CBE 30399

2/11/16

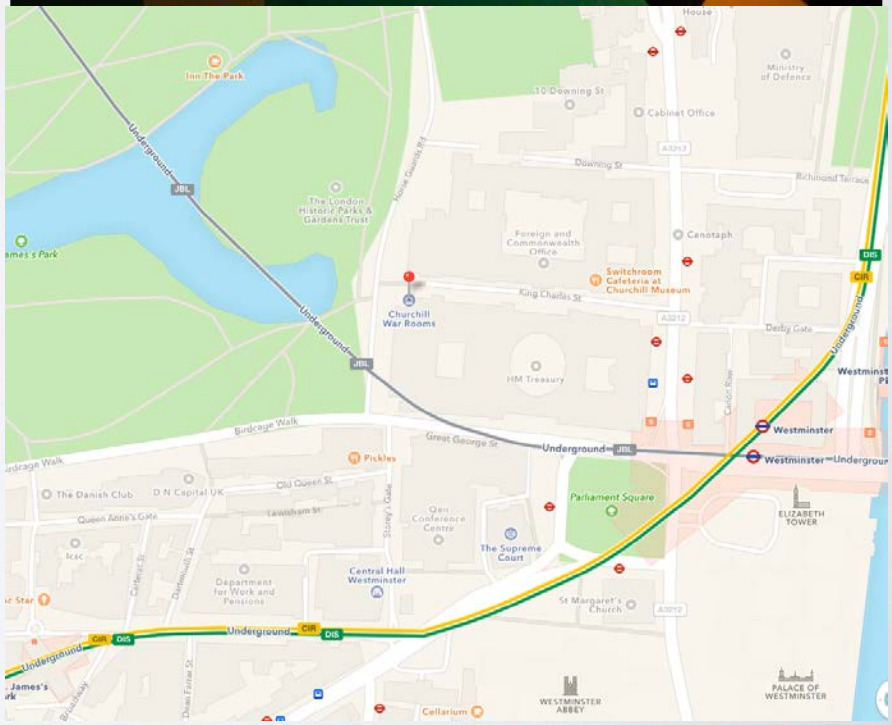
TOPICS

- Something about… London!
- Continuation of discussion of gas absorption

PROFESSOR MCCREADY'S DON'T MISS LIST!

- Cabinet War Rooms and Churchill Museum

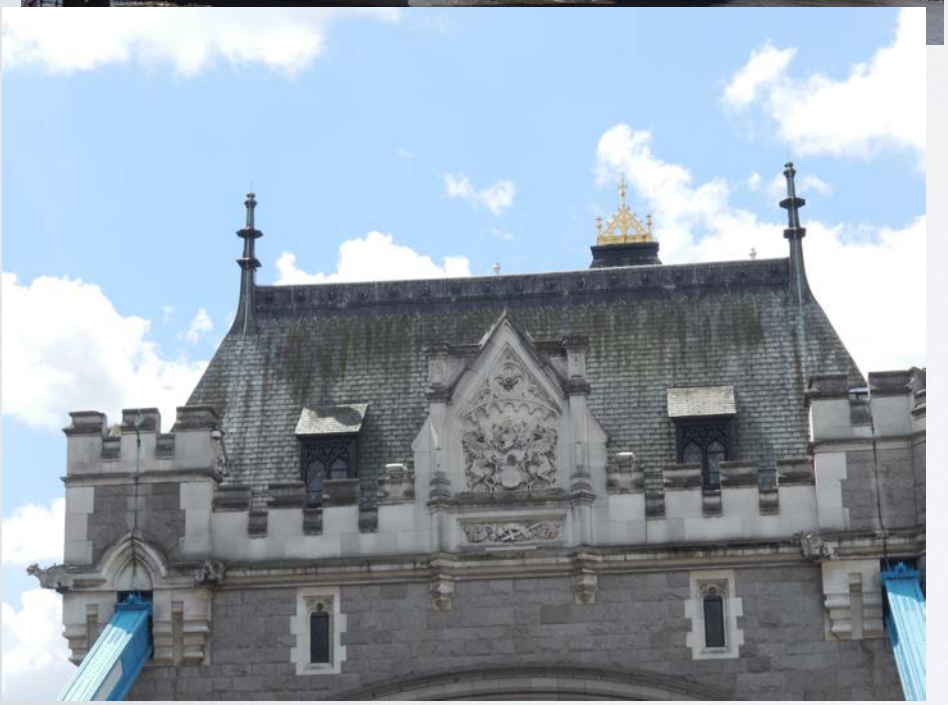
CABINET WAR ROOMS



PROFESSOR MCCREADY'S DON'T MISS LIST!

- Cabinet War Rooms and Churchill Museum
- Tower Bridge tour

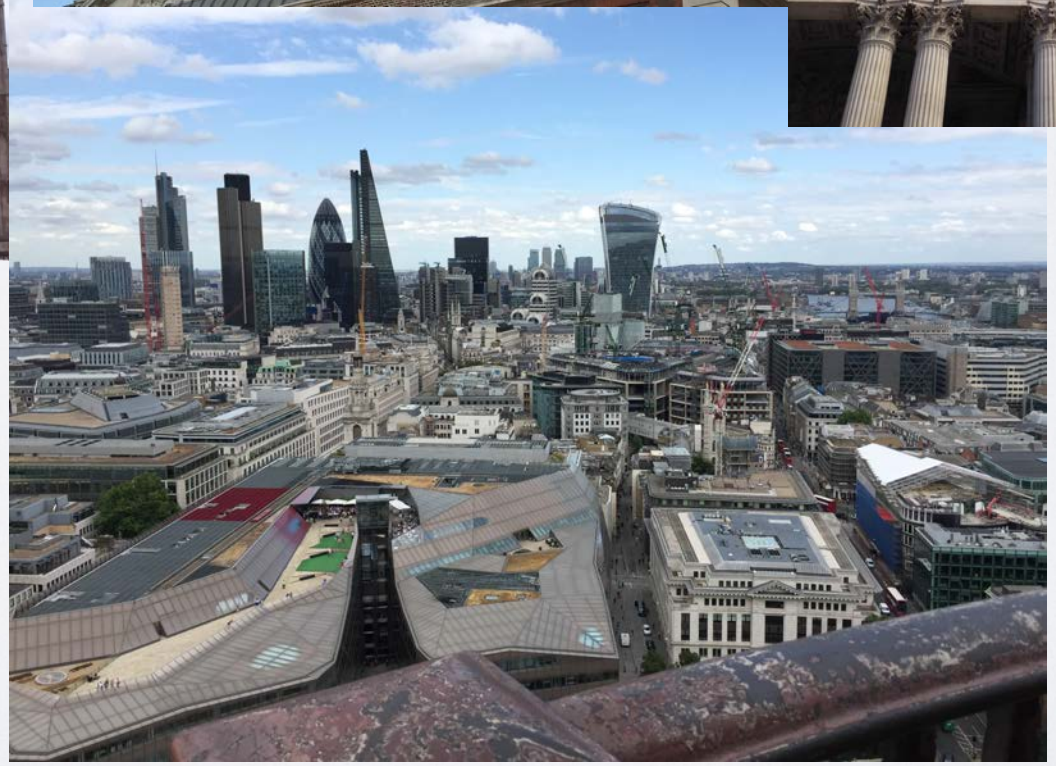
TOWER BRIDGE



PROFESSOR MCCREADY'S DON'T MISS LIST!

- Cabinet War Rooms and Churchill Museum
- Tower Bridge tour
- Westminster Abby (tour and go to Mass there)
- St Paul's Cathedral (tour, climb to the top!)

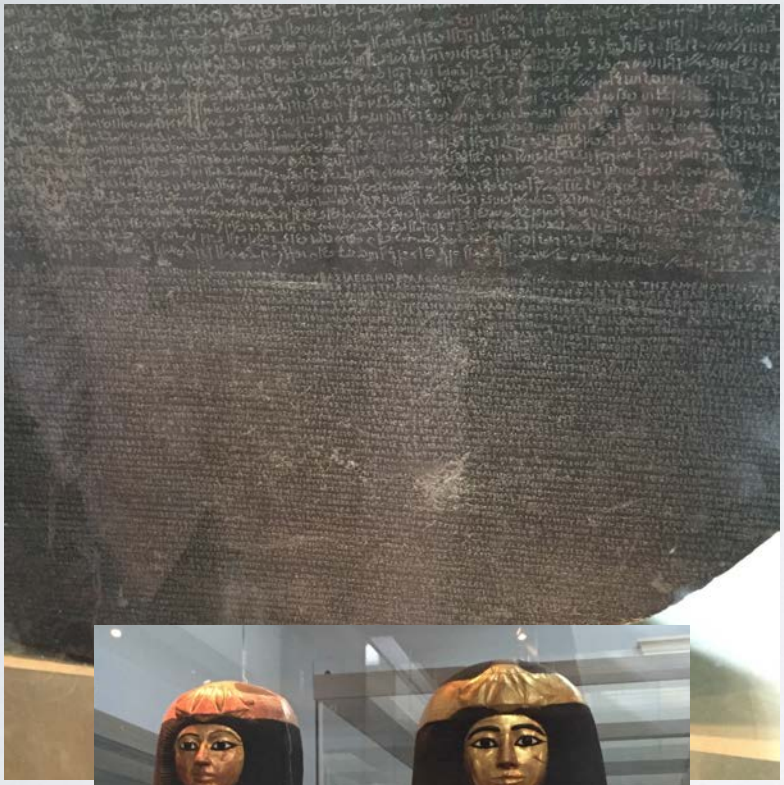
WESTMINSTER ABBY/ST.PAUL'S CATHEDRAL

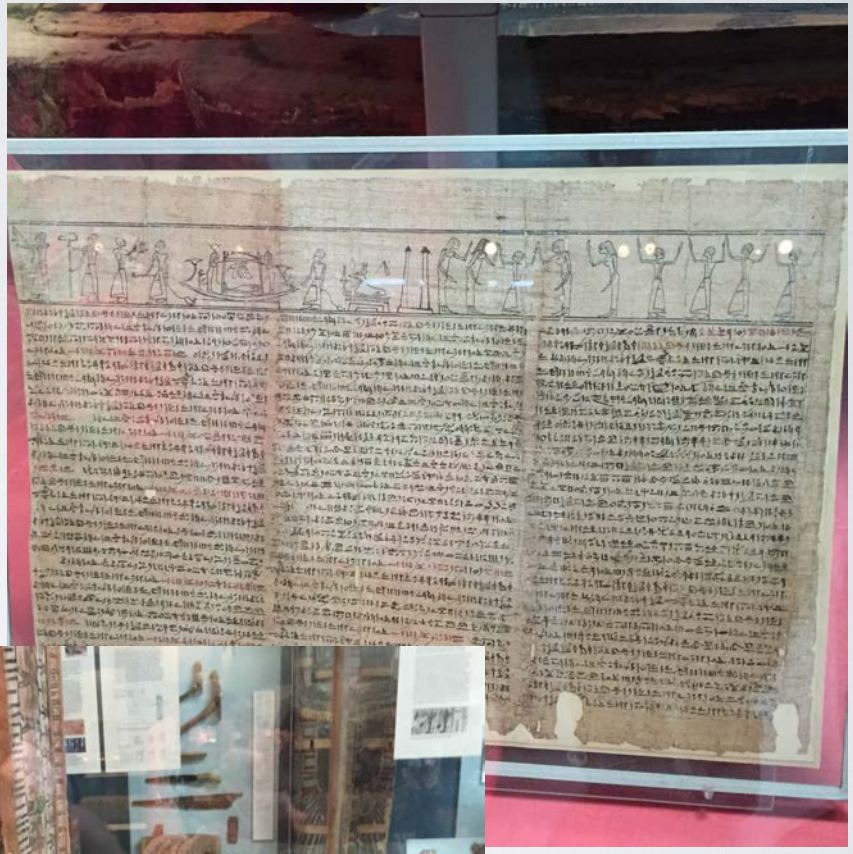


PROFESSOR MCCREADY'S DON'T MISS LIST!

- Cabinet War Rooms and Churchill Museum
- Tower Bridge tour
- Westminster Abby (tour and go to Mass there)
- St Paul's Cathedral (tour, climb to the top!)
- British Museum

BRITISH MUSEUM





ASSUMING YOU SEE THESE OTHER PLACES ON OUR TOURS

- Windsor Castle
- Tower of London
- Thames Cruise
- Bus Tour

GAS ABSORPTION/STRIPING

Imperial Flowsheet

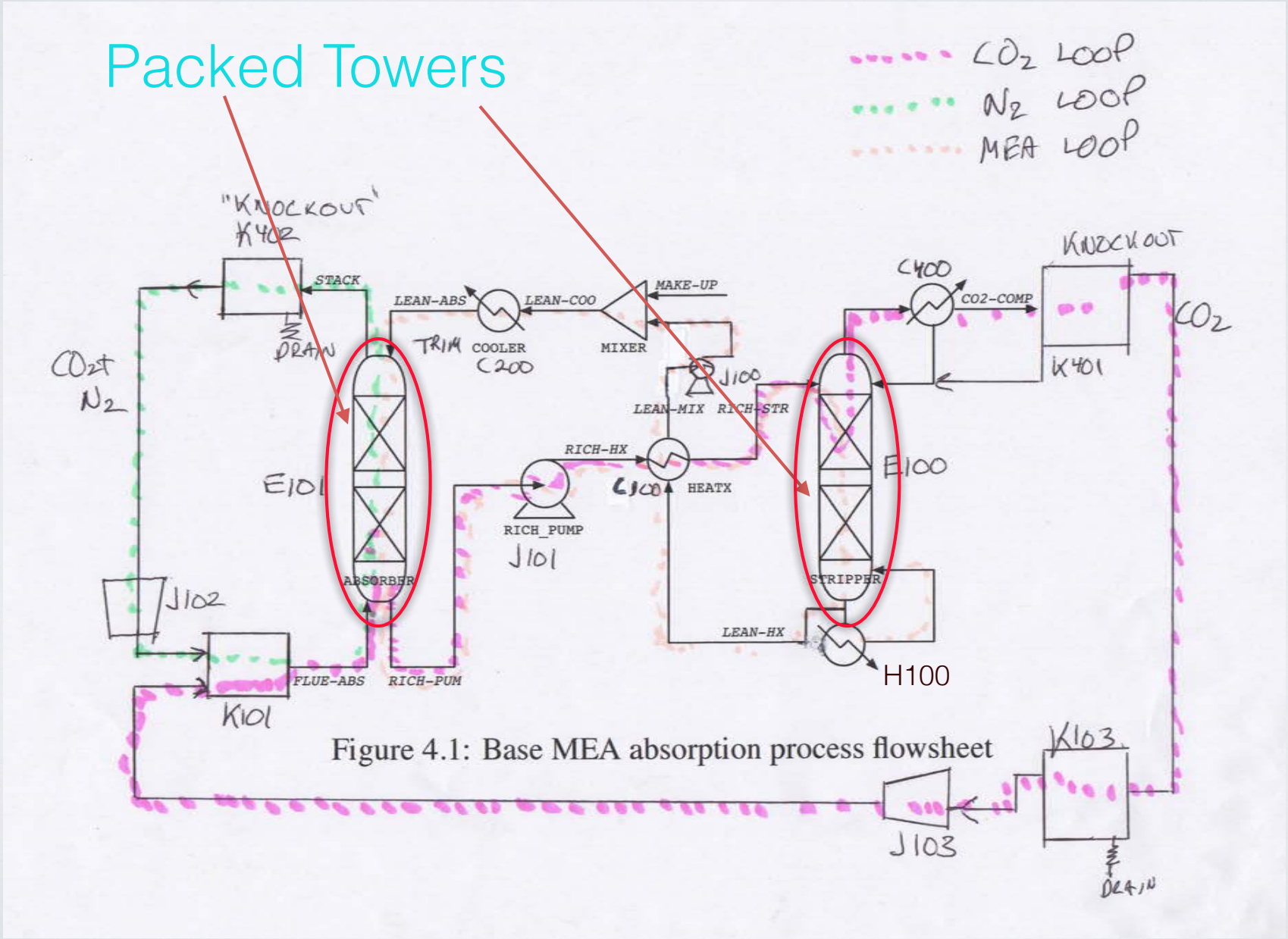


Figure 4.1: Base MEA absorption process flowsheet

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

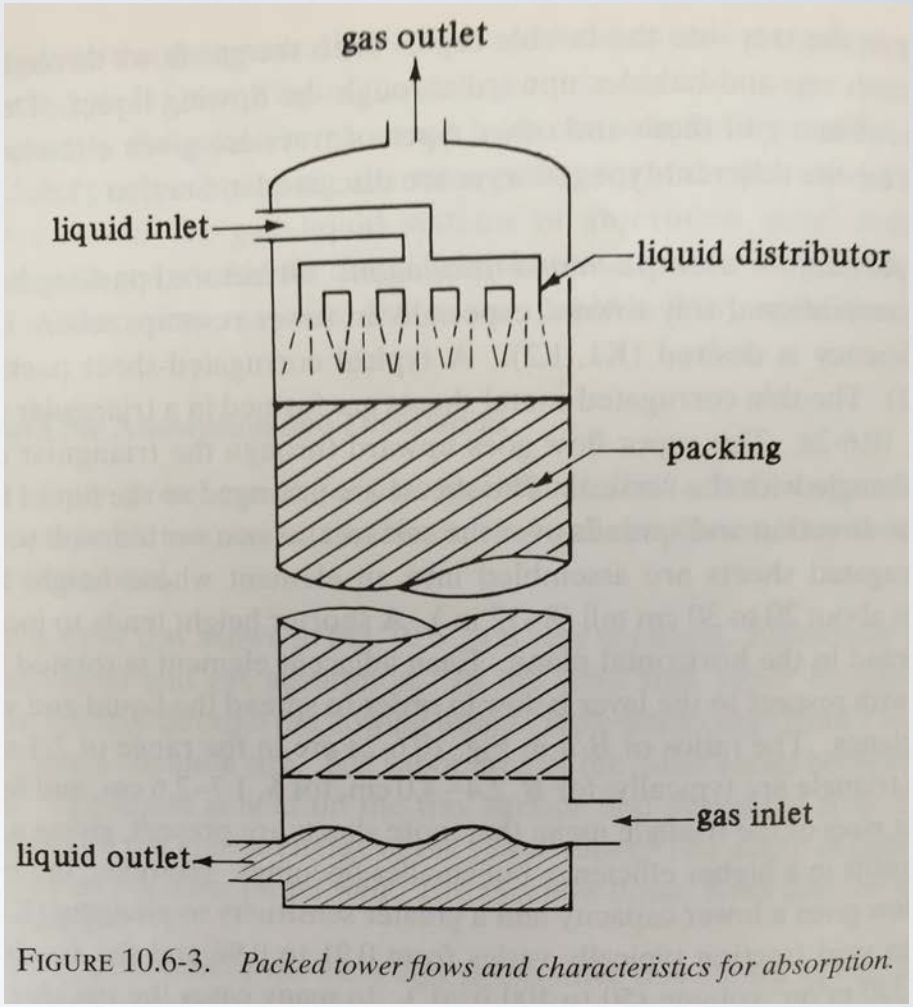
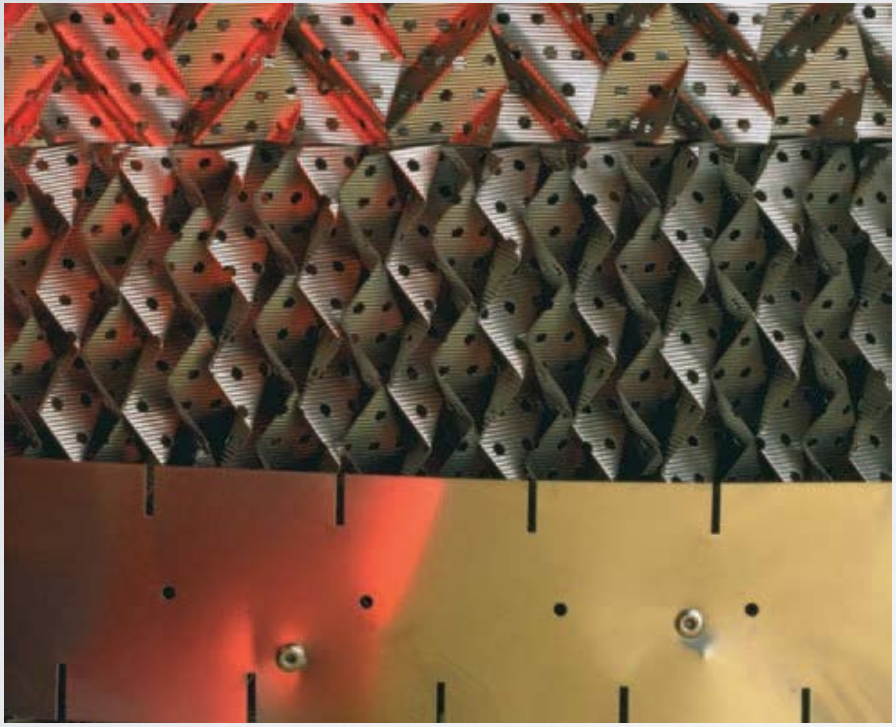
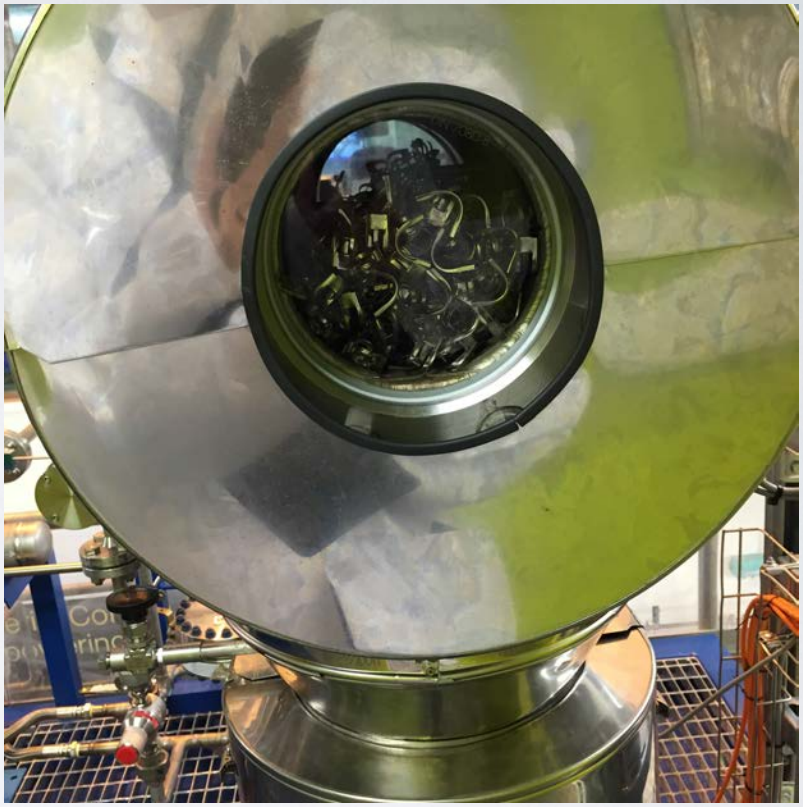


FIGURE 10.6-3. *Packed tower flows and characteristics for absorption.*

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

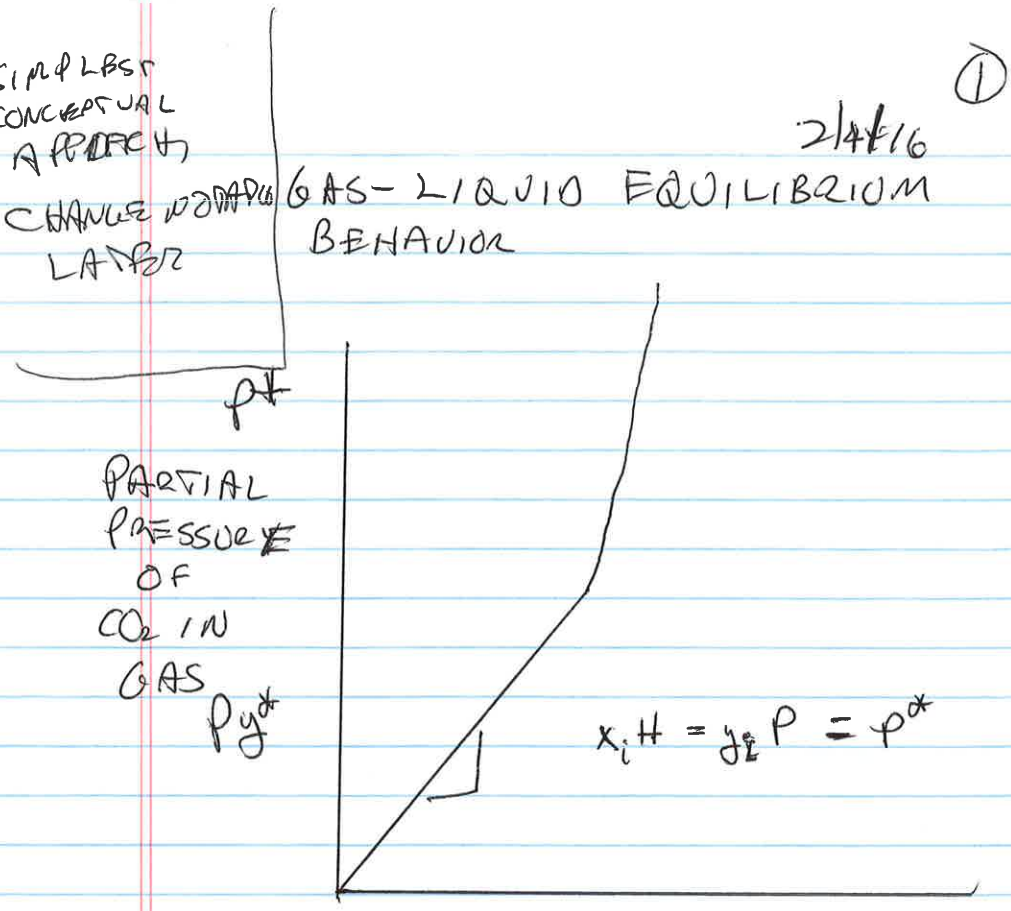
- Conservation of mass
  - Keep track of chemical species and deal with reaction
- Rate of transfer equation
  - analogous to Newton's Law of cooling

2/4/16

SIMPLEST CONCEPTUAL APPROACH

CHANGE IN DRAG LATER

GAS-LIQUID EQUILIBRIUM BEHAVIOR

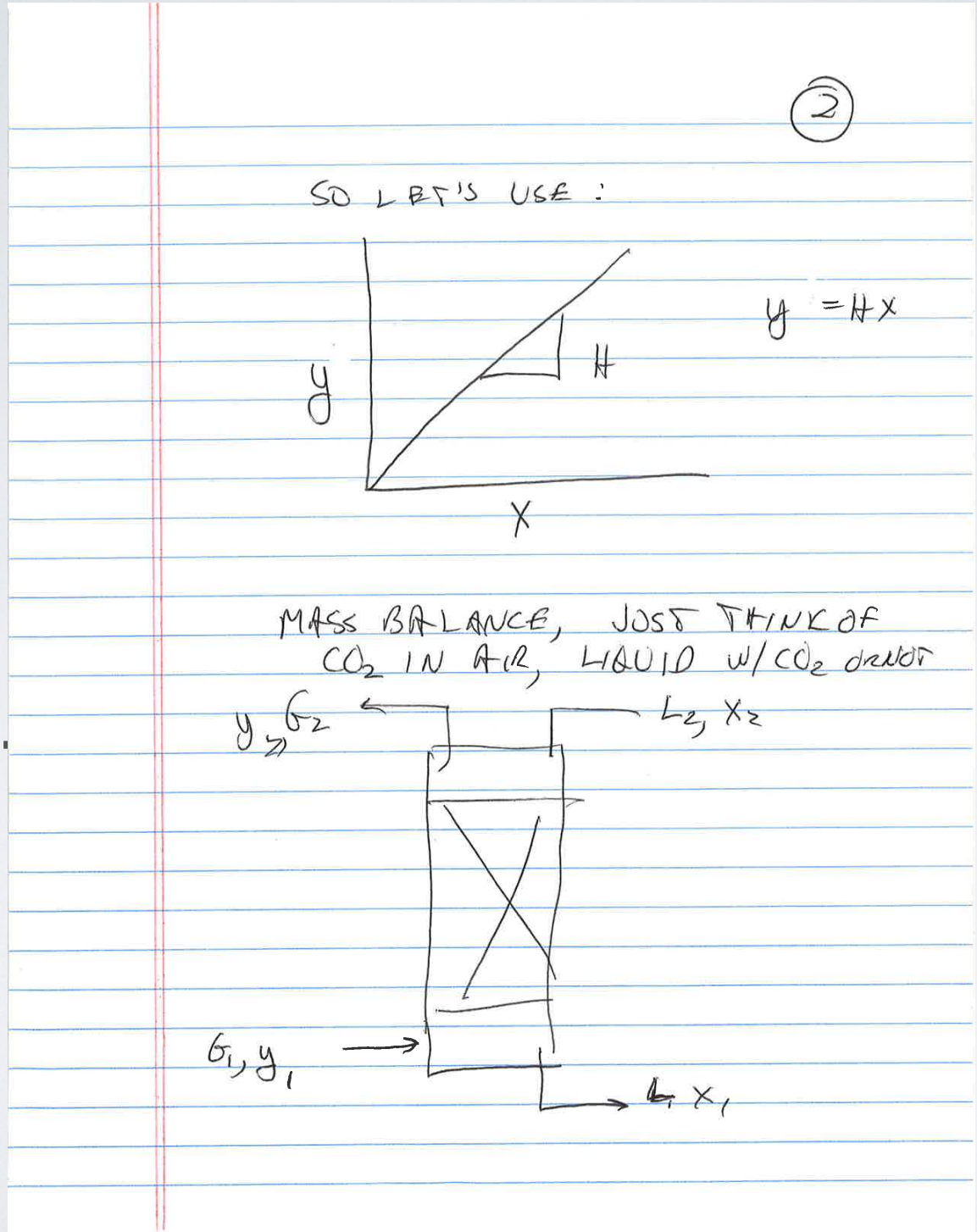


H = HENRY'S LAW COEFFICIENT

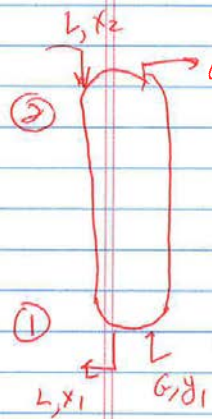
y = MOLE FRACTION OF CO_2 IN GAS.

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)



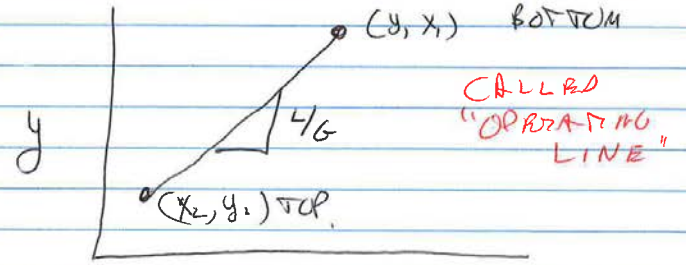
$G_1 + L_2 = G_2 + L_1$

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

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

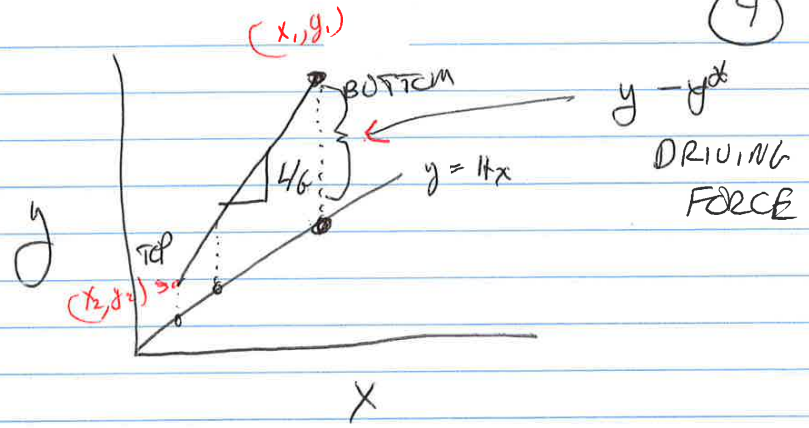
$y_1 G + L x_2 = y_2 G + L x_1$

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

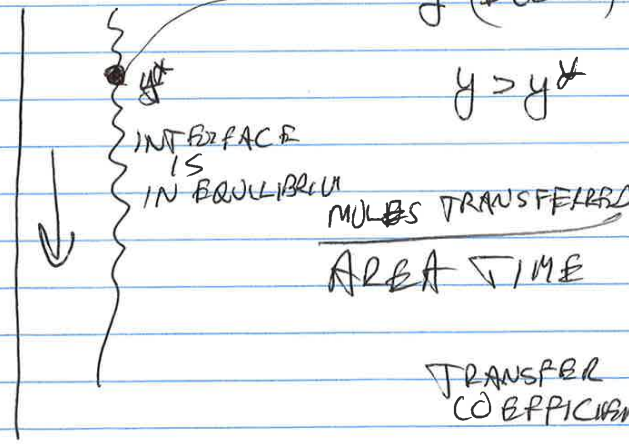


CALLED "OPERATING LINE"

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



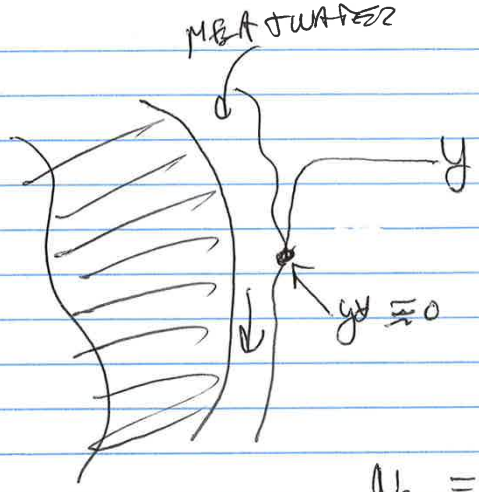
ALL ALONG COLUMN, CONCENTRATION IN GAS OF CO_2 IS > EQUILIBRIUM VALUES, SO CO_2 GOES INTO LIQUID.



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

TRANSFER COEFFICIENT × DRIVING FORCE

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



$CO_2 + N_2$

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

THINGS ARE CHANGING.
HOW DO WE DEAL WITH THIS?

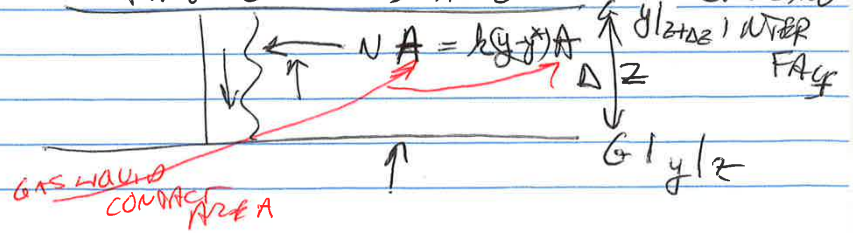
TAKE "CONCEPTUALLY" A

"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,

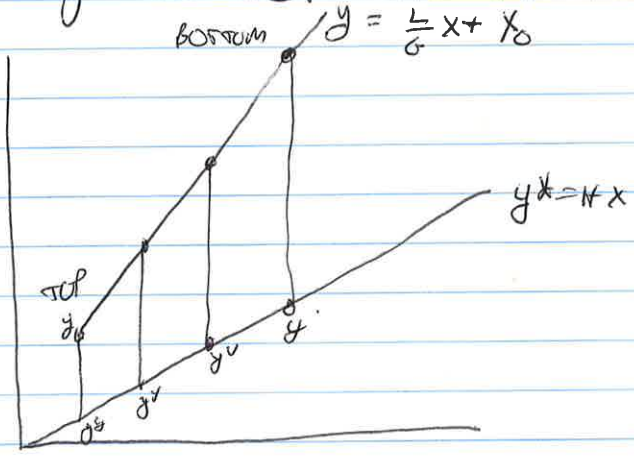
YOU CAN MEASURE y AT BEGINNING MIDDLE END SOME MORE IN BETWEEN.

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

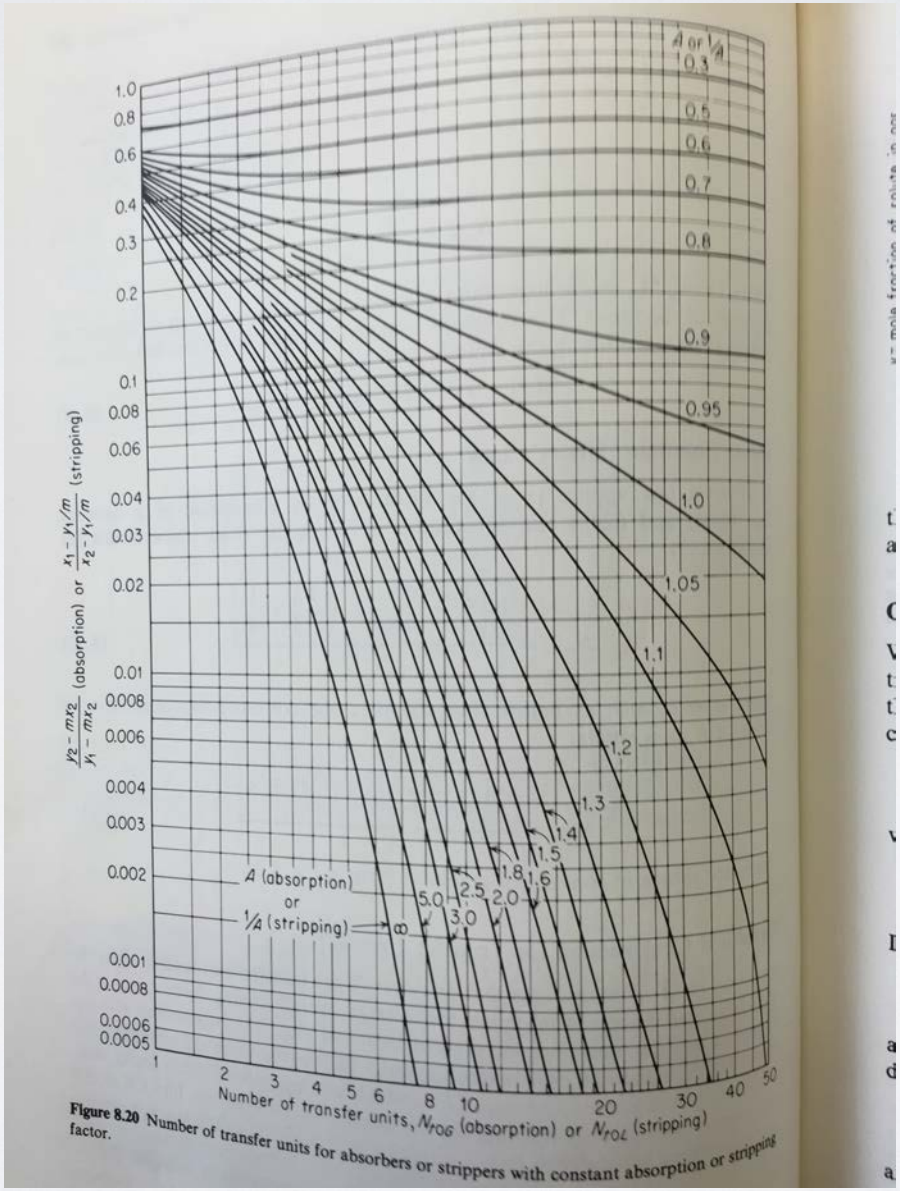
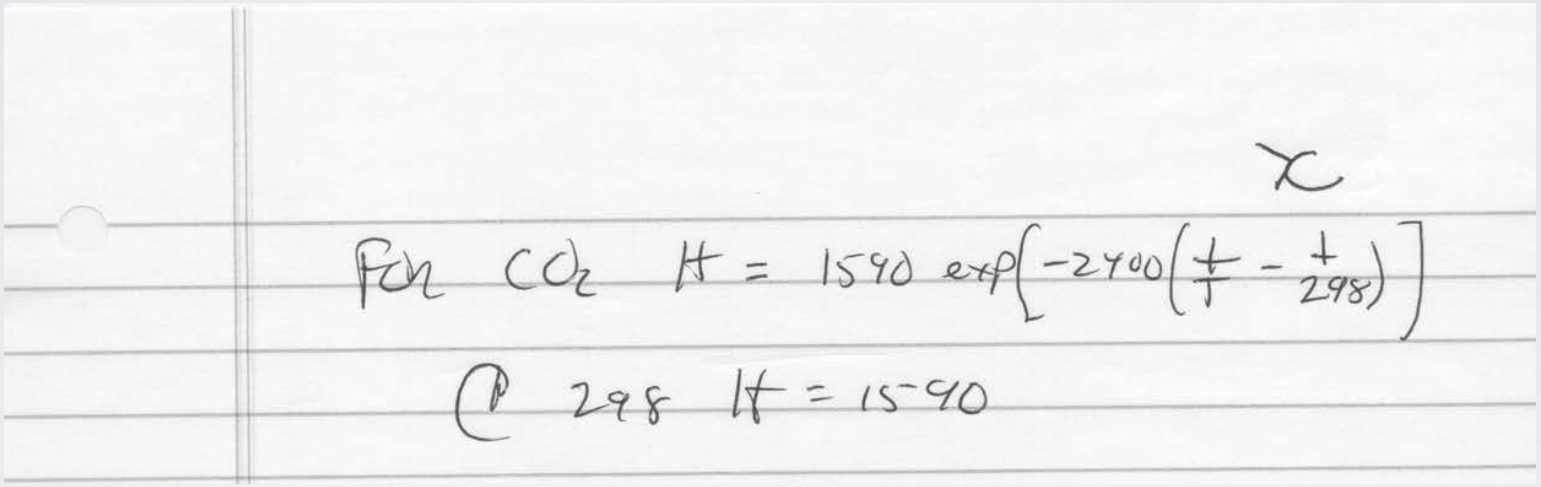


Figure 8.20 Number of transfer units for absorbers or strippers with constant absorption or stripping factor.

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)

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

$A = 50 cm^2$

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

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2/18/16

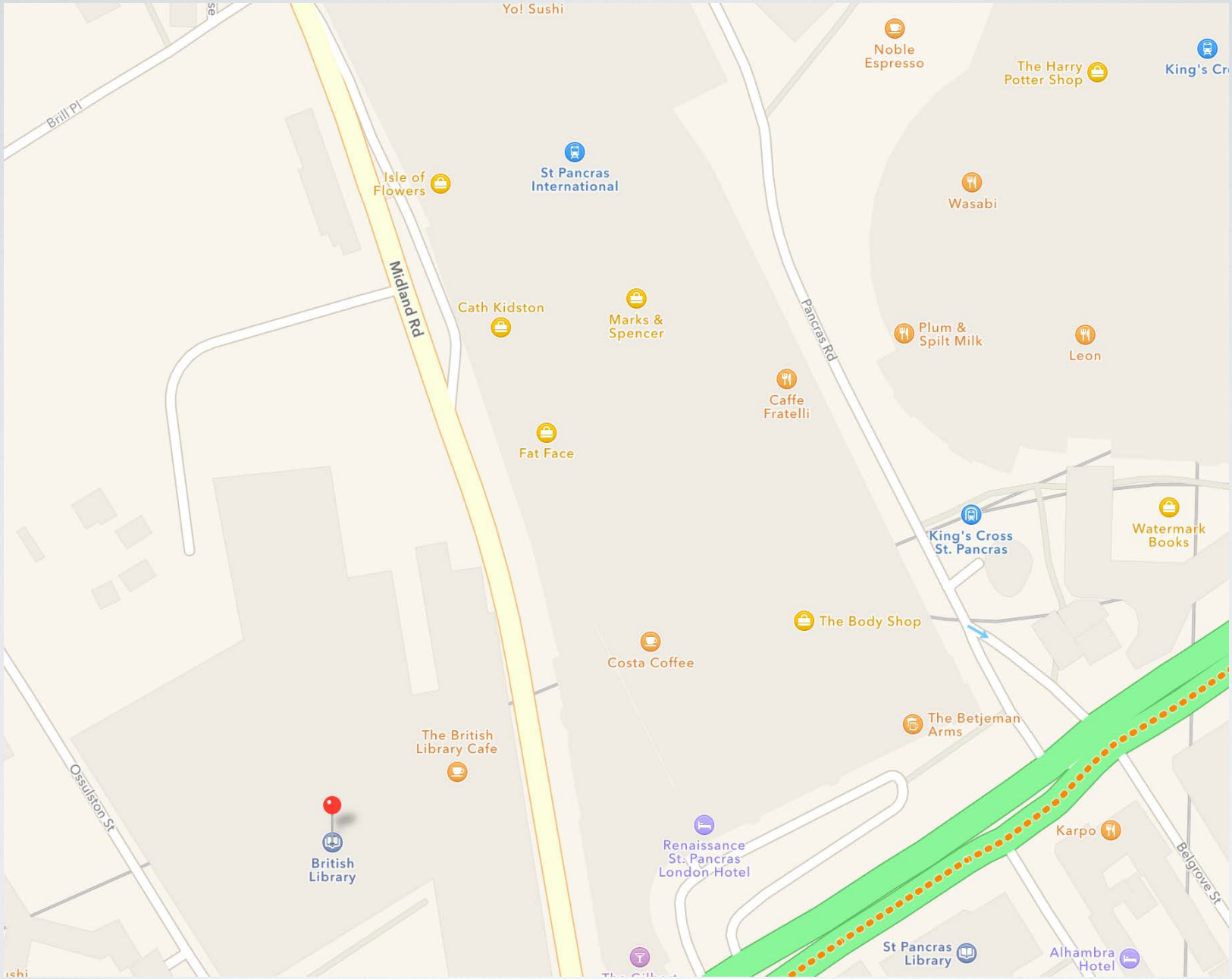
TOPICS

- Something about… London!
- Continuation of discussion of gas absorption

PROFESSOR MCCREADY'S TOP TO-DOS!

- If I am at Imperial and I have an hour:
  - Science Museum and/or Natural History Museum
  - Or go see the really skinny house on the District Line or the fake house-Fronts

- Look at Magna Carta at British Library
  - Origin of individual freedom?
- Right down the street from:
  - King's Cross/St. Pancras


Yo! Sushi
Noble Espresso
The Harry Potter Shop
King's Cr
Brill Pl
Isle of Flowers
St Pancras International
Wasabi
Midland Rd
Cath Kidston
Marks & Spencer
Pancras Rd
Plum & Spilt Milk
Leon
Caffe Fratelli
Fat Face
King's Cross St. Pancras
Watermark Books
The Body Shop
Costa Coffee
The Betjeman Arms
The British Library Cafe
Ossulston St
British Library
Renaissance St. Pancras London Hotel
Karpo
Belgrove St
St Pancras Library
Alhambra Hotel

KING'S CROSS/ST. PANCRAS

ST. PANCRAS

- Longest escalator in the London Underground
    - At "Angel" in the Northern Line
- Or do the entire London Subway Tour
- Off of the Northern line is the Royal Air Force Museum
    - Another subject you could be interested in.
- Walking tunnel under the Thames — it must be cool!
- I think you can see 4 "Prets" from a single location standing in Trafalgar Square!
- While I am there I want to go back to the National Gallery to see the da Vinci and the Michelangelo..
    - There was a work slowdown when I was there last year!

WEST END

- Phantom of the Opera

GAS ABSORPTION/STRIPING

Imperial Flowsheet

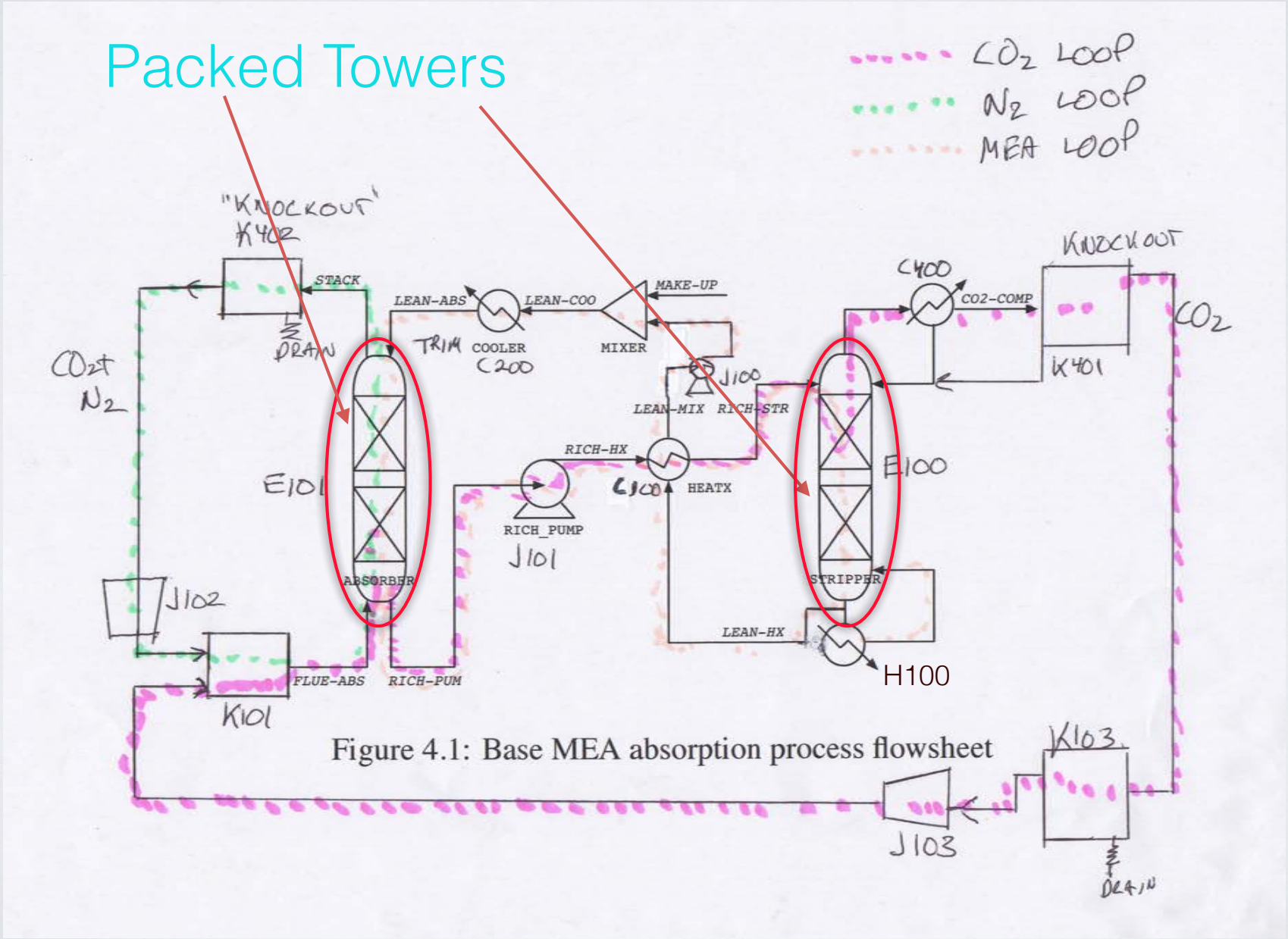
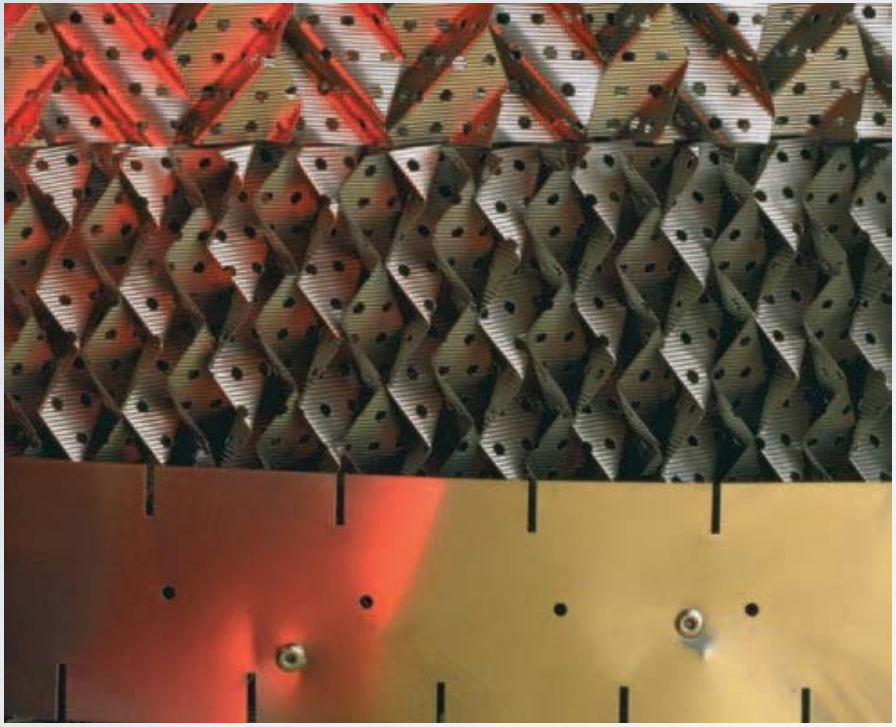


Figure 4.1: Base MEA absorption process flowsheet

ABSORBER AND STRIPPER



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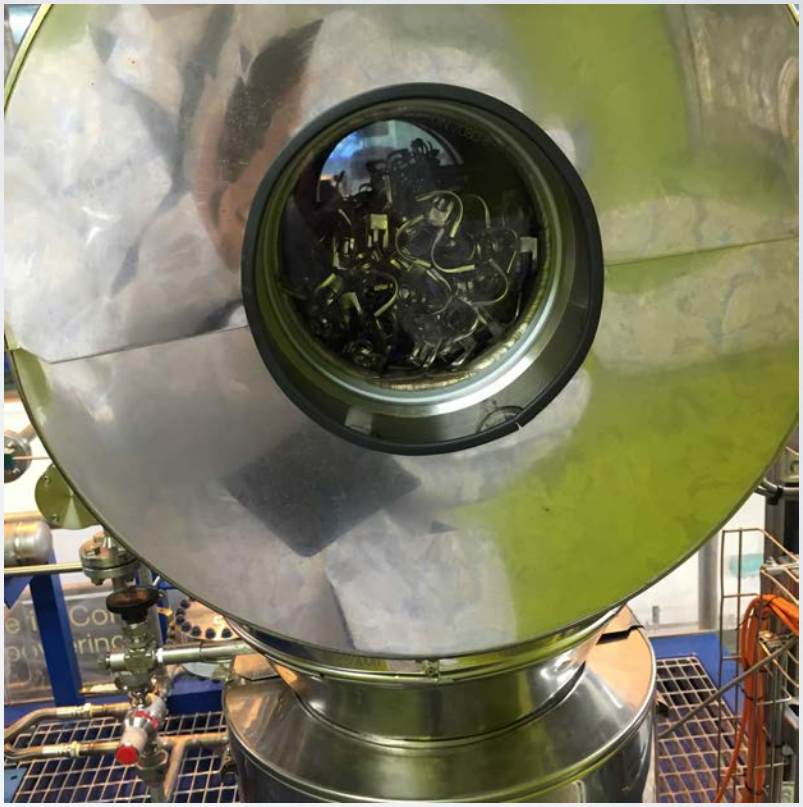


Random

Both give:

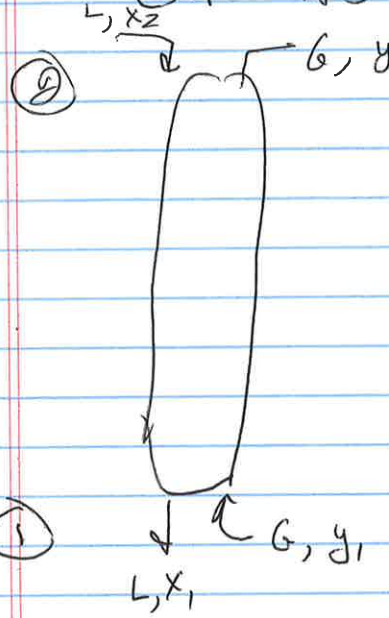
- high surface area between liquid and gas
- continuous mixing of liquid and gas and they flow through column
- high fraction of "void" space so that the pressure drop is low

TWO BASIC PRINCIPLES

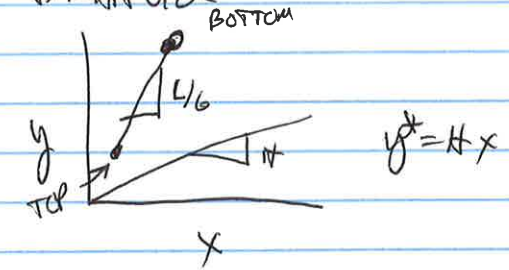
- Conservation of mass
  - Keep track of chemical species and deal with reaction
- Rate of transfer equation
  - analogous to Newton's Law of cooling

30349 2/18/16 ①

GAS ABSORPTION: LAST DAY



PHASE EQUILIBRIUM BEHAVIOR

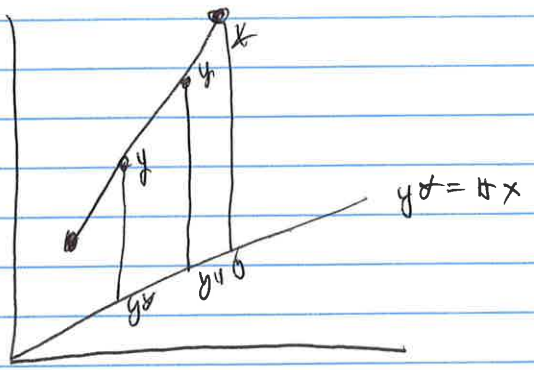


MASS BALANCE ON CO_2 GIVES "OPERATING LINE"

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

RATE AT WHICH CO_2 CROSSES FROM GAS TO LIQUID

$$N_A = k\,(y - y^*)$$



$y - y^*$ IS NOT CONSTANT

SO WE TAKE A DIFFERENTIAL SLICE OF COLUMN AND INTEGRATE

$N_G|_{z+\Delta z}$

$N_{G_y}|_z$

RATE OF CHANGE MOLES LEAVING GAS = RATE AT WHICH MOLES OF GAS CROSS INTO LIQUID

$G_y|_z - G_y|_{z+\Delta z} = a_2 a (y - y^*) \Delta V$

$$V = A_{Tower}\,\Delta z$$

$$a = \frac{\text{GAS-LIQUID CONTACT AREA}}{\text{VOLUME OF PACKING}}$$

$$-\frac{dy}{dz} = k_y a\,(y - y^*)\,A_T$$

A_T USED FOR PILOT PLANT ABSORBER DUE TO UNIT "z"

INTEGRATE

$$z = \frac{G/A_{Tower}}{k_y a}\int_{y_1}^{y_2}\frac{-dy}{y - y^*}$$

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

NEED TO EVALUATE INTEGRAL.

IF $y^* = Hx$

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

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

$A \equiv \frac{L}{HG}$ LARGE A. EASIER TO ABSORB.

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

ABSORPTION FACTOR CHART

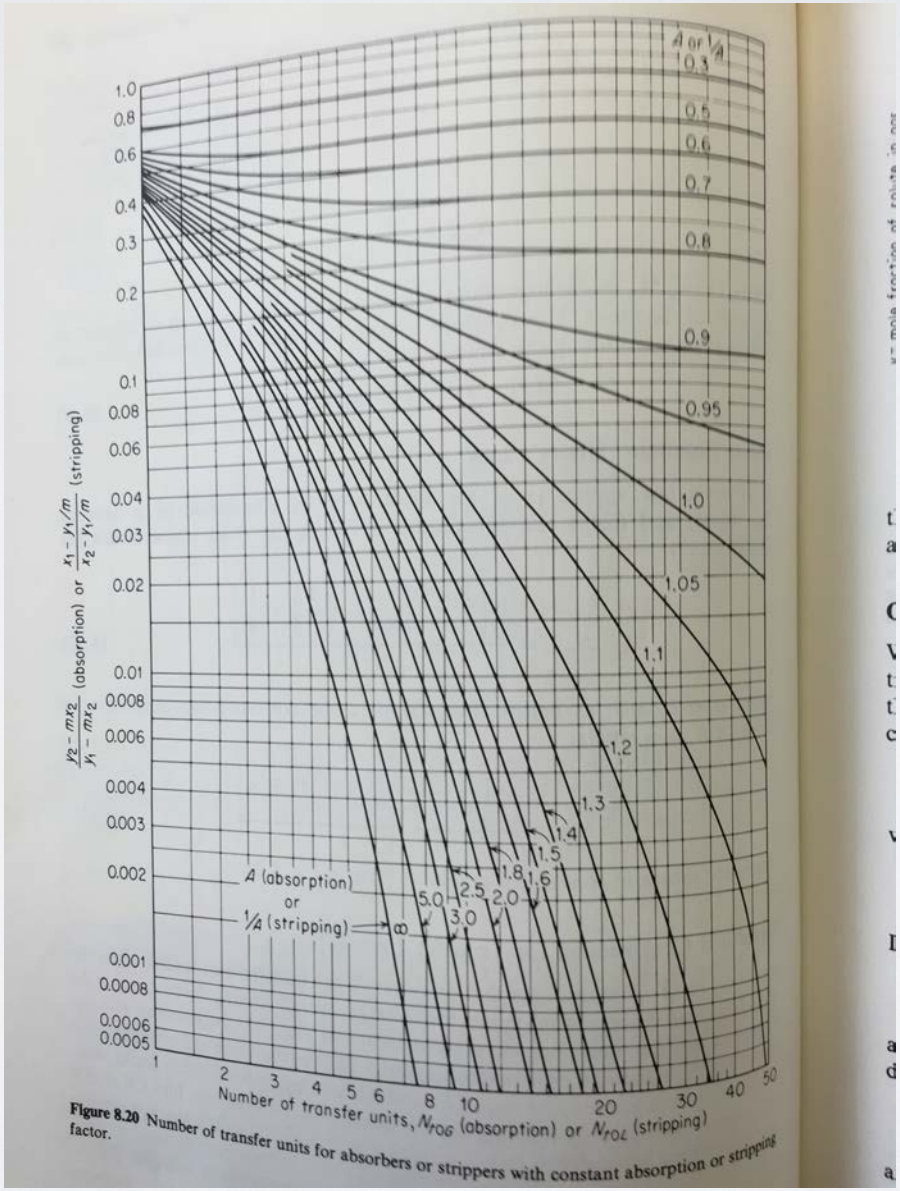


Figure 8.20 Number of transfer units for absorbers or strippers with constant absorption or stripping factor.

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

GO TO

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

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

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

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

← MEASURE AT TWO "STAGES"

← DISTANCE BETWEEN MEASUREMENTS

$y^* = 0$, y

$\frac{G}{A}$ = GAS FLOWRATE / 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 [=] $\frac{\text{KMOLES}}{m^2\ hr\ kPa}$

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

$A_T = .0415\ m^2$

P = TOTAL PRESSURE ~ 1 ATM ~ 101.3 KPa

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

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

COULD BE ↓

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

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

$y_{BOTTOM} \sim .05$

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

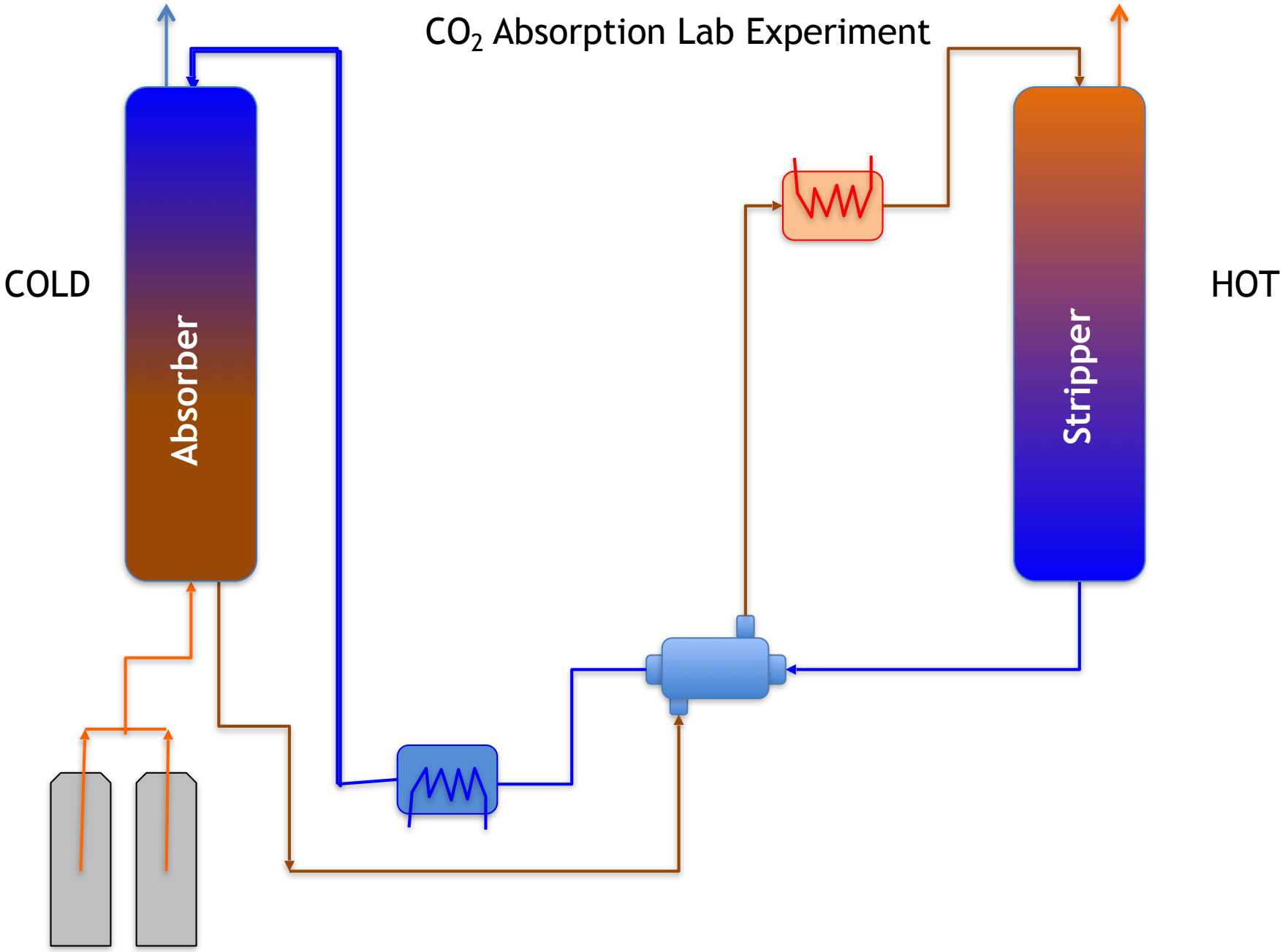
} 1.37 m.

$Y_D = .052$

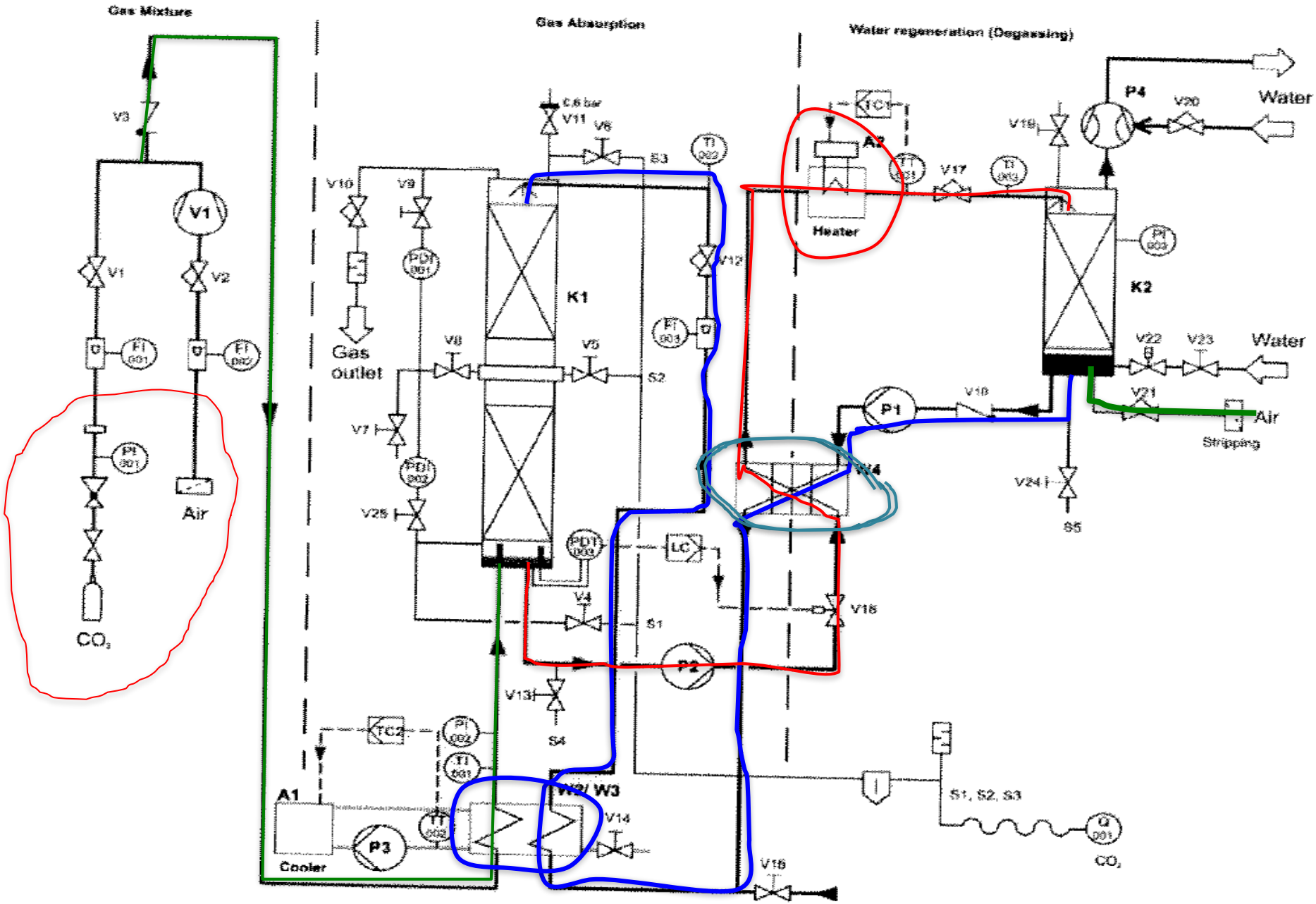
$Y_N = .031$

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

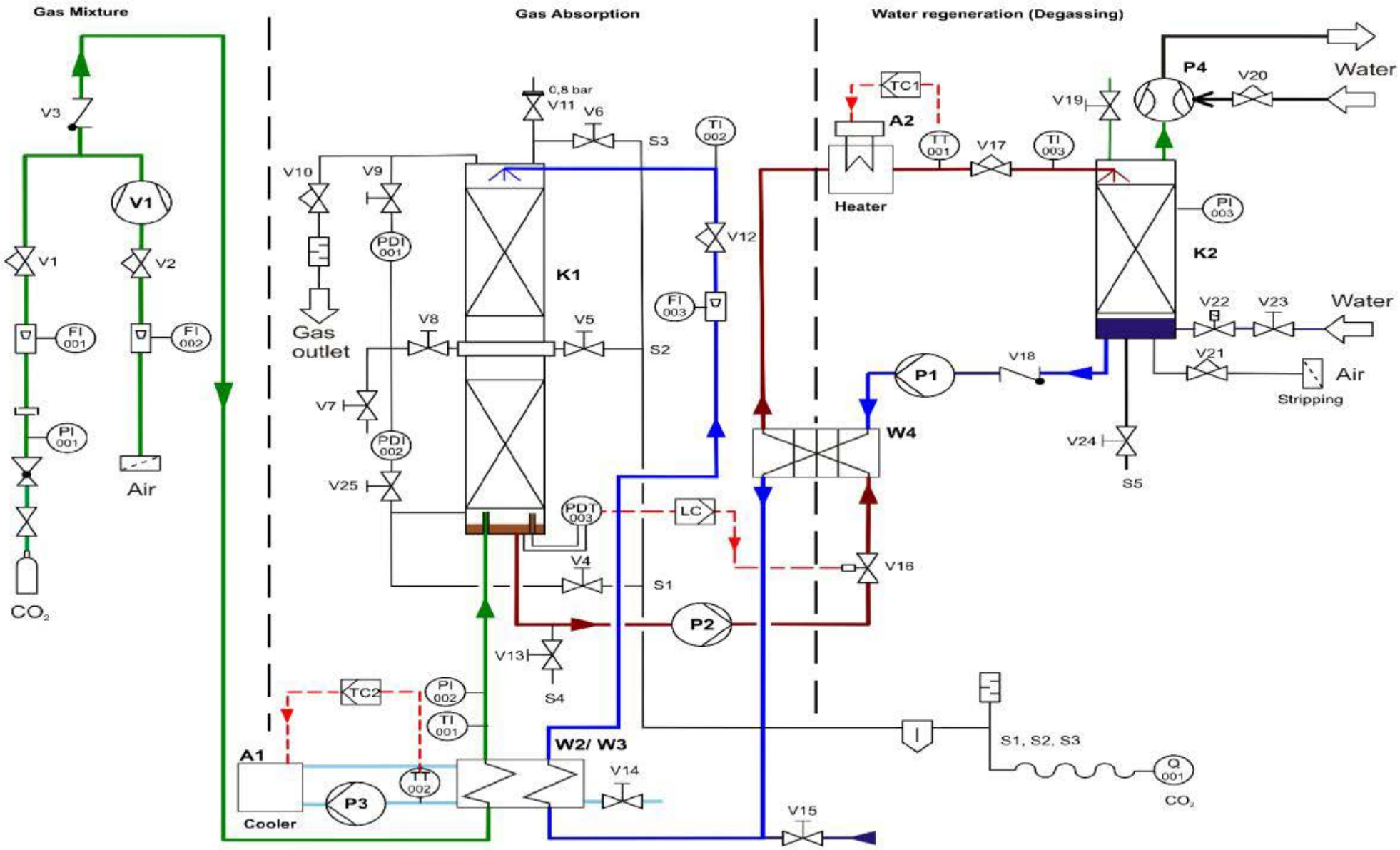
$$K_G = .0013\ \frac{KMOLE}{m^2\,h\,KPa}$$


CO_2 Absorption Lab Experiment
COLD
HOT
Absorber
Stripper

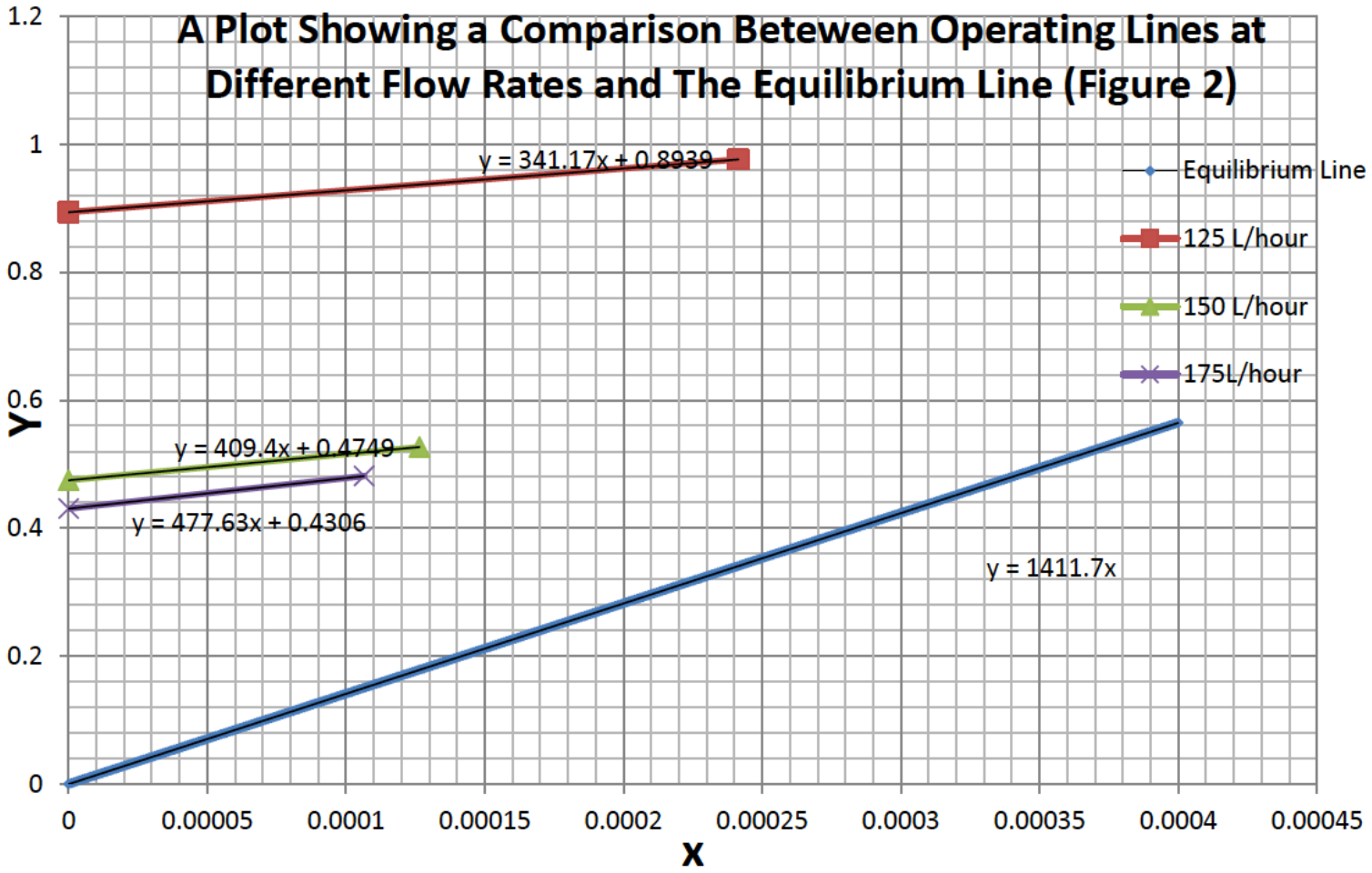

gunt


Gas Mixture
Gas Absorption
Water regeneration (Degassing)
V3
V1
V2
PI 301
Air
CO_2
0.6 bar
V11
V6
S3
TI 002
V10
V9
PDI 001
K1
V12
Gas outlet
V8
V5
S2
FI 003
V7
PDI 002
V25
PDI 003
LC
V4
S1
V13
S4
TC2
PI 002
FI 001
A1
P3
Cooler
TT 002
V14
V15
V16
P2
TC1
A2
Heater
TI 001
V17
TI 003
P4
V20
Water
V19
PI 003
K2
V22
V23
Water
V21
Air
Stripping
P1
V18
V24
S5
S1, S2, S3
FI 001
CO_2

OXYBABY


Gas Mixture
Gas Absorption
Water regeneration (Degassing)
V3
V1
V2
FI 001
FI 002
PI 001
Air
CO_2
0,8 bar
V11
V6
S3
TI 002
V10
V9
PDI 001
K1
V12
Gas outlet
FI 003
V8
V5
S2
V7
PDI 002
V25
PDT 003
LC
V4
S1
V16
P2
V13
S4
TC2
PI 002
TI 001
A1
W2/ W3
TT 002
P3
Cooler
V14
V15
S1, S2, S3
Q 001
CO_2
TC1
A2
TT 001
V17
TI 003
Heater
V19
P4
V20
Water
PI 003
K2
V22
V23
Water
V21
Air
Stripping
P1
V18
W4
V24
S5

Example From Student's Result



FOR THE LABORATORY ABSORBER.

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

$$Z = \frac{G/A_T}{k_a} \int_{y_i}^{y_t} \frac{dy}{(y - y^*)}$$

H_{OG} N_{OG}

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

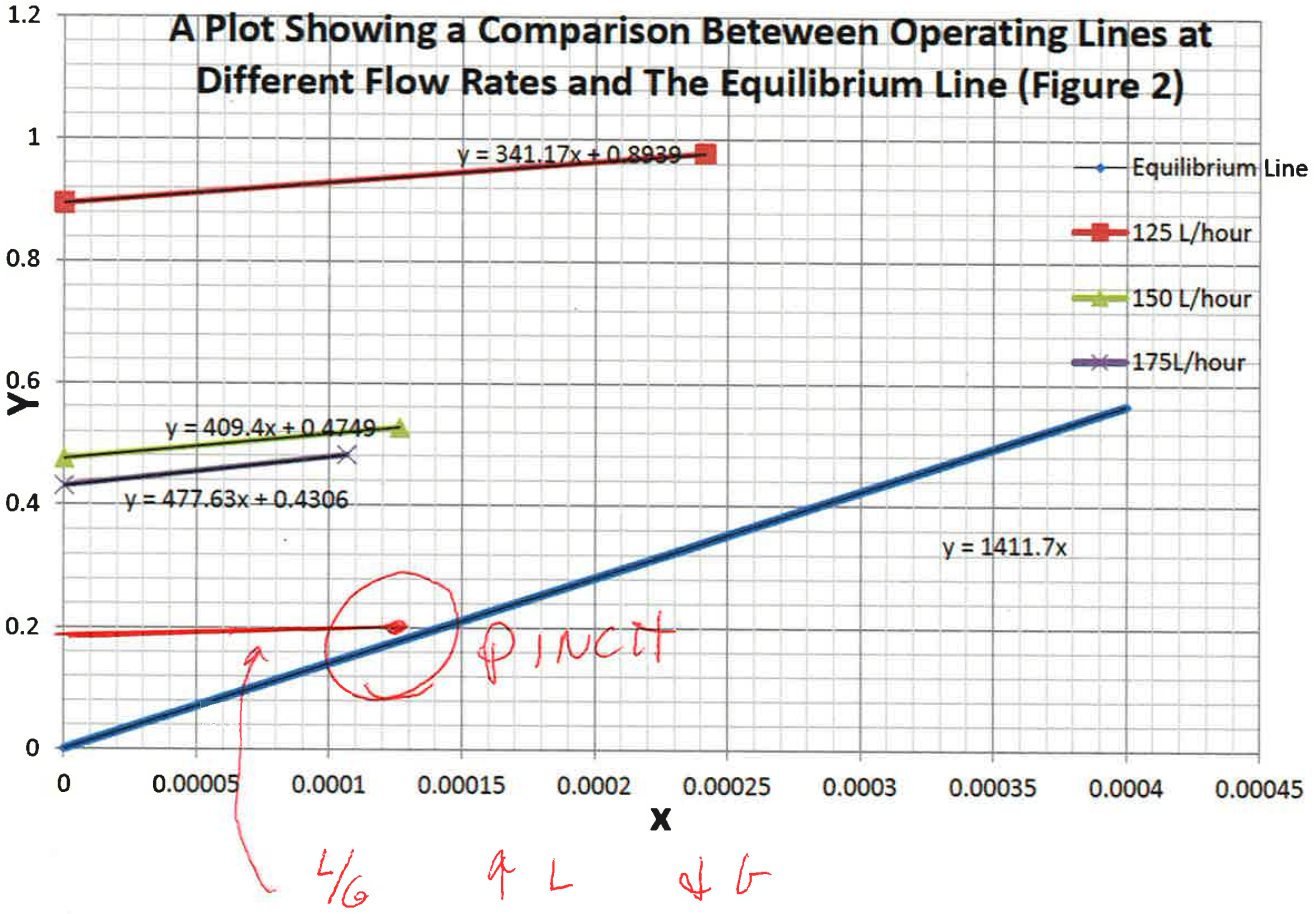
$$A_T = \frac{(80\,mm)^2 \pi}{4}$$

LIQUID FLOW, ~ 150 l/m.

CO_2 FLOW ~ 5 l/MIN

AIR FLOW ~ 20 l/min

Example From Student's Result



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

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

$H = .75\ m$

$V = \frac{20\ell}{MIN} \Rightarrow .014\ mol/s$

$L = 150\ell/HR \Rightarrow 2.3\ MOL/S$

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

$A = .11$

ABSORPTION FACTOR CHART

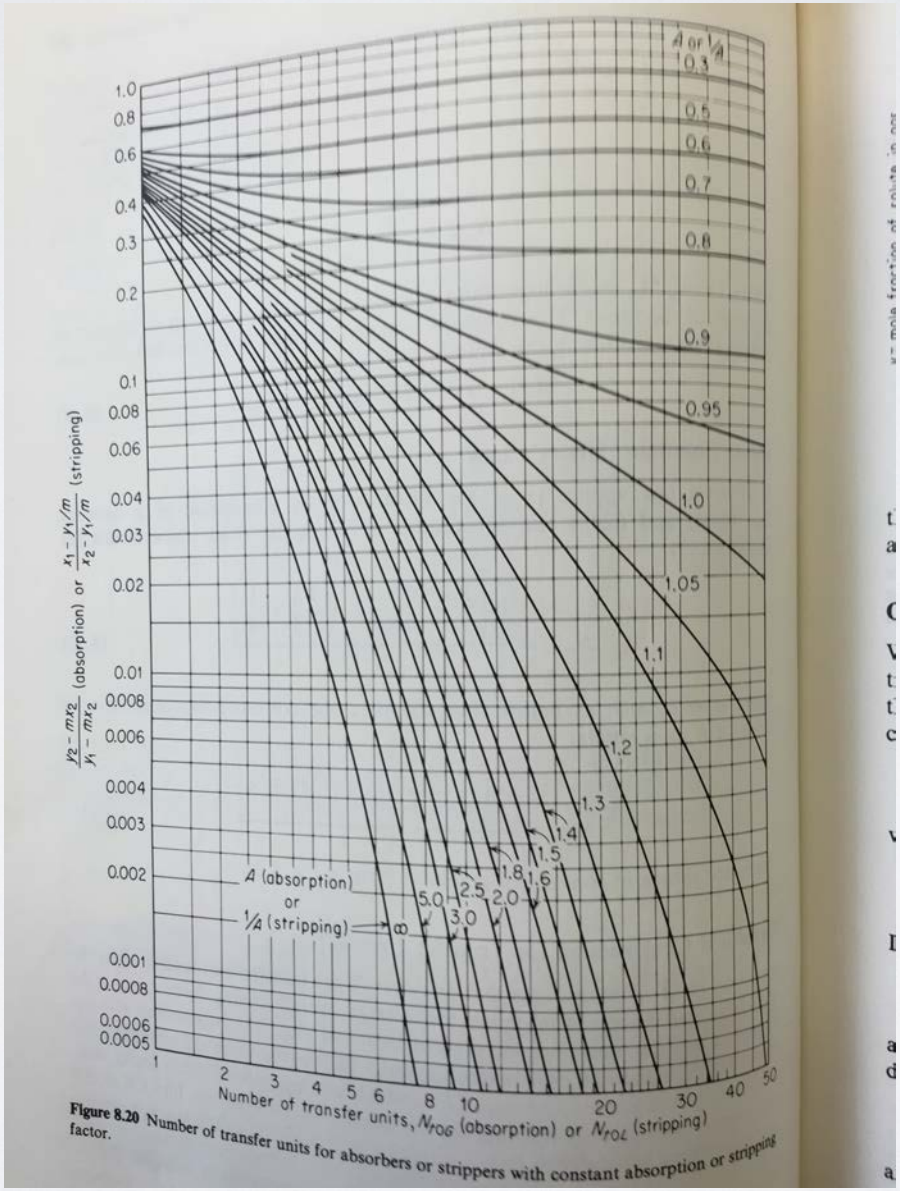


Figure 8.20 Number of transfer units for absorbers or strippers with constant absorption or stripping factor.

10

$$H_{oc} = \frac{H}{NO_c} = \frac{.75}{NO_c}$$

$$A_J = 50 cm^2$$

$$k_a = \frac{U/A_J}{H_{oc}}$$