Examples:

12.4:

$Y_2 = \frac{1}{100} \times 0.03$

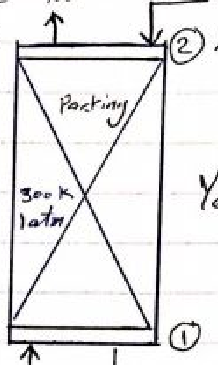
$Y_2 = 0.0003$

Triethanolamine solvent

(2) $X_2 = 0$

(1) bottom

(2) top



$Y_e = 2X$

(1)

$Y_1 = \frac{0.03 \text{ kmol } H_2S}{\text{kmol inert hydrocarbon}}$

$X_1 = 0.013 \frac{\text{kmol } H_2S}{\text{kmol solvent}}$

$G_m = 0.015 \frac{\text{kmol}}{m^2.s}$

solution 1- Dilute solution

2- Equilibrium is straight line from the equation $Y_e = 2X$

$$Z = \frac{G_m}{K_{OG} a P_T} \int_{y_1}^{y_2} \frac{dy}{y - y_e}$$

$Z = ?$

$N_{OG} = ?$

$K_{OG} a P_T = 0.04 \frac{\text{kmol}}{s\, m^3}$

$Y_1 = 0.03$, $Y_2 = 0.0003$

$X_2 = 0 \Longrightarrow Ye_2 = 2X_2 = 0.0$

$X_1 = 0.013 \Longrightarrow Ye_1 = 2X_1 = 2 \times 0.013 = 0.026$

Bottom driving force

$= Y_1 - Ye_1$

$= 0.03 - 0.026 = 0.004$

Top driving force

$= Y_2 - Ye_2$

$= 0.0003 - 0 = 0.0003$

$$Z = \frac{G_m}{K_{OG} a P_T} \times \frac{Y_1 - Y_2}{(Y - Y_e)LM}$$

$$(Y - Y_e)LM = \frac{(Y - Ye_1)_1 - (Y - Ye_2)_2}{\ln \frac{(Y - Y_e)_1}{(Y - Y_e)_2}} = \frac{0.004 - 0.0003}{\ln \frac{0.004}{0.0003}} = 0.0014$$

2

$$Z = \underbrace{\frac{0.015}{0.04}}_{HOG} \times \underbrace{\frac{0.03-0.0003}{0.0014}}_{NOG}$$

$$HOG = \frac{0.015}{0.04} = 0.375\ m$$

$$NOG = \frac{0.03-0.0003}{0.0014} = 21.21$$

$$Z = HOG \times NOG$$
$$= 0.375 \times 21.21$$
$$Z = 7.95\ m$$

$$KOG \cdot a \cdot P_T$$
$$\downarrow \quad \downarrow \quad \downarrow$$
$$\frac{S}{m} \cdot \frac{m^2}{m^3} \cdot \frac{kN}{m^2}$$
$$\downarrow$$
$$\underbrace{\frac{\cancel{S}}{\cancel{m}} \cdot \frac{\cancel{m^2}}{m^3} \cdot \frac{kg\,\cancel{m}}{S^2\,\cancel{m^2}}}$$
$$\downarrow$$
$$\frac{kg}{S.m^3} \text{ or } \frac{kmol}{S.m^3}$$

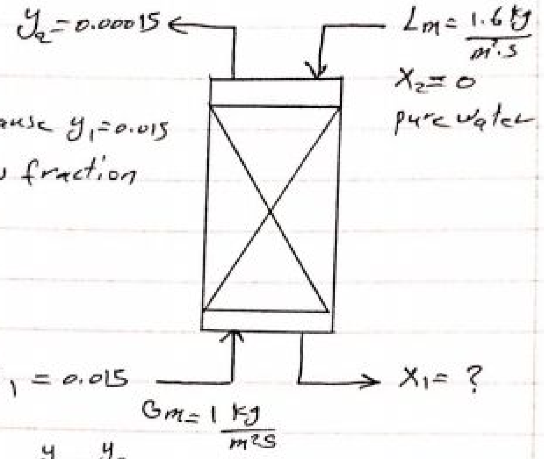
$$\left(kN = \frac{kg\,m}{S^2}\right)$$
$$\downarrow$$
$$(F = M \times A)$$
$$\downarrow$$
$$kg \times \frac{m}{S^2}$$

ملاحظة: في حالة أعطانا الوحدة لـ $KOG.a.P_T$ بشكل

$$\left[\frac{kmol}{S\,m^3} \times \frac{kN}{m^2}\right]$$

وعليه يجب أن يتم ضرب القيمة بالضغط P_T .

EX: 12.2



1) Dilute solution because $y_1 = 0.015$
2) mole fraction $\simeq$ mass fraction

$y_e = 1.75\,X$

NOG = ?

$$NOG = \int_{y_2}^{y_1} \frac{dy}{y - y_e} = \frac{y_1 - y_2}{(y - y_e)LM}$$

$$(y - y_e)LM = \frac{(y_1 - y_{e1}) - (y_2 - y_{e2})}{\ln \frac{(y_1 - y_{e1})}{(y_2 - y_{e2})}}$$

$$G_m = \frac{1}{29} = 0.0345 \ (kmol/m^2 s)$$

$$L_m = \frac{1.6}{18} = 0.0889 \ (kmol/m^2 s)$$

overall Materiel Balance (O.M.B):

$$G_m (y_1 - y_2) = L_m (X_1 - \overset{=0}{\cancel{X_2}})$$

$$0.0345 (0.015 - 0.00015) = 0.0889 (X_1 - 0)$$

$X_1 = 0.00576$ & $y_{e1} = 1.75 X_1 = 1.75 \times 0.00576 = 0.0101$

bottom driving force $= (y_1 - y_{e1}) = (0.015 - 0.0101)$
$= 0.0049$

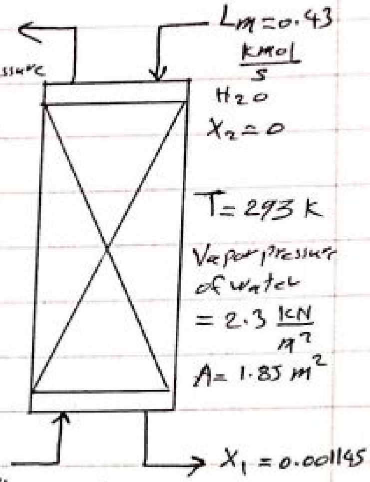
Top driving force $= (y_2 - y_{e2}) = (0.00015 - 0) = 0.00015$

$y_{e2} = 1.75 \overset{=0}{\cancel{X_2}} = 0.0$

$$(y - y_e)LM = \frac{0.0049 - 0.00015}{\ln \frac{0.0049}{0.00015}} = 0.00136$$

$$NOG = \frac{0.015 - 0.00015}{0.00136} = 10.92$$

EX: 12.10:



$$P_G = y_2 \, P_{total}$$

$$y_2 = \frac{P_G}{P_{total}} = \frac{1.14}{101.3} = 0.0113$$

$$Y_1 = \frac{y_1}{1-y_1} = \frac{0.035}{1-0.035} = 0.036$$

$$K_{OL}a = 0.19 \ kmol\ SO_2/s\ m^3$$

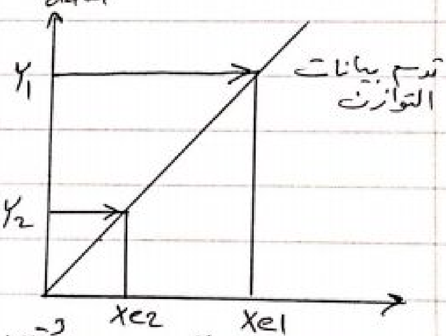
$$Z = \frac{L_m}{K_{OL}a\, C_T} \int_{X_2}^{X_1} \frac{dX}{X_e - X}$$

at $Y_2 = 0.0113$

from drawing   في السؤال معطى equilibrium data نرسم ونجد

$Xe_2 = 0.54 \times 10^{-3}$

at $Y_1 = 0.036 \Rightarrow Xe_1 = 1.41 \times 10^{-3}$



$$(Xe_1 - X_1) = 1.41 \times 10^{-3} - 1.145 \times 10^{-3}$$
$$= 0.265 \times 10^{-3} \ \frac{kmol\ SO_2}{kmol\ H_2O}$$

$$(Xe_2 - X_2) = 0.54 \times 10^{-3} - 0.0 = 0.54 \times 10^{-3}$$

$$(Xe - X)_{LM} = \frac{(0.54 - 0.265) \times 10^{-3}}{\ln \frac{0.54}{0.265}} = 3.86 \times 10^{-4} \ \frac{kmol\ SO_2}{kmol\ H_2O}$$

$$Z = \frac{L_m}{K_{OL}a\, C_T} \times \frac{X_1 - X_2}{(Xe - X)_{LM}}$$

$$Z = \frac{0.43}{1.85 \times 0.19} \times \frac{0.00145 - 0}{3.86 \times 10^{-4}}$$

$$Z = 3.64 \ m$$

$$K_{OL}a\, C_T = \frac{m}{s} \cdot \frac{m^2}{m^3} \cdot \frac{kmol}{m^3} = \frac{kmol}{m^3 s}$$

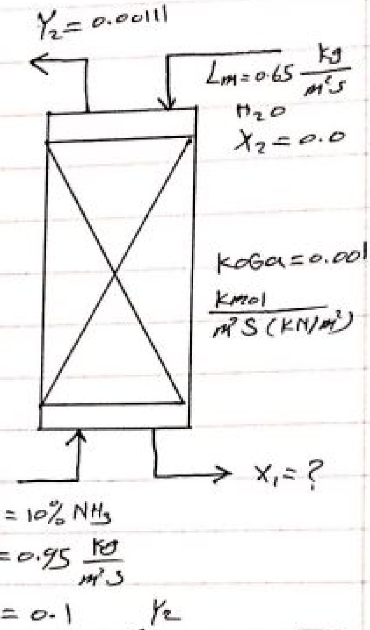
$$L_m = 0.43 \frac{kmol}{s} \times \frac{1}{1.85\ m^2}$$

$$L_m = \frac{kmol}{s\ m^2}$$

5

EX: 12.9 (not dilute solution)

مثال تصميمي للمحاليل المركزة (غير المخففة)



① يجب تحويل G و Lm الى kmol

M.wt of air = 29

M.wt of NH_3 = 17

Average M.wt = 0.1×17 + 0.9×29

= 27.8

$$\frac{0.95}{27.8} = 0.034 \ \frac{kmol}{m^2 S}$$

G_m (inert gas) = 0.034×0.9 = 0.0307 $kmol/m^2.S$

$$L_m = \frac{0.65}{18} = 0.036 \ \frac{kmol}{S\, m^2}$$

$$Y_1 = \frac{y_1}{1-y_1} = \frac{0.1}{1-0.1} = 0.111$$

$$Y_2 = \frac{1}{100} \times 0.111 = 0.00111$$

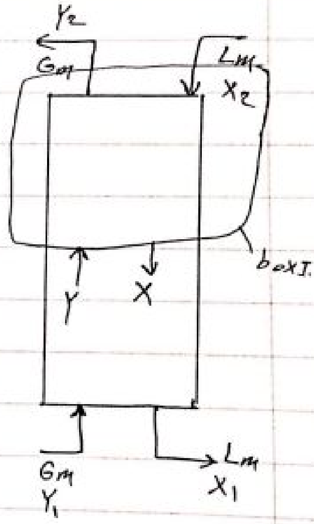
② Find The equation of equilibrium line

box I. Material balance

$$G_m (Y - Y_2) = L_m (X - \overset{=0}{X_2})$$

$$Y = \frac{L_m}{G_m} X + Y_2$$

$$Y = \frac{0.036}{0.037} X + 0.001$$



$$\boxed{Y = 1.137 X + 0.001}$$ operating line equation

معادلة خط التشغيل

$$Z = \frac{G_m}{K_{OG} a P_T} \int_{Y_2}^{Y_1} \frac{(1+Y)(1+Y_i)}{(Y - Y_i)}$$

3- Find the equilibrium data يتم تحديد بيانات التوازن

$P_G = y\, P_T$ لكي نرسم منحني التوازن بين X و Y وكما يلي:

$$P_G = \frac{Y}{Y+1} P_T$$

$$P_G + P_G Y = P_T Y$$

$$Y = \frac{P_G}{P_T - P_G}$$

معطاة →

X $\frac{kmol\ NH_3}{kmol\ H_2O}$	0.21	0.031	0.042	0.053	0.079	0.106	0.15	[illegible]
P_G mm Hg Partial pressure	12	18.2	24.9	31.7	50	69.6	114	
$P_T - P_G$ (P_T → 760 mmHg)	748	741.8	735.1	728.3	710	690.4	646	
$Y = \frac{P_G}{P_T - P_G}$	0.016	0.0245	0.0339	0.0473	0.0704	0.101	0.178	

4- Drawing operating line with equation $Y = 1.137X + 0.001$ and equilibrium curve between X & Y.

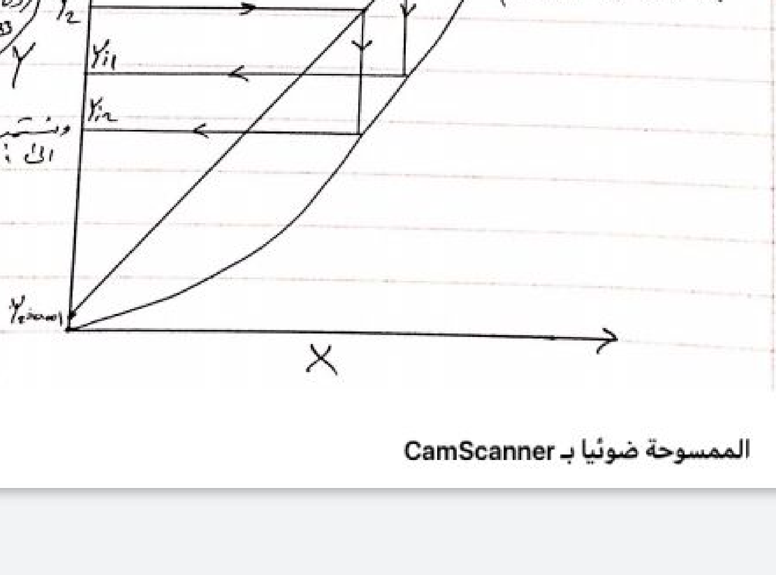
operating line

$X = 0 \Rightarrow Y = 0.001$

$X = 0.05 \Rightarrow Y = 0.059$

$X = 0.1 \Rightarrow Y = 0.1183$

ونستمر بهذه الصورة الى أن نصل الى $Y_2 = 0.0011$



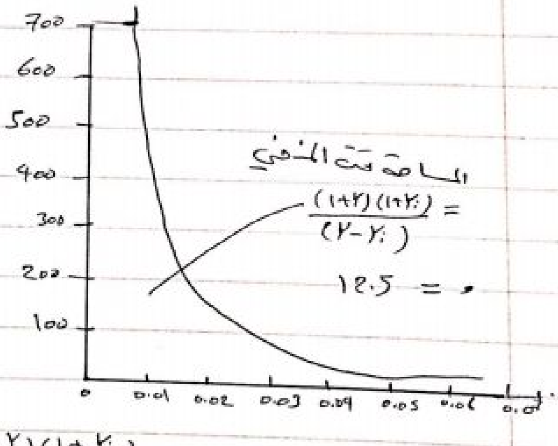
7

Y	Y_i	$\frac{(1+Y)(1+Y_i)}{(Y-Y_i)}$
$Y_1 = 0.111$	0.084	55
0.1	0.078	53.8
0.08	0.059	54.3
0.06	0.042	61.4
0.04	0.027	82.0
0.02	0.013	184
0.01	0.006	25.4
0.005	0.0026	421
$Y_2 = 0.0011$	0.0	1000

5 نحل التكامل التالي بواسطة المساحة تحت المنحني

$$\int_{Y_2}^{Y_1} \frac{(1+Y)(1+Y_i)}{(Y-Y_i)} .$$

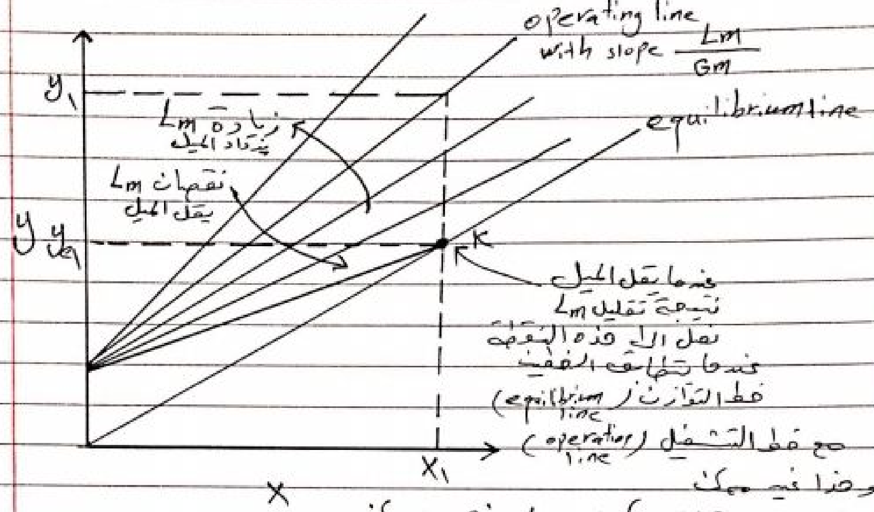
$\frac{(1+Y)(1+Y_i)}{(Y-Y_i)}$



$$Z = \frac{G_m}{K_{OG}a\,P_T} \int_{Y_2}^{Y_1} \frac{(1+Y)(1+Y_i)}{(Y-Y_i)}$$

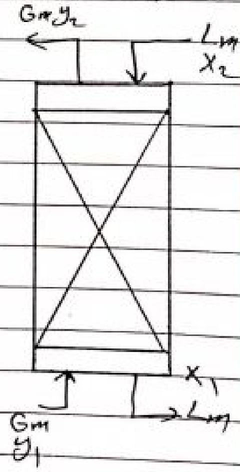
$$= \frac{0.0307}{0.001 \times 101.3} \times 12.5 = 3.82\ m$$

Effect of L_m and $\frac{L_m}{G_m}$ on the absorption design:



عندما تقل الميل
نتيجة تقليل Lm
نصل الى هذه النقطة
عندما تتطابق الخط
خط التوازن (equilibrium line)
مع خط التشغيل (operation line)
وهذا غير ممكن
وعند هذه النقطة يكون Lm أقل ما يمكن
ويسمى $\left(\frac{L_m}{G_m}\right)_{minimum}$

at point K $\Rightarrow y_1 = y_{e1}$
at $\left(\frac{L_m}{L_G}\right)_{minimum} \Rightarrow$



Overall M. B

$$G_m(y_1 - y_1) = L_m(X_1 - \overset{=0}{X_2})$$

$$\left(\frac{L_m}{G_m}\right)_{operating} = \frac{y_1 - y_2}{X_1}$$

$$y_{e1} = m X_1$$

$$X_1 = \frac{y_{e1}}{m}$$

but at $\left(\frac{L_m}{G_m}\right)_{min.} \Rightarrow y_1 = y_{e1}$

$$\therefore X_1 = \frac{y_1}{m}$$

$$\left(\frac{L_m}{G_m}\right)_{min} = \frac{y_1 - y_2}{X_1 - \overset{0}{X_2}} = \frac{y_1 - y_2}{X_1} = \frac{y_1 - y_2}{\frac{y_1}{m}} = \frac{\frac{y_1}{y_1} - \frac{y_2}{y_1}}{\frac{y_1}{m} \times \frac{1}{y_1}}$$

$$\left(\frac{L_m}{G_m}\right)_{min} = \frac{1-\frac{y_2}{y_1}}{\frac{1}{m}} = \left(1-\frac{y_2}{y_1}\right)m$$

$$\therefore \boxed{\left(\frac{L_m}{G_m}\right)_{min} = m\left(1-\frac{y_2}{y_1}\right)}$$

$$\text{but } \boxed{\left(\frac{L_m}{G_m}\right)_{operating} = \frac{y_1 - y_2}{X_1}}$$

وعليه يجب أن يكون $\left(\frac{L_m}{G_m}\right)_{operating}$ أكبر من $\left(\frac{L_m}{G_m}\right)_{min.}$

لكي نتجنب تقاطع الخطين

$$\left(\frac{L_m}{G_m}\right)_{operating} > \left(\frac{L_m}{G_m}\right)_{min.}$$

والقيمة التصميمية لزيادة $\left(\frac{L_m}{G_m}\right)_{ope.}$ هي أكبر من %40

$$\therefore \left(\frac{L_m}{G_m}\right)_{operating} > 1.4\left(\frac{L_m}{G_m}\right)_{min.}$$

EX: 12.12

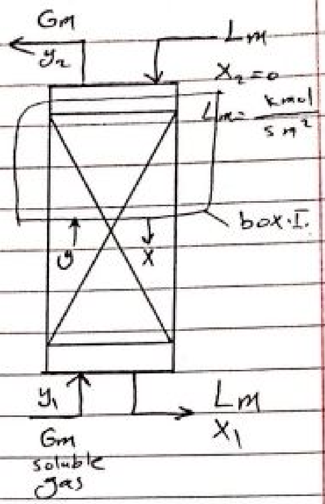
$y_2 = 0.1\, y_1$

$y_e = mX$

$H_{OG} = 0.6\ m$

$$\left(\frac{L_m}{G_m}\right)_{ope.} = 1.5 \left(\frac{L_m}{G_m}\right)_{min.}$$

$Z = ?$



solution

$$N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - y_e}$$

box I M.B.

$$G_m (y - y_2) = L_m (X - \underbrace{X_2}_{=0})$$

$$X = \frac{G_m}{L_m}(y - y_2)$$

If the equilibrium data $y_e = mX$

$$N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - \frac{mG_m}{L_m}(y - y_2)}$$

$$N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y\left(1 - \frac{mG_m}{L_m}\right) + \frac{mG_m}{L_m} y_2}$$

$$N_{OG} = \left[\frac{1}{1 - \frac{mG_m}{L_m}}\right] \ln \left[\left(1 - \frac{mG_m}{L_m}\right)\frac{y_1}{y_2} + \frac{mG_m}{L_m}\right]$$

let $\phi = \frac{mG_m}{L_m}$

$$\boxed{N_{OG} = \frac{1}{1-\phi} \ln \left[(1-\phi)\frac{y_1}{y_2} + \phi\right]}$$

معادلة مهمة ممكن استخدامها لإيجاد .NOG

(11)

1- نجد $\left(\frac{Lm}{Gm}\right)_{min}$

$$\left(\frac{Lm}{Gm}\right)_{min} = m\left(1 - \frac{y_2}{y_1}\right)$$

$$y_2 = 0.1\, y_1$$

$$\left(\frac{Lm}{Gm}\right)_{min} = m\left(1 - \frac{0.1\, y_1}{y_1}\right)$$

$$\left(\frac{Lm}{Gm}\right)_{min} = 0.9\, m$$

but $\left(\frac{Lm}{Gm}\right)_{ope.} = 1.5\left(\frac{Lm}{Gm}\right)_{min}$

$$\therefore \left(\frac{Lm}{Gm}\right)_{ope.} = 1.5 \times 0.9\, m$$

$$\left(\frac{Lm}{Gm}\right)_{ope.} = 1.35\, m \Longrightarrow \boxed{\frac{m\,Gm}{Lm} = \frac{1}{1.35}}$$

$$\Phi = \frac{m\,Gm}{Lm} = \frac{1}{1.35} = 0.74$$

$$\frac{y_1}{y_2} = \frac{y_1}{0.1\, y_1} = 10$$

$$\therefore NOG = \frac{1}{1-\Phi} \ln\left[(1-\Phi)\frac{y_1}{y_2} + \Phi\right]$$

$$= \frac{1}{1-0.74} \ln\left[(1-0.74)\times 10 + 0.74\right]$$

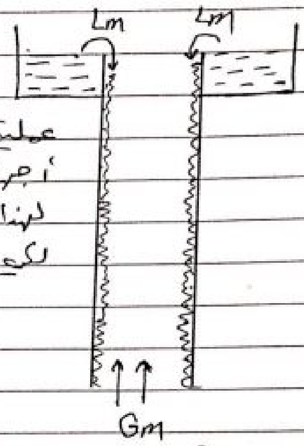
$$NOG = 4.64$$

$$Z = NOG\; HOG$$

$$= 4.64 \times 0.6$$

$$Z = 2.78\, M$$

Wetted-Wall column Absorber:



عملية التلامس في هذا النوع من
أجهزة الامتصاص تتم على جدار العمود
لهذا توصف هذه الأجهزة بطول العمود
لكي تتم زيادة المساحة المعرضة للتلامس

The general equation for mass transfer in a wetted wall column is:

المعادلات للاطلاع فقط.

$$\boxed{\frac{h_D d}{D_v}\,\frac{P_{BLM}}{P_t} = \beta\, Re^{0.83}\, Sc^{0.44}} \quad \text{— (1)}$$

where: Re: Reynold No. $= \left(\frac{\rho u d}{\mu}\right)_{gas}$

Sc: Schmidt No. $= \left(\frac{\mu}{\rho D}\right)_{gas}$

h_D: Mass transfer coefficient $= \left(\frac{D_v}{Z_G}\right)$

D_v: vapor diffusivity $\frac{m^2}{sec}$

Z_G: Thickness of gas film

d: Column diameter (m) $\quad K_G = \left(\frac{h_D}{RT}\right)\left(\frac{P_{BLM}}{P_t}\right)$

P_{BLM}: log mean of (P_B)

P_B: Partial pressure of B

P_t: Total pressure.

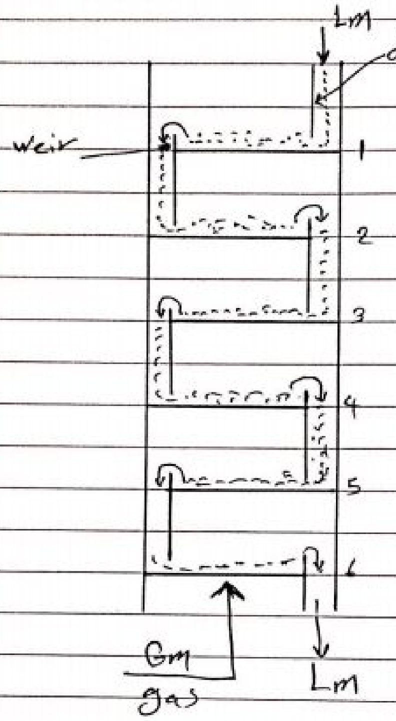
For wetted wall column the mass transfer coefficient for gas film h_D

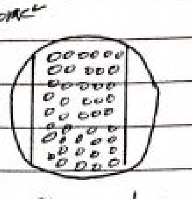
$$\frac{h_D}{u} = 0.04\left(\frac{\rho u d}{\mu}\right)^{-0.25}\left(\frac{\mu}{\rho u d}\right)^{-0.5}\left(\frac{P_t}{P_{BLM}}\right) \quad \text{— (2)}$$

When for packed tower:

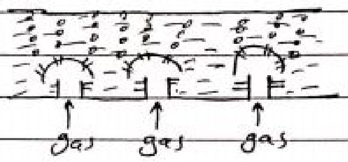
$$\frac{h_D}{u}\cdot\frac{P_{BLM}}{P_t}\left[\frac{\mu}{\rho u d}\right]^{0.56} = \beta\, Re^{-0.17} = j_d = j_{\text{factor for mass transfer}} \quad (3)$$

Plate Tower Absorption: أعمدة الامتصاص ذات الصواني

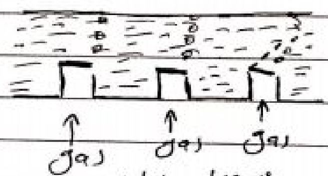




Sieve tray



bubble cup tras



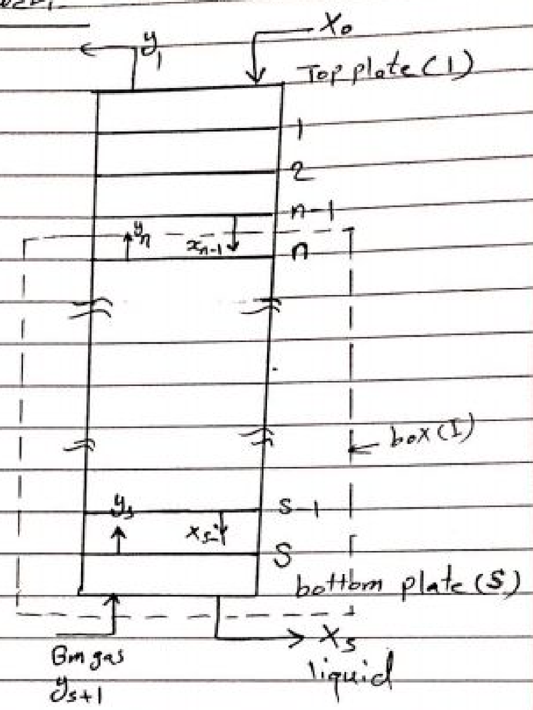
Valve tray

plate Tower:

Bubble-cup, sieve and valve tray are some times used for gas absorption particulary when the load is more than can be handled in a packed tower of about (1m) (When the liquid rate is sufficient to flood in a paked tower. plate tower consist of vertical cylindrical shell with number of plate.
when diameter < 2m packed column are more often used.

في هذا النوع من الأجهزة تتم عملية الامتصاص على الصواني حيث تعمل هذه الصواني على توفير مساحة تلامس كبيرة بين الغاز والسائل عن طريق تكوين فقاعات للغاز الصاعد للأعلى مع السائل النازل للأسفل وهي أجهزة مهمة تستعمل للكميات التدفق العالية للغاز أو السائل

plate Absorption Tower:-



let:

Lm = is the molar rate of liquid per (unit area, unit time)

Gm = is the molar rate of gas per (unit area, unit time)

n = refers to the plate number from the top downward.

X = mole fraction of the absorbed component in the liquid.

y = mole fraction of the absorbed component in the gas

S = Total number of plate in the column.

Plate Absorption Tower:-

For dilute solution $\Rightarrow$ $y = Y$ & $x = X$

The gas leaving of composition y_n in equilibrium with the liquid of composition x_n.

Material Balance for absorber component (box.I) from bottom to a plane above plane (n) will give:

$$G_m y_{s+1} + L_m x_{n-1} = G_m y_n + L_m x_s$$

$$\boxed{y_n = \frac{L_m}{G_m} x_{n-1} + y_{s+1} - \frac{L_m}{G_m} x_s}$$

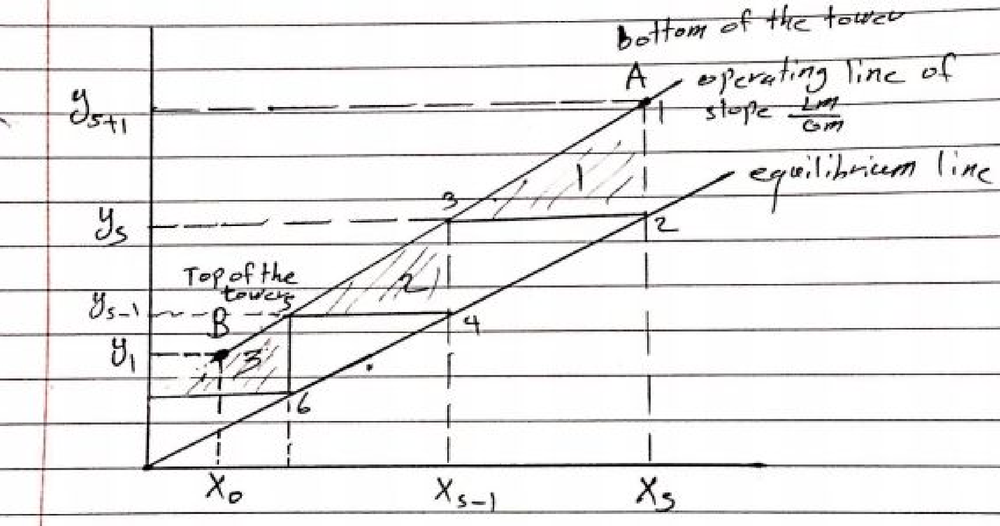
operating line of slope $\frac{L_m}{G_m}$

أقل تركيز للـ (solute) في السائل يكون في Top x_0

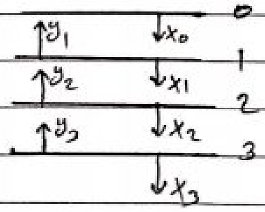
أقل تركيز للـ (solute) في الغاز يكون في Top y_1

أعلى تركيز للـ (solute) في الغاز يكون عند دخول الغاز للـ absorber = y_{s+1}

أعلى تركيز للـ (solute) في السائل يكون عند خروج السائل من absorber = x_s

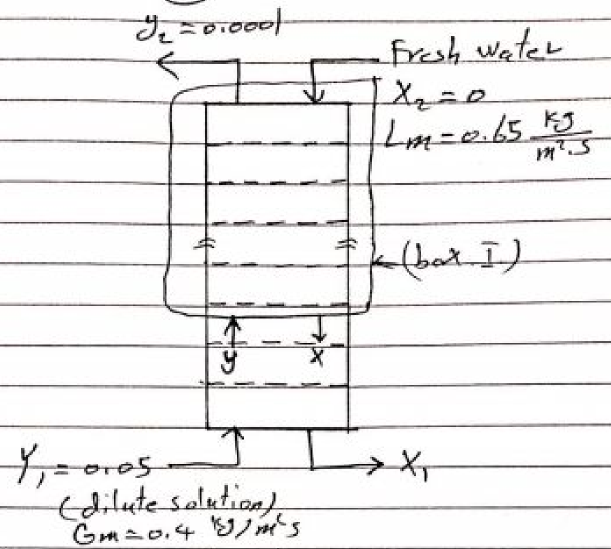


- بالنسبة للـ equilibrium
لا يوجد فرق في رقم الـ stage
بين (x_1, y_1) و (x_2, y_2)
و (x_3, y_3) تكون جميعاً
at equilibrium



- بالنسبة للـ operating
يوجد فرق في رقم الـ stage
بين (x_0, y_1) و (x_1, y_2)
و (x_2, y_3)

EX: 12:17



$$L_m = \frac{0.65}{18} = 0.036 \ \frac{kmol}{m^2.s}$$

$$G_m = \frac{0.4}{29} = 0.0138 \ \frac{kmol}{m^2 s}$$

لحساب عدد المراحل نجد أولاً معادلة operating line

box. I. Material Balance

$$G_m(y - y_2) = L_m(x - \cancel{x_2}^{=0})$$

$$0.0138\,(y - 0.0001) = 0.036\,X$$

$$\boxed{Y = 2.61\,X + 0.0001} \longrightarrow \text{operating line equation}$$

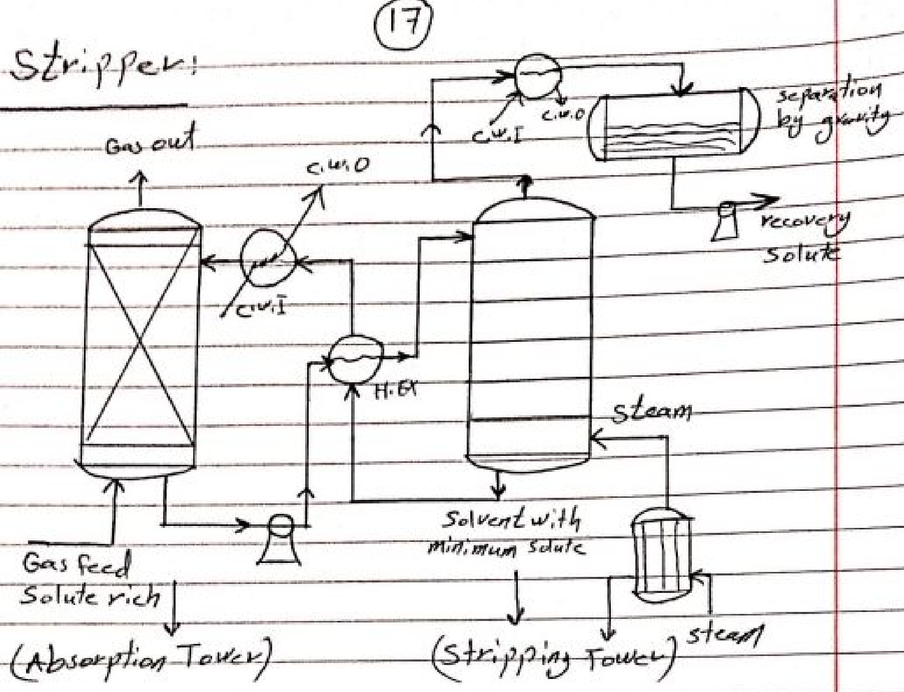
ثم نرسم معادلة الـ operating line و معادلة equilibrium line

equilibrium line $Y = X$ (وتمثل خط 45)

وبعدها نرسم عدد المراحل من $Y_1 = 0.05$ الى $Y_2 = 0.0001$

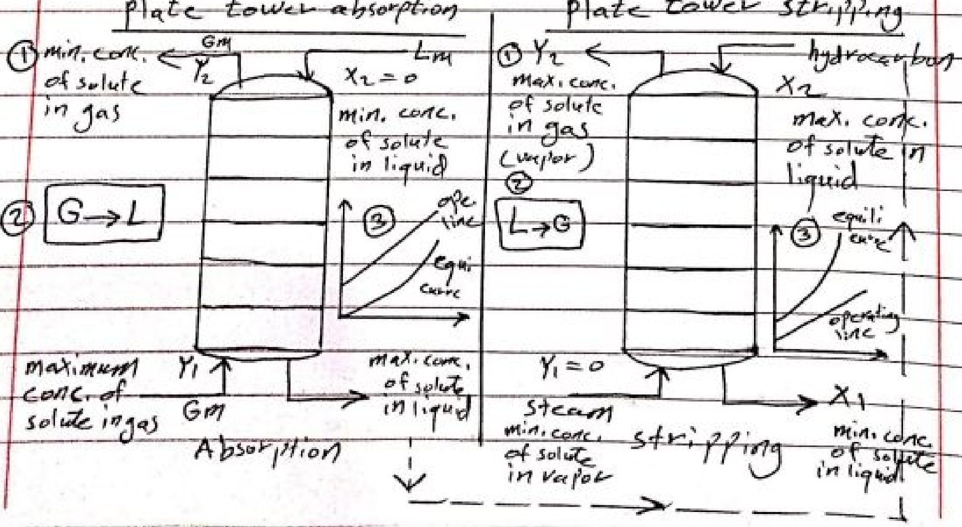
H.W. يتم تكملة السؤال ورسمه من قبل الطلبة.

Stripper:

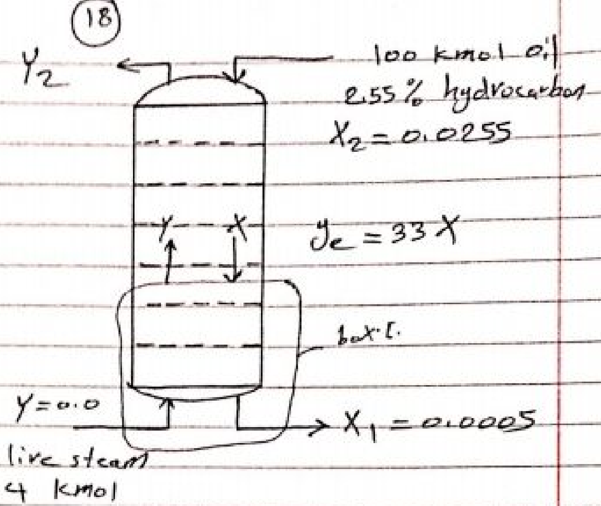


Stripper:

Stripping involves the removal of one or more volatile components from a liquid by contacting with an inert gas such as steam in mass transfer occur from liquid to gas ($L \rightarrow G$)



EX: 12.3



لحل السؤال نجد معادلة operating line و equilibrium curve
ونرسمها ونجد عدد المراحل.

box. I. Material Balance

$$L_m(X - X_1) = G_m(Y - \underbrace{Y_1}_{=0})$$

$$Y G_m = L_m X - L_m X_1$$

$$Y = \frac{L_m}{G_m} X - \frac{L_m}{G_m} X_1$$

$$Y = \frac{100}{4} X - 25 \times (0.0005)$$

$$\boxed{Y = 25X - 0.0125}$$ operating line equation.

$$y_e = 33x$$

$$\frac{Y_e}{1+Y_e} = \frac{33X}{1+X}$$

$$\boxed{Y_e = \frac{33X}{1-32X}}$$ equilibrium curve

نفرض لرسم equilib. curve

$X_1 = 0.005$	$Y_1 = 0.17$
$X_2 = 0.01$	$Y_2 = 0.48$
$X_3 = 0.015$	$Y_3 = 0.75$

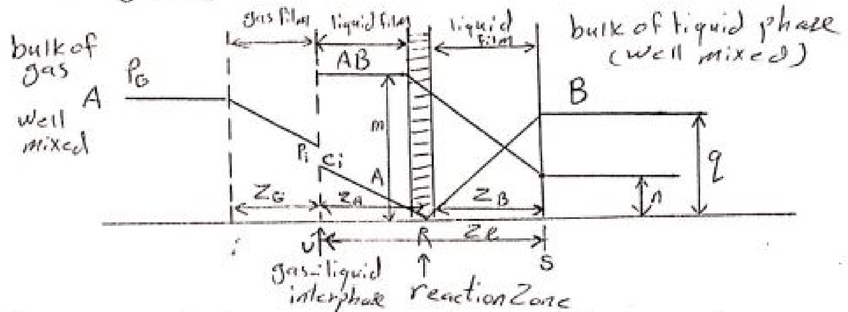
H.W. complete the drawing and find number of stage.

Absorption Associated with chemical reaction

The gas on absorption react chemically with a compone of the liquid phase for example the absorption of carbon dioxide by caustic soda ($CO_{2(g)} + NaOH_{(L)} \longrightarrow Na_2CO_3 + H_2$)
In such process the condition in the gas phase are simila to those already discussed, but in the liquid phase there is a liquid film followed by a reaction Zone.

$A + B \longrightarrow AB$

A: Solute in the gas phase
B: substance in the liquid phase
AB: product in liquid phase



① - The gas A diffuse through part of the liquid film before meeting B

② - The concentration of B at the interphase falls, this result in diffusion of B from the bulk of liquid phase to the interpha.

③ - The new product AB formed, diffuses towards the main body of the liquid.

④ - The driving force of A which is diffuse through the gas film $= P_G - P_i$

⑤ - The driving force of A which is diffuse to the reaction Zone $= C_i - 0$ (in the liquid phase)

⑥ - The component B diffuses from the main body of the liquid to reaction Zone under driving force q.

⑦ - The product AB diffused back to the main bulk of the liquid under a driving force $m-n$.

For transfer in the gas phase $N_A = k_G(P_G - P_i)$
and in the liquid Phase $N_A = k_l (C_i - 0)$

For irreversible chemical reaction at steady state (20)

$\alpha N_A = N_B$, $Z_L = Z_A + Z_B$

$N_A = \frac{D_A}{Z_A}(C_{Ai}-0) \Longrightarrow Z_A = \frac{D_A}{N_A} C_{Ai}$ —— (1)

$N_B = \frac{D_B}{Z_B}(C_B-0) \Longrightarrow Z_B = \frac{D_B}{N_B} C_B$ —— (2)

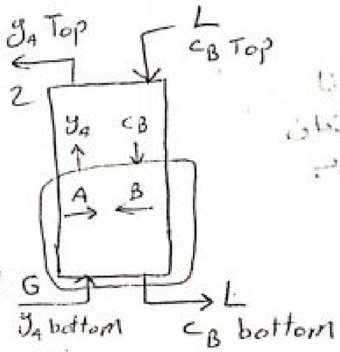
$Z_L = \frac{D_A C_{Ai}}{N_A} + \frac{D_B C_B}{N_B}$

$Z_L = \frac{D_A C_{Ai}}{N_A} + \frac{D_B C_B}{\alpha N_A} = \frac{1}{N_A}\left[D_A C_{Ai} + \frac{D_B C_B}{\alpha}\right]$

$Z_L = \frac{D_A C_{Ai}}{N_A}\left[1 + \frac{D_B C_B}{\alpha D_A C_{Ai}}\right]$ —— (3) $\Longrightarrow \frac{N_A}{C_{Ai}} = \frac{D_A}{Z_L}\left[1 + \frac{D_B C_B}{\alpha D_A C_{Ai}}\right]$

Define $k_L \Longrightarrow N_A = k_L(C_{Ai}-0) \Longrightarrow k_L = \frac{N_A}{C_{Ai}}$

$\therefore k_L = \frac{D_A}{Z_L}\left[1 + \frac{D_B C_B}{\alpha D_A C_{Ai}}\right]$ —— (4)



equation of operating line

M.B $\quad A + B \longrightarrow AB$

$G(y_{A\,bottom} - y_A) = L(C_{B\,bottom} - C_B)$

where $y_A = \frac{P_A}{P_T}$

$y_{A\,bottom} - y_A = \frac{L}{G}(C_{B\,bottom} - C_B)$

$-y_A = \frac{L}{G}(C_{B\,bottom} - C_B) - y_{A\,bottom}$

$y_A = \frac{L}{G} C_B - \frac{L}{G} C_{B\,bottom} + y_{A\,bottom}$ —— (5)

$$\boxed{y_A = \frac{L}{G} C_B + \left(y_{A\,bottom} - \frac{L}{G} C_{B\,bottom}\right)}$$ equation of operating line

$$Z = \frac{G}{K_G a P_T} \int_{P_{A\,Top}}^{P_{A\,bottom}} \frac{dP_A}{P_A + \frac{H D_B C_B}{D_A}}$$