

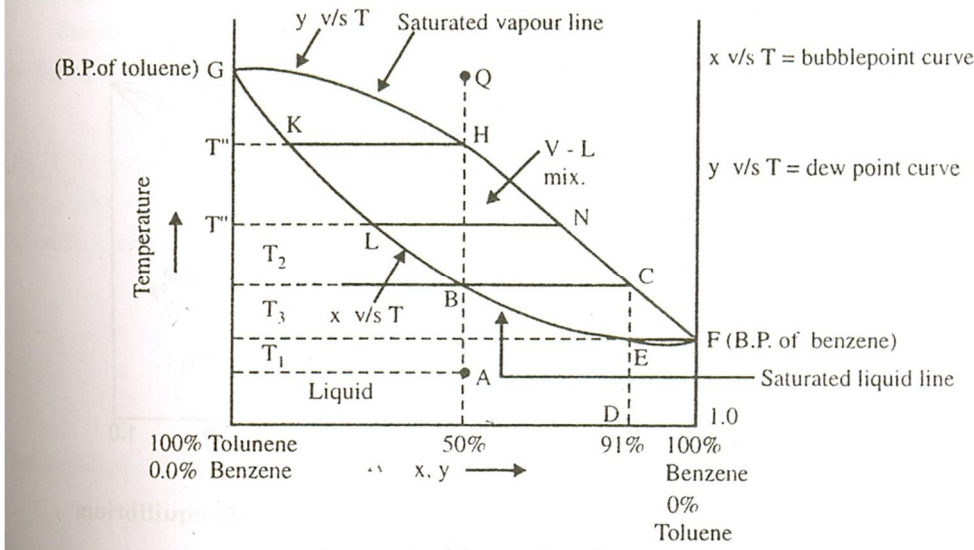
MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION

WINTER-12 EXAMINATION

Model Answer

Subject code :MTO(12297)

Q no:	Answer	Remark
1- a) i)	<p>Ficks law of diffusion: It 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.</p> $J_A = -D_{AB} \frac{dC_A}{dz}$ <p>where <math>J_A</math> – molar flux of A in z direction relative to molar average velocity (kmol/m<sup>2</sup> sec)</p> <p><math>C_A</math> – concentration of A (kmol/m<sup>3</sup>)</p> <p><math>\frac{dC_A}{dz}</math> – concentration gradient in z direction (Kmol/msec)</p> <p>z - distance in the direction of diffusion (m)</p> <p><math>D_{AB}</math> – Proportionality constant, diffusion coefficient for A diffusing through B (m<sup>2</sup>/sec)</p>	<p>2 marks</p> <p>2 marks</p>
ii)	<p>Different theories which explains the mechanism of mass transfer are:</p> <ol style="list-style-type: none"> <li>1. Whitman's two film theory</li> <li>2. Higbie's penetration theory</li> <li>3. Danckwert's surface renewal theory</li> <li>4. Toor and Marchello's film penetration theory</li> </ol> <p>Salient features of two film theory:</p> <ol style="list-style-type: none"> <li>1. Resistance to transfer in each phase is regarded as lying in a thin film close to the interface.</li> <li>2. The transfer in these films is by a steady state process of molecular diffusion.</li> <li>3. The concentration gradient is assumed to be linear in these film and it is zero outside the films.</li> <li>4. The theory assumes that the turbulence in the bulk fluid die out at the interface of the films.</li> <li>5. The film capacity is negligible.</li> </ol>	<p>2 marks</p> <p>2 marks</p>
iii)	<p><b>Raoult's law:</b> It states that equilibrium partial pressure of a constituent at a given temperature is equal to the product of its vapour pressure in pure state and its mol fraction in the liquid phase.</p> $P_A = P_A^0 X_A$ <p><b>Dalton's law:</b></p> <p>It states that the total pressure exerted by a gas mixture is equal to the sum of the partial pressures of components present in it.</p>	<p>1.5 marks</p> <p>1.5 marks</p>

	$P = P_A + P_B$ <b>Gibbs phase rule:</b> The equilibrium in vapour – liquid system is governed by phase rule. $F = C - P + 2$ where F is the degree of freedom, C is the number of components presents and P the number of phases involved.	1 mark
iv)	Boiling point diagram :  <p>Equilibrium data for binary system at constant pressure are presented in temperature composition diagram or by plotting vapour phase composition against liquid phase composition. Boiling point diagram are used to show that how the equilibrium vapour and liquid phase composition changes with temperature .</p> <p>In the diagram the composition of benzene – toluene mixture is plotted on X axis in terms of more volatile component and temperature of the mixture is plotted on Y axis. The upper curve is saturated vapour line and lower curve is saturated liquid line.</p>	2 marks
b i)	Mole fraction of benzene in feed $x_F = 0.4$ Mole fraction of feed that is vaporized $f = 0.5$ Slope of operating line = $-(1-f)/f = -1$ Draw equilibrium diagram. Point of intersection of operating line and diagonal is (0.4,0.4) mark point P (0.4, 0.4) on diagonal and draw operating line through P with slope = -1 which cut equilibrium curve at point Q. Through Q read x and y . $X = 0.3$ is liquid phase composition of benzene $Y = 0.5$ is the vapour phase composition of benzene.	2 marks 2 marks 2 marks

ii)	<p>An azeotrope is a liquid mixture with an equilibrium vapour of the 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.</p> <p>The constituents of binary azeotrope are separated completely by 1) Adding third component to the binary mixture 2) By changing system pressure.</p> <p>The third component added to the binary azeotrope usually form a low boiling azeotrope with one of the feed constituents and withdrawn as distillate. The third component added is called as entrainer of azeotrope breaker. The process of distillation where the third component is added to the binary azeotrope to effect the complete separation is called azeotropic distillation.</p>	2 marks   2 marks  2 marks																
2 - i)	<p><math>\alpha = 2.4</math> <math>y = \frac{\alpha \cdot x}{1 + (\alpha - 1)x}</math></p> <table><tr><td>X</td><td>0</td><td>.1</td><td>.2</td><td>.4</td><td>.6</td><td>.8</td><td>1</td></tr><tr><td>y</td><td>0</td><td>.21</td><td>.375</td><td>.615</td><td>.783</td><td>.906</td><td>1</td></tr></table> <p>Draw x-y diagram and draw diagonal <math>x_F = 0.4, \quad x_D=0.9, \quad x_W = 0.1</math> Construct number of stages between (0.9,0.9) and (0.1,0.1) between equilibrium curve and diagonal. No. of stages =6, theoretical plates= 5.</p>	X	0	.1	.2	.4	.6	.8	1	y	0	.21	.375	.615	.783	.906	1	1 mark  2 marks  2 mark  2 mark 1 mark
X	0	.1	.2	.4	.6	.8	1											
y	0	.21	.375	.615	.783	.906	1											
ii)	<p>Initial moisture content <math>X_1 = 0.35/(1-.35) = 0.5385</math> Final moisture content <math>X_2 = 0.1/(1-.1) = 0.111</math> Critical moisture content <math>X_c = 0.14/(1-.14) = 0.1628</math> Equilibrium moisture content <math>X^* = 0.04/(1-.04) = 0.0417</math> <math>t = t_c+t_f</math></p> <p><math display="block">= \frac{W (X_1 - X_c)}{A.R_c} + \frac{W (X_c - X^*)}{A.R_c} \ln [ X_c - X^* / X_2 - X^* ]</math></p> <p><math>t = 5</math> hours <math>W/ A.R_c = 11.28</math> For second case, final moisture content is 6% <math>X_2 = 0.06/( 1 - 0.06) = .0638</math> <math>t = 11.28[ ( .5385 - .1628) + ( 0.1628 - .0417 )\ln ( .1628 - .0417/.0638 - .0417) ]</math> <math>= 6.56</math> hours</p>	2 marks   1 mark  2 marks  1 mark  2 marks																
iii)	<p>Basis : 100 kg. feed solution Molecular weight of <math>\text{Na}_2\text{S}_2\text{O}_3 = 158</math> Molecular weight of <math>\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O} = 248</math> Water in feed = water in crystal + water in mother liquor. <math>52=90.C/248+L</math> OR <math>L = 52 - 0.363C</math> Material balance for solute</p>	2 marks  2 marks																

	<p>Solute in feed = solute in crystal + solute in mother liquor</p> $.48 * 100 = (158/248)C + LX^1$ $48 = 0.637C + (52 - 0.363C) X^1$ <p>Since the value <math>X^1</math> is not given in the question due consideration should be given</p>	<p>2 marks</p> <p>2 marks</p>
3.i)	<p>For diffusing of A through non diffusing B , The flux is given by</p> $N_A = \frac{D_{AB} P}{RTZ P_{B,M}} (P_{A1} - P_{A2})$ <p> <math>P = 101.3 \text{ KPa}</math>  <math>X_{A1} = 0.2</math>  <math>X_{A2} = 0.1</math>  <math>P_{A1} = P \cdot X_{A1} = 30.26 \text{ Kpa}</math>  <math>P_{A2} = P \cdot X_{A2} = 10.13 \text{ Kpa}</math>  <math>P = P_{A1} + P_{B1}</math>  <math>P_{B1} = 81.04 \text{ Kpa}</math>  <math>P_{B2} = 91.17 \text{ Kpa}</math>  <math>P_{BM} = 86 \text{ Kpa}</math>  <math>N_A = 4.356 * 10^{-5} \text{ Kmol/m}^2.\text{s}</math>            The flux for equimolar counter diffusion is  <math display="block">N_A = \frac{D_{AB}}{RTZ} (P_{A1} - P_{A2})</math>  <math>N_A = 3.7 * 10^{-5} \text{ Kmol/m}^2.\text{s}</math> </p>	<p>2 marks</p> <p>2 marks</p>
ii)	<p>For diffusing of A through non diffusing B , The flux is given by</p> $N_A = \frac{D_{AB} P}{RTZ P_{B,M}} (P_{A1} - P_{A2})$ <p>The flux for equimolar counter diffusion is</p> $N_A = \frac{D_{AB}}{RTZ} (P_{A1} - P_{A2})$ <p>Where <math>D_{AB}</math> = Diffusion Coefficient of A diffusing through B  <math>R</math> = Gas constant  <math>T</math> = Absolute temperature  <math>Z</math> = Distance through which diffusing occurs  <math>P_A, P_B</math> = partial pressures of AB  <math>P_{BM} = (P_{B2} - P_{B1}) / \ln (P_{B2} / P_{B1})</math></p>	<p>1 mark</p> <p>1 mark</p> <p>2 marks</p>
iii)	<p>Different method of distillation are</p> <ol style="list-style-type: none"> <li>1. Simple or differential distillation.</li> <li>2. Flash or equilibrium distillation</li> <li>3. Rectification or fractionation</li> </ol>	<p>2 marks</p>

### Rectification or fractionation :

2 marks

The enrichment of the vapour stream and it passes through the column in contact with reflux is termed that rectification.

Any one method may be given mark

In this separation method , part of condensed liquid is returned back as a reflex and maximum enrichment of more volatile component in the vapour is obtained by successive partial vaporization and condensation by multi stage contact of vapour and liquid. This is achieved in a single unit called fractionating column.

Expression :-

① Operating line of the rectifying section :

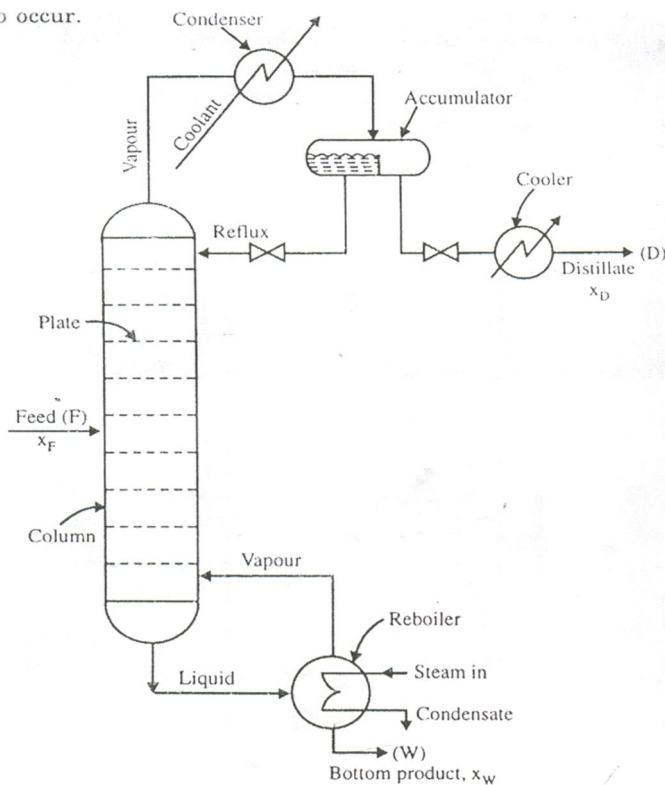
$$y_{n+1} = \frac{L_n}{L_n + D} x_n + \frac{D x_D}{L_n + D}$$

② Operating line for the stripping section :

$$y_{m+1} = \frac{L_m}{L_m - W} x_m - \frac{W x_W}{L_m - W}$$

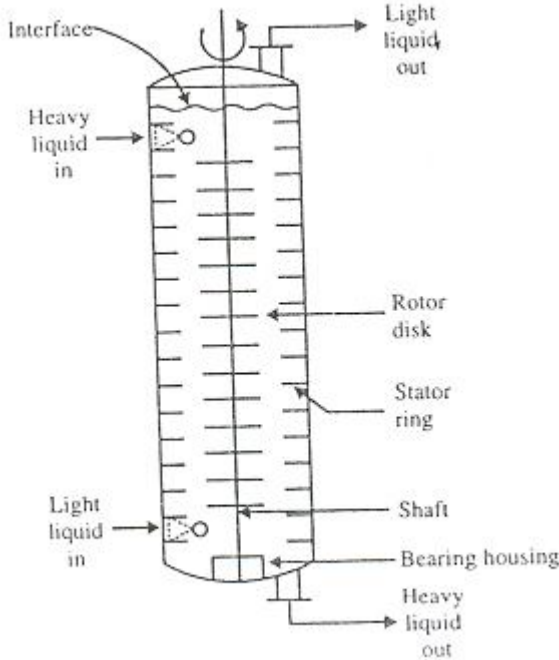
Diagram :-

o occur.

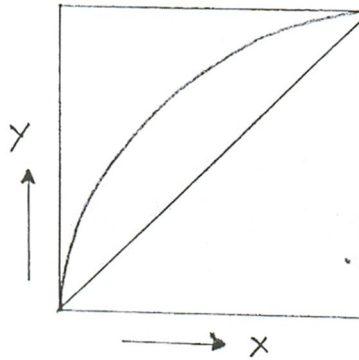


iv)	Gas absorption	Distillation	1 mark each	
	Separation of one gas component from gas mixture	Separation of a liquid mixture to increase purity of product		
	Mass transfer operation	Mass & Heat transfer operation		
	Driving force is solubility of one gas in solvent	Driving force is relative volatility		
	Operation is done at room temperature	Operation is carried at boiling point of any one liquid component		
	It is costly	It is cheap if steam is used as heating medium		
	Packed column is used	Plate or packed column is used		
	Drawbacks of loading and flooding	Weeping , entrainment are drawbacks		
v)	Types of packing: 1. Rasching ring 2. Cross ring 3. Partition ring 4. Interlox saddle 5. Pall ring Channeling in a packed column: Ascending gas and descending liquid are flowing through empty spaces in packings called voids. Liquid while coming down prefers path of least resistance. So liquid doesn't come down but circulates within voids in packings. This is called channeling. Due to this there is no proper contact between gas and liquid. Channeling reduces the performance of column. Channeling cant be eliminated but can be reduced if ratio of column diameter to packing diameter is kept 8:1.		2marks	
			1 mark	
			1 mark	
4.a i)	<b>Property</b>	<b>Packed column</b>	<b>Plate column</b>	1 mark each
	Pressure drop	less	More	
	Corrosive liquid	Preferred as packings can be made of corrosive resistance material	Not useful	
	Handling very small volume of liquid	Effective for small volumes of liquid also	Cant be used as only 1 or 2 plates can be used with very poor efficiency of column	
	Cost	cheap	costly	
ii)	Basis:200 Kg/hr of air flow to tower $V^1[Y_1-Y_2] = L^1 [ X_1 - X_2 ]$			1 mark



	<p>It is a mechanically agitated counter current extractor where in agitation is brought with the help of rotating disc which usually run at much higher speed than turbine type impellers.</p> <p><b>Construction :</b></p> <p>It consist of cylindrical column that is divided in to a number of compartment formed by a series of stator rings. Each compartment contains a rotating , centrally located horizontal rotor disc that create a high degree of turbulence in side the column. The recommended compartment height for a column of diameter 2 meter is 200 to 300 mm. The tower is provided with inlet and outlet connection at the top and bottom for light and heavy phases.</p> 	2 marks  
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2 marks

5.i)

**Equilibrium data :**

x	0	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
y	0	0.13	0.21	0.375	0.5	0.6	0.7	0.77	0.83	0.9	0.95	1

**Solution : Basis :** 100 kmol of feed

$$F = D + W \text{ (overall material balance)}$$

$$F = 100 = D + W$$

$$\text{Mole fraction of benzene in the feed} = \frac{\text{mole \% benzene in the feed}}{100}$$

$$x_F = 0.4$$

$$x_D = 0.9 \text{ and } x_W = 0.1$$

**Material balance of benzene :**

$$x_F \cdot F = x_D \cdot D + x_W \cdot W$$

$$0.4 \times 100 = 0.9 D + 0.1 W$$

$$40 = 0.9 D + 0.1 W$$

2 marks

From equation (A),  $D = 100 - W$   
 $\therefore 40 = 0.9(100 - W) + 0.1W$   
 Solving, we get  $W = 62.5 \text{ kmol}$   
 and  $D = 37.5 \text{ kmol}$

1 mark

$$R = \text{Reflux ratio} = 3 = \frac{L}{D}$$

but  $L = L_n$

$$\therefore L_n = 3D$$

$$L_n = 3(37.5) \\ = 112.5 \text{ kmol}$$

1 mark

$$L_n + D = 112.5 + 37.5 = 150 \text{ kmol}$$

The rectifying section operating line is :

$$x_{n+1} = \frac{L_n}{L_n + D} x_n + \frac{D \cdot x_D}{L_n + D}$$

$$\therefore y_{n+1} = \frac{112.5 x_n}{150} + \frac{37.5 \times 0.9}{150}$$

1 mark

... (B)

$$y_{n+1} = 0.75 x_n + 0.225$$

As the feed is a liquid at its bubble point :

$$L_m = L_n + F$$

$$= 112.5 + 100 = 212.5 \text{ kmol}$$

and  $L_m - W = 212.5 - 62.5 = 150 \text{ kmol}$

The operating line of stripping section is :

$$y_{m+1} = \frac{L_m}{L_m - W} x_m - \frac{W}{L_m - W} x_w$$

$$y_{m+1} = \frac{212.5}{150} x_m - \frac{62.5}{150} \times 0.1$$

$$y_{m+1} = 1.415 x_m - 0.042$$

... (C)

$$\text{Distillate composition} = x_D = 0.9$$

$$\therefore y_n = x_D = 0.9$$

Corresponding  $x_n$  value from the equilibrium diagram Fig. 2.41 is 0.79

$$y_{n+1} = 0.75 x_n + 0.225 \\ = 0.75 \times 0.79 + 0.225 \\ = 0.818$$

Obtain the value of  $x_{n+1}$  from the equilibrium diagram corresponding to  $y_{n+1}$

$$x_{n+1} = 0.644$$

$$y_{n+2} = 0.75 x_{n+1} + 0.225$$

$$y_{n+2} = 0.75 \times 0.644 + 0.225 = 0.708$$

$x_{n+2}$  from the equilibrium diagram corresponding to  $y_{n+2}$  is 0.492

$$y_{n+3} = 0.75 \times 0.492 + 0.225 = 0.594$$

$x_{n+3}$  from the equilibrium diagram corresponding to  $y_{n+3}$  is 0.382

$x_{n+3}$  is near to  $x_F$ , so that feed should be introduced on plate  $n + 3$  from top (4<sup>th</sup> plate).

For the stripping section, operating line is :

$$y_{m+1} = 1.415 x_m - 0.042$$

Writing  $n$  for  $m$  for convenience

$$y_{n+4} = 1.415 x_{n+3} - 0.042$$

$$\begin{aligned} y_{n+4} &= 1.415 \times 0.382 - 0.042 \\ &= 0.498 \end{aligned}$$

$x_{n+4}$  from the equilibrium diagram corresponding to  $y_{n+4}$  is 0.298

$$y_{n+5} = 1.415 \times 0.298 - 0.042 = 0.379$$

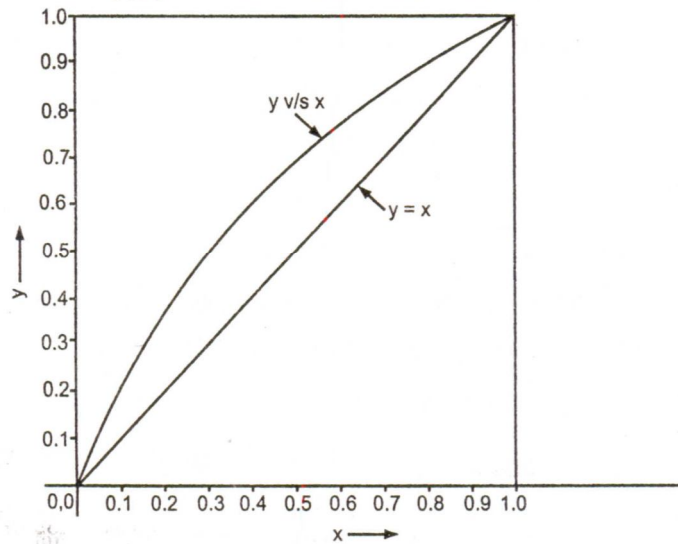


Fig. 2.41 : Equilibrium diagram for benzene - toluene system

$x_{n+5}$  from the equilibrium diagram is 0.208

$$y_{n+6} = 1.4165 \times 0.208 - 0.042 = 0.252$$

$x_{n+6}$  from the equilibrium diagram is equal to 0.120

$$y_{n+7} = 1.415 \times 0.120 - 0.042 = 0.127$$

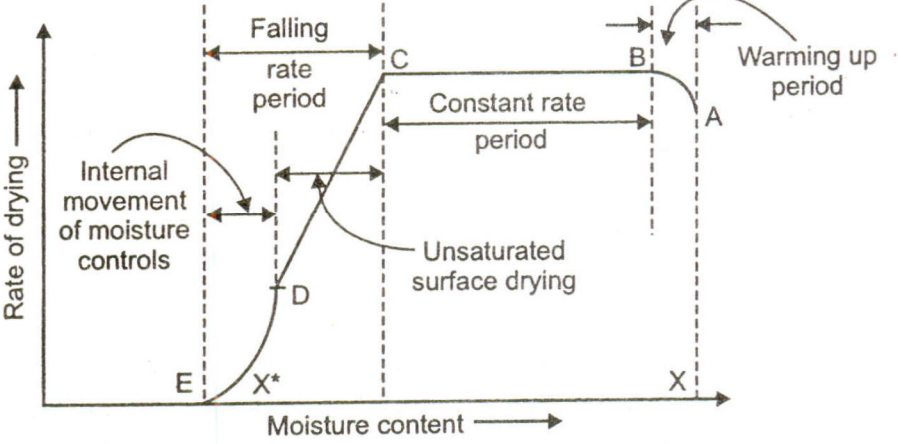
$x_{n+7}$  from the equilibrium diagram is equal to 0.048.

[As  $x_{n+6} = 0.12$  greater than  $x_W = 0.1$ , one more step is incorporated so that the liquid phase composition obtained at any case should not be more than  $x_W$ .]

Hence, there will be 7 plates in the column.

3 marks

ii)	<p> <math>X_1</math> = Initial moisture content. <math>x</math> = wt. fraction of moisture in solid.  <math>= \frac{0.67}{1 - 0.67} = 2.03, \left[ = \frac{x_1}{1 - x_1}, x_1 = 67/100 = 0.67 \right]</math>  <math>X_2</math> = Final moisture content  <math>= \frac{0.25}{1 - 0.25} = 0.333, \left[ = \frac{x_2}{1 - x_2} \text{ with } x_2 = 25/100 = 0.25 \right]</math>  <math>X^*</math> = Equilibrium moisture content  <math>X^* = \frac{0.01}{1 - 0.01} = 0.0101, \left[ = \frac{x^*}{1 - x^*} \text{ with } x^* = 1/100 = 0.01 \right]</math>  <math>X_c = \frac{0.40}{1 - 0.40} = 0.67</math>  <math>R_c = 1.5 \text{ kg}/(\text{m}^2 \cdot \text{h})</math>  <math>\frac{A}{W'} = 0.5</math>  <math>\frac{W'}{A} = 2.0</math>  <math>t = \frac{W'}{A \cdot R_c} \left[ (X_1 - X_c) + (X_c - X^*) \ln \frac{X_c - X^*}{X_2 - X^*} \right]</math>  <math>t = \frac{2}{1.5} \left[ (2.03 - 0.67) + (0.67 - 0.0101) \ln \left[ \frac{0.67 - 0.0101}{0.333 - 0.0101} \right] \right]</math>  <math>t = 2.44 \text{ h}</math> </p>	<p>2 marks</p> <p>2 marks</p> <p>1 mark</p> <p>3 marks</p>
iii)	<p><b>Solution : Basis :</b> 1 litre of original aqueous solution. It contains 0.2 mol of picric acid.</p> <p><math>K = 0.705</math> in final system = <math>C_E/C_R</math></p> <p><math>C_E</math> = concentration of picric acid in benzene = 0.01 mol/l</p> <p>Final concentration of picric acid in the aqueous solution = <math>\frac{0.01}{0.705}</math></p> <p><math>= 0.01418 \text{ mol/l}</math></p> <p><math>[C_R = C_E/K]</math></p> <p>Picric acid in the final benzene solution = <math>0.20 - 0.01418</math></p> <p><math>= 0.18582 \text{ mol}</math></p> <p>Benzene required = <math>\frac{0.18582}{0.01}</math></p> <p><math>= 18.582 \text{ l per l of aqueous solution}</math></p> <p>% extraction of picric acid = <math>\frac{0.18582}{0.2} \times 100</math></p> <p><math>= 92.91</math></p>	<p>1 mark</p> <p>2 marks</p> <p>1 mark</p> <p>2 marks</p> <p>2 marks</p>

6.a)	 <p>The section AB of the curve represents the warming up period during which the temperature of the solid is becoming equal to the temperature of drying air. From B to C, the curve is a straight line parallel to X axis representing the constant rate of drying, thus the section BC is called the constant rate period during which the layer of water on the surface of solid is being evaporated. The rate of drying is constant from B to C as drying takes place from the saturated surface. The section CE of curve represents falling rate period composed of the first falling rate period CD, and the second falling rate DE. From point C onwards some dry patches form from the surface of solid. The rate of drying decreases for the unsaturated portion and hence rate for total surface decreases. Section CD represents the period corresponding to the zone of unsaturated surface drying. The moisture content at which the constant rate period ends and the drying rate starts to fall is known as critical moisture content. After point D, the surface of solid is completely dry and then internal movement of moisture starts coming to the surface and continues up to E, where equilibrium is attained. The rate of drying over section DE is governed by internal moisture content. The second falling period DE represents zone where internal moisture movement controls.</p>	2 marks
b)	<p><b>(i) critical moisture content</b> The moisture content of the material at which the constant rate period ends and falling rate period starts is called critical moisture content.</p> <p><b>(ii) equilibrium moisture content</b> The moisture content of solid material that is in thermodynamic equilibrium with its vapour in the gas phase under the specified humidity and temperature of the hot gas or air is termed as equilibrium moisture content</p> <p><b>(iii) dry bulb temp</b> The temperature of the vapour gas mixture recorded by the thermometer whose bulb is kept dry, is called as dry bulb temperature.</p> <p><b>(iv) wet bulb temp</b> The temp recorded by thermometer whose bulb is kept wet by wrapping wet cloth in the open air is called wet bulb temp.</p>	1 mark  1 mark  1 mark  1 mark

1 mark



- 2 marks

1 mark

## SWENSON WALKER CRYSTALLIZER

1 mark

