Liquid–Liquid Extraction

5.1 Introduction.

The separation of the components of a liquid mixture by treatment with a solvent in which one or more of the desired components is preferentially soluble is known as liquid–liquid extraction—an operation which is used, for example, the separation of hydrocarbons in the petroleum industry and in chemical industries, such as separation of aromatics from kerosene-based fuel oils to improve their burning qualities and the separation of aromatics from paraffin and naphthenic compounds to improve the temperature-viscosity characteristics of lubricating oils. It may also be used to obtain relatively pure compounds such as benzene, toluene, and xylene from catalytically produced reformats in the oil industry and in the metallurgical and biotechnology industries.

In this operation, it is essential that the liquid-mixture feed and solvent are at least partially if not completely immiscible and, in essence, three stages are involved:

(a) Bringing the feed mixture and the solvent into intimate contact.

(b) Separation of the resulting two phases.

(c) Removal and recovery of the solvent from each phase.

It is possible to combine stages (a) and (b) into a single piece of equipment such as a column which is then operated continuously. Such an operation is known as differential contacting. Liquid–liquid extraction is also carried out in stagewise equipment, the prime example being a mixer-settler unit in which the main features are the mixing of the two liquid phases by agitation, followed by settling in a separate vessel by gravity. The extraction operation may be either a physical operation, or a chemical operation.

Extraction is in many ways complementary to distillation and is preferable in the following cases:

(a) Where distillation would require excessive amounts of heat, such as, for example, when the relative volatility is near unity.

(b) When the formation of azeotropes limits the degree of separation obtainable in distillation.

(c) When heating must be avoided.

(d) When the components to be separated are quite different in nature.

(e) When one of the components is present at such low concentration that distillation becomes not possible and economic.

*For high – molecular weight fatty acids can be separated from vegetable oils by extraction with liquid propane or by high vacuum distillation, which is more expensive.

5.2 Choice of Solvent.

1. Selectivity: the effectiveness of solvent B for separating a solution of A and C (desired components) is measured by comparing the ratio of C to A in the B-rich phase to that in A-rich phase at equilibrium. For all useful extraction operation, the selectivity must exceed unity, the more so that the better. If the selectivity is unity , no separation is possible.

2. Recoverability.

3. Density: the larger difference in densities of the saturated liquid phases I necessary.

4. Interfacial tension: should be high, due to more readily coalescence of emulsions will occur but the more difficult the dispersion of one liquid in the other will be.

5. Chemical reactivity: should be stable chemically and inert toward the other components of system and material of construction.

6. Viscosity, Vapor Pressure, Freezing Point: should be low for ease in handling and storage.

7. The solvent should be antitoxic, nonflammable and low cost.

5.3 Extraction Processes.

The three steps outlined in Section above 5.1, necessary in all liquid–liquid extraction operations, may be carried out either as a batch or as a continuous process. In the single-stage batch process illustrated in Figure 5.1, the solvent (B) and solution (A and C) are mixed together and two liquid layers formed which insoluble, then allowed to separate into the two phases-the extract E containing the required solute in the added solvent(rich-B) and the raffinate R, the weaker solution with some associated solvent(rich-A). With this simple arrangement mixing and separation occur in the same vessel. A continuous multistage such as two-stage operation is shown in Figure 5.2,

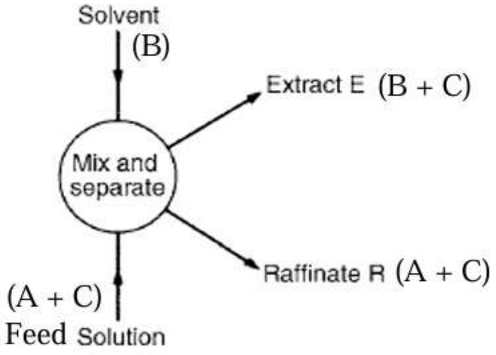


Figure 5.1. Single-stage batch extraction.

where the mixers and separators are shown as separate vessels. There are three main forms of equipment. First there is the mixer-settler as shown in Figure 5.1, secondly, there is the column type of design with trays or packing as in distillation and, thirdly, there are a variety of units incorporating rotating devices. In all cases, the extraction units are followed by distillation or a similar operation in order to recover the solvent and the solute. Some indication of the form of these alternative arrangements may be seen by considering two of the processes referred to in Section 5.1.

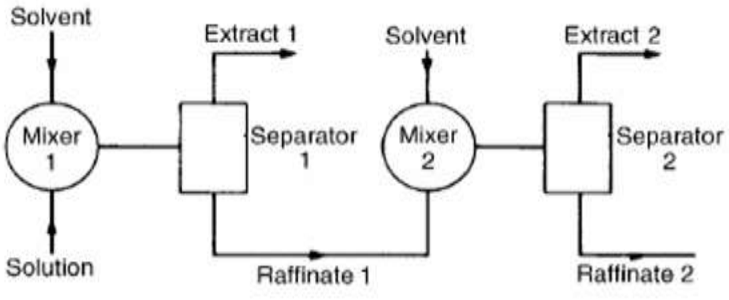


Figure 5.2. Multiple-contact system with fresh solvent.

5.4 Equilibrium Data.

Extraction involves the use of systems composed of at least three substances and although for the most part the insoluble phase are chemically very differently, generally all three components appear at least to some extent in both phases. The following notation scheme will be used to describe the concentrations and amounts of these ternary mixture, for purposes of discussing both material balance and equilibrium.

- A and B are pure, substantially insoluble liquids, and C is the distributed solute. Mixtures to be separated by extraction are composed of A and C, and B is the extracting solvent.

- Quantities are measured by mass foe batch operations, mass/time for continuous operation.

E = mass/ time , extract.
R = mass/ time , raffinate.
B = mass/ time , solvent.
E´ = mass B-free/ time .
x = weight fraction C in the solvent-lean(rich-A).
y = weight fraction C in the solvent-rich(rich-B).

$$x' = \frac{x}{1-x} = \frac{mass\ C}{mass\ non-C-in\ raffinate}$$

$$y' = \frac{y}{1-y} = \frac{mass\ C}{mass\ non-C-in\ extract}$$

$$X = \text{weight fraction C in raffinate on a B-free basis} = \frac{mass\ C}{mass\ A + mass\ C}$$

$$Y = \text{weight fraction C in extract on a B-free basis} = \frac{mass\ C}{mass\ A + mass\ C}$$

$$N = \text{weight fraction B on a B-free basis} = \frac{mass\ B}{mass\ A + mass\ C}$$

The addition of a new solvent to a binary mixture of a solute in a solvent may lead to the formation of several types of mixture:

(a) A homogeneous solution may be formed and the selected solvent is then unsuitable.

(b) The solvent may be completely immiscible with the initial solvent.

(c) The solvent may be partially miscible with the original solvent resulting in the formation of one pair of partially miscible liquids.

(d) The new solvent may lead to the formation of two or three partially miscible liquids.

With conditions of type (b), the equilibrium relation is conveniently shown by a plot of the concentration of solute in one phase against the concentration in the second phase. Conditions given by (c) and (d) are usually represented by triangular diagrams.

Equilibrium Data on Triangular Coordinate.

One pair of partially miscible liquids.

The system, acetone (C) - Water (A) - methyl isobutyl ketone (B), as shown in Figure 5.3a, is of type (c).

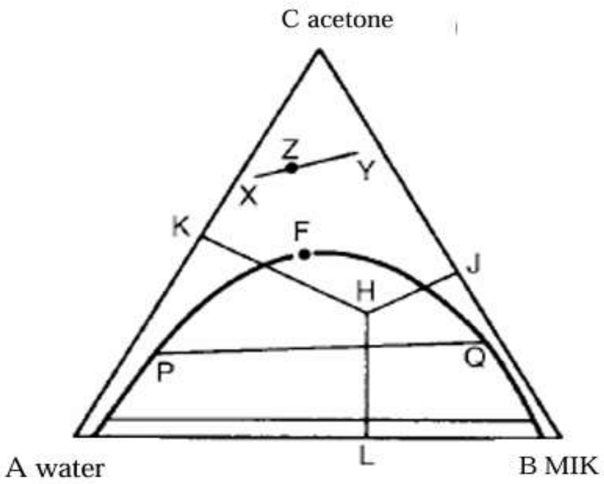


Figure 5.3a

Here the solute **C** is completely miscible with the two solvents **A** and **B**, although the two solvents are only partially miscible with each other. Each point inside the triangle represents the composition of a possible three-component mixture, a mixture indicated by point H consists of the three components A, B and C in the ratio of the perpendiculars HL, HJ, HK. A point at one of the three corners represents a pure component, while the normal distance between an interior point and the side opposite the corner for pure A represents the mole fraction or mass fraction of component A in the mixture. The distance HL represents the mass fraction Xc of C in the mixture at H, HJ represents X_B, HK represents X_A. Where $Xc + X_B + X_A = 1$

The area under the curved line NPFQM, the binodal solubility curve, represents a two-phase region which will split up into two layers in equilibrium with each other. These layers have compositions represented by points P and Q, and PQ is known as a “tie line”. Such lines, two of which are shown in the diagram, connect the compositions of two phases in equilibrium with each other, and these compositions must be found by practical measurement. There is one point on the binodal curve at F which represents a single phase that does not split into two phases. F is known as a ***plait point***, and this must also be found by experimental measurement. The plait point is fixed if either the temperature or the pressure is fixed.

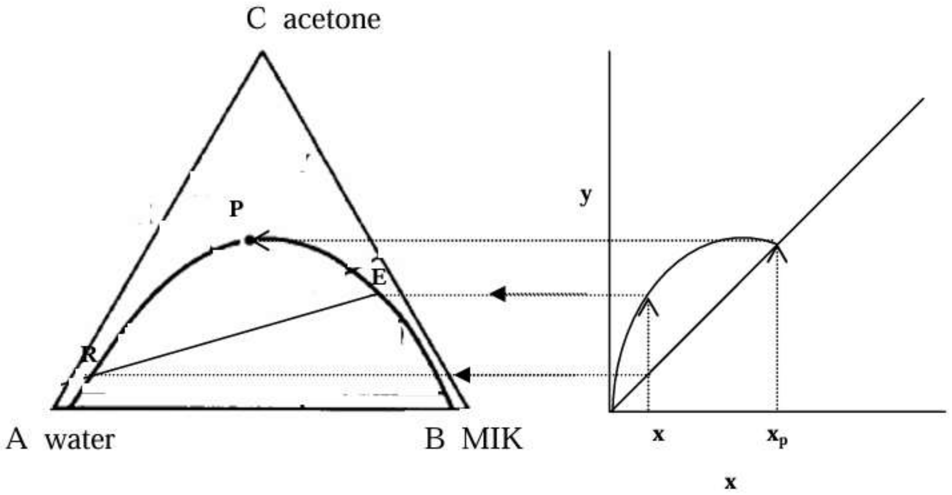


Figure 5.3b

Two or three partially miscible liquids.

In Figure 5.4 the two-phase regions merge on varying the temperature. Aniline (**A**), water (**B**), and phenol (**C**) represent a system of the latter type. Under the conditions shown in Figures 5.4, **B** and **C** are miscible in all proportions, although **B** and **A**, and **A** and **C** are only partially miscible. Figure 5.4 show equilibrium relationship for the aniline–water–phenol at high temperature.

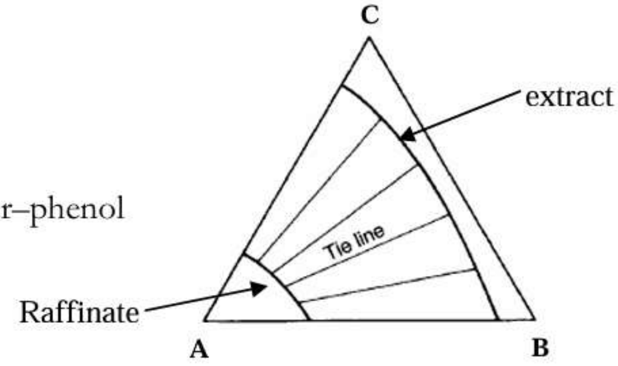


Figure 5.4
relationship for the aniline–water–phenol

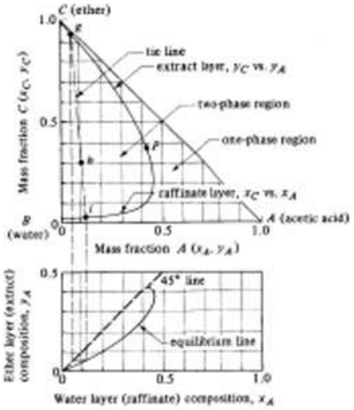
Equilibrium Data on Rectangular Coordinate.

In some system equilateral triangular coordinates have some disadvantage, therefore special cases a more useful method for plotting the three component data using rectangular coordinate as in acetic acid(A)-water(B)-isopropyl ether(C) as shown in Figure 5.5.

The solvent pair B and C partially miscible.
The concentration of component C is plotted in a vertical axis and A in a horizontal axis, while the concentration of B can be obtained as:-

$$X_B = 1 - X_A - X_C$$
$$Y_B = 1 - Y_A - Y_C$$

The line gi is called the tie line, I represent the water Rich layer(raffinate)and j is the solvent rich layer (isopropyl ether).The te line also drawn by distribution Diagram y vs. x plotted below the phase diagram.



- ❖ The system another rectangular system can be plotted on a B-free basis using x , y diagram .The equilibrium data (solubility data) in extraction ,these coordinate are plotted on a B-free basis (solvent free basis).These coordinate are represented by , x , y, N, where x is A rich , y is B rich and N is the B concentration on a B-free basis as shown on Figure 5.5.

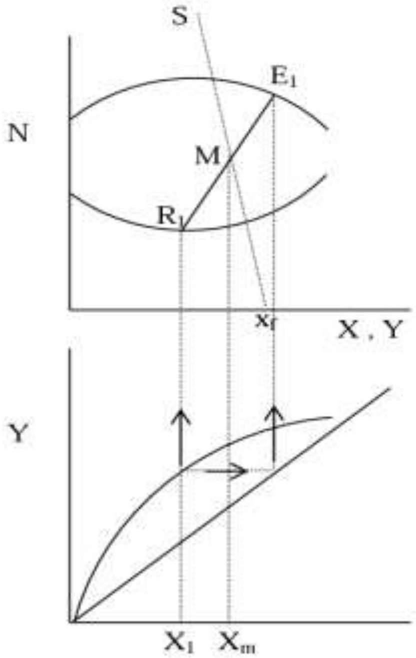


Figure 5.5

5.5 Calculation of the Number of Theoretical Stages.

5.5.1. Co-current contact with partially miscible solvents (Single stage).

Extraction equipment of stage-wise type can be carried out according to

- a- The nature of the system.
- b- The extent of separation.

It is to be understood that the effluent extract and raffinate solutions are in equilibrium with each other. Each stage must include facilities for contacting the insoluble liquids and separating product streams. A combination of a mixer and a settler may therefore constitute a stage. This may be batch or continuous operation.

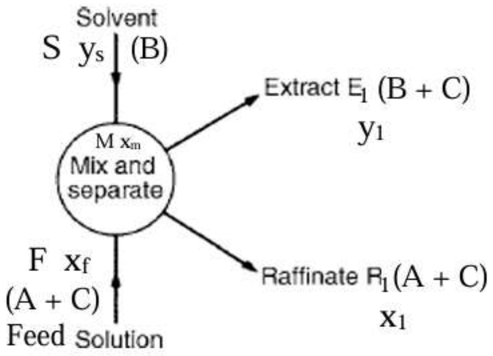


Figure: 5.6

F - mass of feed (batch) or mass of feed/time(continuous) .It contain substances(A+C) at x_f weight fraction C.
S – mass of solvent (batch) or mass of solvent/time (continuous) . The main constituent of this stream is B , containing y_s weight fraction.

R_1 – mass of raffinate (batch) or mass of raffinate/time (continuous) ,x_1 is the mass fraction of C in raffinate.

E_1 – mass of extract (batch) or mass of extract /time (continuous) ,y_1 is the mass fraction of C in extract.

- Adding **S** and **F** produces in the extraction stage a mixture **M_1** which on settling forms the equilibrium phases **E_1** and **R_1** joined by the tie line through **M_1.**
- If the solvent is pure B(y_s=0), it will be plotted at the B apex, but sometimes it has been recovered from a previous extraction and therefore contain a little A and C as well ($y_s \neq 0$).

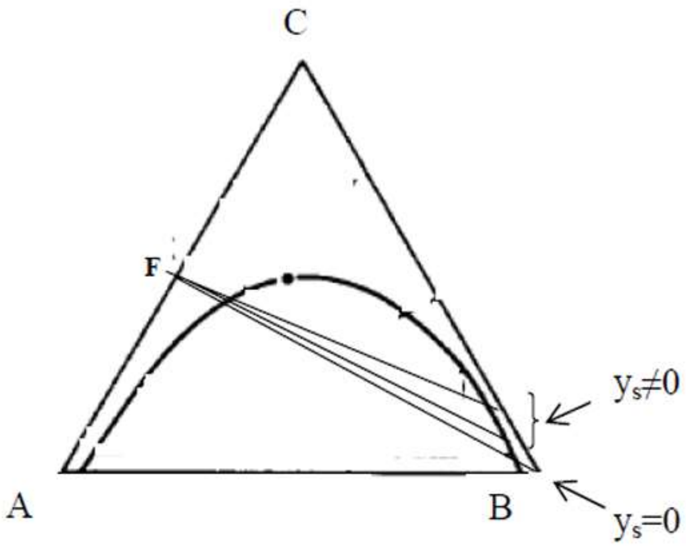


Figure: 5.7

- **Material Balance.**
  - **Total material balance**

$F + S = M_1 = E_1 + R_1$...(1)

M_1 is located on the FS line.

- **C-balance.**

$F\,x_f + S\,y_s = M_1\,x_{m1} = E_1\,y_1 + R_1\,x_1$ .... (2)

x_{m1} is the mass fraction of C in the mixture.

$$x_{m_1} = \frac{F\,x_f + S\,y_s}{F + S} \quad \text{...(3)}$$

The amount of solvent to provide a location for **M_1** on the line **FS** can be complete

$F\,x_f + S\,y_s = M_1\,x_{m1}$ .. .. (4)

$F + S = M_1$ .... sub in (4); then: -

$$\frac{S}{F} = \frac{x_f - x_{m_1}}{x_{m_1} - y_s} \quad \text{(5a)}$$

For pure solvent S=B, y_s=0…then equation(5a) become: -

$$\frac{S}{F} = \frac{x_f - x_{m_1}}{x_{m_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5b)$$

The quantities of extract and raffinate:-

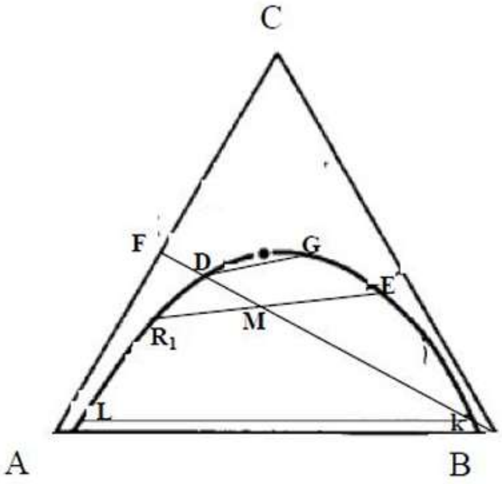
$$\mathbf{E_1 + R_1 = M_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6a)$$

$$\mathbf{E_1\, y_1 + R_1\, x_1 = M_1\, x_{m1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6b)$$

From equations 6a and 6b **E_1** and **R_1** can be estimated as:-

$$E_1 = \frac{M_1\left(x_{m_1} - x_1\right)}{y_1 - x_1} \ldots\ldots\ldots\ldots\ldots\ldots (7a) \quad , \quad R_1 = \frac{M_1\left(x_{m_1} - y_1\right)}{x_1 - y_1} \ldots\ldots\ldots\ldots\ldots (7b)$$

Since two insoluble phases must form for an extraction operation, point M1 must lie within the heterogeneous liquid area, as shown:



The minimum amount of solvent is found by locating **M_1** at **D**, which would then provide an infinitesimal amount of extract at **G** the maximum amount of solvent is found by locating **M_1** at k, which provides an infinitesimal amount of raffinate at **L**. Point L represents the raffinate with lowest possible **C** concentration, and if a lower value were required, the record solvent **S** should to have lower concentration.

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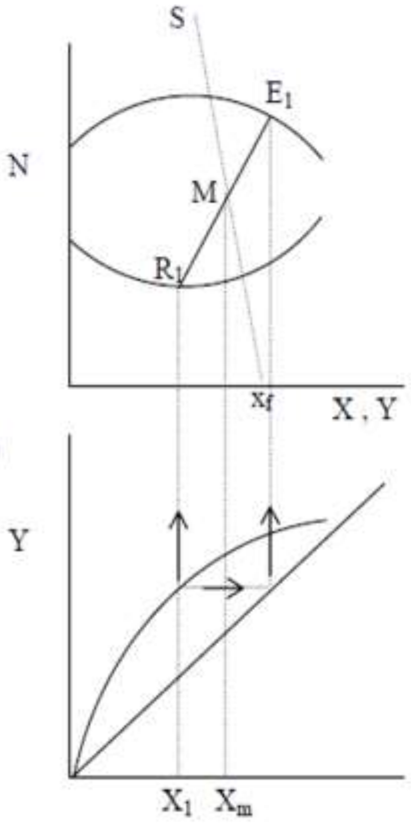
- All the computation can be made on a B-free basis(see figure(5.5)) as follows:-
  Locate **F** and s point ,join **FS** line ,if the solvent **S** is pure **B** ,its **N** value is infinite and the line **FS** is then vertical. The product E_1 and R_1 lie on a lie line through M_1 represents the entire mixture in the extractor.



- Material Balance(B-Free basis).

  $$F' + S' = M'_1 = E'_1 + R'_1 \ldots\ldots(8)$$

  The feed is normally free of **B** and **F = F´**

- **C-Balance.**

  $$F' X_f + S' Y_s = M'_1 X_{m1} = E'_1 Y_1 + R'_1 X_1 \ldots(9)$$

- **B-Balance.**

  $$F' N_f + S' N_s = M'_1 N_{m1} = E'_1 N_{E1} + R'_1 N_{R1} \ldots(10)$$

  Since the feed no contain **B** , $N_f = 0$.

From equations 8,9,and10 ;**E´1** and **R´1** can be estimated as :-

$$E'_1 = \frac{M'_1(X_{m_1} - X_1)}{Y_1 - X_1} \ldots\ldots(11a)$$

$$R'_1 = \frac{M'_1(X_{m_1} - Y_1)}{X_1 - Y_1} \ldots\ldots(11b)$$

$$\frac{R'_1}{E'_1} = \frac{Y_1 - X_{m_1}}{X_{m_1} - X_1} \ldots\ldots(12)$$

The total weight of the saturated extract and raffinate are :-

$$E_1 = E'_1(1 + N_{E1}) \ldots\ldots(13a)$$

$$R_1 = R'_1(1 + N_{R1}) \ldots\ldots(13b)$$

5.5.2. Multistage Cross-current contact with partially miscible solvents.

This is an extension of single-stage extraction wherein the raffinate is successively contacted with fresh solvent, and may be done continuously or in batch.

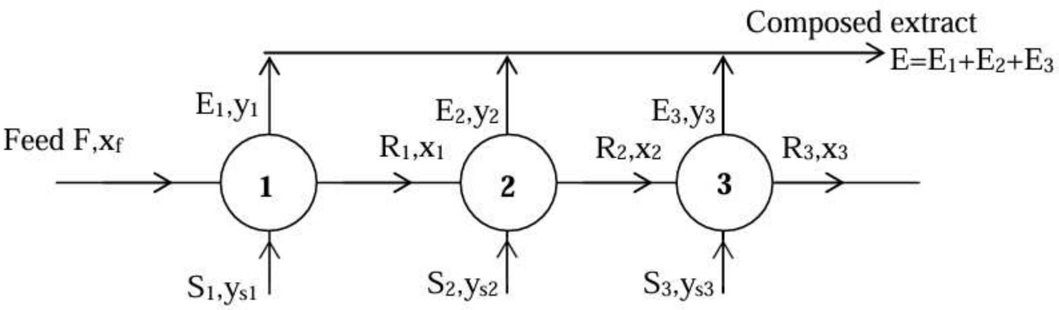


Figure 5.8

Material balance for each stage:-

$\mathbf{F + S_1 = M_1 = E_1 + R_1}$ .... (14)

$\mathbf{R_1 + S_2 = M_2 = E_2 + R_2}$ .... (15)

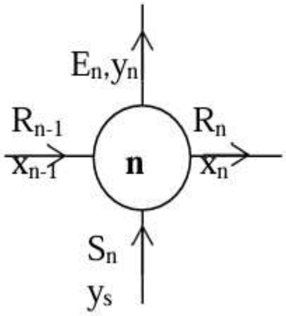
$\mathbf{R_2 + S_3 = M_3 = E_3 + R_3}$ .... (16)

Composed extract $E = \mathbf{E_1 + E_2 + E_3}$ .... (17)

For n stage:-

Total material balance.

$\mathbf{R_{n\text{-}1} + S_n = M_n = E_n + R_n}$...(18)



C – balance.

$\mathbf{R_{n\text{-}1}\, x_{n\text{-}1} + S_n\, y_s = M_n\, x_{mn} = E_n\, y_n + R_n\, x_n}$ .... (19)

For solvent free coordinates:

- A+C balance

$\mathbf{R'_{n\text{-}1} + S'_n = M'_n = E'_n + R'_n}$ .... *

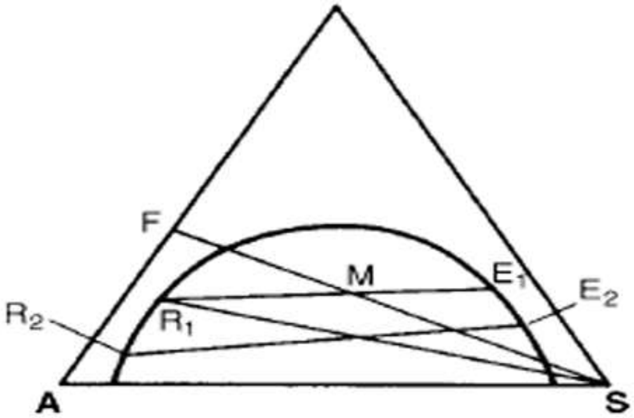
C – balance.

$$R'_{n-1}\,X_{n-1} + S'_n\,Y_s = M'_n\,X_{mn} = E'_n\,Y_n + R'_n\,X_n \;\ldots\ldots\ldots\ldots\; {**}$$

B – balance.

$$R'_{n-1}\,N_{n-1} + S'_n\,N_s = M'_n\,N_{mn} = E'_n\,N_{En} + R'_n\,N_{Rn} \ldots (20)$$

Unequal amount of solvent can be used in various stages , and even different temperatures in which case each stage must be computed with the help of a phase diagram at the appropriate concentration , the greater the number of stages the less total solvent will be used.

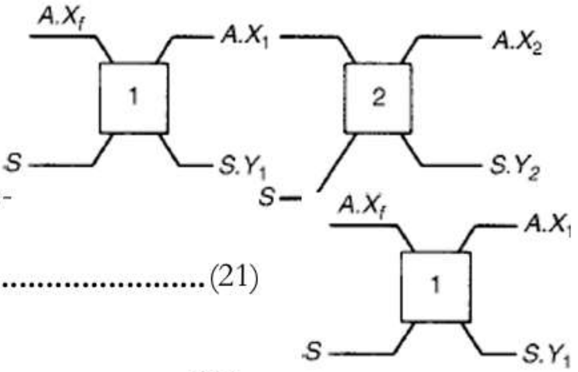


5.5.3. Co-current contact with immiscible solvents.

When the extraction solvent and the feed solution are, insoluble and remain so at all concentrations of the distributed solute occurring in the operation. For this purpose, the equilibrium concentrations are plotted as x´ (x/(1-x)) vs. y´(y/(1-y)).

Since the liquids, A and B are in soluble, there are A kg of this substance in all raffinate. Similarly, the extract from each stage contain all the solvent B fed to that stage.

Figure 5.9. For completely insoluble liquid



A solute C-balance about any stage n :-

$$A\,x'_{n-1} + B_n\,y'_s = B_n\,y'_n + A\,x'_n \qquad \text{.............................}(21)$$

$$A\,(x'_{n-1} - x'_n) = B_n\,(y'_n - y'_s)$$

$$-\frac{A}{B_n} = \frac{y'_s - y'_n}{x'_{n-1} - x'_n} \qquad \text{..............................}(22)$$

This is the operating lie equation for stage n of slope –A/B$_n$, passing through points (x'_{n-1}, y'_s) and (y'_n, x'_n). The concentration for a three stage extraction is shown in figure 5.10, where for each stage a line is drawn of slope appropriate to that stage. Each operation line intersects the equilibrium curve at the raffinate and extract compositions.

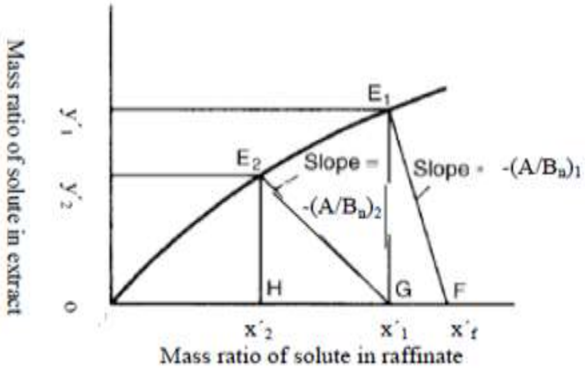


Figure 5.10

This process may be illustrated by allowing the point F to represent the feed solution and drawing a line FE_1, of slope $-(A/B_{n)1}$, to cut the equilibrium curve at E_1. This then gives composition y'_1 of the extract and x'_1 of the raffinate. If a further stage is then carried out by the addition of solvent S to the stream A x'_1, then point E_2 is found on the equilibrium curve by drawing GE_2 of slope $-(A/B_n)_2$. Point E_2 then gives the compositions x'_2 and y'_2 of the final extract and raffinate. This system may be used for any number of stages, with any assumed variation in the proportion of composed extract.

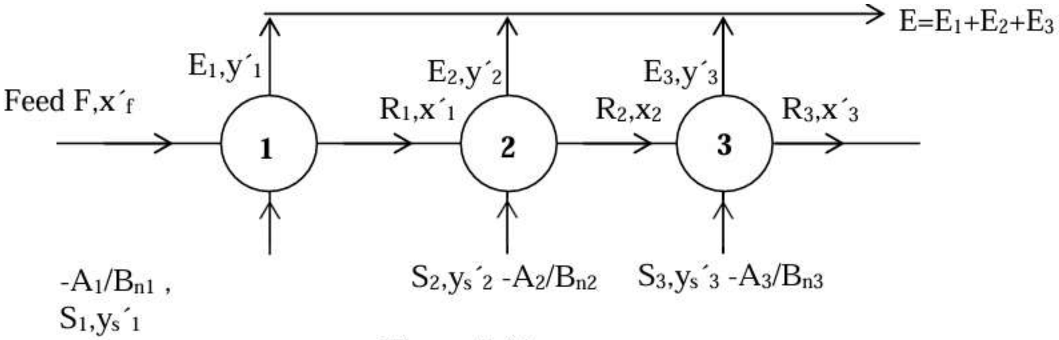


Figure 5.11

If the equilibrium data is a **straight line** (y' vs. x') , to find the number of stages required for separation as :-

1- The equilibrium data is given as $y' = m\ x'$.

2- Make material balance to find the operating line is similar to the condition of equilibrium curve.

C-balance on stage 1

$$\mathbf{A\ x'_f + B_n\ y'_s = B_n\ y'_1 + A\ x'_1} \text{ ....} (23)$$

For pure solvent $y'_s = 0$ $\mathbf{y'_{E1} = m\ x'_{R1}}$ ....(24a)

or $\mathbf{y'_1 = m\ x'_1}$ .... (24b)

where **m** is the slope of equilibrium line; sub equation24b in equation 23:-

$\mathbf{A\ x'_f = B_n\ m\ x'_1 + A\ x'_1}$............ for pure solvent($y'_s = 0$)

$$\mathbf{= x'_1(m\ B_n + A)}$$

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$$x'_1 = \frac{A x'_f}{A + mB_n} \quad \ldots\ldots(25)$$

For second stage equation 25 become:-

$$x'_2 = \left(\frac{A}{A + mB_n}\right) x'_1 \quad \ldots\ldots(26)$$

For nth stage equation 26 become:-

$$x'_n = \left(\frac{A}{A + mB_n}\right)^n x'_f \quad \ldots\ldots(27)$$

Or $$x'_n = \left(\frac{A}{A + mB_n}\right) x'_{n-1} \quad \ldots\ldots(28)$$

The number of ideal stages :-

$$n = \frac{Log\left(\frac{x'_n}{x'_f}\right)}{Log\left(\frac{A}{A + mB_n}\right)} \quad \ldots\ldots(29)$$

Equation 29 is used when equilibrium data is straight line and not a curve.

5.5.4. Countercurrent contact with partially miscible solvents.

If a series of mixing and separating vessels is arranged so that the flow is countercurrent, then the conditions of flow may be represented as shown in Figure 5.12, where each circle corresponds to a mixer and a separator. The initial solution **F** is fed to the first unit and leaves as raffinate **R_1**. This stream passes through the units and leaves from the ***nth*** unit as stream **R_n**. The fresh solvent **S** enters the nth unit and passes in the reverse direction through the units, leaving as extract **E_1**.

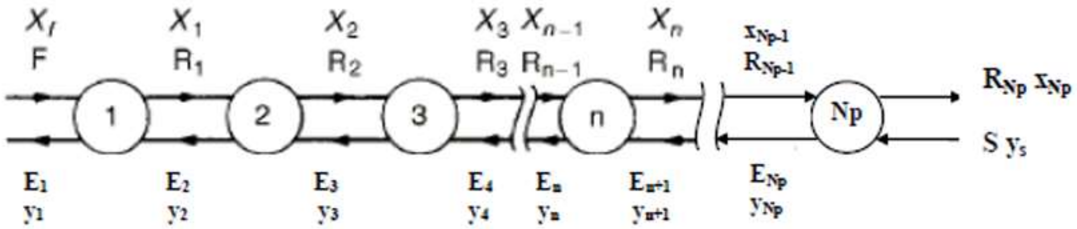

Figure 5.12 Multi-stage counter-current operation.

For a given degree of separation, this type of operation requires fewer stages for a given amount of solvent or less solvent for a fixed number of stages, than the cross-current operation.

A material balance for the entire plant: -

$$\mathbf{F + S = E_1 + R_{Np} = M} \quad \text{.......}(30)$$

C-balance: -

$$\mathbf{F\,x_f + S\,y_s = E_1\,y_1 + R_{Np}\,x_{Np} = M\,x_m} \quad \text{.......}(31)$$

From equations 30 and 31 , get:-

$$x_m = \frac{Fx_f + Sy_s}{M} = \frac{Fx_f + Sy_s}{F + S} \quad \text{.......}(32)$$

Rearrangement equation30 provides: -

$$\mathbf{R_{Np} - S = F - E_1 = \Delta_R} \quad \text{.......}(33)$$

A material balance for any stage n through N_p :-

$$\mathbf{R_{n-1} + S = E_n + R_{Np}} \quad \text{.......}(34)$$

$$\mathbf{R_{n-1}\,x_{n-1} + S\,y_s = E_n\,y_n + R_{Np}\,x_{Np}} \quad \text{.......}(35)$$

$$\mathbf{R_{Np} - S = R_{n-1} - E_n = \Delta_R} \quad \text{.......}(36)$$

Where Δ_R, difference point and is equal to the net flow outward at the least stage N_p, for nth stage the difference in quantity between the raffinate leaving a stage R_N, and the extract entering from next stage E_{n+1}, is constant. Similarly, it can be shown that the difference between the amounts of each component in the raffinate and the extract streams is constant. This means that, with the notation of a triangular diagram, lines joining any two points representing R_n and E_{n+1} pass through a common pole. Equation 30 shows that F, S, M lie on a straight line and also the points E_1, R_{Np}, M. Thus, the point of intersection of line FS and E_1R_{Np} is the point M. Equation 33 shows that ΔR is the meeting point of line F E_1, $R_{Np}S$.

In general, the difference in flow rates at a location between any two adjacent stages is constant, Δ_R, line E_nR_{n-1} extended must therefore pass through Δ_R (lie on a straight line).

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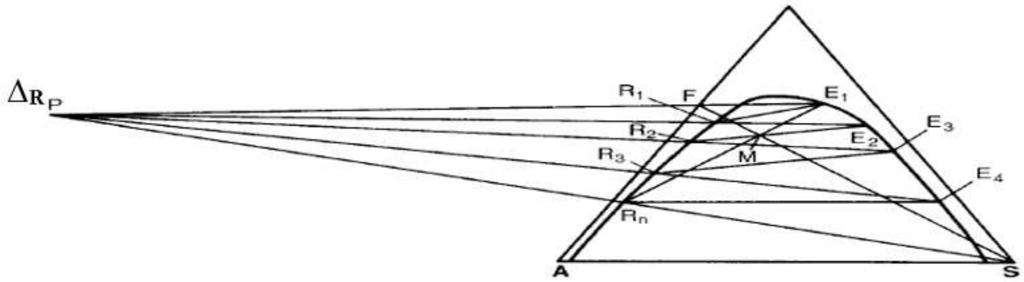
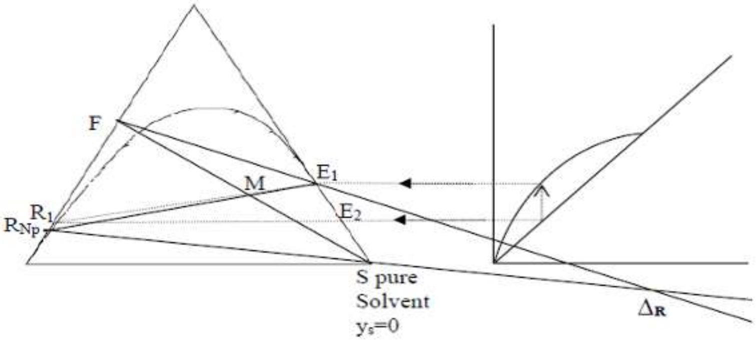
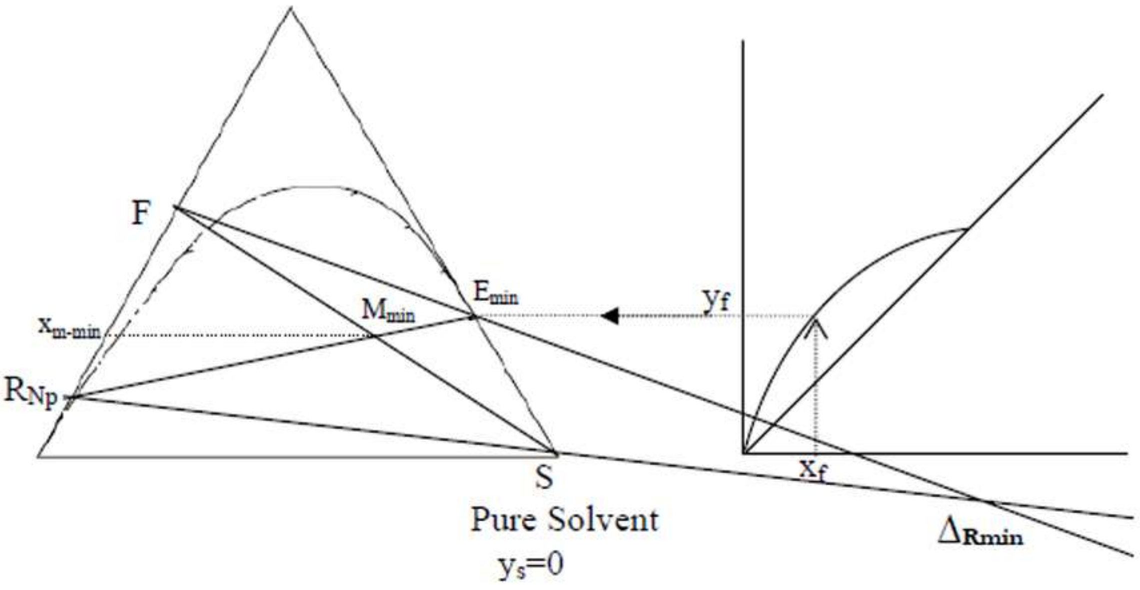




The point **F** at **xf** and **S** at ys are located, point **M** is located on **FS** line at fraction **xm**. $\mathbf{R_{Np}}$ lies on the solubility curve (binodial curve) at mass fraction $\mathbf{x_{Np}}$. The line $\mathbf{R_{Np}M}$ is extended to meet the solubility curve at $\mathbf{E_1}$. The line joining **F** and $\mathbf{E_1}$ and the line joining $\mathbf{R_{Np}}$ and **S** meet at the $\Delta_\mathbf{R}$ point as is evident from equation 33. since $\mathbf{R_1}$ and $\mathbf{E_1}$ leave the stage in equilibrium, these must be the ends of a tie line. Point $\mathbf{E_2}$ is fixed. From the tie line data $\mathbf{x_1}$ corresponding to y1 is found and the point $\mathbf{R_1}$ located on the solubility curve at mass fraction $\mathbf{x_1}$. Equation 33 shows that $\Delta_\mathbf{R}$, $\mathbf{R_1}$ and $\mathbf{E_2}$ lie on a straight line. The line $\Delta_\mathbf{R}$ is extended to meet the solubility curve at $\mathbf{E_2}$. $\mathbf{R_2E_2}$ is a tie line. Corresponding to $\mathbf{y_2}$, $\mathbf{x_2}$ is found from the tie line data, and the point $\mathbf{R_2}$ located on the solubility curve. the line $\Delta_\mathbf{R}$ is now extended to meet the solubility curve at $\mathbf{E_3}$. The procedure is repeated till the tie line passes thought point $\mathbf{R_{Np}}$ or cross it, then determine the number of ideal stages required for separation.

Minimum Solvent Required.

Minimum solvent required for the specified product can be determined by locating the $\Delta_\mathbf{Rmin}$ point for minimum solvent. After locating **S** at $\mathbf{y_s}$, **F** at $\mathbf{x_f}$, $\mathbf{R_{Np}}$ at $\mathbf{x_{Np}}$, the equilibrium composition $\mathbf{y_f}$ at the feed condition, locate on the solubility curve ($\mathbf{E_{min}}$) from the distribution curve. The line $\mathbf{E_{min}}$ **F** is extended to line **S** $\mathbf{R_{Np}}$, to give intersections with line **S** $\mathbf{R_{Np}}$ in $\Delta\mathbf{R_{min}}$ as shown in figure below. The intersection farthest from **S** (if Δ point is on the left side of the diagram) or nearest **S** (if Δ point is on the right side of the diagram).



The minimum(xm-min) is located by joining (**R_{Np}**, **E_{min}**) and (**F**, **S**), the point of intersection is **M_{min}**, then **S_{min}** is calculated: -

$$F + S_{min} = M_{min} \qquad (37)$$

$$F\,x_f + S_{min}\,y_s = M_{min}\,x_{m\text{-}min} \qquad (38)$$

$$x_{m_{min}} = \frac{Fx_f + Sy_s}{F + S_{min}} \; or \; \frac{Fx_f}{F + S_{min}} \; (for\ pure\ solvent) \qquad (39)$$

5.5.5. Countercurrent contact with immiscible solvents.

When the liquid **A** and **B** are insoluble over the range of solute concentrations encountered, the stage computation is made more simply on **x´**, **y´** coordinates. For this case, the solvent content of all extracts and the **A** content of all raffinate are constant.

For the 1st stage: $A\,x'_f + B_n\,y'_2 = A\,x'_1 + B_n\,y'_1$

For the nth stage: $A\,x'_{n-1} + B_n\,y'_{n+1} = A\,x'_n + B_n\,y'_n$

For the whole unit: $A\,x'_f + B_n\,y'_s = A\,x'_{Np} + B_n\,y'_1$ .... (40).

$$\frac{A}{B_n} = \frac{(y'_1 - y'_s)}{(x'_f - x'_{Np})} \quad \text{...(41)}$$

Equation 40 is the operating line of slope (**A/B_n**), which passes through the points (x'_f, y'_1) and (x'_{Np}, y'_s). In Figure 5.13, the equilibrium relation, y'_n against y'_n, and the operating line are drawn in, and the number of stages required to pass from x'_f to x'_{Np} is found by drawing in steps between the operating line and the equilibrium curve. In this example of Figure 5.13, four stages are required, and (x'_{Np}, y'_s) corresponds to (x'_4, y'_5). It may be noted that the operating line connects the compositions of the raffinate stream leaving and the fresh solvent stream entering a unit, x'_{Np} and y'_s, respectively.

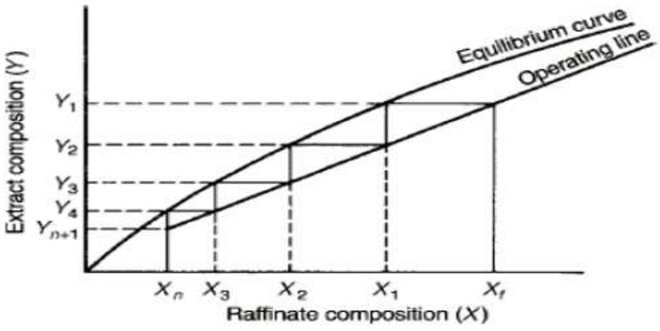


Figure5.13

Similarly equation 41 can be written for stage through n as :-

$$\frac{A}{B_n} = \frac{(y'_1 - y'_{n+1})}{(x'_f - x'_n)} \quad \text{..................................(42)}$$

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