# الجامعة التكنولوجية

## قسم الهندسة الكيمياوية

## المرحلة الثالثة

# انتقال كتلة

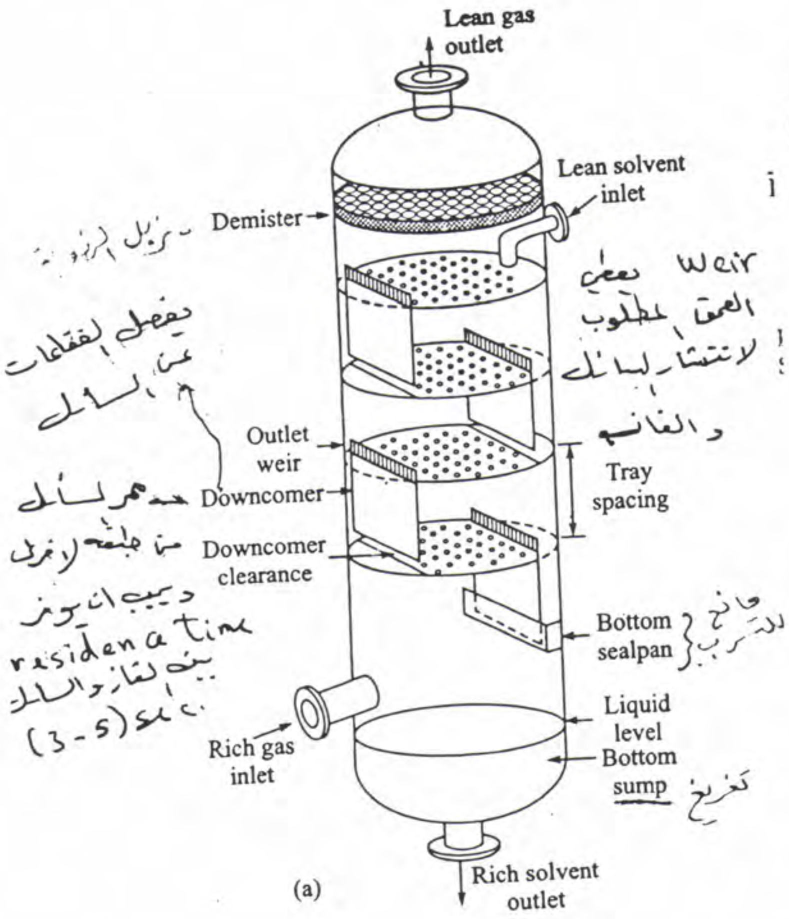
**أ.م. د. عامر عزيز**

# - Tray or Plate Columns -

A tray column primarily consists of a vertical cylindrical shell and a set of "tower internals" that include:

1- Tray or plates on which the gas-liquid contact occurs.
2- Arrangements for flow of the liquid from one tray to the lower one through the down-comer.
3- Inlet and outlet nozzels for the two phases.

Figure below shows a few essential parts of a (sieve-tray) column.



## The Trays:- (Plate)

A tray has two major functions:

① It allows the gas to flow through the holes, the gas bubbles through the liquid to form "gas-liquid dispersion", the tray holds the dispers$^n$. on it.

② The tray seperate the column into a number of campartment, each of which constitutes a stage. M.T. between the phases occurs on a tray. Therefore trays as a whole constitute the "heart of a column". The performance of a column depends upon the performance of the trays.

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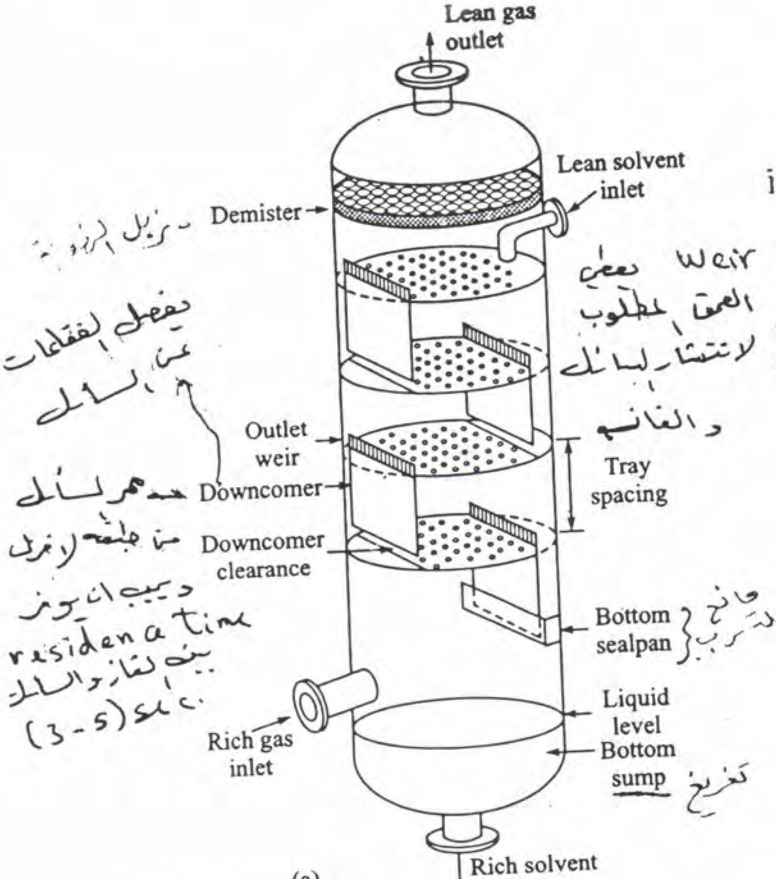

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The Types of trays :- ① Bubble - Cap tray.
② Sieve - Tray. ③ Valve - Tray.

## Stage :-

Any device or combination of devices in which two immicible phases are brough into contact in order to achieve mass transfer of one or more solute from one phase to other is called "Stage".
An efficient contact of the phases in a stage tends to bring them to equil^m. If the contacting is so efficient that the phases reach equil^m when they leave, the stage is called an "ideal stage".
The stage efficiency gives a measure of how close to equil^m the phases may reach in a stage.
An ideal stage has 100% efficiency.

## Difference between Packed and Plate Colums

1- Plate col. provide more positive contact between the two fluid phases by repeated mixing and separation. whereas packed col. may be subject to by-passing or back-mixing.
2- Plate col. can handle greater liquid loads without flooding.
3- " " are more easily cleaned.
4- Packed col. give lower press. drop for gas flow, which is of particular importance in vacc. operations.
5- liquid hold-up is less in packed col.
6- Packed col. may be more economical in processing.
7- Small diameter packed col. are usually cheaper than plate col. of the same size.

# Types of Dispersion

① Spary

سرعة غاز عالية
وسائل واطئة
فيصبح عندنا
سائل dispersion
غاز continuous

② Froth

سرعة سائل عالية
نسبياً فيصبح حدوث
للغاز Spary ولكنها
ليست كافية لحدوث
emulsion
للفقاعات

③ Emulsion

سرعة سائل عالية
والغاز سرعته قليلة
وبالتالي فقاعات الغاز
ستبقى عالقة في السائل

## Overall M.B :-

$$G_s * Y_{N+1} + L_s X_0 = G_s * Y_1 + L_s X_N$$

$$\boxed{G_s * Y_{N+1} + L_s * X_0 = G_s Y_T + L_s X_N}$$

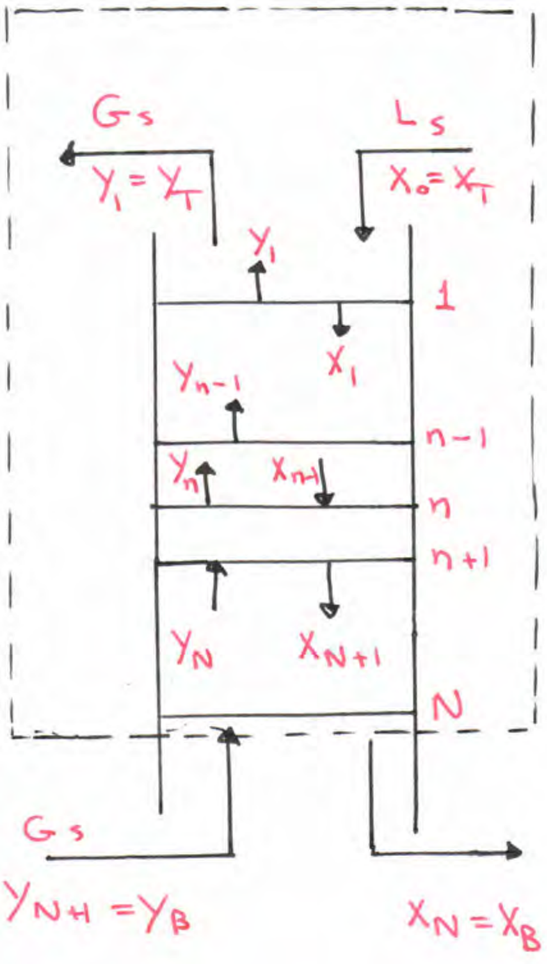
or

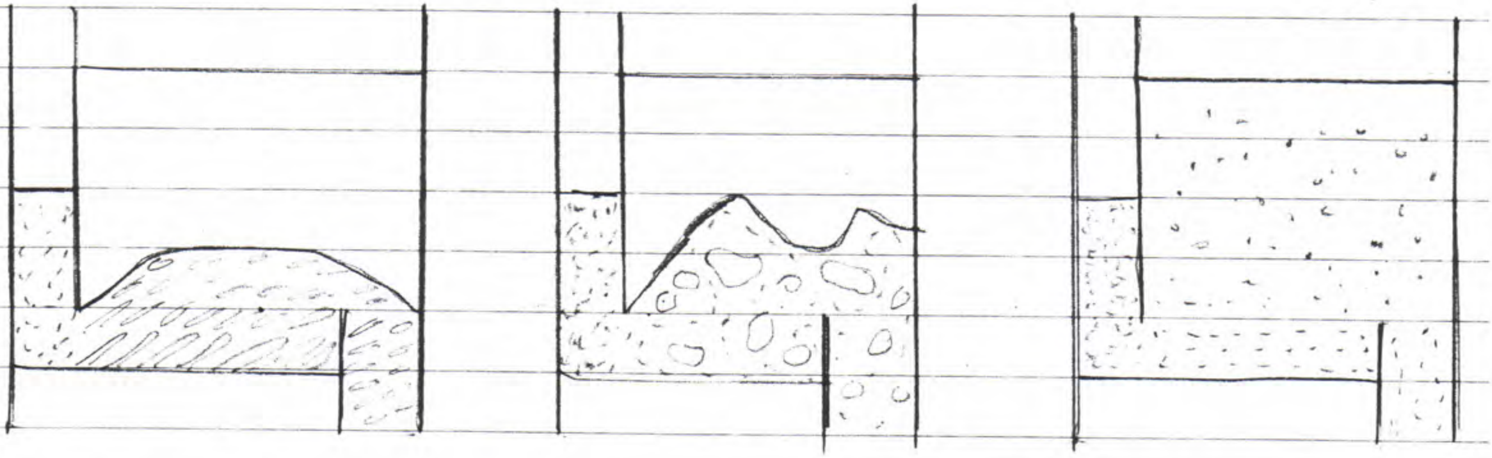
$$\boxed{G_s * Y_B + L_s * X_T = G_s Y_T + L_s X_B}$$

$$G_s(Y_B - Y_T) = L_s(X_B - X_T)$$

$$\boxed{\frac{L_s}{G_s} = \frac{(Y_B - Y_T)}{(X_B - X_T)}}$$ operating

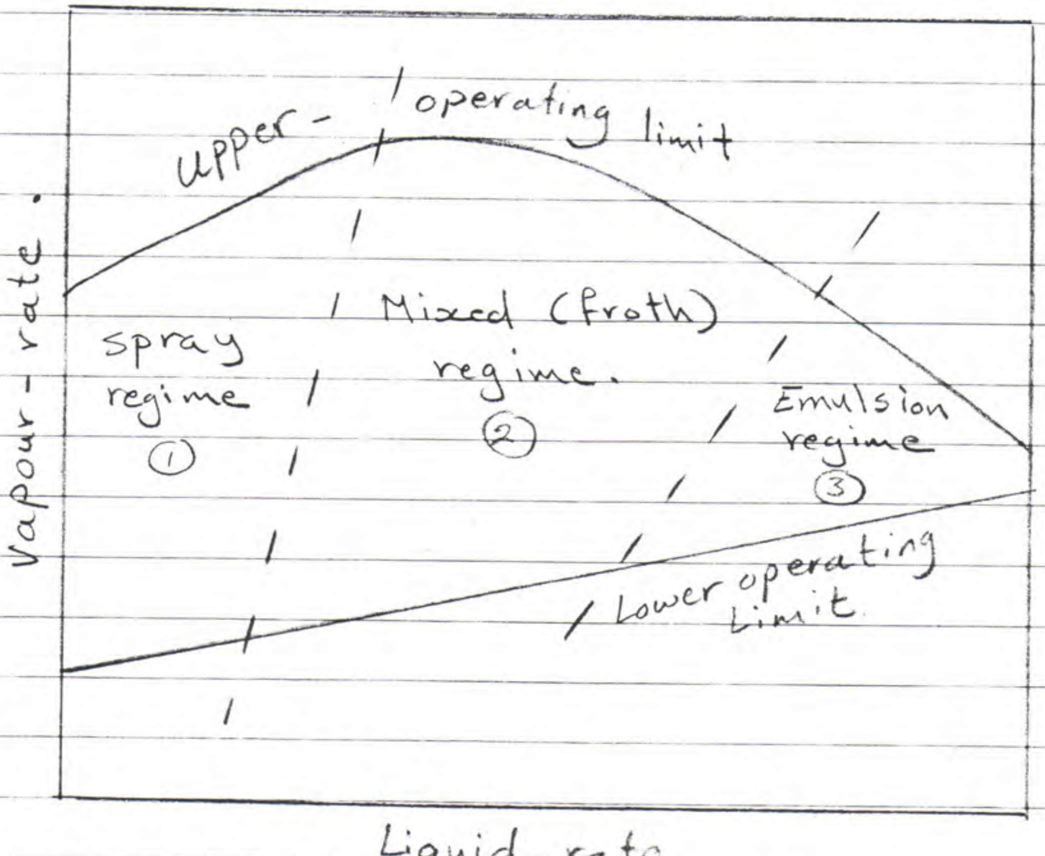
$$\boxed{Y^* = m x}$$ equil^m. relation



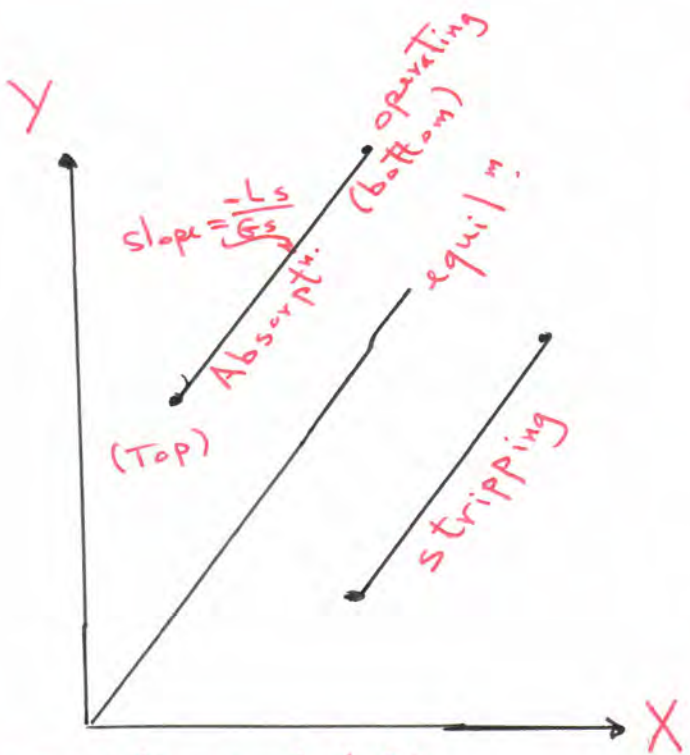


③ Emulsion ② Froth ① Spary

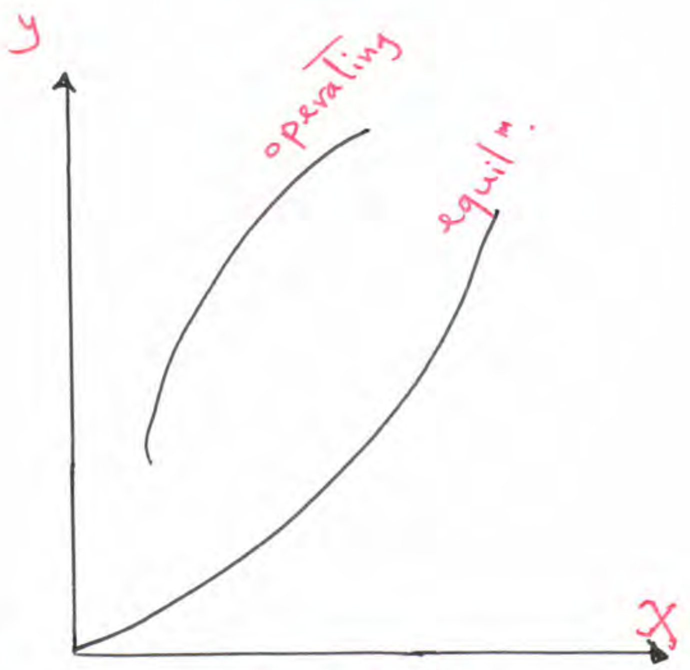
⊛ Type of gas-liquid-dispersion on a tray.



⊛ Flow regimes and operating Limits of a sieve tray.



(Dilute Solut$^n$)



(Conc$^n$. Solut$^n$)

$$G_s(Y-Y_T)=L_s(X-X_T)$$

$$G\cdot y-G_T y_T=Lx-L_T x_T$$

$(G, L)$ not constant (Inlet inert + Carrier)

$(G', L')$ constant (Inlet gas (solute only)

$$G_s=G'=G(1-y)$$
$$L_s=L'=L(1-x)$$

$$G_s=\frac{G}{1+Y}\ ,\quad Y=\frac{y}{1-y}\ \Longrightarrow\ y=Y(1-Y)$$

$$L_s=\frac{L}{1+X}\ ,\quad X=\frac{x}{1-X}\ \Longrightarrow\ x=X(1-X)$$

$G_s$ = rate of flow of phase G on solute-free basis (mole/time)
$L_s$ = 〃 〃 〃 〃 〃 L 〃 〃 〃 〃 〃 〃
G = 〃 〃 〃 〃 〃 G (mol/time)
L = 〃 〃 〃 〃 〃 L (

# Determination of the No. of Stages in Counter-Current flow

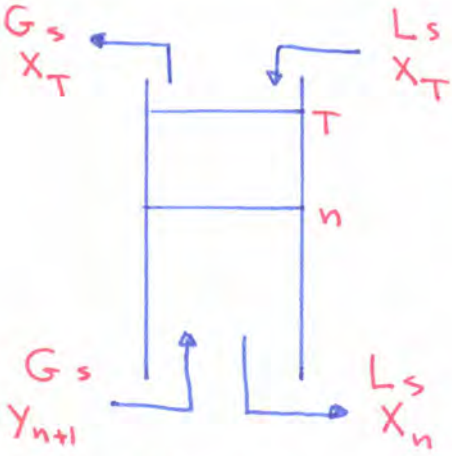
## ① Graphical construction. (if both operating and equilm are straight line)

- M.B on n-tray and the top:-

$$G_s(Y_{n+1} - Y_T) = L_s(X_n - X_T)$$

$$Y_{n+1} = \frac{L_s}{G_s} X_n - \frac{L_s}{G_s} X_T + Y_T$$

$$\therefore \boxed{Y_{n+1} = A X_n + B}$$



$L_s = L^-$
$G_s = G^-$

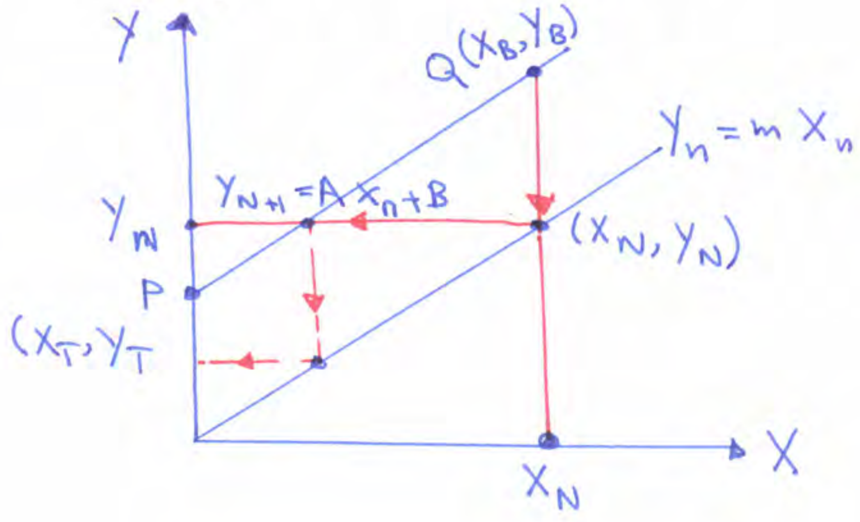
- Total material balance:-

$$G_s(Y_B - Y_T) = L_s(X_B - X_T)$$

$$\boxed{\frac{L_s}{G_s} = \frac{Y_B - Y_T}{X_B - X_T}} \text{ operating}$$

- For ideal plate, concentration pair $(X_n, Y_n)$ should lie on the equilm Curve.

$$\boxed{Y^* = m \cdot X} \text{ equil}^m \text{ relation.}$$



## ② Algebraic Determination.

* Consider the transfer of the solute from gas phase to liquid phase (absorption).

* Concentrations are expressed in the mole ratio unit and the phase flow rates are on solute-free basis.

* operating line is always linear.

$$Y_n = \alpha X_n \quad \text{at point } (X_n, Y_n)$$

Sub. for $X_n$ in operating equation.

$$Y_{n+1} - Y_T = \frac{L_s}{G_s}\left(X_n - X_T\right)$$

$$Y_{n+1} - Y_T = \frac{L_s}{G_s}\left(\frac{Y_n}{\alpha} - X_T\right)$$

$$\boxed{Y_{n+1} - \bar{A}\, Y_n = Y_T - \bar{A}\alpha \cdot X_T} \quad --- ①$$

where :- $\bar{A} = \dfrac{L_s}{\alpha G_s}$ $\boxed{\text{Absorption factor}}$

equation ① is first order - non homogenous linear difference equation.

The final solution for equation ① is :-

$$\boxed{N = \frac{\operatorname{Log}\left[\left(\frac{Y_B - \alpha X_T}{Y_T - \alpha X_T}\right)\left(1 - \frac{1}{\bar{A}}\right) + \frac{1}{\bar{A}}\right]}{\operatorname{Log} \bar{A}}} \quad --- ②$$

Kremser-Brown eq. for $\bar{A} \neq 1$

For $\bar{A} = 1$, Solution of equation ① will be

$$\boxed{N = \frac{Y_B - Y_T}{Y_T - \alpha \bar{A} X_T}} \quad --- \text{③}$$

In this case for $\bar{A} = 1 = \frac{L_s}{\alpha G_s}$, then slope of operating line will be:-

$\alpha = \frac{L_s}{G_s}$, which is the same as the slope of the equil$^m$ Curve. So the operating line and equil$^m$ Curve (line) become parallel, then the concentration change of a phase at each stage is equal. Therefore, the number of plates will be equal to the ratio of the total concentration change over the column to the concentration change over a single stage or plate.

$$N = \Delta C_T / \Delta C_i$$

⊛ In the case of transfer of the solute from liquid phase to gas phase ( stripping)

$$\boxed{N = \frac{\operatorname{Log}\left[\frac{X_B - \left(\frac{Y_B}{\alpha}\right)}{X_T - \left(\frac{Y_B}{\alpha}\right)}\left(1 - \bar{A}\right) + \bar{A}\right]}{\operatorname{Log}\left(\frac{1}{\bar{A}}\right)}} \quad ---\text{④}$$

where $\frac{1}{\bar{A}} = \bar{S}$ ( stripping factor)

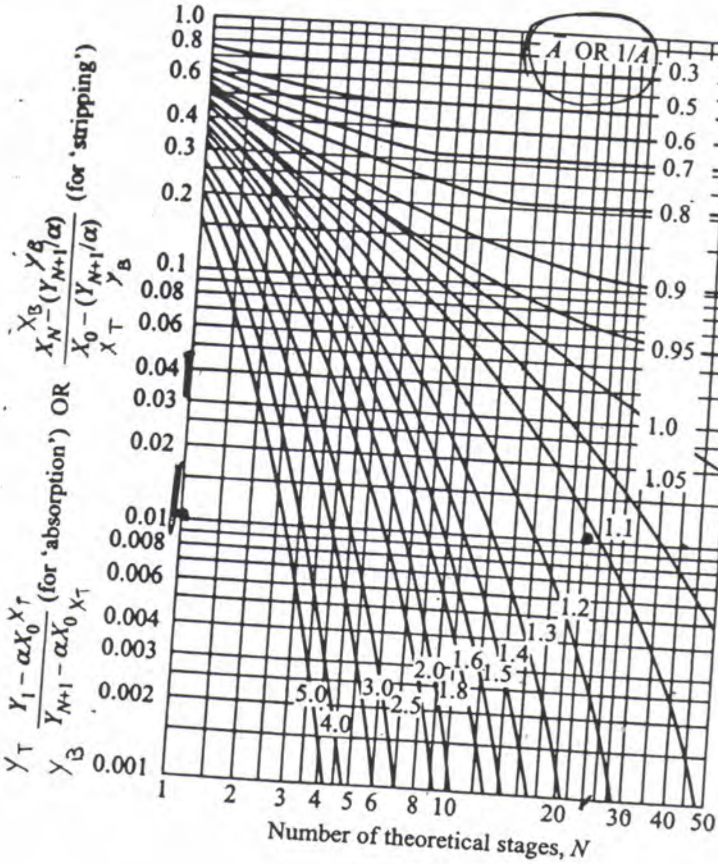
**Note :-** if the concentration of solute about (7%) equations (3) and (4) can be used noticing :-

$$\bar{A}_T = \frac{L_T}{\alpha G_T} \quad , \quad \bar{A}_B = \frac{L_B}{\alpha G_B}$$

and then ($\bar{A}$) final will be the geometric mean of $\bar{A}_T$ and $\bar{A}_B$ :-

$$\bar{A} = \sqrt{\bar{A}_T \cdot \bar{A}_B}$$

③ Using Kremser - Chart.



absorption

$$\frac{Y_T - \alpha X_T}{Y_B - \alpha X_T}$$

$$\frac{X_B - \frac{Y_B}{\alpha}}{X_T - \frac{Y_B}{\alpha}}$$

stripping

# - Tray - efficiency -

An ideal stage provids quite an efficient contact between the phases, so that they attain equilb$^{m}$, or the phases leaving an ideal stage are at equilb$^{m}$ irrespective of the inlet conc$^{n}$. However, the performance of a real stage will expectedly be different from that of an ideal stage.

The tray efficiency is an indicater of how closely the performance of a real tray approaches that of an ideal tray.

We will consider three kinds of efficiency :-

## ① Point - efficiency (EOG).

The tray efficiency is likely to vary from one location to another on a tray.

$$\boxed{E_{OG} = 1 - e^{-NTU_{OG}}}$$

where :- $NTU_{OG} = \dfrac{k_y \cdot \bar{a} \cdot Z}{G}$

للحصول على
كفاءة عالية
يجب ان

$k_y$ = Larg M.T. coeff

$\bar{a}$ = Larg interfacial area

$Z$ = depth of the froth on the tray.

## ② Murphree-efficiency ($E_{MG}$)

$$E_{MG} = \frac{y_{n+1} - y_n}{y_{n+1} - y_n^*}$$ for well mixed condition

There is arelation between ① and ② in two certain cases :-

a- If the liquid well mixed then $E_{MG} = E_{OG}$

b- If the liquid is in plug flow, then :-

$$\boxed{E_{MG} = \bar{A}\left[\exp\left(\frac{E_{OG}}{\bar{A}}\right) - 1\right]}$$ plug flow

## ③ Overall tray efficiency ($E_o$) :-

or (overall column efficiency in section of column) is used to determine No. of real trays.

$$E_o = \frac{\text{No. of ideal trays}}{\text{No. of real trays}} \Longrightarrow \boxed{\text{Real No} = \frac{\text{ideal}}{\text{eff.}}}$$

$$\boxed{E_o = \frac{\ln[1 + E_{MG}(\frac{1}{A} - 1)}{\ln\left(\frac{1}{A}\right)}}$$

Ex.(1) :- Absorption column receiving about 130 kmol/hr of feed gas containing 9 mol% of solute.
It is required to remove 93 % of solute using 150 kmol/hr liquid solvent.
the feed solvent has 0.4 % of solute in it.
The Murphree tray efficiency is to be 45 %
Equilibrium data are:-

| $x$ | 0.013 | 0.033 | 0.049 | 0.064 | 0.074 | 0.093 | 0.106 |
|---|---|---|---|---|---|---|---|
| $y$ | 0.01 | 0.026 | 0.043 | 0.06 | 0.073 | 0.1 | 0.126 |

Determine the No. of trays required ?

Sol. :-

$x_T = 0.004$
$y_T = ?$
$y_B = 0.09$
$x_B = ?$

To remove 93% from 9% initial
$y_T = 0.09\,(1 - 0.93)$
$y_T = 0.0063$

To find $x_B$ make overall M.B

$$G\,(y_B - y_T) = L\,(x_B - x_T)$$

$$130\,(0.09 - 0.0063) = 150\,(x_B - 0.004)$$
$$10.881 = 150\,(X_B - 0.004)$$

$$x_B = 0.07654$$

To find operating line equation
Make M.B between Top of Column and any section.

$G(y - y_T) = L(x - x_T)$

$130(y - 0.0063) = 150(x - 0.004)$

$\boxed{y = 1.15\,x - 0.0017}$ operating line equation.

Plot equilib$^m$ line :-

between :-

(0.004, 0.0063) , (0.0765 , 0.09)

From the Fig. :-

No. of theo. trays = 8

No. of Actual trays $= \frac{8}{0.45} = 18$