# MT
# MASS
# TRANSFER

July 08, 14

# Mass Transfer

Transfer of mass from one pt. to another in a single phase or from one phase to another with the help of a driving force is known as Mass Transfer.

The driving force here is mainly the conc$^n$ diff.

Mass transfer takes place in every case partial pressure diff, temp-diff, Magnetic field diff Bt amount of mass tr is negligible So we consider only conc$^n$ diff"

* The main driving force of M.T is chemical potential diff.

## Types of Mass Transfer

i.) **Molecular diffusion:-** The transfer of mass (moles) or diffusion of a species takes place in a ~~turb~~ stagnent medium.

* If there is a turbulent diffusion, then there must be molecular diffusion.

ii.) **Turbulent or Eddy diffusion:-** If the diffusion of species takes place in a turbulent medium, then the mechanism is known as turbulent or eddy diffusion.

Molecular diffusion occur due to motion & motion is microscopic bt in turbulent diffusion motion is macroscopic.

## Some imp. things to remember:-

$\rho_i$ => mass concentration of ith species in a solution (kg/m³)

$\rho$ => total mass " " all " " " " (kg/m3)

$w_i = \frac{\rho_i}{\rho}$ => mass fraction of the ith species in the solution. (unit less)

$C_i$ => Molar concentration of the ith species in the soln (kmol/m3)

$C$ => total molar concentration of all the specieoin the soln (kmol/m³)

$x_i = \frac{C_i}{C}$ => Mole fraction of the ith species in the solution.

$$\Sigma \rho_i = \rho$$

$$\Sigma C_i = C$$

$$\Sigma x_i = 1$$

$$\Sigma w_i = 1$$

The symbol $x_i$ is mainly used for the liquid sol$^n$.
" " $y_i$ " " " " " " gaseous "

$$y_i = \frac{P_i}{P} = \frac{\text{Partial pressure } i^{th} \text{ species}}{\text{total pressure.}}$$

**Mass avg. velocity:- ($u$)**

$$\boxed{u = \frac{\sum \rho_i u_i}{\sum \rho_i = \rho}} \quad \text{or} \quad \boxed{u = \sum w_i u_i}$$

Unit = m/s

$u_i$ = linear velocity of ith species.

**Molar avg Velocity :- ($U$)**

$$\boxed{U = \frac{\sum C_i u_i}{\sum C_i}} \quad \text{or} \quad \boxed{U = \sum x_i u_i}$$

Flux:-

The net rate at which a species in a solution passes through unit area, which is normal to the direction of diffusion in unit time.

Kg/m²s , Kmol/m²s

mass flux , molar flux.

**Mass flux :-** (denoted by small letter)

$n_i$ = Mass flux of the ith species w.r.t a stationary observer
= $\rho_i(u_i - 0)$ → denotes observer is stationary.
= Kg/m²s.

$i_i$ = Mass flux of the ith species w.r.t an observer moving with mass avg. velocity.
= $\rho_i(u_i - u)$
= Kg/m²s

$j_i$ = Mass flux of the ith species w.r.t an observer moving with molar avg. velocity.
= $\rho_i(u_i - U)$
= kg/m²s.

**Molar flux :-** (denoted by capital letters)

$$N_i = C_i\,(u_i - 0)$$

$$I_i = C_i\,(u_i - u)$$

$$J_i = C_i\,(u_i - U)$$

$$J_i = C_i(u_i - U)$$

$$\Sigma J_i = \Sigma C_i\,(u_i - u)$$

$$= \Sigma C_i u_i - \Sigma C_i U$$

$$= C\,\frac{\Sigma C_i u_i}{C} - \Sigma C_i U$$

$$= CU - CU$$

$$* \quad \boxed{\Sigma J_i = 0}$$

☆ The total molar flux of all the species of a solution wrt an observer moving with molar avg. velocity is zero.

$$i_i = \rho_i(u_i - u)$$

$$\Sigma i_i = \Sigma \rho_i(u_i - u)$$

$$\Sigma i_i = \Sigma \underset{u}{\rho_i u_i} - \Sigma \rho_i u$$

$$= \rho\,\frac{\Sigma \rho_i u_i}{\rho} - \Sigma \rho u$$

$$= \rho u - \rho u$$

$$\boxed{\Sigma i_i = 0}$$

☆ Mass flux of all the species in a solution wrt an observer moving with mass avg. velocity is zero.

When there is mass-mass. mole-mole symmetry flux will be zero, otherwise flux will not be zero.

$$\boxed{\begin{aligned} i_1 + i_2 &= 0 \\ J_1 + J_2 &= 0 \\ N_1 + N_2 &\neq 0 \end{aligned}}$$

## Fick's first Law:-

The molar flux of a species w.r.t. an observer moving with molar avg. velocity is directly proportional to the gradient of the concentration of that species.

$$J_A \propto \frac{dC_A}{dz}$$

If we remove the proportionality, then the constant of proportionality must be introduced, which is known as diffusivity or diffusion coeff, denoted by $D_{AB}$ for a binary mixture or $D_{ij}$ for a multicomponent mixture. This coeff. tell us how easily species i diffuse in the solution, or for a binary mixture how easily A diffuses into B.

if diffusion is defined for 1 dirn complete derivative is used. if diffusion is defined for more than 1 dirn, partial derivative is used.

$$J_{A_z} = -D_{AB}\frac{dC_A}{dz}$$

-ve sign represents the transfer of mass taking place from a region of higher concentration to a region of lower concentration.

$$\frac{kmol}{m^2 s} \leftarrow \underbrace{J_{A_z}}_{\text{quantity}} = -\underset{\substack{\downarrow \\ m^2/s}}{D_{AB}}\underbrace{\frac{\partial C_A}{\partial z}}_{\text{gradient}} \rightarrow \frac{kmol}{m^3}$$

quantity = gradient.

## Fourier Law:-

$$\frac{kJ}{m^2 s} \leftarrow q_z = -k\frac{d\textcircled{T}}{dz} \rightarrow °C, K$$

$$\frac{kJ}{m^2 s} \leftarrow q_z = \frac{-k}{\rho C_p}\frac{d\,\textcircled{T\rho C_p}}{dz} \rightarrow kJ/m^3$$

$$\boxed{q_z = -\underset{\substack{\downarrow \\ m^2/s}}{\alpha}\frac{d\rho C_p T}{dz}}$$

Analogy with fick's law

## Momentum diffusivity :-

$$\tau = -\mu \frac{dv}{dz}$$

Momentum flux

$$\frac{\text{momentum}}{m^2 \cdot s} \rightarrow kg\,m/s$$

$$\nu \rightarrow m^2/s$$

$$\tau_{yz} = -\left(\frac{\mu}{\rho}\right)\frac{d(v\rho)}{dz} \qquad \frac{\text{momentum}}{m^3}$$

not a vector it is tensor

* basic diff mass flux & heat flux is a vector and momentum flux is tensor.

Every quantity is a tenser quantity but of different order like pressure is tenser of zero order because its value is same in all the direction.

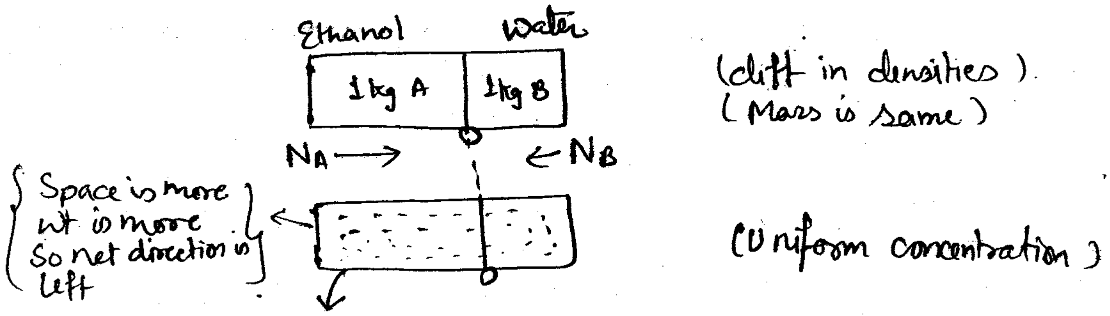
Like stress tenser of second order it is applied in two particular direction.

$$\boxed{J_{Az} = -D_{AB}\frac{dC_A}{dz}}$$

$$\boxed{q_z = -\alpha \frac{d\rho C_p T}{dz}}$$

$$\boxed{\tau_{yz} = -\frac{\mu}{\rho}\frac{dV_y\rho}{dz}}$$

The basic diff in between 3 is that the molar flux & heat flux are vectors or tenser of first order but momentum flux is a tensor of second order.



(diff in densities)
(Mass is same)

(Uniform concentration)

In the first diagram if we put the wt. balance at the partition, then both side are on equal level. If we remove the partition and give sufficient tym to the system so that at each pt., If the wt. balance is in the same position as previously then the system will tilt on the left. This shows that the net rate of flux is ~~in~~ the direction of right to left.

$$\ast\ast \quad \boxed{N_A = J_A + N x_A} \qquad J_A \longrightarrow -D_A \frac{dC_A}{dz}$$

The flux of any species is the sum of convective transport and molecular transport.

$$\begin{aligned} J_A &= C_A(U_A - U) \\ &= C_A U_A - C_A U \\ &= N_A - C_A\left(\frac{C_A U_A + C_B U_B}{C_A + C_B}\right) \\ &= N_A - \frac{C_A (N_A + N_B)}{C} \\ &= N_A - x_A N \end{aligned}$$

$$\boxed{N_A = J_A + N x_A} \qquad J_A \longrightarrow -C D_{AB} \frac{dx_A}{dz}$$

$$\boxed{N_A = J_A + N \frac{C_A}{C}} \qquad J_A \longrightarrow -D_{AB} \frac{dC_A}{dz}$$

$x_A = C_A/C$

$-CD_{AB} \frac{1}{C}\frac{dC_A}{dz}$

$$\boxed{N_A = J_A + N \frac{P_A}{P}} \qquad J_A \longrightarrow -\frac{D_{AB}}{RT}\frac{dP_A}{dz}$$

$\left[ C = \frac{P}{RT} \right.$

$P = CRT$

$x_A = P_A/P \quad CD_{AB}\frac{dP_A}{P}$

$P$

$CRT$

☆ In Heat transfer, there is only one driving force i.e temp. difference but in Mass transfer, there are more than one driving forces like concentration gradient, mole fraction gradient, partial pressure gradient etc.

⇒ Driving force also tells us how far a system is from equilibrium.

$$N_A = J_A + N x_A$$

$$N_B = J_B + N x_B$$

$$N_A + N_B = J_A + J_B + N(x_A + x_B)$$

$$N = J_A + J_B + N$$

$$J_A + J_B = 0$$

$$\boxed{J_A = -J_B}$$

$$-\left(-D_{AB}\frac{d\cancel{C_A}}{\cancel{d}z}\right) = -\left(-D_{BA}\frac{d\cancel{C_B}}{\cancel{d}z}\right)$$

$$\boxed{D_{AB} = D_{BA}}$$

Assumption

$C_A + C_B = C$

$\frac{dC_A}{dz} + \frac{dC_B}{dz} = 0$

$\frac{dC_A}{dz} = -\frac{dC_B}{dz}$

Diffusivity in a binary system are equal to each other for the ideal case when total concentration is constant. Diffusivity are directional dependent for all the cases except the ideal case.

## Diffusional Velocity of species A (Relative Velocity):-

$$C_A(U_A - U) = J_A = -D_{AB}\frac{dC_A}{dz}$$

$$\boxed{U_A - U = -\frac{D_{AB}}{C_A}\frac{dC_A}{dz}}$$

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~~Q.1~~

$N_{A_1} = N_{A_2}$ for rectangular slab

$\frac{N_{A1}}{N_{A2}} = \frac{r_2}{r_1}$ for cylindrical

$\frac{N_{A1}}{N_{A2}} = \frac{r_2^2}{r_1^2}$ for sphere.

Rate of M.T in a given area wether constant or changing is olwoz constant but flux will change if the area change.

★ If there is box, whose radius at bottom is 20, middle is 10 and top 5 and above that is air. Then flux at top is more.

## Diffusion of A through Non-diffusing B

liquid A is evaporating into gas B. We imagine that there is some device that maintains the liquid level at z=0. Solubility of gas B in liquid A is neglible or B is non-diffusing. A stream of gas mixture A+B having concentration $x_{A_2}$ flows slowly over the top of the tube to maintain the mole fraction of A at $x_{A_2}$. Entire System is kept at constant temp. and pressure. Gases A & B are assumed to be ideal.

$$N_A = \overset{(N_A+N_B)}{N} x_A + J_A$$

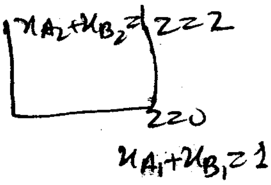
$$N_A = N_A x_A - C D_{AB} \frac{dx_A}{dz}$$

$$N_A (1-x_A) = -C D_{AB} \frac{dx_A}{dz}$$

$$N_A \int_0^z dz = -C D_{AB} \int_{x_{A_1}}^{x_{A_2}} \frac{dx_A}{(1-x_A)}$$

$$N_A z = C D_{AB} \ln \left| \frac{1-x_{A_2}}{1-x_{A_1}} \right|$$

$$x_{A_1} - x_{A_2} = x_{B_2} - x_{B_1}$$



$$N_A = \frac{C D_{AB}}{z} \frac{x_{B_2}-x_{B_1}}{\frac{x_{B_2}-x_{B_1}}{\ln\left(\frac{x_{B_2}}{x_{B_1}}\right)}}$$

$$\boxed{N_A = \frac{C D_{AB}}{z} \frac{x_{A_1}-x_{A_2}}{x_{BLM}}}$$

$$x_{BLM} = \frac{x_{B_2}-x_{B_1}}{\ln(x_{B_2}/x_{B_1})}$$

When the diff btw two concentration $x_{B_2}$ & $x_{B_1}$ is very less then we take the airthmatic mean not the logarithm mean.

$$x_A = C_A/C$$

$$N_A = \frac{D_{AB}}{z} (Cx_{A_1} - Cx_{A_2})$$

$$x_{BLM} = \frac{x_{B_2}-x_1}{\ln \frac{x_{B_2}}{x_1}}$$

Arithmatic mean tell only initial & final state but LMTD tells us in btw diff also.

$$C_{BLM} = \frac{\frac{C_{B2}-C_{B1}}{C_t}}{\ln (C_{B2}/C_{B1})}$$

$$\boxed{N_A = \frac{C D_{AB}}{z} \frac{C_{A1}-C_{A2}}{C_{BLM}}}$$

$$N_A = \frac{C D_{AB}}{z} \frac{\frac{P_{A1}-P_{A2}}{P}}{P_{BLM}}$$

$C = \frac{P}{RT}$

$x_A = \frac{P_A}{P}$

$$P_{BLM} = \frac{\frac{P_{B2}-P_{B1}}{P}}{\ln \frac{P_{B2}}{P_{B1}}}$$

$$\boxed{N_A = \frac{P D_{AB}}{RTz} \frac{P_{A1}-P_{A2}}{P_{BLM}}}$$

## Equimolar Counter diffusion :- EMCD

$$N_A = (N_A+N_B)x_A + J_A$$

$$N_A = -N_B$$

$$N_A = J_A = -C D_{AB} \frac{dx_A}{dz}$$

$$\boxed{N_A = \frac{C D_{AB}}{z} (x_{A1}-x_{A2})}$$

In the case of diffusion of A from non-diffusing B, my governing eqn $N_A = \underset{\text{Bulk term}}{\underbrace{N_A x_A}} + \underset{\text{Molecular term}}{\underbrace{J_A}}$

bcz of bulk term diffusion takes place & $J_A$ ki wajah se bhi diffusion ho raha that's y flux jada hoga.

For the case of EMCD, my governing eqn is $N_A = J_A$

So, in the first case flux will be more bcz of the presence of bulk motion.

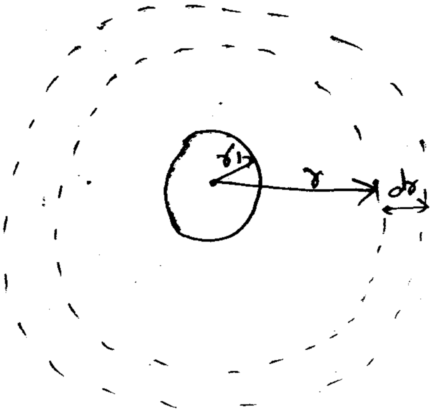
## Diffusion of a spherical napthalene ball in air:—

$$N_A = N x_A + J_A \qquad (N_A + N_B = 0)$$

$$N_A (1 - x_A) = J_A$$

$$N_A (1 - x_A) = -C D_{AB} \frac{dx_A}{dr}$$

$$\frac{W_A}{4\pi r^2} (1 - x_A) = -C D_{AB} \frac{dx_A}{dr}$$



$$\frac{W_A}{4\pi} \int_{r_1}^{r_2} \frac{dr}{r^2} = -C D_{AB} \int_{x_{A_1}}^{x_{A_2}} \frac{dx_A}{1 - x_A}$$

$$-\frac{W_A}{4\pi} \left[\frac{1}{r_2} - \frac{1}{r_1}\right] \cancel{\frac{W_A}{4\pi}\left[\frac{r_2^3}{3} - \frac{r_1^3}{3}\right]} = +C D_{AB} \ln\left|\frac{1 - x_{A_2}}{1 - x_{A_1}}\right|$$

$$\boxed{-\frac{W_A}{4\pi} \left[\frac{1}{r_2} - \frac{1}{r_1}\right] = C D_{AB} \frac{x_{A_1} - x_{A_2}}{x_{BLM}}}$$ governing eqn

$r_2$ = radius of air = infinity

$$\frac{1}{r_2} \simeq 0$$

$$\boxed{\frac{W_A}{4\pi r_1^2} = \frac{C D_{AB}}{r_1} \frac{x_{A_1} - x_{A_2}}{x_{BLM}}}$$

$$\boxed{N_A \Big|_{r = r_1} = \frac{C D_{AB}}{r_1} \frac{x_{A_1} - x_{A_2}}{x_{BLM}}}$$

$$\boxed{N_A \Big|_{r = r_1} = \frac{P D_{AB}}{R T r_1} \frac{P_{A_1} - P_{A_2}}{P_{BLM}}}$$

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The radius of the napthalene ball decreases with tym, bt still we have taken its as steady state condition bcz it satisfy assumption of psuedo steady state diffusion.

Psuedo steady state:—

⇒ The diffusional rate should be very small.

⇒ The species which is diffusing should be very small in comparision to the species in which it is diffusing.

Time taken for the complete evaporation of a napthlene ball:—

$$t=0 \quad , r=r_1$$
$$t=t_f \quad , r=0$$

$$\frac{r_1}{2}\frac{\rho}{M}\frac{1}{N_A}$$

$$N_A = \frac{\text{kmol}}{m^2 s} = \frac{\rho}{M}\frac{dr}{dt} - \frac{\text{kmol}}{m^2 s}$$

$$N_A = \frac{\rho}{M}\frac{dr}{dt}$$

$$\cancel{N_A\int_0^{t_f} dt = \frac{\rho}{M}\int_{r_1}^{0} dr}$$

$$N_A$$

$$-\frac{W_A}{4\pi}\underbrace{\left[\frac{1}{r_2}-\frac{1}{r_1}\right]}_{1/r} = \frac{C D_{AB}}{\cancel{r}}\frac{(x_{A_1}-x_{A_2})}{x_{BLM}}$$

$$-\frac{W_A}{4\pi}\frac{1}{r}\cdot\frac{1}{r} = \frac{C D_{AB}}{r}\left(\frac{x_{A1}-x_{A2}}{x_{BLM}}\right)$$ Multiply r.

$$-N_A = \frac{C D_{AB}}{r}\left(\frac{x_{A1}-x_{A2}}{x_{BLM}}\right)$$

$$-\int_{r_1}^{0} r\,dr = \frac{M C D_{AB}}{\cancel{CtA}\,\rho}\frac{x_{A_1}-x_{A_2}}{x_{BLM}}\int_0^{t_f} dt$$

$$-\frac{r^2}{2}\Big|_{r_1}^{0} = \frac{M C D_{AB}}{\rho}\frac{x_{A_1}-x_{A_2}}{x_{BLM}}\Big|t\Big|_0^{t_f}$$

$$\boxed{t_f = \frac{r_1^2}{2}\frac{\rho}{M C D_{AB}}\frac{x_{BLM}}{x_{A_1}-x_{A_2}}}$$

$$\boxed{t_f = \frac{r_1^2}{2}\frac{\rho R T}{M P D_{AB}}\frac{P_{BLM}}{P_{A_1}-P_{A_2}}}$$

(13)

## Diffusion in liquids :-

Case I :- Diffusion of A through non-diffusing B.

$$\boxed{N_A = \frac{\textcircled{C}\,\overline{D_{AB}}}{z}\,\frac{(x_{A_1}-x_{A_2})}{x_{B,M}}}$$

M = M.M d

$$C_{av.} = \frac{(C_1)+(C_2)}{2}$$

$$\leftarrow \left(\frac{\rho}{M}\right)_{avg} = \frac{\left(\frac{\rho}{M_1}\right)+\left(\frac{\rho}{M_2}\right)_2}{2}$$

Case II :- EMCD

$$N_A = \frac{C\,D_{AB}}{z}\,(x_{A_1}-x_{A_2})$$

$$C \Rightarrow \boxed{\left(\frac{\rho}{M}\right)_{avg} = \frac{\left(\frac{\rho}{M_1}\right)+\left(\frac{\rho}{M_2}\right)}{2}}$$

## Diffusion in Solids :-

Rates are slow in comparision to liquids and gases bt it is important to us in many mass transfer operations.

ex → leaching of foods such soyabean, crystallization, drying and many more.

Types :-

It is of two types.

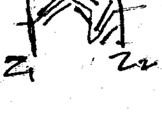
i.) Diffusion that can be considered to follow ficks law and doesn't depend on the actual structure of solid.

for ex → In leaching the solid contains a large amount of water ~~or~~ solute is diffusing through this solution.

ii.) Diffusion in porous solid where the actual structure and the voids are important.

$$\boxed{N_A = \frac{\varepsilon}{\tau}\,D_{AB'}\,\frac{dC_A}{dz}}$$

Actual dist $z_2 - z_1$ bt it has to travel more distance, so these tortuous path are know as tortusity.



Simply was tortuos path's

$\varepsilon$ = void cadge (fractions of voids in solid)

$\tau$ = Tortuosity

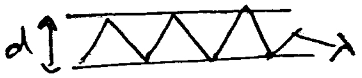
## Unsteady state diffusion :-

$$\boxed{\frac{\partial^2 C_A}{\partial x^2} = \frac{1}{D_{AB}} \frac{\partial C_A}{\partial t}}$$ Ficks second law

## Knudsen diffusion :-

Case-I when meanfree path is greater than pore dia

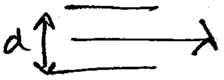
$\lambda \geq d$



Knudsen law

Case-II

$\lambda < d$



Ficks law

$$\boxed{J_k = -D_K \frac{dC_A}{dz}}$$ Knudsen law

$D_K$ = knudsen diffusivity.

$= \frac{2}{3} r_p V_T$

$r_p$ = radius of passage

$V_T = \left(\frac{8RT}{\pi M}\right)^{1/2}$ velocity of particle.

$$\boxed{D_K = 97.0\, r_p \left(\frac{T}{M}\right)^{1/2}}$$

$$= \cancel{97.0 \times 60 \times 10^{10}} \left(\frac{373}{1}\right)$$

## Diffusion in open system :-

If diffusion in porous solids or channels wid no chem. rxns is occuring where total press. P remains constant. Then for a open binary system.

$$\boxed{\frac{N_A}{N_B} = -\sqrt{\frac{M_B}{M_A}}}$$

## Diffusivity dependence :-

For the gases, diffusivity is inversely proportion to the pressure. and diffusivity is directly proportion to (temp)$^{3/2}$.

$$D_A \propto 1/P$$

$$D_A \propto T^{3/2}$$

For the liquids

$$D_{AB} \propto T$$

for pressure = No dependance

## Counter diffusion :-

$$nA + mB \rightarrow PC$$

$$\frac{-r_A}{n} = \frac{-r_B}{m} = \frac{r_C}{P}$$

$$\frac{+N_A}{-n} = \frac{N_B}{-m} = \frac{N_C}{P}$$

Ex→

$$CH_4(A) \rightarrow C + 2H_2(B)$$

find the relationship b/w fluxes of A & B.

$$\frac{N_A}{-1} = \frac{N_B}{2}$$

$$\boxed{N_B = -2N_A}$$

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## Mass Transfer Coefficient :-

The rate of M.T is proportional to the driving force and also proportional to the area.

$$W_A \propto A \Delta C$$

$$\boxed{W_A = \underbrace{K_c}_{\text{M.T coeff.}} A \Delta C}$$

$$\boxed{N_A = \frac{W_A}{A} = K_c \Delta C}$$

Unit $k_c$ = m/s

$= C_A(u_A - 0)$

Like H.T coeff, it is also an experimental quantity and it can be calculated with the help of dimensionless numbers.

**For gases :-** (diffusion of A through non-diffusing B)

$$N_A = \frac{C D_{AB}}{z} \cdot \frac{C_{A_1} - C_{A_2}}{C_{BLM}}$$

Concentration terms.

$$\boxed{N_A = k_c (C_{A_1} - C_{A_2})}$$

$$= \frac{C D_{AB}}{z} \frac{(y_{A_1} - y_{A_2})}{y_{BLM}}$$

mole fraction for gases so y term.

$$\boxed{N_A = k_y (y_{A_1} - y_{A_2})}$$

$$= \frac{P D_{AB}}{RTz} \frac{(P_{A_1} - P_{A_2})}{P_{BLM}}$$

$$\boxed{N_A = k_G (p_{A_1} - p_{A_2})}$$

$$N_A = \underbrace{\frac{D_{AB}}{z} \frac{1}{x_{BLM}}}_{k_c} (C_{A_1} - C_{A_2})$$

No C term, bcz $x_{BLM}$ is not change in $C_{BLM}$ so C term with $D_{AB}$ is not written

$$N_A = \underbrace{\frac{D_{AB}}{RTz} \frac{1}{x_{BLM}}}_{k_G} (P_{A_1} - P_{A_2})$$

Here we put $C = P/RT$ So RT is take separately

$$K_c = \frac{D_{AB}}{z\, x_{BLM}}$$

$$K_y = \frac{C D_{AB}}{z\, y_{BLM}}$$

$$K_G = \frac{D_{AB}}{RTz\, x_{BLM}}$$

* When I calculate M-T coeff, we will not change the term $x_{BLM}$ to $C_{BLM}$ or $P_{BLM}$

$$* \quad \boxed{K_G = \frac{K_y}{P} = \frac{K_c}{RT}}$$

For Liquids:-

$$N_A = \frac{C_{av} D_{AB}}{z} \frac{(x_{A_1} - x_{A_2})}{x_{BLM}} \Rightarrow K_x = \frac{C_{av} D_{AB}}{z\, x_{BLM}}$$

$$N_A = \frac{D_{AB}}{z} \frac{(C_{A_1} - C_{A_2})}{x_{BLM}} \Rightarrow K_L = \frac{D_{AB}}{z\, x_{BLM}}$$

$$* \quad \boxed{K_x = \frac{K_L}{C_{av}}}$$

For gases and liquids, equimolar counter diffusion:-

for gases

$$N_A = \frac{C D_{AB}}{z} \; x_{A_1} - x_{A_2} \qquad K'_y = \frac{C D_{AB}}{z}$$

$$N_A = \frac{D_{AB}}{z} \; C_{A_1} - C_{A_2} \qquad K'_c = \frac{D_{AB}}{z}$$

$$N_A = \frac{D_{AB}}{zRT} (P_{A_1} - P_{A_2}) \qquad K'_G = \frac{D_{AB}}{zRT}$$

$$* \quad \boxed{K'_G = \frac{K'_c}{RT} = \frac{K'_y}{P}}$$

for liquid.

$$N_A = \frac{C_{av} D_{AB}}{z} (x_{A_1} - x_{A_2}) \qquad K'_x = \frac{C_{av} D_{AB}}{z}$$

$$N_A = \frac{D_{AB}}{z} (C_{A_1} - C_{A_2}) \qquad K'_L = \frac{D_{AB}}{z}$$

$$* \quad \boxed{K'_x = \frac{K'_L}{C_{av}}}$$

For the dissolution of sphere in a flowing liquid ; MT coeff will depend upon

i) The velocity of the liquid
ii) Density of the liquid
iii) Viscosity of the liquid
iv) diffusivity of sphere into liquid.
v) diameter

$$k = k_1 V^a \rho^b \mu^c D_{AB}^d D^e$$

$$\left[\frac{L}{T}\right]^1 = k_1 \left[\frac{L}{T}\right]^a \left[\frac{M}{L^3}\right]^b \left[\frac{M}{LT}\right]^c \left[\frac{L^2}{T}\right]^d [L]^e$$

for L $\quad 1 = a - 3b - c + 2d + e$
for T $\quad -1 = -a - c - d$
for M $\quad 0 = b + c$

Calculating the value of d, e, b in terms of (a, c)

$$\boxed{b = -c}$$
$$\boxed{d = 1 - a - c}$$
$$\boxed{e = a - 1}$$

put the values of constant.

$$[k]^1 = k[v]^a \frac{[\rho]^{-c}_{\times\rho^a}}{\rho^a} \left[\frac{\mu}{\mu^a}\right]^c_{\times\mu^a} [D_{AB}]^{1-a-c} [D]^{a-1}$$

$$\searrow \frac{D_{AB}^1}{(D_{AB})^{a+c}}$$

$$\left(\frac{D k}{D_{AB}}\right) = \left(\frac{V \rho D}{\mu}\right)^a \left(\frac{\mu}{D_{AB}\rho}\right)^{a+c}$$

$$\downarrow$$

$$\boxed{Sh = (Re)^a (Sc)^{c'}}$$

We can say that

$$\boxed{Sh = a(Re)^a (Sc)^c}$$

**Nussult Number** :- Convective heat flux divided by heat flux for conduction through a stagnant medium of thickness L for the same temp. diff.

$$\boxed{Nu = \frac{h(\Delta T)}{\frac{K}{L}(\Delta T)} = \frac{hL}{K}}$$

Analogy of nusselt number in mass transfer is scherwood no.

**Sherwood Number** :-

It is equal to convectic molar flux divided by molar flux for molecular diffusion through a stagnant medium of thickness L, under the driving force of pressure difference.

$$Sh = \frac{K_G \cancel{\Delta P}}{\left(\frac{P D_{AB}}{ZRT} \frac{\cancel{P_{A_1} - P_{A_2}}}{P_{BLM}}\right)}$$

$$= \frac{K_G . ZRT \, P_{BLM}}{P D_{AB}}$$

for dilute sol^n

$P_{BLM} = P.$

$P - P_{A_1} = P_{B_1}$

$P - P_{A_2} = P_{B_2}$

$\frac{P - P_{A_1} + P - P_{A_2}}{2}$ $A_1 A_2$ negligible

$\frac{2P}{2} = P$

Assume dilute solution,

$$= \frac{K_G ZRT \cancel{P}}{\cancel{P} D_{AB}}$$

$$= \frac{K_G RT Z}{D_{AB}}$$

$$= \frac{K_C Z}{D_{AB}}$$

Prandlt number (Pr) :- It is defined as the ratio of momentum diffusivity by thermal diffusivity.

$$Pr = \frac{\nu}{\alpha} = \frac{\mu/\rho}{\frac{K}{\rho C_P}} = \frac{C_P \mu}{K}$$

Analogy of Prandlt number is schemid number no.

Schmid Number:—

It is given by momentum diffusivity by mass diffusivity

$$= \frac{\nu}{D_{AB}}$$

ex
$$Nu = 23\, Re^3 \cdot Pr^8$$
$$Sh = 23\, Re^3 \cdot Sc^8$$

* GENRAL VALUES OFS M.TC & DIFFUSIVITIES

MTC for gases :— $\boxed{K_c = 10^{-2}\ m/s}$

for liquids :— $\boxed{K_L = 10^{-5}\ m/s}$

diffusivities

Liquid phase diffusivity

$$\boxed{D_{AB}/_L = 10^{-9}\ m/s}$$

gas phase diffusivity

$$\boxed{D_{AB}/_G = 10^{-5}\ m/s}$$

Turbulent or Eddy diffusion:—

It is defined as rapid and highly irregular fluctuations of velocities at any pt. in the fluid. Some fluid elements move randomly and are responsible for high rate of transport of momentum, heat & mass. These elements are known as eddies. To study these motion, fundamental laws are extended by replacing $D_{AB}$ with eddy transport diffusion.

$$J_{A,\,Turbulent} = -E_D \frac{dC_A}{dz}$$

$$\boxed{J_{A,\,Total} = -\underbrace{(D_{AB}+E_D)\frac{dC_A}{dz}}_{k}} \to C_{A_1} - C_{A_2}$$

molecular + turbulent

$$\boxed{k = \frac{D_{AB}+E_D}{Z_2 - Z_1}}$$

July 15, 14

## Reynold's Analogy

Reynold's analogy is valid for turbulency

$$\frac{Q}{A} = -\rho C_p \left(\alpha + \overset{\text{turbulent}}{\alpha_D}\right) \frac{dT}{dz}$$

$$\tau = -\rho \left(\frac{\mu}{\rho} + \nu_D\right) \frac{dv}{dz}$$

$\alpha_D = \nu_D$

$\nu << \nu_D$

$\alpha << \alpha_D$

* Molecular diffusivity is too much less than turbulent diffusivity

$$\frac{\tau}{Q/A} = \frac{1}{C_p} \frac{dv}{dT}$$

$$\frac{\tau}{Q/A} \cdot C_p \cdot dT = dv$$

$$\frac{\tau}{Q/A} C_p \int_{T_i}^{T} dT = \int dv$$

$$\frac{\tau}{Q/A} C_p (T - T_i) = V$$

$\tau$ = momentum flux,
$Q/A$ = heat flux
∴ there ratio is always a constant quantity.

$$\frac{Q}{A} = h(T - T_i)$$

Convection

$$f = \frac{\tau}{\frac{1}{2}\rho V^2}$$

fanning friction factor.

$$\tau = \frac{1}{2} f \rho V^2$$

$$\frac{\frac{1}{2} f \rho V^2}{h \cancel{(T - T_i)}} C_p \cancel{(T - T_i)} = V$$

$$\boxed{\frac{f}{2} = \frac{h}{\rho C_p V}}$$

$\rho V = G$ mass velocity.

$$\boxed{\frac{f}{2} = \frac{h}{G C_p}}$$

was for momentum & heat.

$$\tau = -\rho(\nu + \nu_D) \frac{dv}{dz}$$

$$N_A = -(D_{AB} + E_D) \frac{dC_A}{dz}$$

Assumption

$\nu << \nu_D$

$E_D \simeq \nu_D$

$D_{AB} << E_D$

$$\frac{\tau}{N_A} = \rho \frac{dv}{dC_A}$$

$$\frac{\tau}{N_A}\frac{1}{\rho}\int_{C_{Ai}}^{C_A} dC_A = \int_0^v dv$$

$$\frac{\tau}{N_A}\cdot\frac{1}{\rho}(C_A - C_{Ai}) = v$$

$$\frac{f}{2}\,\frac{\rho v^2}{\cancel{\rho} k_c \cancel{(C_A - C_{Ai})}}\,\cancel{(C_A - C_{Ai})} = \cancel{v}$$

$$\boxed{\frac{f}{2} = \frac{k_c}{v}}$$

→ It is valid when pradtl no = schmid no = 1

→ It is not valid for viscous sublayer, where the molecular diffusivities becomes important.

$$\boxed{\frac{f}{2} = \frac{h}{\rho v C_p} = \frac{k_c}{v}}$$

Chilton Colburn Analogy :-
It is valid for both turbulence & laminar.

$$\boxed{\frac{f}{2} = \underbrace{\frac{h}{\rho C_p v}(Pr)^{2/3}}_{J_H} = \underbrace{\frac{k_c}{v}(Sc)^{2/3}}_{J_D}}$$

$$\boxed{\frac{f}{2} = J_H = J_D}$$

Determination of Mass Transfer coefficient :-

The avg. mass flux can be calculated from
→ the known area of the ~~vecte~~ wetted section of the ~~area~~ wall.
→ Moisture content at the inlet and outlet of the column
→ Avg. driving force, which the diff. btw the pres of moisture in air & water.

$$* \quad \boxed{k = \frac{\frac{\Delta m}{\Delta t \cdot A}}{P_A - P_{Ai}}}$$

For diff. fluids at diff concentrations, at the diff tyms, I can repeat the experiment. So that a co-relation can be generated.

## Theories of Mass Transfer:-

### Film Theory:-

It is given by Whitman in 1923, and it consider mass transfer from a solid to flowing liquid.

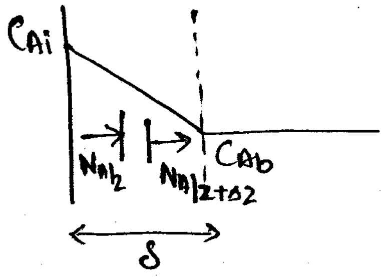
Assumptions:-

1.) MT occurs purely by molecular diffusion at the phase boundary (wall.)

2.) The M.T through the film occurs at steady state.

3.) Bulk flow term will be neglible at the phase boundary, hence it is neglected.

After the film, the fluid is well mixed having the concentration which is the same as that of the bulk fluid concentration. ($C_{Ab}$)



$$\frac{dN_A}{dz} = 0$$

$$N_A = Nx_A + J_A$$

$$\frac{d\left(-D_{AB}\frac{dC_A}{dz}\right)}{dz} = 0$$

$$-D_{AB}\frac{d^2C_A}{dz^2} = 0$$

$$z=0\ ,\ C_A = C_{Ai}$$
$$z=\delta\ ,\ C_A = C_{Ab}$$

$$\cancel{-D_{AB}\int}$$
$$\cancel{-D_{AB}\int d^2C_A} = \cancel{\int dz^2}$$
$$\Rightarrow \cancel{-D_{AB}}\ C_A -$$

$$\frac{d^2C_A}{dz^2} = 0$$
$$\frac{dC_A}{dz} = C_1$$
$$dC_A = C_1 dz$$
$$C_A = C_1 z + C_2$$

$$C_A = C_{Ai} - (C_{Ai} - C_{Ab})\frac{z}{\delta}$$
$$\frac{dC_A}{dz} = -\frac{(C_{Ai} - C_{Ao})}{\delta}$$
$$N_A\Big|_{z=0} = -D_{AB}\frac{dC_A}{dz}$$
$$= -D_{AB}\left(-\frac{(C_{Ai} - C_{Ao})}{\cancel{\delta}\ \delta}\right)$$
$$= \frac{D_{AB}}{\delta}(C_{Ai} - C_{Ao})$$
$$\boxed{k = D_{AB}/\delta}$$

$$k \propto D_{AB}$$
$k \propto 1/\delta$ Boundary layer thickness ↑, k↓,

<u>Profile of concentration</u> — Linear.

## Penetration theory :-

It is given by HIGBIE, Mass transfer from a rising bubble

As the bubble rises, liquid elements from the bulk reach the top of the bubble move along its pheripheri, reach its bottom, then get detached from it. and detached liquid elements eventually get mixed up wid the bulk of liquid.

Assumptions:-

1> Unsteady state mass transfer occurs to a liquid elements as long as it is contact wid the bubble.

2> Equilibrium exist at the gas-liquid interphase.

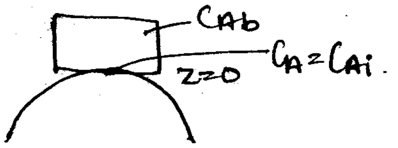
* 3> Each of the liquid element, stay in contact with the gas for the same period of tym.

4> ⇒ $$\boxed{\frac{\partial^2 C_A}{\partial x^2} = \frac{1}{D_{AB}}\frac{\partial C_A}{\partial t}}$$

Initial condition - $t = 0$ , $z \geq 0$ , $C_A = C_{Ab}$

Boundary condition
- $t \geq 0$ , $z = 0$ , $C_A = C_{Ai}$
- $t \geq 0$ , $z > 0$ , $C_A = C_{Ab}$

4> The liquid element will be of infinite thickness.



$$\boxed{\frac{C_A - C_{Ab}}{C_{Ai} - C_{Ab}} = 1 - \text{erf}\,\eta}$$

$$\eta = \frac{z}{2\sqrt{D_{AB}t}}$$

$$\boxed{N_A\Big|_{z=0} = \sqrt{\frac{D_{AB}}{\pi t}}\,(C_{Ai} - C_{Ab})}$$

$$\boxed{k_m = \sqrt{\frac{D_{AB}}{\pi t}}}$$

↓ instantenous M-T coeff.

$$\boxed{k_{Avg} = 2\sqrt{\frac{D_{AB}}{\pi t_c}}}$$

$$\boxed{N_{A\,avg} = \frac{1}{t}\int_0^{t_c} N_A\,dt}$$

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## Surface Renewal Theory:-

It is given by DANCKWERT in 1951, The draw back of penetration theory is the assumption that the contact tym is same for all the liquid element. In turbulent medium some of the liquid elements are swept away and some continue to be in contact for long tym. There will be a distribution of edge for the liquid elements present at the interphase at any moment.

### Assumptions:-

1) Liquid element at the interphase are being randomly replaced by the fresh element from the bulk.
2) At any moment, each of the liquid elements at the surface has the same probability of being replaced.

$$\boxed{k = \sqrt{D_{AB} \cdot S}}$$

where S = fraction of surface area renewed in unit tym.

| Name | Founder | Assumptions | Dependence of K |
|---|---|---|---|
| Film Theory | Whitman 1923 | MT occurs purely by molecular diffusion at phase boundary<br>Steady state<br>Bulk flow term is negligible | $K \propto \overline{D_{AB}}$<br>$\propto 1/\delta$ |
| Penetration Theory | HIGBIE | Unsteady state<br>Equilibrium exist at gas-liq interphase.<br>Contact tym of each liq element with gas is same.<br>Liquid element will be of infite thickness. | |

## Raoult's Law :—

For an ideal gas liquid or vapour liquid System equilibrium relationship can be determine by raoult's law

$$P_A^* = x_A P_A^v$$

$P_A^*$ = equilibrium partial pres. exerted by the solute

$x_A$ = Mole fraction of the solute A in the liquid.

$P_A^v$ = Vap. press of A at a given temp.

Henry's Law:-

It gives the equilibrium data for non-ideal ~~sol~~ systems at low concentration.

$$\boxed{p_A^* = x_A H}$$

H = Henry's Constant
increases with increase in temp.

$$\boxed{y_A^* = x_A m}$$

$$\boxed{p_A^* = C_A H'}$$

Mass transfer between two phases :-

Mass transfer from one phase (say the gas phase G) to another phase (say the liquid phase L), involve following sequenical step.

⇒ Solute A is transported ~~the~~ from the bulk of the gas phase to 'gas liq. interphase bcz of some driving force say $(y_{Ab} - y_{Ai})$.

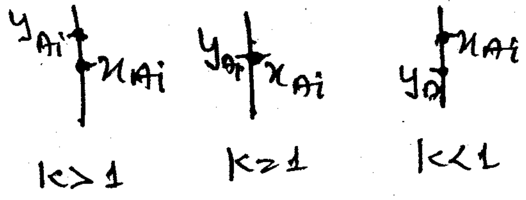
$y_{Ab}$ = Mole fraction of A in ~~gas~~ bulk of gas.
$y_{Ai}$ = " " " " on the gas-liquid interphase on the gas side.

Solute A is absorbed by the liquid phase at the gas liquid interphase such that the two concentrations are related by an equilibrium relationship.

$$y_{Ai} = \phi(x_{Ai})$$

or it is given by distribution coeff. k.

Where $k = \dfrac{y_{Ai}}{x_{Ai}}$



The absorbed solute is transported from the gasliquid interphase to the bulk of liquid bcz of some driving force which ($x_{Ai}-x_{Ab}$)

$x_{Ai}$ = Mole fraction of A at the gas-liquid interphase on liquid side

$x_{Ab}$ = " " " " in the bulk of liquid.

$$\lim_{z\to 0^+} x_A = x_{Ai}$$

$$\lim_{z\to 0} y_A = y_{Ai}$$

The concept of interphase is totally hypothetical and ~~has~~ there is no practical significance. but we study it, to study the concept of mass transfer.

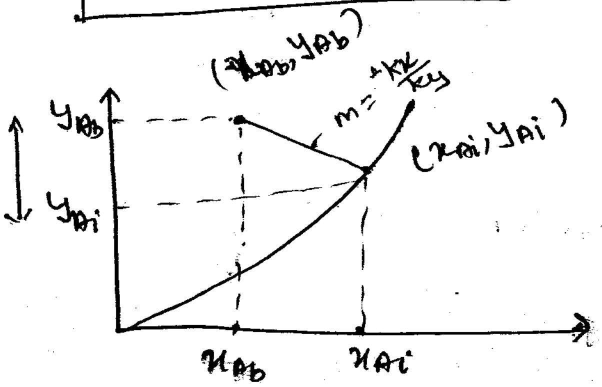
## Determination of interfacial concentration:-

$$N_A = k_y(y_{Ab}-y_{Ai})$$

$$= k_x(x_{Ai}-x_{Ab})$$

Steady state
No accumulation
& no generation.

$$\boxed{\frac{y_{Ab}-y_{Ai}}{x_{Ab}-x_{Ai}} = \frac{-k_x}{k_y}}$$ — slope of line

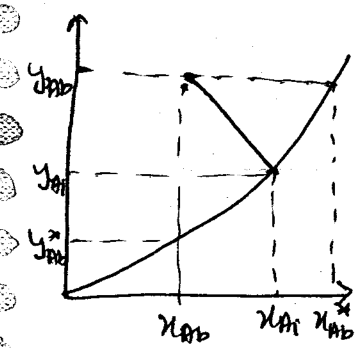


Since the concept of interface is hypothetical. Determination of interfacial concentrations accurately is impossible to solve this problem, we introduce the concept of <u>overall mass transfer coefficient</u>.

Overall M.T coff. is analogous to overall H.T coeff. and for that overall driving force may be defined as based on the liquid side or based on the gas side.

$$N_A = K_y(y_{Ab} - y^*_{Ab})$$

$$= K_x(x^*_{Ab} - x_{Ab})$$



$K_y$ & $K_x$ = Overall M.T coeff based on gas & liquid sides.

$y^*_{Ab}$ = Concn in a gas phase, which can remain in equilibrium ~~for~~ with the bulk liq. phase concentration $x_{Ab}$.

$x^*_{Ab}$ = Concn in a liquid phase, which can remain in equilibrium with the bulk gas phase concentration $y_{Ab}$.

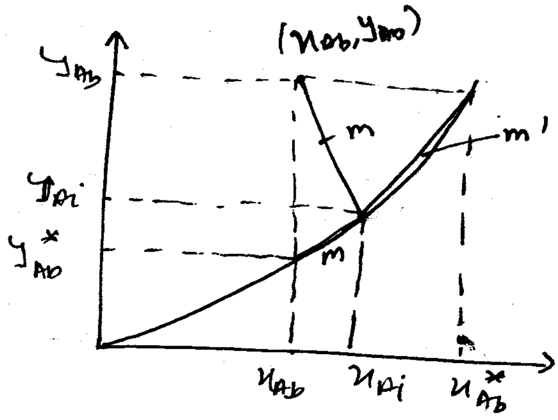
Determination of overall M.T coeff

gas side

$$y_{Ab} - y^*_{Ab} = (y_{Ab} - y_{Ai}) + (y_{Ai} - y^*_{Ab})$$

$$\frac{N_A}{K_y} = \frac{N_A}{k_y} + \frac{N_A}{K_x}$$

$$\frac{1}{K_y} = \frac{1}{k_y} + m\frac{1}{K_x}$$



for Liquids

$$(x_{Ab}^{*} - x_{Ab}) = (x_{Ab}^{*} - x_{Ai}) + (x_{Ai} - x_{Ab})$$

$$= \frac{(x_{Ab}^{*} - x_{Ai})}{(y_{Ab} - y_{Ai})} \times (y_{Ab} - y_{Ai}) + (x_{Ai} - x_{Ab})$$

$$\frac{N_A}{K_x} = \frac{N_A}{m' k_y} + \frac{N_A}{k_x}$$

$$\boxed{\frac{1}{K_x} = \frac{1}{m' k_y} + \frac{1}{k_x}}$$

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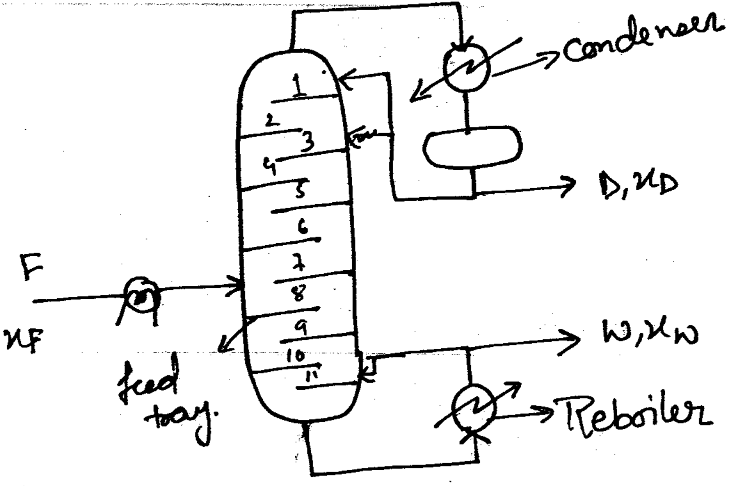
## Distillation



Q:) Why Reboiler partially evaporised the feed not totally?

Q:) Do we alwaz use a condenser (complete condensation)?

*Q:) How much reflux is needed?

Q:) How many types of feed are there & on which plate we introduce the feed?

Q:) The total no. of tray required in a column are?

Q:) General problem during the working of a distillation column.

Q:) Why trays are used not packing?

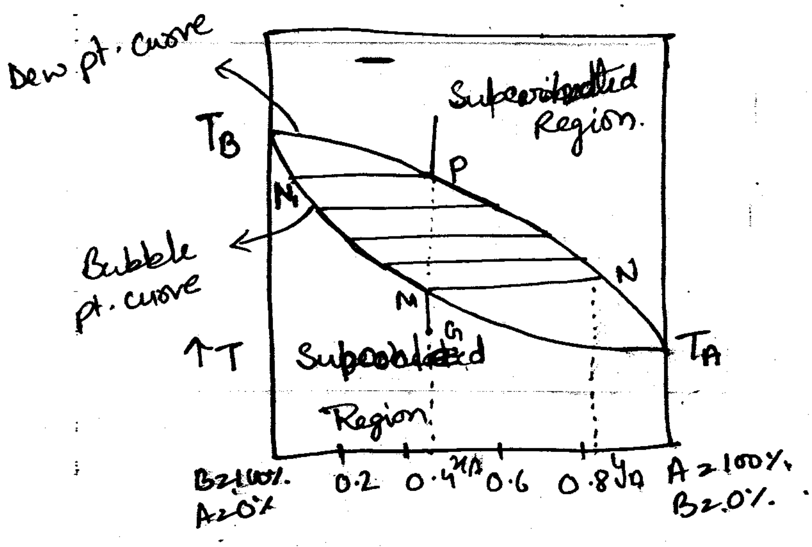
Distillation is the technique of separation of more volatile component from the less volatile ones in a feed solution by partial vaporization of the feed followed by condensation.

In distillation, there are 4 parameters (temp., press, liq composition, vap. comp). If we fix any two of them then the system will be define and in general we fix mainly temp & pressure. So that a data of xy can be generated.

$F = C - P + 2$
$= 2 - 2 + 2 = 2$.
2 variable should be constant.

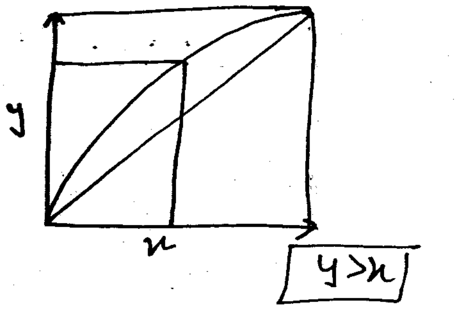
DOF, tells us the system is defined
If DOF is zero then it is defined
If DOF is 1, then we should make 1 variable [illegible] to make it defined

## T-xy diagram :-

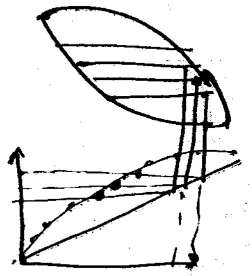


x→ A → increases

B → decreases.



$\boxed{y>x}$



How to draw xy curve.

Suppose a fix temp. & composition of liquid is considered at G, It is heated and when the temp. reaches the pt M, it starts boiling (as bubble pt). The composition of the first vapour so produced can be find out by the point M. Here MN is a tie line, which gives the equilibrium relationship between x & y. Clearly the more volatile component A is rich in the vapour phase i.e $\boxed{y^*>x}$ which is the required condition for the distillation to take place. As the heating proceed the pt. $N_1$ ~~give~~ came when all the liquid is vapourised and last drop of the liquid is left. If we continue heating then the mixture shift into superheated region and vice-versa. The set of x-y so generated can be plotted on the x-y curve, such that the equilibrium line alwaz lie above the diagonal line at each and every pt.

Q.> For a binary mixture of A & B ; saturation temp are given $T_A = 49.2°C$ , $T_B = 80°C$ . The experiment is carried out at 70°C & total pressure is 1 atm

$$\ln P = A' - \frac{B'}{C+T}$$

T °C
P = mm of Hg.

$A' = 15.8602$
$B' = 2589.2$
$C' = 231.36$
for A component

$$\boxed{y_A = \frac{P_A}{P} = \frac{x_A P_A^v}{P}}$$

$A = 15.9037$
$B = 2789.01$
$C = 220.79$
for B component

Find the composition of more volatile in the vapour phase and the solution is ideal.

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## Relative Volatility:-

Ease of separation of component A from component B. or concentration ratio of A to B in the vapour phase to the same ratio in the liquid phase.

$$\boxed{\alpha = \frac{(y_A/y_B)}{(x_A/x_B)}} = \frac{\frac{y}{1-y}}{\frac{x}{1-x}} = \frac{y(1-x)}{x(1-y)}$$

$$\boxed{y = \frac{\alpha x}{1+(\alpha-1)x}}$$

$$\boxed{\alpha = \frac{P_A^v}{P_B^v}}$$

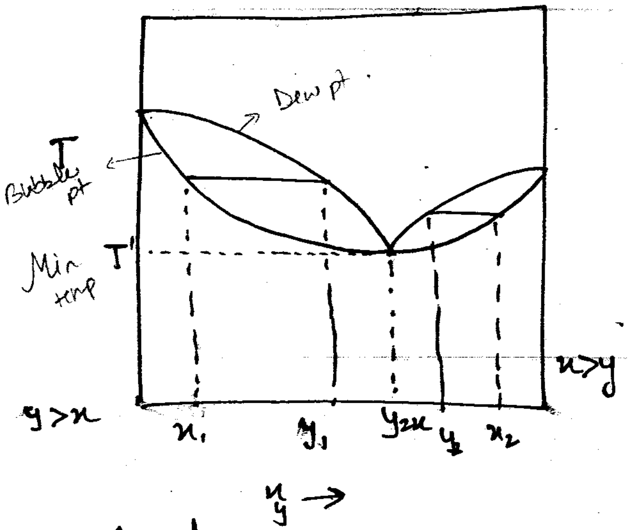
$$\frac{\frac{P_A/P}{P_B/P}}{\frac{P_A/P_A^v}{P_B/P_B^v}}$$

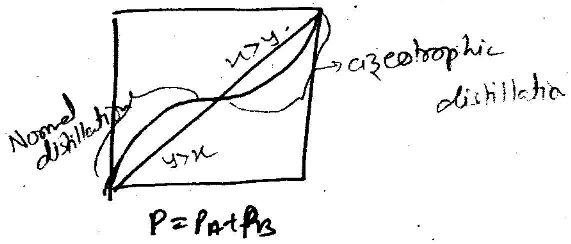
$$\boxed{\alpha = \frac{\exp\left(A - \frac{B}{C+T}\right)}{\exp\left(A' - \frac{B'}{C'+T}\right)}}$$

**Azeotrope:-** A solution which is highly ~~known~~ non- ideal often forms an azeotrope and azeotrope is defined as the mixture ~~at~~ which composition of more volatile is same to that in the liquid phase.

$$\boxed{y^* = x}$$

## Minimum boiling Azeotrope :-

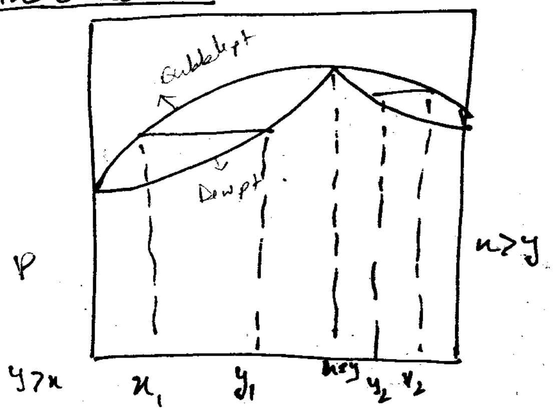




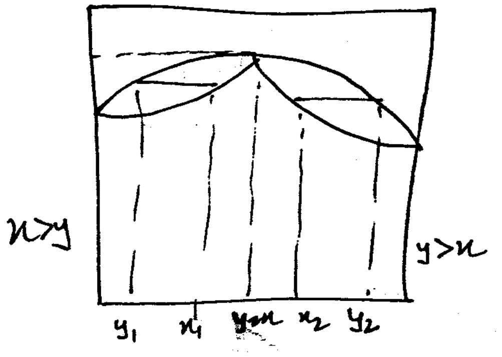
$P = P_A + P_B$

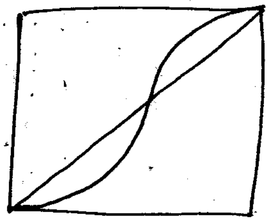
$P = x_A P_A^v + (1 - x_A) P_B^v$

## Positive deviation :-

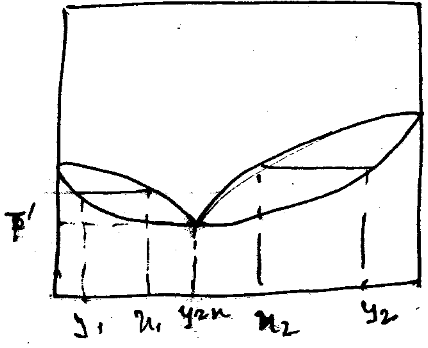


## Maximum Boiling Azeotrope :-





## Negative deviation :-



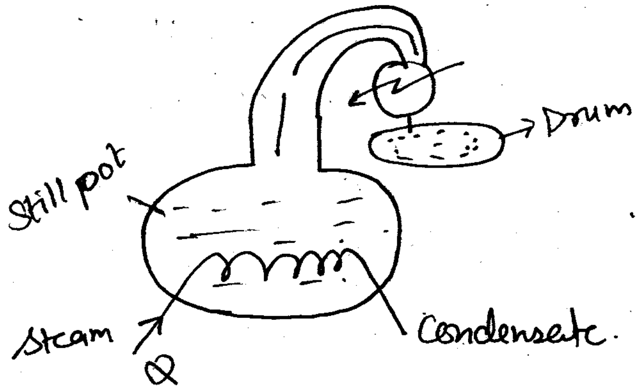
If the desired separation involve the crossing the azeotrophic composition, It is generally not possible to separate components by normal distillation.

$$y = \frac{p_A}{P}$$

activity coeff for vapour phase ← $\boxed{\phi_A^v P y_A = x_A P_A^v \gamma_A}$ activity coeff for liquid phase.

## ***Batch Distillation:–

- The feed is charged to a steel pot into which heat is supplied continously through a steam jacket.
- As the mixture boils, vapours which in more volatile component will form and as it continues concentration of more volatile in the liquid will decrease.
- The vapour are led to a condenser and the condensate ~~as~~ is collected ~~to~~ in the drum.
- At the begning, the condensate will be rich in the more volatiles. but as it continues concencentration of more volatile in the drum will decrease.
- Condensate is usually withdrawn tym to tym having pelts of diff. concentration.



**Mathematical formulation**

Let F be the no. of moles initially in the still pot. After the distillation begin, ~~let~~ let at any moment no. of moles ~~in~~ of liquid present in the still be L with a mole fraction of $x$. Let the moles of condensate will be D with a mole fraction of $y^*$

Material Balance

vaporizes so we use -ve sign

$$\ominus dL = dD$$

differentiating

$$-d(Lx) = y^* dD$$

fraction of more volatile

component Balance

$$-Ldx - x\cancel{dL} = y^*(-dL)$$

vapour & liquid are in equilibrium.

$$\boxed{\frac{dx}{y^* - x} = \frac{dL}{L}}$$

$$\int_F^W \frac{dL}{L} = \int_{x_F}^{x_W} \frac{dx}{y^* - x}$$

$$\boxed{\ln\frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y^* - x}}$$

Rayleigh Eqn

## Solution of Rayleigh Eqn

$$\boxed{y^* = \frac{\alpha x}{1 + (\alpha - 1)x}}$$

$$\ln\frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{\frac{\alpha x}{1+(\alpha-1)x} - x} = \int_{x_W}^{x_I} \frac{dx}{x\left[\frac{\alpha - 1 - (\alpha-1)x}{1+(\alpha-1)x}\right]}$$

$$= \int \frac{dx[1 + (\alpha-1)x]}{x[\alpha - 1 - 2x + x]} = \int \frac{1 + (\alpha-1)x\,dx}{x(\alpha-1)(1-x)}$$

$$= \int \frac{dx}{(\alpha-1)x(1-x)} + \int \frac{dx}{1-x} = \frac{1}{\alpha-1}\left[\frac{dx}{x} + \frac{dx}{(1-x)}\right] + \frac{\ln|1-x|}{-1}\Bigg|_{x_W}^{x_F}$$

$$= \left\{\frac{1}{\alpha-1}\left[\ln x - \ln|1-x|\right] - \ln|1-x|\right\}\Bigg|_{x_W}^{x_F}$$

For the question of batch distillation we can use only these 3 eqn first one is when

$$\boxed{\ln\left[\frac{F x_F}{W x_W}\right] = \alpha \ln\left[\frac{F(1-x_F)}{W(1-x_W)}\right]}$$

valid only if $\alpha$ is constant

$$F = D + W$$

$$F x_F = D x_D + W x_W$$

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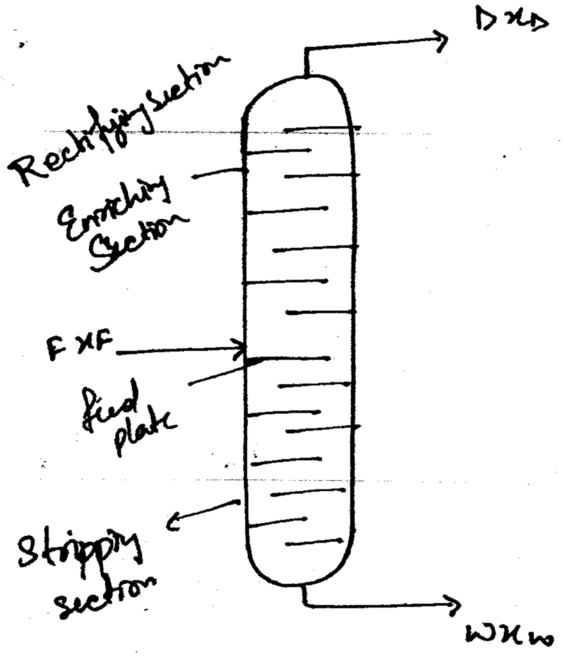
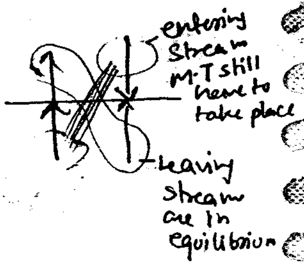


Section above feed plate the

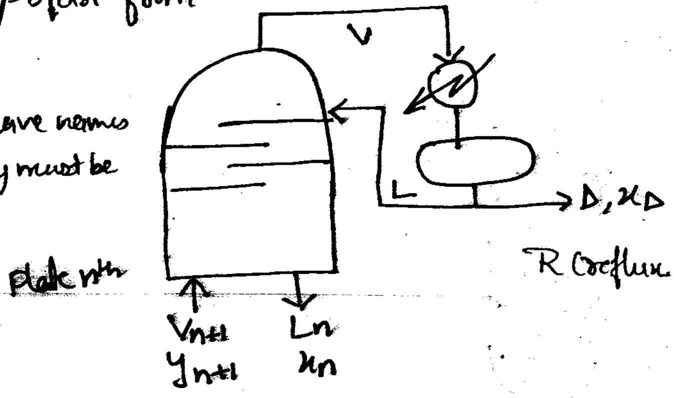
- Section below the feed plate more volatile component is stripped out of the liquid to get a relatively pure B at the bottom. Therefor it is named as stripping section.

✱✱ The molecules of more volatile leaving the liquid phase absorbs latent heat of vapourization. Also molecules of less volatile in the vapour phase condensed by release of latent heat of vaporization. By this process M.T takes place.



## Enriching Section:-

- Counting of trays start from the top.
- Streams must have names of plates and they must be leaving



R (reflux) $= L/D$

$$V_{n+1} = L_n + D$$

**Assumption**

constant molar overflow (cmo). i.e the no. of moles of more volatile vaporized is equals to no. of moles of less volatile condensed.

For enriching section
$$\boxed{\begin{aligned} V_1 &= V_2 = V_3 \cdots = V_{n+1} \\ L_1 &= L_2 = L_3 \cdots = L_{n+1} \end{aligned}}$$

$$V_{n+1} y_{n+1} = L_n x_n + D x_D$$

$$\boxed{y_{n+1} = \frac{L}{V} x_n + \frac{D}{V} x_D.}$$

So suffixes are drops from plates but not from concentration

$$= \frac{L/D}{V/D} x_n + \frac{x_D}{V/D}$$

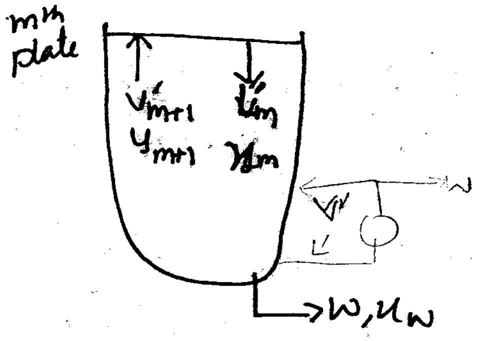
$$\boxed{y_{n+1} = \underbrace{\frac{R}{R+1}}_{m} x_n + \underbrace{\frac{x_D}{R+1}}_{c}}$$

$$R = (L/D)_{\text{rectifying}} = \left(\frac{\text{Amt feed back}}{\text{" withdraw}}\right)$$

$$R+1 = L/D + 1 = \frac{L+D}{D} = \frac{V}{D}$$

$$\boxed{\begin{aligned} x_n &= x_D \\ y_{n+1} &= x_D \end{aligned}}$$

## Stripping Section:-



$$R = L/D \text{ in } \sim$$

$$R_v = V'/W$$

$$R_v + 1 = \frac{V'}{W} + 1 = \frac{V'+W}{W} = \frac{L'}{W}$$

$$L' = V' + W$$

$$L' x_m = V' y_{m+1} + W x_W$$

$$R_v = \frac{V'}{W} = \left(\frac{\text{Amt fed back}}{\text{" withdrawn}}\right)$$

boilup ratio

$$y_{m+1} = \frac{L'}{V'} x_m - \frac{W}{V'} x_W$$

$$= \frac{L'/W}{V'/W} x_m - \frac{W/W}{V'/W} x_W$$

$$\boxed{y_{m+1} = \frac{R_v+1}{R_v}x_m - \frac{x_w}{R_v}}$$

for enriching section
Slope of line $\frac{R}{R+1}$ where $R = L/D$
Intercept of line $\frac{x_D}{R+1}$
intersection pt $(x_D, x_D)$

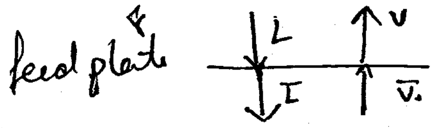
pt $(x_D, x_D)$ satisfies the line.

* $y_{m+1} = \frac{R_v+1}{R_v}x_m - \frac{x_w}{R_v}$, slope $= \frac{R_v+1}{R_v} \Rightarrow R_v = \frac{V'}{W}$, intercept $= \frac{-x_w}{R_v}$

$x$ as $x_w$.

⇒ So again $(x_w, x_w)$ satisfy the line. (intersection pt)

Feed Plate:-



q = fraction of feed i.e in liquid.

$$\boxed{V = \bar{V} + (1-q)F}$$

$$\boxed{\bar{L} = L + qF}$$

$$\frac{V-\bar{V}}{F} = (1-q), \quad \frac{(\bar{L}-L)}{F} = q.$$

$V = L + D \to$ (i) —— $Vy = Lx + Dx_D$
$L' = V' + W \to$ (ii) —— $L'x = V'y + Wx_W$

adding (i) & (ii)

$$\frac{(V-\bar{V})y}{F} = \frac{(L-\bar{L})x}{F} + \frac{Dx_D + Wx_W}{F}$$

$$(1-q)y = qx + x_F$$

$$\boxed{y = \frac{-q}{1-q}x + \frac{x_F}{1-q}}$$

Slope $= -q/_{1-q}$ , intercept $= x_F/_{1-q}$ and intersection pt is $(x_F, x_F)$.

$\boxed{y = x}$

Defination of q :-

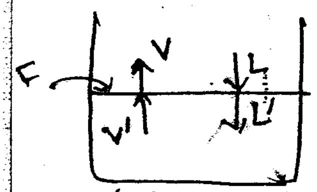
$$\boxed{q = \frac{\text{heat required to change the feed from saturated liquid to saturated vapour}}{\text{molar latent heat of vapourization}}}$$

Types of feed {Vapour stream & liquid stream are at their sat. level} assumption

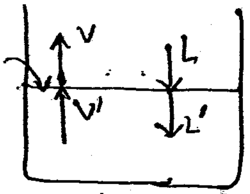
Saturated liquid :- $q = 1$

Partial liquid : or partial vapour $0 < q < 1$

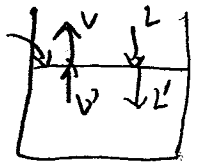
Saturated Vapour $q = 0$



$L' > L$
$V' = V$



$L' > L$
$V > V'$



$L = L'$
$V > V'$

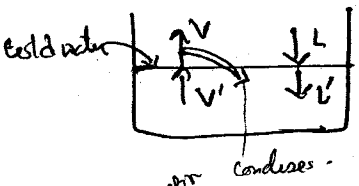
(below sat. temp)
Cold liquid :- $q > 1$

$$\frac{\text{Sensible + latent}}{\text{latent}}$$

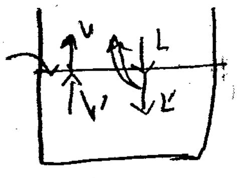
Superheated Vapour

−ve (numerator)

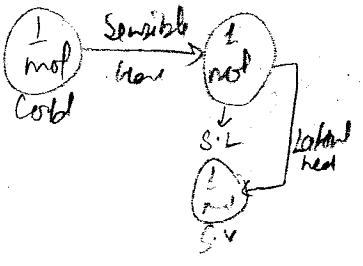
$q < 0$



stripping section flowrates are greater $L' > L$
$V' > V$



$V > V'$ $L' < L$
enriching section flowrates are greater.



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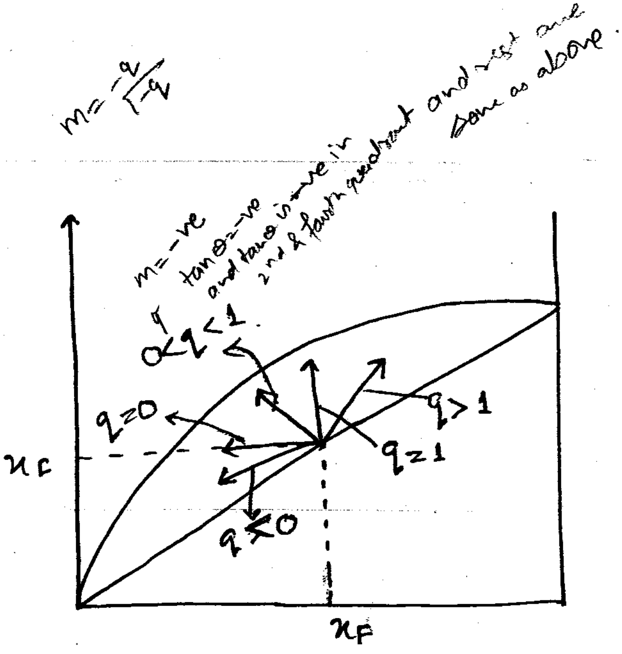
In general form.

$$A + B = C$$

$$\frac{A}{B} = \frac{x_B - x_C}{x_C - x_A} \qquad \frac{B}{A} = \frac{x_A - x_C}{x_C - x_B}$$

$$\frac{C}{A} = \frac{x_A - x_B}{x_C - x_B} \qquad \frac{B}{C} = \frac{x_C - x_A}{x_B - x_A}$$

## q - lines :-



q - lines never intersect the equilibrium line bcz these happens only in ideal conditions

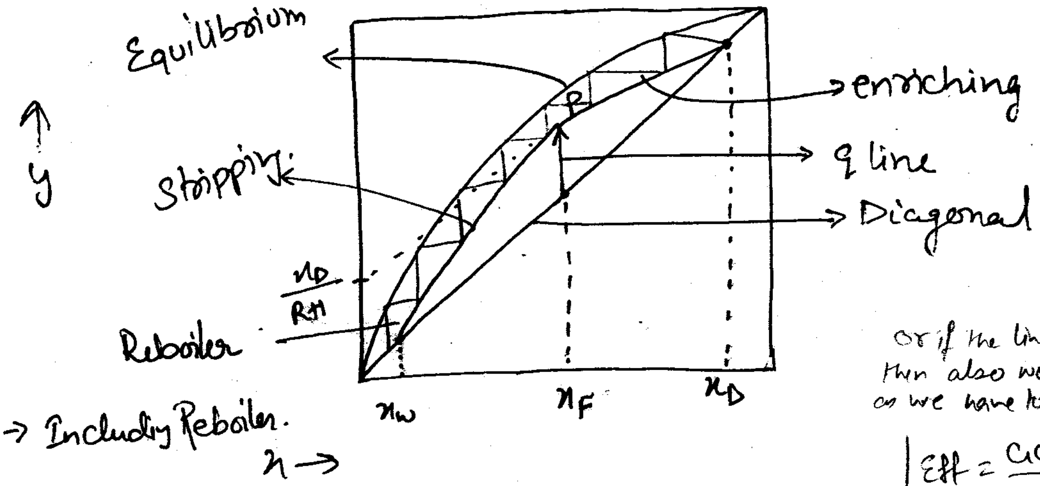
## Mc-Cabe Thiele diagram :—

Assumptions.

i.) Constant Molar heat of vaporization. { no. of moles of vapor condensed in the condenser is equal to the no. of moles of liquid vaporized in the reboiler. }

ii.) Constant Molar overflow { $V_1 = V_2 = V_3 \cdots = V_n$ } { $L_1 = L_2 = L_3 = \cdots = L_n$ }

iii.) No need to take energy balance bcz, ~~ho~~ no heat loss & gain are there.



N → Including Reboiler.

last Δ should include the pt $x_w$. in it, if triangle is just above the the $x_w$ then one more triangle is should be formed. or if the line is exactly on $x_w$ then also we draw a triangle as we have to cross this pt

$$Eff = \frac{\text{actual no. of tray}}{\text{ideal no. of tray}}$$

⇒ Mark the pts $x_D$, $x_F$ & $x_w$ on the diag.

⇒ Calculate the intercept for the enriching line :

in Mc-cabe Thiele ideal no. of tray is found.

» Join $x_D$ with the intercept.

» Draw q-line based on the value of q and intersect this line with the enriching line and mark the pt as P.

» Join pt $x_w$ with P, to get the stripping line.

total no. of tray N, and N incluing Reboiler.

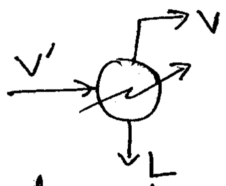
Reboiler act as a tray, bcz separation of Vapour-liq takes place in the reboiler

## Reboiler act as a pressure filler:-

Reboiler act as a pressure filler as it boils the liquids and changes its phase into vapour and increases the pressure.

## Partial Condenser:-

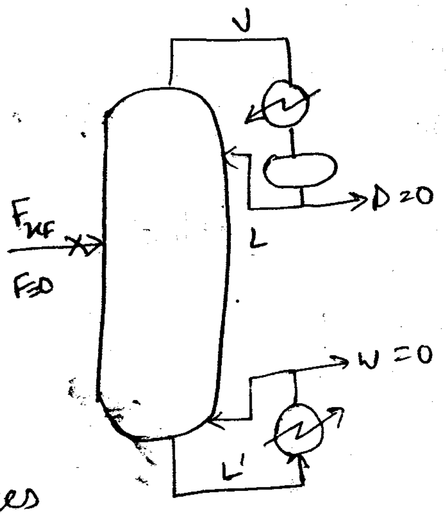
then total no. of tray is N-2,



» Partial condenser is used, when the desired pdt is vapour.

» When there is difficulty to condense all of the vapour.

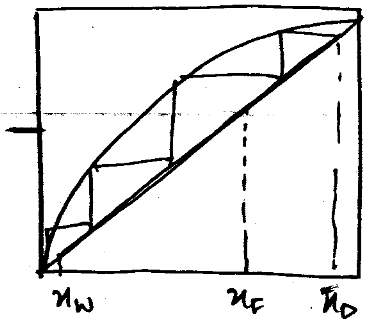
## Total Reflux Ratio:-



1.) The slope of enriching line is given by $\frac{R_\infty}{R_\infty+1} \simeq 1$, in the

Same way the slope of Stripping line is $\frac{R_v}{R_v+1} \simeq 1$.

This means that all the lines merges with diagonal line.



Total no. of trays required in this condition is minimum. therefore fixed cost decreases, but the duty of reboiler and condenser increases therefore operating cost increases.

Feed is once fed, afterwards F=0, D=0, W=0, then that condition is known as total reflux condition and it is denoted by $R_\infty$.

Total reflux condition is used in the start-up of the plant to achieve the desired purity or to achieve equilibrium condition in the column.

## Minimum Reflux Ratio :- ($R_{min}$)

At the condition of minimum reflux ratio, the no. of trays required are maximum, therefore the fixed cost increases but the duty in this case is minimum and the operating cost decreases.

~~Roptimum is 1.1 – 1.4~~.

$$\boxed{R_{opt} = 1.1 \text{ to } 1.4\, R_{min}}$$

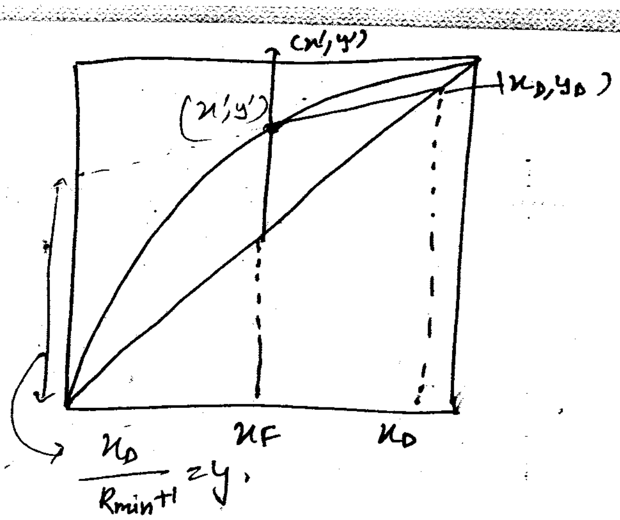
## Calculation of $R_{min}$ :-

The pt. of intersection of ~~equilib~~ q-line, enriching line and equilibrium line is noted and slope i.e $\frac{R_{min}}{R_{min}+1}$ is calculated by $= \frac{x_D - y'}{x_D - x'}$,

$$\frac{R_{min}}{R_{min}+1} = \frac{x_D - y'}{x_D - x'}$$

$$\boxed{R_{min} = \frac{x_D - y'}{y' - x'}}$$

$(x', y')$ · equilibrium pt.

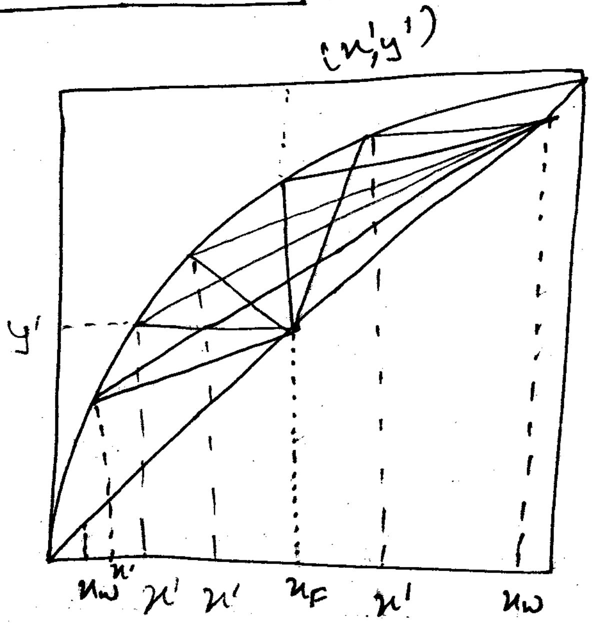


Rmin is more when intercept is less.

$$(y)_{\substack{\text{saturated}\\ \text{liquid}}} > (y)_{\substack{\text{saturated}\\ \text{Vapour}}}$$

$$\left(\frac{x_D}{R_{min}+1}\right)_{SL} > \left(\frac{x_D}{R_{min}+1}\right)_{SV}$$

$$\boxed{(R_{min})_{SL} < (R_{min})_{SV}}$$



» $x' = x_F$
⇓
Saturated Liquid.

» $x' > x_F$ or $x' < x_D$
⇓
Cold Liquid.

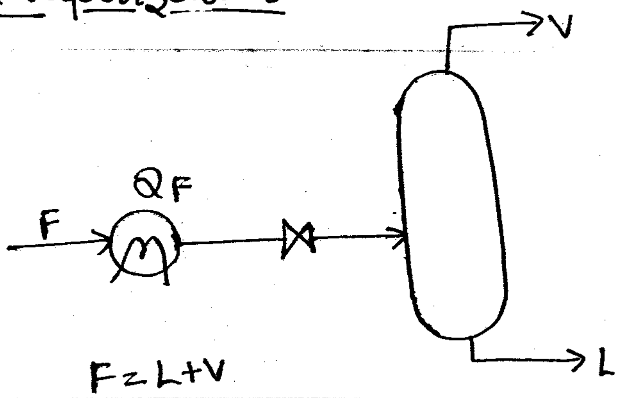
» $x' < x_F \Rightarrow$ Partial Liq

» $y' = x_F \Rightarrow$ Sat. Vap.

» $x' < x_W \Rightarrow$ Superheated Vapour.

$$(R_{min})_{q>1} < (R_{min})_{q=1} < (R_{min})_{0<q<1} < (R_{min})_{q=0} < (R_{min})_{q<0}$$

## ✱ Flash Vaporization :-



$$F = L + V$$

$$F x_F = L x + V y$$

$$F H_F + Q_F = L H_W + V H_D$$

~~Flash Vapourization is simply a stage in which rate of V & L is equal or we seu~~

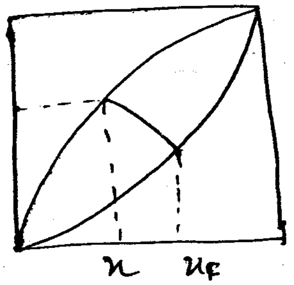
- In this operation, a liquid solution is partially vaporized to generate vapours which are allowed to establish equilibrium with the residual liquid.
- Enough tym is given to the separator, such that the vapour and liquid streams come in equilibrium.
- Flash distillation is also known as ideal distillation or equilibrium distillation, or flash vapourization bcz the liquid and the vapour streams are alwaz in equilibrium.
- A flash distillation unit corresponds to an ideal tray in a Mc-cabe theile diagram. Therefore a continous distillation unit consisting of n ideal trays can be assumed as a network of n-flash distillation unit.
- For the case of flash distillation.

$$F = L + V$$

$$F x_F = L x + V y^* \quad \text{Component balance.}$$

$$\underbrace{F H_F}_{\text{enthalpy of feed}} + Q_H = \underbrace{L H_W}_{\text{enthalpy of btm pdt}} + V H_D \longrightarrow \text{enthalpy of distillate.}$$

$Q_F$ = Heat duty given to the flash distillation unit.



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## Underwood- Fenske Eqn:—

These are used to calculate min reflux ratio.

i) Feed is saturated vapour:-

$$q=0$$

$$R_{min} = \frac{1}{\alpha-1}\left[\alpha\frac{x_D}{x_F} - \frac{(1-x_D)}{(1-x_F)}\right] - 1$$

ii) Feed is saturated liquid:-

$$q=1$$

$$R_{min} = \frac{1}{\alpha-1}\left[\frac{x_D}{x_F} - \alpha\frac{(1-x_D)}{(1-x_F)}\right]$$

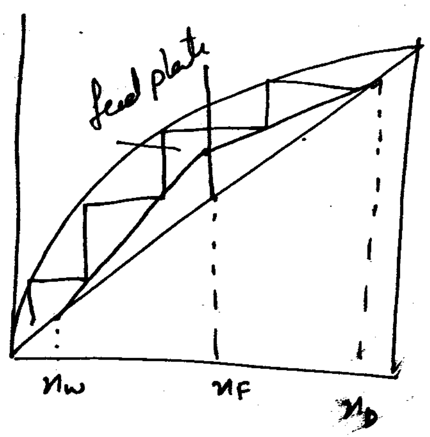
## Fenske Eqn:—

Fenske Eqn for the calculation of minimum no. of ideal trays at the condition of total reflux.

$$\boxed{N_m \underset{\text{Reboiler}}{\underbrace{+1}} = \frac{\ln\left(\frac{x_D(1-x_W)}{x_W(1-x_D)}\right)}{\ln\alpha}}$$

## Introduction of feed :-

In general for the vapour feed, we introduce the feed below the middle section (bottom). If the feed is more in liquid, we introduce it above the middle section (top). The actual location of feed plate be ~~don~~ determine by the Mc-cabe theile dig. The triangle containg the pt $x_F$ in the Mc-cabe theil is the feed plate



## Entrainment :-

liquid carried by vapour upto the tray above and it is caused by high vapour flow rate.

i) It will contaminate the high purity distillate.

ii) Excessive entrainment can led to flooding.

## Flooding :-

It is caused by the excessive vapour flow, causing liquid to be entrained in the vapour up the column, liquid cannt come down through the downcomer and also through the holes and ultimately distillation process stop. It is indicated by sharp increase in column pressure. drop

## Weeping :-

It is caused by the low vapour flow rate. Pressure exerted by the vapour is insufficient to hold up the liquid on the tray. Therefore liquids starts to leave the hole. It is indicated by sharp decrease in column pressure.

## Calculation of the column diameter :-

$$m = \rho A V$$

$$\boxed{\text{Molar Flow Rate} = \frac{\rho}{M} A V} \rightarrow \pi/4 d^2 - \text{Downcomer}$$

A = Area of tray except ~~diameter~~ downcomer

V = operating flooding Velocity.

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## Efficiencies in distillation :-

i) Overall Efficiency ($\eta_o$):— (used for whole column)

Ratio of ideal no. of plates required by act. or real no. of plate required.

ii) Murphree plate Efficiency ($\eta_m$):— (used for plate)

$$\frac{\text{Actual mass transfer}}{\text{Ideal mass transfer}}$$

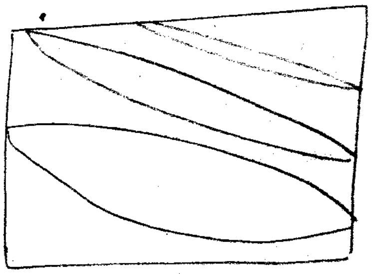
$\eta_m$ can exceed 100% in some cases

iii) Point Efficiency ($\eta_p$):—

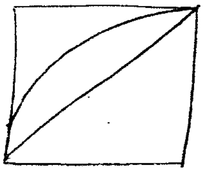
$$\frac{\text{Actual mass transfer}}{\text{Ideal mass transfer}}.$$

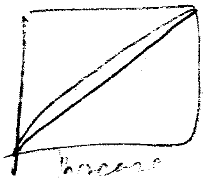
## Effect of Pressure on Distillation :—

1) As pressure increases Txy diagram shifts upwards and the width become narrower and vice versa

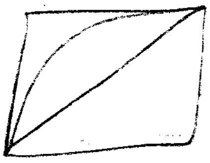


2) As pressure increases equilibrium line shift towards the diagonal line



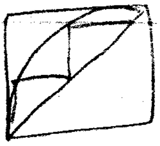


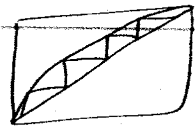
increase pres.



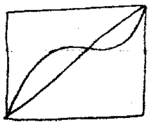
decrease pr.

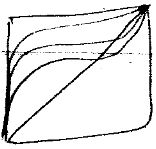
3> When pressure decreases, the no. of plate required for the distillation also decrease.





4.> In case of azeotrope, by decreasing the pressure azeotropic pt can be removed.



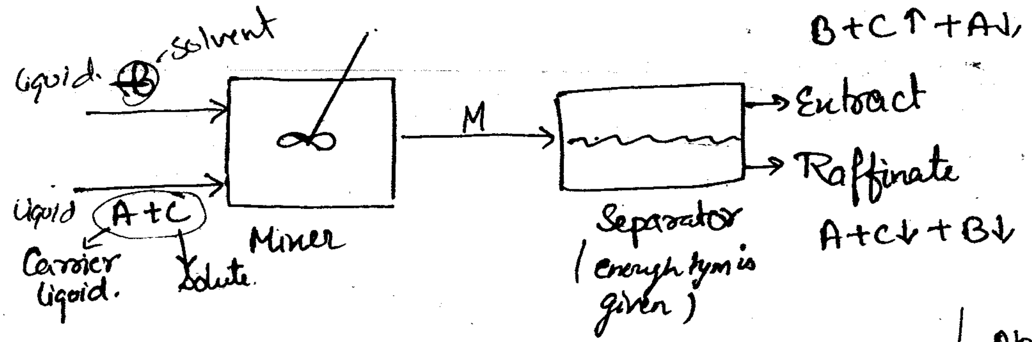


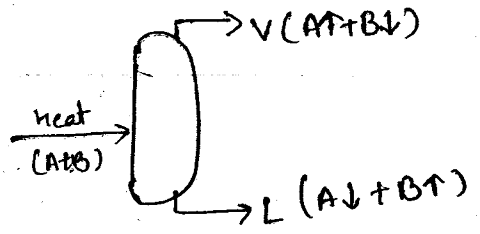
Therefore distillation column are alwaz operated at low pressures.

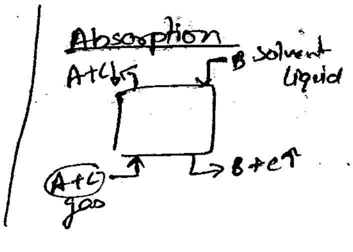
- Flash
- Batch
- Mc-cabe
- Frenske-Eq$^n$

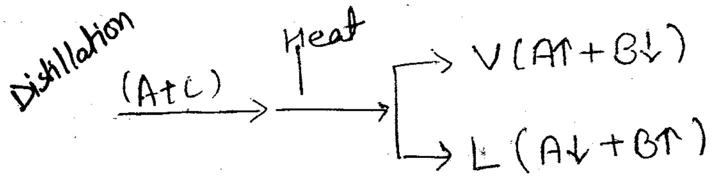
July 30, 14

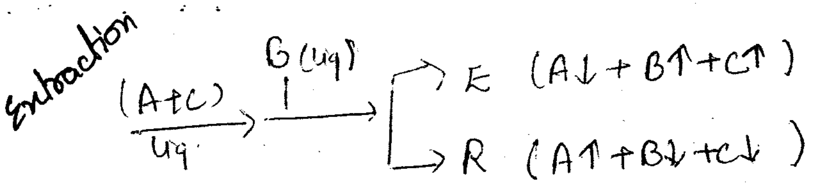
# Extraction

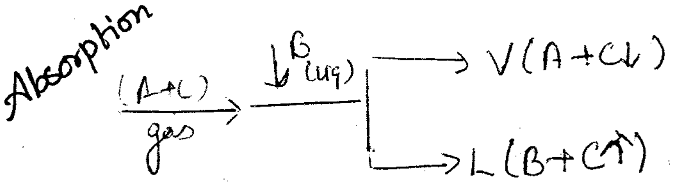








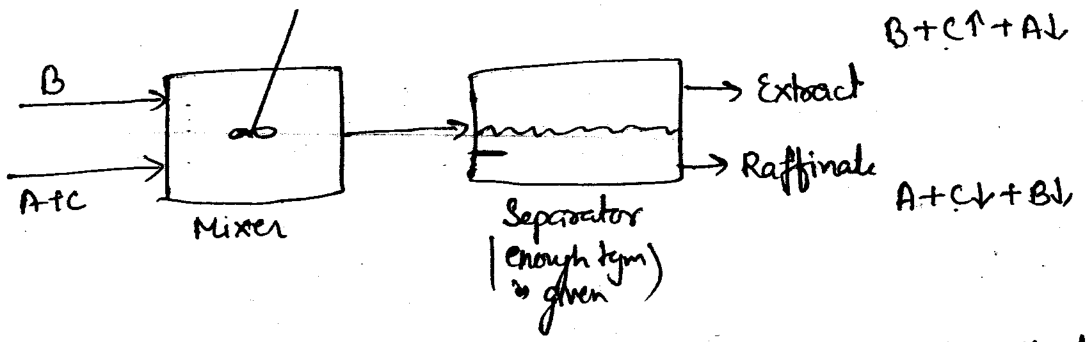




In absorption, we bring another phase (solvent) to gas phase & then the solute is absorbed in the solvent. For ex → to remove $SO_2$, we use water as solvent. The parameter is solubility.

In distillation, liq & vap phase in form of feed are there contain two components A & B. No third component is added and the separation take place bcz of diff. of relative volatility by the application of heat.

In Extraction, the feed is in the liquid phase containg (A+C) where the aim is to remove C, by the help of a solvent B. Also in the liquid phase and the parameter is solubility. In extraction, both the final pdts name EXTRACT & RAFFINATE are in liq. phase and the separation is generally approaches to equilibrium.



C is getting distributed in the two streams and the distribution can be found out by the help of distribution coeff.

$$\boxed{K = \frac{y^*}{x}}$$

→ C in E mole fraction of C in extract phase

→ C in R mole fraction of C in raffinate phase is

⇒ In Extraction, the mole fractions are used for the amount of C present in different streams.

⇒ B should be missible with C but not width A or should be missible wid C ~~&~~ partially missible with A.

Industrial Example :—

→ Acetic acid (C) + water (A) $\xrightarrow{\text{ethyl acetate (B)}}$

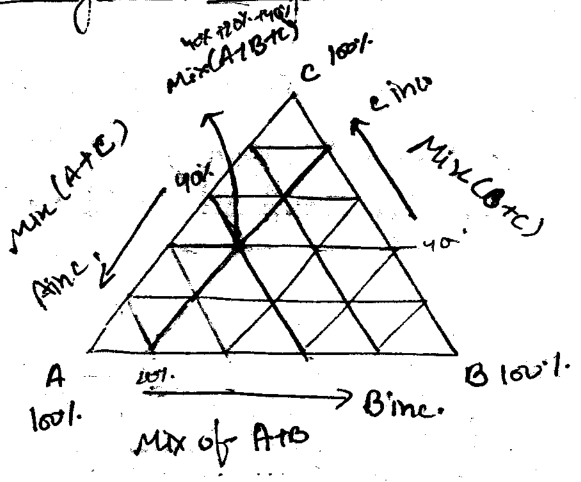
→ Farmasuetical industry.

→ Penicilline, vitamin-B-12

→ Food industry in case of some juices.

→ Petroleum industry for the case of lube oils and paraffins,

Equiletoral triangular diagram:—



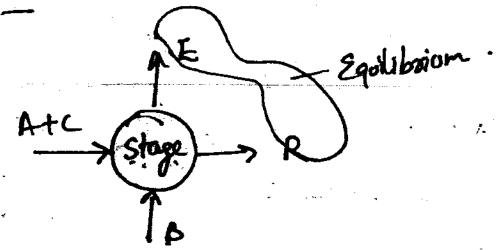
To find fraction
if we have to find the fraction of A, B, C, Draw a line parallel to that

To find concentration of any pt in the triangle

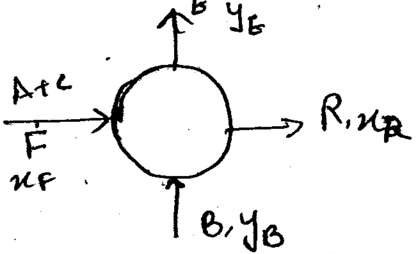
-> Define the direction (either clockwise or anti-clock wise), define the direction in increasing way.

-> To find the concentration of any component, suppose C. Draw a line from a given pt parallel to AB and then find the concn of C from that extreme pt in which C↑.

Stages:-



Two streams are brought in contact for sufficiently long tym for mass transfer. We know that if long tym is given, two ~~living~~ leaving streams will be in equilibrium and the stage is known as ideal stage.



$$F+B = R+E \Rightarrow F+B = M = R+E$$

$$Fx_F + By_B = Rx_R + Ey_E \Rightarrow Fx_F + By_B = Mx_M = Rx_R + Ey_E$$

$$M = R+E$$

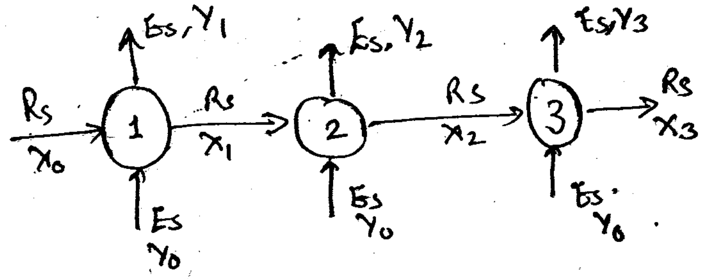
$$\boxed{\begin{aligned} \frac{R}{E} &= \frac{x_E - x_m}{x_m - x_R} \\ \frac{M}{E} &= \frac{x_E - x_R}{x_M - x_R} \\ \frac{M}{R} &= \frac{x_R - x_E}{x_M - x_E} \end{aligned}}$$

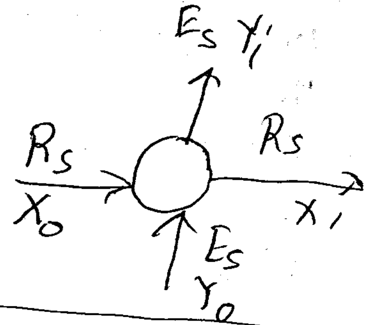
Flowrates & Composition on Solute free basis

so we get str. line,

$X_0 = \frac{C}{A}$ mole fraction of C in carrier liq.

Cross-current ~~stages or~~ cascades





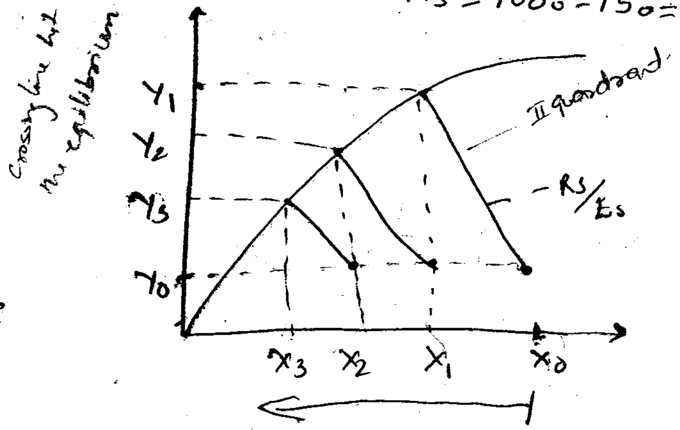
$$R_s X_0 + E_s Y_0 = R_s X + E_s Y$$

$$\boxed{R_s(X_0 - X_1) = E_s(Y_1 - Y_0)}$$

$$\boxed{Y = \left(\frac{-R_s}{E_s}\right) X + \left(\frac{R_s X_0 + E_s Y_0}{E_s}\right)}$$

F = 1000 kg/hr
15% C
$R_s = 1000 - 150 = 850$

Slope = -ive
$= \left(\frac{\text{Raffinate}}{\text{Extract}}\right)$ Solute Free



Slope of line $= -R_s/E_s$, (-ve)

- → ~~from~~ On the diagram, plot the points $x_0$ & $Y_0$. Such that $X_0$ is high $Y_0$ low.
- → Draw operating line with a slope of $-R_s/E_s$. Such that it will ~~[illegible]~~ hit the equilibrium curve (ideal stage).
- → The pt. $Y_0$ & $x_1$ ~~mixtes~~ mixes on the 2nd stage, so we can draw the operating line with the slope mean h such that it hit the equilibrium line again at $X_2, Y_2$ and so on.
- → If i know the extreme pts $(x_1, y_1)$ & $(x_0, y_0)$, then by joining these 2, i can find the slope and from the slope data i can find the flow rate of solvent.

→ If flowrate of solvent in each stage is changed then the slope at each point will change

→ If we change the composition of the solvent, then the pts $(x_0, y_0)$, $(y_0, x_1)$, $(y_0, x_2)$ will not lie on a same line.

Q) An extraction process is going on to separate a feed mix (A+C) in which is C = 15% wt/wt & total feed flow rate is 1000 kg/hr. For extraction we are using a solvent B. (pure solvent - No C). Find the flow rate of the solvent required for the process such that C is removed by 95%.

i) when single stage is used.
ii) when 3 stages are used.

$Y = 3.75\,X$ (if capital letter, on the basis of solute free basis)

mass ratio.

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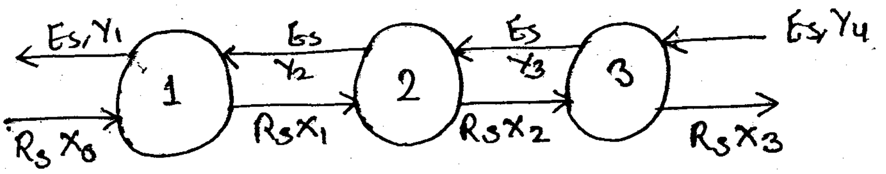
For Counter-Current :- we prefer counter current more, as separation is more in this case



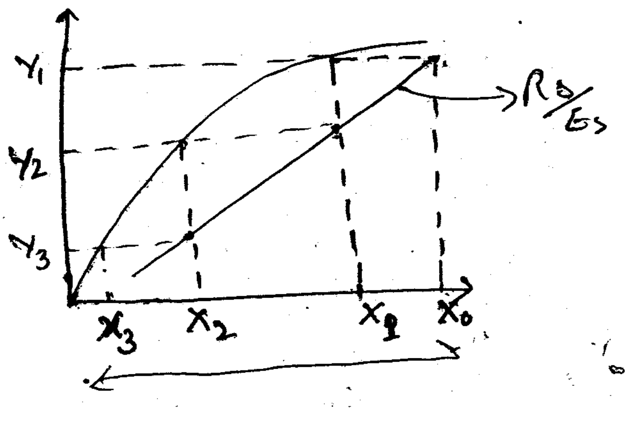
$$R_s(X_0 - X_3) = E_s(Y_1 - Y_4)$$

$$R_sX_0 - R_sX = E_sY_1 - E_sY_4$$

$$\boxed{Y = \left(\frac{R_s}{E_s}\right)X + \frac{E_sY_1 + R_sX_0}{E_s}}$$

Slope for counter current cascade is +ve and is equal to $\frac{R_s}{E_s}$

crossly line doesn't hit the equilibrium.



$x_0, Y_1$ } These are the pts
$x_1, Y_2$ } lie on operating
$x_2, Y_3$ } line.

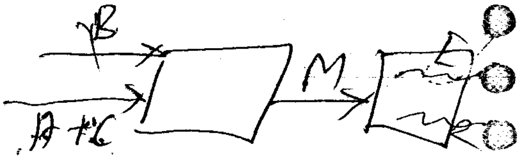
$x_1, Y_1$ } These are the pts
$x_2, Y_2$ } lie on equilibrium
$x_3, Y_3$ } line.

Counter-current extraction is better than cross-current ext. bcz for the required separation we require less no. of stages.

→ Plot the pt. $x_0, Y_1$ on the graph, from this pt draw an operating line with a slope of $R_S/E_S$.

→ We know that $Y_1$ is in equilibrium with $x_1$, so from the $Y_1$ pt we can determine $x_1$.

→ From the $x_1$ pt we can determine $Y_2$ bcz $x_1, Y_2$ lies on the operating line. and so on....

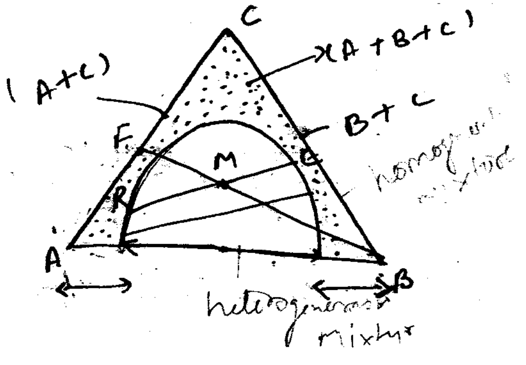


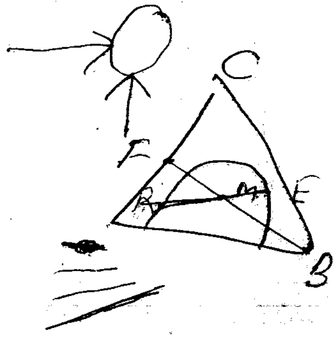
Types of System in Extraction :—

Type 1 :—

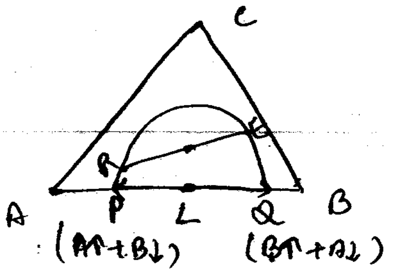
One pair is partially soluble

A+B+C → form a ternary system in which A+B partial missible, B&C comp. miscible, A&C completely missible.





If we take any pt in the phase diagram and allow it to separate, then we get 2 phases one is rich in B known as extract phase and other is rich in A known as Raffinate phase. But both the phases contain A, B, C & all.



Outside this region every pt represent homogenous solution Of A+B+C which are not separated.
Any pt inside the phase diagram on the line AB, they also get separated ~~two~~ components.

The line RE is knos as a tie ~~lyge~~ line and it represent one stage. For multi-stage cascade and there will be more than one tie line and they may or may not be parallel.

Plait Point:-

Plait point is a point upto which we can separate the mixture but which ! Extraction is not possible. It is also defined as ~~that pt~~ that pt. at which slope change and starts decreasing.

Temperature Effect on Type I System

As temperature ↑ and phase diagram shrinks

As " " , ]

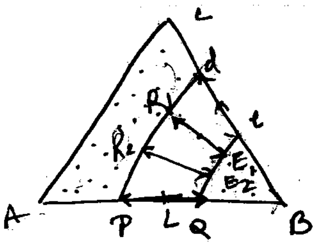
" " ↑, Area of partial miscibility decreases.

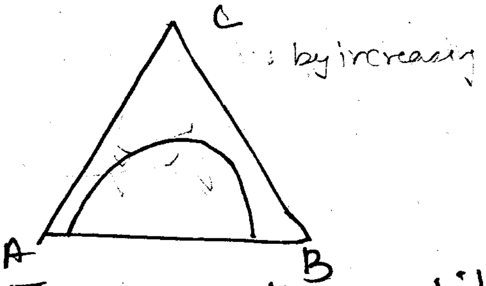
and a stage may come at which phase diagram vanish and we have a complete miscible
~~At~~ this pt. separation is impossible ∴ Extraction is carried

out ~~et~~ generally at room or low temp.

Type 2:-

System of A+B+C, two pairs are partially miscible
A & C completley soluble, A&B partically soluble.
B&C partially soluble.

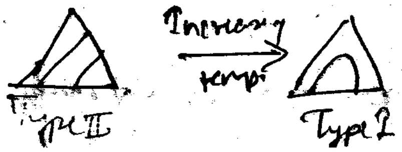




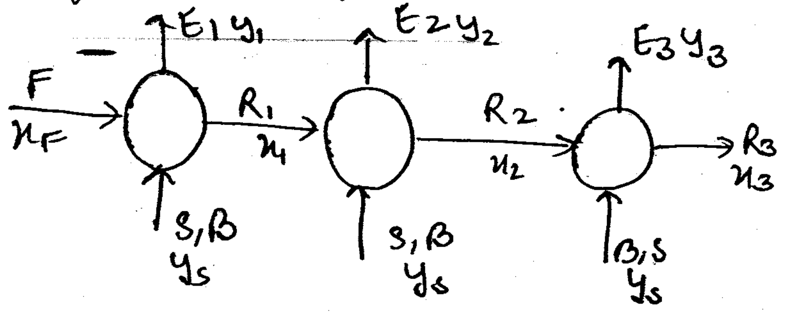
The phase diagram hiting the lines AB & BC bcz these 2 pairs are partial miscible, any pt outside this phase diagram represents a homogenous mixture and cannot be separated. Any pt inside this region ~~of~~ either lies on line on inside Δ will get separated.

In Type-2 system amount of solute present in raffinate phase is more than ~~others~~ present ~~p~~ in the extract phase which is just opposite to the process of extraction.

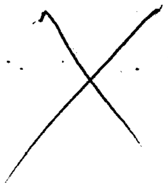
By increasing the temp, solubility will increase and the solubility depend of solvent choose. Solvent B is taken such that solubility of B&C increasing by increasing the temp and type 2 system converted into Type-1 system.

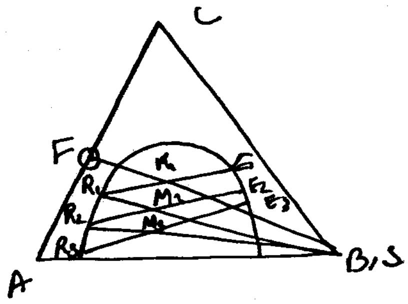


## Multistage Stage Cross-current Extraction :—



Each stage consist of a network of mixer and settler and represents an ideal stage. Streams $R_1E_1$, $R_2E_2$, $R_3E_3$ are in equilibrium and the solvent entering in each Stage have the same flow rate and same composition.





If we change the composition of the solvent in diff. stages when the pt b, whill towards the bzy. If we change the flow rate of solvent in different stages then $M_1, M_2, M_3$ will change.

If amt of solvent ↑, then the mixture point will shift towards B and vice-versa.

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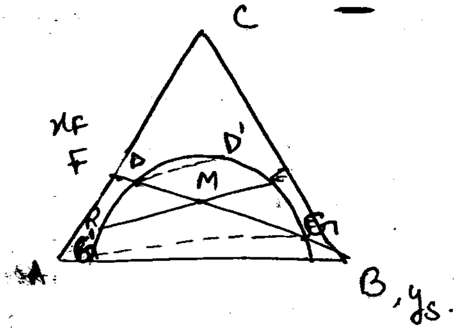
## Minimum amt of solvent required for extraction :-



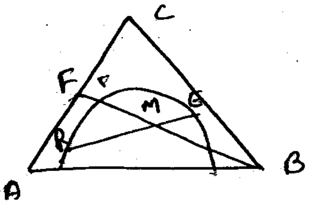
for mini

$$\frac{F}{B} = \frac{y_S - x_M}{x_M - x_F}$$

$$\left(\frac{F}{B}\right)_{min} = \frac{y_S - x_D}{x_D - x_F}$$

In the Δlar diag. we can mix the feed and the solvent to form a mixture m in the mixture which can then be separated in the separator by the help of a tie line shown in the diagram.

$$F + B = M$$



If the amount of solvent is decreased then the point M will shift towards F on the feed line.

The question is how much we can decrease the amount of solvent such that extraction will take place.

The answer is given by the equilibrium line as we know that at any stage we cann't cross the equilibrium line.
When the feed line intersects the equilibrium line at pt D. That points represents the pinch point and also the last point upto which extraction can take place. The minm amt of solvent used at this stage can be find out by the mixing rule.

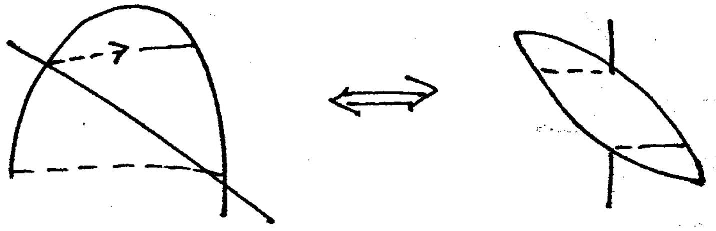
$$\left(\frac{F}{B}\right)_{min} = \frac{y_S - x_D}{x_D - x_F}$$

And at this pt, a very smal amt of extract will form. and this line DD' represent the upper limit of extraction like in the distillation column when we heat a mixture, the pt at which fst vapour is formed is the limit of distillation.

## Increasing amount of Solvent :—

In the previous diagram, if we increase the amount of solvent, then the pt M will shift towards the B on the feed line and the limit is again given the equilibrium curve at the pt. F. ~~Such~~ upto which extraction have minimum. This line FF' shows the upper limit of extraction like in the distillation column, if we heat a mixture a tym comes when last drop of liquid is left. The max$^m$ amt of solvent at this point can be find out by the mixing rule.

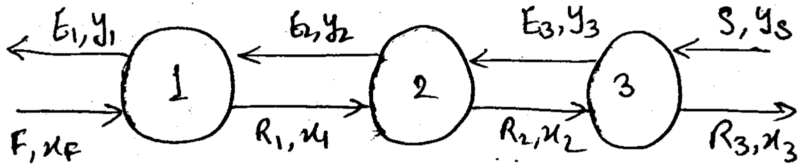
$$\left(\frac{F}{B}\right)_{Max} = \frac{y_S - x_G}{x_G - x_F}$$



Extraction · Distillation

When the mixture is at D in the seperator, it stays at the same concentration as D and a drop of liquid goes out as the extract like in distillation, initial vapour forms. When the mixture is at G, it stays at the same composition as the pt G and the drop of raffinate goes out like in distillation last drop of liquid left.

# Multi-stage Counter Current Extraction:-



$F + S = R_3 + E_1$ overall M.B

$\boxed{F - E_1 = R_3 - S}$

$R_1 + S = E_2 + R_3$

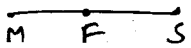
$R_1 - E_2 = R_3 - S$

$F - E_1 = \Delta$

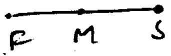
$R_1 - E_2 = \Delta$

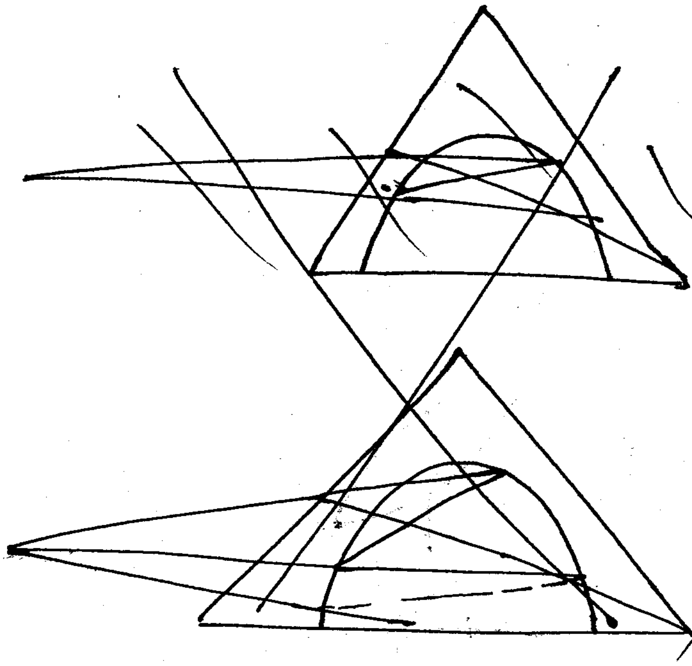
$R_2 - E_3 = \Delta$

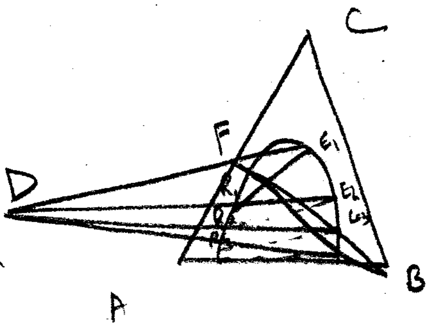
$F - S = M$

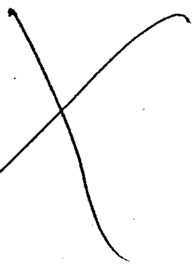


$F + S = M$

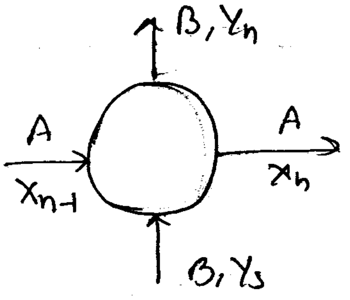








# The value of reduction ratio for cross-current extraction.



$$-\frac{A}{B} = \frac{Y_n - Y_s}{X_n - X_{n-1}}$$

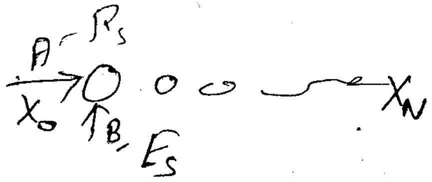
$Y_s = 0$ (solute free/solvent pure)

$Y = mX$ (equilibrium line st.)

$$-\frac{A}{B} = \frac{mX_n}{X_n - X_{n-1}}$$

$$1 + m\frac{B}{A} = \frac{X_{n-1} - X_n}{X_n} + 1 = \frac{X_{n-1} - X_n + X_n}{X_n}$$

$$\boxed{1 + m\frac{B}{A} = \frac{X_{n-1}}{X_n}}$$ for nth stage.



if $n = 1$ $\quad 1 + m\frac{B}{A} = \frac{X_F}{X_1}$

$n = 2$ $\quad 1 + mB/A = \frac{X_1}{X_2}$

$$\frac{X_F}{X_n} = \frac{X_F}{X_1} \times \frac{X_1}{X_2} \times \frac{X_2}{X_3} \times \cdots\cdots \times \frac{X_{n-1}}{X_n}$$

$$= (1 + mB/A) \cdot (1 + mB/A) \cdots\cdots (1 + mB/A)^n$$

$$= (1 + mB/A)^N$$

$$\boxed{\frac{X_F}{X_n} = \left(1 + \frac{mB}{A}\right)^N} \checkmark = \left(1 + m\frac{E_s}{R_s}\right)^N$$

$$\boxed{NB = \frac{AN}{m}\left[\left(\frac{X_F}{X_n}\right)^{1/N} - 1\right]} \checkmark$$

Reduction Ratio formula for counter current ~~ratio is~~ system.

$$\frac{X_F}{X_n} = \frac{\left(\frac{mB}{A}\right)^{N+1} - \left(\frac{mB}{A}\right)^{N}}{\left(\frac{mB}{A}\right)^{N+1} - 1}$$

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## Drying

The removal of moisture from a wet solid, solution ~~solut~~ over a gas tomake it dry is known as drying.

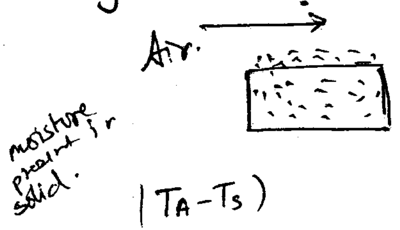
Drying not alwaz demands complete removal of moisture for ex → moisture is not removed completely in the drying of a soap bar.

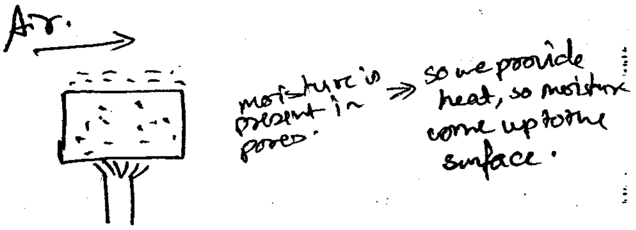
Generally the final pdt in drying is a solid but not alwaz.

Drying is best example of Simultaneos H.T & M.T.

## Physical Mechanism of Drying :-

Generally a moist solid is heated to vapourize the moistur to the Surface and then heat required for drying is supplied by hot air.





$|T_A - T_s)$

$H_A - H_s$

## Mechanism of moisture transport

1.) By liquid diffusion :-

The concn of the moisture inside the bulk of solid is generally more than the moisture content present at the Surface. Bcz of this concentration diff. the moisture will flow from inside to the surface.

" ,, "

2.) By Capillary ~~Process :-~~ forces :-

Generally in porous solids, moisture transport occur due to capillary forces. (when pores are in the form of capillary).

3.) Pressure induced transport

For solids, which shrinks during drying. Auter layer shrinks and compress the inside moisture to come to the Surface.

## 4> Vapour Diffusion :-

Sometimes liquid vapourises inside the surface of solid and these vapours come to the surface known as vapour diffusion.

## Resistances in drying :-

1> Resistance to liquid and vapour diffusion from inside to the surface. (top of solid)

2> Resistance to convective M·T of the vapour from surface of solid to the bulk of Air (gas)

3> Resistance to convective H·T from bulk of drying air to the solid surface.

4> Conductive H·T resistance due to increased temp, of the outer layer of solid to inside

## Bone Drying :-

A solid totally free from moisture is known as bone dry

## Case hardening :-

Sometimes in drying of a soap bar, the drying action is so rapid that the outer layer becomes stiff and hard and stops drying, but inside the surface of solid there is enough amt of moisture present this is known as case hardening.

Types of moisture

## Unbound Moisture :-

Moisture content present over the surface of solid such that no resistance is offered by the solid in the movement of this moisture or the moisture content whose relative humidity is 1 is known as unbound moisture. rate of drying is const during the removal of unbound moisture.

moisture content which is in equilibrium old 100% humidity

## Bound Moisture :-

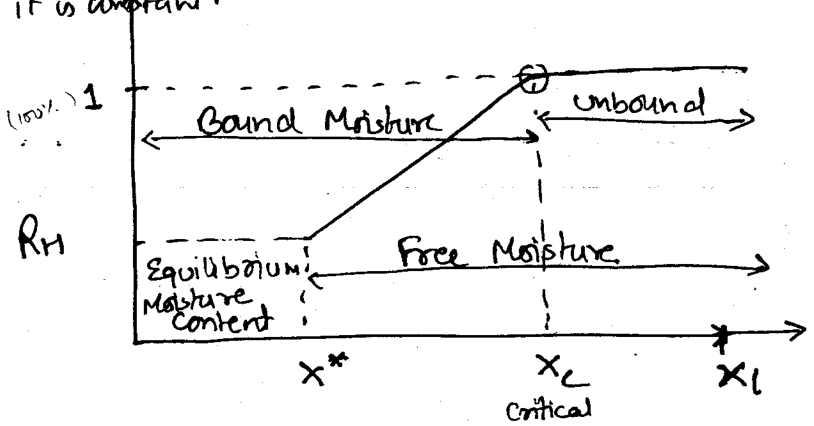
Moisture content present inside the surface of solid such that its relative humidity is less than 1 or Solid is offering resistance in the movement of moisture is known as bound moisture.

## Free Moisture:-

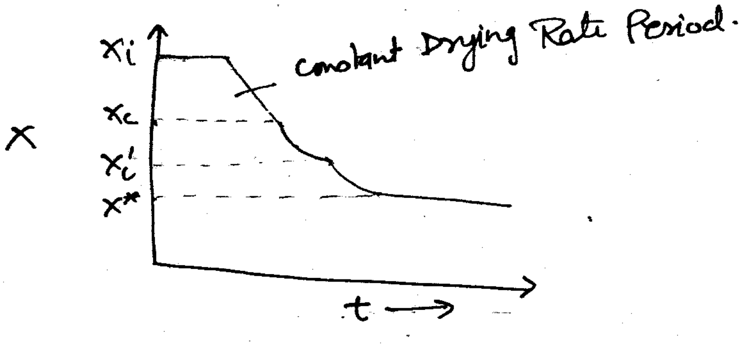
The moisture content which can be removed or which is desired to remove from the solid either bound or unbound is known as free moisture.

## Equilibrium Moisture Content:-

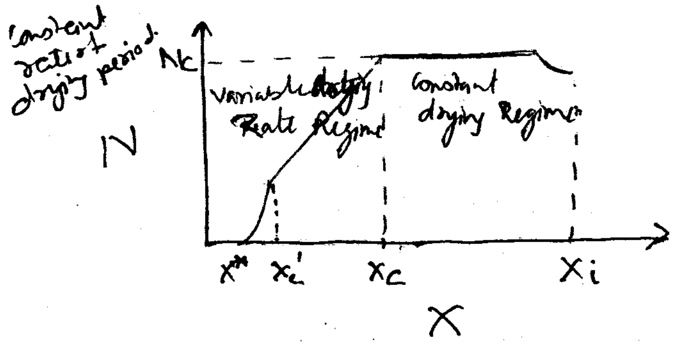
The moisture content at which the dry stops and the V.P of moisture over the solid ~~is eq~~ becomes equal to the partial pressure of water vapour present inside the air. Rate of drying becomes zero. It's not constant, bt depends on the temp, humidity & nature of solid. Bt for the given condition of solid & dry air it is constant.



## Variation of Moisture content with tym:-



## Rate of drying vs Moisture Content



## Rate of drying

$$\boxed{N = -\frac{W_s}{A}\frac{dx}{dt}}$$

$x \rightarrow \frac{\text{kg moisture}}{\text{kg wet solid}}$

$X = \frac{x}{1-x}$

N = Rate of drying

A = Area of drying

$W_s$ = Wt. of bone dry

X = Moisture content (kg moisture/kg dry solid)

T = time

* In quest, we alwaz assume concn of dry basis untill unless it is not mentioned.

## Tym of drying:-

$$\int dt = \frac{-W_s}{A}\int_{x_i}^{x_f}\frac{dx}{N}$$

$$t = \frac{W_s}{A}\left[\int_{x_c}^{x_i}\frac{dx}{N_c} + \int_{x_f}^{x_c}\frac{dx}{N}\right]$$

$$t = \underbrace{\frac{W_s}{AN_c}}_{t_c}(x_i - x_c) + \underbrace{\frac{W_s}{A}\int_{x_f}^{x_c}\frac{dx}{N}}_{tf}$$

$$t = \underbrace{\frac{W_s}{AN_c}(x_i - x_c)}_{t_c} + \frac{W_s}{A}\int_{x_f}^{x_c}\frac{dx}{px+q}$$

Assumption drying rate is linear.

$N = px + q$

$N_c = px_c + q$

$px_c - px^* = N_c$

$p(x_c - x^*) = N_c$

$\frac{1}{p} = \frac{x_c - x^*}{N_c}$

$0 = px^* + q$

$N_f = px_f + q$

$0 = px^* + q$

$$t = \frac{W_s}{AN_c}(x_i - x_c) + \frac{W_s}{pA}\ln\frac{px_c + q}{px_f + q}$$

$\frac{W_s}{pA}$ comes from diffⁿ of integration

$$\text{"} \quad + \frac{W_s}{pA}\ln\frac{px_c - px^*}{px_f - px^*}$$

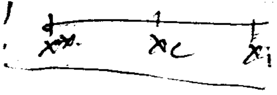
$$\text{"} \quad + \frac{W_s}{pA}\ln\left|\frac{x_c - x^*}{x_f - x^*}\right|$$

$$\boxed{t = \frac{W_s}{AN_c}(x_i - x_c) + \frac{W_s}{AN_c}(x_c - x^*)\ln\frac{x_c - x^*}{x_f - x^*}}$$

$x_f \neq x^*$

If it is go for proper integration don't use this formula.

$$t = \overset{\text{const drying tym}}{t_c} + \overset{\text{variable drying tym}}{t_v}$$



$$\boxed{t = \frac{W_s}{AN_c}\left[(X_i - X_c) + (X_c - X^*)\ln\left|\frac{X_c - X^*}{X_f - X^*}\right|\right]}$$

$X$ = Kg of moisture/kg of dry solid.
↓
Dry Basis

$x$ = kg of moisture/kg of wet solid
↓
wet basis

$$\boxed{X = \frac{x}{1-x}}$$

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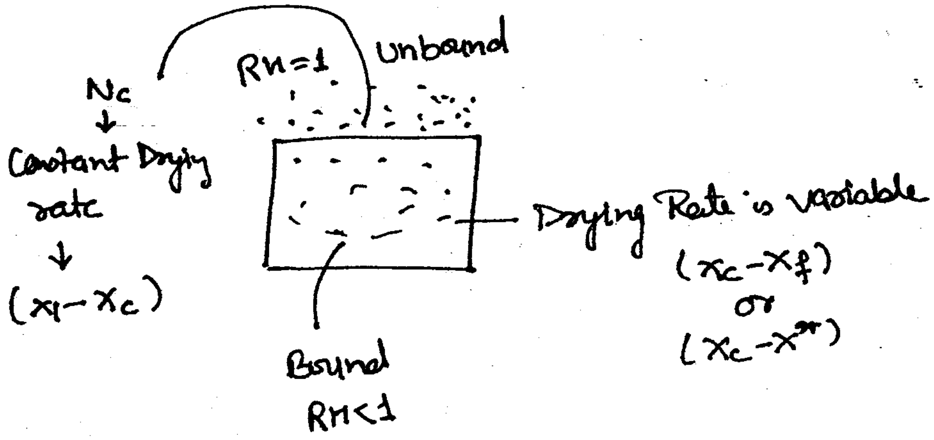


Constant Rate of drying Period :-

Humidity / Sp. humidity / Absolute humidity (H):-

$$\frac{\text{Amount in kg of vapour present in air}}{\text{kg of dry air}}$$

$$H = \frac{m_v \text{ — Vapour}}{m_a \text{ — air}}$$

$P_v V_v = m_v R_v T_v$ — If vapour behaves as ideal gas then only we apply

$P_a V_a = m_a R_a T_a$ — dry gas behaves as ideal ga

⇒ Vapour & air are in thermal equilibrium

$$\boxed{T_a = T_v}$$

$$\boxed{V_a = V_v}$$

for general system.

$$\boxed{\frac{P_v}{P_a} = \frac{m_v}{m_a} \frac{\cancel{R_v}}{\cancel{R_a}}} = \boxed{\frac{m_v}{m_a} \cdot \frac{P_v}{P-P_v}}$$

$P_v$ = Part. pres of water vapour in air
$P$ = total pres.

$$\boxed{H = \frac{m_v}{m_a} = \frac{P_v}{P_a} \times \frac{R_a}{R_v}}$$

$R_a = R/M_a = \frac{8.314}{28.96}$ → 0.287 KJ/kg K

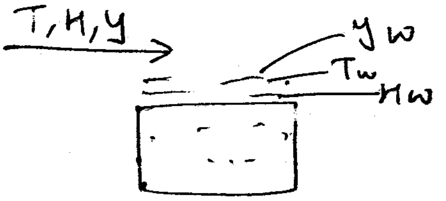
$R_v = R/M_v = \frac{8.314}{18}$ → 0.462 KJ/kgK

for air-water system.

$$\boxed{H = 0.621 \frac{P_v}{P_a}}$$

$$\boxed{H = 0.621 \frac{P_v}{P-P_v}}$$

$P_a$ = dry air never exist
∴ pressure exerted by dry never be calculated.



T - Dry bulb Tem, $T_w$ = wet bulb temp

$Q = hA(T - T_w)$

$N_A = k_y(y_w - y)$

$$H = \frac{P_v}{P-P_v} \times \frac{\cancel{M_v}}{\cancel{R}} \frac{M_v}{M_a}$$

$$P >> P_v$$

for drying gas

$$H = \frac{P_v}{P} \times \frac{M_v}{M_a} = \boxed{y \frac{M_v}{M_a}}$$

; $\boxed{H_w = y_w \times \frac{M_v}{M_a}}$

for near the moisty

$$\boxed{N_A = k_y \frac{M_a}{M_v} (H_w - H)}$$

$$Q = \underset{kg\ \frac{mol}{m^2 s}}{\overset{\text{Mass}}{M_v N_A}} \times \underset{J/kg}{\lambda} \cdot \underset{m^2}{\overset{\text{Area}}{A}}$$

total amt of heat required to vaporise unbound moisture.

---

Amt. of heat neccessary to vapourize $N_A$ amount of water in terms of latent heat of vapourization is given by

$$\boxed{Q = M_v N_A \lambda A}$$

$$h \cancel{A} (T - T_w) = M_v \{k_y (y_w - y)\} \lambda \cancel{A}$$

$$\boxed{\frac{h(T - T_w)}{\lambda} = k_y M_a (H_w - H)} = N_c$$

√ Imp.

Unbound

Assumptions :-

- H.T by radiation & conduction to the solid surface are neglected.
- It has been found that the more reliable method to calculate the constant rate of drying period is temp diff in comparision to humidity difference bcz the temp diff can be measured more accurately with less errors in comparision to humidity diff.

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Effects of variables on Drying :-

1) When air flowing parallel to the surface

h.T coeff $h = 0.0204\, G^{0.8}$

2) when air is flowing ⊥r to the surface

$$h = 1.17\, G^{0.37}$$

G — sv mass velocity $\frac{kg}{m^2} \cdot \frac{m}{V}$

3> As air velocity increase, rate of drying increase by an amount

$$N_c \propto V^{0.8}$$
$$N_c \propto V^{0.37}$$

4> As gas humidity increase, rate of drying decreases.

5> As gas temperature increases, rate of drying increases.

6> As thickness of solid increases, rate of drying remains same under constant drying rate. But under falling drying rate, rate of drying will decrease.

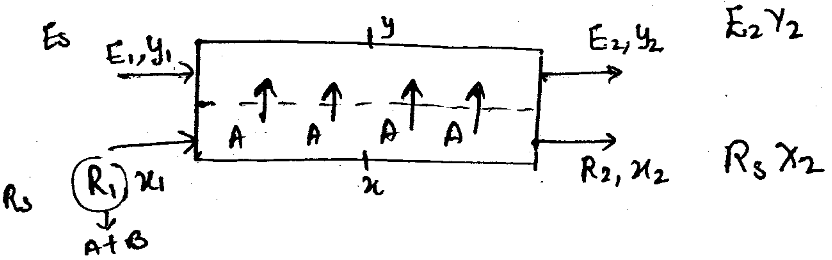
7> As thickness increases, $T_c$ remains the same but $T_v$ increases.

## Relative humidity

Ratio of partial pressure of vapour in air to the V.P of moisture.

# Absorption

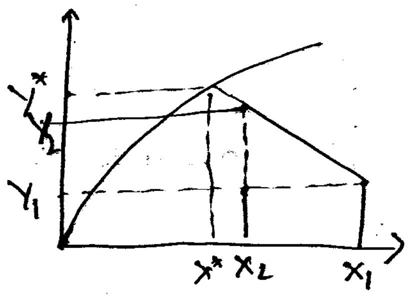
## Contacting Equipment:-



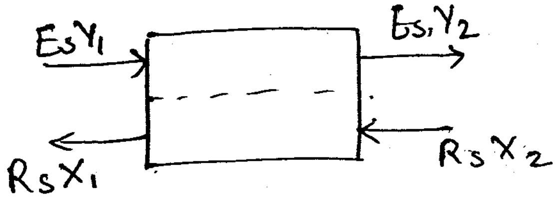
$$R_s(X_1-X_2) = E_s(Y_2-Y_1)$$

$$R_s(X_1-X) = E_s(Y-Y_1)$$

$$\boxed{Y = -\frac{R_s}{E_s}X + \frac{(R_sX_1+E_sY_1)}{E_s}}$$



## Counter Current Contacting Equipment:-



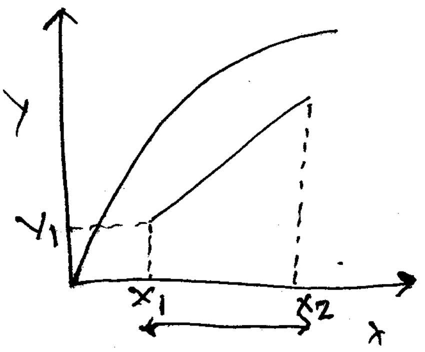
$\underline{X_2 > X_1}$ , $\underline{Y_2 > Y_1}$

$$R_s(X_1-X) = E_s(Y_1-Y)$$

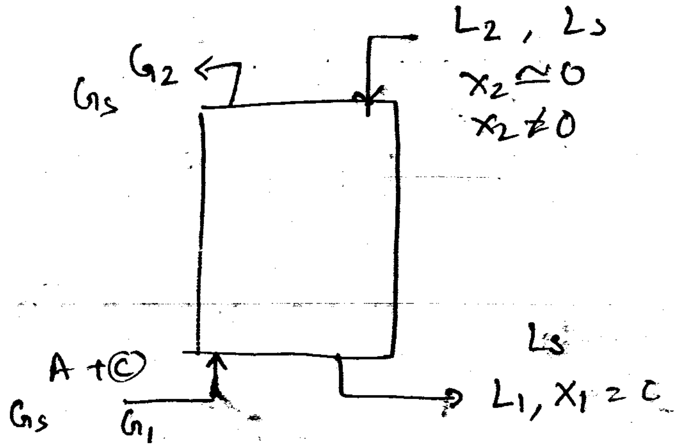
$$\boxed{Y = \frac{R_s}{E_s}X + \left(\frac{E_sY_1-R_sX_1}{E_s}\right)}$$

$$Y = mX + c$$

- » Slop is +ve
- » Gives more separation, than cross - current



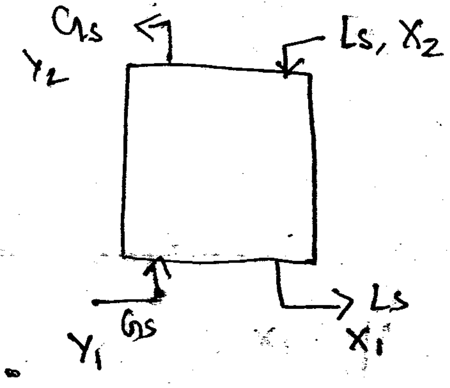
# Absorption



A gas containing two components A & C, in which the component C is undesirable like $H_2S$, $SO_2$, $NO_x$ in air. To separate the component C in the gas phase, we are using solvent like $H_2O$, KOH, ethanol etc which absorbs the solute C. The gas phase and the liquid phase enter counter-currently and the desired removal of C from the gas phase is achieved by adjusting the following parameters.

- Solvent Flow Rate
- Height of column
- Gas flow rate
- Diameter of the column

## Solvent Flow Rate



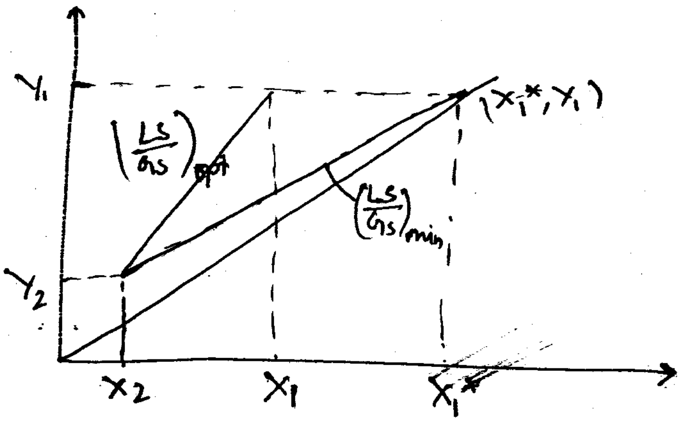
$$G_s Y_1 + L_s X_2 = L_s X_1 + G_s Y_2$$

$$G_s (Y_1 - Y_2) = L_s (X_1 - X_2)$$

$$\boxed{Y = \frac{L_s}{G_s} x + \frac{G_s Y_1 - L_s X_1}{G_s}}$$

$$\boxed{Y = \frac{L_s}{G_s} x + \frac{G_s Y_2 - L_s X_2}{G_s}}$$

drop the suffix of $x_2, Y_2$ as we know the value of $x_2, Y_2$.



$x > y$

$$\left(\frac{L_s}{G_s}\right)_{min} 1.5 = \left(\frac{L_s}{G_s}\right)_{opt}.$$

⇒ Plot the points $X_2, Y_2$, such that applies above the equilibrium line.

⇒ Plot the point $Y_1$, and extend it to hit equilibrium top.

⇒ From the pt $X_2, Y_2$, Draw at line to intersect the point of the intersection of equilibrium line and $Y_1$. That point will give $X_1^*$ (Maximum achievable concentration)

⇒ This line as a slope of $(L_s/G_s)_{min}$ and from the literature if we multiply by 1.5, we will find $(L_s/G_s)_{opt}$.

⇒ From the pt $X_2 Y_2$. Draw another line with a slope of $(L_s/G_s)$ operating/optimum upto the pt where it hits the line $Y_1$

⇒ The pt of intersection of $Y_1$ will give us $X_1$

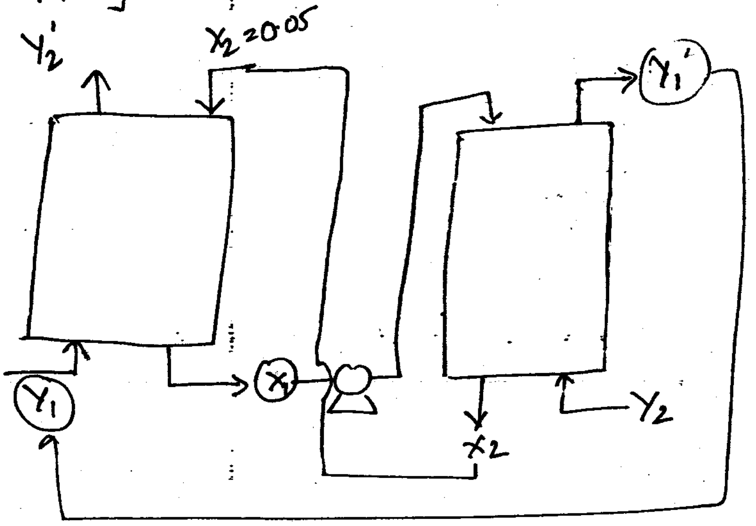
$$L_s(X_1-X_2) = G_s(Y_1-Y_2)$$

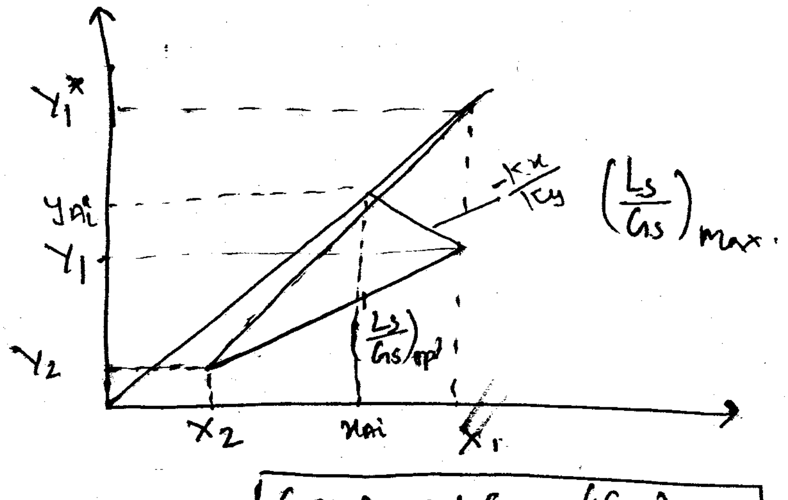
$$Y = f(x)$$

$$\boxed{Y_1 = f(X_1^*)} \qquad Ls_{min}(X_1^*-X_2) = G_s(Y_1-Y_2)$$

$$\boxed{Ls_{opt} = 1.5\,Ls_{min}}$$

For stripping





$$\boxed{(G_s)_{min} \times 1.5 = (G_s)_{opt}}$$

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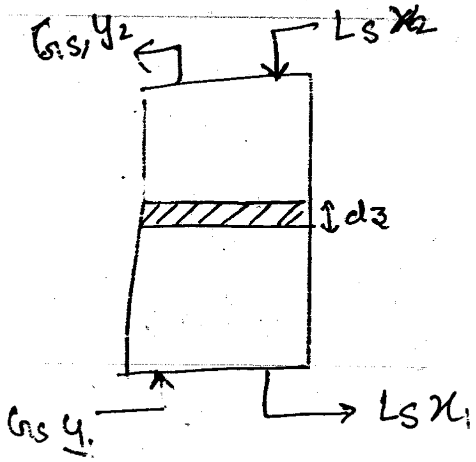
## Height of Absoption Column



$$\boxed{Z = NTU \times HTU}$$

### HTU (Height of Transfer Unit)

Overall HTU is defined as the height of pack section required to accomplish a change in the concentration equal to that avg. driving force in that section.

$$-d(Gy) = d(Lx) = \text{Rate of } M\cdot T$$

$$G_s = G(1-y)$$

$$G_s = G - Gy$$
A , A+C , C

$$-d\left(G_s \frac{y}{1-y}\right)$$

$$G_s\left\{\frac{(1-y)\cdot dy - y(-dy)}{(1-y)^2}\right\} = -G_s dy\left(\frac{1}{(1-y)^2}\right)$$

$$= -\left(\frac{G}{1-y}dy\right)$$

$$L_s = L(1-x)$$

$$-d\left(L_s \frac{x}{1-x}\right)$$

$$-L_s d\left(\frac{x}{1-x}\right)$$

$$-L_s\left\{\frac{(1-x)dx - x(-dx)}{(1-x)^2}\right\} = -L_s dx$$

$$= \frac{L}{1-x}dx$$

Check & solve.

Interfacial area.

$$k_y(y-y_i) \leftarrow \underset{\substack{\downarrow \\ \frac{kmol}{m^2 s}}}{N_A} \cdot \overset{\nearrow}{a}\left(\frac{m^2}{m^3}\right) A_T\,dz = -\frac{G}{1-y}dy$$

$$dz = -\frac{G}{1-y}\,\frac{dy}{k_y(y-y_i)\,a\,A_T}$$

$$\int_0^Z dz = -\int_{y_1}^{y_2}\frac{G}{1-y}\,\frac{dy}{k_y(y-y_i)\,a\,A_T}$$

$$Z = \int_{y_2}^{y_1}\frac{\overset{G'}{\boxed{\frac{G}{A_T}}}}{a\,k_y(y-y_i)(1-y)}\times\frac{(1-y)_{LM}}{(1-y)_{LM}}$$

This quantity is found exp. const

$$= \int_{y_2}^{y_1}\overset{Const}{\boxed{\frac{G'}{K_y(1-y)_{LM}\,a}}}\times\frac{dy\,(1-y)_{LM}}{(y-y_i)(1-y)}$$

$$(1-y)_{LM} = \frac{(1-y_i)-(1-y)}{\ln\frac{1-y_i}{1-y}}$$

to simply the integration as const factor is taken out of $\int$.

$$\boxed{Z = \underbrace{\frac{G'}{K_y(1-y)_{LM}\,a}}_{HTU}\ \underbrace{\int_{y_2}^{y_1}\frac{dy\,(1-y)_{LM}}{(y-y_i)(1-y)}}_{NTU}}$$

for dilute Solution:—

$$(1-y)_{AM} = \frac{(1-y_i)+(1-y)}{2}$$

$$\simeq 1$$

$$\boxed{Z = \underbrace{\frac{G'}{\boxed{K_y\,a}}}_{HTG}\ \underbrace{\int_{y_2}^{y_1}\frac{dy}{(y-y_i)}}_{NTG}}$$

$K_y\,a \rightarrow \frac{kmol}{m^2 s\,\Delta y}$

$\Rightarrow$ $H_{TG} = \frac{G'}{K_y\,a}$

$K_y$ = Individual M.T coeff based on gas side.

$$H_{TOG} = \frac{G'}{K_y a}$$

$K_y$ = Overall M-T coeff. based on gas side.

$H_{TG}$ :- Height of transfer unit based on individual M-T coeff on the gas side.

$H_{TOG}$ :- Height of transfer unit based on overall M-T coeff on the gas side.

$$\boxed{H_{TL} = \frac{L'}{k_x a}}$$

$H_{TL}$ :- Height of transfer unit based on individual M-T coeff on liquid side.

$$\boxed{H_{TOL} = \frac{L'}{K_x a}}$$

$H_{TOL}$ :- Height of transfer unit based on overall M-T coeff on the liquid side.

$$\boxed{N_{TG} = \int_{y_2}^{y_1} \frac{dy}{y - y_i}}$$

$N_{TG}$ :- unit No. of transfer unit based on interfacial concentration on gas side.

No. of transfer unit based on individual transfer unit.

$$N_{TOG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*}$$ $= N_{TG} = N_{TOG} (y - y^*)$

$N_{TOG}$ :- No. of transfer unit based on equilibrium concentration on gas side.

$$\boxed{N_{TL} = \int_{x_2}^{x_1} \frac{dx}{x_i - x}}$$

or $\frac{d(\ln x)}{z-d(\ln y)}$ } check

individual liq phase M-T coeff

$N_{TL}$ :- No. of transfer unit based on interfacial concn on the liq. side.

$N_{TL} = N_{TOL} (x^* - x)$

$$\boxed{N_{TOL} = \int_{x_2}^{x_1} \frac{dx}{x^* - x}}$$

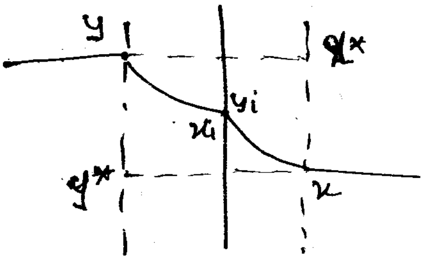
$N_{TG}$ :- No. of transfer unit based on overall compostion on the liq. side.

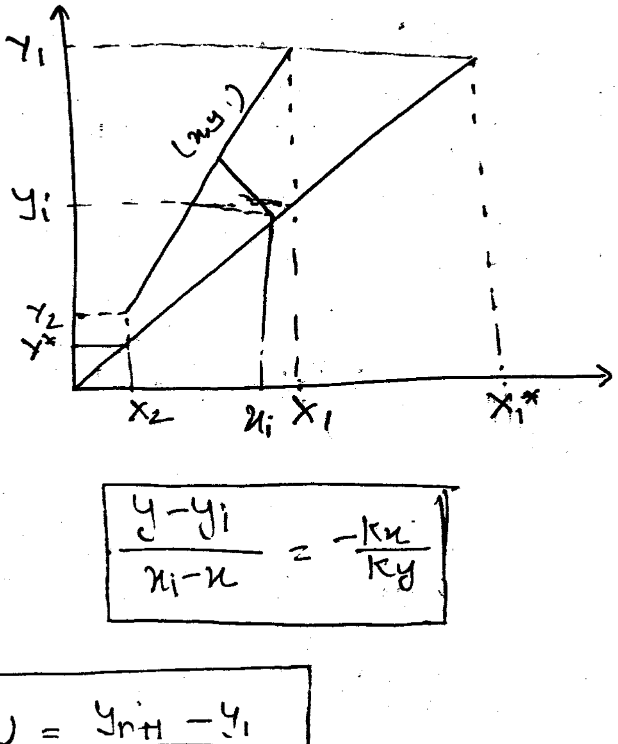
ie:

$$\boxed{Z = N_{TG} \times H_{TG} = N_{TL} \times H_{TL} = \underline{N_{TOG} \times H_{TOG} = N_{TOL} \times H_{TOL}}}$$

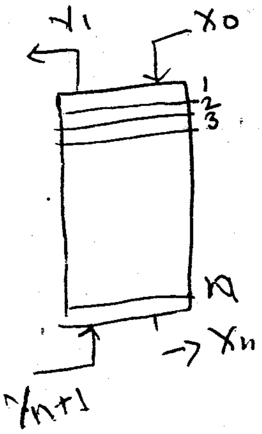
** v. imp

$$\boxed{\begin{matrix} y > y_i > y^* \\ x^* > x_i > x \end{matrix}}$$





$$\boxed{\frac{y - y_i}{x_i - x} = \frac{-k_x}{k_y}}$$



In terms of gas.

$$\boxed{NTU = \frac{y_{n+1} - y_1}{y_1 - y^*}}$$

$y^*$ = $mx_0$

In terms of liquids.

$$\boxed{NTU = \frac{X_n - X_0}{\underset{\downarrow\ \frac{Y_{N+1}}{m}}{X^*} - X_0}}$$

Solute free or not

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$$\boxed{NTU = \int_{y_2}^{y_1} \frac{dy}{y - y^*}}$$

If the equilibrium lines and operating lines are st. and parallel then the no. of transfer unit based on gas phase can be calculated by,

$$N_{TOG} = \ln\left[\frac{\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right)(1-\frac{1}{A}) + A}{1 - 1/A}\right]$$

$y_1 \simeq y_{n+1}$ $x_2 \simeq x_0$

$y_2 \simeq y_1$

$$N_{TOG} = \ln\left[\frac{\left(\frac{y_{n+1} - mx_0}{y_1 - mx_0}\right)(1 - 1/A) + A}{1 - 1/A}\right]$$

A = Absorption factor and is defined by the slope of operating line to the slope of equilibrium line.

$$\boxed{A = \frac{L/G}{m} = \frac{L_S/G_S}{m}}$$

* $\underline{A = 1}$ no. of stages = no. of transfer units.

$$\boxed{N_p = \frac{y_{n+1} - y_1}{y_1 - mx_0}}$$

$\boxed{NTU = N_p}$

$\boxed{HTU = HETP}$

In case of stripping:-

$$N_{TOL} = \ln\frac{\left[\left(\frac{x_2 - y_1/m}{x_1 - y_1/m}\right)(1-A) + A\right]}{1 - A}$$

$1/A$ = stripping factor, .

$$\boxed{\frac{1}{A} = \frac{m}{L/G}}$$

For calculation of theoretical no. of ideal trays we can use ~~Crame~~ kramser eqn

No of trays not stages.

$$N_p = \frac{\ln\left[\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right)(1 - 1/A) + 1/A\right]}{\ln A}$$

$$N_{TOL} = \frac{\ln\left[\left(\frac{(x_2 - y_1/m)}{(x_1 - y_1/m)}\right)(1 - A) + A\right]}{\ln 1/A}$$

HETP :- (Height Equivalent to theoritical plate) :-

It is defined as the height of packed section required to accomplish a change in concentration equal to M.T takes place on a plate.

HETP (in terms of $H_{TOG}$) :-

$$\boxed{\cancel{HETP = H_{TOG}\frac{\ln(1/A)}{(1 - 1/A)}}}$$

$$\boxed{HETP = H_{TOG}\frac{A\ln A}{A - 1}}$$

$$A = \frac{L/G}{m}$$

Relⁿ b/w $N_{TOG}$ & NTP :-

$$\boxed{N_{TOG} = \frac{N_p \cdot \ln A}{(1 - 1/A)}}$$

$N_p$ = no. of theoretical plate

Efficiency in a packed column :-

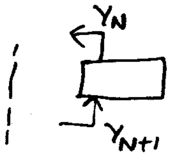
Point Efficiency :- It is defined by $\frac{\text{Actual M-T on any pt in a packed col}^{n}}{\text{ideal M.T.}}$

It is given by

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

Murphree plate Efficiency

$$\frac{\text{Actual M-T on a plate}}{\text{ideal M-T}}$$



$$\boxed{E_{MG} = \frac{y_{n+1} - y_n}{y_{n+1} - y_n^*}}$$

check wether it is capital or not

Overall tray Efficiency / column Efficiency :-

$$= \frac{\text{No. of ideal trays}}{\text{No of real trays}}$$

assumption
equilibrium line & operating line both are straight

$$\boxed{E_O = \frac{\ln\left[1 + E_{MG}\left(\frac{m}{L/G} - 1\right)\right]}{\ln\left(\frac{m}{L/G}\right)}} \longrightarrow \text{Gilliland Equation}$$

If $A = 1$ $\boxed{E_O = E_{MG}}$

Relation b/w $H_{TOG}$ in term $H_{TG} \times N_{TL}$ :-

$$\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{m}{k_x a}$$

$$\frac{H_{TOG}}{G'} = \frac{H_{TG}}{G'} + m\frac{H_{TL}}{L}$$

$$H_{TOG} = H_{TG} + m\frac{H_{TL}}{L}G'$$

$$\boxed{H_{TOG} = H_{TG} + \left(\frac{1}{A}H_{TL}\right)}$$

$H_{TOG} = \frac{G'}{K_y a}$ ; $H_{TG} = \frac{G'}{k_y a}$ , $H_{TL} = \frac{L'}{k_x a}$ , $H_{TOL} = \frac{L'}{K_x a}$

Relation between

$$\frac{1}{K_x a} = \frac{1}{k_x a} + \frac{1}{m k_y a}$$

$$\frac{H_{TOL}}{L'} = \frac{H_{TL}}{L'} + \frac{H_{TG}}{m L'}$$

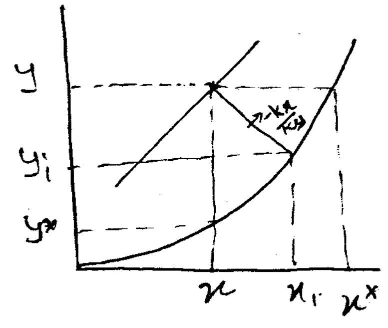
$$\boxed{H_{TOL} = H_{TL} + A H_{TG}}$$

one more formula for NTU, when $L_s/G_s$ are not given only composition are given
≫ equilibrium curve must be ∂.

$$= \frac{y_1 - y_2}{(y - y^*)_{LM}}$$

$$(y - y^*)_{LM} = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln \frac{y_1 - y_1^*}{y_2 - y_2^*}}$$

In absorption



$$\boxed{\begin{array}{l} y > y_i > y^* \\ x^* > x_i > x \end{array}}$$

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## Humidity

This term is used to integrate the concentration of vapour in a gas-vapour mixture. It can be defined on mass basis or mole-basis.

mass basis $H = \frac{m_A}{m_B} = \frac{P_v}{P-P_v} \cdot \frac{M_v}{M_a}$ | $\boxed{H = 0.622 \frac{P_v}{P-P_v}}$ for air-water system.

mole basis $H' = \frac{n_A}{n_B} = \frac{P_v}{P-P_v}$

$$\boxed{H = H'\frac{M_v}{M_a}} \qquad \boxed{H = 0.622 H'}$$

If the gas were saturated with vapour.

* At saturation $\boxed{\text{partial press}_{\text{of water vapour in air}} = \text{Vapour pressure}_{\text{of water}}}$ at same temp.

$$\boxed{P_v = P_s}$$

Molal humidity at saturation

$$\boxed{H_s' = \frac{P_s}{P-P_s}} = \frac{n_v}{n_a}$$

$$\boxed{h_s = 0.622 H_s'}$$

Mass humidity at saturation

$$\boxed{H_s = \frac{P_v}{P-P_v}}$$

% Saturation or degree of saturation ($\mu$) = defined as ratio of kg of vapour present in given mass of air at given dry bulb temp (DBT) for same ratio at saturation.

$$\boxed{\mu = \frac{H}{H_s}} \neq \boxed{\frac{H'}{H_s'}}$$

$$\mu = \frac{H}{H_s} = \frac{\frac{P_v}{P-P_v}}{\frac{P_s}{P-P_s}}$$

$$= \frac{P_v}{P_s} \times \frac{P-P_s}{P-P_v}$$

Relative humidity :- ($\phi$)

It is given by the ratio of partial pressure of w.v in air to the vapour pressure of pure water. At saturation $\phi = 1$

$$\boxed{\phi = \frac{P_v}{P_s}}$$

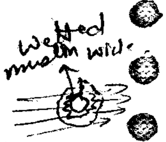
$*$ $\boxed{\phi = 1}$ when $P_v = P_s$

$$\phi = \frac{\mu}{\left[1-(1-\mu)\frac{P_s}{P}\right]}$$

Drybulb temp :- (true temp)

The temp. recorded by a thermometer whose bulb is perfectly dry and is not affected by the presence of any moisture content present in the atmosphere and also not by any radiations present in the surrounding.

Wet bulb temp :-



The temp. recorded by the thermometer whose bulb is covered wid a ~~wetten~~ wetted muslin wick and move pass the unsaturated air wid a velocity of 2-5m/sec, the moisture present on the wick will tend to evaporate, making the surrounding thin film of air saturated. For the evaporation the heat required is picked up from the surrounding air making the temp. of the air down. This decreased temp. ~~of~~ of the surrounding air is named as wet bulb temp.

$\Rightarrow$ DBT > WBT$_2$

## Dew point temp :—

Let us consider a mixture of air and water vapour at 314 K at and atm. press with a relative humidity of 30%. Calculate the vapour pressure.

$P_V = 2.33$ KPa , $R_H = 30\%$.

T↓
P↑
RH↑

$\boxed{314K}$ $R_H = \frac{P_V}{P_S}$

300K $P_S = 7.76$

293K If $R_H = 65\%$.

$P_S = 3.58$ .

The V.P of the water at 314 K is 7.76 KPa and Partial pressure of water vapour in air is 2.33 KPa. and the absolute humidity is 0.146 kg vapour/kg dry air.

Suppose air is cooled at constant pressure, on cooling the humidity for the partial pressure of water vapour will not change initially, but vapour pressure will change as given by the antoine eqn and thus this results in increasing the relative humidity.

Then the temp of air drops to 300 K the VP of water drops to 3.58 KPa. Such the relative saturation in this case is 65%. ~~On~~ further cooling the temp will be reached at which the V.P of water is equal to the partial press. of water vapour in the air. The air becomes saturated with the water vapour present in it. This temp is known as dew pt temp. and for air it is 293K.

Dewpt. is the lowest temp. to which a gas vapour mixture can be cooled w/o condensation at constant pressure.

It is temp at which the vapour just begins to condensed when cooled at constant pressure.

OR

The dewpt. is the temp at which the existing vapour content is sufficient to saturate the gas.

OR

Dew pt is that temp at which the vapour pressure of the ~~vapour~~ water is equal to the partial pressure of the vapour in the given vapour gas mixture

$$\boxed{T_s = T_v}$$

At the dew pt. the humidity of the air-water vapour system is the saturation humidity which can be calculated by using the vapour pressure data or humidity chart.

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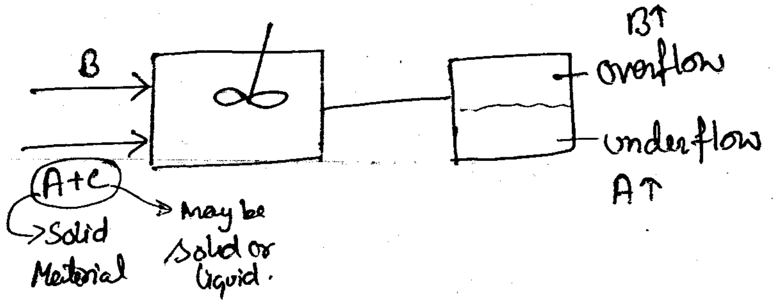
# Leaching

It is a process of separation of soluble consituent of a solid material using a suitable solvent.



$F+S=M$ , $M=O+U$

$$\boxed{Fx_c + Sy_c = Mx_c}$$

$$\boxed{Oy_c + Ux_c = Mx_c}$$

* Valuable pdt is the soluble material. and residue solid is generally a waste.

for ex → Extraction of oil from oil seeds.

Sometimes residue solid is a valuable pdt.

for ex → Extraction of non-protien solids.

* In leaching, a substancial part of solid doesnt ~~resolve~~ dissolve

Rate of extraction depends upon

i) Solvent - non(toxic, flammable), cheap etc.

ii)

## Physical Characteristics of Solid :-

⇒ For the porous, powder form. the rate of extraction in general will be high.

⇒ Aglatation

Rate of extraction ↑ with increase in rate of agitation.

Temperature

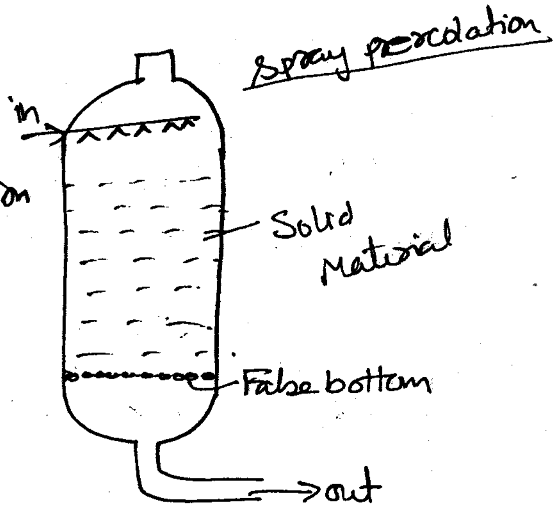
As temp ↑, rate of extraction ↑
as ( solubility ↑ )
( viscosity ↓ )

## Contacting Pattern :-

Spray percolation

* This solved is recirculated again again till definite concentration in exit stream is achieved.

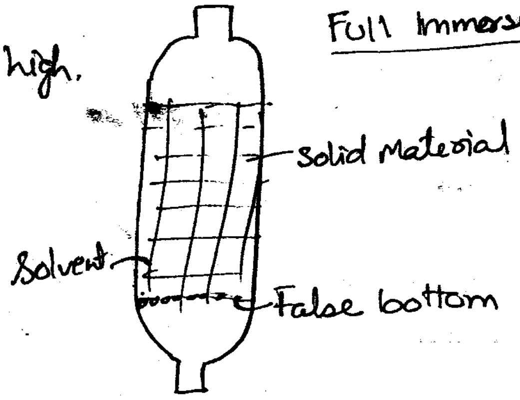
Channel forming (bcz of which mixing is not proper) M.T ↓
less amt of solvent is required.



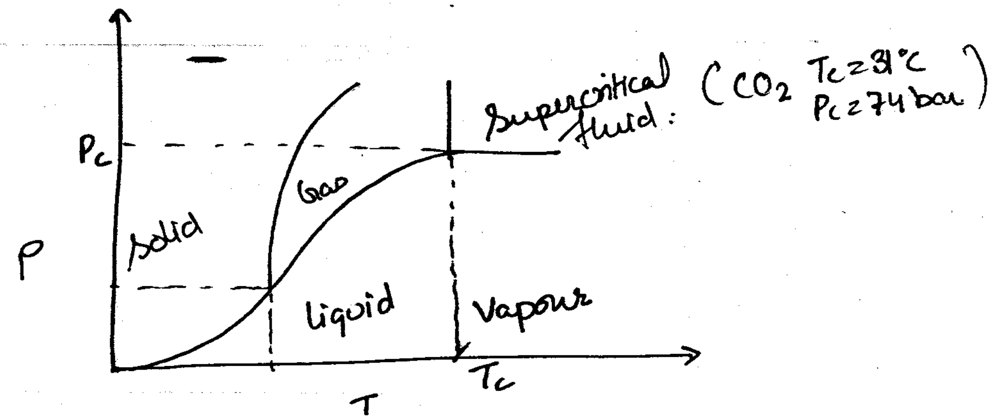
Full Immersion

* ⇒ Solvent amt required is very high.

⇒ Proper mixing.



# Supercritical fluid Extraction



The fluid is called supercritical if both temp. and pressure are above critical values. At super critical state a fluid remains as a highly condensed phase and may have a density even more than its density in the liquid state. Critical pt. is a pt. of a material above which ~~distion~~ distintion b/w liq. & gas becomes impossible.

Supercritical fluid shares the properties of both gas and liquid, its viscosity remains somewhat smaller than the normal liquid viscosity and the diffusivity of solute in the Super critical fluid. becomes high than the normal solvent.

# Adsorption

The phenomena of attracting and retaining the molecules of a substance on the surface of a solid resulting into a higher concentration of the molecules on the surface is known as adsorption.

In adsorption the molecules of a substance are present in higher concentration at the surface of the solid material. (∵ it is a surface phenomena), where as in absorption, the molecules of a substance are uniformly distributed through out the body of a liquid. There fore it is a bulk phenomena.

The substance on the surface of which adsorption takes place is called adsorbent and the substance adsorb is known as adsorbate

The process of removal of adsorbed substance from the surface on which it is adsorbed is known as disorbtion.

Sometimes adsorbtion and absorbtion takes place simutaneously and this process is known as sorption.

Types of Adsorption

| Physical Adsorption | Chemical Adsorption |
|---|---|
| Adsorbate is held on the surface by weak vander-wall forces | Adsorbate is held on the surface by chemical bonds. |
| It is lyk a physical processe<br>eg→ condensation. | It features a chemical process lyk a chemical rxn. |
| The enthalpy of adsorption is of the order of 20 kJ/mole | The enthalpy of adsorption is of the order of 200 kJ/mole |

The enthalpy change for adsorption of 1 mole of an adsorbate on adsorbent surface is called enthalpy of adsorption.

| | |
|---|---|
| Usually takes place at low temp & decreases wid ↑(temp) | Usually takes place at relatively high temp. |
| It is not specific, all the gases are adsorb to some extent on all the solid. | Highly specific in nature. |
| Multi moleculak layer may form. | Single layer will form. |

<u>Adsorption Isotherms</u> :-

The extent of adsorption of a gas on a solid is expressed by $x/m$, where $m$ is the mass of adsorbent and $x$ is no of moles of adsorbate.

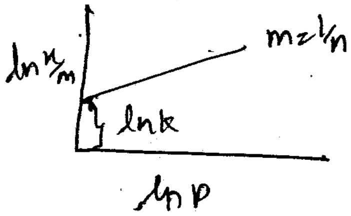
A relation between $x/m$ and pressure of gas at constant temperature is known as <u>Adsorption Isotherms</u>.

1.) Freundlich Adsorption Isotherm

$$\boxed{x/m = kp^{1/n}}$$

$$\boxed{\ln x/m = \ln k + 1/n \ln p}$$

$$y = c + mx$$



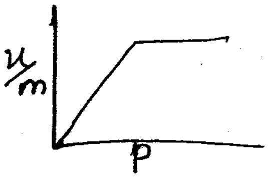
It fails when press. is very high.

## 2> Langmuir Adsorption Isotherm

$$\boxed{\frac{x}{m} = \frac{aP}{1+bP}}$$

$$\boxed{x/m = aP}$$ low pressure.

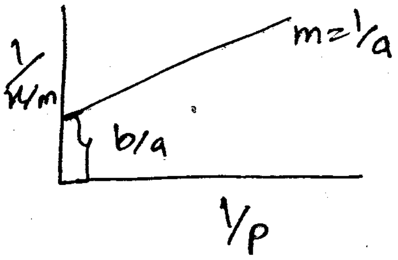
$$\boxed{x/m = \frac{a}{b}}$$ High Pressure



$$\frac{1}{x/m} = \frac{1+bP}{aP}$$

$$\boxed{\frac{1}{x/m} = \frac{1}{aP} + \frac{b}{a}}$$

$$y = mx + c$$



e)

## Adsorption Isobar:-

A relation b/w extent of adsorption and temp of gas at constant pressure is known as adsorption Isobar.