frequencies. The absolute value of the phase shift increases linearly with frequency. The element has she transfer function
a. $e^{-\tau s}$
b. $\frac{\tau_1 s + 1}{\tau_2 s + 1}$
c. $\frac{\tau_1 s}{\tau_2 s + 1}$
d. $\frac{\tau s + 1}{\tau_2}$

47. The second order system with the transfer function $\frac{4}{s^2 + 2s + 4}$ has a damping ratio of
a. 2.0
b. 0.5
c. 1.0
d. 4.0

48. In a closed loop system, the process to be controlled is an integrating process with transfer function $\frac{1}{2s}$. The controller proposed to be used is an integral controller with transfer function $\frac{1}{T_1 s}$. When a step change in set point is applied to such a closed loop system, the controlled variable with exhibit
a. Overdamped response
b. Underdamped response
c. Undamped response
d. Unstable response

49. A certain pressure vessel manufacturer avoids doing reinforcement calculations for openings by always providing a reinforcing pad extending up to double the diameter of the opening and of the same material and thickness as that of the shell wall. If area compensation is accepted as a

a. only if the opening is on the spherical vessel.
b. only if the opening is on a vertical cylindrical vessel.
c. only if the opening is on a horizontal cylindrical vessel.
d. irrespective of the shape of the vessel.

50. For a cylindrical vessel of moderate height, the weld joint efficiency for joints parallel to the cylinder axis is given as 1.0 while for joints along the girth (circumference) it is given as 0.8. In calculating the shell wall thickness using code formula, for an internally pressurized cylindrical vessel, what value of weld joint efficiency should be used?
a. 0.8
b. 0.9
c. 1.0
d. $(0.8)^{0.5}$

FIVE MARKS Questions (51 & 55)

51. Ethylene Oxide is produced by the oxidation of Ethylene over a catalyst. Safety considerations dictate that the gaseous mixture entering the reactor should contain 10 mol air per mol Ethylene. The conversion per pass is 30%. The Ethylene oxide formed is completely condensed out and the remaining gases recycled
Make up oxygen is added to maintain the requisite oxygen levels. For a plant producing 440 kg/h of Ethylene-oxide,
(i) Calculate the quantity of pure makeup oxygen to be supplied, in kg/h, in steady state operation.
(ii) Draw a neat block diagram showing the major units, flows and compositions, and indicate the envelope / boundary around which the requisite mass balance(s) is / are being made.
The relevant reaction is represented by

$$2C_2H_4 + O_2 \rightarrow 2C_2H_4O$$
$$(g) \quad (g) \quad (g)$$

[Assume atomic masses as: C = 12, O = 16, H = 1].

52. A fluid is pumped through a long horizontal pipe of diameter D and length L, using a centrifugal pump. The flow in the pipe is laminar with the Fanning constant and V is the av[illegible] in the pipe. The pump head (H) rate (Q) characteristic is given b[illegible]

$$H = \alpha - \beta Q$$

where α and β are constants.
a. Obtain an expression for the pressure drop in the pipe (ΔP) in terms of the volume flow rate (Q).
b. Obtain an expression for the [illegible] operating flow rate in the system, assuming that the only pressure loss in the system is due to the pipe flow.

53. In the lower portion of a spray tower, urea pellets (diameter D = 2 mm) are cooled by air at a temperature T_a = 20° C. The pellets are falling at their terminal velocity u_t = 6.9 m/s. The temperature within the pellets is uniform at all times, and the initial temperature of the pellets as 80°C. The heat transfer coefficient for a pellet falling in air is h = 208 W/m² K.
a. Obtain an expression for the change of temperature of a pellet with time [T(t)].
b. Calculate the height of the tower for a pellet to cool to 60° C.

54. 100 moles of an Acetonitrile - nitromethane mixture is differentially distilled in a batch still at a pressure of 70 kPa. The feed contains 74 mole % acetonitrile. Distillation is continued till the liquid let behind in the stilt contains 32 mole % acetonitrile. The vapour-liquid equilibria for the system at this pressure are correlated as follows :

$y^* = 1.05x + 0.13$ for $0.3 \le x \le 0.52$
$y^* = 0.77x + 0.28$ for $0.52 \le x \le 0.8$,

where x and y^* refer to the mole fractions of acetonitrile in the liquid and equilibrium vapour, respectively.
Find the average composition of the distillate collected.

55. A liquid phase, first order, reversible reaction A ⇌ B is carried out in a continuous stirred tank reactor (CSTR). Molar densities of A and B are same. Other things (such as space time, flow rate, temperature) remaining the same, a feed of pure A to the reactor results in 40% conversion of A, while a feed of pure B results in 50% conversion of B. Estimate the reaction equilibrium constant. Assume steady state operation in both the cases.

SECTION B

Five Marks Questions (55 to 77)

Answer any TEN questions from this section. Write all your answers in the answer book. All questions carry equal marks.

$(10 \times 5 = 50$ Marks)

56. The mass balance equations of a blender are

$$0.2\,F_1 + 0.8\,F_2 = 0.5\,F$$
$$F_1 + F_2 = F$$

Express the equation set given above in a matrix form $A\,X = b$ where

$$X = \left[\frac{F_1}{F} \quad \frac{F_2}{F}\right]^T$$

Find the inverse of the matrix A. Use matrix inverse A^{-1} to calculate $\frac{F_1}{F}$ and $\frac{F_2}{F}$.

57. Find the dimensions of a hollow cylinder with both ends closed which can hold $\frac{27\pi}{4}$ m^3 of water and has minimum outer surface area.

58. Each item of equipment mentioned in the left hand column is identified with the manufacturing process for one of the products mentioned in the right hand column. Match the equipment with the corresponding product.

(I) Fermentor
(II) Membrane Cell
(III) Waste heat boiler
(IV) Rotary kiln
(V) Prilling Tower
(A) Ammonium Nitrate
(B) Ethanol from molasses
(C) Caustic soda
(D) Diammonium phosphate
(E) Sulphuric acid
(F) Cement
(G) Yellow phosphorus
(H) Sodium metal

59. Answer the following :

a. Each of the products mentioned in the left hand column requires one or more of the raw materials / starting materials mentioned in the right hand column. Match the products with the appropriate raw material(s) / starting

(I) Urea
(II) Phenol
(A) Air
(B) Toluene
(C) Carbon dioxide
(D) Nitric oxide
(E) Methanol
(F) Ammonia
(G) Propylene
(H) Cumene

60. Which of the following gaseous fuels is likely to have the highest Gross calorific value ?

a. Sewage Gas
b. LPG
c. Producer Gas
d. Natural Gas

61. 1000 kg/h of an aqueous solution of 20% Na_2CO_3 is cooled gradually to t °C, to crystallize out $Na_2CO_3.10H_2O$. The solubility of Na_2CO_3 at t° C is 2.1%. Calculate the percentage of Na_2CO_3 recovered in the form of crystals. (Assume, no loss of Na_2CO_3 through the mother liquor adhering to the crystals and no carry over of crystals with the mother liquor). Draw a neat block diagram showing the inlet and exit compositions and flow rates.

[Molecular weight of Na_2CO_3 can be assumed to be 106 and that of water to be 18].

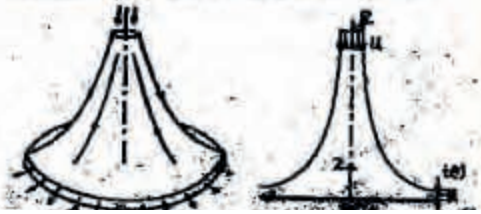
62. 1000 kg/h of a thermic fluid, to be used as a heat transfer medium, is being indirectly heated in a heater, from 380 K to 550 K. Calculate the heat load on the heater, in kW. Also estimate the mean heat capacity of the thermic fluid over the temperature range of interest.

The heat capacity equation for the thermic fluid is :

$C_p = 1.436 + 0.00218\,T$,

where C_p is in kJ/kg K, and T is in K.

63. A round fluid jet impinges on a flat plate and spreads out radially to form a film of decreasing thickness as shown below.



64. The radius of the jet far from the stagnation point (O) is it, and the velocity is u. Assume the flow to be inviscid and axisymmetric, and neglect gravity. Also assume that the velocity profiles are flat far from the stagnation point. The pressure outside the jet is atmospheric and the density of the fluid (ρ) is constant.
   a. Obtain the velocity of the fluid in the film ($-v(r)$) and the thickness of film ($t(r)$) at any radial distance r far from the stagnation point
   b. Obtain the normal force acting on the plate.

65. A concentrated suspension of spherical quartz particles in Water settles under gravity. The particle diameter is $D_p = 10^{-5}$ m and the particle density is $\rho_p = 2650$ kg/m^3. The initial voidage in the suspension is $\varepsilon = 0.8$.
   a. Obtain the expression for the terminal velocity (u_t) of a single particle assuming Stoke's law to be valid.
   b. Find the initial setting velocity (u_s) of the particle in the suspension given $u_s = u_t \varepsilon^{4.6}$
   c. Calculate the upward velocity of water in the suspension resulting from the setting of the particles for $\varepsilon = 0.8$

66. The wall of a cold storage unit comprises a brick layer (thickness $\delta_B = 0.1$ m, thermal conductivity $k_B = 1.4$ W/mK) and an inner layer of polyurethane foam (thickness $\delta_p = 0.05$ m, thermal conductivity $k_p = 0.015$ W/mK). Assume one dimensional heat transfer by conduction through the composite wall, and that the inner surface of the polyurethane layer is at temperature T_c and the outer surface of the brick layer is at temperature T_h.
   a. Obtain an expression for the heat flux per unit area through the wall.
   b. Calculate the rate of heat gain when $T_c = -10$°C and $T_h = 40$°C. The surface area for heat transfer is 260 m^2.

67. A fluid is heated from a temperature T_i to T_0 in a double pipe heat exchanger with steam condensing in the outer pipe at a temperature T_s. The flow rate of fluid in the inner pipe (inside diameter D) is Q, and the heat transfer coefficient is h_i. The film heat transfer coefficient for the
   a. Obtain an expression for the length of the heat exchanger required to carry out the heating operation. Assume the outer diameter of the inner pipe is nearly equal to its inside diameter. The specific heat capacity of the fluid is c_p and its density is ρ.
   b. Obtain an expression for the optimum diameter at which the heat exchanger length is minimum assuming $h_i = CD^{-1}$ where C is a constant.

68. A pure gas is bubbling through a column of liquid at a sufficiently low rate that the bubbles are well separated from each other. The bubbles are spherical, are 3 mm in diameter, and rise with a constant velocity of 0.24 m/s. At any given time, ten bubbles can be seen in the liquid, the liquid volume being 3.14×10^{-4} m^3. The liquid contains no dissolved gas to start with, and may be assumed to be well mixed at all times. The mass transfer coefficient for this situation is given by Higbie's Penetration theory as
$$k = \sqrt{\frac{4D}{\pi t^*}}$$
where
D = diffusivity of the gas in the liquid $= 2 \times 10^{-9}$ m^2/s, and
t^* = time of contact between liquid elements and the gas, s.
Determine the time it takes for the liquid to attain 50% of the saturation concentration

69. The carbon dioxide issuing out of a Fermenter contain 0.01 mol fraction of ethanol, which has to be reduced to 0.0001 mole fraction by scrubbing with water in a countercurrent packed tower. The gas flowrate is 227.3 kmol/h and may be assumed constant throughout the tower. The equilibrium mole fraction of ethanol in the gas phase(y^*) is related to that in the liquid (x) as
$y^* = 1.07\,x$
Determine the minimum liquid rate needed, and the number of overall gas-side transfer units needed at 1.5 times the minimum liquid rate. The entering liquid may be assumed to be free of ethanol.

70. Steady state plug flow reactor (PFR) data for isotherjm1 irreversible reaction
A → B

is as shown in the table. Reactor space time was 10 seconds in both the cases. Other things such as feed and product density, reactor temperature etc. are same in both the cases.

	Concentration of A(k mol/m^3)	
	In Feed	In Product
Case I	1	0.5
Case II	2	0.555

If the reaction is known to be of non-zero integer order, find the reaction order and the rate constant.

71. A particular metal reacts with a certain liquid and the product passes into solution. Three non-porous solid spheres of same metal and of diameters 10, 20 and 30 mm. respectively were placed in a very large stirred pool of reactive liquid at the same time. After an hour, it was found that the pool had only two spheres of diameter 10 and 20 mm, respectively. After another hour, the pool had only one sphere of diameter 10 mm. This sphere also disappeared after another hour.
Explain these observations through appropriate derivation using a more likely rate controlling step out of the following two.
(i) Film mass transfer
(ii) Surface reaction

72. A mixture of A and B conforms closely to Raoult's law. The pure component vapour pressures P_A^{sat} and P_B^{sat} in kPa are given by (t in °C)

$$\ln P_A^{sat} = 14.27 - \frac{2945}{t+224}$$

$$\ln P_B^{sat} = 14.20 - \frac{2972}{t+209}$$

If the boiling point of a certain mixture of A and B is 76° C at a total pressure of 80 kPa, find the composition of the first vapour that forms.

73. The reaction $N_2 + O_2 = 2NO$ takes place in the gas phase at 2700° C and 2025 kPa. The reaction mixture initially comprises 15 mole % oxygen, 77 mole % nitrogen and the rest inerts. The standard Gibbs Energy change for the reaction is 173 kJ/mole at this temperature. Assuming ideal gas behaviour, calculate the partial pressures of all species at equilibrium.

74. The characteristic equation of a closed loop control system is
$0.25\,s^3 + 0.8\,s^2 + 5.6\,s + 1 + 0.35\,K = 0$.
Find the limiting value of $K = K_c$ above which the closed loop system will be unstable

75. A photoelectric pyrometer is used to measure the temperature of hot billets having a temperature of 900° C and placed on a moving grate. The pyrometer has a first order response with a time constant of 1 s. Each billet is in the field of view of pyrometer for 2s. The billets are so placed on the grate that there is a one second interval between the exit of one-billet from the field of view of pyrometer and entry of the next billet in line. The ambient temperature is 50°C. Assume that the system is in operation for a few hours. Write equations for the rising and falling portions of the pyrometer response.

76. For a flanged joint, is proposed to use bolts on a flange with bolt root diameter of 12.5 mm. The allowable stress for the bolt material is 150 MN/m^2. The total bolt load is 1.6 MN. Recommend a minimum number of bolts that should be provided.

77. Capital cost of a pipeline of exotic material is estimated as $3\,D^{1.5}$ Rs/m, where D is pipe diameter in mm. The annual maintenance cost is estimated as 10% of the total capital cost. Annual operating cost of the pipe is given as follows :

$$\text{Annual operating cost} = \frac{3\times10^5}{D^5}\ \frac{Rs}{m\ year}$$

Estimate the most economic pipe diameter based on the least annual cost approach to the nearest multiple of 10mm. Estimated amortization period is 10 years