

Mass Transfer - 2

→ Distillation

- CM part → (1) Liquid - liquid extraction

(2) Distilling

(3) Adsorption

→ Back to R.E. Transfer

→ liquid - liquid extraction

To separate two miscible liquids

$B + C$ solvents such phase

solvent

C is miscible with B

A is immiscible in B



Feed solution (solution of two liquids)

$B + C$ solvents such phase

solvent

C is miscible with B

A is immiscible in B

\rightarrow carrier (miscible with C)

carrier

carrier

carrier

→ fraction of C raffinate < fraction of C in extract \rightarrow successful process.

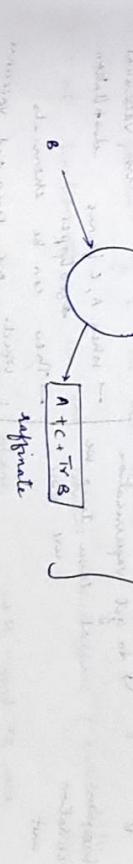
→ The solute is miscible in the solvent and the carrier is not miscible

solute misc phase

two phases.

$A + C$ solvents such phase

two phases.

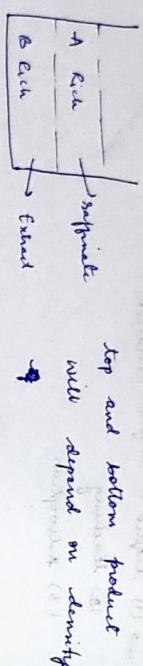


\rightarrow Product is extract

\rightarrow Problem : Product is not pure. $(B+C) \rightarrow$ subsequent additional processing is needed to separate

→ Extraction is isothermal (mostly at room temp)

→ There is significant density difference in A, B.



→ partition coefficient

→ If C is miscible in both A & B, why to choose B over A?

(i) choose B in such a way that solute is more soluble in B

(ii) solvent might have lesser solubility of C in it when compared to A.

→ extract = solvent rich phase (higher solvent)

There is not distinction between extract and raffinate based on the relative composition of C in the two phases.

→ composition of C can be lower in extract when compared to raffinate.

→ Extraction is important when distillation fails

→ extraction is based on low A.P. difference i.e. low B.P. difference

high temp might be

be sensitive to few sig.

→ A DU / VDU → vacuum distillation unit

to get vaporization

At lower temp we use VDU

These can be chemicals

which are temp and vacuum sensitive.

+ similar heat. int.

→ Distillation works based on difference in bp of components \rightarrow VLE \rightarrow vapour / liquid equilibrium

→ Extraction → difference in solubility of C in two components

(i) fluid phase

Notations in extraction

A → carrier

B → solvent

C → solute

Mass or

Mass flow rate

Continuous extractor

Batch extractor



→ Extraction can never involve a solid

→ If solid is involved it is heating \rightarrow A, C are solids \rightarrow extraction Eq: melting of tea B + tea using tea bags [water + tea bag] \rightarrow not

A → tea leaves

B → water

C → tea

D → raffinate

E → extract

→ Why there is no instant tea in instant coffee?

If tea is separated from tea leaves, it gets contaminated in the presence of atmospheric air.

→ E = mass or mass flow rate of extract

→ R = mass or mass flow rate of the raffinate.

$A + B + C = E + R$

other notations

x → wt fraction of C in the solvent - tea phase (raffinate) \rightarrow Y_{TE}

y → wt fraction of C in the solvent rich phase (extract) \rightarrow Y_E

x and y \rightarrow both are liquid phase \rightarrow Y_E and x_E are in equilibrium

Distillation: $x \rightarrow$ vapour phase

$y \rightarrow$ vapour phase

\rightarrow C different from A to B

[difference \rightarrow not mass transfer]

\rightarrow diffusion occurs until saturation is reached.

$x_R, y_E \rightarrow$ fraction of C in E, E

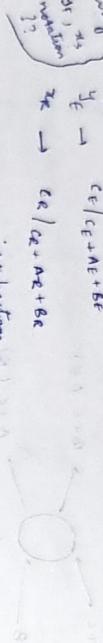
\rightarrow fraction of feed wt C = C/CA

$y_F \rightarrow$ fraction of feed wt C = $C/B = 0 \rightarrow$ pure solvent

$y_E \rightarrow$ fraction of C in solvent = $C/CA + CE + BE$

$x_R \rightarrow$ $CE/CA + CE + BE$

$\rightarrow x_R, y_E \rightarrow$ all weight fractions of C



\rightarrow N → weight fraction of B on a B free basis (solvent free basis)

\rightarrow N → one can calculate for all 3 streams

For any stream

$$N = \frac{B}{A+C}$$



feed is

A/C

Generally

Ns → ∞

NR =

$B/E / A/C + C/E$

$x_R \rightarrow$ wt fraction of C in R

$y_E \rightarrow$ wt fraction of C in E

$x' = \frac{x}{1-x}$ = weight fraction of C on a C free basis in R

$y' = \frac{y}{1-y}$ = weight fraction of C on a C free basis in E

$x =$ wt fraction of C on B free basis in R

$y =$ wt fraction of C on B free basis in E

n	y'	N	x	y	→ fractions
①	y'	N	x	y	
②	y	$3A$	$3B$		

$$x'_R = \frac{CE}{AC + CE}$$

stream

solvent

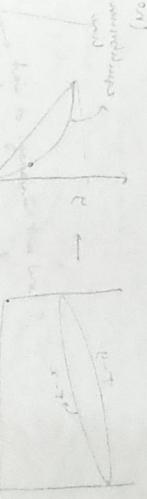
solvent

solvent

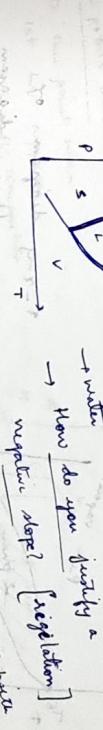
$x'_R =$

$$\frac{CE}{AC + CE}$$

solvent



① phase diagram → 1 component



positive slope
[melting PT decreases with increase in pressure]

decrease in pressure

negative slope
[regulation]

increase in pressure

② 2 component

③ 3 component

④ 4 component

⑤ 5 component

⑥ 6 component

⑦ 7 component

⑧ 8 component

⑨ 9 component

⑩ 10 component

⑪ 12 component



total vapor pressure

constant T

increasing T

constant P

increasing x

increasing P

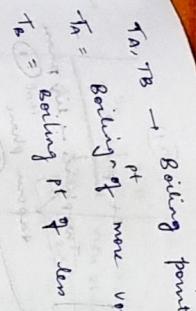
increasing x

increasing P

increasing x

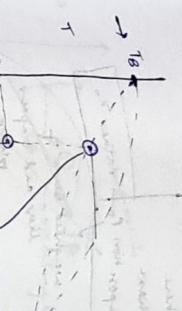
- \rightarrow olute $c \rightarrow$ is in a solution with $\textcircled{1}$ -carrier separate from a solution of A and C
- \rightarrow Boiling pt of more volatile component \rightarrow high vapour pressure
- $T_B =$ boiling pt of less volatile component \rightarrow low vapour pressure
- $T_A =$ boiling pt of intermediate component

what should be done?



\rightarrow Boiling point of a mixture?

Does not have a specific bp \rightarrow less range of temp.



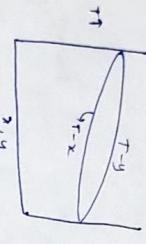
- property of solvent ($\textcircled{1}$)
- A and $B \rightarrow$ immiscible
- $B + C \rightarrow$ fully miscible
- $A + C \rightarrow$ fully miscible

based on what do we determine temperature of the mixture?

- A and B should be immiscible
- boiling temp depends on extent of immiscibility

\rightarrow for two miscible liquids

(not no mutual solubility)



DISTILLATION

separation of $\textcircled{1}$ through $\textcircled{2}$ (miscible and immiscible) volatile component

two ways to separate $\textcircled{1}$ (1) by distillation

note one point when
1st air appears

at air composition
in vapour phase

new point curve

how to generate this line?

Note new temp when
the bubble appears
for a particular composition

vertical axis

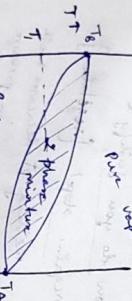
for pure \rightarrow during phase transition
component \rightarrow temp does not change

what is composition of bubble?

will have the
1st bubble

what is composition with intersecting
points enough?

at $x = 0.5$



\rightarrow y-y diagram or
T-x diagram
than diagram
of two liquids

Possible situations (slim)

- $\textcircled{1}$ miscible
- $\textcircled{2}$ immiscible (approaches $\textcircled{1}$)

on content of distillation

dist - vapour phase
transition of mix
system

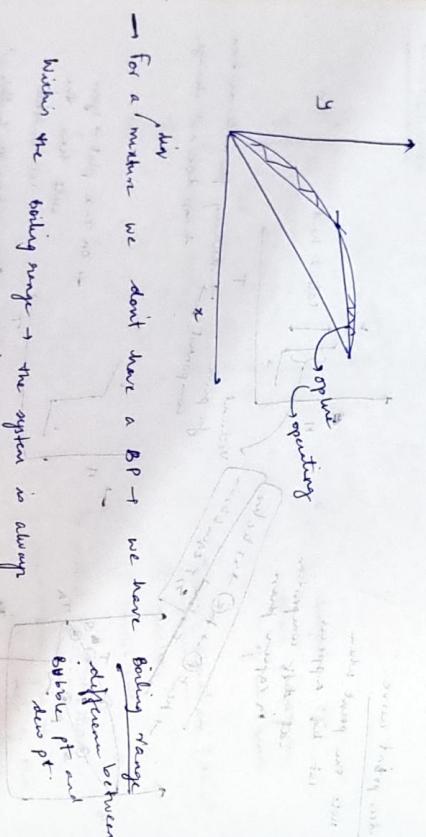
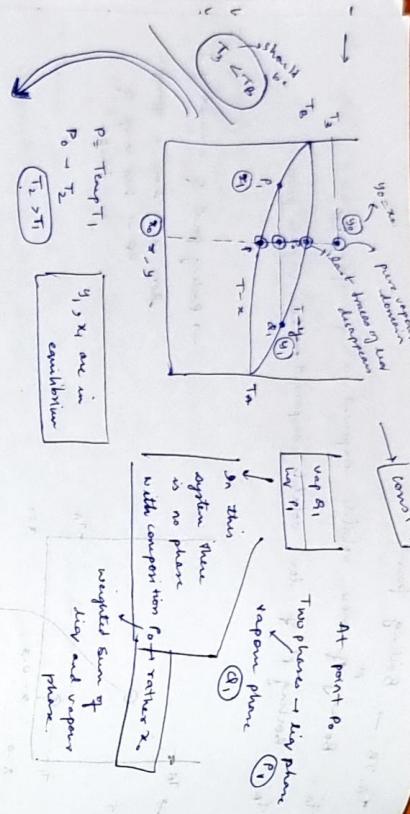
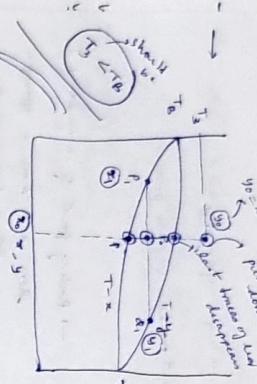
$x = 0 \Rightarrow 100\%$ immiscible component

y-fraction of more volatile component in vapour phase

$x = 0 \Rightarrow 100\%$ immiscible component

too little
not enough
not enough
 \rightarrow will boil
in air bubbles

\rightarrow vapour pressure
is not constant



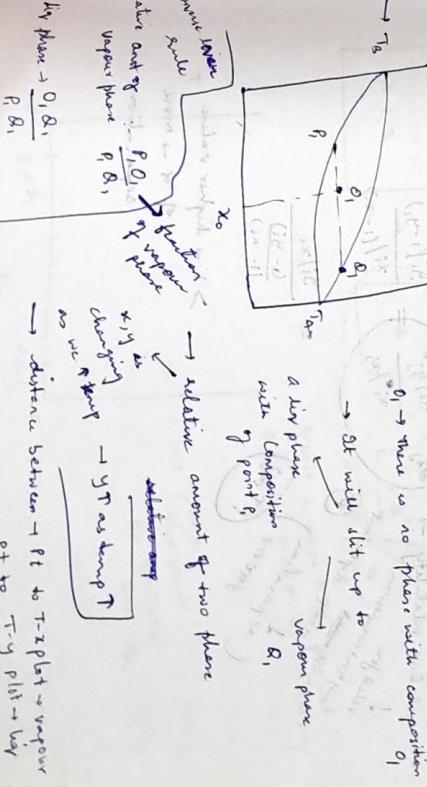
Within the boiling range the system is always in 2-phases (liquid and vapour)

composition of two phases are in equilibrium

For a mixture we don't have a BP → we have different between boiling range and evap. pt. and dist. pt.

Within the boiling range → the system is always in 2-phases (liquid and vapour)

composition of two phases are in equilibrium



partial pressure of liquid phase is zero at T_B

partial pressure of vapour phase is zero at T_B

relative amount of two phase

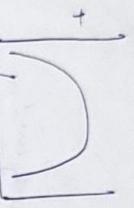
as we keep changing $\rightarrow y_1$ as y_2

distance between \rightarrow P_0 to T - x plot \rightarrow vapour

P_0 to T - y plot \rightarrow liquid

→ solubility increases with increase in temp.

Two liquids which are immiscible at room temp.
In many cases
Their miscibility +



sphere region
immiscible region will be in

one region or

two regions

and

one region

When we have two liquids

partial miscibility
immiscible

rarely happens

depends on

solubility & miscibility

c → soluble
A → carrier liquid
B → solute

l

T

C

Two liquids have $\frac{\mu}{\mu} = 1$

see liquids will flow
at same rate no mixing

more viscous

less viscous

less miscible

more miscible

as

more

less

more

less

more

less

more

less

a + b
 \rightarrow
 $\begin{pmatrix} 1 & -1 \\ 0 & 0 \end{pmatrix}$ + $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$
2 new phases

→ same $\frac{\mu}{\mu} = 1$

see liquids will flow
at same rate no mixing

more viscous

less viscous

less miscible

c, A → miscible
c, B → completely miscible
A, B → partially miscible / immiscible

→ miscibility ↑ with temp.

Postural miscibility → 2 new phases (separate)

(1) stratified phase
(2) dispersed phase

as before

$$x_1(y_1/x_1) \left(\frac{(1-x_1)}{(y_1/x_1)} \right) = \frac{y_1/x_1}{(1-y_1/x_1)} \quad (1-1)$$

$$A + B \rightarrow$$

$$\begin{pmatrix} 1 & -1 \\ 0 & 0 \end{pmatrix}$$

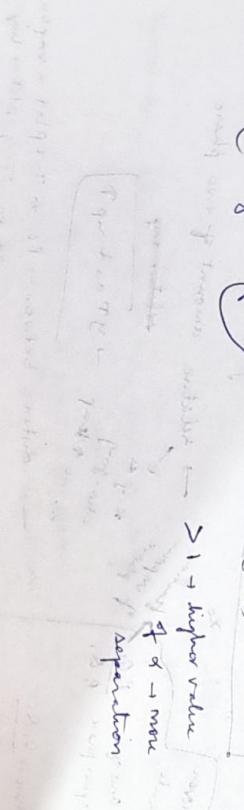
A with + some B
B with + some A
of partial miscibility

A with + some B
B with + some A
of partial miscibility

→ phase diagram
or partially miscible

separates into 2 immiscible regions

Y vs X

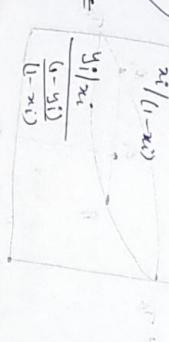


→ relative volatility \rightarrow
value for composition
independent of temperature

and composition

constant (1)

$$\sigma_{ij} = \frac{y_{ij}/y_j^*}{x_{ij}^*/(1-x_{ij})}$$



2 regions

x_i

y_ij

Y vs X
T is constant for each phase

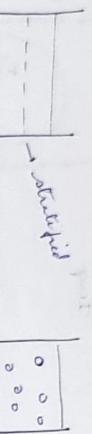
Y vs X
T is constant for each phase

Y vs X
T is constant for each phase

→ stratified or dispersed → depends on density difference and interfacial surface
 high density difference → less density difference

more dominant tension (T_{ij}) leads to reduced coalescence in droplet area

$\rightarrow T_{ij}$ is high → stratified → greater probability of coalescence



→ droplets will be less likely to join or merge to form one mass

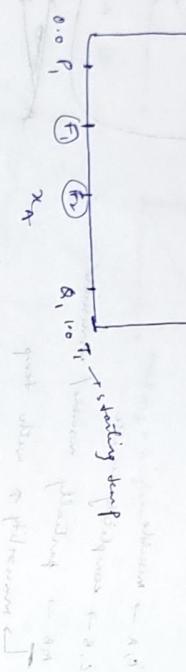
→ energy penalty

→ below T_{max} → phases can be separated

→ What is T_{max} called? → upper critical solution temperature (UCST) with respect to temperature

$\rightarrow \rho_1\alpha_1 > \rho_2\alpha_2 \rightarrow$ tie lines between different phases will be vertical

→ fraction of A rich = B rich as a function of T (temperature)



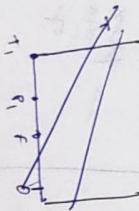
→ if you take any composition between P_1 & P_4 then compositions giving us x_A we will have 2 rich phases. (will be α_1 at P_1 and α_4 at P_4 → A rich $\rightarrow \alpha_1$)
 by x_A at P_1 \rightarrow α_1 \rightarrow $\alpha_1 + \alpha_2$

$\rightarrow f_1, f_2 \rightarrow$ mixture of P_1, α_1

$\rightarrow f_2 \rightarrow$ richer \downarrow or α_1 rich phase compared to f_1

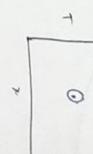
\rightarrow fraction of A rich phase in $f_2 \rightarrow F_2 P_1 / P_1 \alpha_1$

\rightarrow fraction of A rich phase in $f_1 = F_1 P_1 / P_1 \alpha_1$

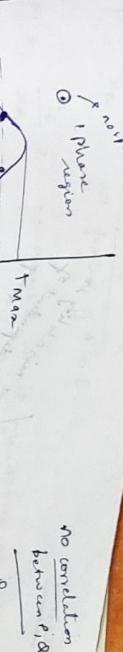


A rich $\rightarrow \alpha_1$
 B rich $\rightarrow \alpha_2$

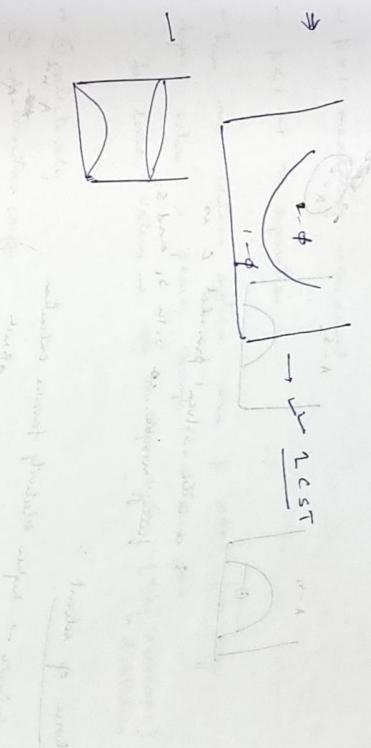
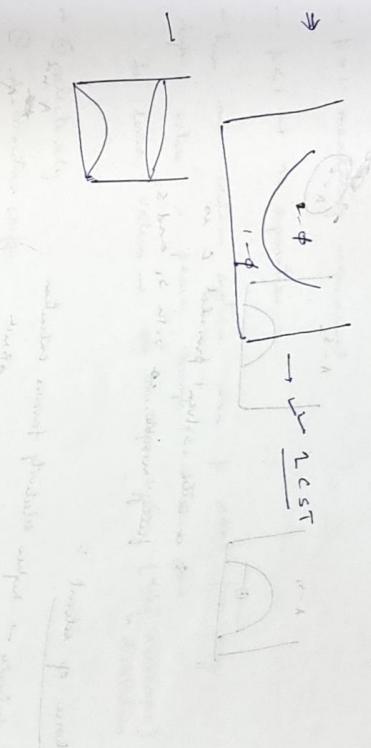
fraction of $\alpha_1 = F_1 P_1 / P_1 \alpha_1$



Perfectly miscible



no correlation between ρ_i



Case - 1

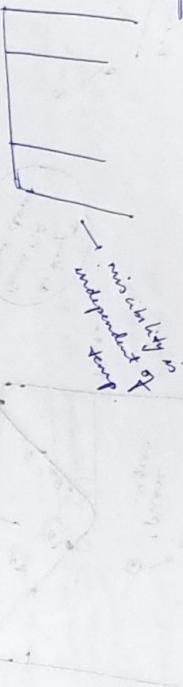
$\beta = \frac{y_E}{x_E} \times \frac{\text{wt fraction of A in R}}{\text{wt fraction of A in E}}$

$\beta > 1 \rightarrow \text{expected} \rightarrow \text{not mandatory} \rightarrow \text{desirable}$

$$\text{distribution coefficient} = \frac{y_E}{x_E}$$

distribution coeff

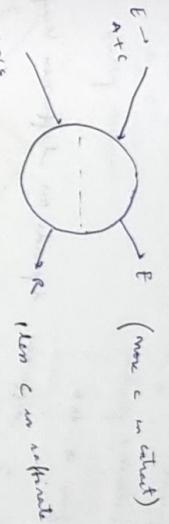
→ better extraction + selectivity should be as high as possible



→ What determines the choice of solvent?

④ C must be completely miscible with B as possible

A → must be immiscible with B as possible
B → must be miscible with C as possible



(more C in extract)

→ $\beta > 1$ mandatory requirement

→ $\beta < 1 \rightarrow$ no separation

When we certain options when β starts from very high value, passes through 1 and then goes to lower values → the selective option (like azeotropic distillation)

choice of solvent:

① selectivity → higher selectivity favours extraction

$$\beta = \frac{(\text{wt fraction of C in E}) / (\text{wt fraction of C in R})}{(\text{wt fraction of A in E}) / (\text{wt fraction of A in R})}$$

A rich
B poor

→ $\beta > 1$

② distribution coeff

③ miscibility of the solvent → higher is the carrier solvent, better it is

④ recuperability: E' comprise of $\frac{B + C + \text{trace of A}}{1}$

solvent → pure B.

→ separating A and C using B

and C in distillation?

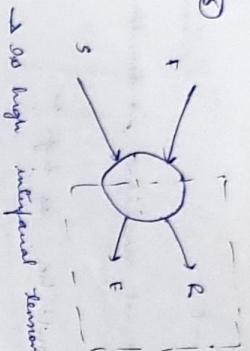
→ separating A and C using B in distillation?

extraction solubility

→ B and C does not an azeotope

C is taken out
left with B

(5)



- do high interfacial tension desired?

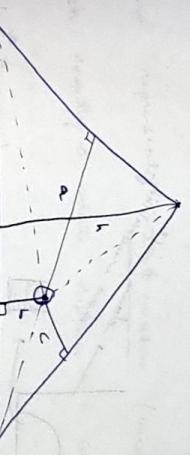
high interfacial tension would need to foster / prevent coalescence.

- total time of diffusion depends on diffusion length
- high density difference and interfacial tension cause coalescence

→ But high interfacial tension has • less MT area.

Comparison of $\Delta \gamma$ and $\Delta \rho$ for different dispersed systems

is it point to
interfacial tension?
physically



triangle with equal distance

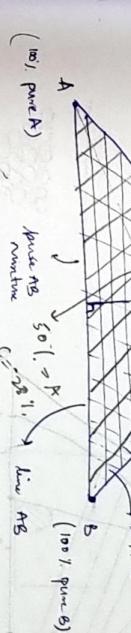
$$h = a + b + c$$

$$c = 100\% \text{ pure } C$$

$$b = 100\% \text{ pure } B$$

$$a = 100\% \text{ pure } A$$

line with equal distance



- any open indicates 100% pure component

Any pt on BC
line can be
written in terms
of a , b , c

$$0 + \left(\frac{72 - 30}{12 - 0} \right) \left(\frac{12 - 0}{20 - 10} \right) 0 + \left(\frac{14 - 10}{20 - 10} \right) 0 + 20 \left(\frac{192 - 0}{30 - 0} \right)$$

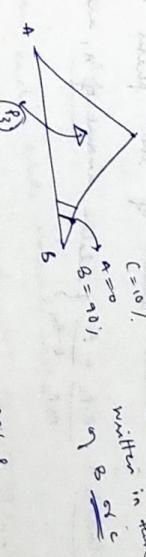
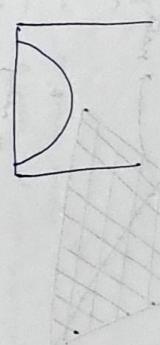
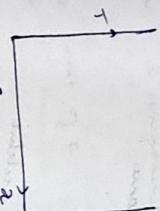
$$6 + 27 = 33$$

31/29

TRIANGULAR PLOT

do you represent a ternary system

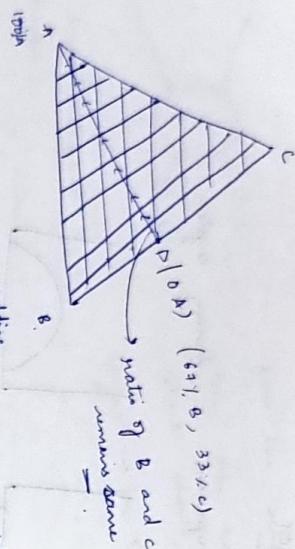
fully miscible



33/1

→ add C

→ What happens in 3-component system, temp is analogous to c in 3 component system in



100%

A

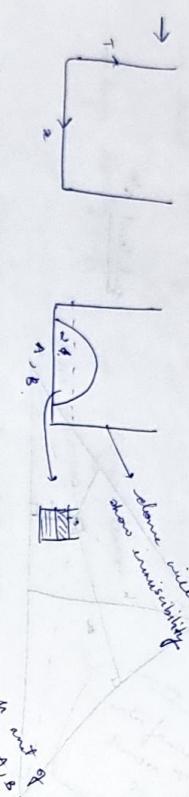
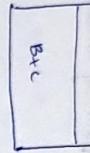
B

C

→ large amt of C, entire A will dissolve in C

B will dissolve in

↓ we will get homogeneous solution.



A

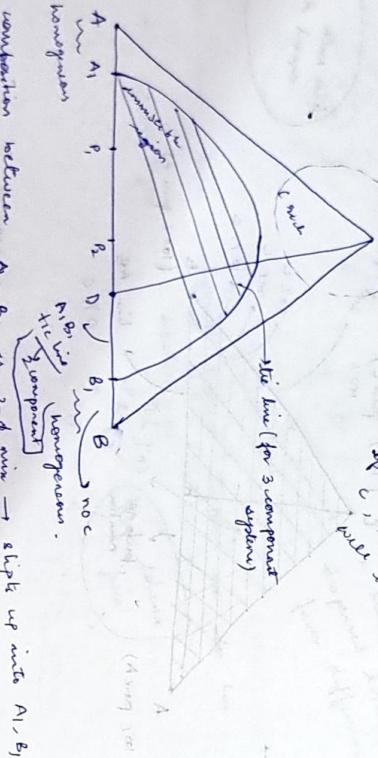
B

C

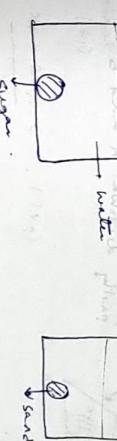
100%

→ Three component at const temp

↓ line (for 3 component system)
↓ we have enough amt of A, B,
↓ C, entire dissolve
↓ with dissolved

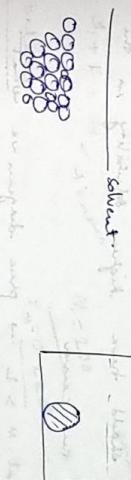


→ When creating a solute dissolves in a solvent?
→ When creating a solute dissolves in a solvent?



sugar

↓ solubility → dissolution means + wif solvent molecule to is surrounded by solvent molecules. (Adhesion is favoured than cohesion)



any comparison between A, B, C in 2 of mix → shift up into A, B, C

P₁, P₂ → relative amount of the phases will be different

→ Point P₁: $\frac{B_1 P_1}{A_1 P_2} < \frac{A_1}{K_{B_1}}$ } relative amount of A₁ and B₁

Point P₁: $\frac{B_1 P_1}{A_1 P_2} > \frac{A_1}{K_{B_1}}$

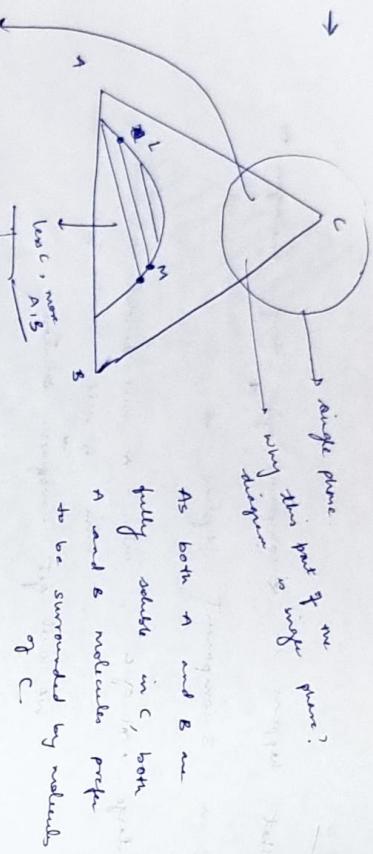
→ What determines whether each solute molecule will be surrounded by solvent molecules? depends on

surrounded by solvent intermolecular forces

→

single phase
why this part of the plane?
more dilute

As both A and B are
fully soluble in C, both
A and B molecules prefer
to be surrounded by molecules
of C.



when we
have more C
large amount of C screens solvents A and B
so they are surrounded
by C molecules

C is expensive

→ why we do not have adequate amt of C to disolve A, B.
Cervative >> adhesive.

partly dissolve A and B.

↓ done represents
solubility.

→ why the other two are not horizontal?

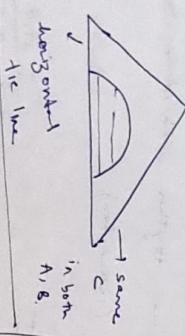
[C is more miscible than A] → then think gas behaviour

→ ideally solute (C) should have higher solubility in one

→ solvent (B) than the other

→ composition of C at $n > 1 \rightarrow$ pure diagram we want

→ ~~horizontal~~



horizontal line

A,B with C
less, more A,B

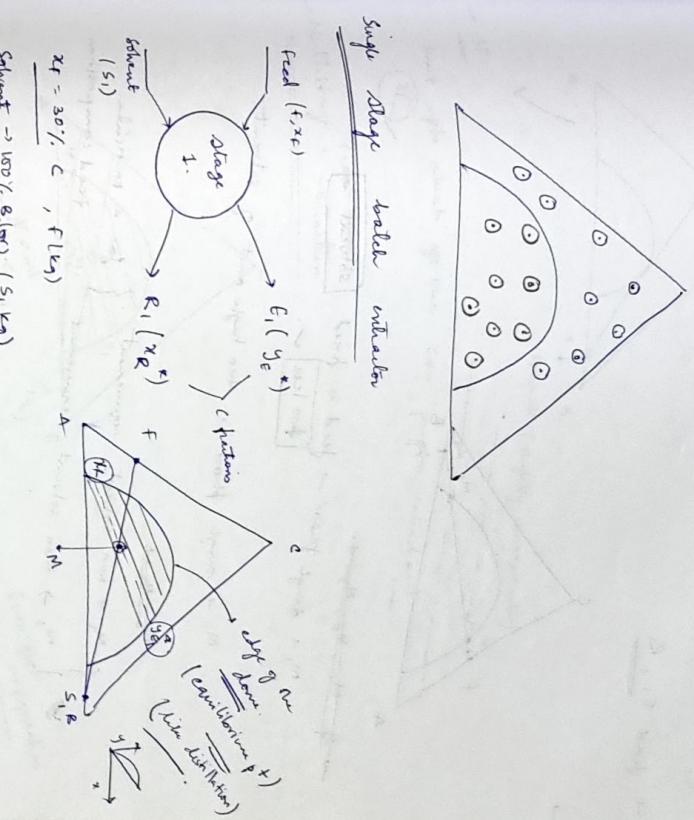
unmixing?

rich

pure C composition?

↓ hence C is expensive

→ C is expensive



$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

right

left

$$S_1 + F = R_1 + E_1$$

$$96\% B, 4\% A$$

(M)

total amt of liquid stage

in hand

no liquid separation

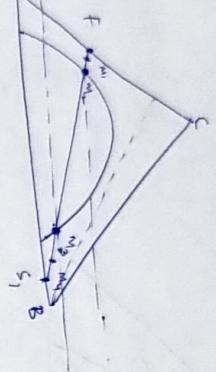
right

left

→ we have a few components and mix them and leave it
for some time.

$y_{P_1}, x_e \rightarrow \infty$

fixed t_1, P_1



$M_1 \rightarrow$ single phase \rightarrow feed is pured [solvent is ~~too less~~]

$M_1 \rightarrow$ single phase \rightarrow too high amt of solvent.

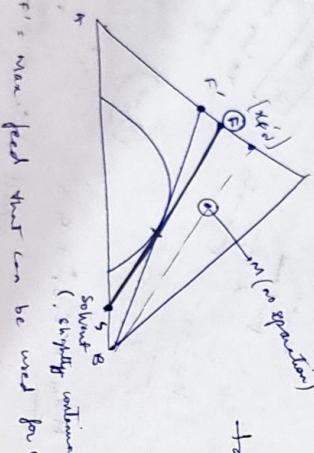
$M_1 \rightarrow M_2, M_3$

$\left. \begin{array}{l} M_2 \rightarrow \text{non solvent requirement} \\ M_3 \rightarrow \text{non solvent requirement} \end{array} \right\}$ for a particular feed composition

$x_m \rightarrow$ must lie between M_1, M_2 & M_3 on a binary

tangent to the curve done

What is the significance of F' ?

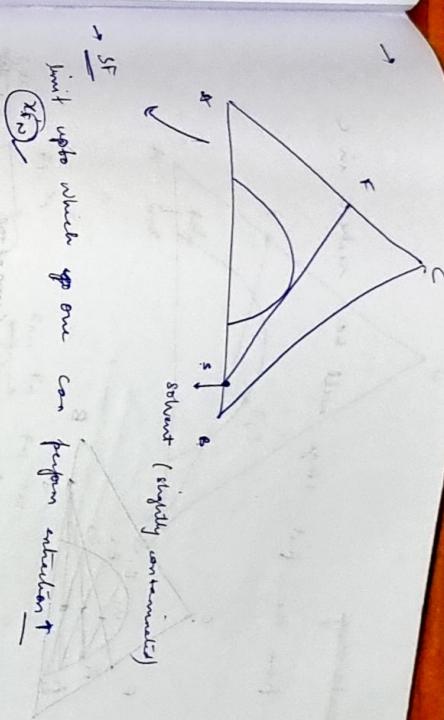


$x_e, y_s \rightarrow \infty$ \rightarrow no separation

$F' = \text{max feed that can be used for extraction}$

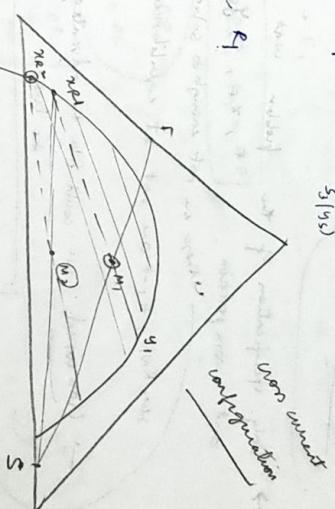
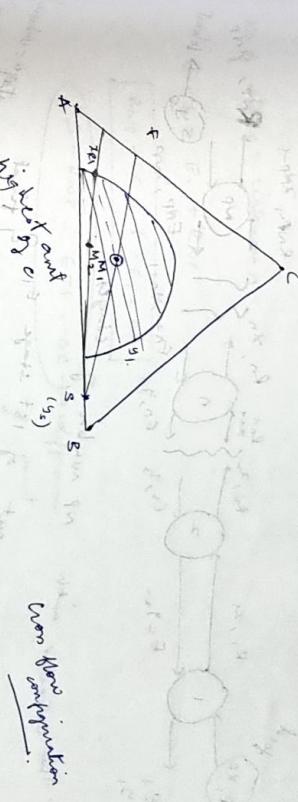
\rightarrow if $x_e > x_e' \rightarrow$ extraction will not work.

x_e as the limit of x_e for the feed for which a successful extraction is possible



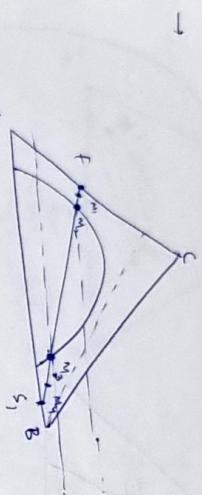
\rightarrow ~~upto~~ upto which you can perform extraction \uparrow

\rightarrow multistage \downarrow extraction



$y_{t_1} + x_t \rightarrow \dots$

find c_1, R_1



if $M_1, M_2 \rightarrow$

$M_1 \rightarrow$ single phase \rightarrow feed is fixed [solvent is fixed less]

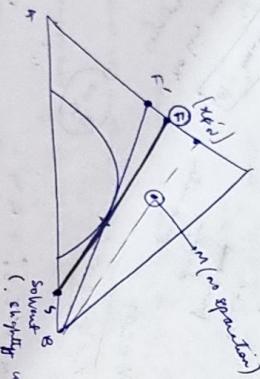
$M_2 \rightarrow$ single phase \rightarrow too high ant. to solvent

$\Rightarrow \begin{cases} M_2 \rightarrow$ min solvent requirement for a particular feed composition \\ $M_3 \rightarrow$ min solvent requirement for a particular feed composition \end{cases}

$x_m \rightarrow$ must lie between M_1, M_2 and M_3

Tangent to the curve

What is the significance of F' ?



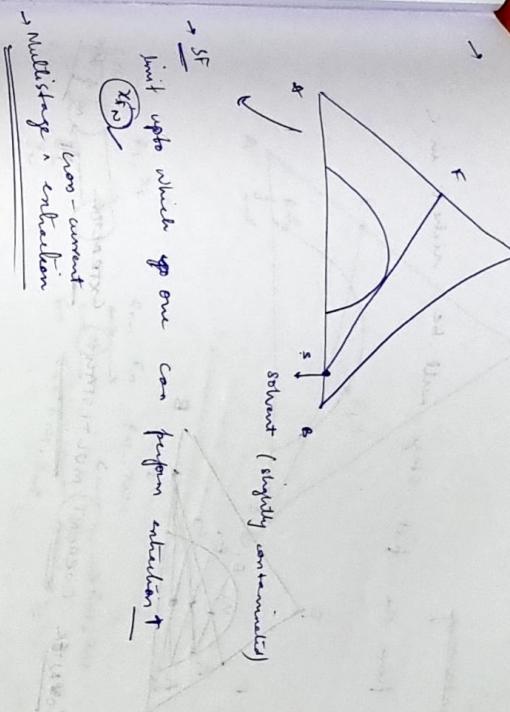
Solvent B
(solvent unimolar)

F' = max feed that can be used for extraction

\rightarrow if $x_t > x_t' \rightarrow$ extraction will not work.

x_t is the limit of x_t for the feed for which a successful extraction is possible

Net - loss



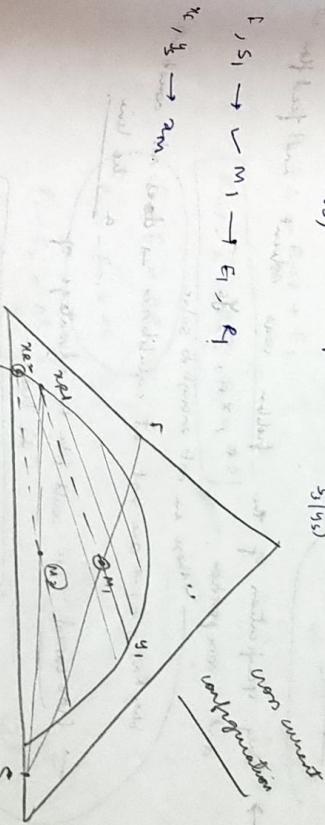
\rightarrow SF upto which you can perform extraction

(x_{t_1})

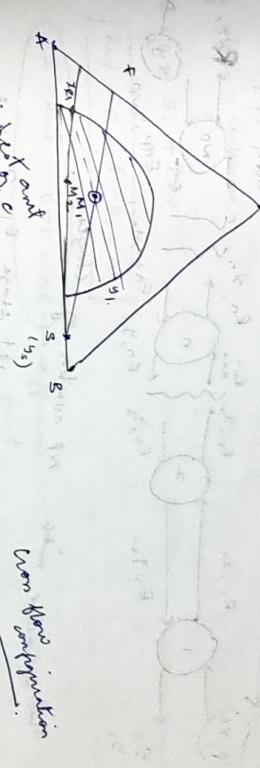
\rightarrow Multistage extraction

limit upto which you can perform extraction \uparrow

solvent (slightly contaminated)



non flow configuration



weighted ant. to solvent

$E_1(y_1^*)$

$E_2(y_2^*)$

$E_2(y_2)$

$S_1(y_1)$

$S_2(y_2)$

R_1

R_2

x_{t_1}

x_{t_2}

x_{t_3}

x_{t_4}

x_{t_5}

x_{t_6}

x_{t_7}

x_{t_8}

x_{t_9}

$x_{t_{10}}$

$x_{t_{11}}$

$x_{t_{12}}$

$x_{t_{13}}$

$x_{t_{14}}$

$x_{t_{15}}$

$x_{t_{16}}$

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$x_{t_{96}}$

$x_{t_{97}}$

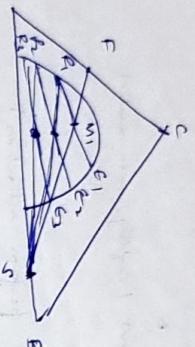
$x_{t_{98}}$

$x_{t_{99}}$

$x_{t_{100}}$

Product containing

→ The extract from the first stage will be richest in C



CONTINUOUS COUNTERTCURRENT MULTISTAGE EXTRACTOR
No. of stages = n



The extractor with NP number of stages

Extract will come out of 1st stage E_1 final
Raffinate will come out of NP stage R_{NP} [No. of stages = unknown]

$$\text{Overall balance: } F + S = E_1 + R_{NP} = M$$

$$C - \text{balance: } F_{x_F} + S_{y_S} = M_{x_M} = E_1 y_1 + R_{NP} x_{NP}$$

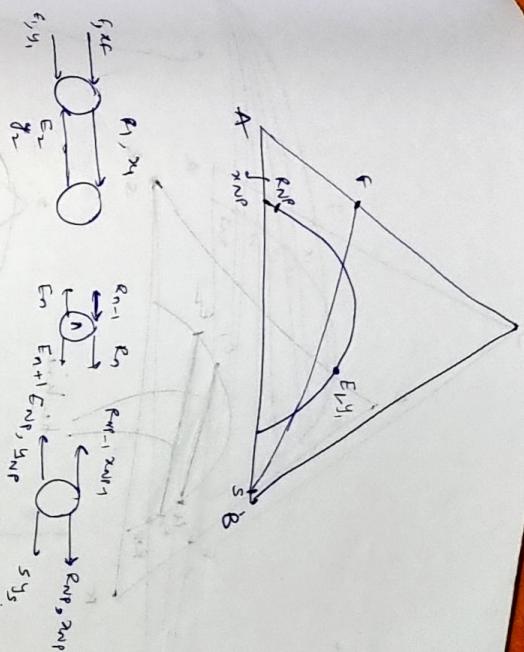
Only specification of the problem was solvent and feed flow rate

and composition. These are not enough to solve

but, R_{NP} , E_1 are not at equilibrium → does not constitute a tie line.

→ Misment: we could take the advantage of tie line.

$$\therefore E_1, y_1 \rightarrow \text{need to be specified}$$



$$N.o. \text{ of stages} = \text{unknown } n$$

$$F + S = E_1 + R_{NP}$$

$$R_{NP} - S = F - E_1 = \Delta R$$

$$S - R_{NP} = E_1 F = -\Delta R \rightarrow \text{difference}$$

↓ point
net flow out
from any stage in one particular direction

$$R_{n-1} + S = E_n + R_{NP}$$

$$R_{n-1} - E_n = R_{NP} - S = \Delta R$$

$$F + S = R_{NP} + E_1$$

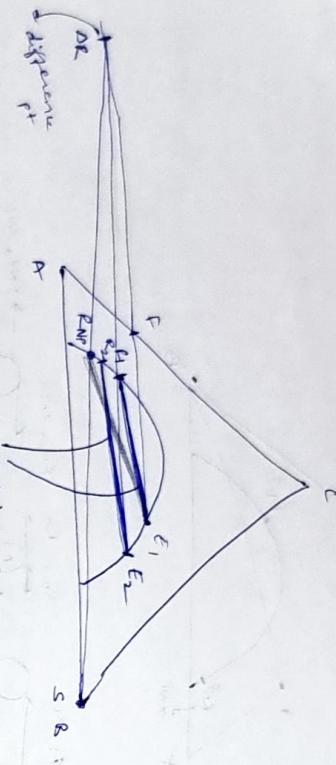
$$R_{NP} - S = R_{n-1} - E_n = \Delta R$$

$$F - E_1 = \Delta R$$

$$E_1 - E_2 = \Delta R$$

$$R_2 - E_2 = \Delta R$$

OK



$E_1 - E_2 \rightarrow$ one in equilibrium

$E_1, F \rightarrow$ not in equilibrium

$E_1, F_2 \rightarrow$ interest at ΔR

ΔR

$\Delta R = R_{n+1} - E_n$

$$\Rightarrow R_{n+1} - S = F - E_1 = R_n - E_2 = \dots = R_{n+1} - E_n$$

difference equation

$$S = 1 - F + 2 - R_{n+1}$$

$$S = 1 - F + 2 - R_n + 2$$

$$S = 1 - F + 2 - R_n + 1 - nS$$

$$S = 2 - F + 1 - nS$$

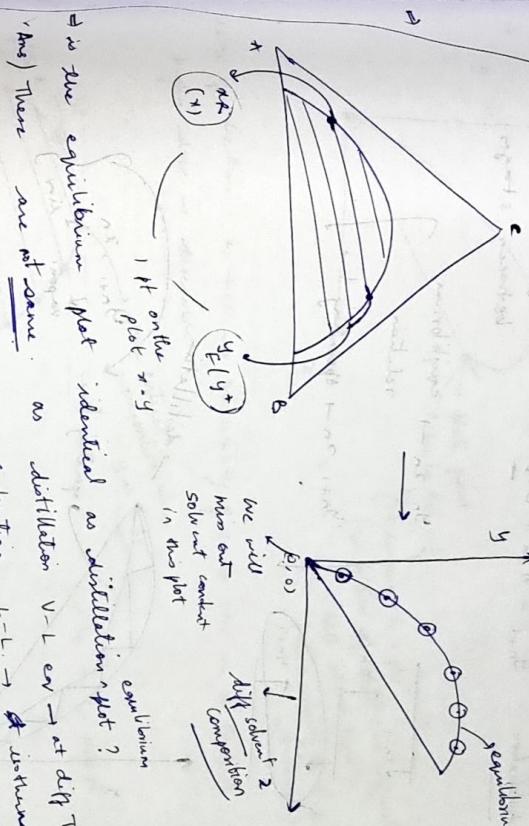
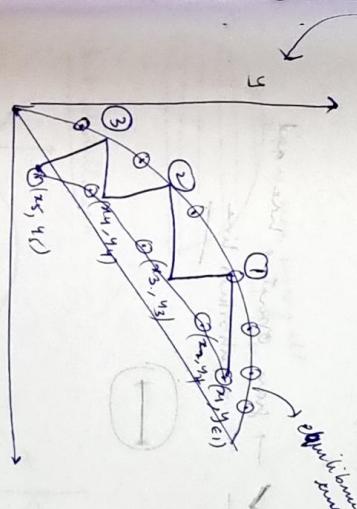
$$S = 2 - F + 1 - nS = 0$$

→ When will be the solution find?

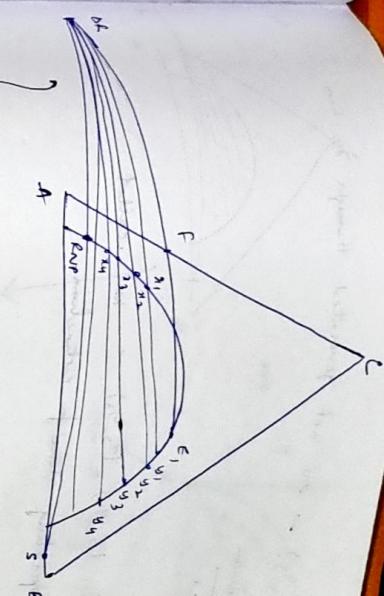
① If E_n will serve

the line will serve as number

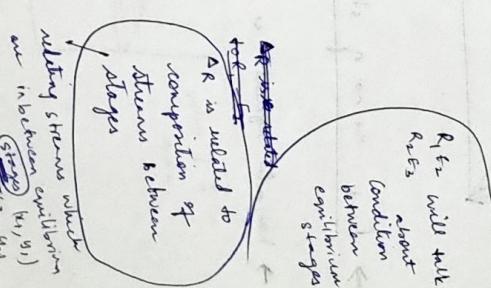
of stages.



→ is the equilibrium plot identical as distillation plot?
(Ans) There are at same as distillation V-L cur → at diff T
extraction L-L → not same



From ΔR draw some random lines which intersect the curve at $(x_1, y_1), (x_2, y_2), (x_3, y_3)$ etc. not at equilibrium



R_{n+1} will talk about R_{n+2} condition between equilibrium stages

ΔR is related to composition of streams between stages

relating streams which are in between equilibrium or stages $(x_1, y_1), (x_2, y_2)$

$(x_1, y_1), (x_2, y_2), (x_3, y_3)$... are not generated through the line.

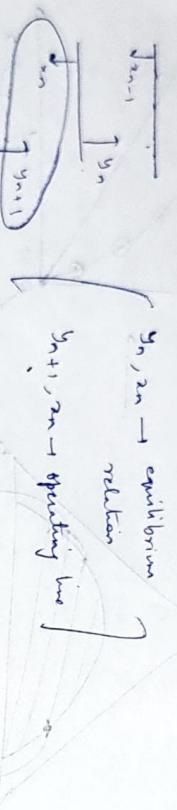
can exist only between stages and not at equilibrium.

equilibrium.

wave joining $(x_1, y_1), (x_2, y_2), (x_3, y_3)$... is called operating curve \rightarrow operating line for extraction.

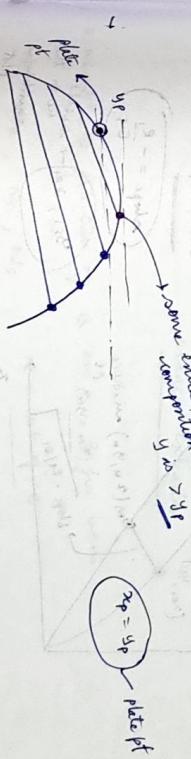
distillation $\rightarrow y_{n+1} = Ax_n + Bx_n \rightarrow$ locus of composition between stages

distillation $\rightarrow y_{n+1} = Ax_n + Bx_n \rightarrow$ locus of composition between stages

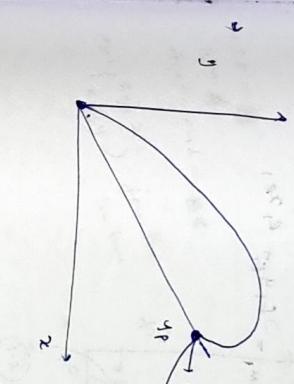


slope of tie line is +ve \rightarrow miscibility of C is more in B than A . Higher slope \rightarrow separable.

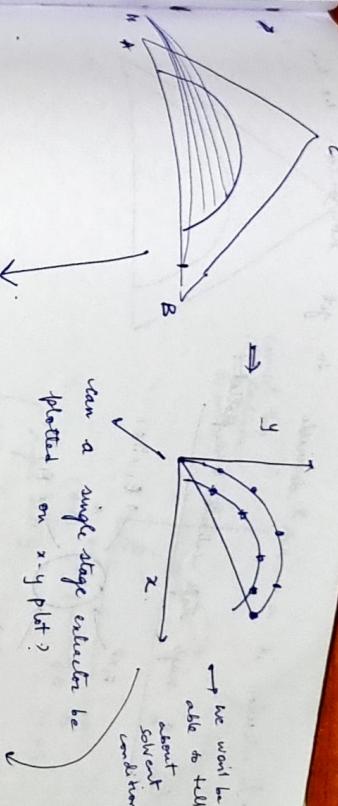
some composition $y_A > y_B$



$y_B = y_P$ \rightarrow plate pt
 $x_P = y_P$ \rightarrow plate pt

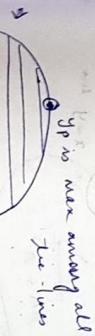


tie line does not exist (converges to a pt)
 (composition of liquid and vapour (composition of liquid and vapour curve))
 (miscibility of A, B
 is not visible)



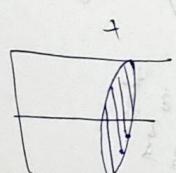
\rightarrow find no. of stages $\checkmark \rightarrow$ from operating line and equilibrium line

\rightarrow horizontal segment \Rightarrow single stage



y_B no max. among all tie lines

max. distillation



max. value of y_A in

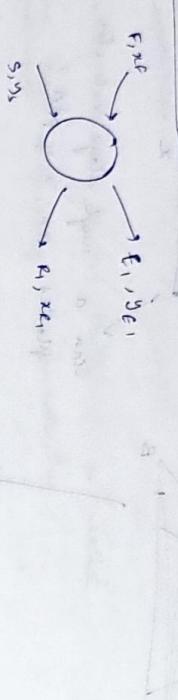
and also all y_A

and x_B in

and x_A in

→ In extraction it is not desirable to get horizontal tie lines

Can a single stage extractor be plotted?

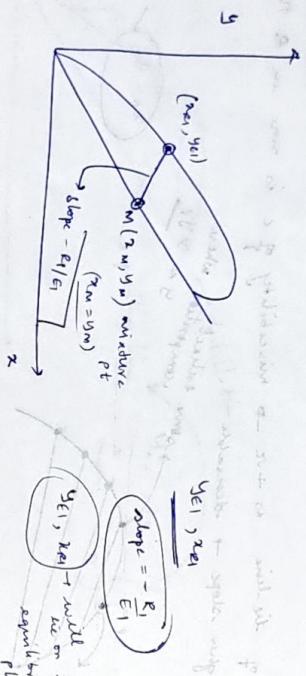


$$S + F = M_1 = E_1 + R_1$$

$$S_F + F_{x_F} = M_1 x_{M_1} = E_1 y_{E_1} + R_1 x_{R_1}$$

$$y_{E_1} E_1 + R_1 x_{R_1} = M_1 x_{M_1}$$

$$y_{E_1} = \frac{R_1}{E_1} x_{R_1} + \frac{M_1}{E_1} x_{M_1}$$



Parameters provided: F, x_F, y_S, S

If we don't have this information, we can't solve the problem.

∴ We don't have enough information to solve the problem.

∴ We don't know the reflux ratio.

∴ Slope

if we also know

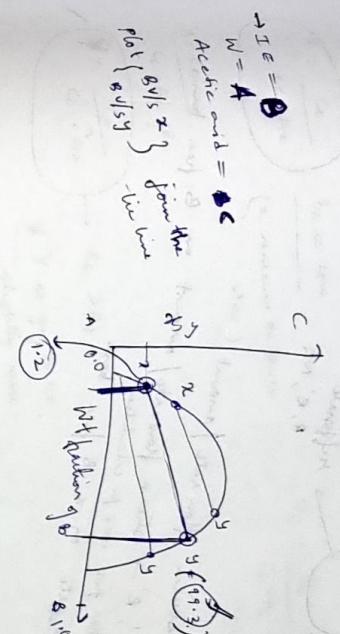
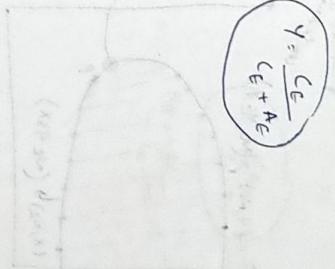
y_E , we can use

reflux ratio

$C_R = \text{wt of } C \text{ in raffinate}$

$C_L = \text{wt of } C \text{ in the extract}$

$A = \text{wt of } A \text{ in raffinate}$



⇒ N-X-Y (0-ordinate) system for a single stage extractor

N-weight fraction of B on a B-free basis

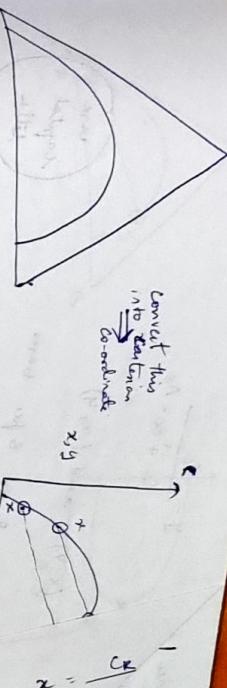
N_E, N_K, N_C, N_S

$N = \frac{\text{wt of } B}{\text{wt of } (A+C)}$

$$X = \frac{C_R}{C_R + A_R}$$

$$Y = \frac{C_L}{C_L + A_C}$$

equilibrium data
(x, y)
given in the question
(horizontal row \rightarrow tie line)



$$x = \frac{Ce}{Ce + Be + Ae}$$

$$y = \frac{Ce}{Ce + Be + Ae}$$

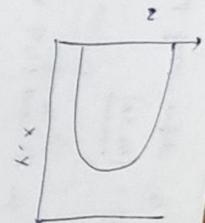
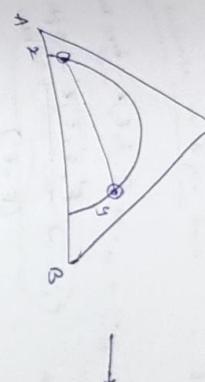
\rightarrow diff. between (x_1, y) and (x_2, y)

$\rightarrow N = \text{wt. fraction of } B \text{ in } S \text{ per basis}$



use capital letter

convert $x \rightarrow X$



$$N_R = \frac{Be}{Ce + Ae}$$

$$x = \frac{Ce}{Ce + Be + Ae}$$

$$y = \frac{Ce}{Ce + Be + Ae} \quad \begin{matrix} \text{Be is low} \\ (\text{e remains on lower} \\ \text{side}) \end{matrix}$$

$$y = \frac{Ce}{Ce + Ae} \quad \begin{matrix} Ae > Be \\ y is going to be \\ slightly more \\ higher \end{matrix}$$

$\rightarrow N_F = \text{wt. \% } B \text{ in feed}$

wt. % $(A+C)$ in feed

$$(N_F = 0)$$

$$f = f'$$

$$\begin{cases} f = \text{total amt. of } A, C \\ (B=0) \end{cases}$$

$$\begin{matrix} \text{top side of the curve} \rightarrow (N_E \text{ vs } Y) \\ \text{bottom part} \rightarrow (N_E \text{ vs } X) \end{matrix}$$

$\rightarrow X, Y \rightarrow B \text{ free basis}$

$\rightarrow (X_1, Y_1) \text{ or } (Y_1, N_E) \rightarrow \text{using stream will have these values.}$

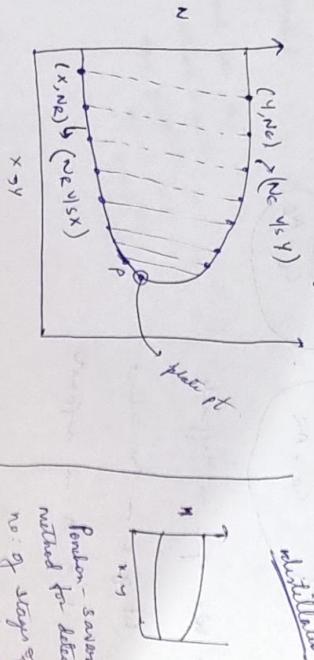
$$N_E = \frac{\text{wt. \% } B}{\text{wt. \% } (A+C)}$$

$$N_E = \frac{Ce}{Ce + Ae} \rightarrow B \text{-free}$$

$$\text{Solvent} \rightarrow (Y_S, N_S)$$

$$\text{extract} \rightarrow (Y_E, N_E)$$

$$\text{raffinate} \rightarrow (X_R, N_R)$$



Potential-solvent method for determining no. of stages of distillation column?

$x-y$

→ In order to define wiping point

① different: (N_E, X_E)

N_E

X_E

→ Calculate the N and (X, Y) values.

• Feed: \rightarrow $F = \min\{A, C\}$

$N_E \rightarrow 0, F' = F$

different:

$$N_S = \frac{B_E}{A_E + S}$$

for pure solvent $\rightarrow [N_S \rightarrow \infty]$

$$\begin{cases} S' = 0 \\ S' = 0 \end{cases}$$

→ ① Separation data must be converted into $N/x/X$, $N/y/Y$

Infinite without correction

different

different

$$N_S = \frac{B_E}{A_E + S}$$

$$N_S = \frac{S}{S'}$$

$$N_S S' = S$$

$$N_S = \frac{S}{S'}$$

$$N_S = \frac{B_E}{S'}$$

$$N_S = \frac{B_E}{A_E + S}$$

$$N_S = \frac{B_E}{A_E + S}$$

always join the two lines

the two lines

join the two lines

join the two lines

→ $r', s', m', E', R' \rightarrow$ none of these flow rates are there

$F, S, E, R \rightarrow$ true amounts

$F', S', E', R' \rightarrow$ a force

balance

$$\left. \begin{array}{l} F'x_F + S'y_S = M'x_M = E'_1y_{E_1} + R'_1x_{R_1} \\ F' + S' = M' = E' + R' \\ E'_1 + R'_1 = M' \\ E'_1 N_{E_1} + R'_1 N_{R_1} = M' N_M \end{array} \right\} \text{single stage}$$

$$(F = r')$$

$$F' = C_F + A_F + B_F$$

$$C_F = C_F + A_F$$

$B_F = 0 \rightarrow$ feed devoid

have solvent

$$N_F = 0, F' = F$$

$$\begin{cases} S' N_S = M'_1 N_M \\ S' = 0 \end{cases}$$

$$N_S = \frac{B_S}{A_S + S} \rightarrow \text{pure solvent} \rightarrow [N_S \rightarrow \infty]$$

$$N_S = \frac{B_S}{S'} \rightarrow [B_S = S]$$

$$N_S = \frac{S}{S'} \rightarrow [N_S S' = S]$$

$$N_S = \frac{B_S}{S'} \rightarrow [N_S = 0]$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_S = \frac{B_S}{S'} \rightarrow [N_S = 0]$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_S = \frac{B_S}{S'} \rightarrow [N_S = 0]$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_S = \frac{B_S}{S'} \rightarrow [N_S = 0]$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_S = \frac{B_S}{S'} \rightarrow [N_S = 0]$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_S = M'_1 N_M \rightarrow \text{from } B \text{ balance on } B \text{ for } M_M$$

$$N_M = 0.45$$

$$N_M = 100$$

x

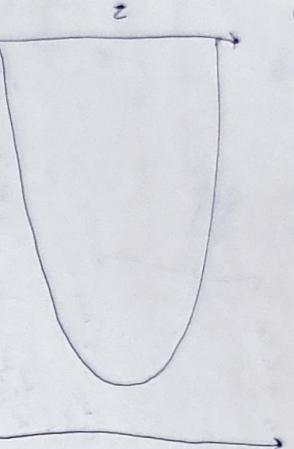
y

balance on B pure basis

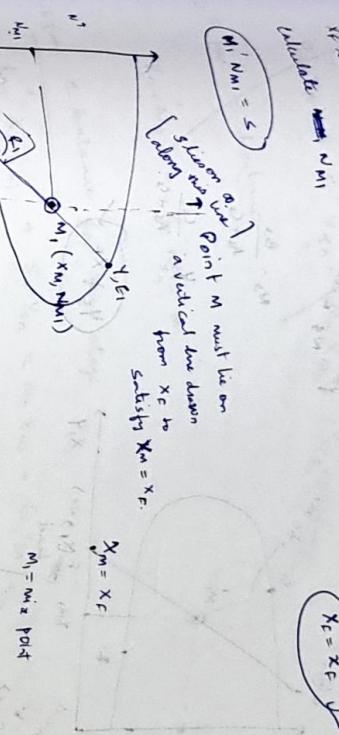
$\rightarrow N$ can be ≥ 1

$\rightarrow M = 0$
 N can be calculated
 M_1 can be calculated
 N_1 can be calculated
 M_1, N_1 can be calculated

$$S = M' NM \\ M' = F = F'$$



$\rightarrow N_C = 0$
 $\rightarrow [x_F = \text{can be calculated}]$



$x_E = x_F$

\rightarrow from S free & balance, overall balance and S free overall balance

$$\begin{aligned} N_1 &= N \\ F'x_F + S'y_S &= N'_1 x_M \\ F'x_F + S'y_S &= M'_1 x_M \end{aligned}$$

$$\begin{aligned} 0 \\ F'x_F + S'y_S &= M'_1 x_M \\ F'x_F &= M'_1 x_M \end{aligned}$$

$$F'x_F = 0$$

$$S'y_S = 0$$

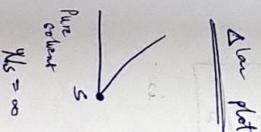
$$S'y_S = 0$$

$$S \neq 0$$

$$y_S = 0$$

$$\text{pure solvent}$$

②
 $F + S = N$
 $F' + S' = N'$
 $F' = F - M'_1$
 $S' = S - M'_1$
 $F' = F - M'_1$
 $S' = S - M'_1$
 \downarrow
 $M'_1 = F' - F$
 \downarrow
 $\text{for a system which reactants & products are known, and feed composition } x_F \text{ is known}$



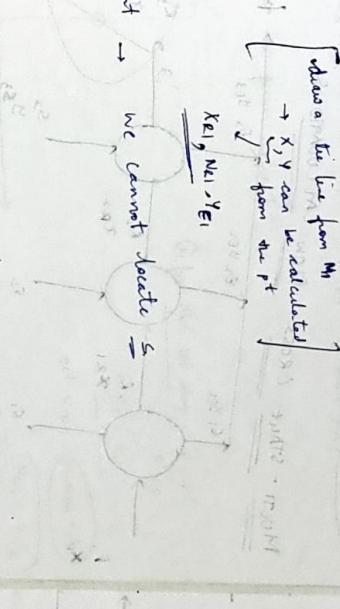
\rightarrow for a pure solvent \rightarrow we cannot locate S

\rightarrow will lie extended along x & N

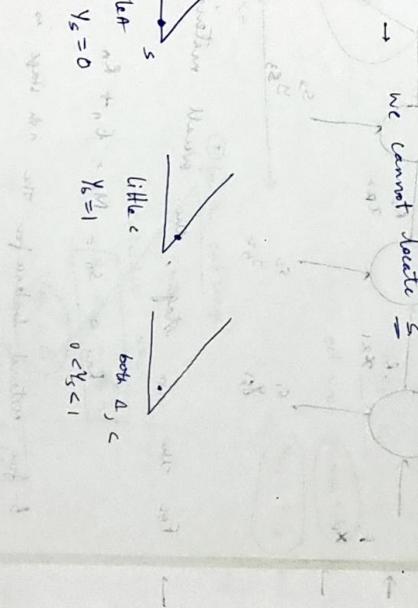
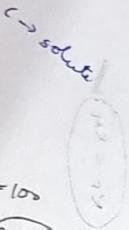
\rightarrow draw tie line from M_1
 $\rightarrow x_2, y$ can be calculated

$$K_E, N_E, y_E$$

$$\begin{aligned} M_1 &= \text{mix point} \\ x_m &= x_F \\ y_m &= y_F \end{aligned}$$



③
 $F = LC + RS + AP$
 $F' = LR + AS$
 $F = F'$
 $L = L$
 $R = R$
 $A = A$
 $C = C$
 $S = S$
 $AP = AP$
 $F = F'$
 $M'_1 = F'$
 $\frac{F}{N} = \frac{F'}{N}$
 $\frac{F}{N} = \frac{100}{250} = 0.45$



$$M'_1 = \frac{100}{250} = 0.45$$

Impure solvent

stage

for impure solvent with
NS will be very high
in case of dilution.

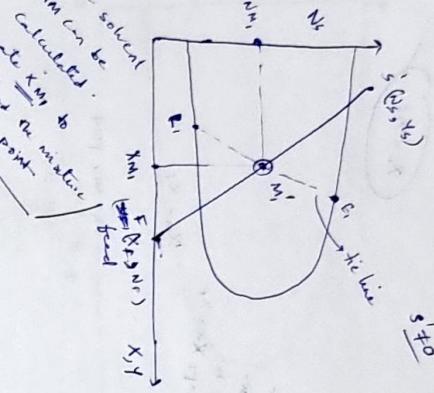
$$\begin{aligned} & \text{for balance for } n\text{th stage} \\ & R_n' X_{R,1} + S_n' Y_{S,n} = M_n' X_{M,n} - E_n' Y_{E,n} - R_n' \\ & R_n' N_{R,1} + S_n' N_{S,n} = M_n' \end{aligned}$$

for R_n' to balance

$$\begin{aligned} & M_n' = \frac{B_n}{A_n + C_n} \\ & Y_n' = \frac{C_n}{A_n + C_n} \end{aligned}$$

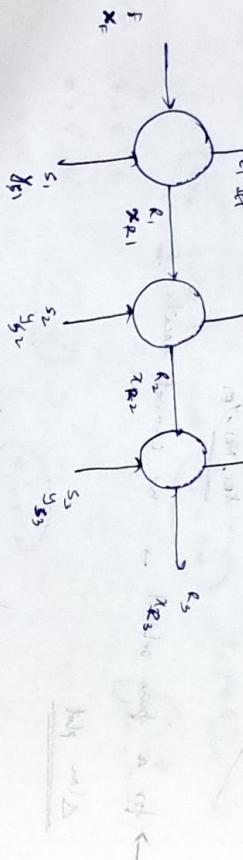
$$Y_S \neq X_E$$

for solvent
impurity can be
calculated
from eqn to
locate point on
mixing point



MULTI-STAGE CROSS FLOW CALCULATIONS.

find extent



For new stage, the overall material balance is:

$$R_{n-1} + S_n = M_n = E_n + R_n$$

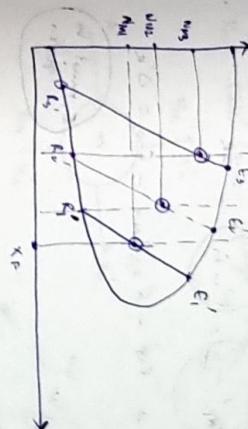
b-free material balance for the n th stage is

$$R_{n-1}' + S_n' = M_n' = E_n' + R_n'$$

In case here we have a pure solvent

$$R_n' N_{R,n-1} + S_n' N_{S,n} = M_n' N_{M,n} = E_n' N_{E,n} + (R_n' - E_n' N_{E,n})$$

$$\begin{aligned} & \text{for } R \text{ balance:} \\ & R_n' N_{R,n-1} + S_n' N_{S,n} = M_n' N_{M,n} = E_n' N_{E,n} + (R_n' - E_n' N_{E,n}) \end{aligned}$$



(1) for

the 1st stage:-

$$F = F'$$

$$S' = 0$$

$$X_F = X_{M,1}$$

$$get N_{M,1}$$

$$N_{M,1} = S_1$$

$$N_{M,1} = S_1/F$$

(2) for the 2nd stage

$$X_E = X_{M,2}$$

calculate $N_{M,2}$

$$N_2' N_{M,2} = S_2$$

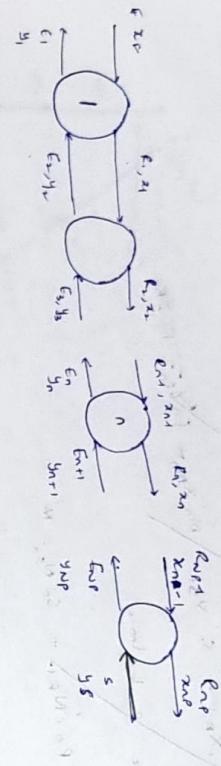
$$N_2' = S_2$$

$$N_{M,2} = S_2 / R_1'$$

Extraction with carrier and solvent completely insoluble

Multi-stage cross flow

Continuous counter current extraction on three boards



Basis material balance

$$F' + S' = M' = E'_1 + R_{NP}'$$

$$S'Y_S = 0 \quad [S'N_S = S]$$

$$\frac{P'_1 + S'}{R_{NP}'} = \frac{P'_1 - L_1'}{R_{NP}'} = \frac{P'_1}{R_{NP}'} + \frac{S'}{R_{NP}'} = \boxed{\frac{S'}{R_{NP}'}}$$

→ B free column

$$P'_1 X_F + S' Y_S = N' X_M$$

→ B free column

$$X_F = X_M \quad [N_S Y_S]$$

$$E'_1 + S' = E'_1 + R_{NP}' \rightarrow R_{NP}' - S' = P'_1 - L_1' = \Delta' R$$

$$E_{N-1}' + S' = E_N' + R_{NP}' \rightarrow R_{NP}' - S' = R_{N-1}' - E_N' = \Delta' R$$

$$P'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

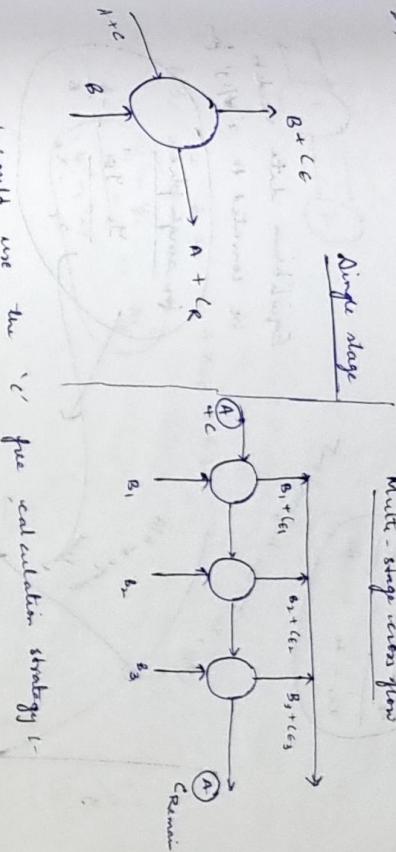
$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

$$E'_1 + S' = P'_1 - L_1' = \Delta' R$$

(1) locate X_F

(2) calculate N_M

from $E'_1 F + S' Y_S = M/N_M$



$$A x_n' + B y_s' = B y_{n+1}' + A x_1'$$

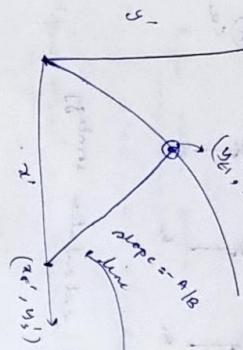
$$\frac{y_s' - y_n'}{x_{n+1}' - x_n'} = -\frac{A}{B}$$

on behalf of

Equilibrium data needs to be converted to x', y', y_s' from

for single phase

$$\frac{y_s' - y_E'}{x_{n+1}' - x_E'} = -\frac{A}{B}$$



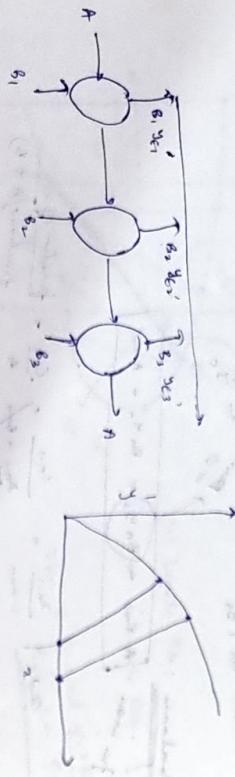
\rightarrow $x_E', r \rightarrow$ given \rightarrow A can be found

$y_S, s \rightarrow$ given

Multiplex flow

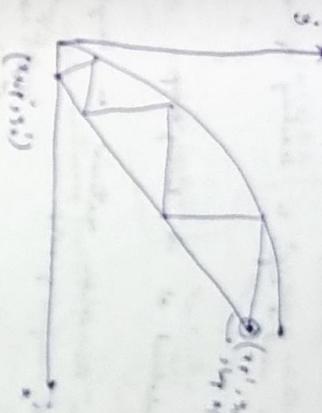
$$\frac{y_s' - y_{E'}}{x_{n+1}' - x_{E'}} = -\frac{A}{B}$$

$$\frac{y_s' - y_E'}{x_{n+1}' - x_E'} = -\frac{A}{B}$$

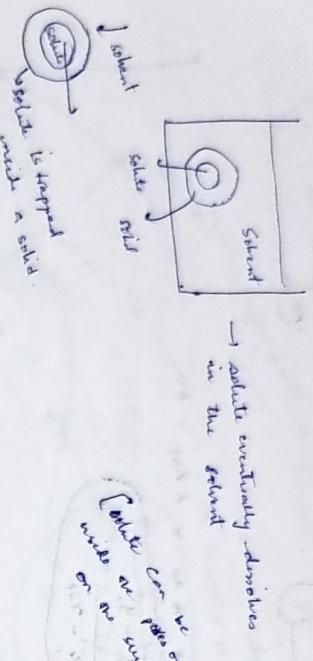


$$B y_s' + A x_E' = A x_{n+1}' + B y_1'$$

$$\frac{y_s' - y_1'}{x_{n+1}' - x_{n+1}'} = -\frac{A}{B}$$



→ Solute is trapped inside a solid.



→ solute eventually dissolves in the solvent

→ solid to be (α , mass of insolubles)

→ leaked solid

$B = \text{mass of insoluble}$

$E_1 = \text{mass of A} + C$

$y_{E_1} = \frac{B}{E_1}$

$y_{E_1} = \frac{(A+C)}{(A+C)_1}$

$F = C_1$

$N_E = (\frac{B}{C})_{\text{initial}}$

$y_F = 1$

$y_E = 1$

$$\begin{aligned} R - \text{mass of solid} &\sim (A+C) \approx A \\ \frac{R}{A+C} &= \frac{C}{A} \\ N_E &= \frac{B}{A+C} \quad (\text{no insoluble}) \end{aligned}$$

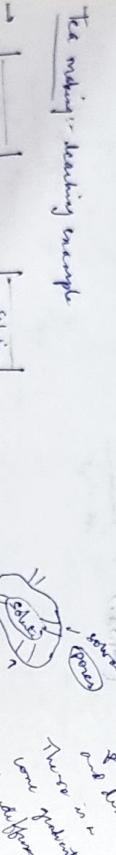
$$\begin{aligned} R_1 - \text{mass of solution} &= \frac{C}{A+C} \\ x_{E_1} &= \frac{C}{A+C} \\ N_{E_1} &= \frac{B}{A+C} \end{aligned}$$

Dissolution: When solvent is introduced at its boiling point
less frequently used → refers to leaching or attack

from wood ash ...

Decoction: When solvent is introduced at its boiling point

Leaching or leaching example: When the solute material is largely on the surface of solid



Leaching: When solvent is introduced at its boiling point

(i) Leaching → high temp is favored as leaching involves dissolution

100% solute or diffusion will occur down with time in pure water

→ most impossible to remove solute or diffusion is known through the surface.

→ extraction → much simpler → diffusion is

→ leaching → much simpler method in mining → mining leaching

→ leaching is extracting metal ion mining → mining leaching

Principle

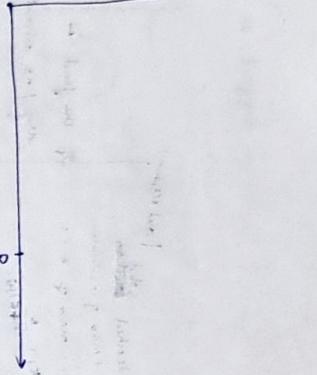
Solvent is passed over fine
solids to remove heat

N

Point E \rightarrow infinity

N

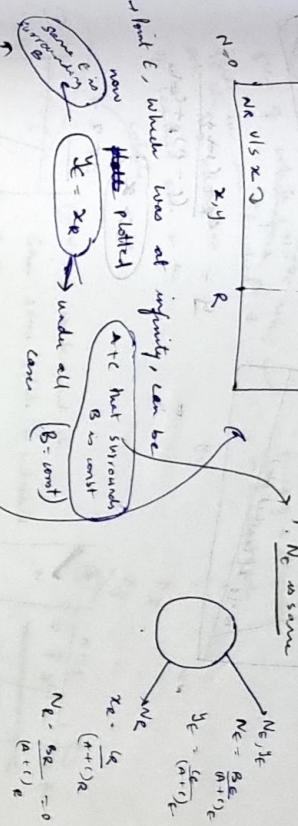
\rightarrow now to get larger
to get higher
 \downarrow
 \hookrightarrow Band C \rightarrow const



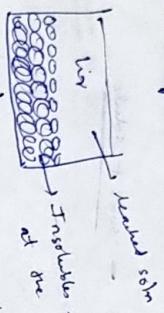
- Based on the concept of 100% efficient demulsification

- Based on the concept of 100% efficient demulsification size

$N_c = \frac{B_c}{(A_c + B_c)}$



\rightarrow practically



at one time

settling

What is meant by settling?

(some and it entrapped liquid
between the particles)

Au B has aggregated and settled own

but is still at the interface

$(A+C) \rightarrow$ some liquid

Residually $A+C$

Insoluble

More particle combinations

Settling does not occur

(i) No solvent is adsorbed on any

settled solid

(ii) No dispersion of settled solid in the liquid

(iii) All solute have been removed from the

settled solid.

(iv) $N_c = 0$

(v) settling pattern of insoluble is

independent of A present

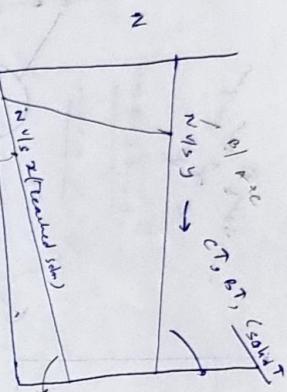
$(A+C)$

some B is suspended

$N_c \neq 0$

B is surrounded by

(e) P_{atm} , C_1 , B_1 , C_2
When some C is adsorbed in
the solid (B)



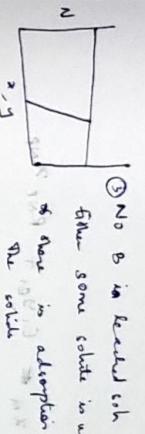
when some
 C is adsorbed

$$y = \frac{C_2 + (solute + C)_1}{(C + A) P + C_1}$$

$A \rightarrow B$ being
 $C \rightarrow$

- ① Particles are totally
free of solute, no
adsorbate in the leached
solid. No adsorption
on unadsorbed con or
on colloid.

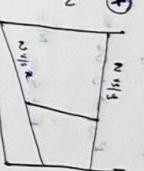
②



Assumption: Both A and C have infinite solubility.
Every particle has finite solubility.

$$(1-x)^{0.8} = 0.8 + 0.2 - 1.8$$

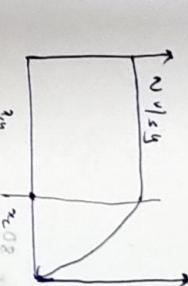
$N \neq 0$
presence of dissolved
in leached soln.



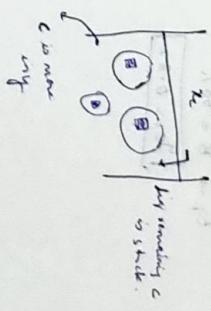
③

$$\frac{B}{C} = 0$$

$x = \text{max conc}$
that can dissolve
in A

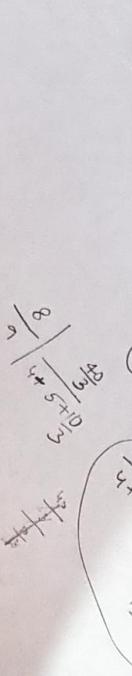
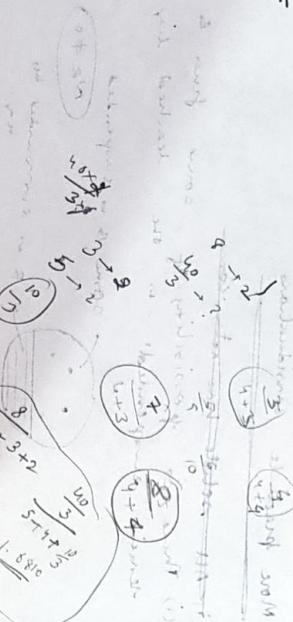


$$(2x)^{0.8} = (0.8)x + (1.2 - x)$$

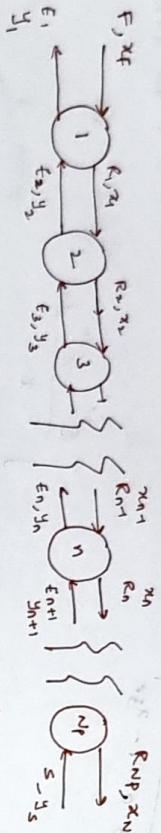


$$x(1-0.8) = 0.2 - 1.2$$

$$\frac{8}{7} \left| \frac{42}{42+10} \right|$$



Continuous Counter current (multistage)

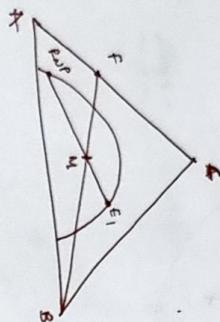


$$\begin{cases} F - E_1 = \Delta R \\ R_{n-1} - S = \Delta R \end{cases}$$

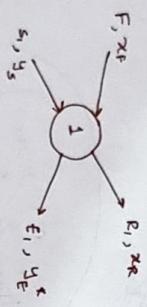
$$F + S = E_1 + R_{n-1} = M$$

$$F x_F + S y_S = E_1 y_1 + R_{n-1} x_{RNP}$$

$$\left[\begin{array}{l} R_{n-1}, E_1 \text{ are not} \\ \text{at equil} \end{array} \right]$$



Single stage extractor

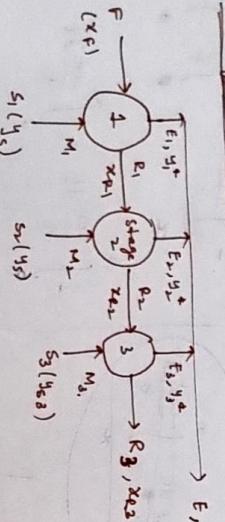


$$F + S = M = E_1 + R,$$

$$F x_F + S y_S = M x_M = E_1 y_E + R, x_R$$

Multistage mass - current extraction

$$y^* = \frac{E_1 y_1 + E_2 y_2 + E_3 y_3}{E_1 + E_2 + E_3}$$



$$S_1(y_{S1})$$

$$S_n(y_{Sn})$$

DRP.

Continuous Counter current (multistage)

$$\begin{cases} x = \frac{c}{A+c} \\ y = \frac{c}{A+c} \end{cases} \quad \begin{cases} N = \frac{b}{A+c} \\ R = \frac{b}{A+c} \end{cases}$$

$$\begin{aligned} & \text{B-pure basis} \\ & X = \frac{c}{A+c} \quad Y = \frac{c}{A+c} \\ & N = \frac{b}{A+c} \quad R = \frac{b}{A+c} \end{aligned}$$

single stage

pure solvent

pure solute

extract

balance

B-free balance for n_n stage

$$R_{n+1}' + S_n' = M_n' = E_n' + R_n'$$

C_n-balance

$$R_{n+1}' (X_{R(n+1)}) + S_n' X_n = M_n' X_{mn} = E_n' Y_m + R_n' X_m$$

B-Balance

$$N_{E(n)} R_{n+1}' + N_{S(n)} (S_n') = M_n' N_{mn} = E_n' N_m + R_n' N_m$$

→ 2nd stage :- $R_1' + S_2' = M_2'$

$$X_{E1} R_1' = M_2' X_{M2}$$

$$M_2' = R_1'$$

$$R_1 + S_1 = M_1 = E_1 + R_1$$

$$\rho \cdot 3 / (100) = 140 X_M$$

$$X_{R1} = 0.2655 \quad \checkmark$$

$$E_1 - y_{E1} = 0.112 \quad \checkmark$$

Continuous counter current

$$F' + S' = M' = E_1' + R_{NP}' \quad N_F F' + N_S S' = N_M X_M$$

$$F' X_F + S' Y_S = M' X_M$$

$$X_M = X_F$$

$$M_2 = 130.89$$

$$M_2 (X_M) = (0.265)(90.89)$$

$$\frac{E_1 = 49.103}{R_1 = 90.89}$$

$$130.89 = E_2 + R_2$$

$$y_{E2} = 0.06$$

$$\frac{X_{M2} = 0.18401}{X_{R2} = 0.124}$$

$$\frac{E_2 = 45.8}{R_2 = 85.044}$$

$$R_2 + S_2 = E_3 + R_3 = M_3$$

$$X_{M3} = 0.16325$$

$$\frac{R_3 = 85.044}{X_{R3} = 0.05}$$

$$M_3 = 125.086$$

$$y_{E3} = 0.21$$

$$\frac{X_{R3} = 0.05}{E_3 = 0.05}$$

