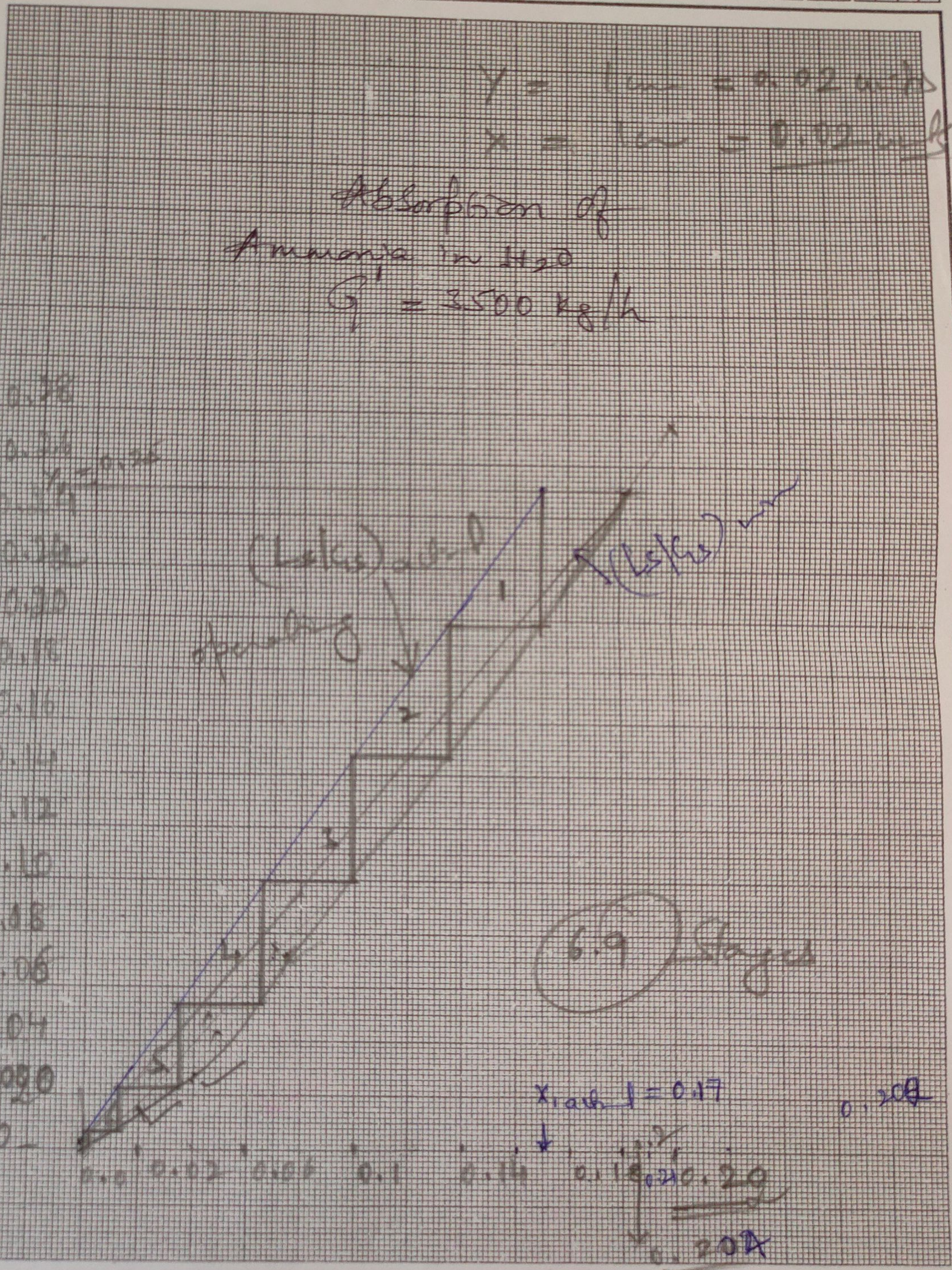
BMS COLLEGE OF ENGINEERING, BANGALORE - 560 019

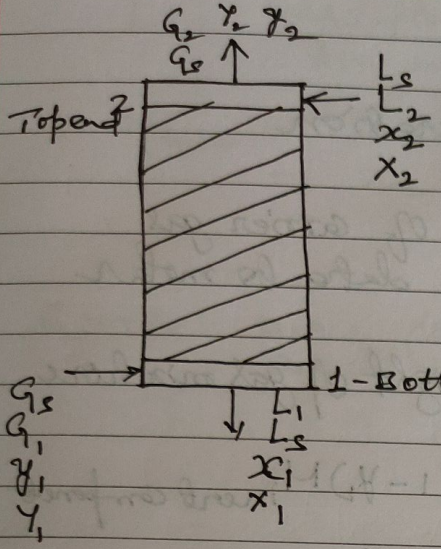
(Autonomous College Affiliated to Visvesvaraya Technological University, Belgaum)

Batch No. : ....

Date : 28/8/2020



Nomenclature and Material balance



G – Gas
L – Liquid absorbent
s – Solute free basis

x = Mole fraction of solute gas in liquid

$$x = \frac{\text{Moles of solute}}{\text{Moles of solute + Moles of solvent}}$$

X = Mole ratio of solute to solvent

$$= \frac{\text{Moles of solute}}{\text{Moles of solvent}}$$

y = Mole fraction of solute gas in inlet gas stream

$$y = \frac{\text{Moles of solute}}{\text{Moles of solute + Moles of inert gas component of the mixture}}$$

Y = Mole ratio of solute to inert gas component

$$Y = \frac{\text{Moles of solute}}{\text{Moles of inert gas component}}$$

Absorption operation involves several optimisable variables affecting the system design. A ~~Simplified~~ Simplified design approach followed includes the following steps.

i. Material balance

Basis:

Ex: 1 hour operation

OR G_1 kmol/h

OR Unit volume of carrier gas

Conversion of given data to molar flow rate

Average molecular weight of gas mixture

$$M_{av} = \Sigma y_i M_i$$

$$= y_1 M_1 + (1 - y_1) M_{inert\ component}$$

$$\rho_g = \frac{P M_{ave}}{RT} = \text{Density of gas}$$

$G_s = G(1 - y)$ = Inert gas molar flow rate

$$G = \frac{\text{Mass flow rate of gas}}{M_{av}} \quad \frac{kg/h}{kg/kmol} = \frac{kmol}{h}$$

Given volume of gas to be treated

Basis: 1 hour operation

$$G = \frac{PV}{RT} \quad (\text{from } n = \frac{PV}{RT})$$

G = Moles of solute + Moles of inert gas

$$L = \frac{\text{kmol of Solvent (adsorbent solution)}}{\text{time}}$$

L_s = kmol of pure solvent / time

$L_s = L(1 - x_2)$

$$G' = \frac{\text{kg of gas mixture}}{\text{time}} = G \times M_{ave}$$

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L = Mass flow rate of absorbent solution, kg/h / Ave mole wt of absorben solution

$M_{Lave} = \Sigma x_i M_i$

$= x_2 M_{solute} + (1 - x_2) M_{solvent}$

Given pure solvent, $x_2 = 0$

availability $1 - x_2 = 1$

$x_2 = 0$

$1 - x_2 = 1$

ii Solute (material) balance, on solute free basis

$L_s(x_1 - x_2) = G_s(Y_1 - Y_2)$

From $(G_s Y_1 + L_s X_2) = (Y_2 G_s + X_1 L_s)$

$$L_s/G_s = \frac{Y_1 - Y_2}{X_1 - X_2}$$

$$(L_s/G_s)_{min} = \frac{Y_1 - Y_2}{X_{1_{min}} - X_2}$$

$X_{1_{min}}$ corresponds to $L_{s_{min}}$ condition

Note that G_s' is fixed by statement of problem (numerical)

iii. Equilibrium data

X

Y

Given i. mole fraction,

conversion to mole ratio, $X = \frac{x}{1-x}$

and $Y = \frac{y}{1-y}$ ii. partial pressure

$$Y = \frac{\text{partial pressure of Solute}}{\text{partial pressure of inert}}$$

$$= \frac{\text{partial pressure of Solute}}{\text{Total pressure of system} - \text{partial pressure of Solute}}$$

iii. Given wt ratio

$$Y = \frac{\frac{\text{wt of Solute}}{\text{Mole wt of Solute}}}{\frac{\text{wt of inert}}{\text{Mole wt of inert}}}$$

$$X = \frac{\frac{\text{wt of Solute}}{\text{Mole wt. of Solute}}}{\frac{\text{wt. of Solvent (pure)}}{\text{Mole wt of pure solvent}}}$$

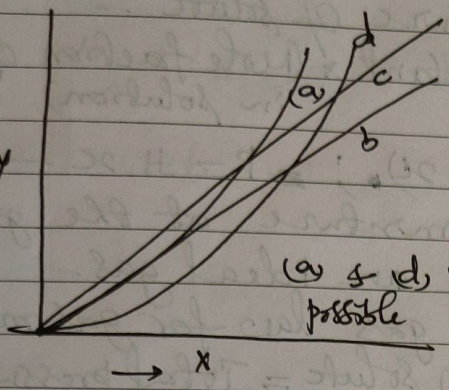
iv. Given wt %.

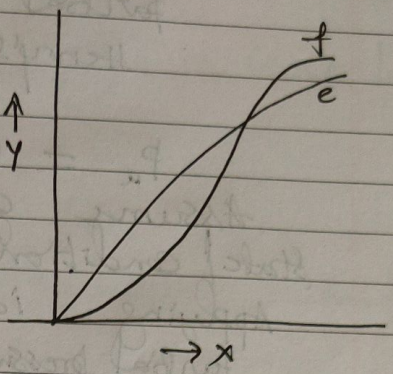
Take basis as 1 kg for each set of data

$$X = \frac{(\text{wt. of Solute}/\text{Mole wt. of Solute})}{\text{wt. of pure solvent}/\text{Mole wt. of pure solvent}}$$

If x, y are in the range, so that $x \approx X$, $y \approx Y$, Need not to convert the data to X and Y, x and y may be used to draw equilibrium curve.

iv. Equilibrium curve
Y versus X

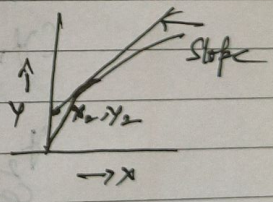




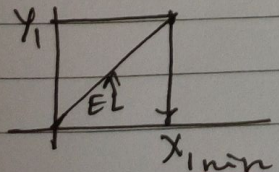
v. Operating line
Locate Y_1, Y_2, X_2

a. If equilibrium data results in curve profile draw tangent from (X_2, Y_2) to the curve. Tangent drawn to the curve should intersect the curve at one point.
Slope of the tangent drawn gives $(L_s/G_s)_{min}$
Calculate $(X_{1\,min})$ using
~~$(X_{1\,min}$ represents~~

$$X_{1\,min} = \frac{Y_1 - Y_2}{(L_s/G_s)_{min}} + X_2$$



b. If equilibrium data results in straight line
Draw horizontal from Y_1 to intersect the line (equilibrium). Read the X-axis value corresponding to Y_1 intersection with the E.L. as $X_{1\,min}$



Find $(L_s/G_s)_{min}$ using the equation

$$\frac{L_{s\,min}}{G_s} = \frac{Y_1 - Y_2}{X_{1\,min} - X_2}$$

(iii) Equilibrium curve

Given Henry's constant

partial pressure of solute = Henry's constant x (Mole fraction of solute in solution)

$P_a = (H_a x)_a$; $P = H x$ — (i)

Assume gas mixture at the given state condition as an ideal gas.

Applying ideal gas law for gas mixture

partial pressure of solute = Total pressure of system x (mole fraction of solute in gas mixture)

$P_a = P_T y$; $P = P y$ — (ii)

Since gas & liquid attain equilibrium in the operation

Equating equation (i) and equation (ii)

$P = H x = P y \longrightarrow H x = P y$ — (iii)

Statement of numerical / operation gives y_1 & y_2.

Given the inlet and outlet solute concentration (y_1 and y_2)

Assume "different y values from y_2 to y_1, calculate x values.

Convert x, y to X, Y.

iv. $L_{s\,operating}$ = Solute free solvent operating molar flow rate = $L_{s\,actual}$

Given

$L_{s\,op}$ (or $L_{s\,actual}$) = 'n' time $L_{s\,min}$

Calculate $L_{s\,op}$

Find $X_{1\,operating}$ = $X_{1\,operating} = X_{1\,actual}$

using $X_{1\,op} = \dfrac{Y_1 - Y_2}{\left(\frac{L_s}{G_s}\right)_{op}} + X_2$

Report $X_{1\,operating}$

Find $L'_{s\,min}$ = Mass flow rate of minimum solvent flow rate on solute free basis

OR

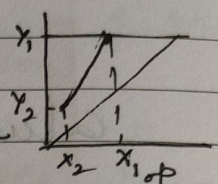
$L'_{op} = \dfrac{L_{s\,op}}{(1 - X_2)}$ where $L_{s\,min} = \left(\frac{L_s}{G_s}_{min}\right) \times G_s$

and $L_{s\,op} = \left(\frac{L_s}{G_s}\right)_{op} \times G_s$

v. Number of transfer units (NTU)

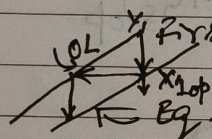
Draw $(L_s/G_s)_{op}$ line (operating line)

using ⓐ Slope of $(L_s/G_s)_{op}$



or ⓑ Locate $X_{1,operating}$, Join (X_2, Y_2) and (X_1, Y_1) points

Draw stages from (X_1, Y_1) between the $(Y_1, (X_{1\,actual}))$ operating line and the equilibrium line

(Note: 

)

Find out the fraction of theoretical stage if any, find the percentage of vertical line till (X_2, Y_2) locus, by drawing the complete stage.

Use efficiency of the column to find the actual number of stages.

$$\text{Actual number of transfer units} = \frac{\text{Theoretical stages}}{\text{efficiency of the column}}$$

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Vi Selection of packing material

Use if Given the type and characteristics of packing otherwise

Choose from the Perry's handbook

P –

T –

Ex: A packed column/tower with ceramic raschig ring of 1¼" nominal size randomly packed would be suitable and would have an HETP (height equivalent of one theoretical plate) of 0.6 to 1 m (may be assumed).

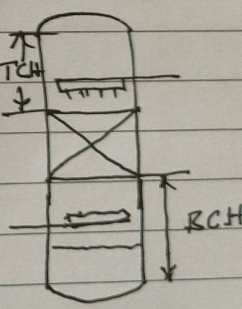
Height of packing = NTU (actual) × HETP

Height of the tower Z = Height of packing + TCH + BCH

TCH — Top chamber height

BCH — Bottom chamber height

(Assume 500 mm to 900 mm)
↳(TCH) (↳BCH)



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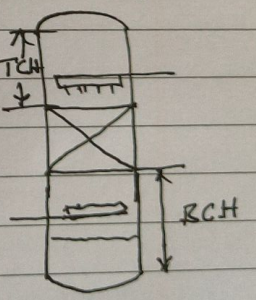

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vii. Diameter of the packed column

Reference P- 18-23

Figure 18-39

Evaluate $\frac{L_m}{G_m}\sqrt{\frac{\rho_G}{\rho_L}}$

Given the pressure drop, refer corresponding y-axis value

$$Y\text{-axis} = \frac{G_{op}^2 F_p \Psi \mu^{0.2}}{\rho_G \rho_L g}$$

Assume pressure drop of 1"/packed height

L_m and G_m represent mass flow rates

Use $(L_s/G_s)_{operating} \times \frac{M_{solvent}}{M_{ave.gas\ mixture}} = \frac{L_m}{G_m}$

Note:

$G_{op} = \frac{kg}{m^2 h}$; ρ_G - kg/m^3 ; ρ_L - kg/m^3

g - m/s^2 ; $\Psi = \frac{\text{Density of water}}{\text{Density of solvent}}$

μ = viscosity of liquid solvent (absorbent solution) cp

= ____ cp (centipoise)

F_p - packing factor from Ref { Perry's T-18-5, P-18-22

Cross sectional area of the column

$\boxed{A = G'/G_{op}}$ G' - kg/h, $G_{op} = kg/m^2 h$

$A = \pi d_i^2/4$

$d_i = \sqrt{\frac{4A}{\pi}}$ = ____ m