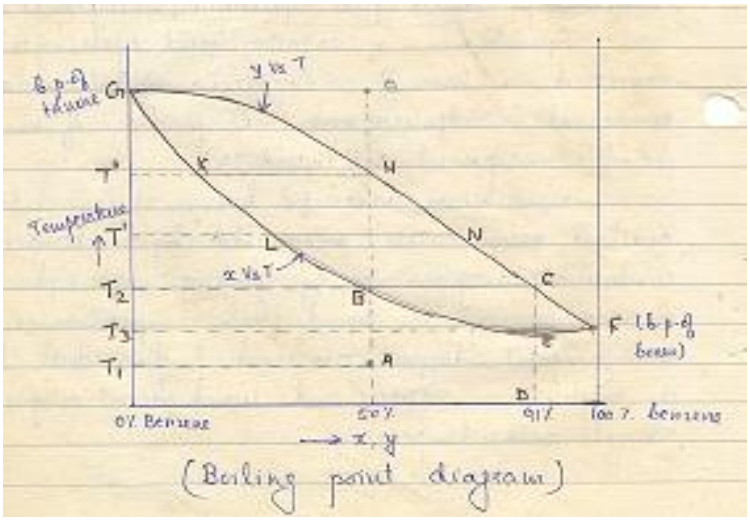
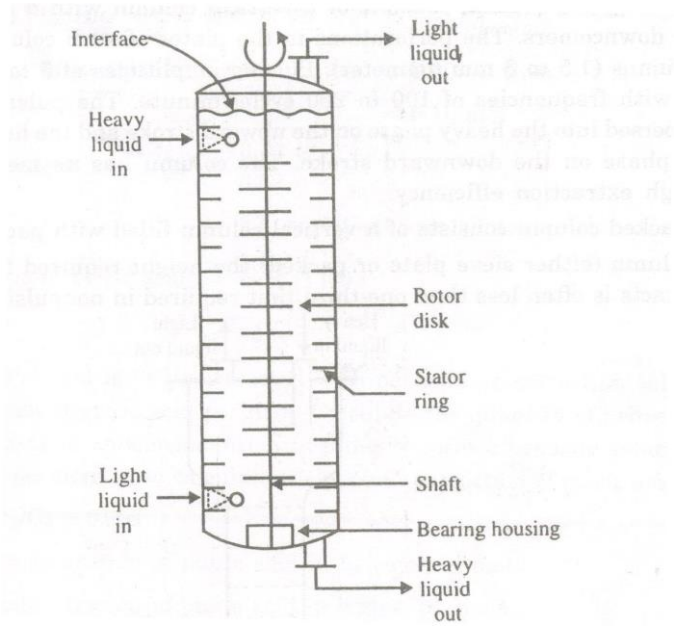
Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

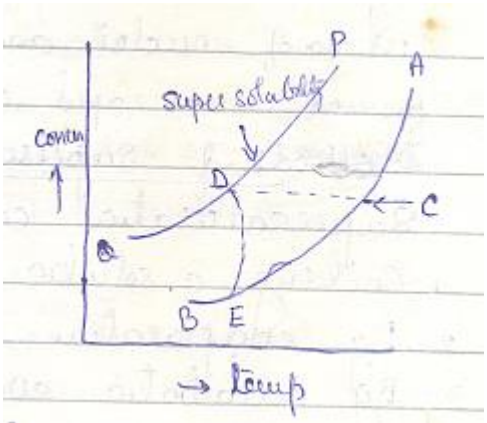
Q No.	Answer	Marking scheme
1 a	Attempt any 3	12
1A-a	**Higbie's penetration theory- Salient features:** 1) As the time of exposure of fluid for mass transfer generally being short, development of the concentration gradient of film theory is not possible. 2) The transfer is largely because of fresh material brought to the interface by the eddies. 3) A process of unsteady state transfer occurs for a fixed period at the freshly exposed surface. 4) Each fluid element (eddy) resides for the same length of time period at the surface. According to this theory, the mass transfer coefficient is proportional to the square	1 mark each
1A-b	**Boiling point diagram**  Consider the process of boiling a binary mixture consisting of benzene (mvc)	

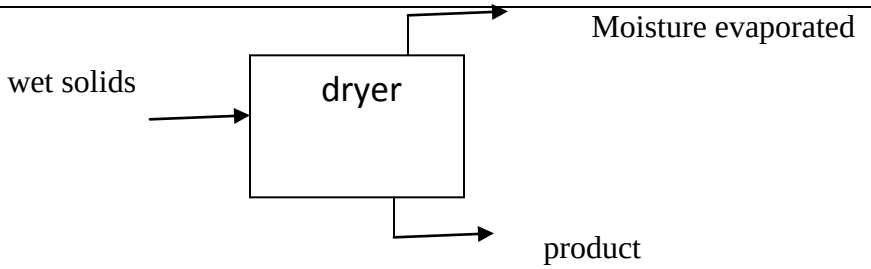
	and toluene. The composition of the mixture is plotted on x-axis in terms of mvc and temperature of the mixture is plotted on y-axis. The mixture represented by point A is at a temperature of T1 and contains 50% benzene. When we heat the mixture it will boil at a temperature T2, vapours will contain more of mvc. The vapoursat C is in equilibrium with liquid at B and thus BC is known as the tie line.If we reheat the condensate obtained at this stage, it will boil at T3 and the vapours issuing will contain more of mvc,thus enrichment of benzene takes place . In the process of boiling, the mixture boils over a temperature range, so the term used is bubble point.The liquid represented by any point on the lower curve is at its bubble point and the lower curve is called bubble point temperature curve. When a mixture of vapours is cooled, at a point condensation starts. The first drop of liquid will have composition represented by point K.While cooling the vapour becomes richer in mvc than liquid. The condensation starts at any point on the upper curve. The upper curve is the dew point temperature curve.	2 2
1A-c	**Selection criteria for solvent in gas absorption** : While selecting a particular solvent for absorption operation , the following properties of the solvent are considered. 1) Gas solubility : the solubility of solute gas in a solvent should be high . the solvent selected should have a high solubility for the solute to be absorbed 2) Volatility : As the gas leaving an absorption unit is generally saturated with the solvent, there will be a loss of the solvent with the gas leaving the unit operation, hence to minimize the solvent loss , the solvent should be less volatile. 3) Corrosive nature : the solvent should not be corrosive towards common materials of construction so that the construction material for an absorption	1 mark each for any 4

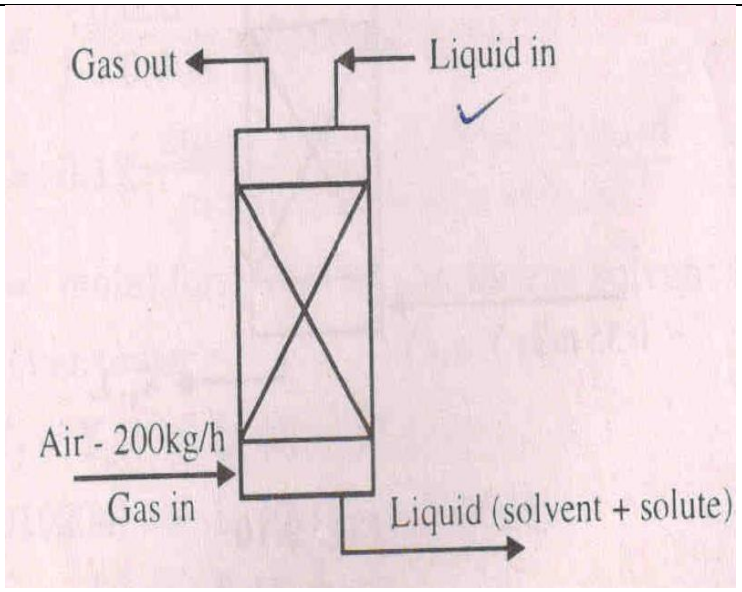
	equipment will not be too expensive. 4) Viscosity : the solvent should have a low viscosity for rapid absorption rates, low pumping cost and better heat transfer. The solvent should be non viscous. 5) Cost and availability : the solvent should be cheap and readily available 6) Miscellaneous : the solvent should be non-toxic, non-flammable, non-foaming, and chemically stable from a handling and storage point of view.	
1A-d	**Rotating disc contactor:**  Fig,Shows rotating disk contactor for light phase dispersed. In these units,disks disperse the liquid & impel them outward towards the tower wall , where stator rings create quiet zones wherein the 2 phases can separate. Rotating disc contactor is a mechanically agitated counter current extractor agitation is brought with the help of rotating disc.	2

		2
1B	Attempt any 1	6
1B-a	**Time of drying under constant rate period:** Consider that the wet solids are to be dried by passing the hot air over them under constant drying conditions. The time of drying required to dry the material from initial moisture to the final moisture content of solids, is the sum of the time required during the falling rate period. **Constant rate period :** Let X1 be the initial moisture content of the wet solids and X_2 be the final moisture content of the wet solids during the constant rate period. Let X_C be the critical moisture content of the wet solids. The rate of drying is given by $R = -\frac{W'}{A} \times \frac{dX}{dt}$ ----------(1) $R = R_C$ = rate during constant rate period $R_C = -\frac{W'}{A} \times \frac{dX}{dt}$ ----------(2) Where W' = mass of dry solids in kg A = area of drying surface in m^2 R_C = rate in $kg/(m^2.h)$ t = time in hours (h) Rearranging Equation (2), we get, Type equation here. $dt = \frac{W'}{A.RC} dX$ ----------(3) Integrating Equation (3) between the limits :	1 1 1 1

	$t = 0, \quad X = X_1$ and $t = t, \quad X = X_2$, we get $\int_0^t dt = -\frac{W'}{A.RC} \int_{X1}^{X2} dX$ ----------(4) $t = -\frac{W'}{A.RC} [X_2 - X_1]$ ----------(5) $t = \frac{W'}{A.RC} [X_1 - X_2]$ ----------(6) equation (6) gives the time required for drying the material from X_1 to X_2 in the constant rate period. If the material is to be dried to the moisture content ofX_C, then the time required during the entire constant rate period is given by $t_C = \frac{W'}{A.RC} [X_1 - X_C]$ ----------(7)	1 1
1B-b	**Mier's supersaturation theory:** According to Mier's theory there is a definite relationship between the conc and temp at which crystals will spontaneously formed in a pure solution. This relationship is represented by the super solubility curve which is approximately parallel tp the solubility curve. The curve AB is the solubility curve and curve PQ is the super solubility curve. The curve AB represents maximum conc of solution which can be achieved by bringing solid-solute into eqm with liquid solvent. If a solution having the composition and temp indicated by point C is cooled in the direction shown by the arrow it first crosses the solubility curve AB and it is expected to start of crystallization. Actually if the process started	3

	with initially unseeded solution crystal formation will not begin until the solution is super cooled considerably passed the curve AB. According to Mier's theory , crystallization will start in the neighbourhood of the point D and the concentration of the solution then follows roughly along the curve DE. For an initially unseeded solution , the curve PQ represents the limit at which spontaneous nuclei formation begin and consequently, crystallization can start.  	3
2	**Attempt any 4**	16
2-a	**Supersaturation:** It is the quantity of solute present in the solution in which crystals are growing compared with the quantity of the solute that is in equilibrium with the solution. **Different methods of obtaining super saturation(any 4)** i) By cooling a concentrated, hot solution trough indirect heat exchange. ii) By evaporating a part of solvent/ by evaporating a solution. iii) By adiabatic evaporation and cooling. iv)By adding a new substance which reduces the solubility of the original solute, i.e. by salting. v)By chemical reaction with a third substance	1 mark each
2-b		1

	 Basis: 100 kg dried product Let X kg wet solids and Y kg moisture evaporated Overall balance is X = Y + 100 Solid balance is 0.2 X = 0.95* 100 Or X = 475 kg moisture evaporated 475-100 = **375 kg**	1 1 1
2-c	1. **Etract phase**: Solent rich product of liquid-liquid extraction operation is called extract.The extract phase contains desired product in large proportion. 2. **Raffinate phase**: The residual liquid solution from which solute is removed is called raffinate 3. **Distibution Coefficient** = $$\frac{concentration\ of\ solute\ in\ extract\ phase}{concentration\ of\ solute\ in\ raffinate\ phase}$$ Higher value D.C is desirable for quantity of solvent required for desired separation. 4. **Selectivity**: The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase. Selectivity should be high.	1 1 1 1
2-d	Basis : 200kg/hr of air flow to absorption tower.	



X_1' = NH3 composition at bottom = 0.006 kg of NH_3/kg of water

X_2' = NH3 composition at top = 0.000013 kg of NH_3/kg of water

Y_1 = NH3 composition in inlet gas to tower = 0.0084 kg of NH_3/kg of inert gas

Y_2= NH3 composition in outlet gas from tower = 0.0044 kg of NH_3/kg of air

L' = mass flowrate of solute free solvent in kg/hr

V'= mass flowrate of solute free gas or air in kg/hr 2

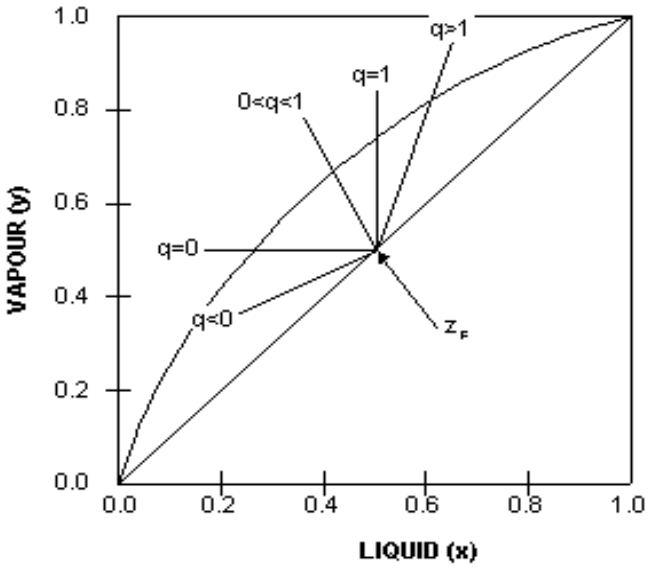
$V' (Y_1-Y_2) = L' (X_1-X_2)$

200 (0.0084 - 0.0044) = L' (0.0006 - 0.000013)

L' = 1362.86 kg/hr

Mass flow rate of water = **1362.86 kg/hr**

1

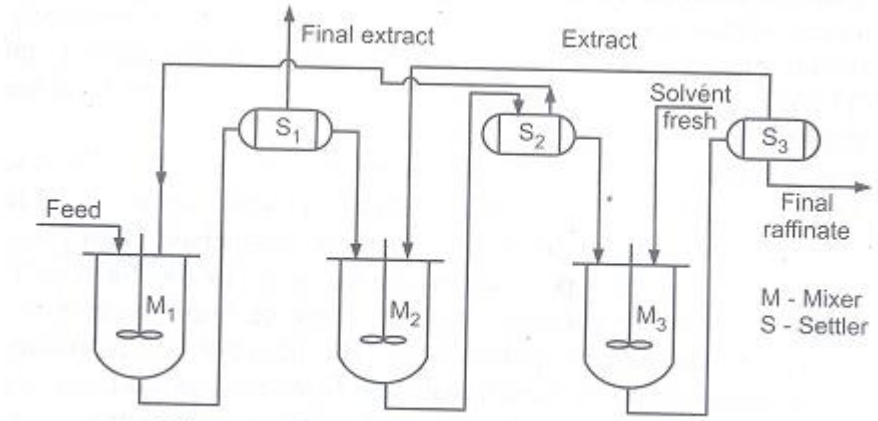
		1
2-e	**Fick's law** is the basic law of diffusion Fick's law states that the flux of a diffusing component A in z direction in a binary mixture of A and B is proportional to the molar concentration gradient. $J_A = -D_{AB}dC_A/dZ$ Where J_A- molar flux of A in z direction C_A – concentration of A dC_A/dZ – concentration gradient in z direction D_{AB} – proportionality constant, diffusion coefficient Z – distance in the direction of diffusion	2 2
2-f	 q >1 (cold liquid) q = 1 (saturated liquid) 0 < q < 1 (mix of liquid and vapour)	4

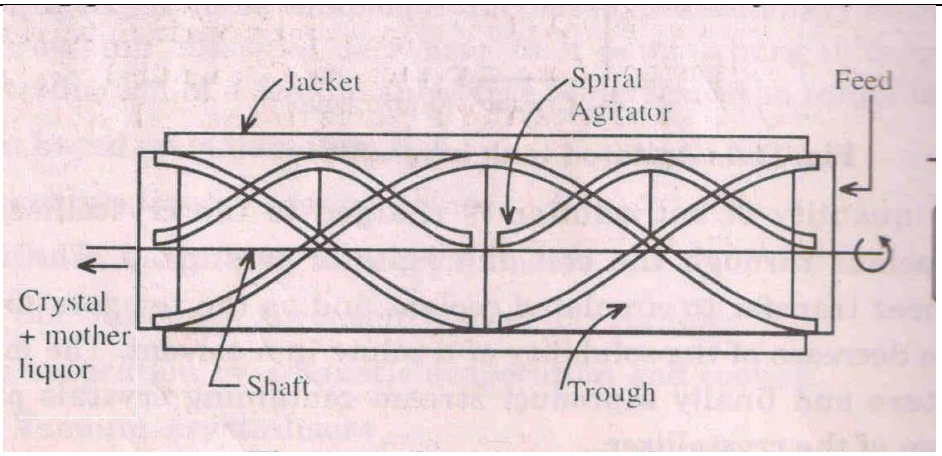
	q = 0 (saturated vapour) q < 0 (superheated vapour)	
3	**Attempt any 2**	16
3-a	Relative volatility $\alpha = P^0_A / P^0_B$ $\alpha = 101.3 / 16.1 = 6.29$ Similarly α =5.91,5.32,4.91,4.59 and 4.5 Average α = **5.25** y= αx/1+(α-1)x empirical relation is **y=5.25 x / 1+4.25 x** calculate y for different values of x=0, 0.1,0.2…….1	1 2 2 2
	Plot x-y diagram with x on x axis and y on y axis	1
3-b	Basis: 100 kmol feed D= 60, W=40 x_F=0.4 Plot 1/(y-x) vs x Ln(F/W)= li(100/40)= 0.916 From the graph measure the area under curve from x_F=0.4 till area equals 0.916 and the corresponding value of x is noted as x_W. **x_W = 0.07** $Fx_F=Dx_D=Wx_W$ 100*0.4= 60*x_D+ 40*0.07 Solving the equation **x_D = 0.62**	 1 1 1 2 1 2

x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
y	0	0.37	0.57	0.69	0.78	0.84	0.89	0.92	0.95	0.98	1

	Composition of distillate = 62% **Composition of residue = 7%**	
3-c	Basis: 1kmol of feed. X_F = mole fraction of hexane in the feed = 50/100=0.5 Feed is 50 mole% vaporized f= 50/100=0.5 The operating line for flash distillation is Y=-((1-f)/f)X+XF/f Slope= -(1-f)/f = -(1-0.5)/0.5 = -1 The point of intersection of the operating line with the diagonal is (0.5,0.5). Draw the equilibrium curve and draw the operating line with the slope to -1 passing through (0.5,0.5) on the diagonal. It intersects the equilibrium curve at P which gives us the equilibrium liquid and vapour compositions as **0.3** and **0.69** mole fraction hexane respectively. liquid compositions = **0.3** vapour compositions = **0.69**	1 1 1 1 2 2
4 A	**Attempt any 3**	12
4A-a	**Equation for steady state equimolar counter diffusion for gases:** $N_A = D_{AB} / RTZ (P_{A1} - P_{A2})$ Where N_A = molar flux of A D_{AB} = Diffusivity of A in B R = Universal gas constant T = absolute temperature Z = distance through which diffusion occurs P_{A1} = partial pressure of A at beginning of diffusion P_{A2} = partial pressure of A at end of diffusion	2 2

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>4A-b</td><td>Differentiate between distillation and extraction
<table>
<tr><th>Distillation</th><th>Extraction</th></tr>
<tr><td>Constituents of liquid mixture are separated by using thermal energy</td><td>Constituents of liquid mixture are separated by using insoluble liquid solvent</td></tr>
<tr><td>It utilizes the difference in vapour pressure of the components to effect separation</td><td>It utilizes the difference in solubilities of the components to effect separation</td></tr>
<tr><td>Relative volatility is used as a measure of degree of separation</td><td>Selectivity is used as a measure of degree of separation</td></tr>
<tr><td>A new phase is created by addition of heat</td><td>A new insoluble liquid phase is created by addition of solvent to feed</td></tr>
<tr><td>Gives almost pure product</td><td>Doesn’t give pure product</td></tr>
<tr><td>Requires thermal energy</td><td>Requires mechanical energy for mixing and separation</td></tr>
<tr><td>Needs heating and cooling provisions</td><td>Doesn’t need heating and cooling provisions</td></tr>
<tr><td>Primary choice for separation</td><td>secondary choice for separation</td></tr>
</table></td><td>1 mark each for any 4</td></tr>
<tr><td>4A-c</td><td>3 stage mixer-settler:</td><td>4</td></tr>
</table>

	 Mixer settler battery for counter current extraction	
4A-d	**Factors on which the rate of drying depends:** 1) **Gas Velocity**: When the velocity of the gas or air is high the rate of drying will also be high. 2) **Humidity of gas** : Lesser the relative humidity, the more will be the rate of drying. 3) **Area of drying surface**: If the area of the wet surface exposed to the gas or air is more, the rate of drying will also be more. 4) **Temperature**: If the temperature of the gas is increased' it's relative humidity decreases (i.e gas becomes more unsaturated) and thus increase a driving force (i.e the concentration difference of moisture between the solid and gas) and so the rate of drying increases.	1 mark each
4B	**Attempt any 1**	**6**
4B-a	**Swenson-walker Crystallizer:**	2



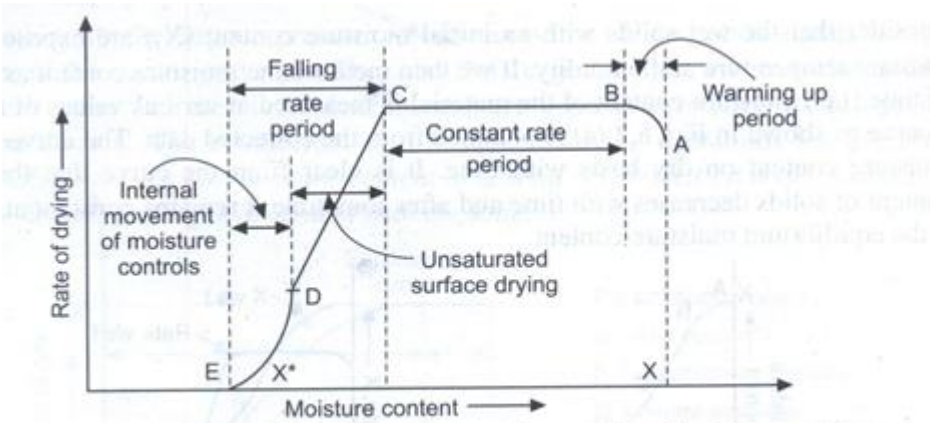
It is the cooling type continuous jacketed trough crystallizer. It is an example of scrapped surface crystallizer.

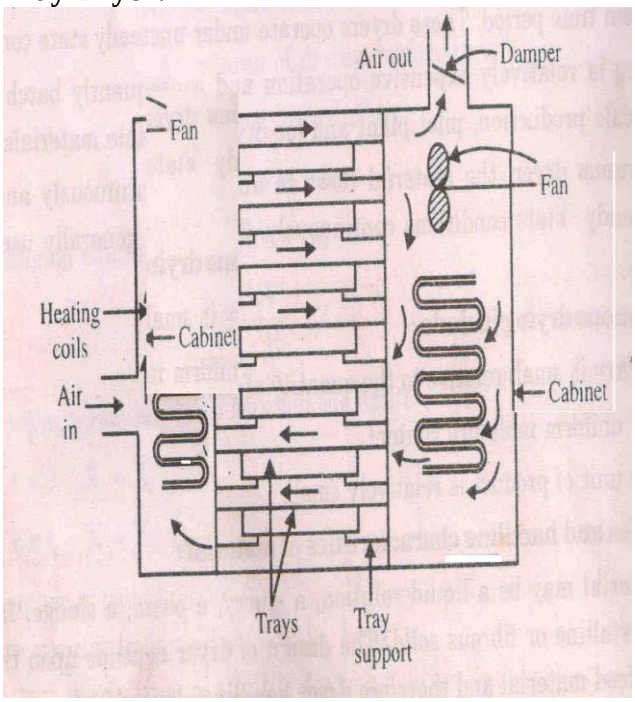
Construction:

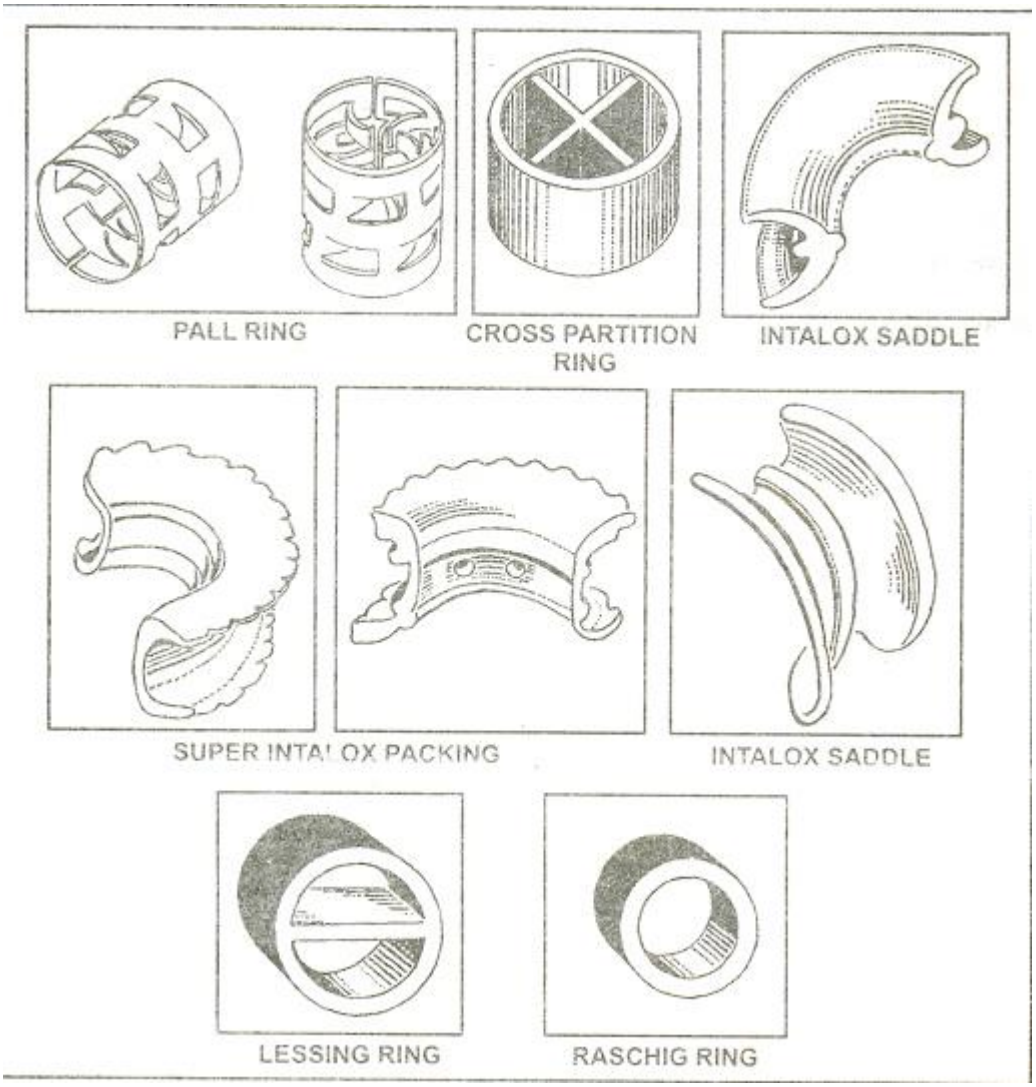
It consists of a long open rectangular trough with a semi cylindrical bottom that is u shaped trough,of width 0.6m and length 3-6m. The trough is jacketed externally for circulating the coolant during operation. A spiral agitator rotating at about 7 rpm is incorporated in the trough in such a way that it is as close to the bottom of the trough as possible. It helps to transport crystals from one point to another point and doesn't allow crystals to settle at the bottom. At one end of the crystallizer an inlet foe hot solution isprovided.an at the other end, an over flow gate for the crystals and mother liquor discharge is provided, The function of spiral agitator include to scrap crystal, to lift and shower the crystal of uniform size, and to convey crystal from one end to the other end of equipment. 2

Working:

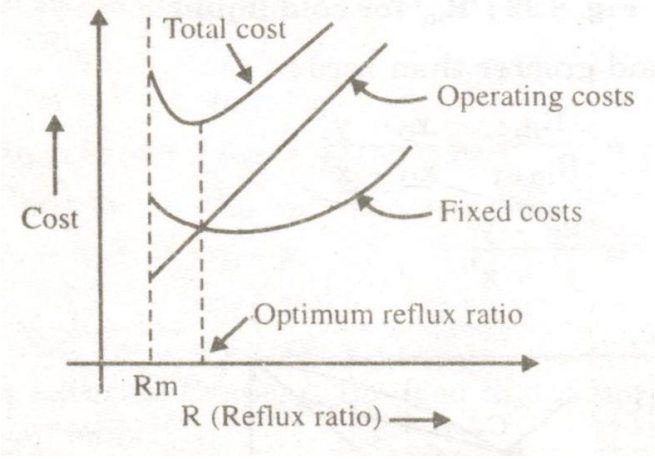
The hot concentrated solution is fed at one end of the open trough and flows slowly towards the other end of trough. Water is fed to the jacket in such a way that it flows in a counter current fashion with respect to the solution. 2

	The solution while flowing trough the trough is cooled by heat transfer to water. Once the solution becomes super saturated crystals starts forming and building. A spiral agitater keeps the crystal in suspension so that previously formed crystal grow instead of formation of new crystal. Ultimately the two phase mixture of crystal an liquor leaves the crystallizer through an overflow gate.	
4.B b	**Rate of drying curve** :  **Typical rate of drying curve under constant drying conditions** Rate of drying curve is plotted with rate of drying on y-axis and moist. Content on x-axis. Section AB of the curve represents the **warning up period** during which this temperature of the solid is becoming equal to the temperature of drying air. BC is straight line that to x=axis in presenting **constant rate** of drying during which the layers of water on the surface of solid is being evaporated. The section CE of the curve represents the **falling rate period** composing of first falling rate period CD and second falling rate period DE from point C onwards some dry patches have started forming on the surface of the solid. The rate of drying decreases for the unsaturated portion and hence rate for total surface	2 4

	portion and hence rate for total surface decreases. The section CD of the curve represents the period corresponding to the zone of unsaturated surface drying the moisture content at which constant rate period ends is known as critical moisture content. After point D, the surface of the solid is completely dry and now internal movement of moistures starts coming to the surface and this is continued up to the point E, where eqm. Is attained the rate of drying over section DE is governed by the internal moisture movement.	
5	**Attempt any4**	**16**
5-a	**Tray Dryer:**  **Working:** The material to be dried is spread over the trays and put into the cabinet then it is closed. Steam is continuously passed through the coil and the fan is started. Air is	2

	heated by heating coils, so its relative humidity decreases and the hot air then passes over the trays. The moisture is evaporated from the wet feed, gets added in air and finally air leaves the dryer through the outlet. The process is continued until the solids are dried.	2
5-b	**Types of packings (any four)**  	1 mark each

5-c	**Selection criteria for solvent selection in liquid-liquid extraction:** **1. Selectivity:** The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase is called selectivity factor. It is the measure of effectiveness of solvent for separating the constituents. **2. Recoverability:** As solvent should be recovered for reuse frequently by distillation, it should not form an azeotrope with extracted solute and for low cost recovery, relative volatility should be high. **3. Distribution coefficient:** Higher values are desirable as less solvent will then be required for given extraction duty. **4. Density:** The difference in densities of saturated liquid phases should be larger for physical separation. **5. Insolubility of solvent:** The solvent insoluble in original liquid solvent should be preferred and it should have high solubility for solute to be extracted, then small amounts of solvent are required. **6. Chemical Stability:** The solvent should be stable chemically and inert towards other components and should not be corrosive. **7. Cost:** The solvent should be cheap. **8.** The solvent should be non toxic, non flammable. **9.** Solvent should have low viscosity, freezing point, vapor pressure for ease in handling and storage. **10. Interfacial tension:** It should be high for coalescence of emulsions to occur more readily, as the same is of greater importance than dispersion.	½ mark each for any 8
5-d	**Optimum reflux ratio is an economic approach:** Infinite reflux ratio requiring minimum number of plates and minimum reflux ratio requiring infinite number of plates is a workable system which requires finite stages for the desired degree of separation. At minimum reflux ratio as infinite number of plates are required, the fixed cost is also infinite while the	3

	cost of heat supply to the reboiler and condenser coolant is minimum. As the reflux ratio is increased, the number of plates decreases and the fixed cost decreases at first, passes through a minimum and then increases as with higher reflux ratio the diameter of the column and sizes of reboiler and condenser increases. The operating cost increases continuously with reflux ratio as it is directly proportional to (R + 1). At total reflux, though the number of plates are minimum, the cost of heat supply to reboiler and condenser coolant is maximum and also large capacity Reboiler and condenser are needed. The total cost which is the sum of the fixed cost and the operating cost also decreases to a minimum and then increases with reflux ratio. The optimum reflux ratio occurs at a point where the sum of the fixed cost and operating cost is minimum. As a rough approximation, **the optimum reflux ratio usually lies in the range of 1.1 to 1.5 times the minimum reflux ratio**.  	1
5-e	**BUBBLE CAP TRAYS** A bubble cap tray has riser or chimney fitted over each hole, and a cap that covers the riser. The cap is mounted so that there is a space between riser and cap to allow the passage of vapour. Vapour rises through the chimney and is directed downward by the cap, finally discharging through slots in the cap, and	4

finally bubbling through the liquid on the tray.

SIEVE TRAYS

Sieve trays are simply metal plates with holes in them. Vapour passes straight upward through the liquid on the plate. The arrangement, number and size of the holes are design parameters.

VALVE TRAYS

In valve trays, perforations are covered by liftable caps. Vapour flows lifts the caps, thus self creating a flow area for the passage of vapour. The lifting cap directs the vapour to flow horizontally into the liquid, thus providing better mixing than is possible in sieve trays.

5-f $y= \alpha x/1+(\alpha-1)x$ — 1

$\alpha = 2.5$

calculate y for different values of x=0, 0.1,0.2…….1 — 3

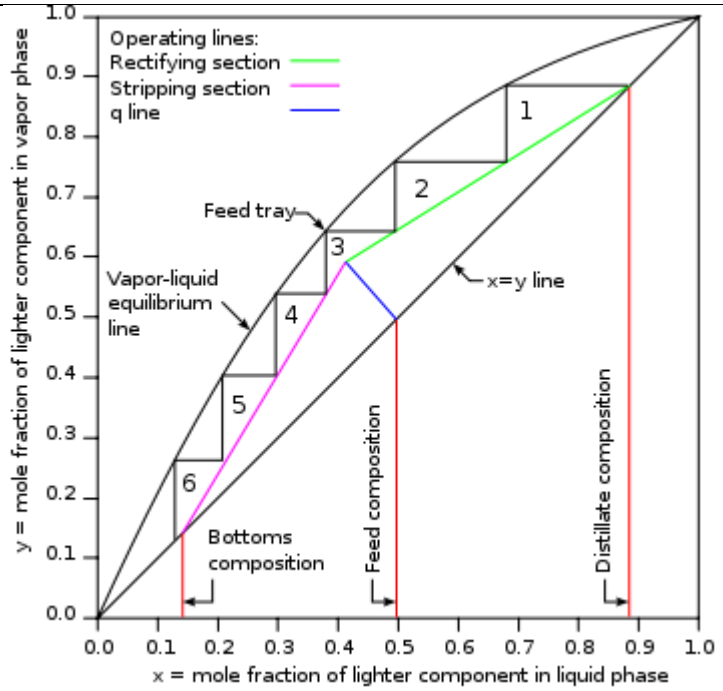
x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
y	0	0.22	0.385	0.52	0.625	0.714	0.79	0.85	0.91	0.96	1

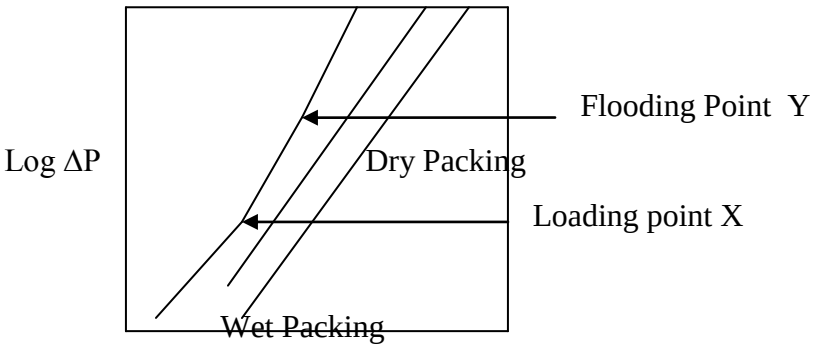
6 Attempt any 2 — **16**

6-a **Stepwise procedure to obtain theoretical plates by McCabe Thiele method:** — 8

1. By material balance, evaluate the terms D,W,F

	2. Draw the equilibrium curve and diagonal with the help of x-y data. 3. Draw the operating line of rectifying section through point(x_D,x_D) on diagonal with intercept equal to x_D / (R+1) 4. Draw feed line on equilibrium curve based on feed conditions. 5. Draw operating line of stripping section through (x_W, x_W) on diagonal and point of intersection of feed line and rectifying section line. 6. Starting from (x_D,x_D) on diagonal, draw a horizontal line to meet the equilibrium curve, drop a vertical to meet the operating line. 7. Proceed this way, constructing the triangles between equilibrium curve and operating line of rectifying section, till we are above the point of intersection . Once we cross this point of intersection, construct the triangles between equilibrium curve and operating line of the stripping section 8. Proceed in the same manner till we reach across the point (x_W, x_W) 9. Count the number of triangles between x_D and x_W. Each triangle represents a theoretical plate. If numbers of triangles are n, then (n-1) represents the number of theoretical plates in the column.	

		
6-b	(i)**Milk powder** – Spray dryer Reason: Milk can be sprayed in form of fine spray in hot & dry air in counter current direction in spray chamber to get dried milk powder. **(ii)Wet lumpy solids** – Tunnel dryer / Tray drier Reason : Wet lumps can be placed on trays which can be loaded on trucks which can be put in tunnel in which hot air is flowing in counter current direction. **(iii)Free flowing material** – Rotary dryer Reason : Free flowing material is allowed to flow down in a slightly inclined cylinder which is rotating material fed is advanced through dryer by gravity in opposite direction to hot air/ flue gases admitted at bottom to flow towards top of cylinder. Spiral flights help to keep material in suspension in flow of hot & dry air. **(iv)Pharmaceutical products** – Tray dryer	1 1 1 1 1 1 1

	Reason : relativly cheap, low maintainance cost , no loss of product during drying , Easy in cleaning.	1
6-c	**Hydrodynamics / pressure drop characteristics in packed column:** In a packed column there are two flows flowing in counter current direction. Liquid fed at the top of column flows down the column through the void spaces in the packings, the same time gas mixture is forced up through the void spaces by using a blower or a compressor. To maintain flow of gas, pressure at the top must be less than that at the bottom. In packed column as same channels are available for liquid down flow & gas up flow, the gas pressure drop is a function of both phase flow rates & is important in design of packed column. The variation of pressure drop with gas velocity is plotted on log-log graph as shown in fig.  In case of dry packing, the relationship between pr.drop and gas velocity is represented by a straight line indicating that pressure drop is proportional to $G^{1.8-2}$. For wet packing, the relationship is indicated by straight line, but for a	2 3

	given velocity, pressure drop will be more than that for dry packing. With the liquid flow down the tower at low and moderate gas velocities, pr.drop is proportional to 1.8^{th} power of gas velocity. Up to point X the amount of liquid held up in packing is constant. At point X the gas flow begins to impede the down flow of liquid and local accumulation of liquid appears here and there in packings. As the gas velocity increases further liquid hold up progressively increases due to which free area for gas flow becomes smaller and pressure drop rises much more quickly. At gas flow rates beyond Y, pr.drop rises very steeply. At point Y, entrainment of liquid by gas leaving the top of tower increases and tower is then said to be flooded. The gas velocity corresponding to the flooding conditions is called as flooding velocity.	3