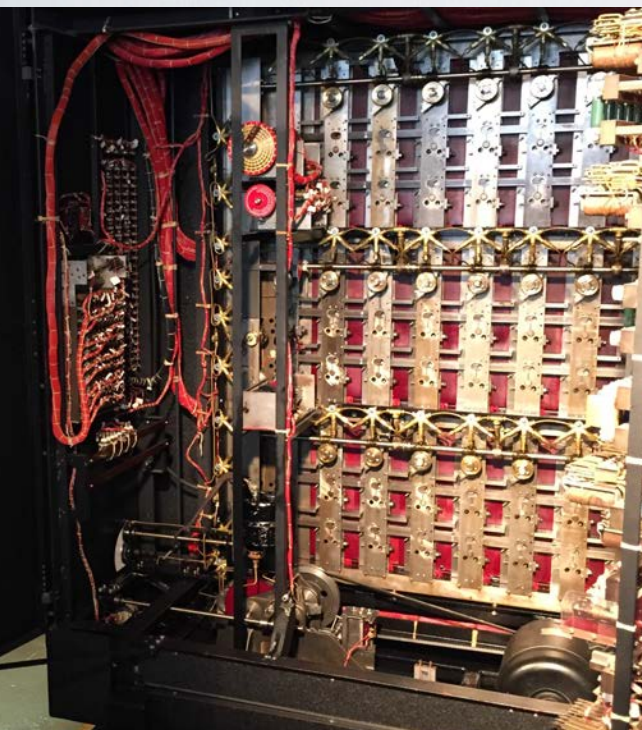
CBE 30399

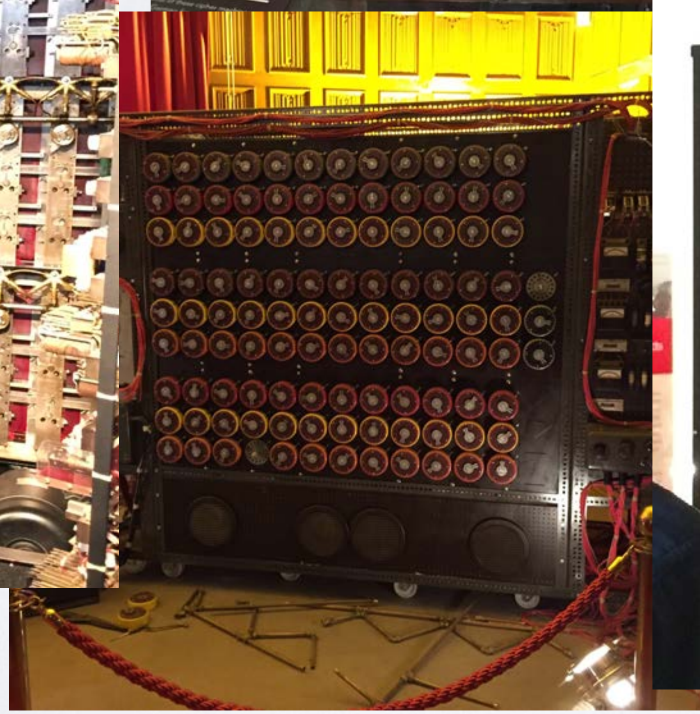
2/4/16

TOPICS

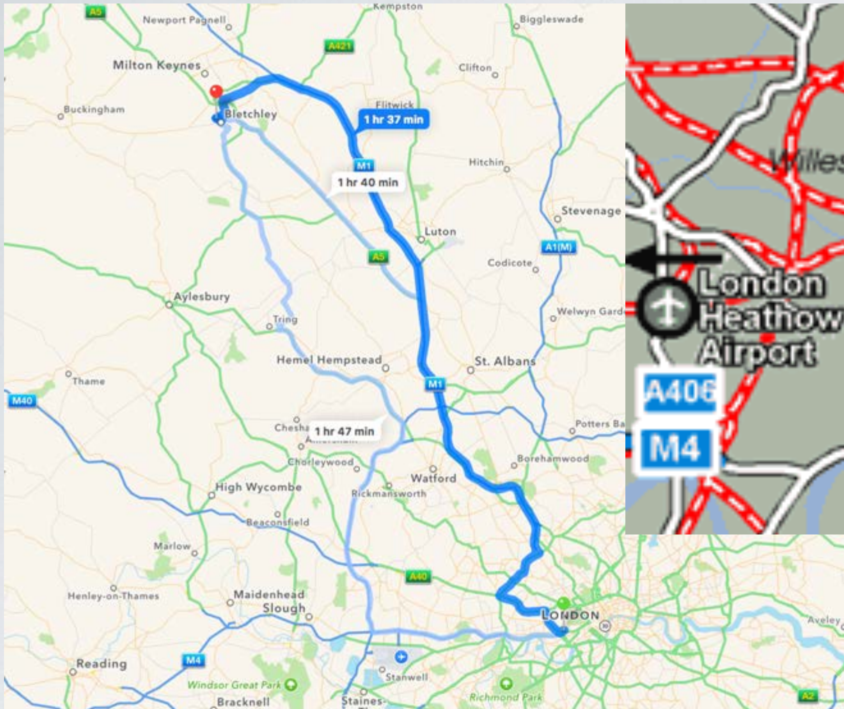
- Something about… London!
- Review of heat transfer and heat exchangers
- Continuation of discussion of gas absorption

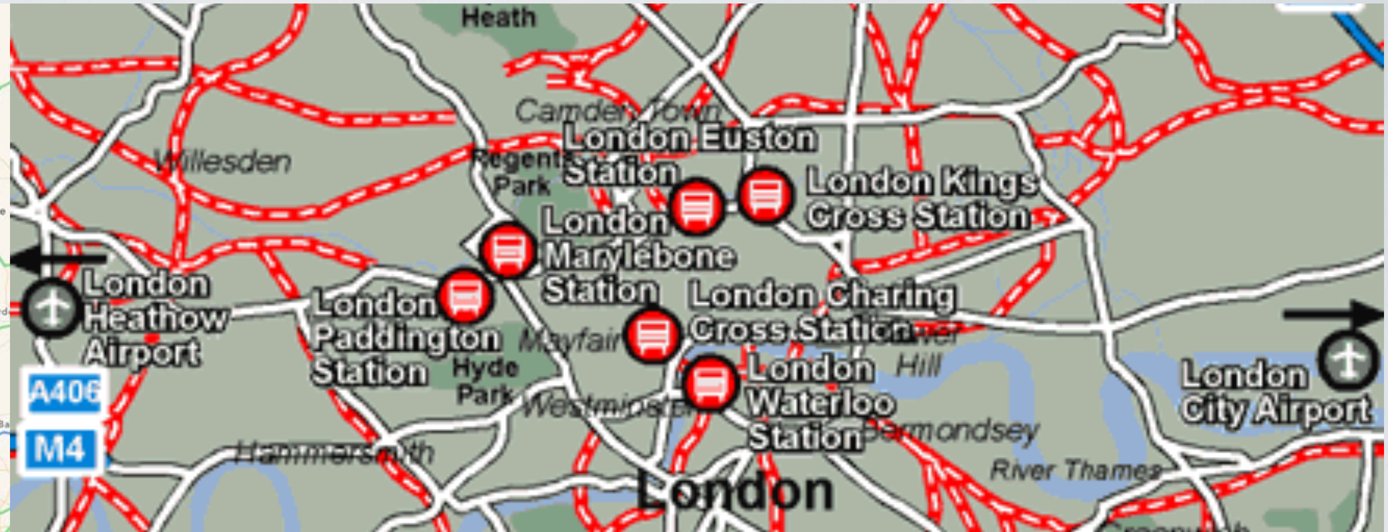
BLETCHLEY PARK (CODE BREAKING)

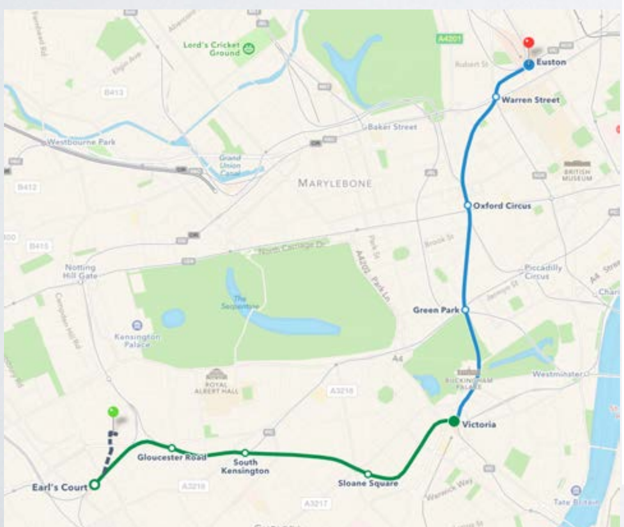


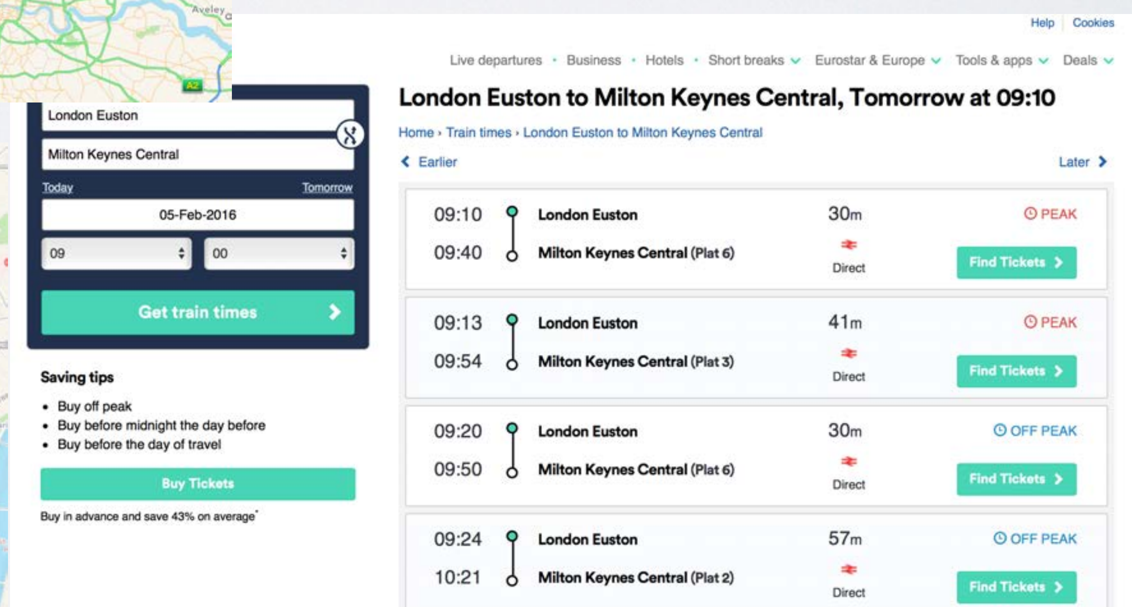


TRAINS (TO BLETCHLEY)









IMPERIAL FLOWSHEET

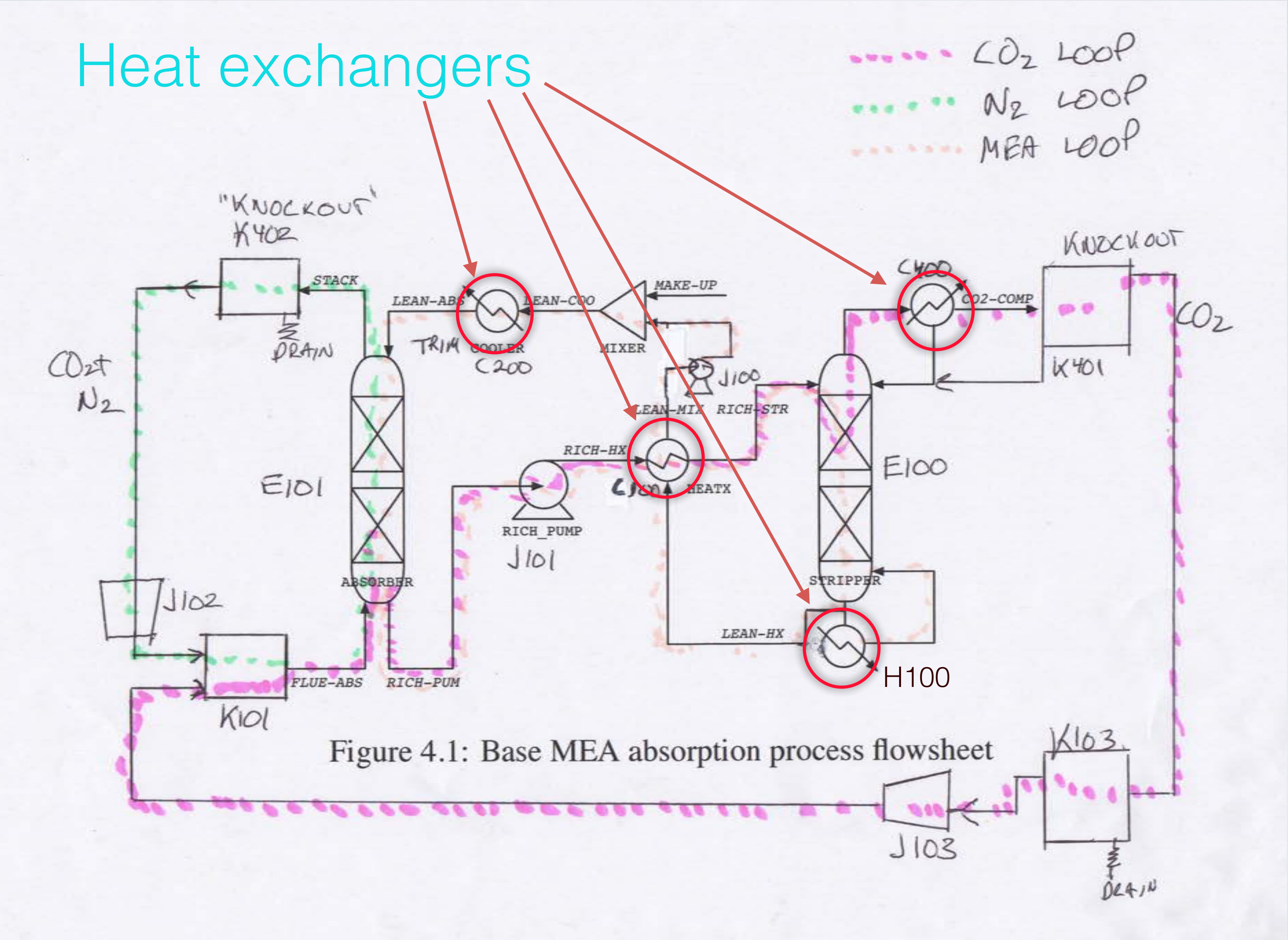


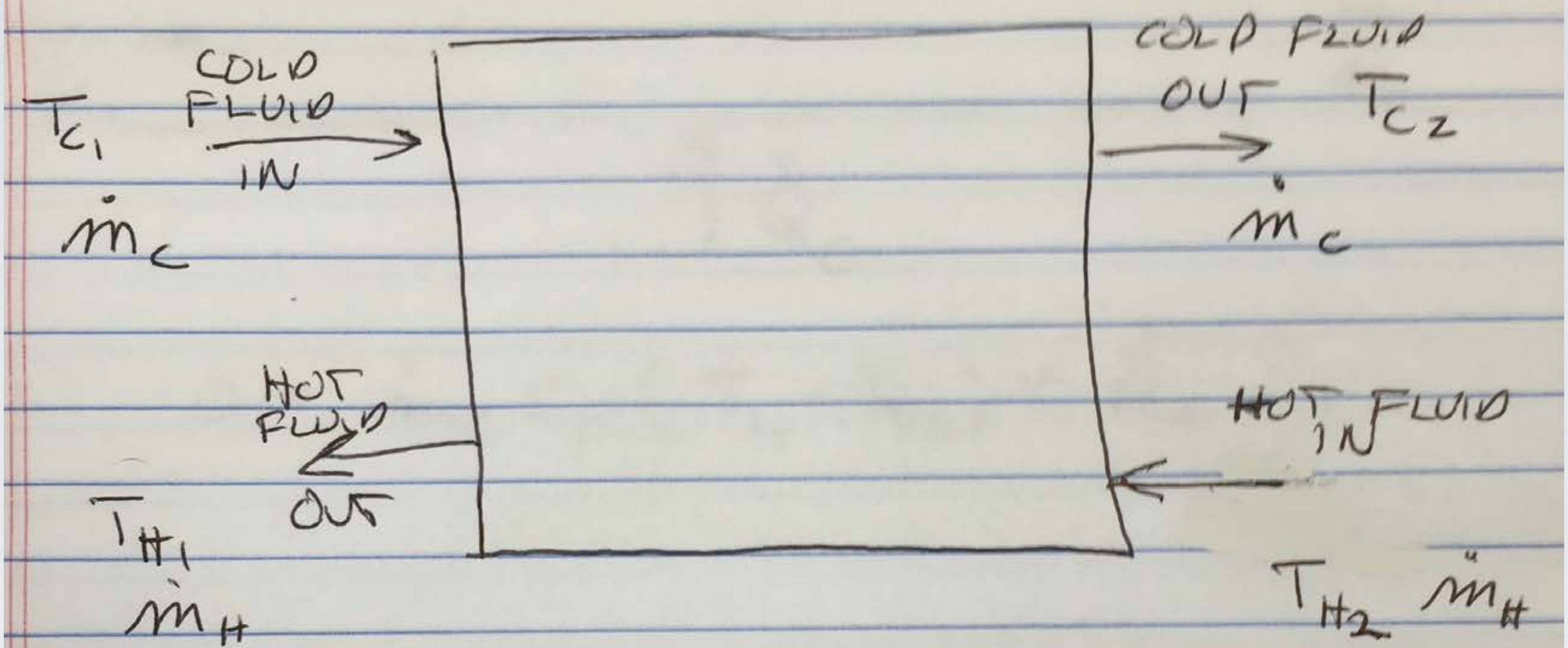
Figure 4.1: Base MEA absorption process flowsheet

HEAT EXCHANGERS

- Two basic "ideas"… a.k.a. equations:
  - Energy is conserved
    - First law of thermodynamics
  - We have accurate equations to quantify how fast heat will flow through fluids and walls
    - Newton's law of cooling

HEAT EXCHANGER EQUATIONS

FIRST LAW FOR "BLACK BOX" HEAT EXCHANGER



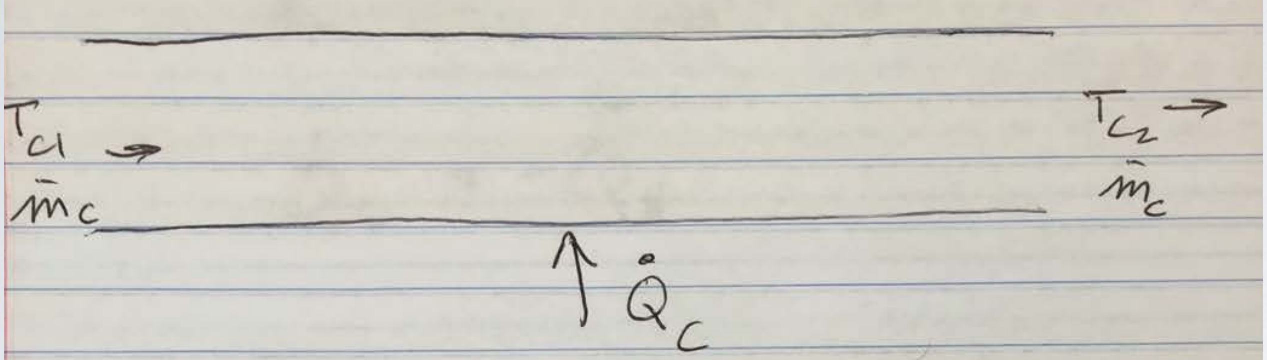
$$0 = \dot{m}_C\left(\hat{H}_{C1} - \hat{H}_{C2}\right) + \dot{m}_H\left(\hat{H}_{H2} - \hat{H}_{H1}\right)$$

$$\Delta H \cong C_p \Delta T$$

$$0 = \dot{m}_C C_p \left(T_{C1} - T_{C2}\right) + \dot{m}_H C_p \left(T_{H2} - T_{H1}\right)$$

ENERGY BALANCE FOR EACH "PIPE" SEPARATELY

"COLD" "PIPE"

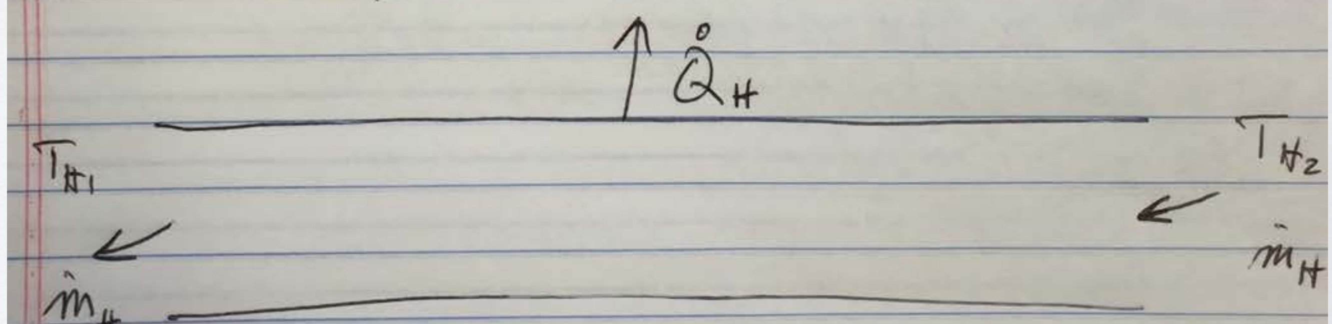


$$0 = \dot{m}_C c_p (T_{C1} - T_{C2}) + \dot{Q}_C$$

$$\dot{Q}_C > 0, \quad \dot{Q}_H < 0$$

$$\dot{Q}_C = -\dot{Q}_H$$

"HOT" "PIPE"



$$0 = \dot{m}_H c_p (T_{H2} - T_{H1}) + \dot{Q}_H$$

OVERALL RATE EQUATION

$$\dot{Q} = UA\,\Delta T_{LM}$$

$U \equiv$ OVERALL HEAT TRANSFER COEFFICIENT

A MEASURE OF OVERALL EFFICIENCY OF HEAT TRANSFER

$A \equiv$ CONTACT AREA BETWEEN COLD AND HOT STREAMS

I.E. INSIDE OR OUTSIDE AREA OF "PIPE"

$\Delta T_{LM} \equiv$ "LOG MEAN" TEMPERATURE DIFFERENCE

THE OVERALL AVERAGE "DELTA T" BETWEEN HOT AND COLD STREAMS

OBTAINED BY <u>INTEGRATING</u> A DIFFERENTIAL HEAT BALANCE ALONG THE LENGTH OF PIPE.

$$\Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

$$= \frac{(T_{C_2} - T_{H_2}) - (T_{C_1} - T_{H_1})}{\ln\left(\frac{(T_{C_2} - T_{H_2})}{(T_{C_1} - T_{H_1})}\right)}$$

"DELTA T LOG-MEAN" W/NUMBERS

$$= \frac{(30-100)-(15-40)}{\ln \frac{(30-100)}{(15-40)}}$$

$$= -43.7\,C$$

WHAT IF COCURRENT?

$$= \frac{(15-100)-(30-40)}{\ln \frac{(15-100)}{(30-40)}}$$

$$= -35\,C^{\circ}$$

GAS ABSORPTION/STRIPING

Imperial Flowsheet

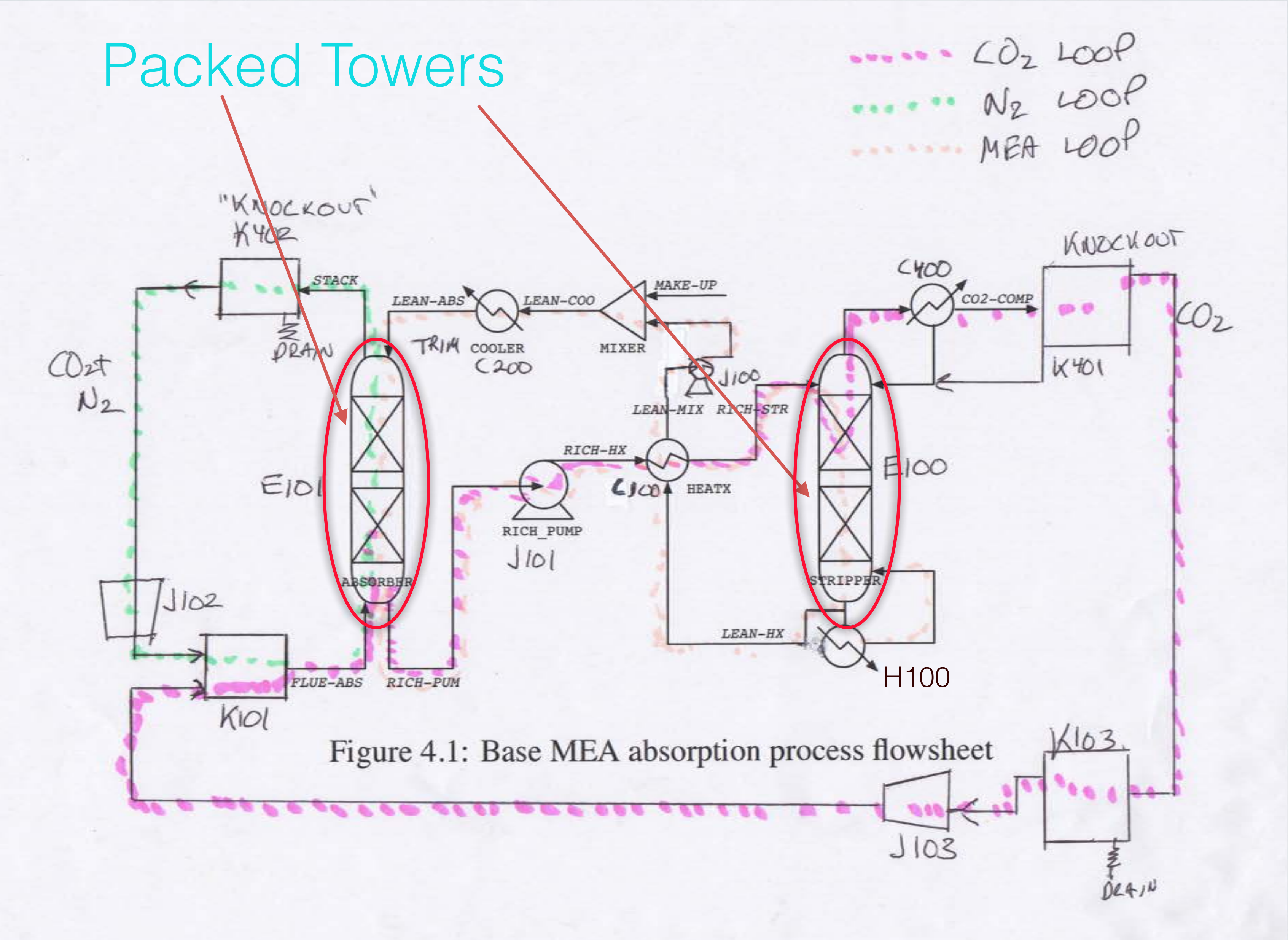


Figure 4.1: Base MEA absorption process flowsheet

THE TWO COLUMNS

PACKED TOWER

- **Countercurrent**
  - greater overall "driving force" (concentration difference)
  - (potentially) no limitation on amount of CO2 removed
    - could contact lowest concentration exiting gas with "pure" solvent

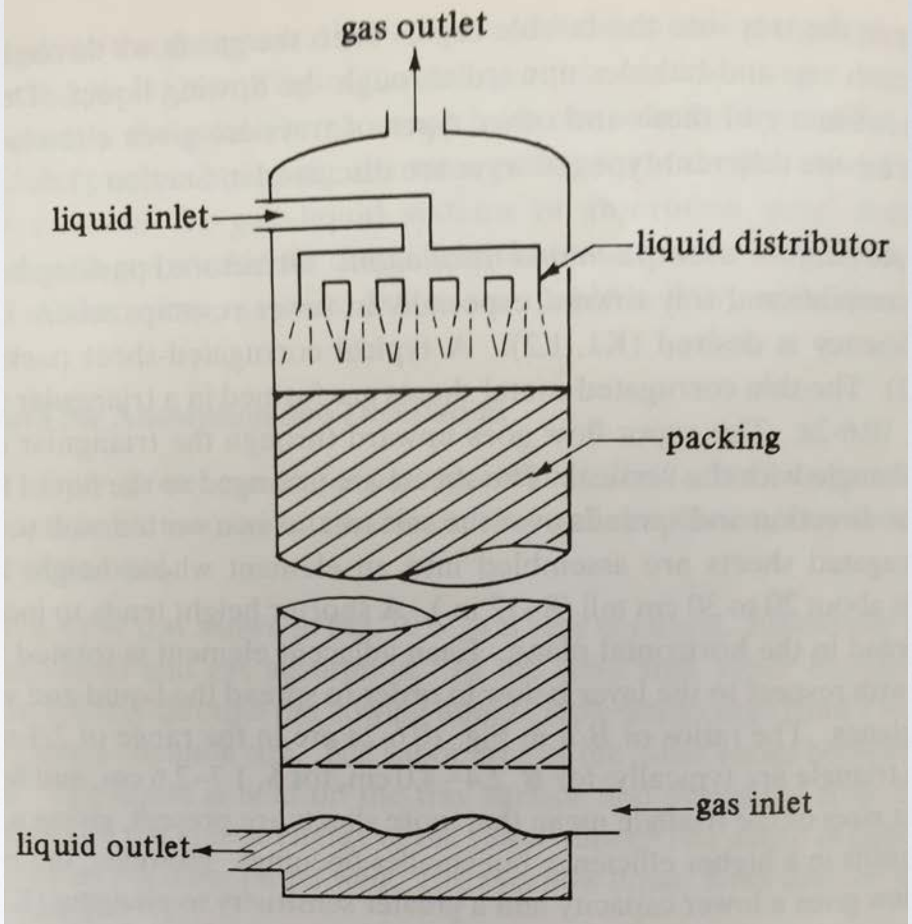


FIGURE 10.6-3. *Packed tower flows and characteristics for absorption.*

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

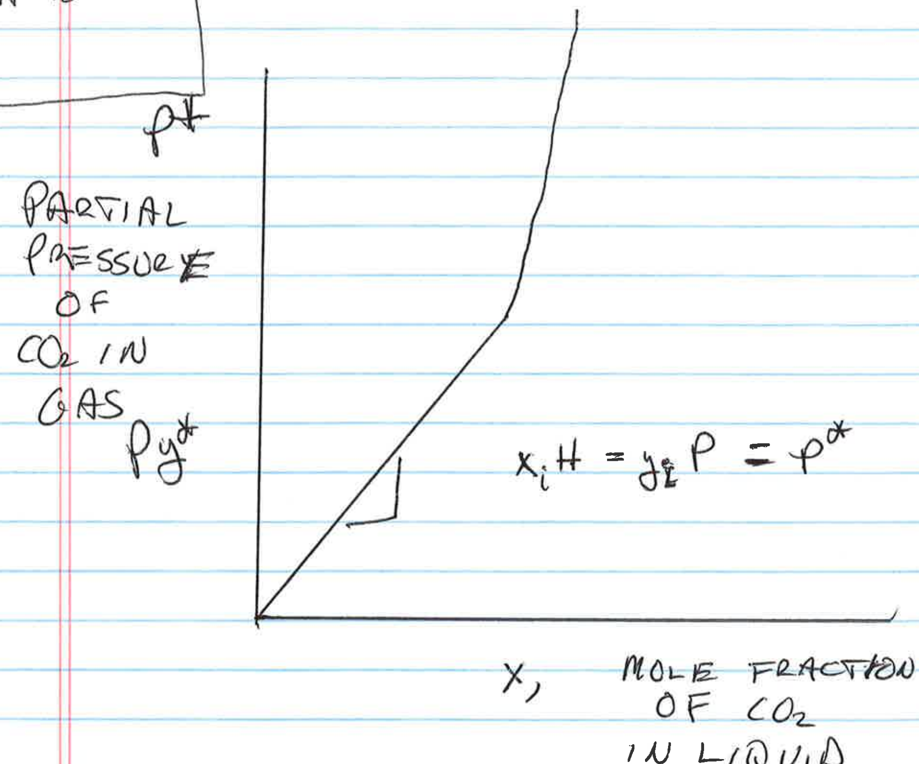
SIMPLEST CONCEPTUAL APPROACH

CHANGE NOTATION LATER

2/4/16

①

GAS-LIQUID EQUILIBRIUM BEHAVIOR



$$x_i H = y_i P = p^*$$

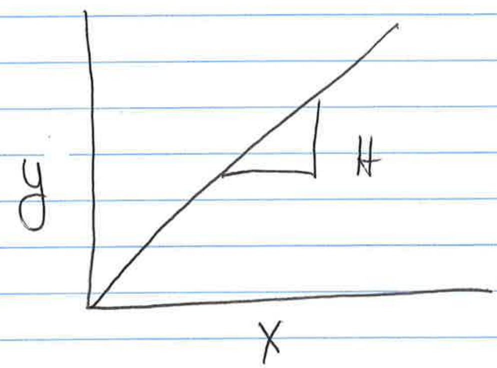
H = HENRY'S LAW COEFFICIENT

y = MOLE FRACTION OF CO_2 IN GAS.

SMALLER H $\Longrightarrow$ HIGHER SOLUBILITY

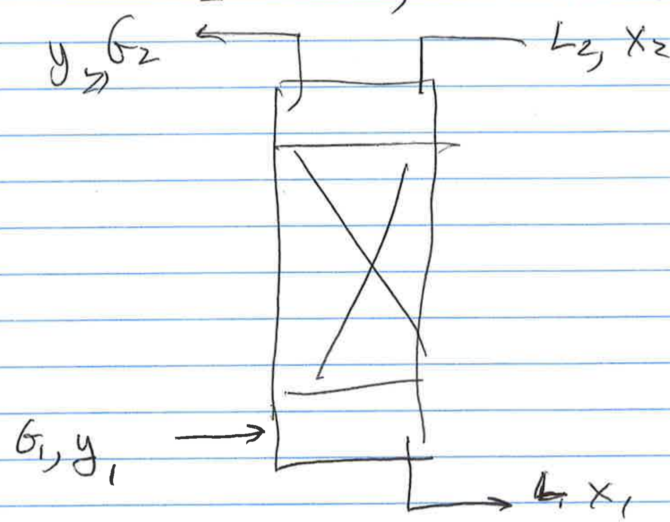
- Chalk...

SO LET'S USE:



$y = Hx$

MASS BALANCE, JUST THINK OF CO_2 IN AIR, LIQUID W/ CO_2 OR NOT



(3)

MASS BALANCE (MOLES)

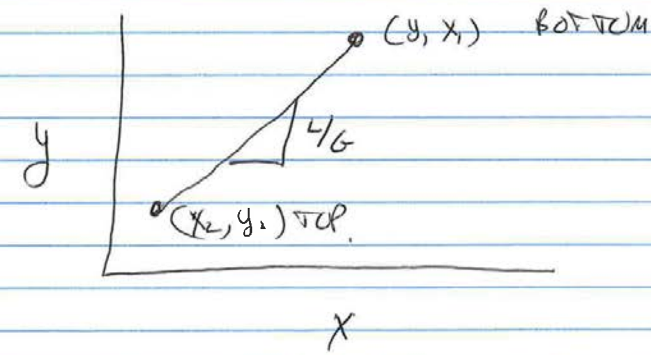
$$G_1 + L_2 = G_2 + L_1$$

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

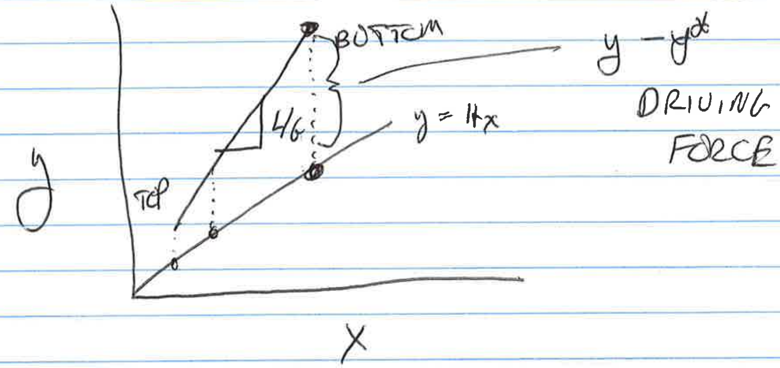
$CO_{2\,IN} = CO_{2\,OUT}$

$$y_1 G + L X_2 = y_2 G + L X_1$$

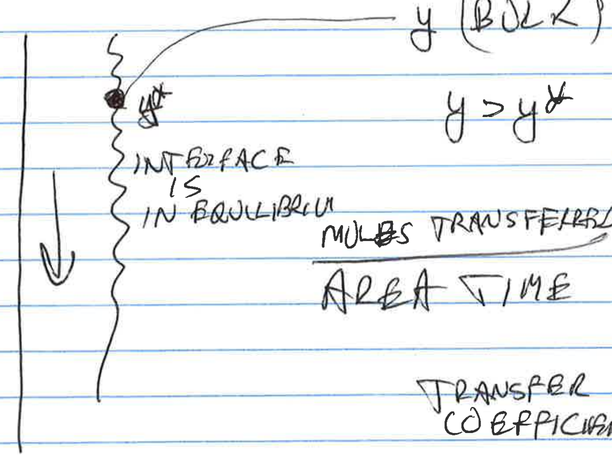
$$(y_1 - y_2)\, G = (X_1 - X_2)\, L$$



$$\frac{L}{G} = \left(\frac{y_1 - y_2}{X_1 - X_2}\right)$$



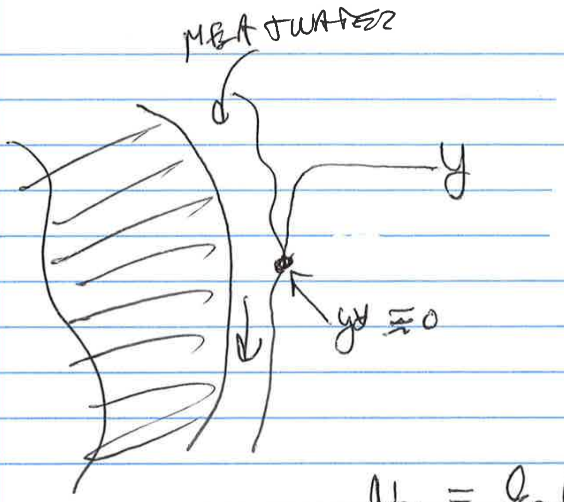
ALL ALONG COLUMN, CONCENTRATION IN GAS OF CO_2 IS > EQUILIBRIUM VALUES, SO CO_2 GOES INTO LIQUID



$y > y^*$

$$\frac{\text{MOLES TRANSFERRED}}{\text{AREA TIME}} = \text{TRANSFER COEFFICIENT} \times \text{DRIVING FORCE}$$

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



$CO_2 + N_2$

$$N_{CO_2} = k_{G}(y - y^*) \cong k_G y$$

THINGS ARE CHANGING.
HOW DO WE DEAL WITH THIS?

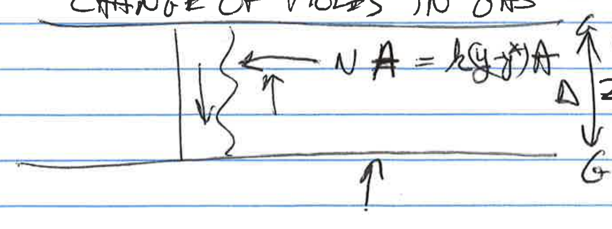
TAKE "CONCEPTUALLY" A

"DIFFENTIAL SLICE"

ACROSS COLUMN - (X-SECTION)

DO A MASS BALANCE

CHANGE OF MOLES IN GAS = MOLES CROSSING INTERFACE



CHANGE IN MOLES/TIM

$$G y\big|_{z} - G y\big|_{z+\Delta z} = k\,a(y-y^*)\,\Delta V$$

CROSS-SECTION AREA

$$\Delta V \equiv A_{TOWER}\,\Delta z$$

$$a \equiv \frac{\text{CONTACT AREA FOR MASS TRANSFER}}{\text{VOLUME OF PACKED REGION}}$$

$$-G\,\frac{\left(y\big|_{z+\Delta z} - y\big|_{z}\right)}{\Delta z} = k\,a\,(y-y^*)\,A_{TOWER}$$

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

$$\int_0^z dz = -\frac{G/A}{k\,a}\int_{y_1}^{y_2}\frac{dy}{(y-y^*)}$$

$$z = \left(\frac{G/A}{k\,a}\right)\int_{y_1}^{y_2}\frac{-dy}{(y-y^*)}$$

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

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

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

IF $y^* = 0$.

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

FOR THE 2 IMPERIAL EXPTS,

YOU CAN MEASUERE y AT
BEGINNINL MIDDLE, END
SOME MORE IN BETWEEN.

YOU KNOW "Z",
CONCENTRATIONS GIVE N_{OG}
DETERMINE
$\Longrightarrow$ H_{OG}.

FOR 516 COLUMN.
DON'T INTEGRATE FORMULAE...

GO TO

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

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

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

$\frac{dy}{dz} = \frac{\Delta y}{\Delta z}$ ← MEASURE AT TWO "STAGES"

Δz ← DISTANCE BETWEEN MEASUREMENTS

$y^* = 0$, y

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

$\Delta z \to 0$

$$K(y-y^*)\,a_v\,A_c = G\,\frac{dY}{dz}\,A_c$$

$$K = \frac{\frac{dY}{dz}\,\frac{1}{(y-y^*)}\,\frac{G}{P}}{a_v}$$

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

$P = 101.3\times10^3\ \cancel{\ }\ Pa$

$G = 100\ \frac{Kg\,mol}{hr\,m^2}$

$y = .05$

$$\frac{dY}{dz} = \frac{.02}{1\,m.}$$

$$= \frac{\left(\frac{.02}{1m}\right)\left(\frac{1}{\cancel{0}\,.05}\right)\left(\frac{100\,Kg\,mol}{m^2\,hr}\right)}{350\,m^2/m3\ \ 101\,kPa}$$

$$\frac{dy}{y - y^*} = \frac{K a_v P}{G}$$

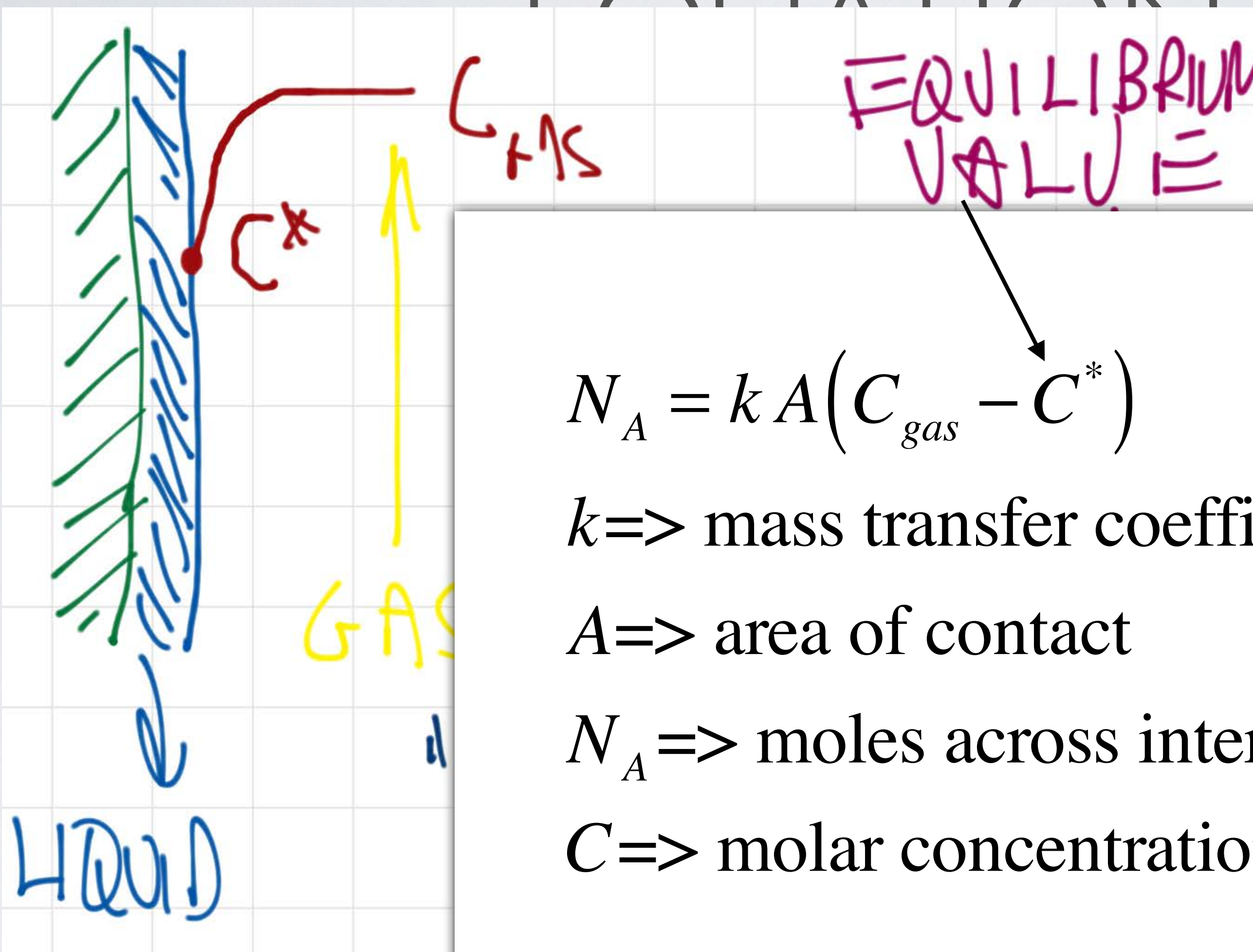
$$dz = \frac{G}{K a_v P} \int_{y_1}^{y_2} \frac{dy}{y - y^*}$$

$$= \underbrace{\left(\frac{G}{K a_v P}\right)}_{H_{OG} = 2.5\ m} \underbrace{(y_s - 1)\left(y + (y_s - 1)\ln(y - y_s)\right)\Big|_{y}^{y_2}}_{4.86}$$

$$A = .0415\ m^2$$

$$K = .001 \frac{Kmol}{h\ KPa\ m^2}$$

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