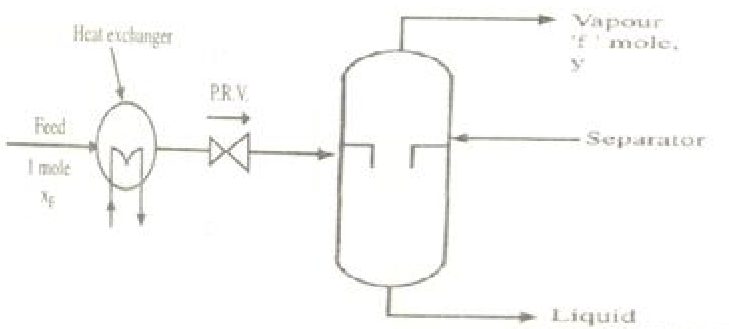
SUMMER-14 EXAMINATION

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	marks	Total marks
1a-a	**Analogy between momentum, mass and heat transfer operations** **1) General molecular transport equation** Rate of transfer process=Driving force/ resistance 2) **Molecular diffusion equations**. For momentum transport Newton's equation is $\tau_{ZX} = -\mu/\rho\ d/dz(u_x\rho)$ For heat transfer Fourier's equation is $q/A=-k\ d/dz(T)$ For Mass diffusion Fick's equation is $J_A = -D_{AB}\ dC_A/dZ$ 3) **Turbulent diffusion equations** : Momentum transport $\tau_{ZX} = -(\mu/\rho+\varepsilon_M)\ d/dz(u_x\rho)$ Heat transfer $q/A=--(k+\varepsilon_H)\ d/dz(T)$ Mass transfer $J_A = -(D_{AB}+\varepsilon_D)\ dC_A/dZ$	4	4
1a-b	**Fick's law** is the basic law of diffusion Fick's law states that the flux of a diffusing component A in z direction in a binary mixture of A and B is proportional to the molar concentration gradient. $J_A = -D_{AB}\ dC_A/dZ$ Where J_A- molar flux of A in z direction C_A – concentration of A dC_A/dZ – concentration gradient in z direction D_{AB} – proportionality constant, diffusion coefficient Z – distance in the direction of diffusion	4	4
1a-c	Three variable parameters that can be controlled in distillation are: 1. Temperature 2. Pressure	4	4

	3. Concentration		
1a-d	**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 vapourises 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.	2 2	4
1b-a	**Flash distillation** 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  Consider one mole of liquid mixture having x_f mole fraction , f moles of feed that is vapourized and of composition y. Then (1-f) will be the moles of residual liquid obtained. Let x be the mole fraction of more volatile component in liquid. Material balance for more volatile component is $x_F = fy+(1-f)x$ OR $y= -(1-f)x/f+ (x_f/f)$ The above equation is operating line for flash distillation with slope = -(1-f)/f and y- intercept = x_F/f The point of intersection of operating line and diagonal (x=y) is (x_F , x_F)	1 2 1 2	6

1b-b (Total: 6)

Vapour phase composition $y=\dot{\alpha}x/[1+x(\dot{\alpha}-1)]$ — 1

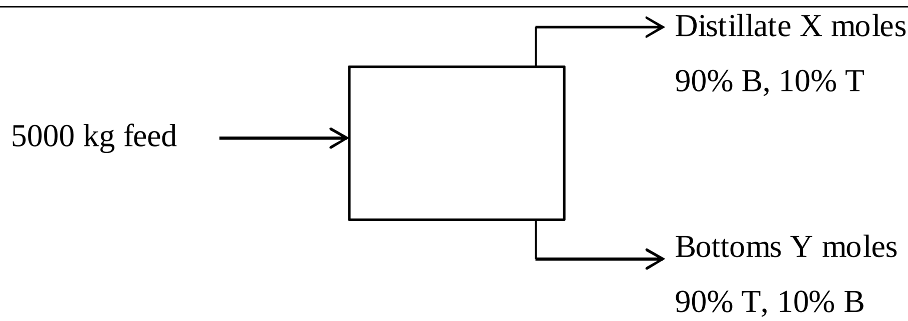
Assume x=0.1

The different value of y for different relative volatility($\dot{\alpha}$) values are calculated. — 4

$\dot{\alpha}$	1.1	1.3	1.5	1.8	2	2.5
y	0.1089	0.126	0.142	0.167	0.1818	0.2

From this it can be proved that purity of a binary mixture decreases with decrease in relative volatility. — 1

2-a (Total: 8)



Weight of feed is = 5000 kg

Weight of benzene = 3000 kg = 38.46 kmoles. — 2

Weight of Toluene = 2000 kg = 21.74 kmols.

Mole fraction of benzene in feed = 0.64

Mole fraction of toluene = 0.36 — 1

Total moles of feed = 5000/83.04 = 60.21 kmol

Overall balance is 60.21 = X + Y…………..(1)

Benzene balance is 0.64*60.21 = 0.9X+0.1Y ………(2) — 1

Solving (1) and (2) X = 40.65 kmoles and Y=19.56 kmoles

Benzene in distillate = 40.65*0.9=36.59 kmoles = 2853.63 kg.

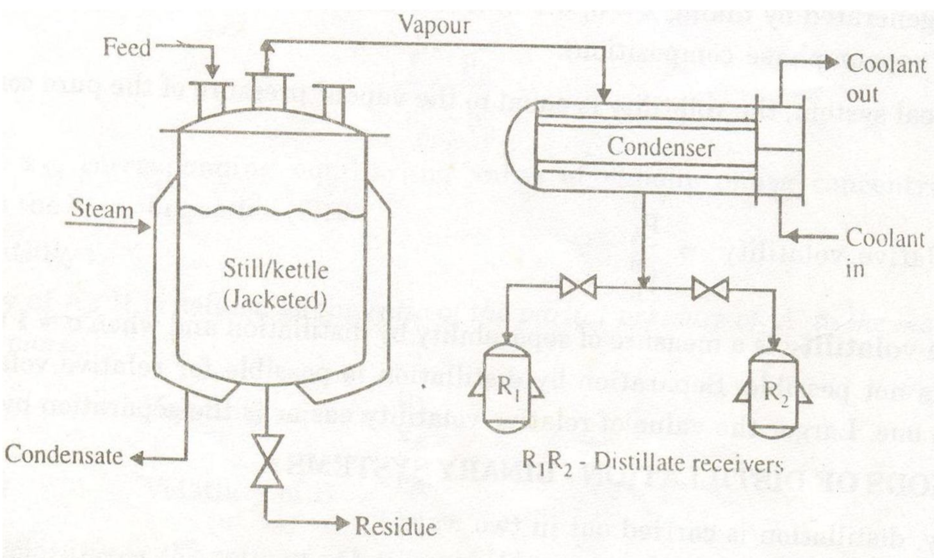
Toluene in distillate = 40.65*0.1=4.065 kmoles = 373.98 kg. — 2

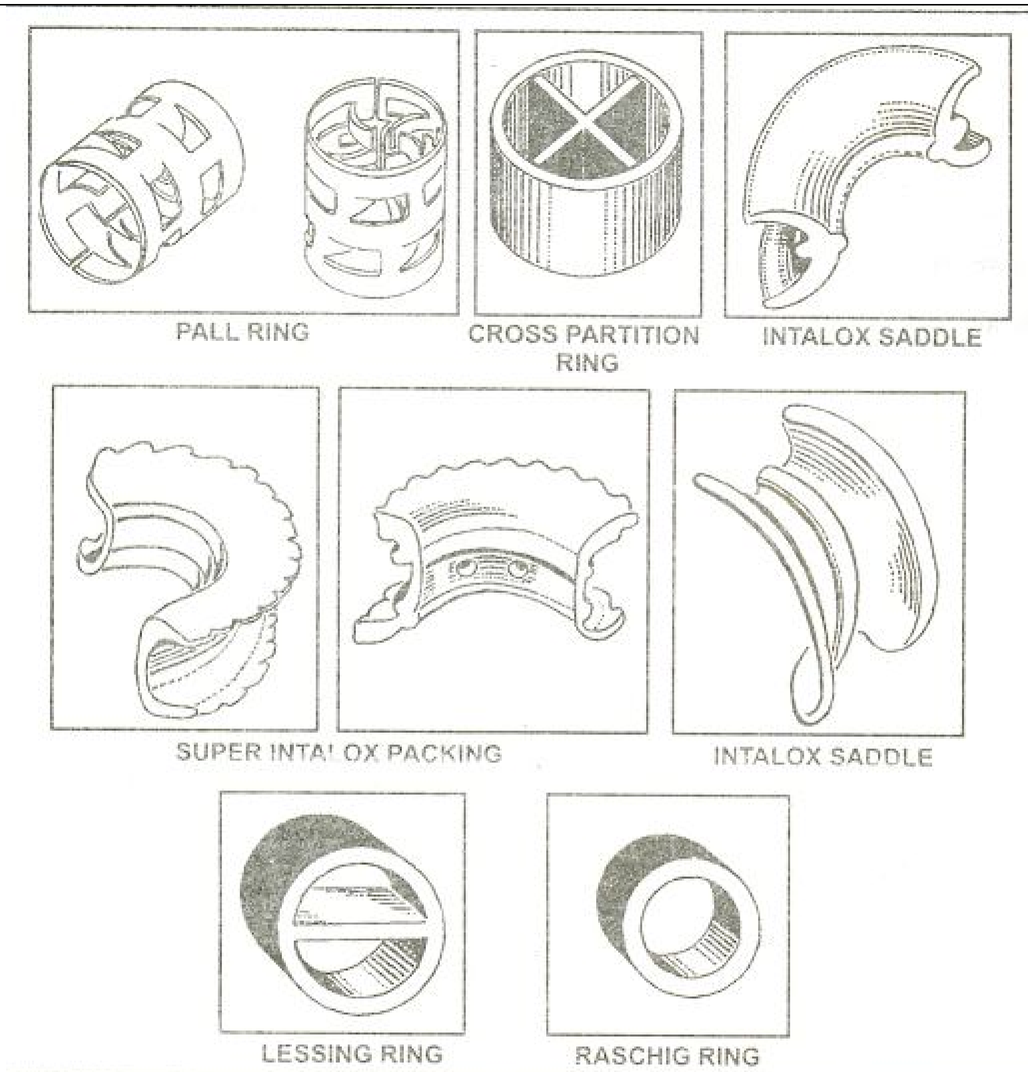
Benzene in bottom = 19.56*0.1=1.956 kmoles = 152.57 kg.

Toluene in bottom =19.56*0.9 = 17.601 kmoles = 1619.57 kg. — 2

2-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 Equilibrium moisture content X^*=0.01/(1-0.01)=0.0101 Critical moisture content X_c=0.4/(1-0.4)=0.67 Rc = 1.5 kg/ m^2 hr. A/W'=0.5 or W'/A=2 $t = W'/ARc \{ (X_1-X_c) + (X_c - X^*)\ln[(X_c - X^*)/(X_2 - X^*)]\}$ $= 2/1.5\{ (2.03-0.67) + (0.67 - 0.0101)\ln[(0.67 - 0.0101)/(0.333 - 0.0101)]\}$ **= 2.44 hr.**	 2 1 2 3	8
2-c	Basis 100 kg feed solution F=100 kg. x_F=0.48 Solvent balance is $F(1- x_F) = L$ 100 (1-0.48)=L or L=52 kg. $NaNO_3$ balance $NaNO_3$ in feed = $NaNO_3$ crystals + $NaNO_3$ in mother liquor. 0.48*100=C+L* solubility of $NaNO_3$ 48 = C+52*0.8018 **Yield of $NaNO_3$ crystals(C)=6.31 kg.** **% Yield of $NaNO_3$ crystals = (6.31/48)*100=13.14%**	 2 2 2 2	8
3-a	Mole fraction of A in tank 1 = xA = .90 Mole fraction of B in Tank 2 = xA2 = 0.05 $D_{AB} = 4.3 \times 10^{-3} \frac{m^2}{s}$ Z = 150mm = 0.15m = length of diffusion	 1	4

	Area = $\frac{\pi}{4}D^2 = \frac{\pi}{4}(0.05)^2$ $= 1.963 \times 10^{-3}$ m^2 $P_{A1} = x_{A1}$ P = 0.9 × 101 = 90.9KPa $P_{A2} = x_{A2}$ p = 0.05 × 101 = 5.05KPa R = 8.31451 $\frac{m^3.KPa}{Km\pi,K}$ Rate of transport of A = NA.A $= \frac{DAB\ (p_{A1} - P_{A2})}{RTZ} \times A$ $= \frac{4.3 \times 10^{-3}\ (90.9-5.05)\times 1.963 \times 10^{-3}}{8.31451 \times 298 \times 0.15}$ $= 1.95 \times 10^{-6}$Kmol/S	1 1 1	
3-b	**Process of diffusion in distillation** : Diffusion is the movement of an individual component through a mixture from a region of high concentration to one of low concentration at fixed temperature & pressure with or without an external force. Diffusion may occur in one phase or both phases in all the mass transfer operation. In case of distillation, the more volatile component diffuses through the liquid phase to the interface between the phases & away from interface into vapour phase. The less volatile component diffuses in opposite direction & passes from vapour phase to the liquid phase. As such diffusion takes place across both the phase.	2 2	4
3-c	**Differential distillation** : In this distillation technique, a known quantity of a liquid mixture is charged into a jacketed kettle or still. The jacket is provided for heating the liquid mass in the still with the help of a heating media such as steam. the charge is boiled	3	4

	slowly, vapours formed are withdrawn and fed to a condenser where they are liquefied and collected in a receiver as a distillate. in the early stage of distillation, vapours leaving the still are richest in the more volatile component and as the distillation proceeds the liquid in the still becomes lean with  respect to the more volatile component. The composition of the less volatile component thereby increases and hence the boiling point increases. The produce (distillate) from such units can be collected in several receivers, called cuts, to give products of various purities over the length of distillation period. the distillation is continued till the boiling point of liquid reaches a predetermined value and the content of the still is finally removed as residual liquid containing majority of the less volatile component. **Rayleigh's equation** : $\ln \frac{F}{W} = \int_{xw}^{xf} \frac{dx}{y-x}$	1	
3-d	**Tower packing** :		4

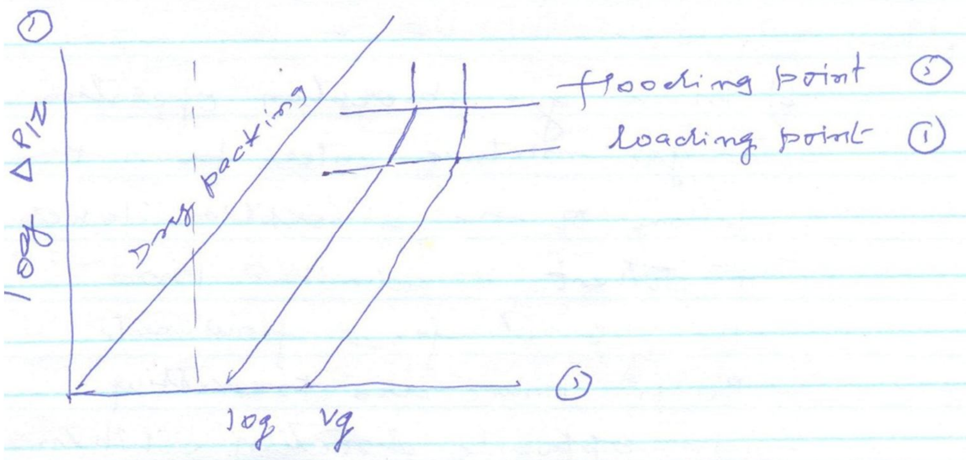


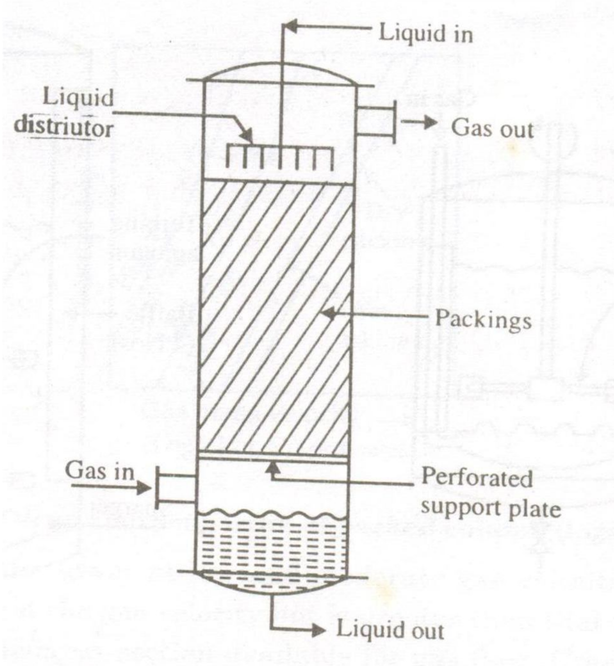
1 mark each for any two

Important properties

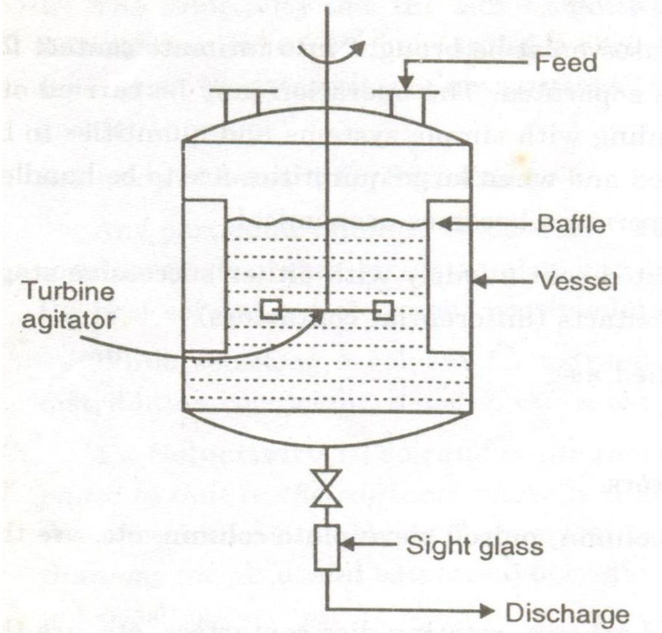
1. Light weight
2. Large wettable surface area
3. Low cost
4. Large void volumn

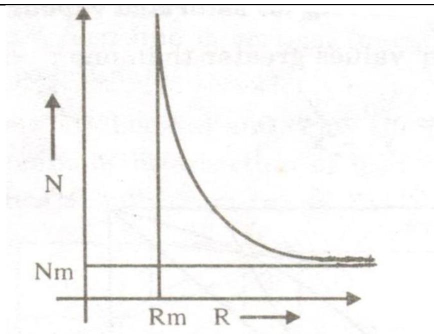
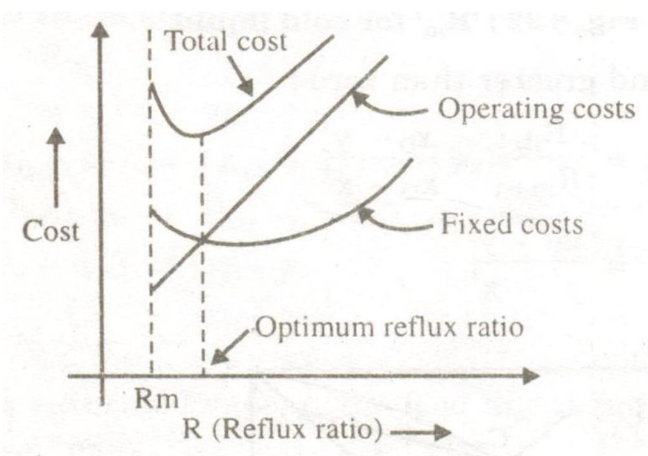
1 mark each for any two

3-e		4	4
4a-a	**Gas absorption equipment are :** i. Mechanically agitated vessel ii. Packed column/towers iii. Plate column **Packed column :** In packed column the liquid is dispersed in form of film and gas flows as a continuous phase. They are continuous , counter current. It consist of vertical , cylindrical shell constructed out of metal , plastic etc. and filled with suitable packings which offer large interfacial area for gas liquid contact for mass transfer between phases. The bed of packing rests on a support plate which offers very low resistance to gas flow. The liquid is introduced from top through liquid distributor ,which irrigates the packing uniformly and liquid trickles down the bed , and finally liquid phase leaves the bottom of the column. The gas is introduced from the bottom of the tower and rise upward. The lean gas leave the tower from top.	2 1	4

		1	
4a-b	In gas absorption operation a gas mixture enters from the bottom of the absorption tower. A solvent is admitted from the top at fixed flow rate. Both phase are travelling in opposite direction. When liquid is coming down, it fills in the voids between the packing. This point is known as loading point. This is represented by a point where there is a change slope of the line drawn between log V_G vs log $\frac{\Delta P}{Z}$. Due to this resistance in the packing increase which is shown by increase in ΔP. to overcome this additional resistances gas velocity is increased. At some gas velocity there is reversal in the flow of liquid & liquid instead of coming down starts flowing in upward direction. This point is called flooding point. Change in slope of line drawn between logV_6 Vs log $\frac{\Delta P}{I}$. No contact of gas & liquid takes place which is undesirable. Working velocity of gas **50 to 70% of the flooding velocity**	1 1 2	4

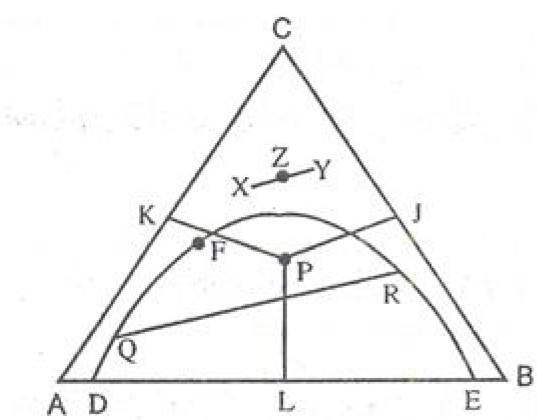
4a-c	Liquid-liquid extraction (liquid extraction) is an unit operation in which the constituents of a liquid mixture are separated by contacting it with a suitable insoluble liquid solvent, which preferentially dissolves one or more constituents. This operation is sometimes also termed as solvent extraction. Extraction utilizes the differences in the solubilities of the constituents/components. 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 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 liquids and so is a liquid-liquid operation. The mass transfer of the solute (liquid) takes place from the feed solution to the solvent phase.	4	4
4a-d	**The mixer-settler** is the most simple type of extractor. It is a stage-type extractor and has many variations. For extraction operations carried out batchwise, the mixture and settler may be the same unit. 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.	2	4

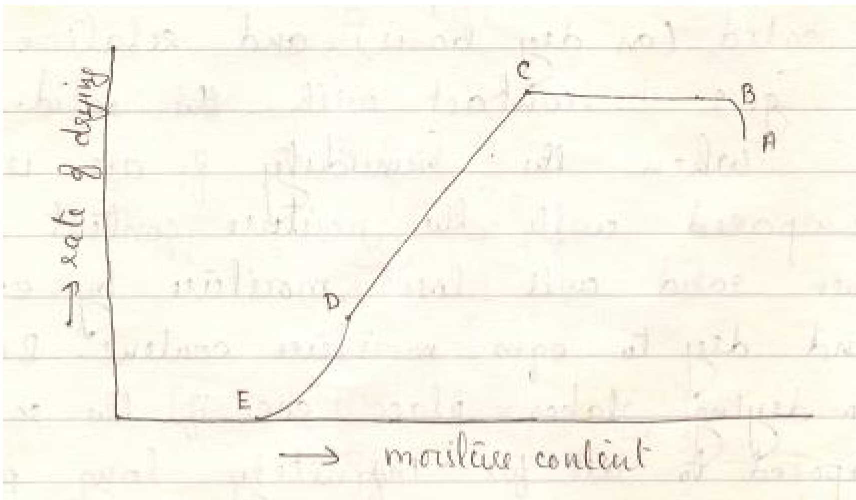
	 ***Any other extraction equipment answered by the student should be given marks.***	2	
4b-a	Infinite reflux ratio requiring minimum number of plates and minimum reflux ratio requiring infinite number of plates is a workable system which requires finite stages for the desired degree of separation. At minimum reflux ratio as infinite number of plates are required, the fixed cost is also infinite while the cost of heat supply to the reboiler and condenser coolant is minimum. As the reflux ratio is increased, the number of plates decreases and the fixed cost decreases at first, passes through a minimum and then increases as with higher reflux ratio the diameter of the column and sizes of reboiler and condenser increases. The operating cost increases continuously with reflux ratio as it is directly proportional to (R + 1). At total reflux, though the number of plates are minimum, the cost of heat supply to reboiler and condenser coolant is maximum and also large capacity	4	6

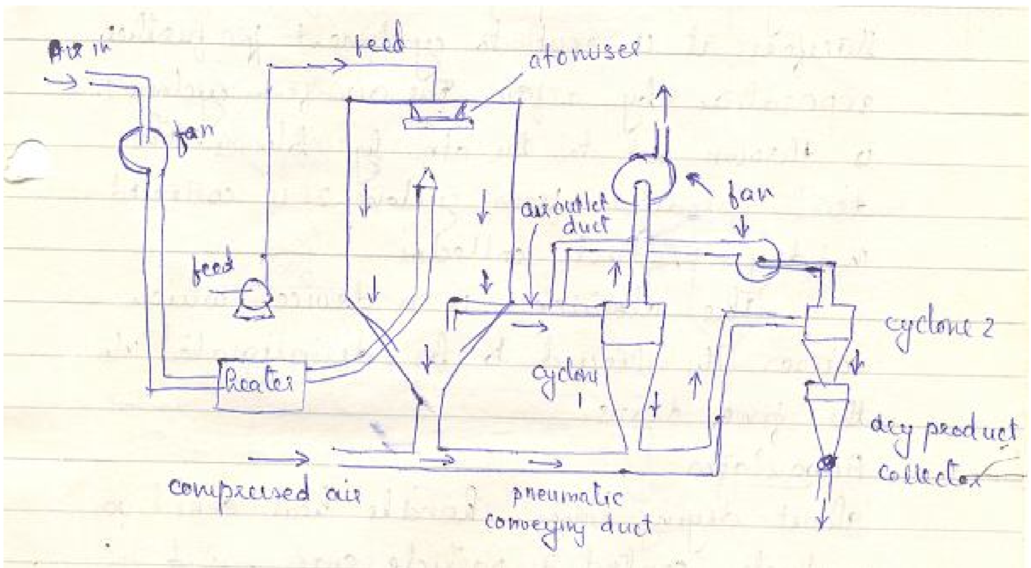
	 Reboiler and condenser are needed. The total cost which is the sum of the fixed cost and the operating cost also decreases to a minimum and then increases with reflux ratio. The optimum reflux ratio occurs at a point where the sum of the fixed cost and operating cost is minimum. As a rough approximation, **the optimum reflux ratio usually lies in the range of 1.1 to 1.5 times the minimum reflux ratio**. 	2	
4b-b	Where, C_R = concentration of picric acid in water. Mol/τ C_E = concentration of picric acid in benzene, mol/τ **Basis:** 1 litre of solution of picric acid in benzene.		6

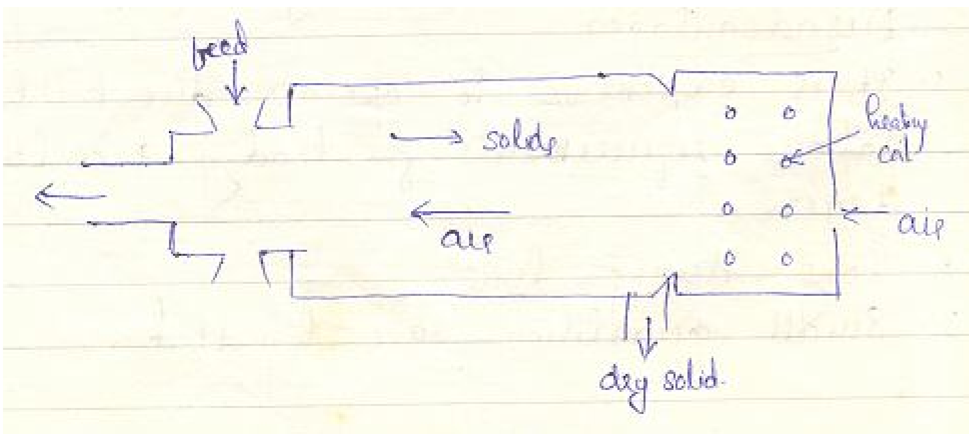
	Initial picric acid = 30g Final picric acid = 4g Picric acid extracted = 30 – 4 = 26g $= \frac{26}{229} = 0.1135$ mol Picric acid in benzene = 4 g/τ $= \frac{4}{229} = 0.01746$ mol $C_E = 0.01746$ mol/ lit $K = \frac{C_E}{C_R} = 0.548$ $C_R = \frac{C_E}{0.548} = \frac{0.01746}{0.548}$ = 0.03186 mol/ lit Quantity of water required $= \frac{0.1135}{0.03186} = 3.56$ lit	2 1 1 1 1	
5-a	**x_F=0.6 x_D=0.95 x_W=0.1** **Operating line of rectifying section:** Slope)R/(R+1) = 2.5/(2.5+1) = 0.714 y-intercept= x_D/(R+1) = 0.95/(2.5+1) = 0.271 Draw operating line of rectifying section with point (0.95,0.95) on diagonal and with y-intercept=0.271 **Feed line** As the feed is at its bubble point, feed line is parallel to y-axis through (x_F,x_F) on diagonal. Draw feed line through (0.6,0.6)and parallel to y-axis. **Operating line of Stripping section** Draw operating line of stripping section through (0.1,0.1) on diagonal and passes through intersecting point of rectifying section line and feed line. Starting from (0.95,0.95) on diagonal construct no. of stages.	1 2 2 1 2	8

	No. of theoretical stages = 9 **Feed plate= 4^{th} from top**		
5-b	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 2 1 2	8
5-c	**Triangular diagram:** 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. It is a ternary system. Consider a system C (acetic acid),A (Water) and B(chloroform) at 25^0C wherein acetic acid is the solute, water and $CHCl_3$ are the solvents. C represents 100% acetic acid , B represents 100% $CHCl_3$ and A represents 100% water. Along line BC the concentration of A is zero. Similarly along line AB the concentration of C is zero and along line CB the concentration of A is zero. The ternary system represented by point P consists of the three components C,B,A in the ratio of perpendiculars PL,PJ,PK. The distances AD and BE represents solubility of solvent B in A and that of A	4	8

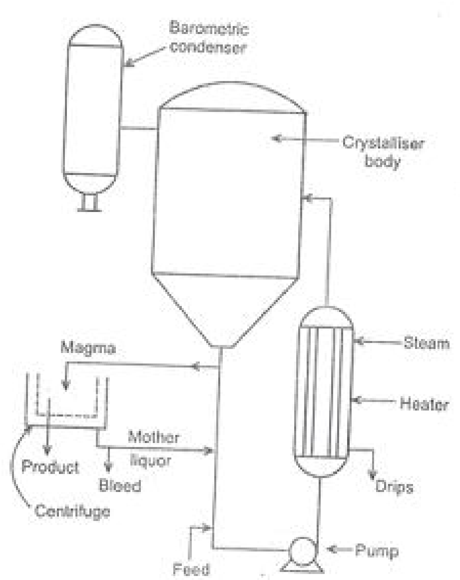
	in B. The curve DQF indicates the composition of saturated water layer and the line ERF indicates the composition of saturated $CHCl_3$ layer. XZ/YZ= Amount of Y/Amount of X. The area under the curve represents a two phase region that that will split up into two layers in equilibrium with each other. These two layers have composition represented by points Q and R and QR is called tie line . **The tie line** is 1 which connects together two phases in equilibrium which each other. The point F on bimodal curve represents a single phase which does not split in to two phases and corresponds to a tie line of 0 length and is known as **plait point**. 	1 1 2	

6-a	**Rate of drying curve** :  	1	4
	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 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	3	

	section DE is governed by the internal moisture movement.		
6-b	**Spray Dyer** :  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. **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	2 2	4

	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.		
6-c	**Rotary dryer** :  This type of dryer that may be directly or indirectly heated is adopted for drying of face flouring grander material on large scale . It consists of a hollow cylindrical shell having dia of 1 m to 3m and length 3m – 30m set with its axis at a slight angle to this horizontal, so that material is consequently advanced through the dryer from one end to another end. It is supported on this supporting rolls so that it can be rotated to avoid its slipping over rollers. It is fitted with thrust wheels. It is fitted inside with flights which lift the material upward and shower it down from the top. The material to be dried is fed at high end of the dryer by hopper and the product is taken out from the lower end of the dryer. The cylindrical shell is rotated by gear mechanism at a speed of 2.25 rpm. Air is taken into the dryer from product end, it is heated in the heater, and then moves this the dryer in counter current fashion. The moisture of the feed	2 2	4

	evaporates and gets added into the air . An exhaust fan is used to pull this air through this dryer. The air leaving the dryer will contain some dust particles which can be removed by using a cyclone separator between dryer fan.		
6-d	**Solubility:** It is the concentration of a solute in a saturated solution at a given temperature. **Saturated solution:** It is the solution which is in equilibrium with an excess of solid solute at given temperature. **Super saturated solution** : It is the solution which contains more solute than that in saturated solution **Different methods of obtaining 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.	1 1 1 1	4

6-e	**Vacuum crystallizer**  	2	4
	Working of vacuum crystallizer: The magma from the bottom of a cylindrical vessel goes to a pump via a down pipe and is pumped through a vertical tubular heater where it is heated by means of a condensing steam and finally a hot stream enters the cylindrical vessel tangentially just below the level of the magma surface. Flash evaporation of the solution takes place and produces rapid cooling, resulting into super saturation, which is the driving force for nucleation and growth. Fresh solution enters the down pipe just before the suction of the circulating pump and a suspension of crystals are continuously taken out from a discharged pipe located above the feed inlet in the down pipe. The suspension of crystal is fed to a centrifuge machine, the crystals are taken out as a product and the mother liquor is recycled to the down pipe with small part of it continuously bled. It is used for production of large crystal.	2	