



**SUMMER-16 EXAMINATION**  
**Model Answer**

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**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.





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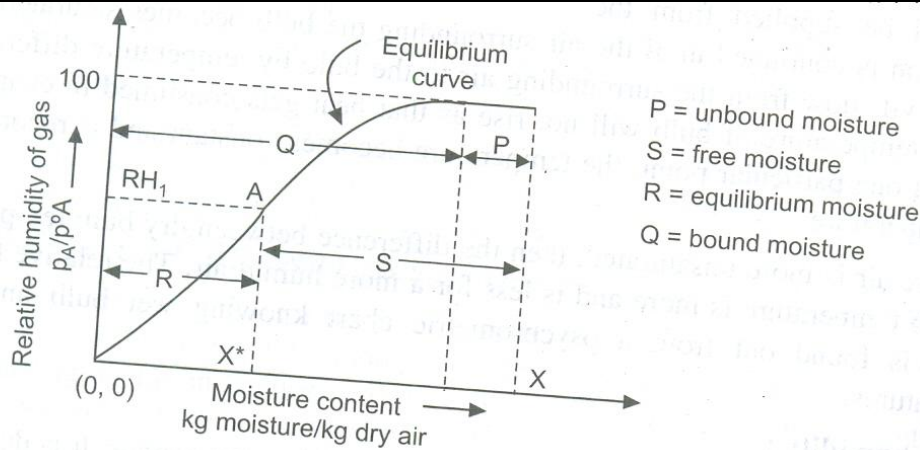
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	$\alpha x_A (1-y_A) = y_A (1-x_A)$ $\alpha x_A - \alpha x_A y_A = y_A (1-x_A)$ $\alpha x_A = y_A + y_A x_A (\alpha - 1)$ $= y_A [1 + x_A (\alpha - 1)]$ $y_A = \alpha x_A / [1 + x_A (\alpha - 1)]$ <p>or <math>y = \alpha x / [1 + x (\alpha - 1)]</math></p>	1	
1a-iii	<p><b>Selectivity:</b> The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase is called selectivity factor.</p> <p>It is the measure of effectiveness of solvent for separating the constituents.</p> <p>When selectivity = 1, separation is not possible. Selectivity should be greater than 1..</p>	2	4
1.a-iv	<p><b>(i) Critical moisture:</b> The moisture content of material at which constant rate period ends and falling rate period starts is called critical moisture content.</p> <p><b>(ii) Equilibrium moisture content:</b> It is the moisture content of the substance that is in thermodynamic equilibrium with its vapour in gas phase under specified humidity and temperature of gas. It represents the limiting moisture content to which a given material can be dried under constant drying conditions.</p> <p><b>(iii) Bound moisture:</b> It is the moisture in the substance which exerts a vapour pressure less than that of pure liquid at the given temperature.</p> <p><b>(iv) Unbound moisture content:</b> It is the moisture held by a material in excess of equilibrium moisture content corresponding to saturation in the surrounding atmosphere. It is the moisture in the substance which exerts an equilibrium vapour pressure equal to that of pure liquid at the given temperature.</p>	1 1 1 1	4



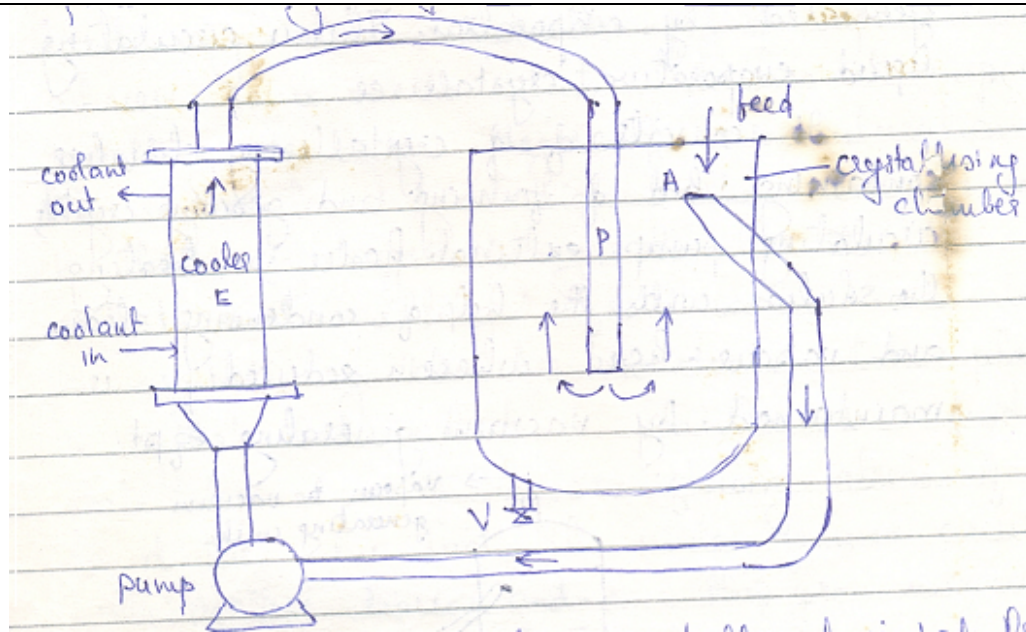
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1b	Attempt any 1		6
1b-i	<p><b>Situations where liquid- liquid extraction is preferred(any 2)</b></p> <ol style="list-style-type: none"> <li>Whenever very large amounts of latent heats are required</li> <li>Whenever we are dealing with substances which are heat sensitive</li> <li>Whenever we are dealing with liquid mixture forming azeotrope or close boiling mixture.</li> </ol> <p><b>Selectivity :</b> The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase. Selectivity should be high.</p> <p><b>Significance of selectivity:</b> It is a measure of separation by extraction. When selectivity = 1, separation is not possible. Selectivity should be greater than 1.</p>	2	6
1b-ii	<b>Oslo Cooling type crystalliser</b>		6



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**Construction :**

It consists of a crystallizing chamber, a circulating pump and an external cooler for cooling the solution. It is a circulating liquid cooling crystalliser.

2

**Working :**

The solution to be crystallized is fed from the top. Mother liquor from a crystallizing chamber is withdrawn near a feed point 'A' with the help of a circulating pump and it is then admitted to a cooler (E) where supersaturation is achieved by cooling. The supersaturated solution from the cooler is finally fed back to the bottom of the crystallizing chamber through a central pipe (P). Usually, nucleation takes place in the bed of crystals in the crystallizing chamber. The nuclei formed circulate with mother liquor and once they become sufficiently large, they will be retained in the fluidised bed. Once the crystals grow to a required size, they are removed as product from the bottom of the crystallizing chamber through a valve 'V' as these cannot be retained in the

2



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	fluidised bed by the circulation velocity.		
2	<b>Attempt any 4</b>		16
2-a	<p><b>Solubility:</b> Solubility of a solute in a given solvent is the concentration of the solute in a saturated solution at a given temperature.</p> <p><b>Nucleation:</b> The generation of new solid phase either on an inert material in solution or in the solution itself is called nucleation.</p> <p><b>Super saturation:</b> It is the quantity of the solute present in the solution in which crystals are growing compared with the quantity of the solute that is in equilibrium with the solution.</p> <p><b>Crystal growth:</b> Increase in size of the nucleus with layer by layer addition of solute is called crystal growth.</p>	1 1 1 1	4
2-b	<p><b>Factors on which the rate of drying depends:</b></p> <ol style="list-style-type: none"><li>1) <b>Gas Velocity:</b> When the velocity of the gas or air is high the rate of drying will also be high.</li><li>2) <b>Humidity of gas :</b> Lesser the relative humidity, the more will be the rate of drying.</li><li>3) <b>Area of drying surface:</b> If the area of the wet surface exposed to the gas or air is more, the rate of drying will also be more.</li><li>4) <b>Temperature:</b> 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.</li></ol>	1 1 1 1	4
2-c	<p><b>Principle methods of distillation:</b></p> <ol style="list-style-type: none"><li>1. Simple or differential distillation</li><li>2. Flash or equilibrium distillation</li></ol>	3	4



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	<p><b>3. Fractionation or rectification</b></p> <p><b>Fractional distillation is</b> better because reflux is there in fractionation and hence purity of the product is higher.</p>	1							
2-d	<p><b>Reflux ratio <math>R = L/D</math></b></p> $= \frac{\text{Amount of liquid fed back to column}}{\text{Amount of liquid taken out as distillate}}$ <p>The column is neither run at total reflux nor minimum reflux. It is run at optimum reflux ratio. The optimum reflux ratio is defined as reflux ratio at which total cost of operation (sum of fixed charges and operating charges) is minimum. The optimum reflux ratio is usually lies in the range of 1.1 to 1.5 times the minimum reflux ratio.</p> <p>The graph plots Cost on the y-axis and Reflux ratio (R) on the x-axis. It shows three curves: 'Total cost' (a U-shaped curve), 'Operating costs' (a straight line increasing with R), and 'Fixed costs' (a curve that decreases and then levels off as R increases). The minimum point of the 'Total cost' curve is indicated by a vertical dashed line down to the x-axis, labeled 'Optimum reflux ratio' and 'Rm'.</p>	1  2  1	4						
2-e	<p><b>Differentiate between distillation and extraction</b></p> <table border="1"> <thead> <tr> <th><b>Distillation</b></th> <th><b>Extraction</b></th> </tr> </thead> <tbody> <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</td> <td>It utilizes the difference in solubilities of the components to</td> </tr> </tbody> </table>	<b>Distillation</b>	<b>Extraction</b>	Constituents of liquid mixture are separated by using thermal energy	Constituents of liquid mixture are separated by using insoluble liquid solvent	It utilizes the difference in vapour pressure of the components to effect	It utilizes the difference in solubilities of the components to	1 mark each for any four	4
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	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding: 5px;">separation</td> <td style="width: 50%; padding: 5px;">effect separation</td> </tr> <tr> <td style="padding: 5px;">Relative volatility is used as a measure of degree of separation</td> <td style="padding: 5px;">Selectivity is used as a measure of degree of separation</td> </tr> <tr> <td style="padding: 5px;">A new phase is created by addition of heat</td> <td style="padding: 5px;">A new insoluble liquid phase is created by addition of solvent to feed</td> </tr> <tr> <td style="padding: 5px;">Gives almost pure product</td> <td style="padding: 5px;">Doesn't give pure product</td> </tr> <tr> <td style="padding: 5px;">Requires thermal energy</td> <td style="padding: 5px;">Requires mechanical energy for mixing and separation</td> </tr> <tr> <td style="padding: 5px;">Needs heating and cooling provisions</td> <td style="padding: 5px;">Doesn't need heating and cooling provisions</td> </tr> <tr> <td style="padding: 5px;">Primary choice for separation</td> <td style="padding: 5px;">secondary choice for separation</td> </tr> </table>	separation	effect separation	Relative volatility is used as a measure of degree of separation	Selectivity is used as a measure of degree of separation	A new phase is created by addition of heat	A new insoluble liquid phase is created by addition of solvent to feed	Gives almost pure product	Doesn't give pure product	Requires thermal energy	Requires mechanical energy for mixing and separation	Needs heating and cooling provisions	Doesn't need heating and cooling provisions	Primary choice for separation	secondary choice for separation		
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3	<b>Attempt any 2</b>		16														
3-a	<p><b>Rayleigh equation:</b></p> <p>Let F be moles of liquid mixture containing <math>x_F</math> mol fraction of A, D kmoles of distillate and W kmoles of residual liquid in still which are obtained at the end of operation. Let <math>y_D</math> and <math>x_W</math> be the mol fr of A in distillate and bottom residual liquid.</p> <p>Let L be kmoles of liquid in the still at any time during the course of distillation and let x be mol fr of A in liquid. Let very small amount dD kmol of distillate of composition y in equilibrium with the liquid is vaporized. Then composition and quantity of liquid decreases to (x-dx) and L to (L-dL) respectively.</p> <p>Overall material balance is <math>L=L-dL+dD</math></p> <p>Or <math>dL= dD</math></p> <p>Material balance for component A is <math>Lx=(L-dL)(x-dx)+y_dD</math></p> <p><math>Lx= Lx-Ldx-xdL+dLdx+y_dD</math></p>	1  1  1  1	8														





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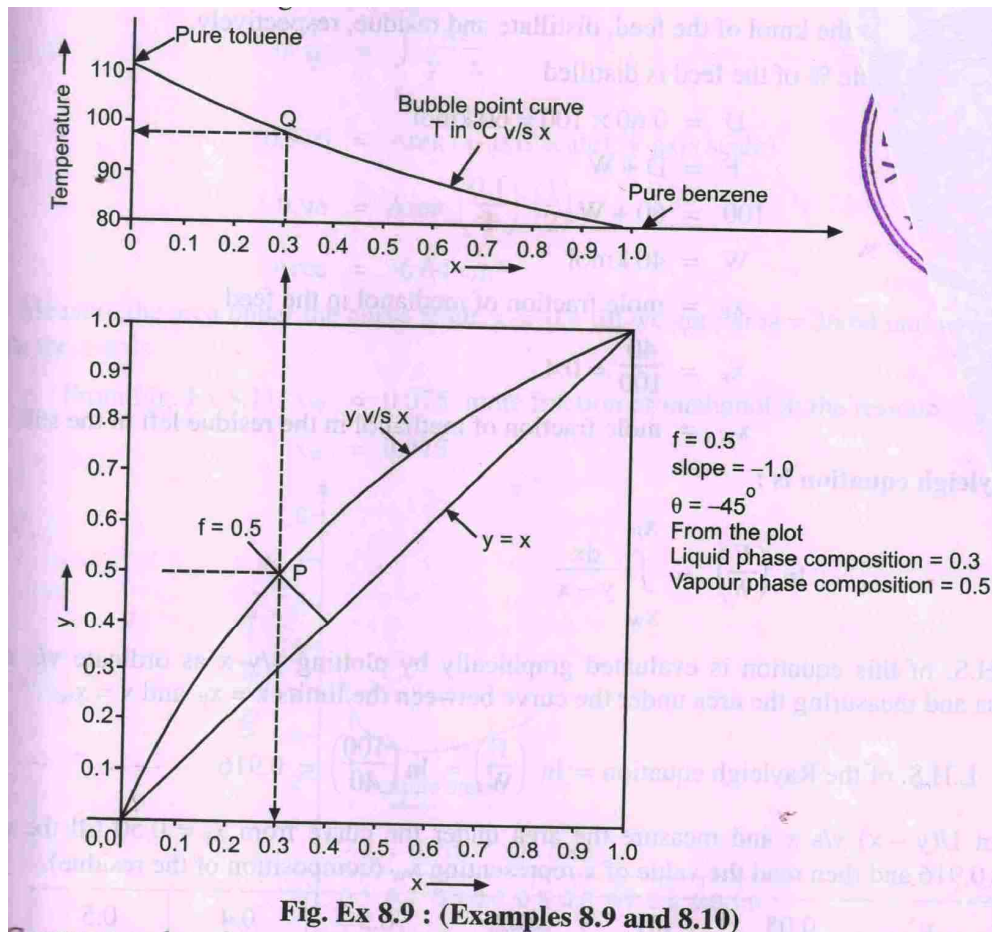
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	<p><math>dLdx=0</math></p> <p><math>0= -Ldx-xdL+ydL</math></p> <p>But <math>dD=dL</math></p> <p>i.e. <math>0=-Ldx-xdL+ydL</math></p> <p><math>Ldx=(y-x)dL</math></p> <p><math>dL/L=dx/(y-x)</math></p> <p>Integrating the equation between the limits <math>L=F, x=x_F, L=W, x=x_W</math></p> <p><math>\int_F^W \frac{dL}{L} = \int_{x_F}^{x_W} \frac{dx}{(y-x)}</math></p> <p><math>\ln\left(\frac{F}{W}\right) = \int_{x_F}^{x_W} \frac{dx}{(y-x)}</math></p> <p>This equation is known as Rayleigh equation.</p>	<p>1</p> <p>1</p> <p>2</p>	
<p>3-b</p>	<p>Feed containing 40 mole % benzene</p> <p><math>x_F =</math> mole fraction of benzene in feed</p> <p><math>=</math> mole % benzene /100</p> <p><math>x_F = 40/100 = 0.4</math></p> <p>given 50 mole % of the feed is vaporized. Therefore,</p> <p><math>f =</math> molal fraction of feed that is vaporized. Therefore,</p> <p><math>f =</math> molal fraction of feed that is vaporized</p> <p><math>50/100 = 0.5</math></p> <p>Slope of operating line for flash distillation <math>= -\frac{(1-f)}{f}</math></p> <p>Slope <math>= \frac{-(1-0.5)}{0.5} = -1.0</math></p> <p>Draw the equilibrium curve with the help of data given.</p>	<p>1</p> <p>1</p>	<p>8</p>

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The point of intersection of the operating line and the diagonal is  $(x_F, x_F)$   
Mark that point on the diagonal and draw operating line through it with slope =  
-1.0 which will cut the equilibrium curve at point say P. through P read the  
equilibrium liquid phase and vapor phase compositions from the x-axis and y-  
axis respectively.



**Equilibrium : liquid phase composition = 0.3 mole fraction of benzene**

**Equilibrium : vapour phase composition = 0.5 mole fraction of benzene**

2

1

2



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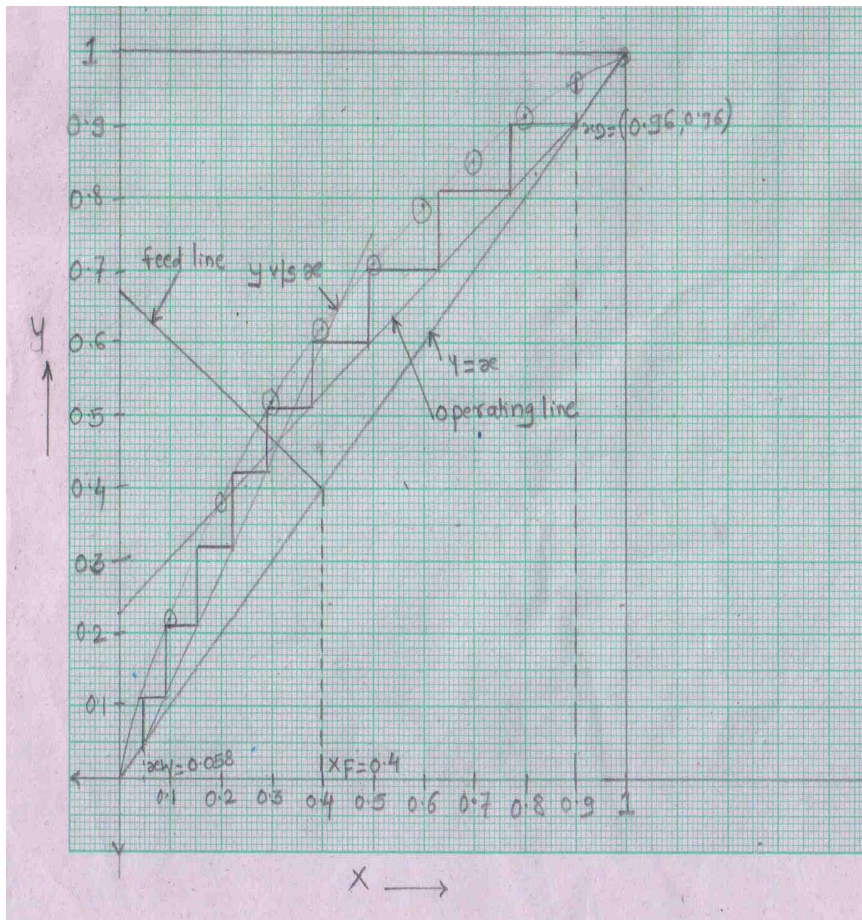
	<p>Construct a plot of temperature v/s liquid phase composition , equilibrium curve and draw the operating line through the point (0.4,0.4) on the diagonal with a slope equal to minus one which one will cut the equilibrium curve at point P .through point P , draw a vertical to cut the bubble point curve at point Q and then read the corresponding temperature from the y-axis</p> <p><b>Temperature in the separator = 371° k (98° c )</b></p>	1	
3-c	<p><b>solution :</b></p> <p>basis : 100 kg feed containing 40% benzene and 60% toluene</p> <p>molecular weight of benzene = 78</p> <p>molecular weight of toluene = 92</p> <p>xf = mole fraction of benzene in feed</p> $= \frac{96/78}{\frac{96}{78} + \frac{4}{92}} = 0.966$ <p>xW = mole fraction of benzene in the bottom product</p> $= \frac{5/78}{\frac{5}{78} + \frac{95}{92}} = 0.058$ <p>Operating line of rectification section: Point A (0.966,0.966) on the diagonal. Intercept of the rectifying section operating line is</p> $= \frac{x_D}{R+1}$ $= \frac{0.966}{3.14+1} = 0.232$ <p>Draw the operating line of rectifying section On the x-y diagram through the point A with intercept on y-axis equal to 0.232, draw operating line of the stripping section starting from the point (0.0581,0.058) on the diagonal passing through the point Q .</p> <p>Do step by step construction of stages between the equilibrium curve and the</p>	1	8
		1	
		1	
		1	



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operating lines starting from the point A upto point B and count the number of stages.

From the plot (fig.)



Number of theoretical stages required including the reboiler =  $n = 9$

Number of theoretical stages required in the column =  $n - 1 = 9 - 1 = 8$

2

1

4 a **Attempt any 3**

12

4a-i

**Extraction** refers to an operation in which the constituents of liquid mixture are separated by contacting it with suitable insoluble liquid solvent, which

4

2



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	<p>preferentially dissolves one or more constituents. This operation is sometimes also termed as solvent extraction. Extraction utilizes the differences in solubility of constituents to effect a separation. In this operation, a solute in a liquid solution is removed by contacting the solution with another liquid solvent. The solvent is relatively immiscible with the solution. In the liquid extraction, the feed solution to be handled represents one phase and the solvent to be used to effect separation represents the second phase. In this operation, the two immiscible phases in contact are both liquid and so is a liquid- liquid operation. The mass transfer of the solute takes place from the feed solution to the solvent phase.</p> <p><b>Applications of extraction:</b></p> <ol style="list-style-type: none"><li>1. Recovery of acetic acid from dilute aqueous solution.</li><li>2. Recovery of long chain fatty acid from vegetable oil by liquid propane.</li><li>3. Separation of petroleum products having approximately same boiling point</li><li>4. Recovery of penicillin from the fermentation both using butyl acetate.</li></ol>	2	
4a-ii	<b>Expression for steady state equimolar counter diffusion</b>		4



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$$N_A = J_A + x_A (N_A + N_B)$$
$$= -D_{AB} \frac{dc_A}{dz} + \frac{c_A}{c} (N_A + N_B)$$

For ideal gas  $P_A = c_A RT$

$$c_A = \frac{P_A}{RT}$$
$$dc_A = \frac{dP_A}{RT}$$
$$c = \frac{P}{RT}$$

putting values of  $c_A$ ,  $dc_A$  &  $c$

$$N_A = -D_{AB} \frac{dP_A}{RT} \frac{1}{dz} + \frac{P_A/RT}{P/RT} (N_A + N_B)$$

1

1

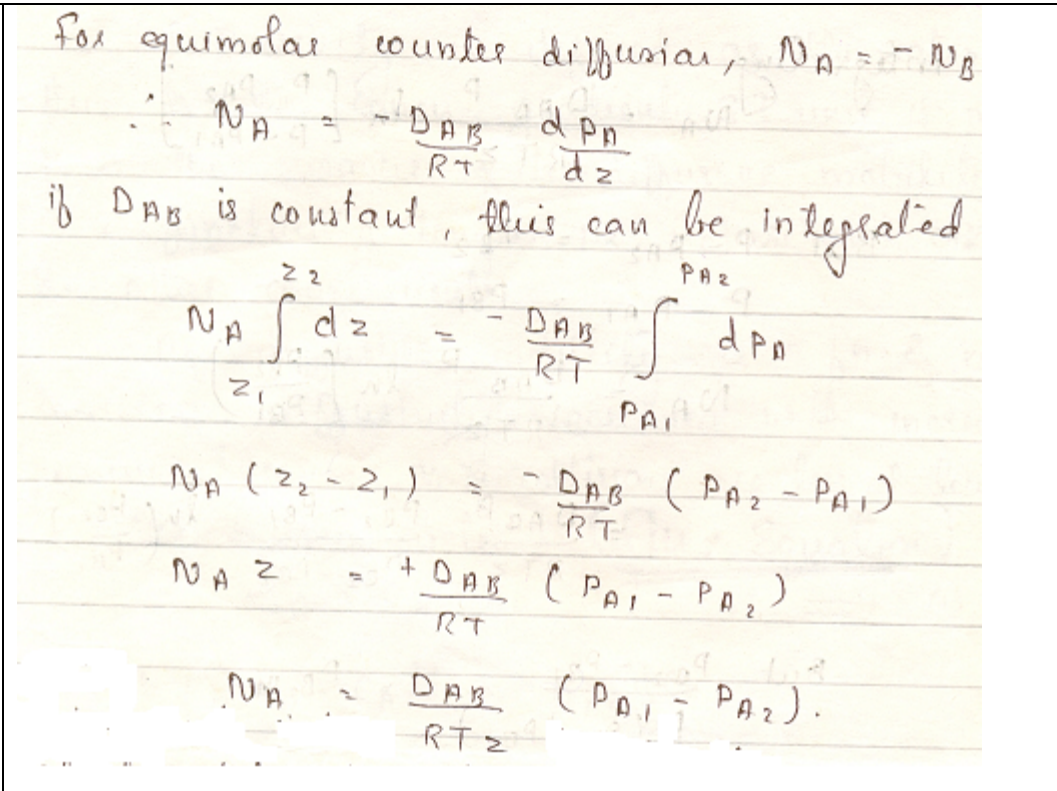
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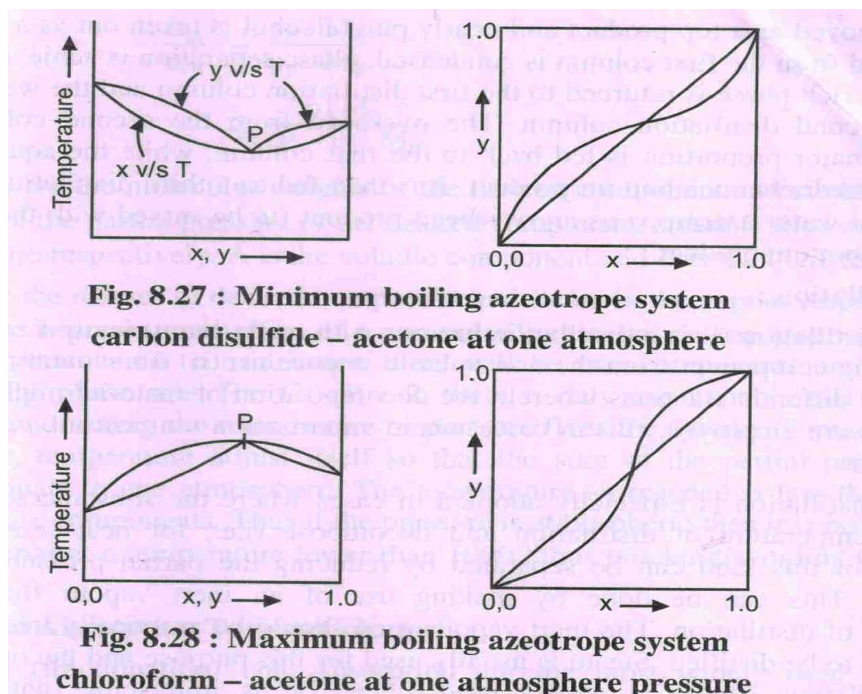
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		1	1
4a-iii	<p>Azeotrope is a liquid mixture with an equilibrium vapour of the same composition as the liquid.</p> <p>The dew point and bubble point are identical at azeotropic composition and the mixture vaporizes at a single temperature, so azeotropes are called constant boiling mixtures. when an azeotrope is boiled , the vapour produced will have the same composition as the liquid from which it is produced .boiling of an ordinary solution takes place from the bubble point to the dew point , whereas the boiling point of an azeotropes remains constant till the entire liquid is vaporized.</p> <p>the temperature composition diagrams and equilibrium diagrams for liquid mixtures forming azeotropes at constant pressure are shown in fig. here we will see that the equilibrium curves crosses the diagonal –which is an indication of</p>	2	4

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the existence of an azeotrope.



For all mixtures of composition less than P ,the equilibrium vapour is richer in more volatile component than the liquid, while for all mixtures of compositions greater than P , the equilibrium vapour is less rich in more volatile component than the liquid . the mixture composition P gives the vapour composition identical with the liquid.

2

4a-iv

**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

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each for  
any 4

4



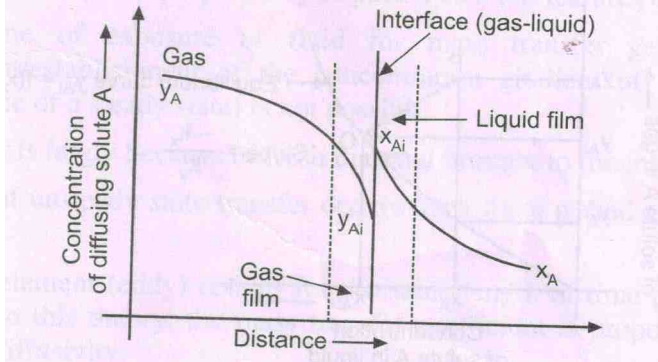


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	<p>the solvent, there will be a loss of the solvent with the gas leaving the unit operation, hence to minimize the solvent loss , the solvent should be less volatile.</p> <p>3) Corrosive nature : the solvent should not be corrosive towards common materials of construction so that the construction material for an absorption equipment will not be too expensive.</p> <p>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.</p> <p>5) Cost and availability : the solvent should be cheap and readily available</p> <p>6) Miscellaneous : the solvent should be non-toxic, non-flammable, non-foaming, and chemically stable from a handling and storage point of view.</p>		
4a-v	<p><b>Salient features of two film theory :</b></p> <p>1) Resistance to transfer in each phase is regarded as lying in a thin film close to the interface.</p> <p>2) The transfer in these films is by a steady state process of molecular diffusion.</p> <p>3) The concentration gradient is assumed to be linear in these films and it is zero outside the films,i.e.,zero in the bulk fluid</p> <p>4) The theory assumes that the turbulence in the bulk fluid vanishes at the interface of the films.</p> <p>5) The film capacity is negligible,i.e.,the time taken for a concentration gradient to establish is small compared to the time of transfer.</p>	4	4



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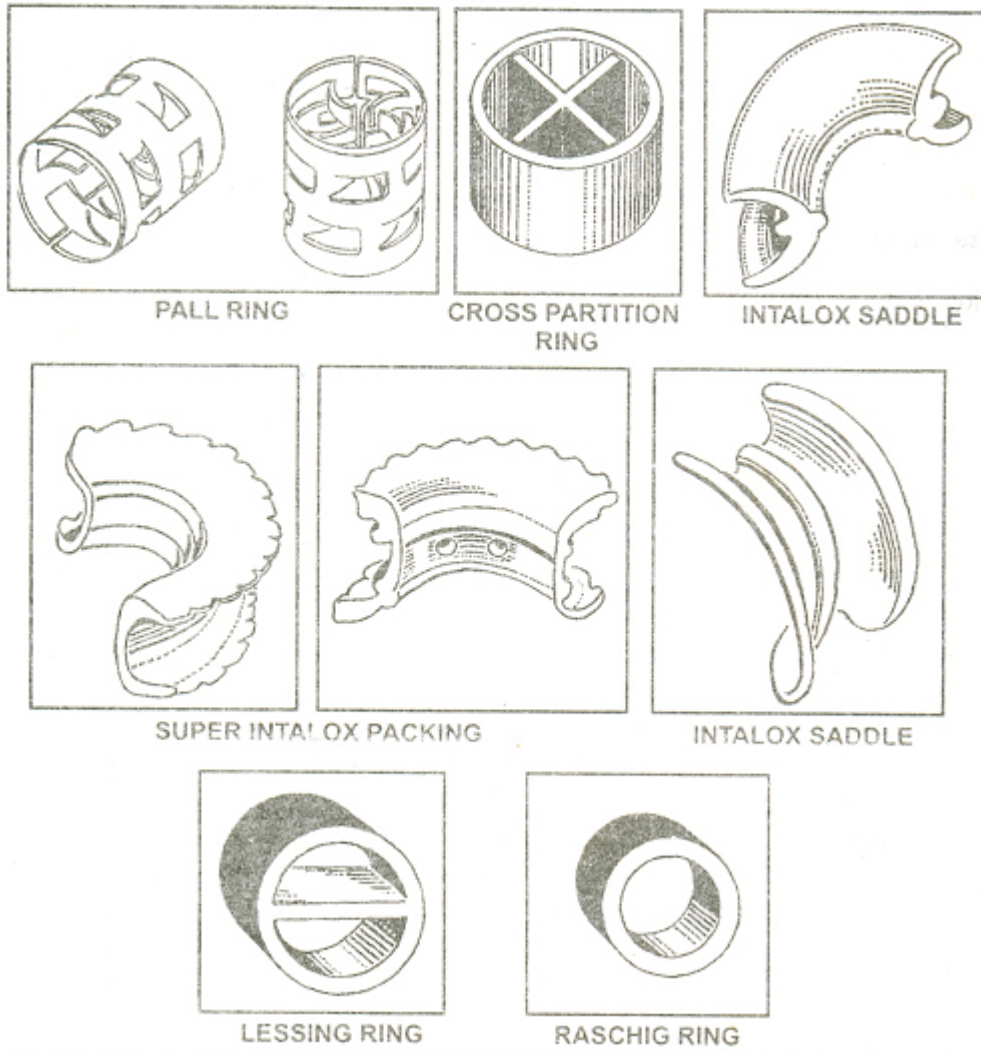
4b	Attempt any 1		6
4-b i	<p><b>Types of packings:</b> In order to obtain the efficient gas liquid contact, many different types of packings are available ranging from simple to complex geometrical shapes but are generally classified as random packings and regular packings.</p> <p>If the packing are simply dumped into the tower during installation and fall in random fashion they are called <b>random packings</b>. The packings arranged in a particular pattern are called <b>stacked packings</b>.</p> <p>Most common random packings are :</p> <ol style="list-style-type: none"><li>1) Raschig rings.</li><li>2) Pall rings.</li><li>3) Hy-pak.</li><li>4) Berl saddles.</li><li>5) Intalox saddles.</li><li>6) Super intalox saddles .</li></ol>	3	



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**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.



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	6) It should be chemically inert to the fluids handled in the tower.		
4.b ii	<b>Construction &amp; working of Spray dryer :</b> spray dryers are used mostly for liquid or slurry solutions and in general for any product that is pumpable. The material is usually sprayed by spray nozzles or high speed rotating spray discs in the form of a mist of fine droplets into a hot gas stream inside a vertical cylindrical chamber with a conical bottom. The material is dried due to rapid evaporation of water from the droplets. Finally the dried material is separated from the gas stream. The flow of gas and liquid in the spray chamber may be co current, counter-current or mixed. Care must be taken to see that droplets or wet particles of solid do not strike and stick to solid surfaces before drying has taken place. In order to avoid this , large chambers are used. The dried solids are taken out from the bottom of chamber through a screw conveyer. The exhaust gases are fed into a cyclone separator to remove any fines. The solids collected by the cyclone 1 are fed to the pneumatic conveying duct. The air leaving the cyclone 2 may contain some dust and therefore it is sent to the cyclone 1 for further separation, by fan. The dried product from the cyclone 2 is collected in dry product collector	3	6

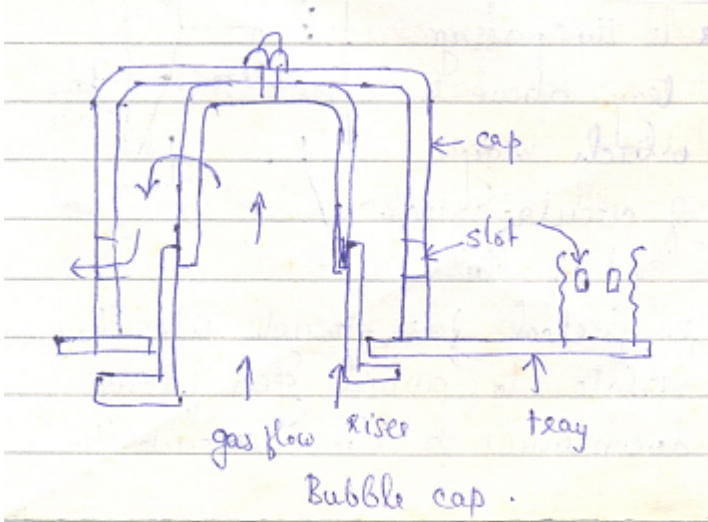
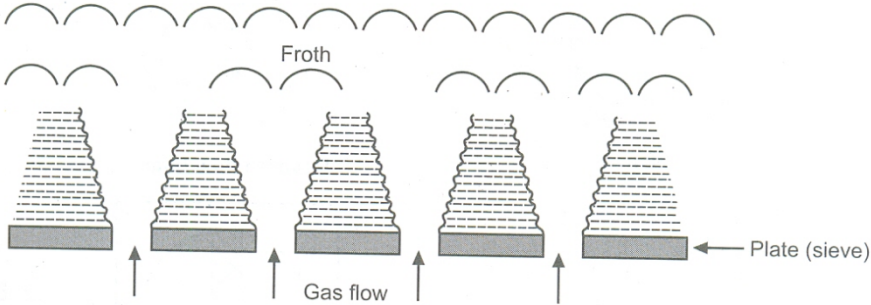


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5	Attempt any 4		16
5-a	<p><b>Flash distillation</b> is carried out in a continuous manner. In this method, a liquid mixture is partially vaporized the vapor and liquid are allowed to attained equilibrium and finally withdrawn separately</p> <p>Consider one mole of liquid mixture having <math>x_f</math> mole fraction , <math>f</math> moles of feed that is vapourized and of composition <math>y</math>. Then <math>(1-f)</math> will be the moles of residual liquid obtained. Let <math>x</math> be the mole fraction of more volatile component in liquid. Material balance for more volatile component is</p> $x_F = fy+(1-f)x$	2	4

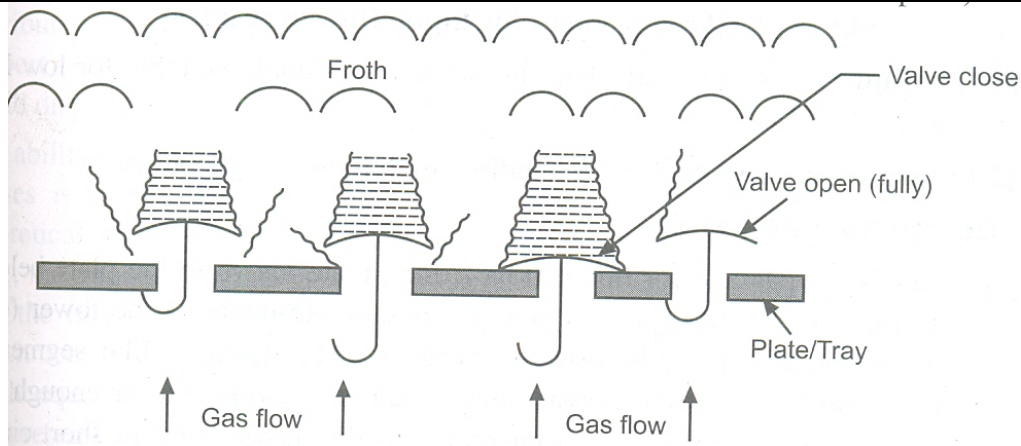


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	<p>OR <math>y = -(1-f)x/f + (x_F/f)</math></p> <p>The above equation is operating line for flash distillation with slope = <math>-(1-f)/f</math> and y- intercept = <math>x_F/f</math></p> <p>The point of intersection of operating line and diagonal (<math>x=y</math>) is <math>(x_F, x_F)</math></p>	2	
5-b	<p><b>Plates used in plate columns:</b></p> <p><b>1. Bubble cap plate</b></p>  <p><b>2. Sieve plate:</b></p>  <p><b>3. Valve plate:</b></p>	1	4



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**Valve plate gives better performance**

1

5-c

**Minimum liquid – gas ratio:**

Consider that the values of the terms  $V^1$ ,  $Y_1$ ,  $Y_2$  and  $X_2$  are fixed by a process requirement and the value of  $L^1$  is decreased through the absorption tower. The operating line on x-y coordinates passes through the points  $(X_2, Y_2)$  and has a slope equal to  $L^1/V^1$ . As liquid flow rate is decreased, the slope of operating line decreases and liquid composition increases. Reduction in liquid flow rate reduces the driving force for mass transfer and absorption becomes more and more difficult. Further reduction in liquid flow rate lead to a situation where upper end of operating line touches equilibrium curve and liquid composition is then in equilibrium with inlet gas. Thus driving force for mass transfer becomes zero at bottom of tower, required time of contact becomes infinite, and infinitely tall towers results. The value of  $L^1/V^1$  corresponding to this situation represents a minimum liquid-gas ratio. If tower is to operate practically, the liquid flow rate should be greater than that corresponding to minimum  $L^1/V^1$  ratio.

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5-d	<p>Basis: 5000 Kg/hr Methanol – water solution</p> <p>Let x kg/hr distillate and Y kg/ hr residue</p> <p>Overall balance is <math>5000 = X + Y</math>-----(1)</p> <p>Balance for methanol is</p> <p><math>0.5 * 5000 = 0.95 X + 0.01 Y</math>------(2)</p> <p>Solving the above equations</p> <p><b>Distillate (X)=2606 Kg/hr</b></p> <p><b>Residue(Y) =2394 Kg/hr</b></p>	<p>1</p> <p>2</p> <p>1</p>	<p>4</p>
5-e	<p><b>HETP(Height Equivalent to a Theoretical Plate):</b> It is the height of a section of packing that will give the same separation as that achieved with one theoretical plate.</p> <p><b>Channeling in packed column:</b> The tendency of the liquid to segregate towards the wall and to flow along the wall is termed as channeling.</p>	<p>2</p> <p>2</p>	<p>4</p>
5-f	<p><b>Factors on which the rate of drying depends:</b></p> <ol style="list-style-type: none"><li>1) <b>Gas Velocity:</b> When the velocity of the gas or air is high the rate of drying will also be high.</li><li>2) <b>Humidity of gas :</b> Lesser the relative humidity, the more will be the rate of drying.</li><li>3) <b>Area of drying surface:</b> If the area of the wet surface exposed to the gas or air is more, the rate of drying will also be more.</li><li>4) <b>Temperature:</b> 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.</li></ol>	<p>I mark each</p>	<p>4</p>
6	<p>Attempt any 2</p>		<p>16</p>
6-a	<p><b>Time of drying under constant drying conditions:</b></p>		<p>8</p>





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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  $X_1$  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

$$R = -\frac{W'}{A} \times \frac{dX}{dt} \quad \text{-----(1)}$$

$R = R_C =$  rate during constant rate period

$$R_C = -\frac{W'}{A} \times \frac{dX}{dt} \quad \text{-----(2)}$$

Where

$W'$  = mass of dry solids in kg

$A$  = area of drying surface in  $m^2$

$R_C$  = rate in  $kg/(m^2 \cdot h)$

$t$  = time in hours (h)

Rearranging Equation (2), we get, Type equation here.

$$dt = \frac{W'}{A \cdot R_C} dX \quad \text{-----(3)}$$

Integrating Equation (3) between the limits :

$$t = 0, \quad X = X_1$$

and  $t = t, \quad X = X_2$ , we get

$$\int_0^t dt = -\frac{W'}{A \cdot R_C} \int_{X_1}^{X_2} dX \quad \text{-----(4)}$$

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$$t = -\frac{W'}{A.RC} [X_2 - X_1] \quad \text{-----(5)}$$

$$t = \frac{W'}{A.RC} [X_1 - X_2] \quad \text{-----(6)}$$

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 of  $X_C$ , then the time required during the entire constant rate period is given by

$$t_C = \frac{W'}{A.RC} [X_1 - X_C] \quad \text{-----(7)}$$

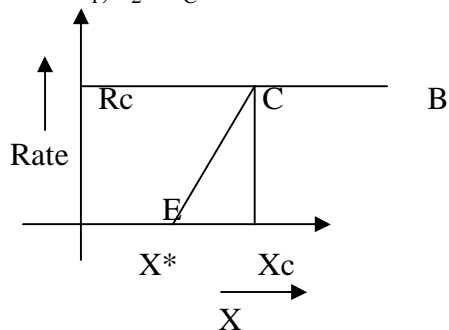
**Falling rate period :**

During this period the rate of drying is proportional to the free moisture content.

$$-\frac{W'}{A} \times \frac{dX}{dt} = m [X - X^*] \quad \text{-----(8)}$$

Where  $X^*$  is the equilibrium moisture content and  $X$  is the moisture content of wet solids less than critical moisture content.

Let  $X_1$  be the initial moisture and  $X_2$  be the final moisture content such that  $X_1, X_2 < X_C$ .



Assume that the entire falling rate period is represented by a straight line CE, then

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$$m = \frac{RC}{[X_C - X^*]} \quad \text{-----(9)}$$

$m = \text{slope of line CE}$

Equation (1) then becomes

$$- \frac{W'}{A} \times \frac{dX}{dt} = \frac{RC}{[X_C - X^*]} [X - X^*] \quad \text{-----(10)}$$

$$- \frac{dX}{[X - X^*]} = \frac{RC A}{[X_C - X^*] W'} dt \quad \text{-----(11)}$$

Integrating Equation (11) between the limits :

$$X = X_1$$

$$X = X_2 [X_1, X_2 < X_C], \text{ we get}$$

$$\int_{X_1}^{X_2} \frac{dX}{[X - X^*]} = \frac{RC A}{[X_C - X^*] W'} \int_0^t dt \quad \text{-----(12)}$$

$$t = \frac{[X_C - X^*] W'}{RC A} \ln \frac{X_1 - X^*}{X_2 - X^*} \quad \text{-----(13)}$$

Equation (13) gives the time of drying during the falling rate period to dry the material from  $X_1$  to  $X_2$ .

If the material is to be dried from the critical moisture content  $X_C$  to the final moisture content  $X_2$  ( $X_2 < X_C$ ), then the time required for drying during the entire falling rate period is given by  $t_f$  as :

$$t_f = \frac{[X_C - X^*] W'}{RC A} \ln \frac{X_C - X^*}{X_2 - X^*} \quad \text{-----(14)}$$

[As  $X_1$  becomes  $X_C$  ]

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	$t_f =$ drying time during entire falling rate period. Total time of drying = $t_c + t_f$  $t = \frac{W'}{A.R_C} [(X_1 - X_C) + (X_C - X^*)] \ln \frac{X_C - X^*}{X_2 - X^*} \text{ -----(15)}$	1	
6-b	Initial moisture content $X_1 = 0.67/(1-0.67) = 2.03$ Final moisture content $X_2 = 0.25/(1-0.25) = 0.333$ Critical moisture content $X_c = 0.4/(1-0.4) = 0.67$ Equilibrium moisture content $X^* = 0.01/(1-0.01) = 0.0101$ $R_C = 1.5 \text{ Kg/m}^2 \text{ hr}$ $A/W^1 = 0.5$ or $W^1/A = 2.0$ $t = W^1/AR_c\{ (X_1-X_c) + (X_c- X^*)\ln[(X_c - X^*) / (X_2-X^*)]\}$ $t = 2/1.5\{( 2.03-0.67)+(0.67-0.0101) \ln[(0.67-0.0101) / (0.333-0.0101)]\}$ <b>= 2.44 hr</b>	2 2 2 2	8
6-c	Basis: 100 kg solution $F = 100 \text{ kg}$ $x_F = 0.32$ Molecular weight of $\text{Na}_2\text{SO}_4 = 142$ Molecular weight of $\text{Na}_2\text{SO}_4 \cdot 10 \text{ H}_2\text{O} = 322$ Material balance for water is $68 = C.(180/322) + L$ Or $L = 68 - 0.559C$ Material balance for solute is $320 = C (142/322) + (680 - 0.559C) (19.4/100)$ $C = 56.55 \text{ kg}$ $\text{Na}_2\text{SO}_4 \cdot 10 \text{ H}_2\text{O}$ in feed = $32 * 322/142 = 72.56$ $\% \text{ yield} = (56.55/72.56) * 100$ <b>= 77.93%</b>	1  1 2  2 1 1	8



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