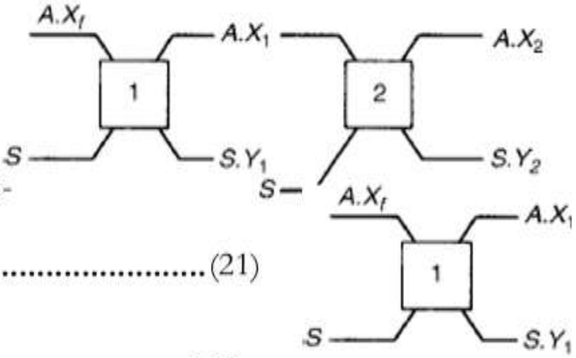
Co-current contact with immiscible solvents

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 :-

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

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

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

This is the operating lie equation for stage n of slope –A/Bn, 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.

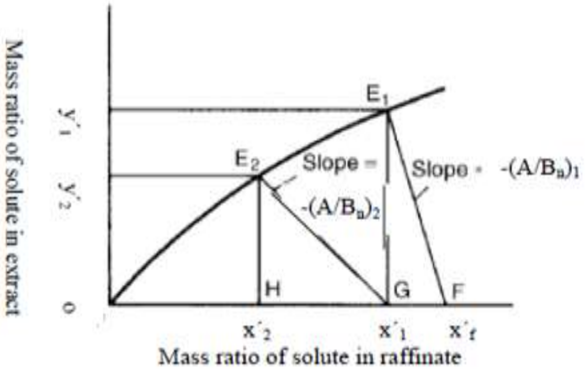


Figure 5.10

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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.

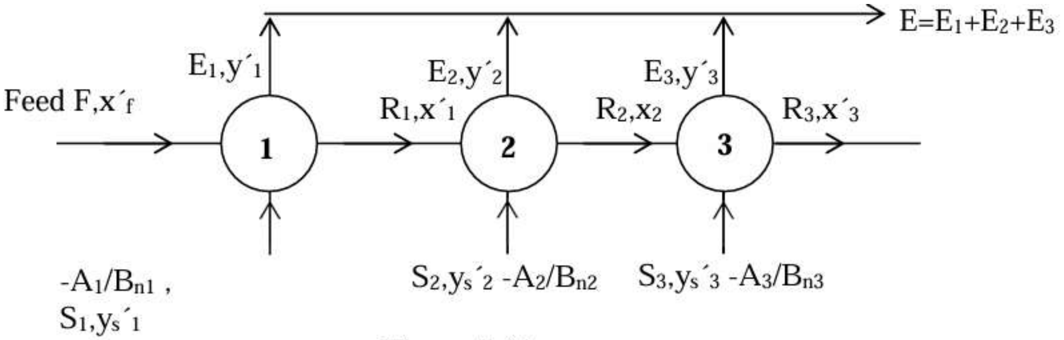

Figure 5.11

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

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

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

For second stage equation 25 become:-

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

For nth stage equation 26 become:-

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

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

The number of ideal stages :-

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

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**.

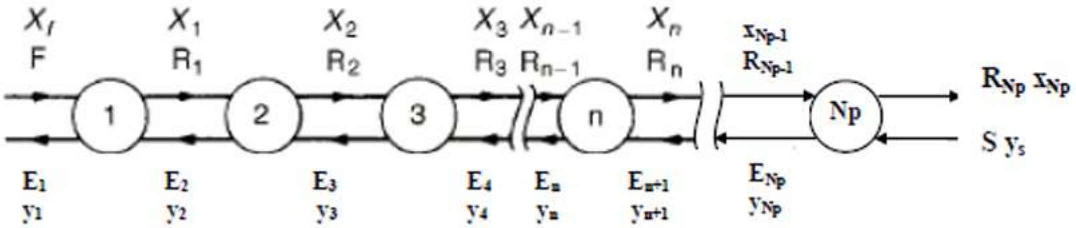


Figure 5.12 Multi-stage counter-current operation.

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: -

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

C-balance: -

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

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: -

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

A material balance for any stage n through N_p :-

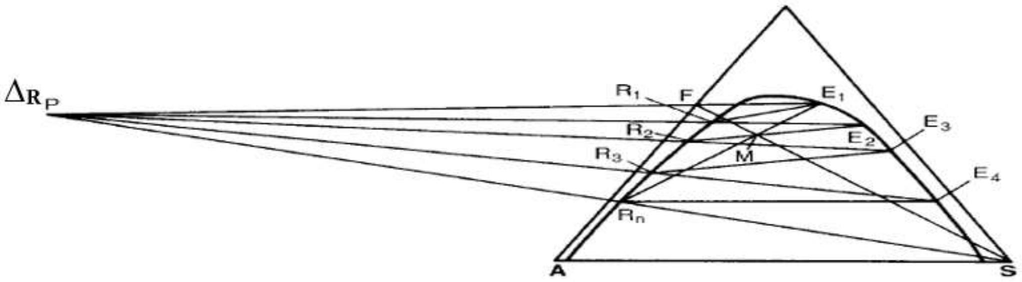
$$R_{n-1} + S = E_n + R_{Np} \quad \text{.........} (34)$$

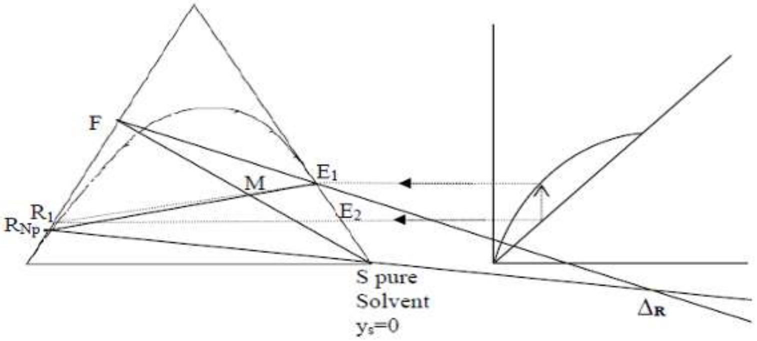
$$R_{n-1} x_{n-1} + S y_s = E_n y_n + R_{Np} x_{Np} \quad \text{.........} (35)$$

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

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).





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).

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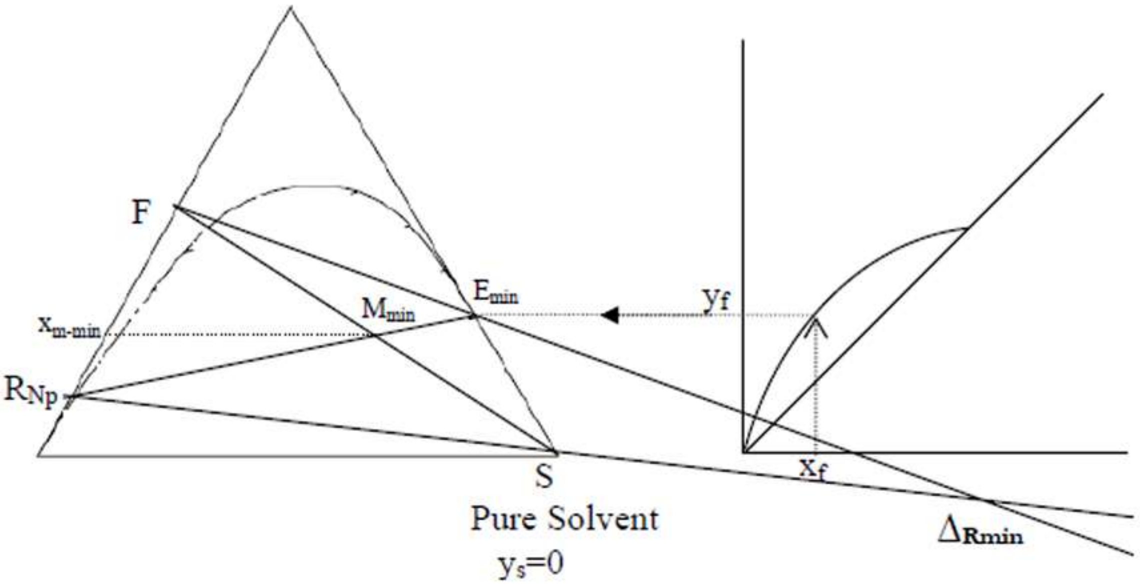

The minimum(xm-min) is located by joining (**R_{Np}**, **E_{min}**) and (**F**, **S**), the point of intersection is **M_{min}**, then **S_{min}** is calculated: -

$$F + S_{min} = M_{min} \quad \text{.........(37)}$$

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

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

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: $\mathbf{A\,x'_f + B_n\,y'_2 = A\,x'_1 + B_n\,y'_1}$

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

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

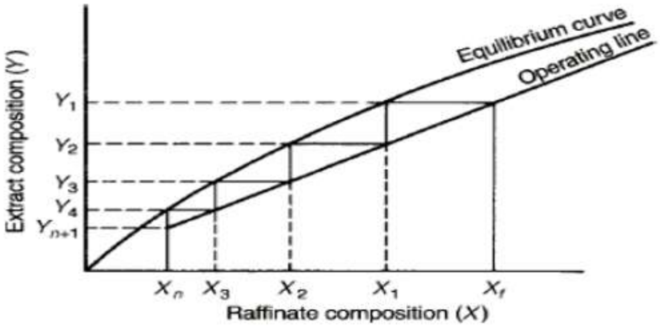

Figure5.13

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

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