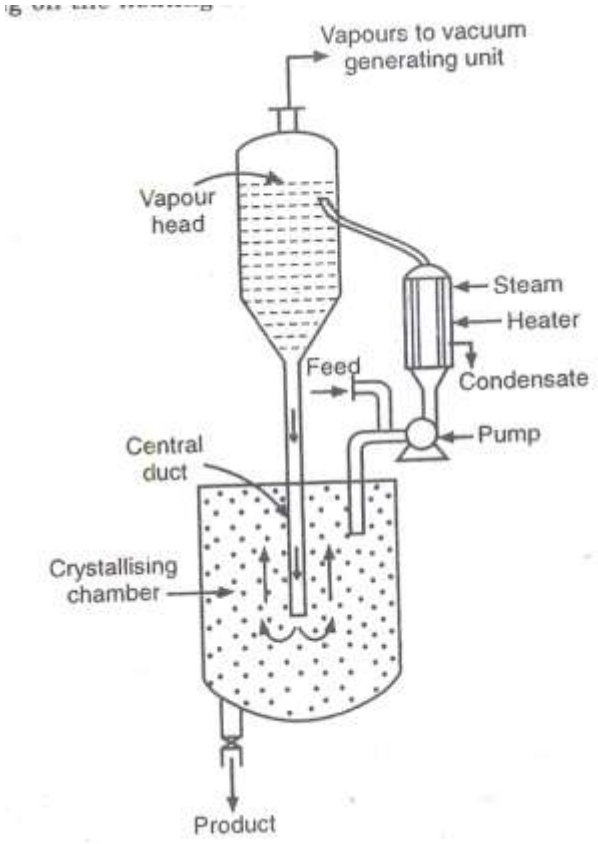
Important Instructions to examiners:

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.

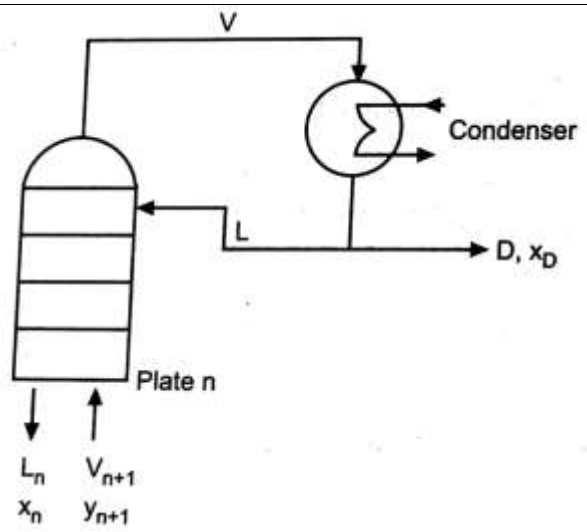
Q No.	Answer	Marking scheme
1 a	**Attempt any 3**	**12**
1A-a	**Different terms involved in two film theory:** K_y – Overall mass transfer coefficient m=slope=$(y_{Ai} - y_A^*) / (x_{Ai} - x_A)$ y_{Ai} - concentration of solute at vapour interface y_A^* - composition of solute in gas phase which is in equilibrium with x_A x_{Ai} - concentration of solute at the liquid interface x_A – concentration of solute in bulk liquid k_y – mass transfer coefficient in vapour phase k_x - mass transfer coefficient in liquid phase	4
1A-b	**Raoult's law:** It states that at a given temperature, the partial pressure of a component A is equal to the product of mol fraction of the component A in the liquid phase and the vapour pressure of the pure component A	1
	$p_A = p^0_A x_A$	1
	where, p_A - partial pressure of A p^0_A - vapour pressure of the pure component A x_A - mol fraction of the component A in liquid phase	
	i) Daltons law : It states that the total pressure exerted by gas/vapour mixture is equal to the sum of the partial pressures of components present in it, thus it expresses the additive nature of the partial pressure.	1
	Mathematically, for binary system $P = p_A + p_B$	1

	Where, P is the total pressure of gas mixture, p_A, p_B are partial pressures	
1A-c	**1. Solubility:** It is the concentration of a solute in a saturated solution at a given temperature. 2. **Distibution Coefficient** = $$\frac{concentration\ of\ solute\ in\ extract\ phase}{concentration\ of\ solute\ in\ raffinate\ phase}$$ 3. **Critical Moisture content**: The moisture content of a material at which the constant rate period ends and the falling rate period starts is called critical moisture content. 4. **Selectivity**: The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase.	1 mark each
1A-d	**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
1B	**Attempt any 1**	**6**
1B-a	**Channeling:** The tendency of liquid to segregate towards the walls and to flow along to walls (region of greatest void space) is termed as channeling which lead to low mass transfer efficiencies. **It can be prevented** by: 1. Providing tower diameter to packing size ratio greater than 8	2 2

	2. Providing good liquid distribution system. **Channeling leads to flooding and loading:** When channeling occurs, liquid flows along the walls and liquid hold up in the column starts to increase. This is loading. When the gas velocity increases further, entrainment of liquid by the gas leaving the top of the tower increases and flooding of tower takes place.	2
1B-b	**Oslo evaporative crystallizer:**  In this crystallizer, super saturation is generated or achieved by evaporation. **Construction:** It consist of a crystallizing chamber containing a bed of forming and growing crystals .A circulating pump and external heater for heating the solution with the help of condensing steam and a vapor head maintained by a vacuum	2 2

	generating equipment. **Working:** The solution from crystallizing chamber is pump by a circulating pump on the suction side of which the feed solution forming a small part of the total circulating liquid is introduced into a heater. Where it is heated by means of condensing steam and then fed to a vap head where some of the solution flashes into vap resulting into some degree of super saturation. The supersaturated solution is returned to the bottom of the crystallizing chamber through a central duct into a crystallizing chamber. Nucleation takes place in the crystal blade which is maintained In a fluidized state by means of upward flowing steam. Then the nuclei converted to crystal of required size and withdrawn as product from the bottom.	2
2	**Attempt any 4**	16
2-a	**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
2-b	**Working of fluidized bed dryer**: A fluidized bed system in addition to a fluidizing chamber also needs an air blower, a hot air generator, a feed conveyor, a cyclone separator and a product conveyor. In this drier, hot air is used to keep the wet feed in a fluidized state. In the drier	4

	the wet material is dried and cooled in the same bed. Wet feed material is admitted to the top of the bed through a hopper via a rotary valve and hot air is distributed at the bottom of the bed through a diffuser plate and dry product is taken out from the side or near the bottom. Heat and mass transfer coefficient are high because of the turbulence created in the bed. The material to be dried and hot air are in cross-flow with respect to the direction of flow of each other. The residence time can be controlled from seconds to hour. The moist air from the drier containing fines is admitted to a cyclone separator for the recovery of fines.	
2-c	**Reflux ratio** is the ratio of amount of distillate fed back to the column to the amount of liquid taken out as distillate or top product. It is represented by 'R' $R = L/D$ **Reflux improves purity:** By allowing reflux, liquid and vapour phases are coming into contact with each other on every plate and mass transfer takes place every time. This will make the vapour richer in more volatile component and liquid in less volatile component. Thus the composition of more volatile component in the final distillate will be more, hence the purity.	2 2
2-d	**Expression for operating line of rectifying section:**	



Material balance around condenser is

$V = L + D$

Or $L = V – D$; $D = V – L$

Overall balance is — 1

$V_{n+1} = Ln + D$

Component balance for A

$V_{n+1}\, y_{n+1} = L_n\, x_n + D\, x_D$ — 1

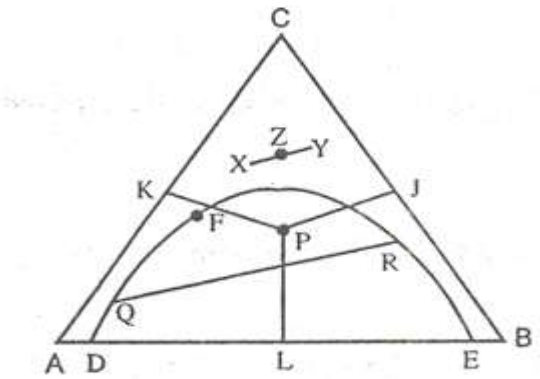
$y_{n+1} = L_n\, x_n / V_{n+1} + D\, x_D / V_{n+1}$

But $V_{n+1} = L_n + D$

$y_{n+1} = L_n\, x_n / L_n D + D\, x_D / L_n D$ — 1

This is Expression for operating line of rectifying section.

2-e **Triangular diagram**:



2

Where

A=dilutent

B=solvent

C=solute

Uses: In liquid -liquid extraction, when the solvent is partially miscible with the original solvent, the solubility and equilibrium relations are often shown on a triangular diagram. The composition of ternary system can be shown by a point lying inside an equilateral triangle

This is used to find equilibrium between extract phase and raffinate phase.

It is used to give concept of tie line, plait point

It can be used for finding out number of stages for complete recovery of solute.

Binodial curve: It represents two phase region that will split up into two layers in equilibrium with each other.

Tie line: Tie line is a line which connects two phases in equilibrium with each other.

Plait point: The plait point on binodial solubility curve represent a single phase where the length of tie line is zero.

2

3	**Attempt any 2**	16
3-a	**q-line:** The 'q' is a measure of the thermal condition of the feed and is defined as the number of moles of saturated liquid resulting in the stripping section for each mole of feed introduced. Thus for a feed we get , $L' = L + qf$ $V = V' + (1-q)F$ **Derivation of q-line :** The liquid flow in the stripping section is $L' = L + qf$ $\therefore \quad L' - L = qf$ ---------- (1) Similarly, the vapour flow in the rectifying section is $V = V' + (1 - q) F$ ---------- (2) $\therefore \quad V - V' = (1 - q) F$ ---------- (3) Overall material balance in the upper section of coloumn : $V = L + D$ ---------- (4) Material balance of A in the upper section : $V_y = Lx + D\,x_D$ ---------- (5) Overall material balance in the lower section : $V' = L' - W$ ---------- (6) Material balance of A in the lower section : $V'y = L'x - W\,x_w$ ---------- (7) Subtracting Equation (7) from Equation (5) $y (V - V') = x (L - L') + D\,x_D + W\,x_w$ ---------- (8) Overall material balance of A over the coloum as a whole :	4

$x_f . F = D x_D + W x_w$ ---------- (9)

∴ Equation (8) becomes

$y (V – V') = x (L – L') + x_F . F$ ---------- (10)

Substituting the values of V - V' and L' – L from Equation (3) and (1) into Equation (10) gives

$y (1 - q) F = x(-qF) + x_F . F$

$\therefore \quad y = \frac{-q}{1-q} x + \frac{XF}{(1-q)}$ ---------- (11)

Equation (11) is known as the **feed line or q-line** equation

Types of q lines for various feed conditions:

q = 0 (saturated vapour)

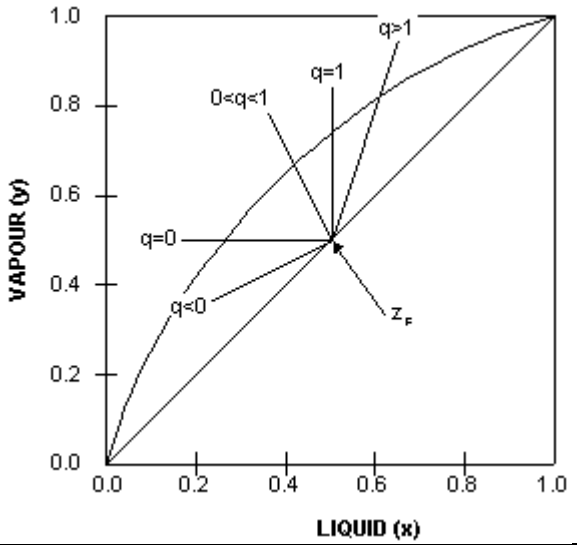
q = 1 (saturated liquid)

0 < q < 1 (mix of liquid and vapour)

q > 1 (subcooled liquid)

q < 0 (superheated vapour)

4



3-b	**Basis:** Feed containing 40% benzene and 60% toluene Molecular weight of benzene=78 Molecular weight of toluene= 92	1
	Xf= mole fraction of benzene in the feed = (40/78)/(40/78 + 60/92) =0.44 Similarly xd= (96/78)/(96/78+4/92)=0.966	1
	Xw= (5/78)/(5/78+95/92)=0.058 Relative volatility = α= 2.5 With the help of relative volatility, generate x-y data and plot the equilibrium diagram. For generating x-y data assume X= 0,0.1,0.2,……1 and find the corresponding values of y from the relation	1
	Y= α x/(1+(α-1)x Procedure for finding out the minimum reflux ratio q=1/3 slope of feed line=-(q/1-q)= -0.5 Intercept on y axis=xf/(1-q) =0.66	1
	Draw the feed line through the point (0.44,0.44) on the diagonal with a slope equal to -0.5 or intercept equal to 0.66 which will cut the equilibrium curve at point P. Through the point A(0.966,0.966) on the diagonal ,draw the operating line A-P of the rectification section (dotted line) and read y' and x' on y axis and x axis respectively. Minimum reflux ratio Rm= (x_D-y') / (y'-x') From graph y'=0.515, x'=0.3	1
	Rm= 2.1 R=1.5Rm=1.5x 2.1=3.14	1

	Operating line of rectification section: Point A(0.966,0.966) on the diagonal. The intercept of the rectifying section of operating line is = x_D /R+1 =0.966/3.14+1=0.232 From the graph the theoretical stages required including reboiler = n=10. Number of stages required in column=n-1=10-1=9	1 1
3-c	**Lewis Sorel method of determination of number of theoretical plates:** Equation of operating line of rectifying $y_n+1 = \frac{L_n}{L_n + D} x_n + \frac{D.X_D}{L_n + D}$ eq.1 Operating line of stripping section $y_m+1 = \frac{L_m}{L_m - W} x_m - \frac{W.X_W}{L_m - W}$ eq.2 1. From the data cited in a given problem, evaluate the terms – D,W,L,etc. 2. From the x-y data provided (or can be generated knowing the relative volatility) draw an equilibrium diagram. 3. Substistute the values of L_n(L), x_D,D in equation(1),in order to get a relationship between y_n+1 and x_n. 4. Similarly ,substitute the values L_m,W,x_W in equation(2) , to get a relationship between y_m+1 and x_m. Lm is to be evaluated by taking into consideration the condition of feed. For example, if it is a liquid at its bubble point $L_m = L_n$+F. 5. The distillate composition (x_D) given in the problem statement represents	8

the composition of vapour (y_n) as it is obtained by condensing the vapour l;eaving the column.

6. From the vapour phase composition : $y_n = x_{D,\ find}$ the liquid phase composition x_n+1 from the x-y curve drawn and substitute the value of x_n+1 in the equation of the operating line of the rectifying section to get y_2
7. Find x_n+2 value from the equilibrium diagram corresponding to y_n+2
8. Find y_n+3 and proceed with the same equation till we reach the point when the liquid phase composition equal to or less than x_F

9. Then make use of the material balance equation or operating line of stripping section and proceed in the same way as described above till we get the liquid phase composition equal to or below x_W ,suppose we end with y_n+10,it means that there will be 10 plates in the column.

4 A **Attempt any 3** — 12

4A-a **Differentiate between distillation and extraction** — 1 mark each

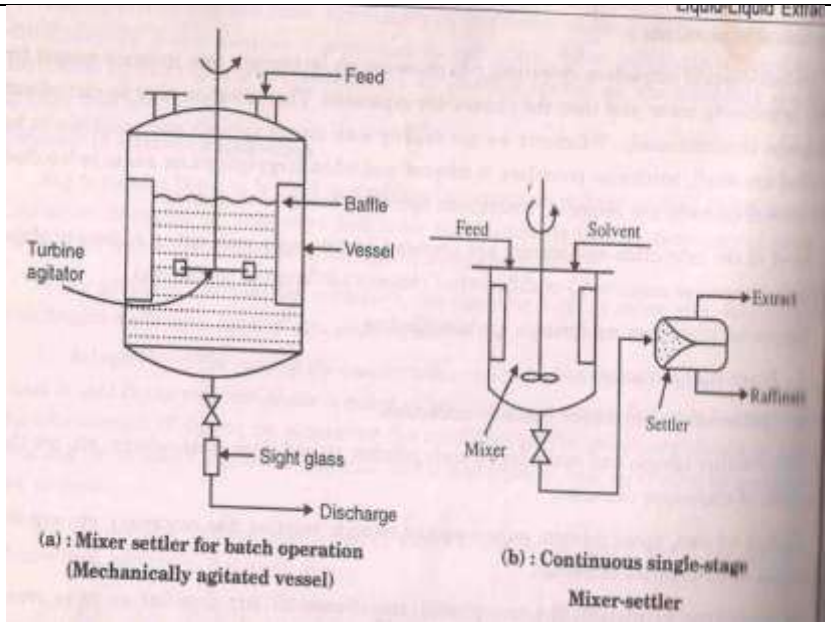
points	Distillation	Extraction
Thermal energy	Requires thermal energy	Requires mechanical energy for mixing and separation
Operating cost	Cost is Low.	Cost is high.
Equipment	Needs heating and cooling provisions	Doesn't need heating and cooling provisions
Quality of product	Gives almost pure product	Doesn't give pure product

4A-b **Equation for steady state equimolar counter diffusion for gases:**

$N_A = D_{AB} / RTZ (P_{A1} - P_{A2})$ — 2

	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
4A-c	**Application of Steam Distillation:** 1. For separating high boiling component from non volatile impurities. 2. For separating high boiling mixture into different fractions wherein the decomposition of material might occur if direct distillation were employed 3. Where vaporization temperature cannot be reached by heat **Application of batch Distillation:** 1. Where small quantities of liquid mixture are to be handled. 2. When more than one product is to obtained 3. When liquid mixture to be separated are high in solid content. **Steam distillation:** Steam distillation is adopted in cases where substance involved cannot withstand temp of distillation and decompose. Substance of this kind can be separated by reducing the partial pressure of the volatile component. This can be done by making use of inert vapour that decreases the temperature of distillation. The inert vapour used should be practically immiscible with components to be distilled. Steam is used for this purpose. In steam distillation, steam is directly admitted into the liquid in the still. The mixed vapour containing desired component is taken as overhead, condensed and desired component is separated from water phase by gravity while non volatile material remains behind in the still.	½ mark each for any 2 ½ mark each for any 2 2

4A-d	Most common packings are : 1) Raschig rings. 2) Pall rings. 3) Hy-pak. 4) Berl saddles. 5) Intalox saddles. 6) Super intalox saddles 7) Lessing ring	½ mark each for any 4
	Characteristics of a tower packing : 1) It should provide a large interfacial area for phase contacting 2) It should possess good wetting characteristics. 3) It should have a high corrosive resistance. 4) It should be relatively cheap. 5) It should possess enough structural strength. 6) It should be chemically inert to the fluids handled in the tower.	½ mark each for any 4
4B	**Attempt any 1**	**6**
4B-a	**Mixer settler:**	



(a) : Mixer settler for batch operation (Mechanically agitated vessel)

(b) : Continuous single-stage Mixer-settler

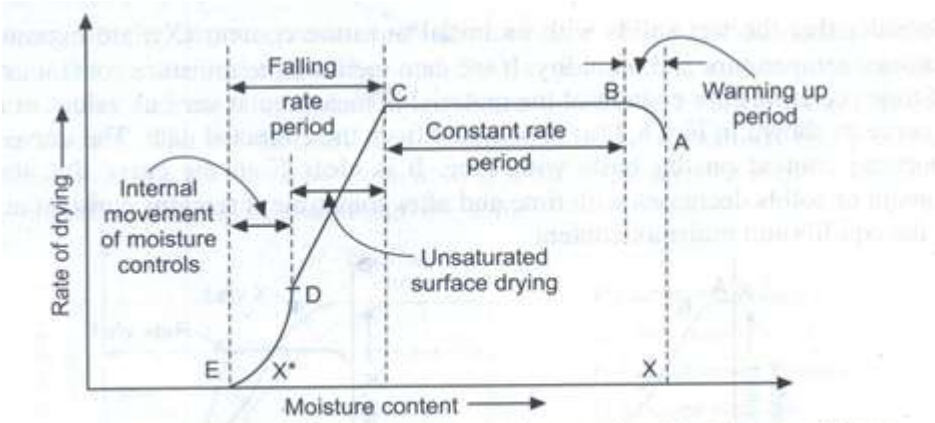
3

The mixer-settler is the most simple type of extractor. It is a stage-type extractor and has many variations.

Construction and working: For extraction operations carried out batch wise, the mixture and settler may be the same unit(fig.a). It consists of a vertical tank incorporating a turbine or propeller agitator. It is provided with charging nozzles at the top and discharge connection carrying a sight glass at the bottom. Feed solution to be extracted is taken into an agitated vessel, and then the required amount of solvent is added, and whole mass is agitated for predetermined time. At the end of mixing cycle, agitation is stopped and settling is applied for a phase separation. Afterwards, the raffinate and extract phases are withdrawn from the bottom into separate receivers.

3

For continuous operation, the mixer and settler are separate units Fig.(b). The mixer is a small baffled agitated tank provided with inlet-outlet connections and settler is often a continuous gravity decanter. In this extractor, two phases are

	continuously in contact with each other in the mixer under thorough agitation before flowing to settler for phase separation.	
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 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	2 4

<table>
<tr><td></td><td>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.</td><td></td></tr>
<tr><td>5</td><td>Attempt any4</td><td>16</td></tr>
<tr><td>5-a</td><td>y= αx/1+(α-1)x

α = 2.3

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

<table><tr><td>x</td><td>0</td><td>0.1</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.5</td><td>0.6</td><td>0.7</td><td>0.8</td><td>0.9</td><td>1</td></tr><tr><td>y</td><td>0</td><td>0.203</td><td>0.365</td><td>0.496</td><td>0.605</td><td>0.697</td><td>0.775</td><td>0.843</td><td>0.902</td><td>0.954</td><td>1</td></tr></table></td><td>1

3</td></tr>
<tr><td>5-b</td><td>Azeotrope :
An azeotrope is a liquid mixture with an equilibrium vapour of same composition as the liquid. The dew point and bubble point are identical at azeotropic composition and mixture vaporizes at single temperature, so azeotropes are called constant boiling mixture.
Azeotrope can not be separated by distillation because the dew point and bubble point are identical.
Complete separation of constituents of binary azeotrope can be done by
1. Adding third component to the binary mixture and
2. Changing the system pressure.
The third component added to a binary azeotrope usually forms a low boiling azeotrope with one of the feed constituents and withdrawn as distillate. The third component added is called as entrainer or azeotrope breaker. The process of distillation where the third component is added to the binary azetrope to effect the complete separation is called azeotropic distillation</td><td>1

1

2</td></tr>
<tr><td>5-c</td><td>Selection criteria for solvent in gas absorption : (any 4)</td><td></td></tr>
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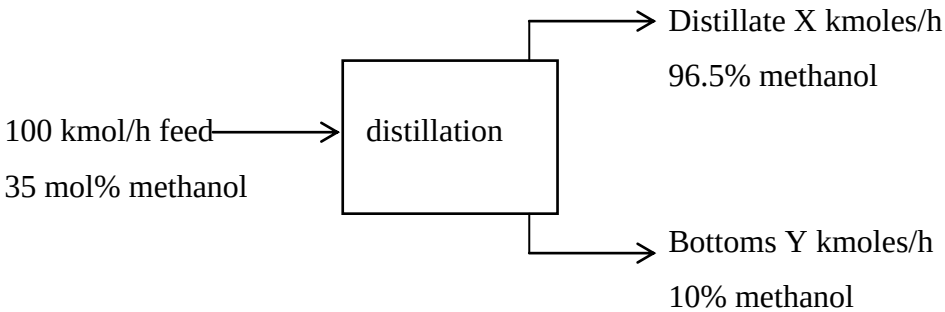
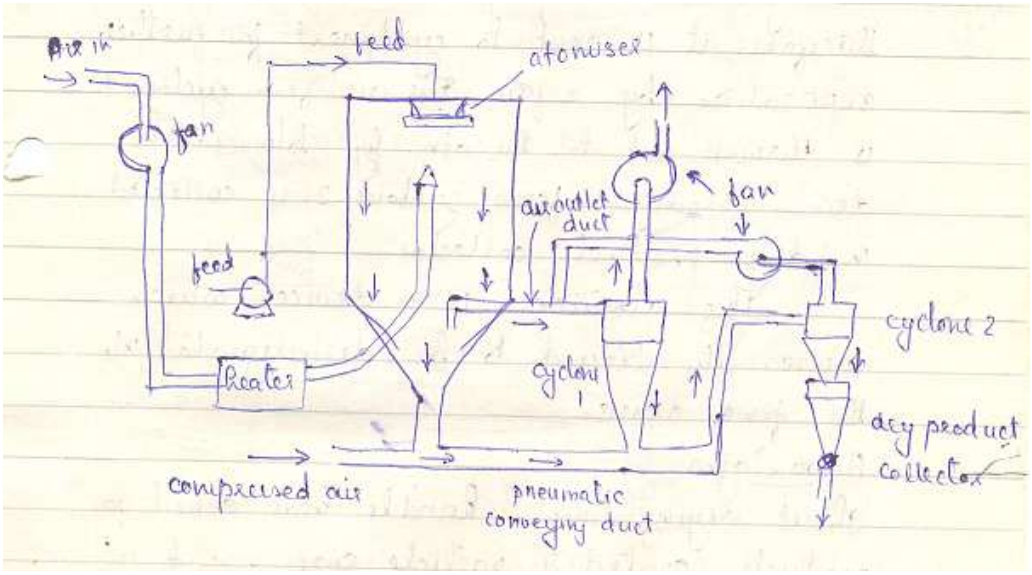
	While selecting a particular solvent for absorption operation , the following properties of the solvent are considered. 1) Gas solubility : the solubility of solute gas in a solvent should be high . the solvent selected should have a high solubility for the solute to be absorbed 2) Volatility : As the 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 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.	1 mark each
5-d	 Basis: 100 kmol/h feed Let X kmoles/hr distillate and Y kmol/hr bottom product Overall balance is 100 = X + Y……..(1)	1 1

	Methanol balance is 0.35*100 = 0.965X+0.1Y ……(2) Solving (1) and (2) X = 28.9 kmoles and Y=71.1 kmoles Molal flow rate of distillate **= 28.9 kmoles/h** Molal flow rate of bottom product = **71.1 kmoles/h**	1 1
5-e	**Relative merits of plate and packed columns** 1. Plate columns operate over a wide range of liquid flow rates without flooding. 2. Plate columns by repeated mixing and separation provide more positive contact between fluid phases. 3. Because of difficulties arising in dispersion of liquid in packed tower, plate tower is more reliable. 4. Side streams are very easily taken out from plate towers 5. For plate towers, design information is generally more readily available. 6. Whenever liquid mixtures containing dispersed solids are to be handled, plate towers should be preferred. 7. Whenever inter stage cooling is required, plate towers are preferred. 8. For a given duty, total weight of dry plate tower is less than the weight of packed towers. 9. High values of liquid- gas ratio are best handled in packed tower. 10. For liquids having tendency to foam, packed towers are preferred. 11. The liquid hold up is low in packed tower. 12. Pressure drop through packed tower is usually low. 13. Packed towers are more economical when highly corrosive fluids are to be handled. **14.** Plate towers are preferred when large temperature changes are involved.	½ mark each for any 8
6	**Attempt any 2**	**16**
6-a	Initial moisture content X_1=0.67/(1-0.67)=2.03	1

	Final moisture content X_2=0.25/(1-0.25)=0.333	1
	Equilibrium moisture content X^*=0.01/(1-0.01)=0.0101	1
	Critical moisture content X_c=0.4/(1-0.4)=0.67	1
	Rc = 1.5 kg/ m^2 hr.	
	A/W'=0.5 or W'/A=2	1
	$t = W'/ARc \{ (X_1-X_c) + (X_c - X^*)\ln[(X_c - X^*)/(X_2 - X^*)]\}$	1
	$= 2/1.5\{ (2.03-0.67) + (0.67 - 0.0101)\ln[(0.67 - 0.0101)/(0.333 - 0.0101)]\}$	
	= 2.44 hr.	2
6-b	**Spray Dyer** : 	3
	It is continuous direct contact dyer employed for drying of solutions, slurries and pastes. In this dyer, the feed is introduced in the form of very fine droplets into a stream of hot gas.	
	Construction: It consists of a drying chamber where feed is contacted with hot gas, heater for heating fresh air sucked by fan or blower, cyclone separators for dust separation and collection, pneumatic conveying duct and blowers. The	2

	material is spread in the form of a mist of fine droplets by spray nozzles, into a hot gas stream inside the chamber. **Working** : The feed is pumped to the top of this dyer where it is disintegrated into small droplets by atomizes . The large quantity of fresh air is taken in by fan, it is heated in the heater and finally fed below the atomizer in drying chamber. As the surface area of drops is very large, the liquid portion of these drops rapidly evaporates and before they touch the bottom of drying chamber they are completely dried. The dried product is taken out and conveyed in the cyclones dust collector by stream of air major portion of the air is taken out through air outlet duct which mostly contains dust and is sent to cyclones. The solids collected are fed to pneumatic conveying duct. The air leaving the cyclone to may contain some dust and therefore it is sent to cyclone 1 for further separation by a fan., The air from cyclone 1 is thrown out to the atmosphere by blower. The dried product from cyclone 2 is connected in dry product connector.	3
6-c	Basis 1000 kg feed solution at 353K F=1000 kg. x_F=64.2/164.2= 0.391 Water in feed = 1000(1-0.391) = 609 kg Water evaporated = 0.1*609= 60.9 kg Mol wt of $MgSO_4$=120, Mol wt of $MgSO_4 7H_2O$ = 246 Solvent balance is $F(1- x_F) = V+C8(126/246)+ L$ 100 (1-0.391)=60.9+0.5122C+L or L=609-60.9+0.5122C kg. $MgSO_4$ balance $MgSO_4$in feed = $MgSO_4$ crystals + $MgSO_4$ in mother liquor.	1 1 1 1 1 1

	0.391*1000=C(120/246)+[609-60.9+0.5122C] * solubility of $NaNO_3$	
	391 = 0.488C+[609-60.9+0.5122C]*0.408	1
	Or C=599.7 kg	
	Yield of $MgSO_4$ crystals **(C)=599.7 kg.**	1