

Stage efficiency and theoretical stage

An ideal theoretical stage

one in which the contact b/w liq & gas phase is perfectly achieved so as to be in perfect equilibrium

In 'Actual' case - full equilibrium conditions are not achieved & only a fractional level of equilibrium conditions are attained.

Hence the stage efficiency varies from 0-1.0

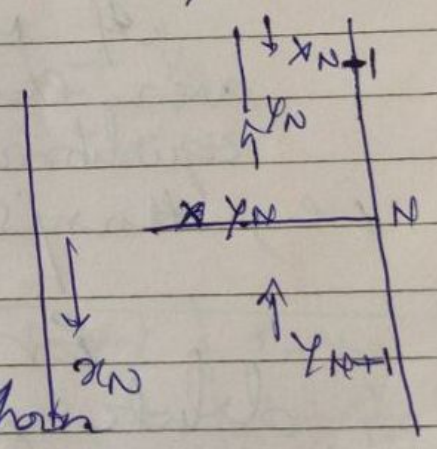
Achieving higher levels is possible/feasible with innovative designs of ~~the~~ better mixing, larger contact area etc.,

Types of efficiencies

various locations considered in a column or tower to different definitions of efficiency.

Point ~~of~~ E

Fraction of achievement of equilibrium at a particular local point in the tray/plte. as shown



Let y_{N+1} local concⁿ of gas approaching the pt. and $y_{N,local}$ leaving the column pt. The local eq. concⁿ is assumed to be constant in the z -direction

$$y_{eq} = E_{og} = \frac{y_{n+1}^{local} - y_n^{local}}{y_{n+1}^{local} - y_{local}^*}$$

y_{local}^* is the equilibrium conc. w.r.t x_{local}

Murphree efficiency

Only concentrations are considered
Efficiency of a plate/tray on a stage

$$E_M = \frac{y_{n+1} - y_n}{y_{n+1} - y_n^*}$$

Overall efficiency : Efficiency as a % of the
Equivalent performance.

$$E_o = \frac{\text{No. of ideal stages needed}}{\text{No. of stages incorporated}}$$

If Murphree efficiency is const. for all stages over the entire column, this happens when equilibrium curve becomes straight line, i.e., Henry's law applies.

For isothermal operations and with dilute solutions, E_o can be calculated by 'A'

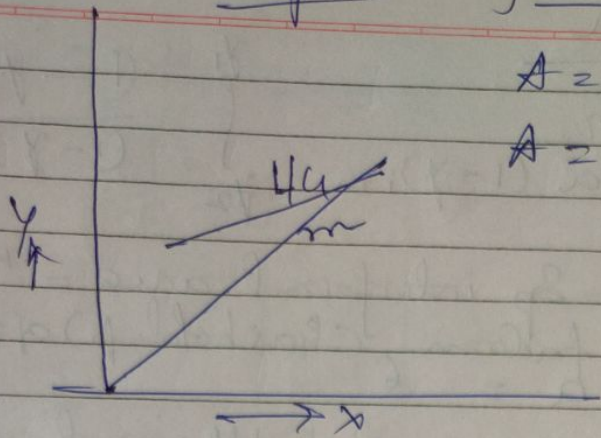
$$A = \frac{y_m}{x_m}; \quad E_o = \frac{\text{Ideal trays}}{\text{Actual trays}}$$

$$= \frac{\log [1 + \frac{E_M}{A} (Y_A - 1)]}{\log (Y_A)}$$

Absorption factor

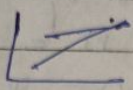
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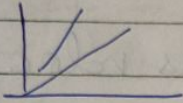
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$$A = \frac{\text{Slope of O.L}}{\text{Slope of E.L}}$$

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

If $A < 1$  infinite no. of stages

$A > 1$  Solute dissolved in more of y .
Less expensive / lesser no. of stages

↑ Cost of operation } Economical value
↓ Capital cost } of $A \rightarrow 1.25 - 2$

Enrichment

For dilute solutions

Absorption

$$N_p = \frac{\log \frac{Y_{Np+1} - mX_0 [1 - \frac{1}{A}] + \frac{1}{A}}{\log A}}$$

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

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

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

$$G = \frac{G_s}{1-y}$$

$$= \frac{L_s}{(1/1+x)} = \frac{L_s(1+x)}{(1/1+x)}$$

$$\begin{aligned} &1-y \\ &= 1 - \frac{y}{1+y} \\ &= \frac{1+y-y}{1+y} = \frac{1}{1+y} \end{aligned}$$

$$G =$$

$$y \neq 2$$

Derivation

$$Z = \frac{Q}{k_y a (1-\gamma)_{im}} \quad \left. \begin{array}{c} \gamma_1 \\ \gamma_2 \end{array} \right\} \frac{(1-\gamma)_{im}}{(1-\gamma)(\gamma-\gamma_2)}$$

a - Sp interfacial area = m^2/m^3

[$\psi_g \Rightarrow$ volume fraction (gas holdup) of the gas liquid occupied by gas. $a = \frac{6}{d_p}$]

(n = no. of bubbles of d_p dia)

$$n = \frac{a}{\pi d_p^2} = \frac{m^2}{m^3} \cdot \frac{1}{m^2}$$

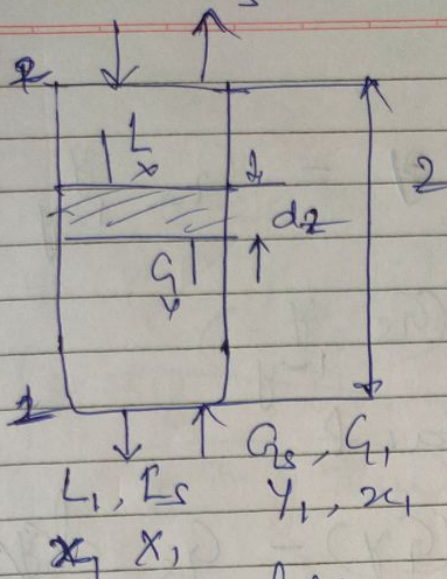
$$n = \psi_g / \pi d_p^3 / 6$$

Superficial gas velocity = $\frac{\text{volume rate of flow of gas}}{\text{area of vessel}}$

$$= v_{g1} =$$

$$\frac{v_{g1}}{\psi_g} = \text{True gas velocity}]$$

x_2, x_2 y_2, y
 L_s, L_s G_s, G



Consider a differential height dz
 Consider ds , Interaction area
 $ds = a \, dz$
 $a = \text{Specific Interfacial area}$
 $= \frac{m^2}{m^3}$

Moles of solute 'A' = N_A in terms of k
 and Co-eff, $N_A = k_y (y - y_i)$ — (1)
 $N_A = \text{moles of A absorbed / interfacial area} \times \text{time}$
 N_A can also be written in terms of

$$N_A = \frac{d(Gy)}{ds} = \frac{k_m b}{m^2, \text{ time}}$$

$Gy \Rightarrow \text{moles of A}$
 $ds \Rightarrow \text{interfacial area ; } ds = a \, dz$

$$N_A = \frac{d(Gy)}{a \, dz} \quad \text{--- (2)}$$

$$k_y (y - y_i) = \frac{d(Gy)}{a \, dz} \quad \text{--- (3)}$$

Let us consider

$$\text{Since } G y = G_s \frac{y}{1-y} = \text{neglect } \frac{1}{1-y}$$

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

G_s is a constant

$$\text{hence } d(Gy) = G_s d\left(\frac{y}{1-y}\right)$$

$$\text{differentiation of } \left[G_s d\left(y \times \frac{1}{1-y}\right)\right] = G_s d\left(\frac{y}{1-y}\right)$$

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

$$= \frac{G_s}{1-y} \times \frac{1}{1-y} dy$$

$$\text{From } Gy = G_s \frac{y}{1-y}$$

$$\Rightarrow \frac{G_s}{1-y} = G$$

$$\text{Hence } d(Gy) = \left(\frac{G}{1-y}\right) dy$$

$$\text{Single step } d(Gy) = d\left(G_s \frac{y}{1-y}\right) = G_s \frac{dy}{(1-y)^2} = \frac{G}{1-y}$$

$$\int_{y_1}^{y_2} (y - y_1) = \frac{G dy}{1-y} \int_a^b dz = \frac{G}{(1-y)} \frac{1}{a} \frac{d}{a}$$

$$z \Rightarrow 0 - z$$

$$y \Rightarrow y_2 - y_1 \quad \text{Stages numbered from top to bottom}$$

$$a k_y (1-y)^n (y-y_i)$$

$$= \frac{Q}{a k_y} \int_{y_2}^{y_1} \frac{1}{(1-y)(y-y_i)} dy$$

$$\Rightarrow \left[\frac{1}{k_y a} \geq \frac{1}{k_y a} \right] = \frac{Q}{k_y a p (1-y_{in})}$$

$$2 = \frac{Q}{k_y a (1-y_{in})} \int_{y_2}^{y_1} \frac{(1-y) \ln y}{(1-y)(y-y_i)} dy$$

$$\Rightarrow \frac{Q}{k_y a (1-y_{in})} = N_{Gy}$$

$$\int_{y_1}^{y_2} \frac{(1-y) \ln y}{(1-y)(y-y_i)} dy = N_{Gy}$$

Here $(1-y) \ln y \Rightarrow$ can be solved arithmetically

Add, subtract by y

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

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

Open the brackets

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

$$1-y_i + 1-y + y - y_i$$

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

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

Then

$$Z = \frac{q}{k_y a (1-y)_{in}} \times \int_{y_2}^{y_1} \frac{(1-y)_{in} dy}{(1-y)(y-y_i)}$$

and for dilute solutions $1-y_1 \approx 1-y_2$
changes to

$$Z = \frac{q}{k_y a (1-y)_{in}} \times \int_{y_2}^{y_1} \frac{dy}{(y-y_i)}$$

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

Approximate
eqn to

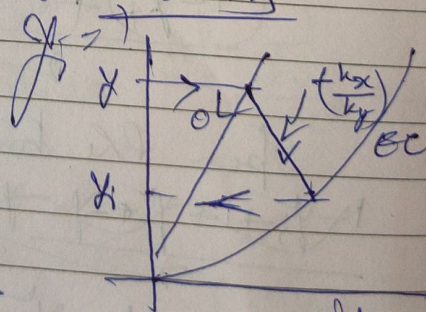
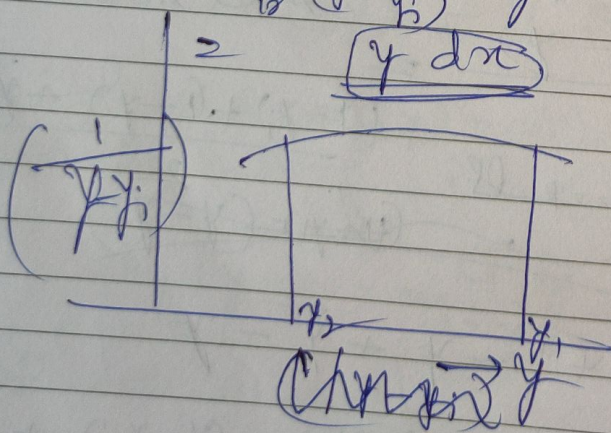
$$\approx \frac{(1-y_i) + (1-y)}{2}$$

$$N_{H_2} = \frac{K_p}{y_2} \frac{dy}{y-y_i} + \left(\frac{1}{2} \ln \frac{1-y_2}{y-y_i} \right)$$

$$= \int_{y_2}^{y_1} \frac{1}{(y-y_i)} dy$$

$y dx$

negligible for dilute
solutions



if graph is y vs x
from $\frac{1+y_2}{1+y_1}$

First term
of N_{H_2} remains
the same

if not dilute sol band

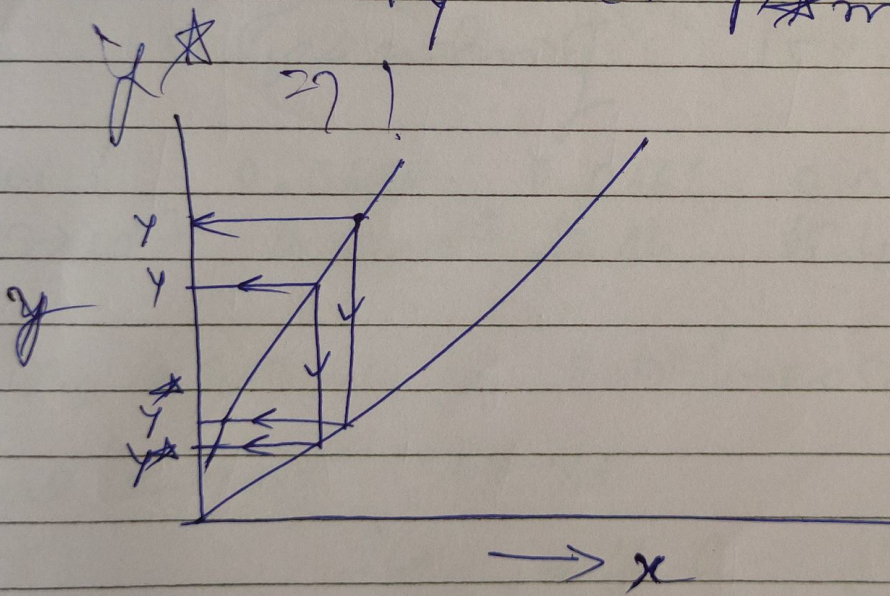
$$N_{G1} = \frac{1}{2} \ln \left(\frac{1-y_2}{1-y_1} \right) + \int_{y_2}^{y_1} \left(\frac{1}{1-y} \right) dy$$

If K_y is given

$$z = (H_{G1})_0 \times (N_{G1})_0$$

$$(H_{G1})_0 = \frac{G}{K_y a P_t (1-y)_m}$$

or
$$\frac{G}{K_y a (1-y)_m}$$



if graph is drawn for x, x

First form of N_{G1} remains the same i.e. $\frac{1}{2} \ln \frac{1-y_2}{1-y_1}$ but second

form becomes $\frac{1}{2} \ln \frac{1+y_2}{1+y_1}$

If k_L is given

$$(N_{fg})_0 = \frac{1}{k_L a (1-x)^{\star m}}$$

$$= \frac{L}{k_L a c (1-x)^{\star m}}$$

$$= \frac{1}{2} L \ln \frac{1-x_1}{1-x_2} + \int_{x_2}^{x_1} \frac{dx}{x^{\star} - x}$$

as entering 15% CO_2 is ~~not~~ scrubbed using a solvent (initially contains 0.058 mole CO_2 /mole solvent). Gas enters the column at 1.2 atm and 25°C. Gas leaving the scrubber contains 2% CO_2 .
 Molar flow rate of gas entering = 1.2 m³/s
 Molar flow rate of solvent = 0.058 0.06 0.064 0.066 0.068 0.07

Solvent used is monoethanol amine.

For CO_2 molar flow rate 5.6 18.8 29 56 98.7 155.232

$$P_1 = P_T x_1$$

$$= 912 (0.15) = 136.8 \text{ mm Hg}$$

$$y_1 = \frac{136.8}{912 - 136.8} = 176.5 \times 10^{-3} = 0.1765$$

$$P_2 = P_T y_2 = 912 (0.02) = 18.24 \text{ mm Hg}$$

$$y_2 = \frac{18.24}{912 - 18.24} = 20.41 \times 10^{-3} = 0.02041$$

$$P_T = 1.2 \text{ atm}, T = 25^\circ \text{C}$$

$x_2 = 0.058$ mole CO_2 /mole solvent
 Gas leaving 2% CO_2
 Gas entering 15% CO_2

0.0616 0.0638 0.0661 0.0684 0.0707 0.0733
 6.17×10^{-3} 14.23×10^{-3} 32.84 65.42 121.3 341.1

$$x_2 = 0.0616 = 0.058 / (1 - 0.058)$$

Gas entering 1 m³/s

$$\text{Slope} = 14.6$$

$$\text{Ideal gas } PV = nRT$$

$$n = 0.0490 \text{ kmol/s}$$

$$n = \frac{1.2 \times 1}{0.0821 (273 + 25)}$$

$$G_1 = 0.0490 \text{ kmol/s}$$

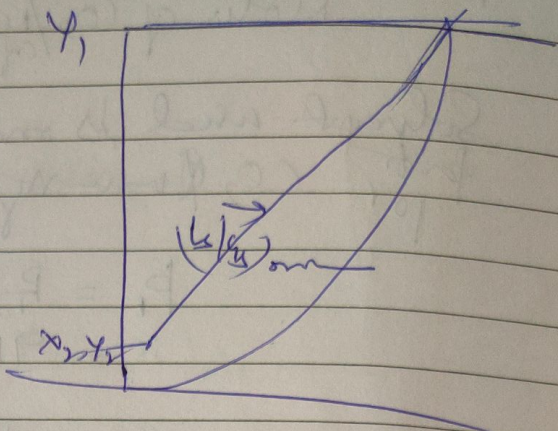
$$G_2 = G_1 (1 - y_1) = 0.042 \text{ kmol/s}$$

$$L_s/L_{gs} = 1.2 \times 14.6 = 17.52$$

$$L = 0$$

Distillation

y_1



$$\text{Actual} = 1.2 (L/G)$$

$$= 1.2 \times 14.6$$

$$= 17.53$$

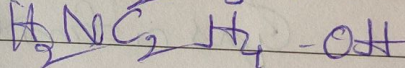
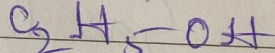
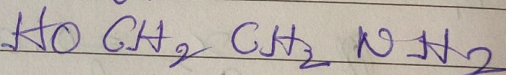
$$L_s = 17.53 \times G_s$$

$$= 0.736 \text{ kJ}$$

$$L_2 = \frac{L_s}{1 - x_2} = \frac{0.736}{1 - 0.0586} = 0.7814 \text{ kJ}$$

$$L_2 = 0.7814 \times 61.08$$

$$= 48 \text{ kg}$$



Absorption of NH_3 in water

To evaluate the equilibrium data

NH_3 — is the solute

Given partial pressure of NH_3
(NH_3 in Gas stream)

$$Y = \frac{\text{NH}_3 \text{ (moles)}}{\text{Inert (moles)}}$$

P_{IG} — Inert gas (atm)

$$P = Y P \quad ; \quad y = \frac{P_{\text{NH}_3}/P_{\text{IG}}}{P}$$

$$Y = \frac{12}{748} = 0.016$$

$$Y = \frac{y_{\text{NH}_3}}{y_{\text{Inert}}} = \frac{P_{\text{NH}_3}/P}{P_{\text{IG}}/P}$$

We have Dalton's

$$P = P_{\text{NH}_3} + P_{\text{IG}}$$

$$P - P_{\text{NH}_3} = P_{\text{IG}}$$

Given

$$P = 1 \text{ atm} = 760 \text{ mmHg}$$

$$P_{\text{IG}} = 760 - 12 = 748 \text{ mmHg}$$

Similarly calculate 'Y' values from given 'P' values

Y	0.016	0.024	0.044	0.070	0.10	0.279
X	0.021	0.00318	5.3×10^{-2}	7.95×10^{-2}	0.0106	0.0212

To find the values of $X = ?$

$$X = \frac{\text{moles of } \text{NH}_3}{\text{moles of solvent (pure)}}$$

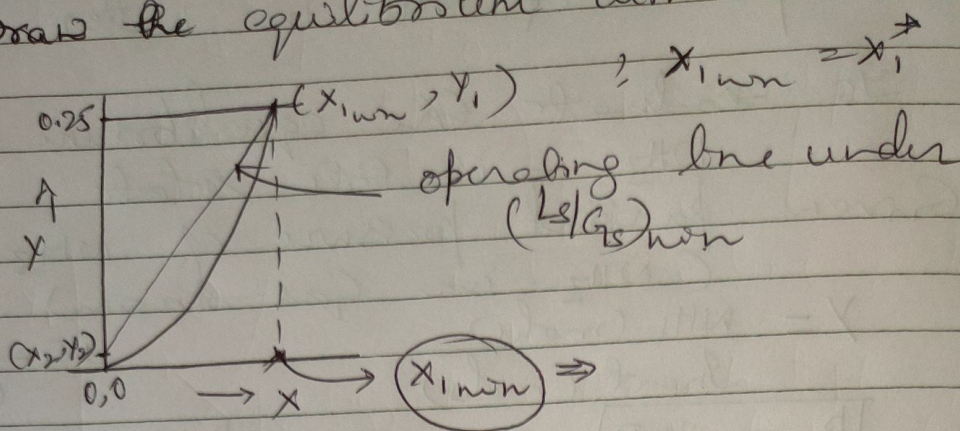
Given g of NH_3
10g NH_3

$$X = \frac{(81.8 \text{ g/mole})_{\text{NH}_3}}{(81.8 \text{ g/mole})_{\text{H}_2\text{O}}} = \frac{0.217}{10.18} = 0.021$$

$$= 0.021$$

$$= \left(\frac{1}{17/10.18} \right)$$

Draw the equilibrium curve



Now

i. Locate the data (x, y) on the graph sheet and draw the curve (line)

ii. Locate y_1, y_2 and x_2 on y -axis and inside the graph (y_2, x_2) point

$$y_1 = 0.25, \quad y_2 = 0.002 \quad \text{and} \quad x_2 = 0$$

No information is given about NH_3 content in the solvent hence assume that the solvent is pure water.

$$\text{Hence } x_2 = 0$$

iii. Draw horizontal line at y_1 to intersect the equilibrium curve. ^(see the fig) This means that equilibrium is attained between y_1 and $x_{1,\min}$ and the flow rate of solvent refers to minimum solvent rate. Slope of the line = $\frac{L_{\min}}{G_s}$

iv. To find minimum solvent rate Join (x_2, y_2) point to the y_1 intersection point at $x_{1,\min}$ (referred as) on equilibrium curve (x-axis). Find the slope of the line (O.L) drawn.

to find the slope $\therefore x_{1min} = 0.194$

$$\left(\frac{L_e}{G_s}\right)_{min} = \frac{y_1 - y_2}{x_{1min} - x_2}$$

$$= \frac{0.25 - 0.002004}{0.194 - 0} = 1.278$$

v. use the slope value to find $L_{e min}$

$$\left(\frac{L_e}{G_s}\right)_{min} = G_s (\text{slope of O.L. min})$$

$$= 105. (1.278)$$

$$= 134 \text{ kmol/h}$$

vi. Find the L_e operating

$$\text{Given } L_{e \text{ operating}} = 1.2 L_{e \text{ minimum}}$$

note: If not given assume 1.2 to 2 times

$$L_{e op} = 1.2 (134)$$

$$= 160.8 \text{ kmol/h}$$

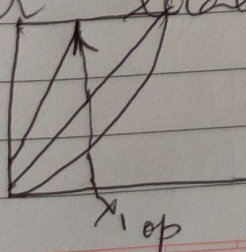
- Mass flow rate: To convert to kg/h , since it is liquid ($L_{e op}$), use mole wt of solvent

$$L_{op} = L_{e op} \cdot 18 = 160.8 \times 18 = 2894.4 \text{ kg/h}$$

$$L_{op} \frac{\text{kg}}{\text{h}} \times \frac{\text{kmol}}{\text{kg}} = L_s \times M_{H_2O} \frac{\text{kmol}}{\text{h}} \times \frac{\text{kg}}{\text{kmol}}$$

viii. Stages

Draw $(L_{e op}/G_s)_{op}$ line from (x_2, y_2) after locating $x_{1 op}$ on x-axis



b) locating $x_{2 op}$ on y_1 horizontal line (point $x_{1 op}, y_1$)

Find $(L/G_s)_{\text{operating}} =$

$$\left(\frac{160.8 \text{ kmol/h}}{105.2 \text{ kmol/h}} \right) = 1.53 = \text{slope of operating line}$$

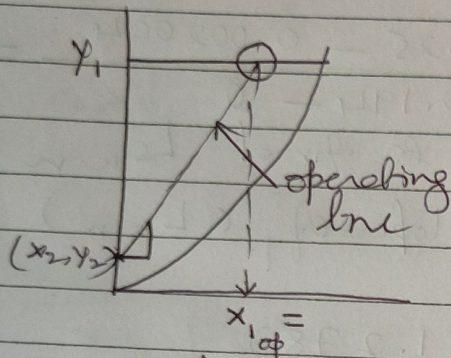
Method 1:

To draw a line of slope = 1.53

Locate the initial pt

Locate a point - 1 cm (to the right)

Then 1.53 cm up from the end of 1 cm

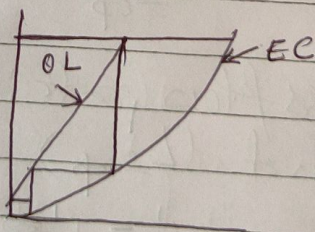
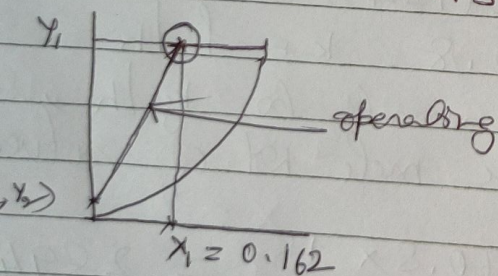


Method 2:

$$(L/G_s)_{\text{op}} = \frac{Y_1 - Y_2}{X_{1,\text{op}} - X_2}$$

$$X_{1,\text{op}} - X_2 = \frac{Y_1 - Y_2}{(L/G_s)_{\text{op}}} + X_2$$

$$X_{1,\text{op}} = \frac{0.25 - 20 \times 10^{-4}}{1.53} + 0 = 0.1621$$



Absorption numerical

Page No.

Date / /

Illustration 2.2

Page 20

Given

System: Gas mixture contains NH_3 in air

Mole % of $\text{NH}_3 \Rightarrow 20$

" " " Air = 80

$$P_1 = 1 \text{ atm}, T = 20^\circ\text{C}$$

Remove 99.1% NH_3 entering absorber.

$$y_1 = 0.2$$

$$y_2 = (0.01) \times 0.2 = 0.02$$

$$Y_1 = \frac{0.2}{1-0.2} = 0.25$$

$$Y_2 = \frac{0.02}{1-0.02} = 0.0025$$

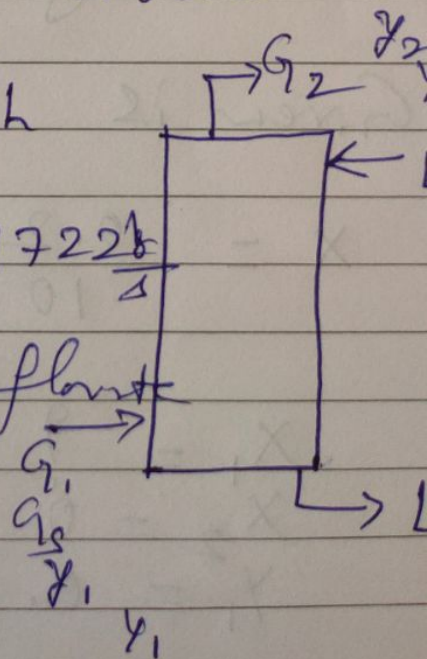
Given $G_1' = 3500 \text{ kg/h}$

$$= \frac{3500}{3600} = 0.972 \text{ kg/s} = 0.9722 \frac{\text{kg}}{\text{s}}$$

To convert into molar flow

Find out what is

Ave. Mole wt of G_1'



$$\text{Ave. mole wt} = \sum y_i \text{ MW}_i$$

$$= (0.2 \times 17) + (0.8 \times 29)$$

$$G_1 = \frac{G_1'}{AMW} = \frac{0.9722}{26.6} = (131.6/860) \\ \frac{131.6 \text{ kJ}}{h} = \underline{\underline{0.0365 \text{ kJ/s}}}$$

Conversion data to obtain equilibrium data

Given p $\Rightarrow$ P_p of NH_3 in gas mixture

$$Y = \frac{p}{P_t - p} = \frac{12}{760 - 12} = 0.01604$$

Given data to be regressed from

Y	0.016	0.0243	0.044	0.070	0.101	0.1
X	$0.02 \times \frac{18}{17}$	$0.03 \times \frac{18}{17}$	$0.05 \times \frac{18}{17}$	$0.07 \times \frac{18}{17}$	$0.1 \times \frac{18}{17}$	$0.12 \times \frac{18}{17}$
X	0.021	0.032	0.052	0.0794	0.106	0.126

$$X = \frac{\text{kg } \text{NH}_3}{\text{kg of water}}$$

Given is

$$\frac{\text{kg } \text{NH}_3}{10 \text{ kg } \text{H}_2\text{O}}$$

$$X = \frac{0.2}{10} = 0.02$$

$$\frac{0.2 \text{ kg } \text{NH}_3 - 10 \text{ kg}}{10} = \leftarrow 1 \text{ kg}$$

$$X_1 = 9$$

$$X_2 = 0$$

$$Y_1 = 0.25$$

$$Y_2 = 0.0025$$

Pure solvent is used

$$\left(\frac{L_s}{G_s}\right)_{\min} = \frac{y_1 - y_2}{x_1 - x_2} = \frac{0.25 - 0.025}{0.204 - 0} =$$

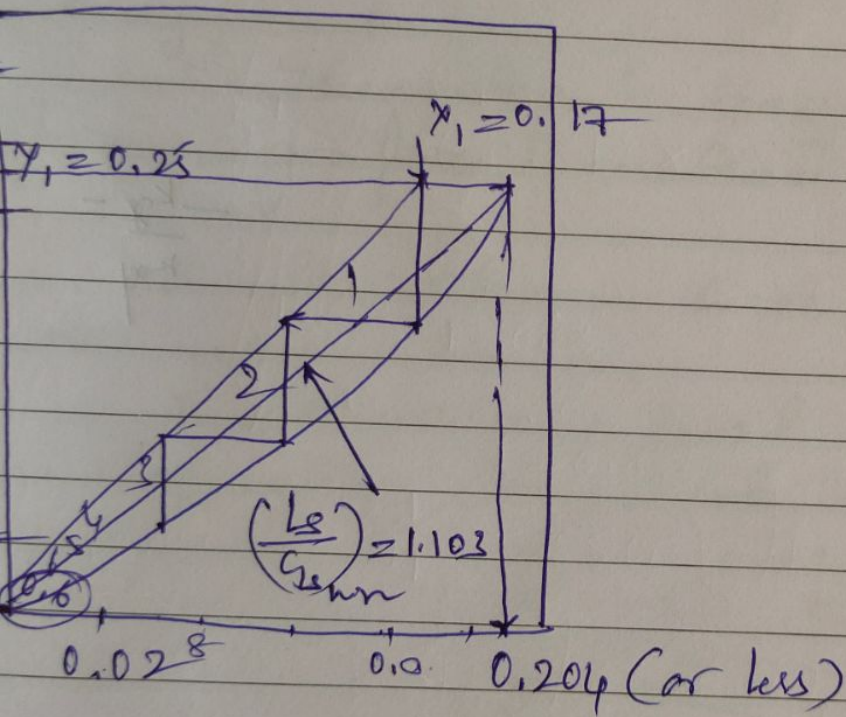
$$\left(\frac{L_s}{G_s}\right)_{\text{actual}} = 1.2 \quad (\cancel{0.9375})$$

$$= 1.323 \geq 1.323$$

$$1.323 = \frac{y_1 - y_2}{x_{1\text{act}} - x_2}$$

$$x_{1\text{act}} = \frac{0.25 - 0.025}{1.323} =$$

$$= 0.17$$



Stages
6.6 - 6.9

$$\left(\frac{L_s}{G_s}\right)_{\text{act}} = 1.323$$

$$L_s = 1.323 \times G_s$$

$$G_s = G_1 (1 - y_1) = 0.0365$$

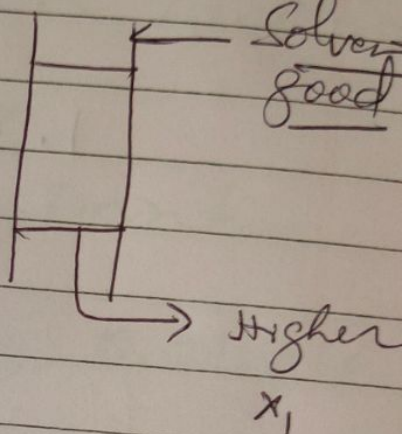
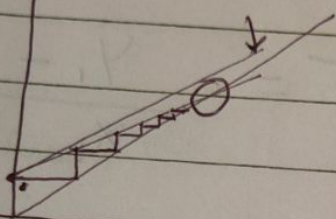
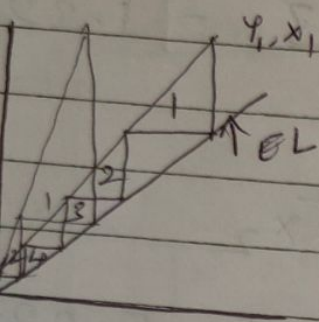
$$G_s \geq 0.0292 \text{ kmol}$$

$$L_s = 1.323 \times 0.0292 = 0.0388$$

$$= \frac{139 \text{ kmol}}{h} = 2503 \text{ kg/h}$$

$$L_2 = L_s \quad (\text{since } x_2 = 0)$$

$$L_s =$$



Solve
good

Higher
 x_1

$$\frac{-K_{xy}}{K_{xy}} =$$

Packed Column Design

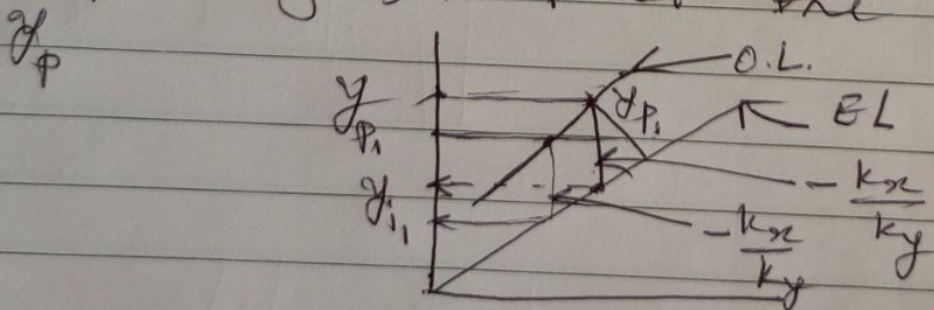
NTU = Number of Transfer units
 HETP = Ht. equivalent to one theoretical plate

HTU = Ht. of one Transfer unit

$$\begin{aligned} HTU &= HETP \times NTU \\ &= 700 \text{ mm} \times 9 \\ &= 6300 \text{ mm} = 6.3 \text{ m} \end{aligned}$$

To find HTU using local mass transfer coefficients

1. Theoretical stages is evaluated from graphical method / numerical method
2. Equilibrium curve (line) and operating lines are drawn
3. Locate any point on y-axis on operating line. Let the point be y_p



4. $-k_x/k_y = \text{Slope}$

y	x
y_p	x_1
y_{p2}	x_2

= 9

$$\frac{9 \text{ g NH}_3}{100 \text{ g H}_2\text{O}} \Rightarrow \frac{9 \text{ NH}_3 / \text{Mole wt}}{100 \text{ g H}_2\text{O} / \text{Mole wt}}$$

$$= \frac{\text{g mol solute}}{\text{g mol solvent}}$$

$$2 \text{ g} \rightarrow \text{First dot pt}$$

100 g H₂O

$$\Rightarrow \frac{2/17}{100/18}$$

$$100/18$$

$$\text{M. wt of NH}_3 = 17$$

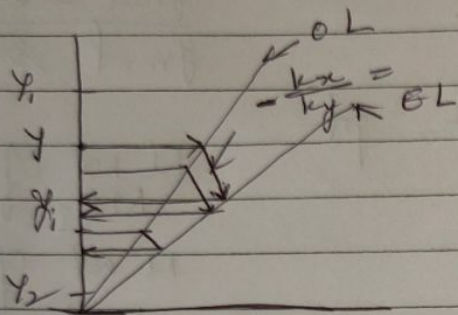
$$\text{M. wt of H}_2\text{O} = 18$$

$$= 0.0211$$

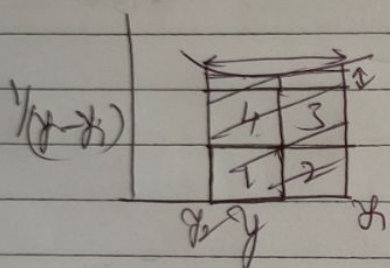
$$\frac{3 \text{ g NH}_3}{100 \text{ g H}_2\text{O}}$$

$(1-y)_{lm}$ = log mean diff of solute concn between at the bottom and top of the column

$$(1-y)_{lm} = \frac{(1-y_1) - (1-y_2)}{\ln \frac{(1-y_1)}{(1-y_2)}}$$

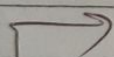


$$\frac{k_x}{k_y} =$$



y	x_i	$\frac{1}{y-x_i}$
0.2		
0.005		

Area = 4.6 x scale of x-axis x scale of y-axis
 st. of s.t. $\Rightarrow 0.03 \times 0.05 = y_2 = 0.0015$

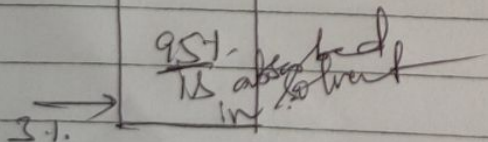


← pure water

$$y_i = \frac{0.0015}{1 - 0.0015}$$

$$= 1.5023 \times 10^{-3}$$

$$= 0.0015023$$



Given

p of NH_3

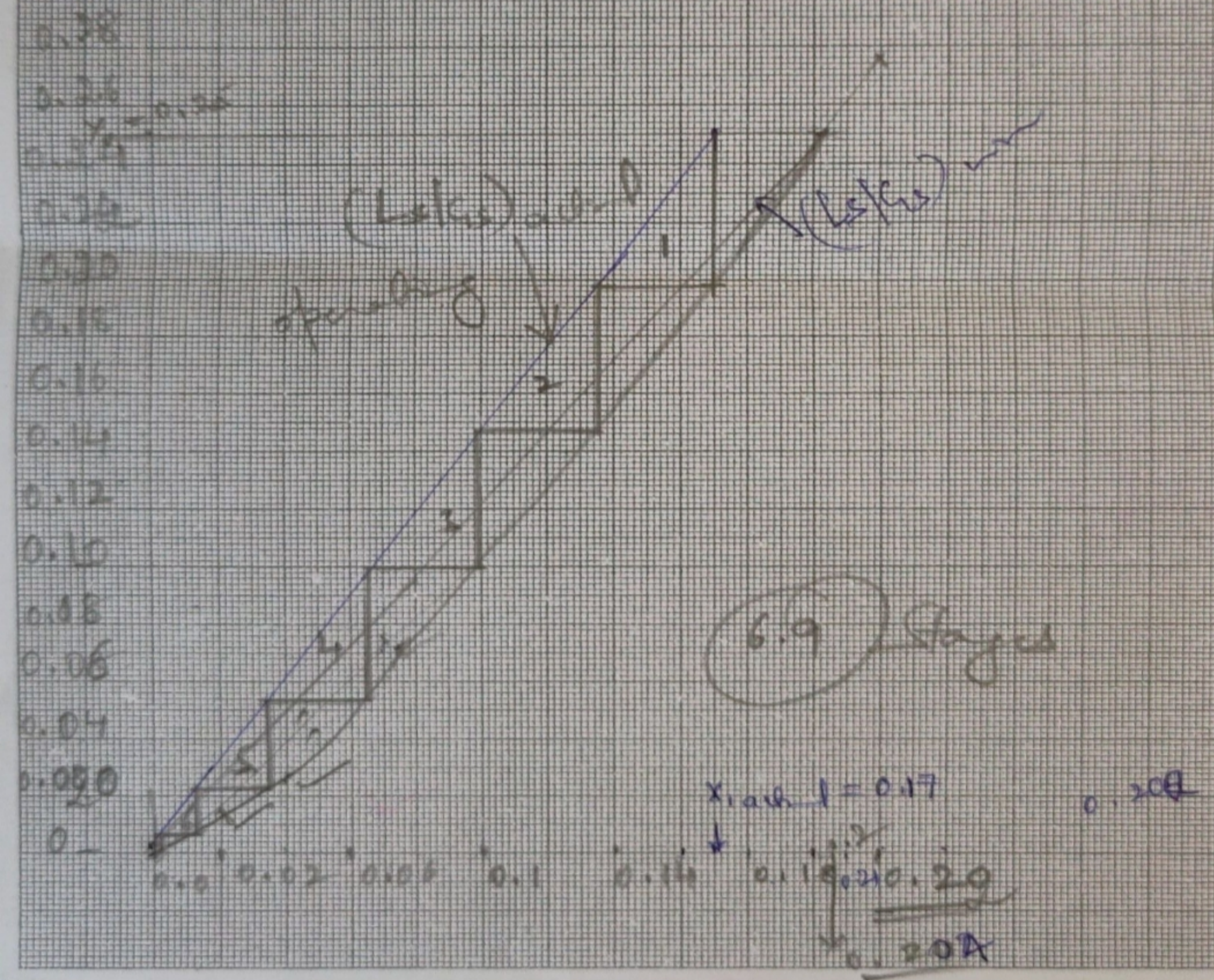
$$y = \frac{P_{\text{NH}_3}}{P_T} ; y = \frac{P_{\text{NH}_3}}{P_{\text{air}}} = \frac{P_{\text{NH}_3}}{P_T - P_{\text{NH}_3}}$$

$$y = \frac{12}{760 - 12} = 0.016$$

Total pr $P_T = 760 \text{ mm Hg}$; $P_T = P_{\text{NH}_3} + P_{\text{air}}$
 $P_{\text{air}} = P_T - P_{\text{NH}_3}$

$$Y = 1 \text{ cm} = 0.02 \text{ units}$$

$$X = 1 \text{ cm} = \underline{0.02 \text{ units}}$$



HETP - Height Equivalent to a Theoretical Plate

$$Z = N_p \times \text{HETP}$$

Pr drop - driving force
Dist b/n plates & by. seals

As ΔP for $\uparrow$ gas flow rates - the two phase mixture $\uparrow$ and eventually fill up the whole packing / trays resulting $\downarrow$ E. $\rightarrow$ flooding

$\rightarrow$ by forced out of exit pipe at top leading $\rightarrow \uparrow$ gas rates $\uparrow$ hold up & $\Delta P \uparrow \rightarrow \uparrow \Delta P$ as called

At forced gas vel, $\Delta P \uparrow$ with by. flow rate

HITU & NTU

$a \rightarrow$ Specific interfacial area m^2/m^3 of packing
Consider dz with interaction area $dS = a dz$

$$N_A = k_y (y - y_i)$$

$$= \frac{d(Gy)}{dS} = \frac{d(Gy)}{a dz}$$

$$\text{Consider } \rightarrow d(Gy) = d\left[G_s \left(\frac{y}{1-y}\right)\right]$$

Since G_s is constant

$$G = G_s d\left(\frac{y}{1-y}\right) = G_s \left[\frac{1-y - y(-1)}{(1-y)^2} \right] dy$$

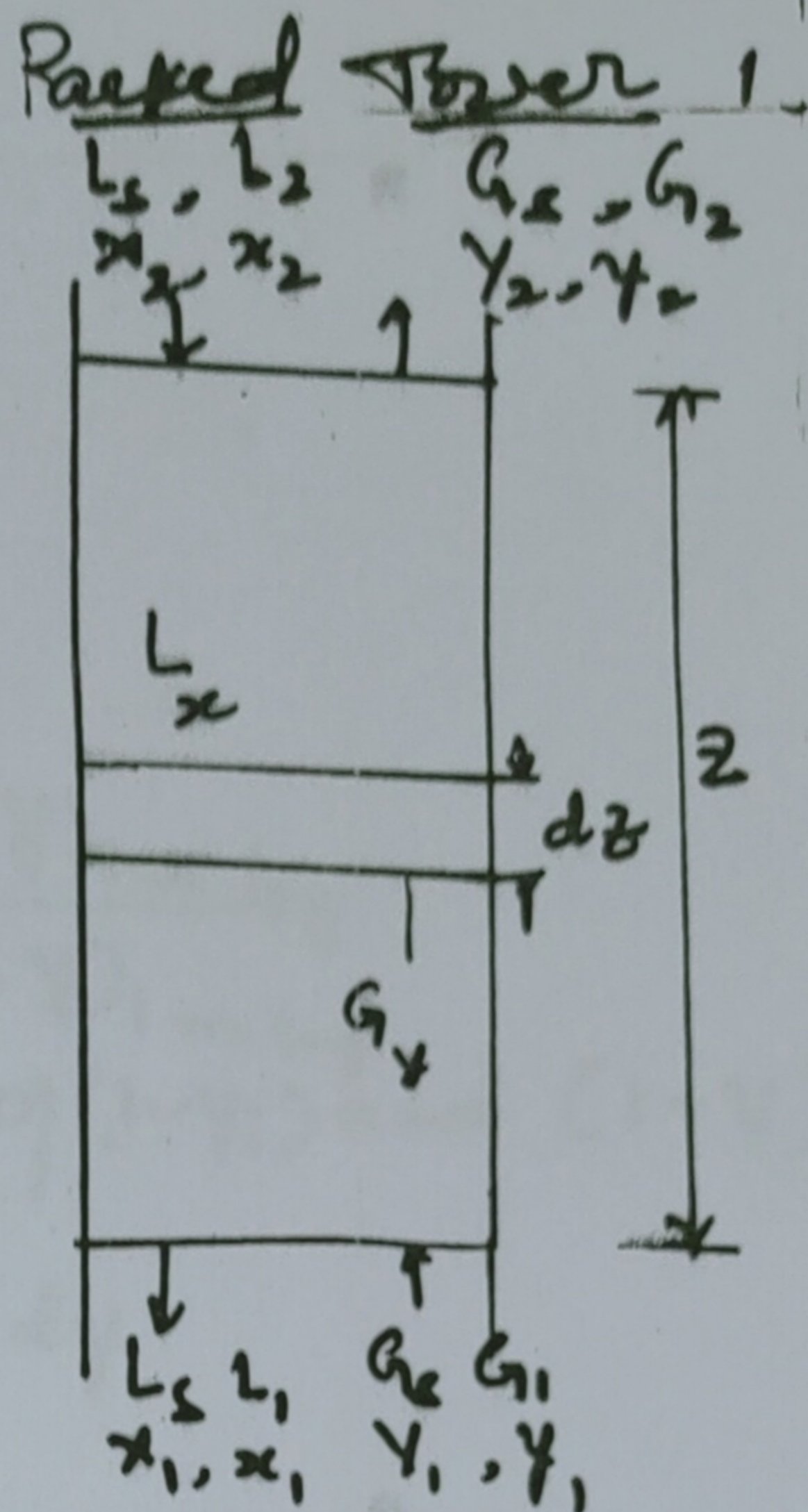
$$= G_s \left[\frac{1}{(1-y)^2} \right] dy = \frac{G_s}{1-y} \frac{1}{1-y} dy$$

$$= (G / (1-y)) dy = d(Gy)$$

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

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

Integrating over the full ht of packing from 0 to z and b/n y_1 and y_2



$$\int_0^z dz = \int_{y_2}^{y_1} \frac{Q dy}{k_y a (1-y)(y-y_i)}$$

$$z = \int_{y_2}^{y_1} \frac{Q dy}{k_y a (1-y)(y-y_i)}$$

$$z = \int_{y_2}^{y_1} \frac{Q dy}{k_y a (1-y)(y-y_i)} \frac{(1-y)_{lm} \log}{(1-y)_{lm} \log}$$

Where $(1-y)_{lm}$ is the log mean of $(1-y_i)$ and $(1-y)$

$$z = \frac{Q}{k_y a (1-y)_{lm}} \cdot \int_{y_2}^{y_1} \frac{(1-y)_{lm}}{(1-y)(y-y_i)} dy$$

$$z = H_{TU} \cdot NTU$$

$$z = H_{TU} \cdot NTU$$

$$H_{TU} = \frac{Q}{k_y a (1-y)_{lm}} ; NTU = \int_{y_2}^{y_1} \frac{(1-y)_{lm} dy}{(1-y)(y-y_i)}$$

Instead of considering log mean ave of $(1-y)_{lm}$, consider an arithmetic mean

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

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

$$\therefore NTU = \int_{y_2}^{y_1} \frac{\left[\frac{(y-y_i) + (1-y)}{2} \right] dy}{(1-y)(y-y_i)} \Rightarrow \int_{y_2}^{y_1} \left[\frac{1}{2} \left(\frac{y-y_i}{(1-y)(y-y_i)} + \frac{1}{(1-y)(y-y_i)} \right) \right] dy$$

$$= \int_{y_2}^{y_1} \frac{(y-y_i)}{2(1-y)(y-y_i)} dy + \int_{y_2}^{y_1} \frac{(1-y)}{(1-y)(y-y_i)} dy = \frac{1}{2} \ln \frac{1-y_2}{1-y_1} + \int_{y_2}^{y_1} \frac{dy}{y-y_i}$$

In case of dilute solutions $(1-y_1) \approx (1-y_2)$

... based on log phase mass transfer

$$H_{TL} = \frac{L}{k_y a (1-y)_{lm}} \quad \& \quad NT_L = \frac{1}{2} \ln \left[\frac{1-x_1}{1-x_2} \right] + \int \frac{dx}{x-x_i}$$

Method 1 : Use of k_g 's

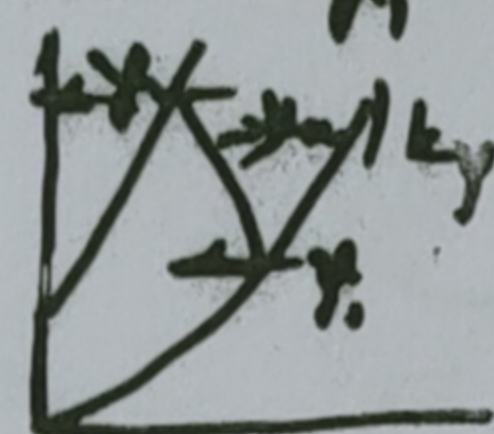
1) Draw Eq. Curve & op. line. Select a pt of op. line & draw a line with slope $-k_a/k_y$ to intersect at y_i .
Tabulate $y, y_i, \frac{1}{y-y_i}$ and a graph of y vs $\frac{1}{y-y_i}$.

$$HTU = \frac{G}{k_g a (1-y)_{im}}$$

$\Rightarrow (1-y)_{im}$ - log mean driving force from top of tower to bottom

of tower under curve of tower values of y_2 & y_1 from y_1 and to y_2

$$\therefore NTU = \frac{1}{2} \ln \left[\frac{1-y_2}{1-y_1} \right] + \int_{y_2}^{y_1} \frac{dy}{y-y_i}$$

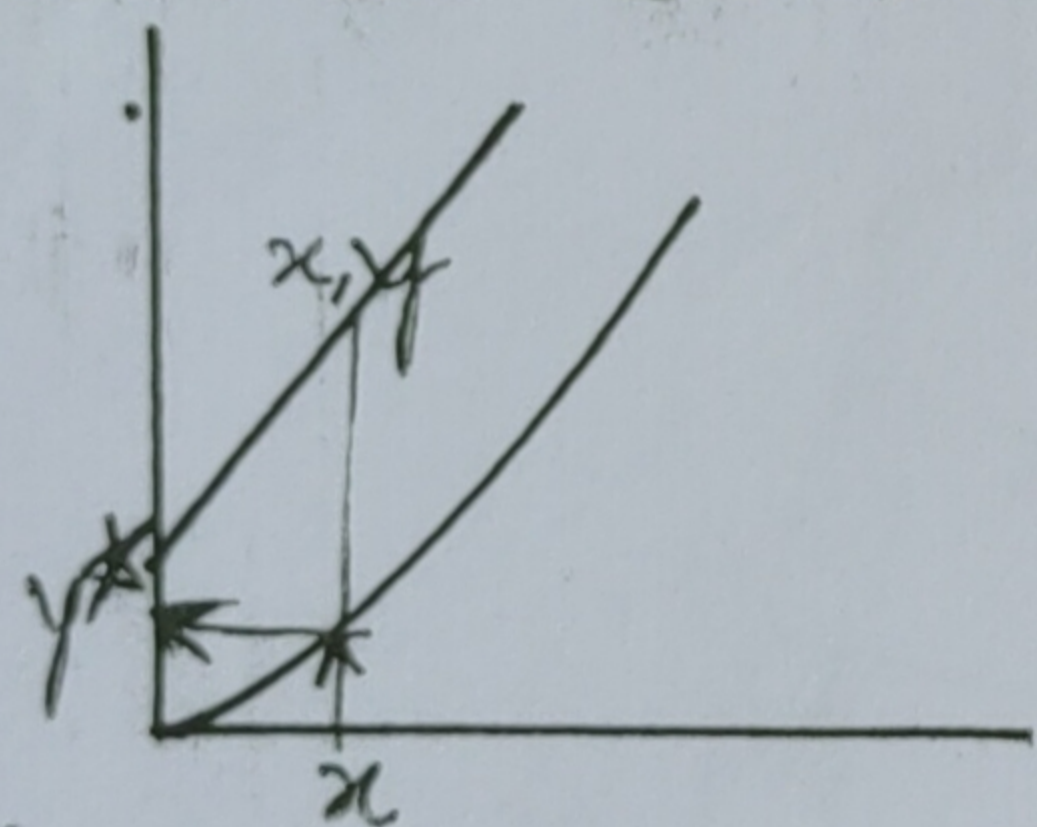


$$\text{Total HT} = (HTU)_{og} \times (NTU)_{og}$$

Method 2 : Use of K_G ; $Z = (HTU)_{og} \times (NTU)_{og}$

$$(HTU)_{og} = G / K_G P_a (1-y)_{im} ; \Rightarrow (1-y)_{im} \Rightarrow \text{log mean at top and bottom of tower conditions}$$

Select arbitrary pts on op line, the y^* composition can be obtained. Tabulate $y, y^*, y-y^*$.



Draw a graph of y vs $y-y^*$. Area under curve b/w x_1 & x_2

$$\Rightarrow \int_{y_2}^{y_1} \frac{dy}{y-y^*}$$

$$\begin{aligned} (NTU)_{og} &= \frac{1}{2} \ln \frac{1-y_2}{1-y_1} + \int_{y_2}^{y_1} \frac{dy}{y-y^*} \\ &= \frac{1}{2} \ln \frac{1+y_2}{1+y_1} + \int_{y_2}^{y_1} \frac{dy}{y-y^*} \quad ; Z = \checkmark \end{aligned}$$

If K_L is available

$$(HTU)_{ol} = \frac{L}{K_L a \cdot c (1-x)_{xm}}$$

$$(NTU)_{ol} = \frac{1}{2} \ln \left[\frac{1-x_1}{1-x_2} \right] + \int_{x_2}^{x_1} \frac{dx}{x^*-x}$$

$$= \frac{1}{2} \ln \left[\frac{1+x_1}{1+x_2} \right] + \int_{x_2}^{x_1} \frac{dx}{x^*-x} ; Z = (HTU)_{ol} \times (NTU)_{ol}$$

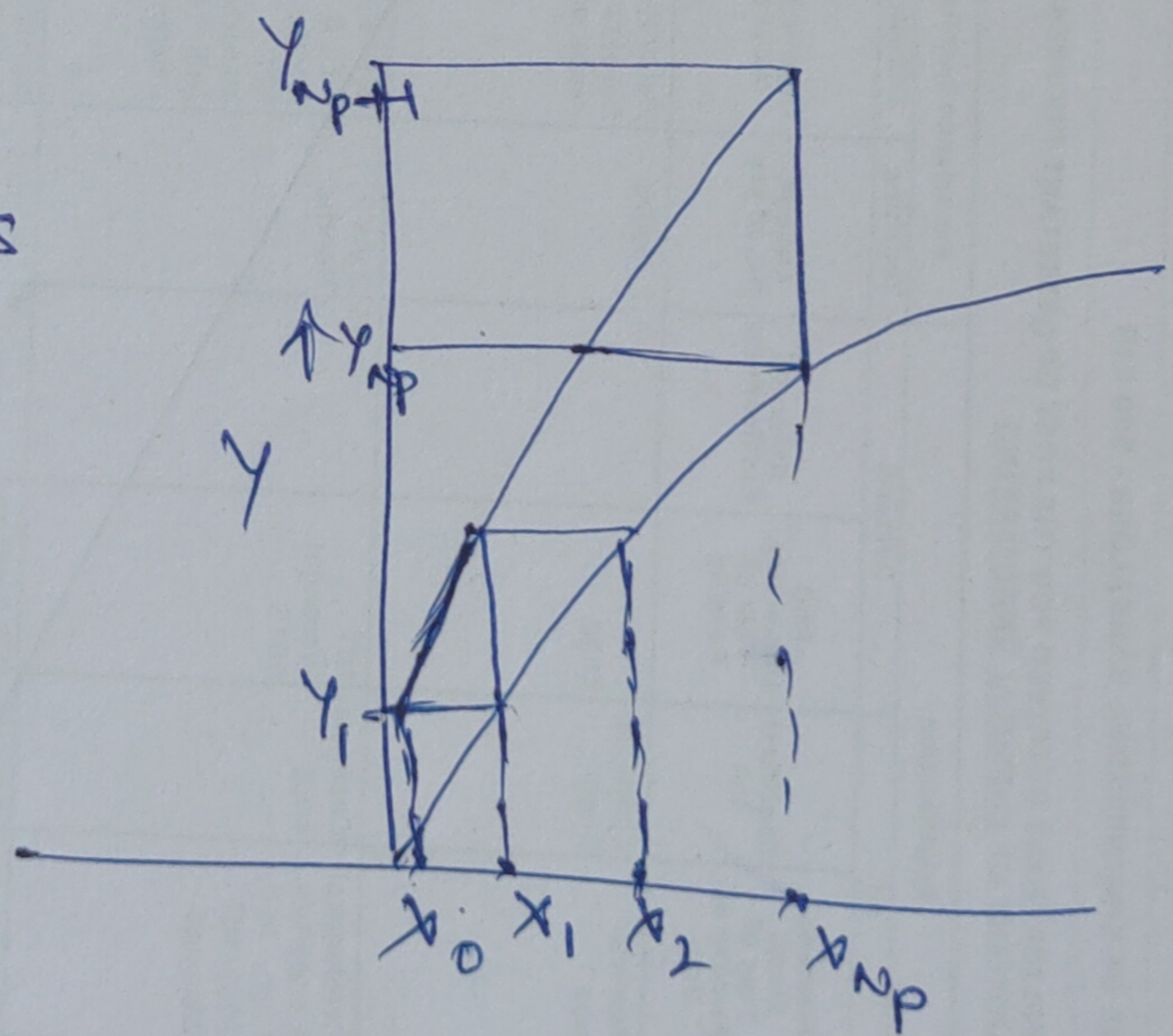
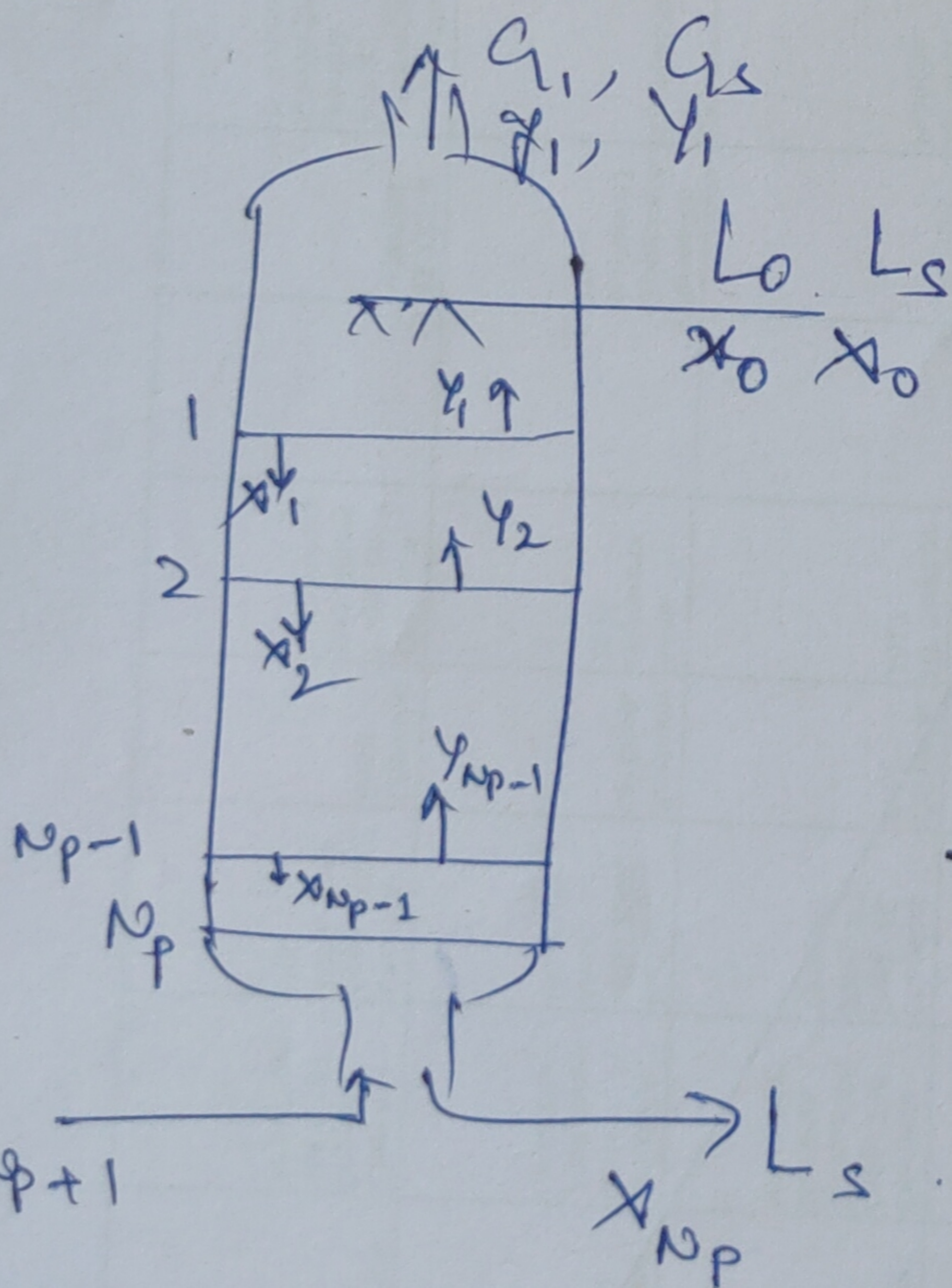
Absorption in plate or Tray towers

P and T towers bring about stepwise contacts of liquid and gas.

In each plate by and gas come into intimate contact and get separated at the space between two such plate or trays.

A tray is defined as one where the top and bottom heavy are in equilibrium.
OR

The average composition of gas is in equilibrium with average composition of liquid leaving the tray.



The trays are numbered from the top and last tray or plate of N_p .

$$G_S (Y_{Np+1} - Y_1) = L_S (X_{Np} - X_0)$$

or

$$\frac{L_S}{G_S} = \frac{Y_{Np+1} - Y_1}{X_{Np} - X_0} \rightarrow \text{eqn of operating line}$$

Draw a solute balance in top of
tower up to plate 2 (

$$G_S (Y_3 - Y_1) = L_S (X_2 - X_0)$$

$$\frac{L_S}{G_S} = \frac{Y_3 - Y_1}{X_2 - X_0}$$

This is equation ~~is~~ for operating line.