Pilot Plant

- Device: Remove CO2 from a gas mixture
- ~15 wt% MEA in water is the working fluid; chemically enhanced absorption (about 2 orders of magnitude greater than physical solubility, >3 OoM than N2) recycle by heating and contact with CC “steam/MEA” flow in packed tower. Recycle everything
- You measure: gas composition at 6 points along absorber, many temperatures, pressures,
- You can vary gas and liquid flows, steam flow to reboiler, etc.
- Verification of process, learning operating procedures, running process are critical outcomes
- Main results:
  - You determine mass transfer coefficients in absorber, heat transfer coefficients in C100 and C200 and verify pump performance

GAS ABSORPTION/STRIPING

Imperial Flowsheet

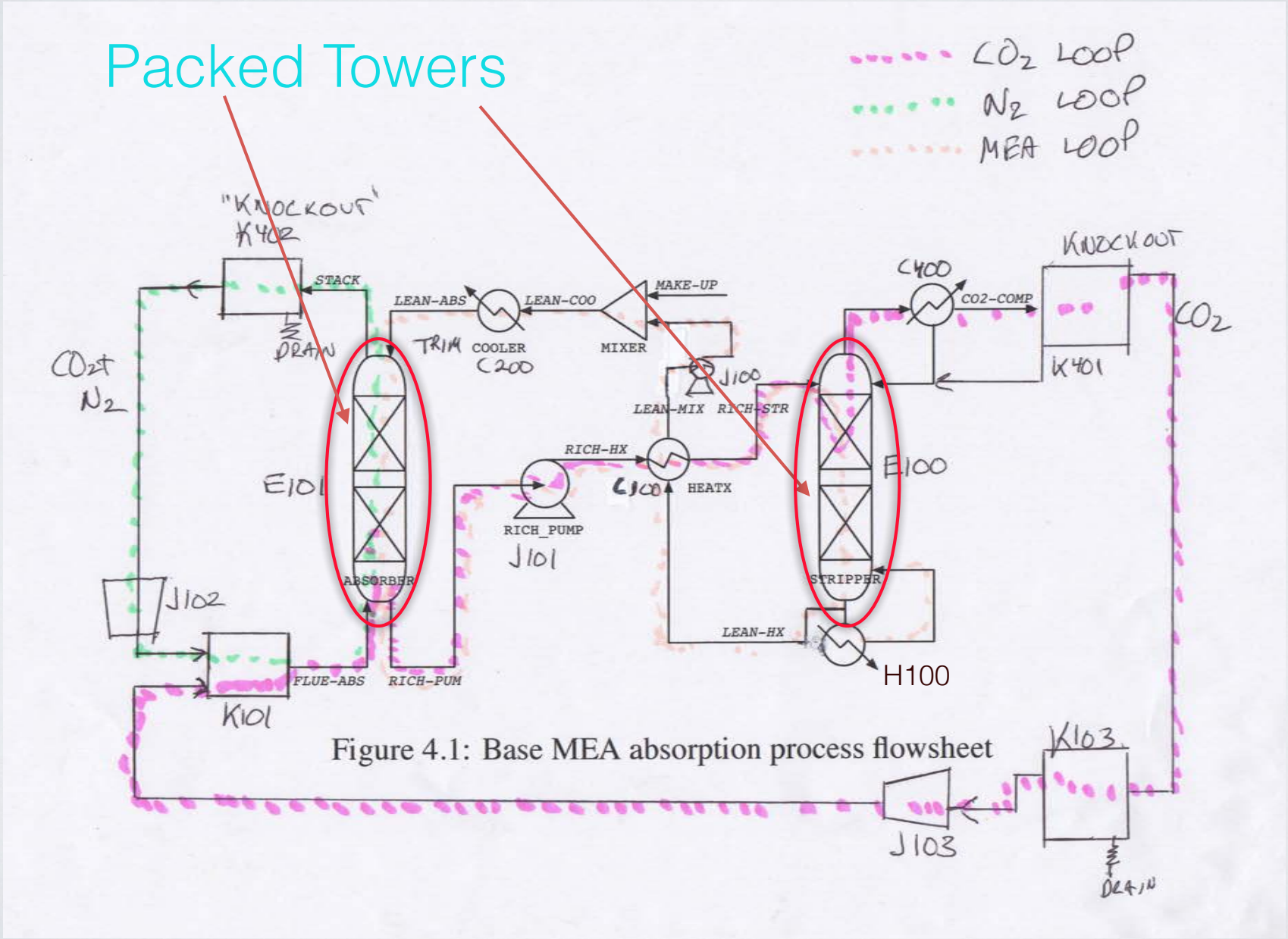


Figure 4.1: Base MEA absorption process flowsheet

THE TWO COLUMNS

PACKED TOWER

- **Why Countercurrent**
  - greater overall "driving force" (concentration difference)
  - (potentially) no limitation on amount of CO_2 removed
    - could contact lowest concentration exiting gas with "pure" solvent

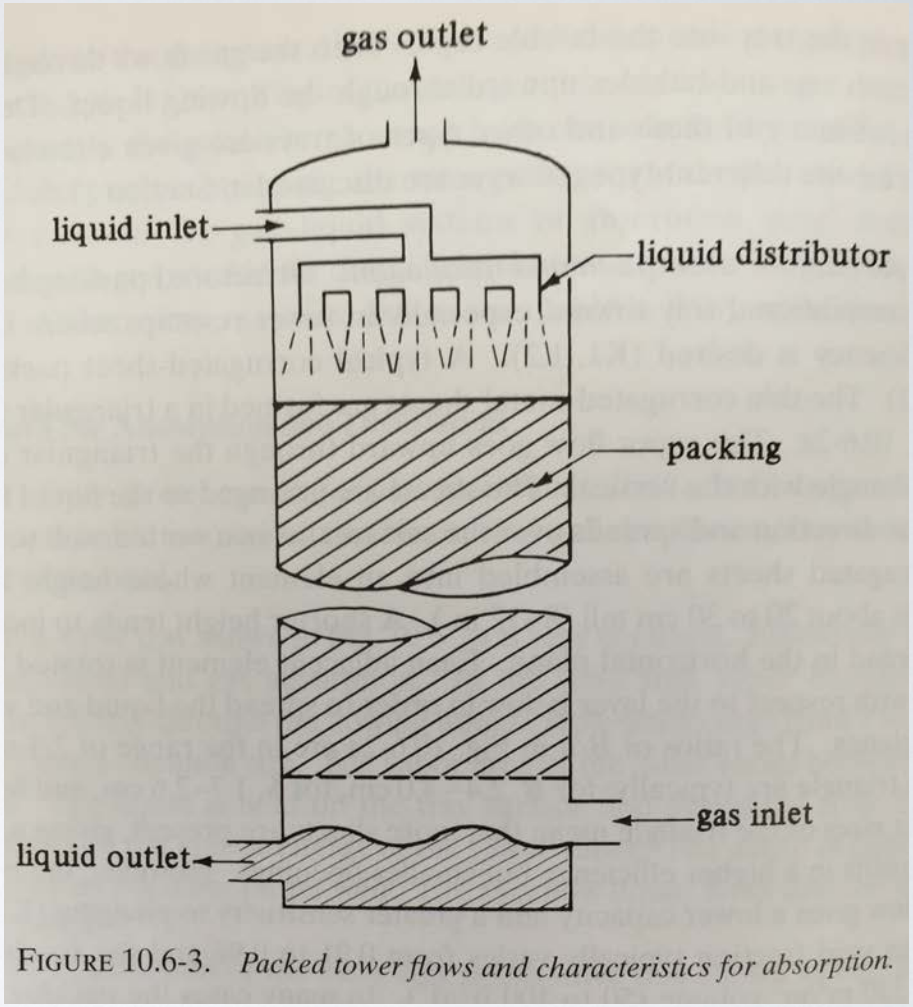
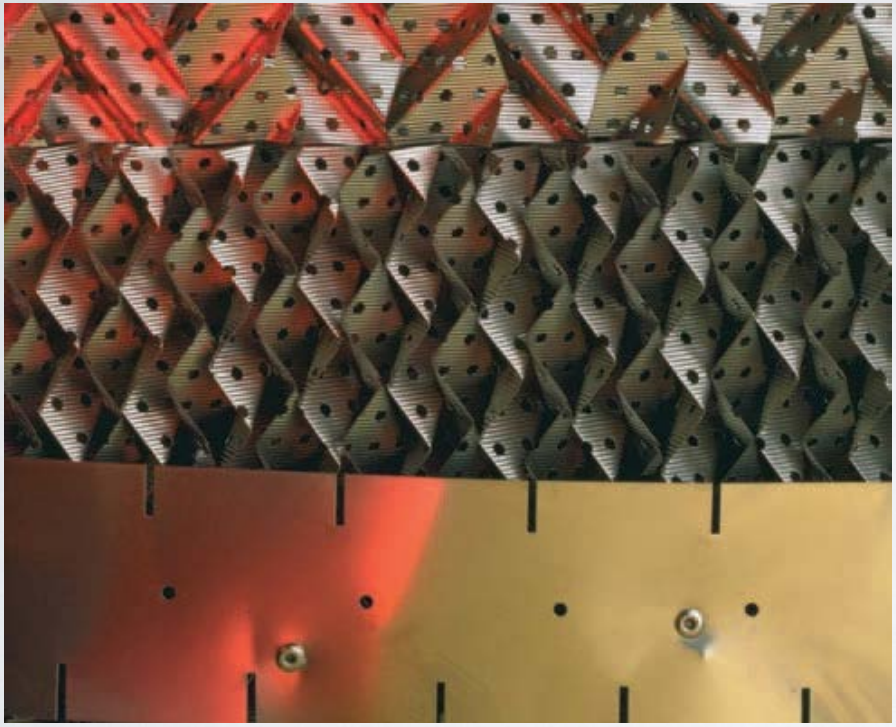
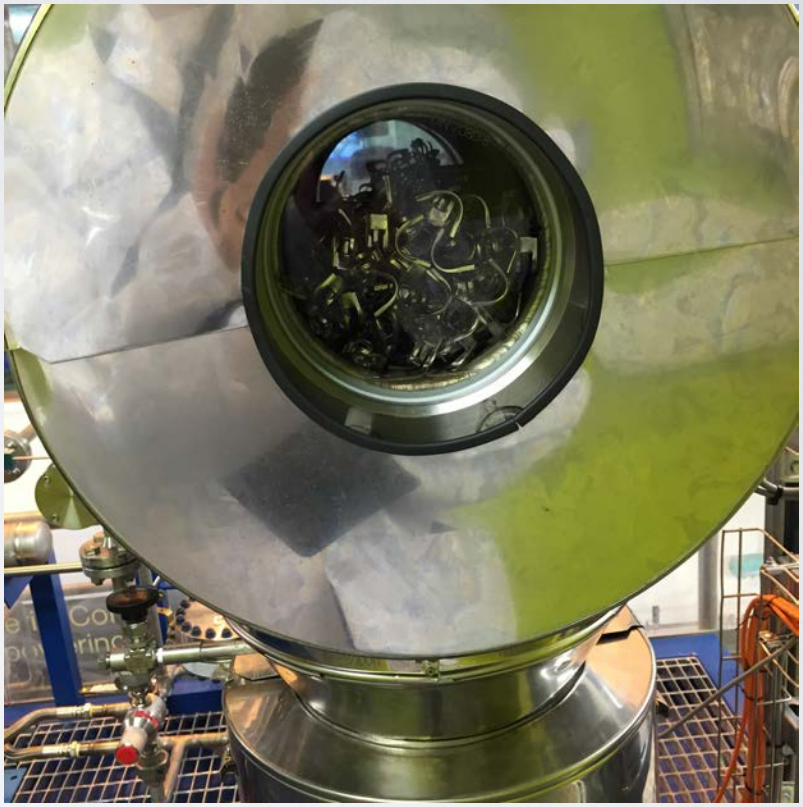


FIGURE 10.6-3. *Packed tower flows and characteristics for absorption.*

ABSORBER AND STRIPPER



Structured



Random

Both give:

- high surface area between liquid and gas
- continuous mixing of liquid and gas and they flow through column
- high fraction of "void" space so that the pressure drop is low

TWO BASIC PRINCIPLES

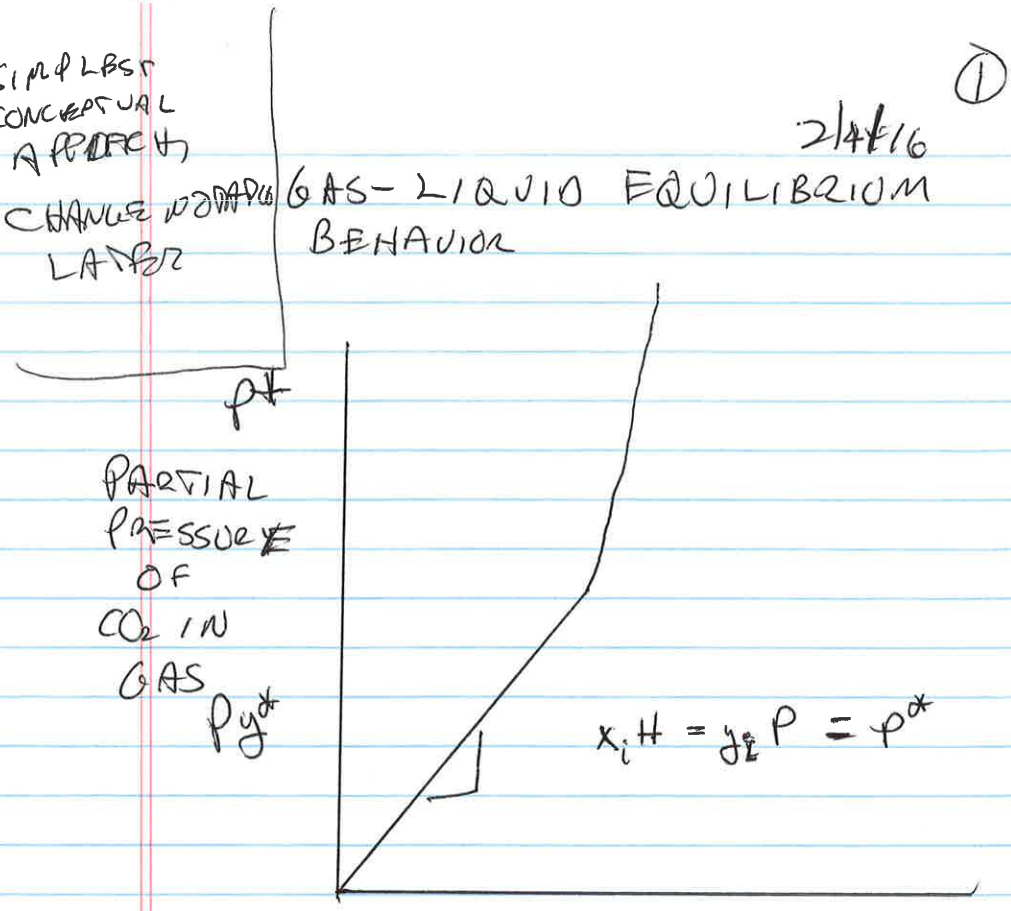
- Conservation of mass
  - Keep track of chemical species and deal with reaction
- Rate of transfer equation
  - analogous to Newton's Law of cooling

2/4/16

SIMPLEST CONCEPTUAL APPROACH

CHANGE IN DRAG LATER

GAS-LIQUID EQUILIBRIUM BEHAVIOR

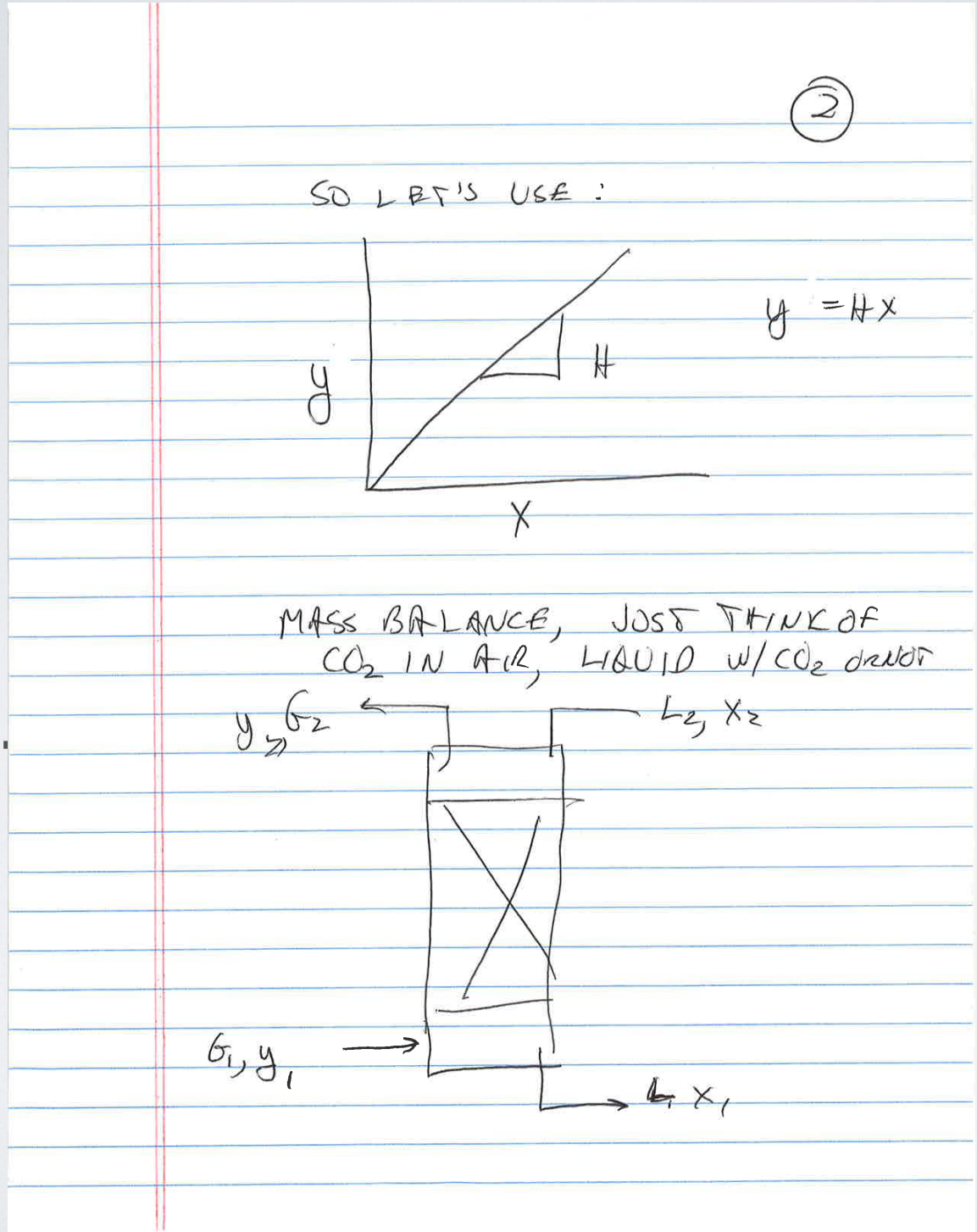


H = HENRY'S LAW COEFFICIENT

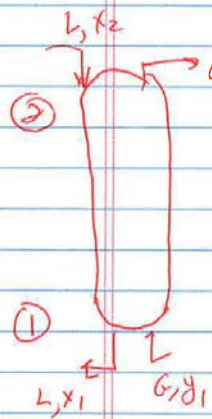
y = MOLE FRACTION OF CO_2 IN GAS.

SMALLER H ⇒ HIGHER SOLUBILITY

- Chalk…


2
SO LET'S USE:
y = Hx
y
H
X
MASS BALANCE, JUST THINK OF
CO2 IN AIR, LIQUID W/ CO2 DRNOT
y2, G2
L2, x2
G1, y1
L1, x1

MASS BALANCE (MOLES)



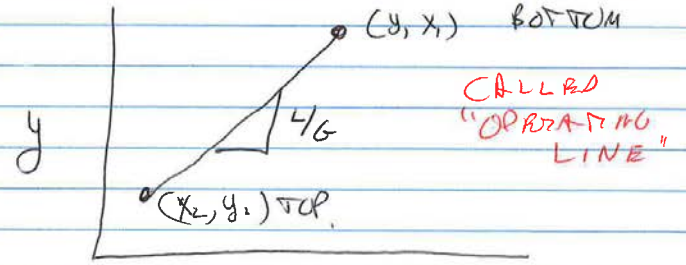
$G_1 + L_2 = G_2 + L_1$

COULD BE A CONST, $L_1 = L$, $G_1 = G$

$CO_{2,IN} = CO_{2OUT}$ COMPONENT MASS BALANCE..

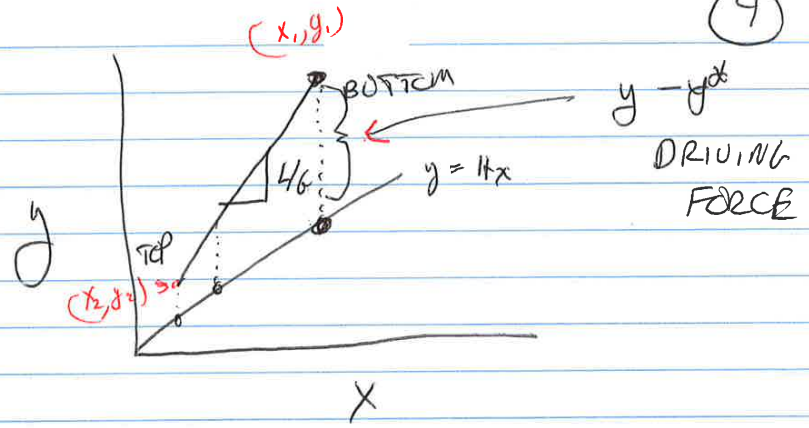
$y_1 G + L x_2 = y_2 G + L x_1$

$(y_1 - y_2) G = (x_1 - x_2) L$

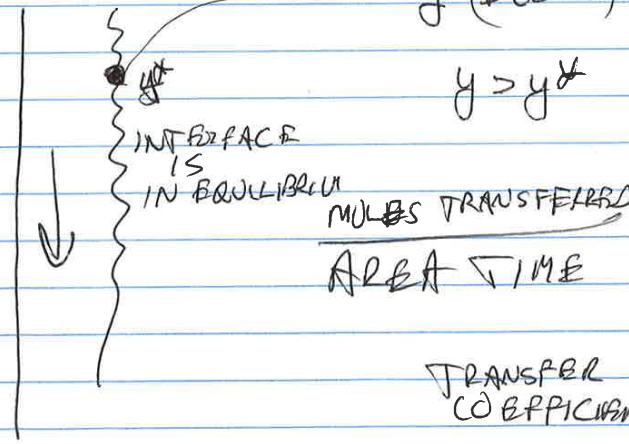


CALLED "OPERATING LINE"

$\frac{L}{G} = \left(\frac{y_1 - y_2}{x_1 - x_2}\right)$



ALL ALONG COLUMN, CONCENTRATION IN GAS OF CO_2 IS > EQUILIBRIUM VALUES, SO CO_2 GOES INTO LIQUID.

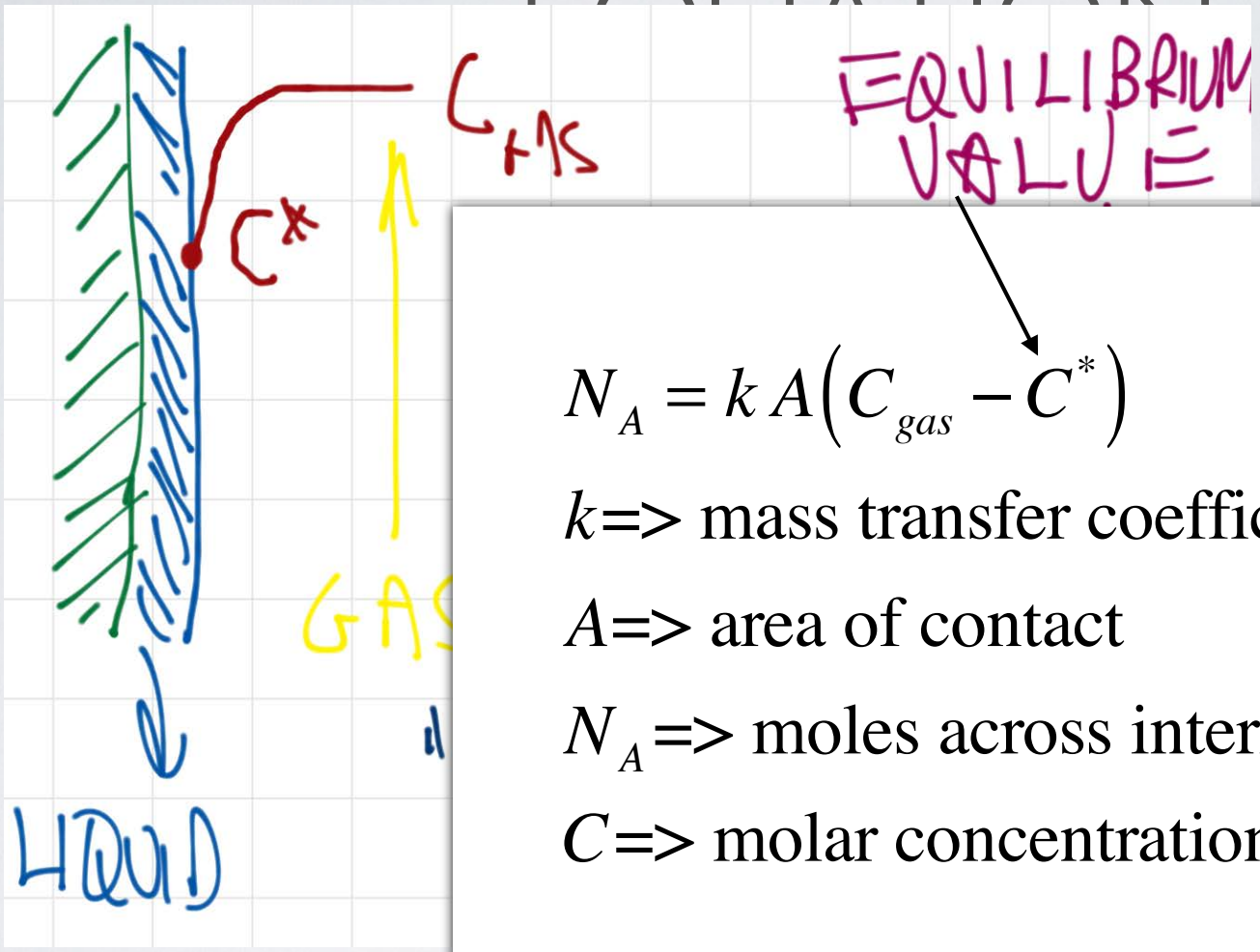


$$\frac{\text{MOLES TRANSFERRED}}{\text{AREA} \cdot \text{TIME}} =$$

TRANSFER COEFFICIENT × DRIVING FORCE

$$N_{CO_2} = k_G (y - y^*)$$

MASS TRANSFER RATE EQUATION



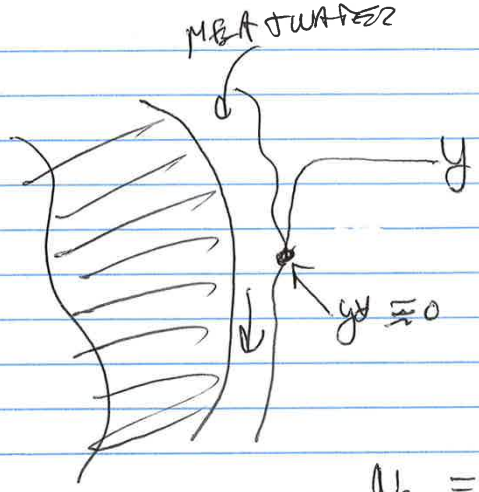
$$N_A = k\,A\left(C_{gas} - C^*\right)$$

k=> mass transfer coefficient

A=> area of contact

N_A=> moles across interface/time

C=> molar concentration of CO_2 in gas



$CO_2 + N_2$

$$N_{CO_2} = k_{co}(y - y^*) \cong k_{co}\, y$$

THINGS ARE CHANGING.
HOW DO WE DEAL WITH THIS?

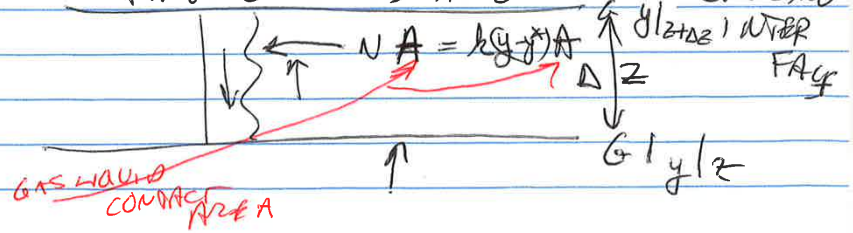
TAKE "CONCEPTUALLY" A

"DIFFENTIAL SLICE"

ACROSS COLUMN - (X-SECTION)

DO A MASS BALANCE

CHANGE OF MOLES IN GAS = MOLES CROSS/N



FOR OUR (DIFFERENTIAL) CONTROL VOLUME CO_2 BALANCE

$$\frac{\text{MOLES } CO_2 \text{ IN}}{\text{TIME}} - \frac{\text{MOLES } CO_2 \text{ OUT}}{\text{TIME}} = \begin{matrix}\text{RATE AT}\\ \text{WHICH}\\ CO_2\\ \text{CROSSES}\\ \text{FROM}\\ \text{GAS} \rightarrow \text{LIQUID}\end{matrix}$$

$$G_y|_z - G_y|_{z+\Delta z} = N_A \quad \begin{matrix}(\text{MOLAR}\\ \text{FLUX})\end{matrix}\left(\begin{matrix}\text{CONTACT}\\ \text{AREA}\end{matrix}\right)$$

$$G_y|_z - G_y|_{z+\Delta z} = k_y a (y - y^*) \Delta V$$

$\Delta V = A_{\text{CROSS SECTION}} \Delta z$

a = CONTACT AREA OF PACKING / VOLUME OF PACKING.

$$-G\frac{(y|_{z+\Delta z} - y|_z)}{\Delta z} = k_a(y-y^*)A_{TOWER}$$

$$-\frac{dy}{dz} = \frac{k_a}{G}(y-y^*)A_T$$

$$\int_0^z dz = -\frac{G/A_T}{k_a}\int_{y_1}^{y_2}\frac{dy}{(y-y^*)}$$

$$z = \left(\frac{G/A_T}{k_a}\right)\int_{y_1}^{y_2}\frac{dy}{(y-y^*)}$$

HEIGHT OF PACKING

INVERSE EFFICIENCY OF MASS TRANSFER

HOW HARD IS SEPARATION TO ACCOMPLISH

$$z = H_{OG} N_{OG}$$

NUMBER

IF $y^* = \text{CONST}$

$$-\int_{y_1}^{y_2} \frac{dy}{y - y^*} = \ln\left(\frac{y_1 - y^*}{y_2 - y^*}\right)$$

IF $y^* = 0$. I.E. FOR MEA REACTION W/ CO_2

$$-\int_{y_1}^{y_2} \frac{dy}{y} = \ln\left(\frac{y_1}{y_2}\right)$$

FOR DXB 2 IMPERIAL EXPTS,

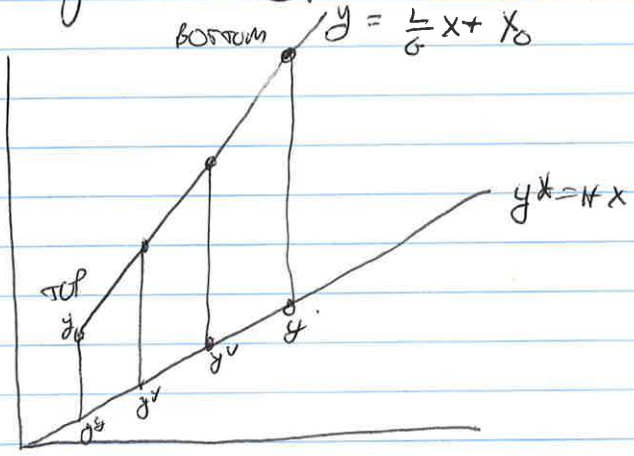
YOU CAN MEASURE y AT BEGINNING MIDDLE END SOME MORE IN BETWEEN.

YOU KNOW "Z", CONCENTRATIONS GIVE N_{OG}

DETERMINE

$\Rightarrow$ H_{OG}.

IF y^* IS NOT CONSTANT



$$y - y^* = y(x) - Hx$$

SAME X

IF WE HAVE A y_1 WHICH X DO WE NEED:

$$y = \frac{L}{G}x + \left(y_2 - \frac{L}{G}x_2\right)$$

SOLVE FOR X

$$x = \frac{G}{L}(y - y_2) + x_2$$

SO THE INTEGRAL IS:

$$= -\int_{y_1}^{y_2} \frac{dy}{y - Hx} =$$

$$= -\int_{y_1}^{y_2} \frac{dy}{y - H\left(\frac{G}{L}(y - y_2) + x_2\right)}$$

$$A = \frac{L}{HG}$$

EASIER TO ABSORB IF A IS MADE LARGER —

$$= -\int_{y_1}^{y_2} \frac{dy}{\left(1 - \frac{1}{A}\right)y + \frac{y_2}{A} + Hx_2}$$

$$= -\frac{1}{\frac{1}{A} - 1} \ln\left[\frac{A(Hx_2 - y_2) + (y_1 - y_2)}{A(Hx_2 - y_2)}\right]$$

$$= \frac{\ln\left[\frac{(y_1 - Hx_2)}{(y_2 - Hx_2)}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right]}{1 - 1/A}$$

ABSORPTION FACTOR CHART

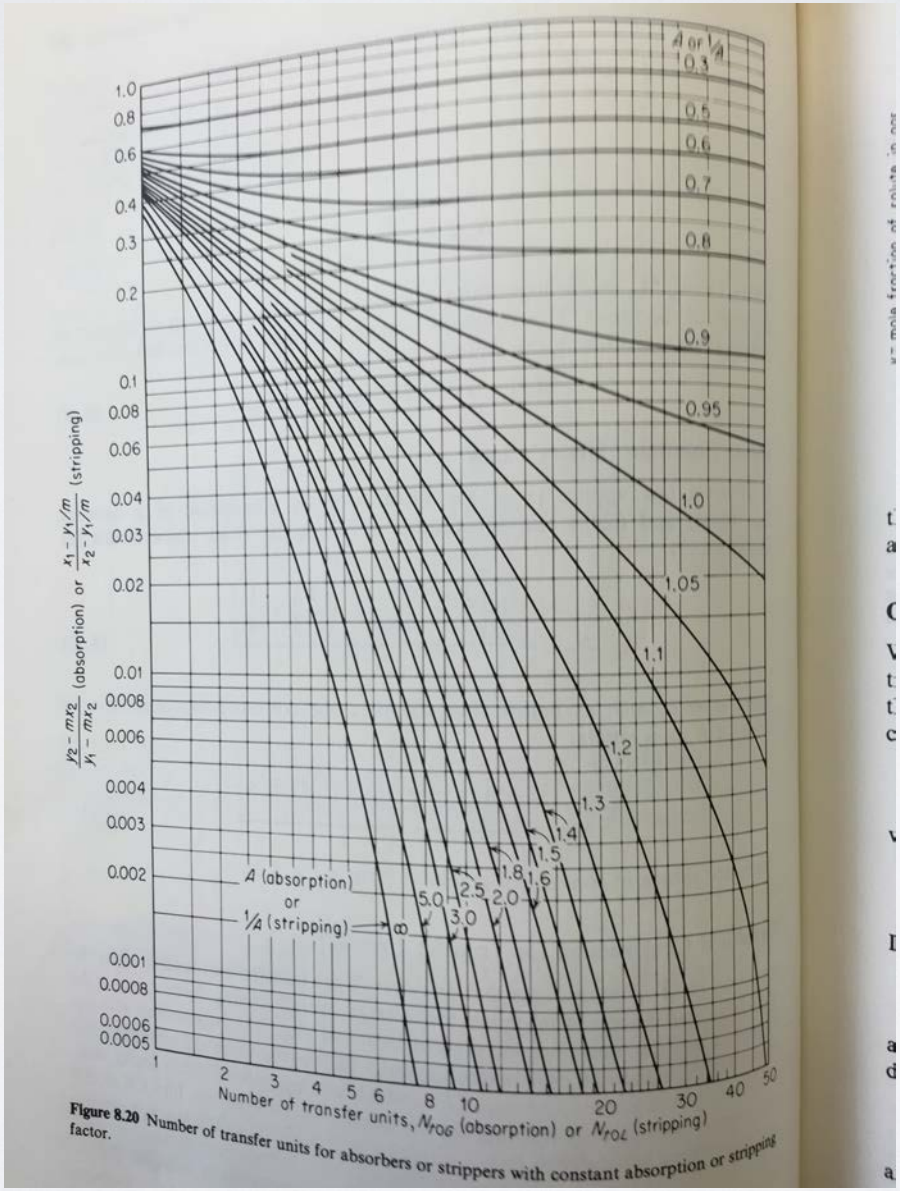
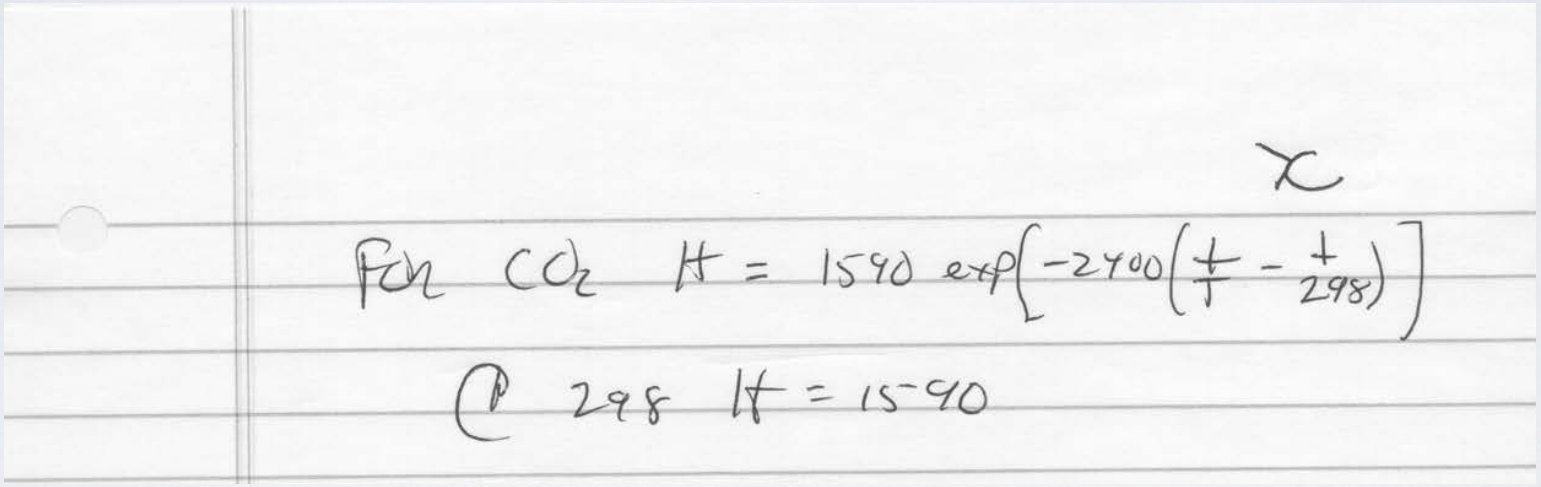


Figure 8.20 Number of transfer units for absorbers or strippers with constant absorption or stripping factor.

HENRY'S LAW FOR CO2 IN WATER



FOR SIA COLUMN.
DON'T INTEGRATE FORMULAE...

GO TO

$$-\frac{dy}{dz} = \frac{k_G}{G}(y - y^*)A$$

$$k_G = \frac{\left(\frac{G}{A}\right)\frac{1}{(y-y^*)}\left(-\frac{dy}{dz}\right)}{a_v}$$

a_v = PROPERTY OF "PACKING"
350 m^2/m^3

$$\frac{dy}{dz} = \frac{\Delta y}{\Delta z}$$

Δy ← MEASURE AT TWO "STAGES"

Δz ← DISTANCE BETWEEN MEASUREMENTS

$y^* = 0$, y

$$\frac{G}{A} = \frac{\text{GAS FLOWRATE}}{\text{CROSS AREA OF TOWER.}}$$

NOW SWITCH TO NOTATION FOR THE PILOT PLANT.

YOU WANT TO CALCULATE "K_G"

$$K_G = \frac{\frac{G}{P(y_a - y_a^*)}\frac{dy_a}{dz}}{a_v}$$

K_G (=] $\frac{\text{KMOLES}}{m^2\ hr\ kPa}$

$G = \frac{\text{KMOLES}}{\text{HOUR} \cdot m^2} = \frac{G}{A_T}$ SLOPE

$P =$ TOTAL PRESSURE ~ 1 ATM ~ 101.3 KPa

$a_v = \frac{350\ m^2}{m^3}$

(10)

$$\frac{dY_A}{dz} = \frac{\Delta Y_A}{\Delta z}$$

COULD BE

$\Delta z = 1.37\ m$ BETWEEN MEASUREMENT POINTS.

$$Y = \frac{y}{1-y}$$

$y_{BOTTOM} \sim .05$

$y_{NEXT\ POINT} \sim .03$

1.37 m.

$Y_B = .052$

$Y_N = .031$

$$K_G = \frac{\left(119\ \frac{K\ MOLE}{Hr\ m^2}\right)\left(\frac{.052-.031}{1.37\ m}\right)}{\frac{101.3\ KPa\ (.04-0)}{350/m}}$$

$$K_G = .0013\ \frac{KMOLE}{m^2\ h\ KPa}$$

FOR THE LABORATORY ABSORBER.

DIDN'T WORK LAST YEAR,
SO I AM GUESSING SOME...

$$Z = \frac{G/A_T}{k_G a} \int_{y_i}^{y_c} \frac{dy}{(y - y^*)}$$

H_{OG} N_{OG}

$$N_{OG} = \frac{1}{1 - \frac{mV'}{L'}} \ln\left[\left(1 - \frac{mV'}{L'}\right)\left(\frac{y_B}{y_T}\right) + \frac{mV'}{L'}\right]$$

$$A_T = \frac{(80\,mm)^2 \pi}{4}$$

LIQUID FLOW, ~ 150 l/m.

CO_2 FLOW ~ 5 l/MIN

AIR FLOW ~ 20 l/mm

$$Z = H_{OG} N_{OG}$$

DILUTE GAS

$$N_{OG} = \frac{1}{1-\frac{1}{A}} \ln\left[\left(1-\frac{1}{A}\right)\frac{y_B}{y_t} + \frac{1}{A}\right]$$

$$H_{OG} = \frac{V}{K_{OG} a A}$$

V = MOLAR GAS FLOW RATE

$H = .75\ m$

$V = \frac{30\ l}{MIN} \Rightarrow .014\ mol/s$

$L = 150\ l/HR \Rightarrow 2.3\ MOL/s$

$H = 1580 \qquad A = \frac{2.3}{(1580)(.0136)}$

$A = .11$

(13)

$$A_{oc} = \frac{A}{N\delta_c} = \frac{.75}{N\delta_c}$$

$A = 50 cm^2$

$$\ell_{ca} = \frac{U/A}{A_{oc}}$$