WINTER-19 EXAMINATION

Model Answer

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-i	**Fick's 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
1a-ii	1. **Volatility:** It is the ratio of partial pressure of A to the mole fraction of A in the liquid phase. Volatility of A = p_A / x_A 2. **Relative volatility:** It is the ratio of volatility of more volatile component to the volatility of less volatile component. **Relative volatility (α_{AB})=** $p_A.x_B / x_A.p_B$ It is the measure of the separability by distillation.	2 2
1a-iii	**Mixer settler:**	4

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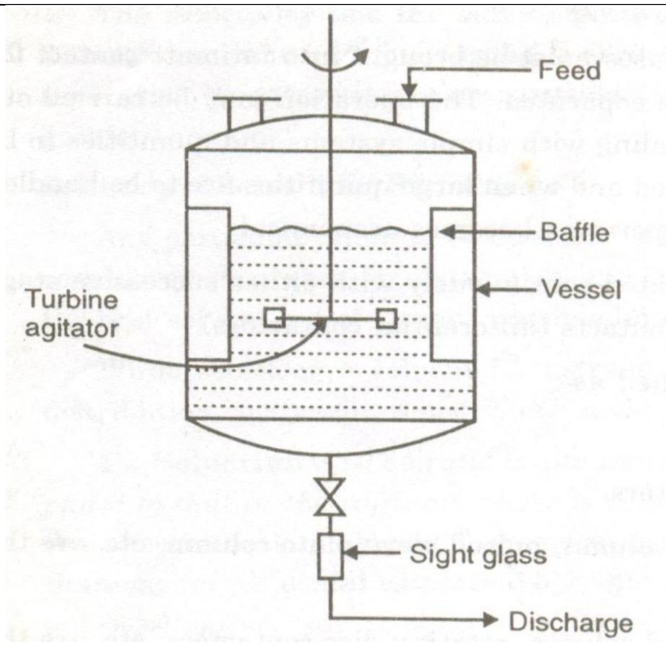
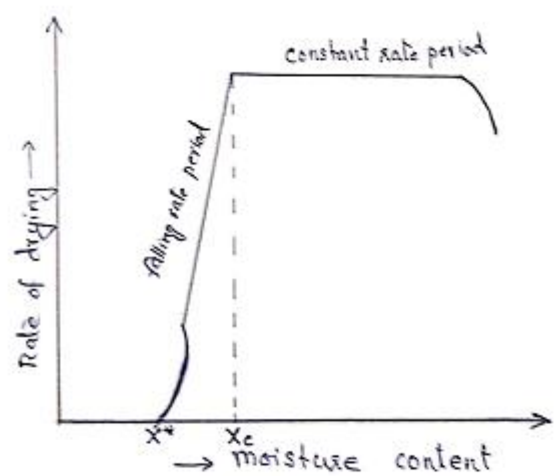
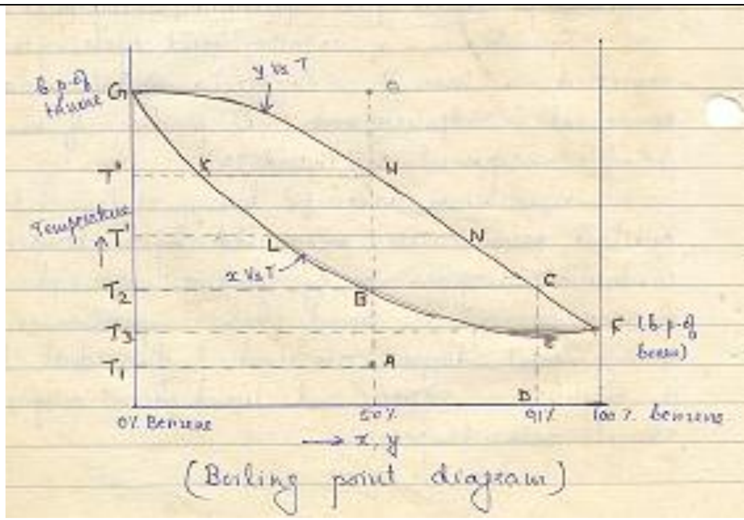
<tr><td></td><td>
</td><td></td></tr>
<tr><td>1a-iv</td><td>Rate of drying curve:


Xc – critical moisture content
X* - Equilibrium moisture content</td><td>4</td></tr>
<tr><td>1b</td><td>Attempt any 1</td><td>6</td></tr>
<tr><td>1b-i</td><td>Vapour- liquid equilibrium diagram</td><td></td></tr>
</table>



3

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 . 3

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.

1b-ii	Basis: 100 kg solution F = 100 kg x_F = 0.48 Molecular weight of $Na_2S_2O_3$ = 158 Molecular weight of $Na_2S_2O_3 .5 H_2O$= 248 Material balance for water is 52= C.(90/248) + L Or L = 52-0.363C Material balance for solute is 48 = C (158/248) + (52-0.363C) (X') ***Note: Since the value of X' is not given, student can assume any value of X' and solve for C.***	1 1 1 1 1 1
2	**Attempt any 4**	16
2-a	**Different methods of attaining super saturation:** 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 for any 4
2-b	**Fluidised bed dryer:**	4

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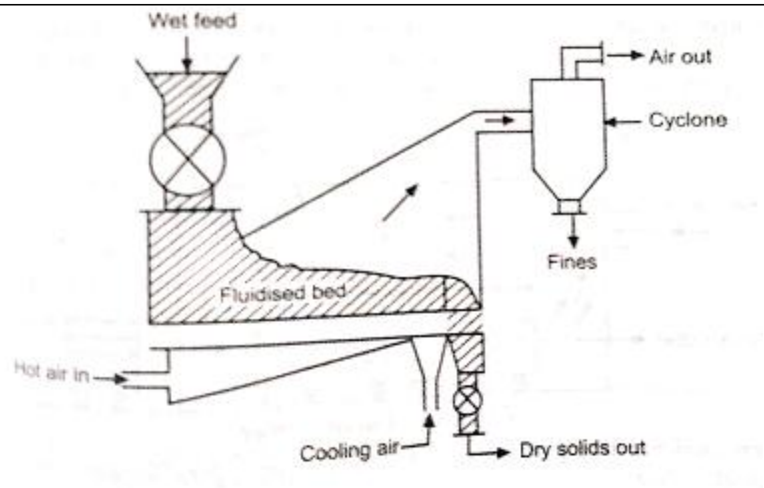
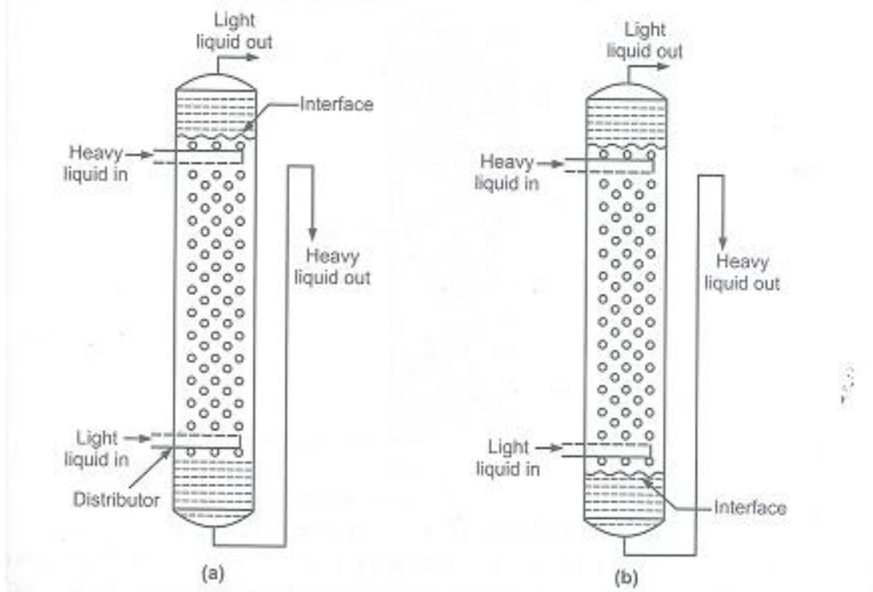
<tr><td></td><td>
</td><td></td></tr>
<tr><td>2-c</td><td>Different mass transfer theories:
1. Whitman’s two film theory
2. Higbie’s penetration theory
3. Danckwert’s surface renewal theory
4. Toor and Marchello’s film penetration theory</td><td>1 mark each</td></tr>
<tr><td>2-d</td><td>Spray Column:</td><td>4</td></tr>
</table>

	 . **Spray towers (a) for light liquid dispersed and (b) for heavy liquid dispersed**	
2-e	**i)** **Distibution Coefficient** = $$\frac{concentration\ of\ solute\ in\ extract\ phase}{concentration\ of\ solute\ in\ raffinate\ phase}$$ **ii)** **Selectivity**: The ratio of concentration ratio of solute to feed solvent in extract phase to that in raffinate phase. **iii)** **Extract phase**: Solvent rich product of liquid-liquid extraction operation is called extract. The extract phase contains desired product in large proportion. **iv)** **Raffinate phase**: The residual liquid solution from which solute is removed is called raffinate	1 1 1 1
3	**Attempt any 2**	16
3-a	**Rayleigh equation:** Let F be moles of liquid mixture containing x_F mol fraction of A, D kmoles of	

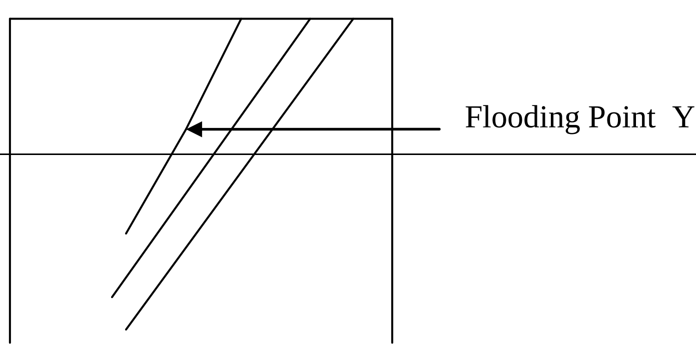
	distillate and W kmoles of residual liquid in still which are obtained at the end of operation. Let y_D and x_W be the mol fr of A in distillate and bottom residual liquid.	2
	Let L be kmoles of liquid in the still at any time during the course of distillation and let x be mol fr of A in liquid.Let very 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. Overall material balance is L=L-dL+dD Or dL= dD Material balance for component A is Lx=(L-dL)(x-dx)+ydD	2
	Lx= Lx-Ldx-xdL+dLdx+ydD dLdx=0 0= -Ldx-xdL+ydL But dD=dL i.e. 0=-Ldx-xdL+ydL	2
	Ldx=(y-x)dL dL/L=dx/(y-x) Integrating the equation between the limits L=F, $x=x_F$, L=W $x=x_W$ $\int_{W}^{F} dL/L = \int_{xW}^{xF} dx/(y-x)$ $Ln(F/W) = \int_{x_W}^{x_F} dx/(y-x)$	2
	This is Rayleigh's equation	
3-b	Feed containing 40 mole % benzene xF = mole fraction of benzene in feed	

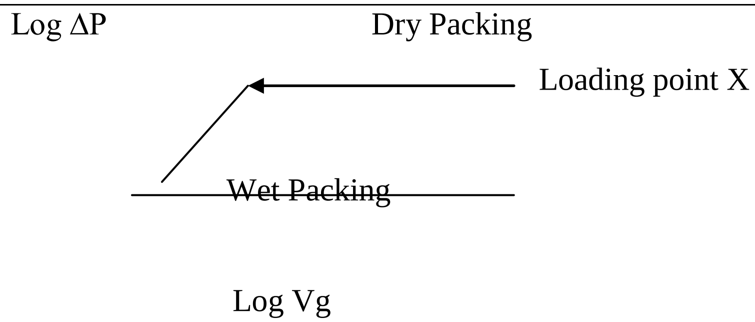
	= mole % benzene /100 x_F = 40/100 = 0.4 given 50 mole % of the feed is vaporized. Therefore, f = molal fraction of feed that is vaporized. Therefore, f = molal fraction of feed that is vaporized 50/100 = 0.5 Slope of operating line for flash distillation = $-\frac{(1-f)}{f}$ Slope = $\frac{-(1-0.5)}{0.5}$ = -1.0 Draw the equilibrium curve with the help of data given. 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**	1 1 1 1 2 2
3-c	**Basis:** Feed containing 40% benzene and 60% toluene X_F= mole fraction of benzene in the feed = 40/100 =0.4 Similarly X_D = 90/100=0.9 X_w= 10/100=0.1 Relative volatility α= 2.4 With the help of relative volatility, generate x-y data For generating x-y data assume X= 0,0.1,0.2,……1 and find the corresponding values of y from the relation Y= α x/(1+(α-1)x	2

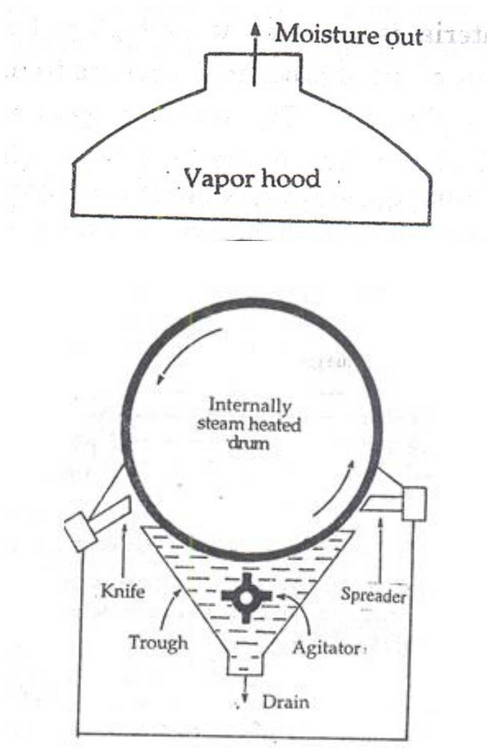
	<table><tr><td>X</td><td>0</td><td>.1</td><td>.2</td><td>.3</td><td>.4</td><td>.5</td><td>.6</td><td>.7</td><td>.8</td><td>.9</td><td>1</td></tr><tr><td>y</td><td>0</td><td>.21</td><td>.38</td><td>.51</td><td>.62</td><td>.71</td><td>.78</td><td>.85</td><td>.91</td><td>.95</td><td>1</td></tr></table>	2
	Draw diagonal and plot the equilibrium diagram.	1
	Start constructing stages from point (0.9,0.9) on diagonal till (0.1,0.1) on diagonal between diagonal and equilibrium diagram. Count number of completed triangles.	2
	From the graph the theoretical stages required including reboiler n =6 Number of stages required in column= n-1= 6-1= **5**	1
4 a	**Attempt any 3**	12
4a-i	**Differentiate between distillation and extraction** <table><tr><th>Points</th><th>Distillation</th><th>Extraction</th></tr><tr><td>Purity of product</td><td>Gives almost pure product</td><td>Doesn't give pure product</td></tr><tr><td>Operating cost</td><td>Cost is Low.</td><td>Cost is high.</td></tr><tr><td>Phases involved</td><td>Phases involved are liquid and vapour</td><td>Phases involved are liquid</td></tr><tr><td>Temperature conditions</td><td>Needs heating and cooling provisions. High temperature is required</td><td>Does not need heating and cooling provisions. Takes place at room temperature</td></tr></table>	1 mark each
4a-ii	**Analogy between mass and heat transfer operations** **1) General molecular transport equation** Rate of transfer process=Driving force/ resistance 2) **Molecular diffusion equations**. For heat transfer Fourier's equation is q/A=-k d/dz(T)	4

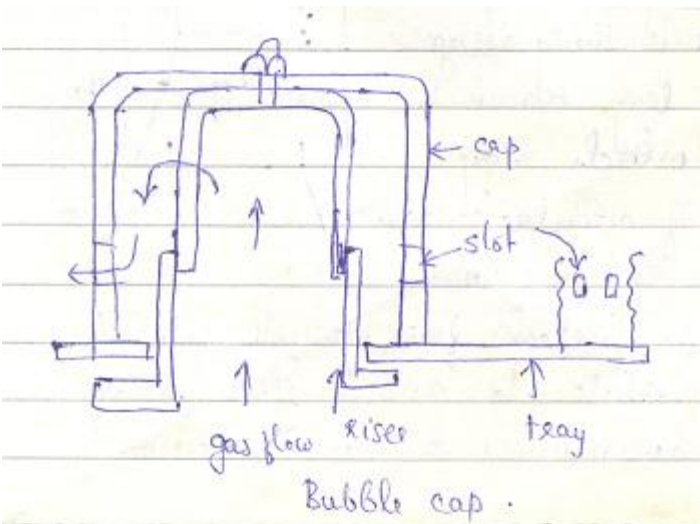
	For Mass diffusion Fick's equation is $J_A = -D_{AB}\, dC_A/dZ$ 3) **Turbulent diffusion equations** : Heat transfer $q/A = -(k+\varepsilon_H)\, d/dz(T)$ Mass transfer $J_A = -(D_{AB}+\varepsilon_D)\, dC_A/dZ$	
4a-iii	**Derive Y= α.x / [1+x(α-1)]** Relative volatility (α)is the ratio of volatility of more volatile component to that of less volatile component $\alpha = p_A.x_B / x_A.p_B$ But $P.y_A = p_A$ and $P.y_B = p_B$ Therefore $\alpha = P.y_A.x_B / x_A.Py_B$ $= (y_A/y_B) / (x_A/x_B)$ Thus relative volatility is the ratio of concentration ratio of A to B in vapour phase to that in liquid phase. $A = y_A.x_B / x_A.y_B$ But $y_B = 1- y_A$ and $x_B = 1- x_A$ Therefore $\alpha = y_A.(1-x_A) / x_A.(1-y_A)$ $\alpha x_A.(1-y_A) = y_A.(1-x_A)$ $\alpha x_A - \alpha x_A y_A) = y_A.(1-x_A)$ $\alpha x_A = y_A + y_A x_A(\alpha -1)$ $= y_A[1+ x_A(\alpha -1)]$ $y_A = \alpha x_A / [1+ x_A(\alpha -1)]$ **or** $y = \alpha x / [1+ x(\alpha -1)]$	1 1 1 1
4a-iv	**Selection criteria for solvent in gas absorption** : (any 4) 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	1 mark each

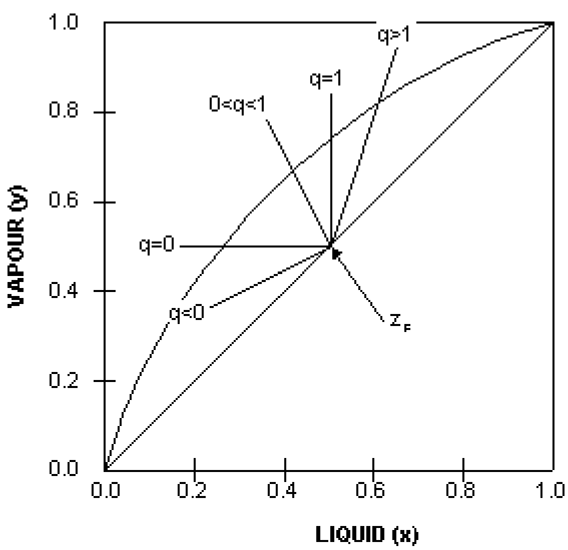
	2) Volatility : As the gas leaving an absorption unit is generally saturated with the solvent, there will be a loss of the solvent with the gas leaving the unit operation, hence to minimize the solvent loss , the solvent should be less volatile. 3) Corrosive nature : the solvent should not be corrosive 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.	
4b	**Attempt any 1**	**6**
4b-i	**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.	2



		1
	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 given velocity, pressure drop will be more than that for dry packing.	1
	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.	1
	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.	1
4.b ii	**Rotary drum Dryer:** A rotary vacuum filter consists of a large rotating drum covered by a cloth. The drum is suspended on an axial over a trough containing liquid/solids slurry with approximately 50-80% of the screen area immersed in the slurry. **Working**: As the drum rotates into and out of the trough, the slurry is sucked	

	on the surface of the cloth and rotated out of the liquid/solids suspension as a cake. When the cake is rotating out, it is dewatered in the dying zone. The cake is dry because the vacuum drum is continuously sucking the cake and taking the water out of it. At the final step of the separation, the cake is discharged as solids products and the drum rotates continuously to another separation cycle.	3
		3
5	**Attempt any4**	**16**
5-a	Basis: 100 kmoles/hr Methanol – water solution	
	X_F = 0.36, X_D = 0.965, X_W =0.1	1
	Let D kmoles/hr distillate and W kmoles/ hr residue	
	Overall balance is 100= D+W-----(1)	1
	Balance for methanol is	
	$F.X_F = D.X_D + W.X_W$	

	0.36* 100 = 0.965 D + 0.1 W-------(2) Solving the above equations **Distillate (D)= 30.05 kmoles/hr** **Residue(W) =69.95 kmoles/hr**	1 1
5-b	**Bubble cap tray:**  	4
5-c	**Types of gas absorption:** 1. **Physical absorption:** It is a purely physical phenomenon. Example: Absorption of ammonia from ammonia- air mixture by water 2. **Absorption accompanied by a chemical reaction.** Example: Absorption of NO_2 in water to produce nitric acid.	1 1 1 1
5-d	**Values 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)	2

		2
5-e	**(i) 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. Providing good liquid distribution system. **(ii) HETP(Height Equivalent to a Theoretical Plate):** It is the height of a section of packing that will give the same separation as that achieved with one theoretical plate Height of packed column = NTU*HTU Where, NTU = Number of transfer units HTU = Height of transfer units **Factors on which HETP depends:** 1. Type of feed mixture 2. Feed conditions	2 2

	3. Process conditions 4. Type of packing	
6	**Attempt any 2**	**16**
6-a	Initial moisture content X_1=0.35/(1-.0.35)=0.5385 Final moisture content X_2=0.1/(1-0.1)=0.111 Equilibrium moisture content X^*=0.04/(1-0.04)=0.0417 Critical moisture content X_c=0.14/(1-0.14)=0.1628 t = W'/ARc { (X_1-X_c) + (X_c – X^*)ln[(X_c –X^*)/(X_2 – X^*)]} 5= W'/ARc { (0.5385-0.1628) + (0.1628 – 0.0417)ln[(0.1628–0.0417)/(0.111 – 0.0417)]} W'/Arc= 11.28 For second case X2 = 0.06/(1-0.06)=0.0638 t= 11.28 { (0.5385-0.1628) + (0.1628 – 0.0417)ln[(0.1628–0.0417)/(0.0638 – 0.0417)]} **t = 6.56 hr.**	2 1 1 1 1 2
6-b	**Time of drying under constant drying conditions:** 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)	1

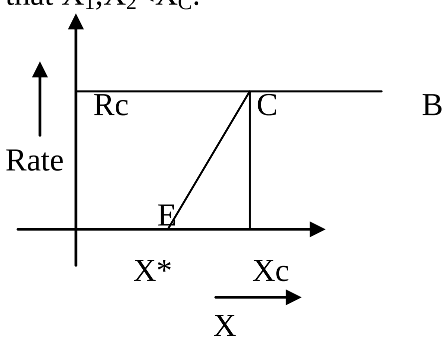
	$R = R_C$ = rate during constant rate period $R_C = -\frac{W'}{A} \times \frac{dX}{dt}$ ----------------(2) Where W' = mass of dry solids in kg A = area of drying surface in m^2 R_C = rate in kg/(m^2.h) t = time in hours (h) Rearranging Equation (2), we get,Type equation here. $dt = \frac{W'}{A.RC}\ dX$ ----------------(3) Integrating Equation (3) between the limits : $t = 0,\quad X = X_1$ 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) **Falling rate period :**	1 1 1

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

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

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 $X_1, X_2 < X_C$. 1



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

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

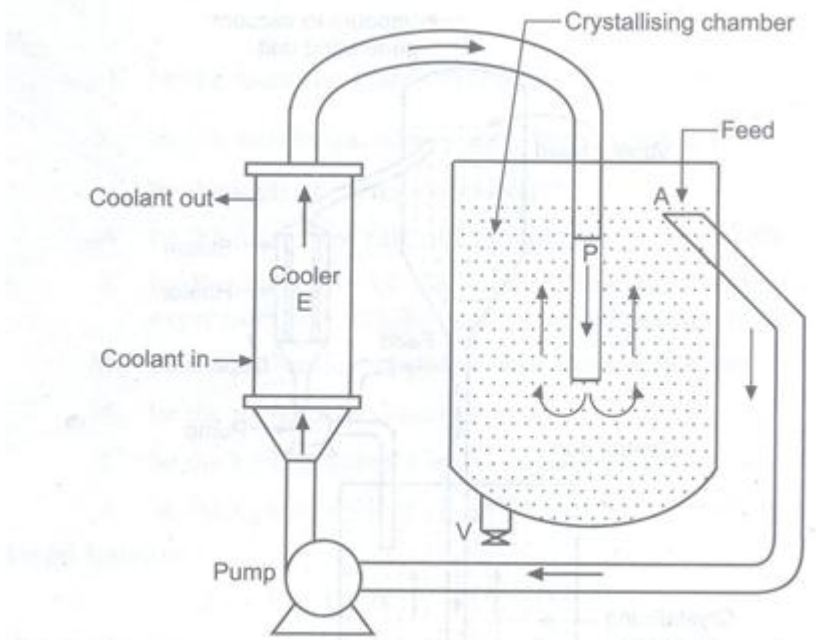
m = slope of line CE

Equation (1) then becomes

$$-\frac{W'}{A} \times \frac{dX}{dt} = \frac{RC}{[XC - X^*]}\,[X - X^*] \qquad \text{----------------(10)}$$ 1

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

	Integrating Equation (11) between the limits : $X = X_1$ $X = X_2$ [$X_1, X_2 < X_C$], we get $$\int_{X1}^{X2} \frac{dX}{[X-X^*]} = \frac{RC\ A}{[XC-X^*]W'} \int_0^t t \quad \text{----------------(12)}$$ $$t = \frac{[XC-X^*]\ W'}{RC\ A} \ln \frac{X1-X^*}{X2-X^*} \quad \text{----------------(13)}$$ Equation (13) gives the time of dying 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 : $$t_f = \frac{[XC-X^*]\ W'}{RC\ A} \ln \frac{XC-X^*}{X2-X^*} \quad \text{----------------(14)}$$ [As X_1 becomes X_C] t_f = drying time during entire falling rate period. Total time of drying = $t_C + t_f$ $$t = \frac{W'}{A.RC} [(X_1 - X_C) + (X_C - X^*)] \ln \frac{XC-X^*}{X2-X^*} \quad \text{--------(15)}$$	1 1
6-c	**Oslo Cooler crystallizer:**	

	 **Oslo / Krystal Cooling Crystalliser**	3 2
	Construction : It consist of a crystallizing chamber, a circulating pump and a external cooler for cooling the solution. It is a circulating liquid cooling crystalliser. In this crystallizer, a supersaturated solution is passed upward through a bed of crystals which are maintained in a fluidized state wherby uniform temperature is maintained and the crystals segregate in the bed with larger ones at the bottom and small ones at the top. **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) whrein supersaturation is achieved by cooling. The supersaturated solution from the cooler is finally	3

	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 crystallising chamber. The nuclei formed circulate with mother liquor and once they go 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 crystallising chamber through a valve 'V' as these cannot be retained in the fludised bed by the circulation velocity.	