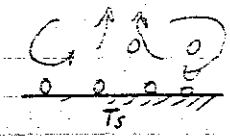
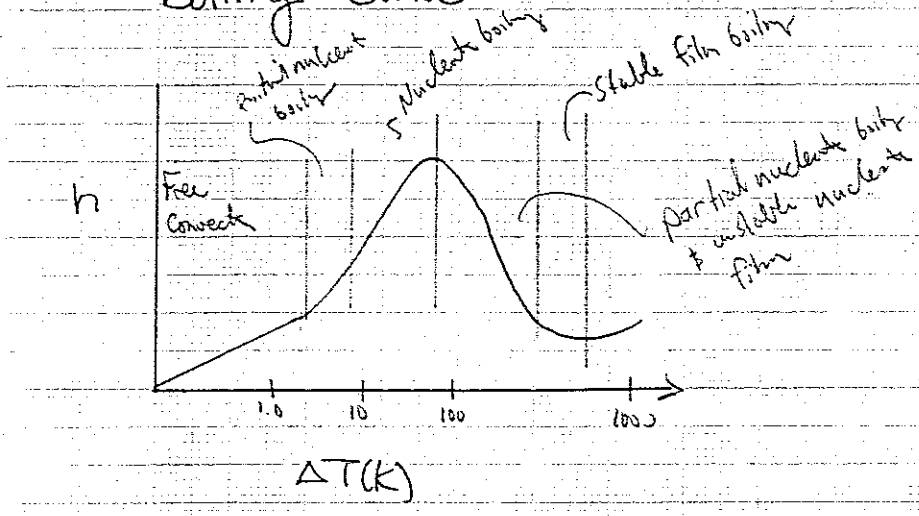
Boiling

Nucleate boiling ~ bubbles form at heat exchange surface and exert appreciable agitation on the system.



Film boiling ~ at very high ΔT the bubbles form so rapidly that they cannot escape the surface and the heat transfer is greatly reduced

Boiling Curve



Reason why steam is used to control distillation column reboiler (T_s = const.) allows control of flux into the system.

Dehydration by adsorption

what is adsorption:

1) physical adsorption
2) chemical adsorption

Physical adsorption is used to take advantage of the fact that molecules will adsorb onto surfaces, leaving a higher concentration on the surface than in the bulk phase.

~ Molecules will adsorb usually up to one or two molecular layers on the surface, so adsorption is not practical unless adsorbants with high surface area / volume ratio are used.

$\frac{S}{V}$: synthetic zeolites: 750 cm^2/cm^3

coconut shell charcoals: 1000 cm^2/cm^3

Disadvantages of adsorption:

1) usually a fixed bed process requiring two or more adsorption beds for continuous operation
2) because of the limited capacity it is not practical to remove large amounts of impurity.

Advantages:

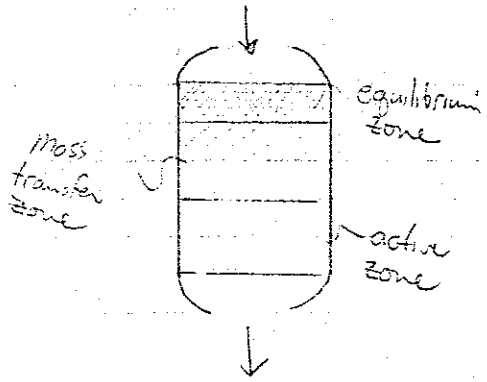
for dehydration of Natural gas it is possible to achieve a higher degree of dehydration with adsorbants than is possible with glycols.

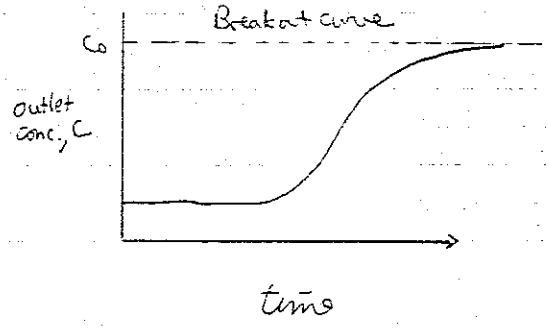
Industrial Adsorbants:

1. Silical gel (pure SiO_2)
2. activated alumina (hydrated form of aluminum oxide, Al_2O_3)
3. Molecular sieves (synthetic zeolite)

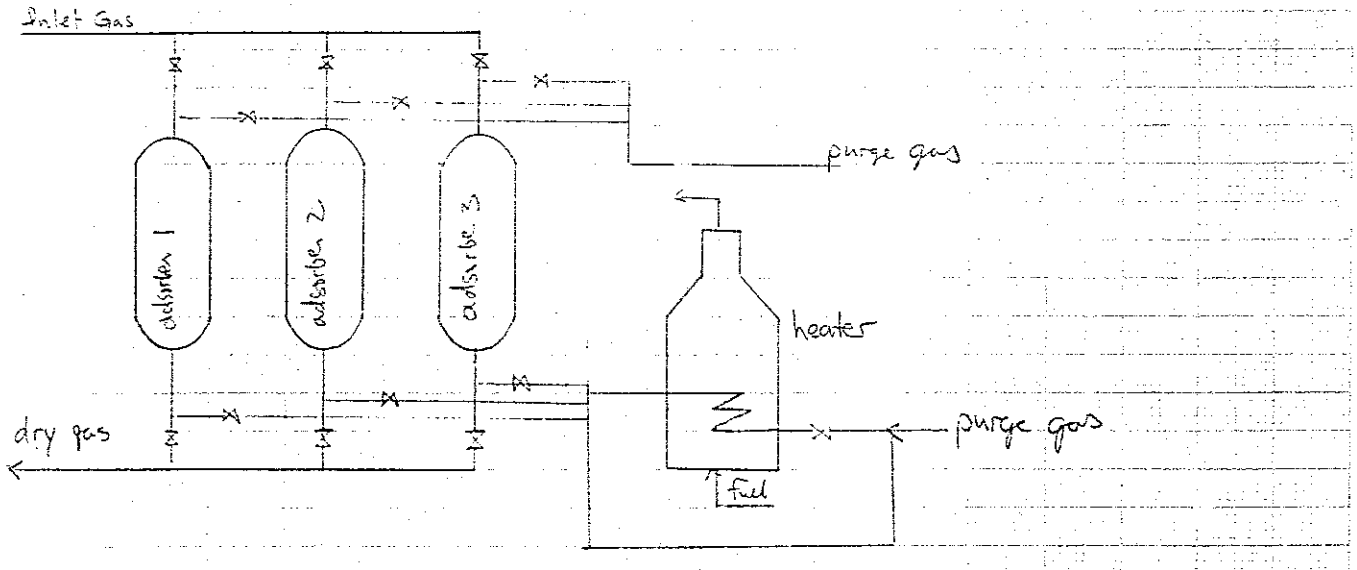
- Industrial adsorption processes are batch rather than continuous, so more than one bed must be used to achieve continuous operation

Fundamentals of adsorbant beds





Typical Three bed adsorption scheme:



Operation of adsorber: Inlet < 100°F

1. Initially bed #1 is adsorbing, bed #2 has been regenerated and is on standby, and bed #3 is undergoing regeneration. The moment the mass transfer zone appears at the outlet of bed #1, the outlet flow is directed to bed #2 such that beds #1 & #2 are in series. Flow is continued through bed #1 until the mass transfer zone is entirely in bed #2, so that all the adsorbent in bed #1 is at equilibrium loading. Bed #1 is now placed on regeneration and when the mass transfer zone appears at the outlet of bed #2, the flow is directed to bed #3.

Regeneration: 400-600°F

Heat the adsorbant while sweeping the bed with a dry purge gas at low pressure.

- adsorption capacities decrease with high temperature and low pressure

Dehydration

Absorption: Gas is contacted with a liquid that preferentially absorbs the water vapor

Liquid used for absorption should have the following properties:

a) a high affinity for water, and a low affinity for the remaining components in the gas.

b) low volatility at the absorption Temp. to reduce vaporization losses

c) low viscosity for ease of pumping and good contact between gas and liquid phases

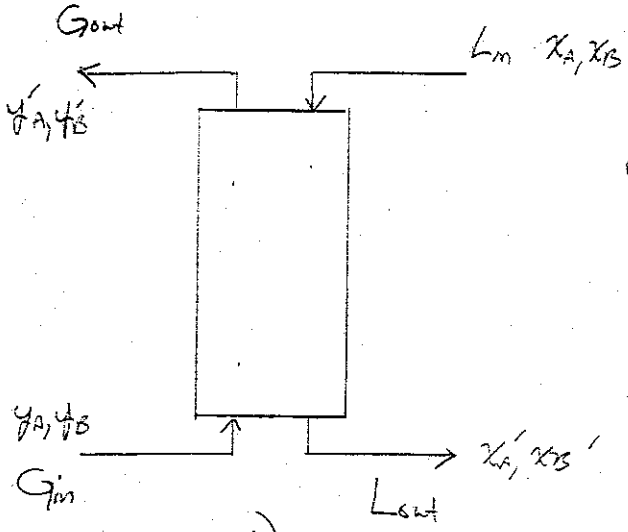
d) thermal stability to prevent decomposition during regeneration.

e) low potential for corrosion

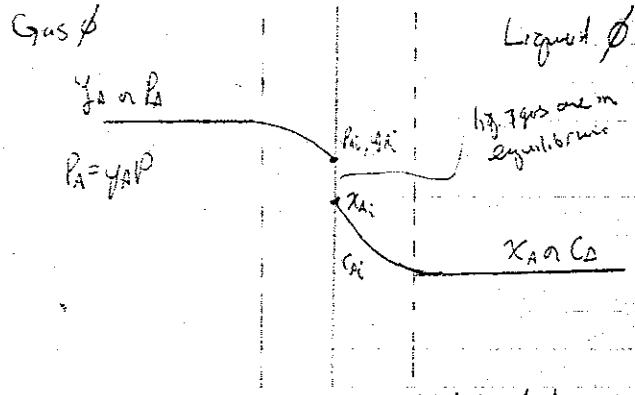
Glycols are most commonly used

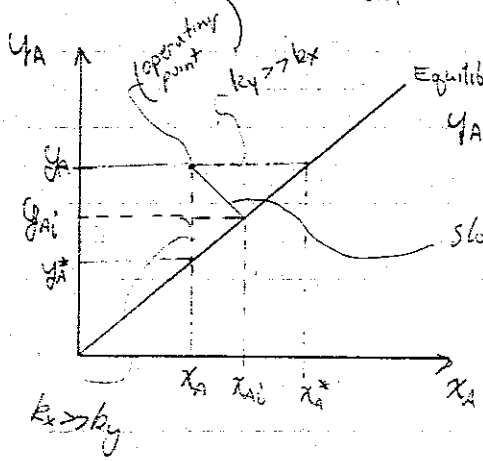
Ethylene Glycol (EG)	$HO-CH_2-CH_2-OH$
diethylene Glycol (DEG)	$HO-CH_2-CH_2-O-CH_2-CH_2-OH$
triethylene Glycol (TEG)	$HO-CH_2-CH_2-O-CH_2-CH_2-O-CH_2-CH_2-OH$
tetraethylene Glycol (TREG)	$C_8H_{18}O_5$
propylene Glycol	$HO-CH_2-CH_2-CH_2-OH$

Absorber



for Absorption





for a dilute solution

$$p_A^* = HC_A$$

$$y_A = \frac{Hx_A}{P}$$

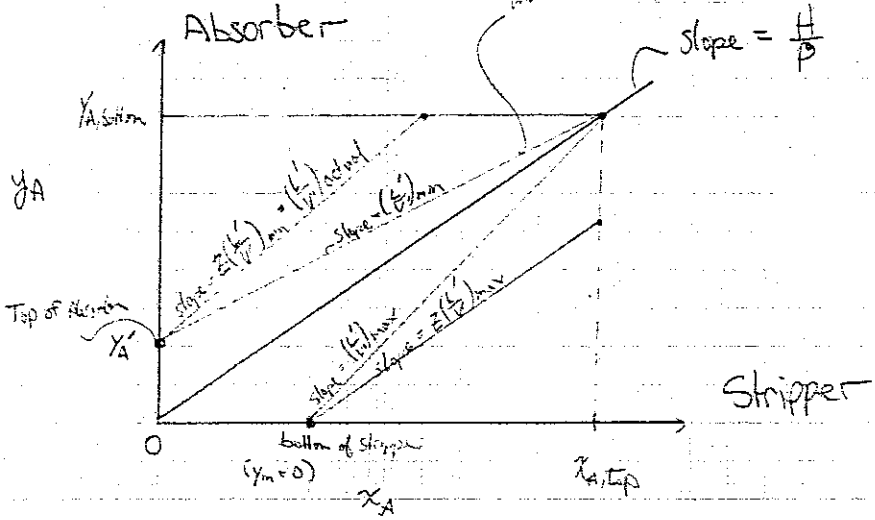
$$N_{Ag} = N_A X$$

$$k_y (y_A - y_{Ai}) = k_x (x_{Ai} - x_A)$$

$$-\frac{k_x}{k_y} = \frac{(y_A - y_{Ai})}{(x_A - x_{Ai})}$$

x_{Ai} & y_{Ai} must lie on equilibrium line

General Absorption



Stripper

$Z > 1$ absorber
$Z < 1$ stripper

Height of Tower:

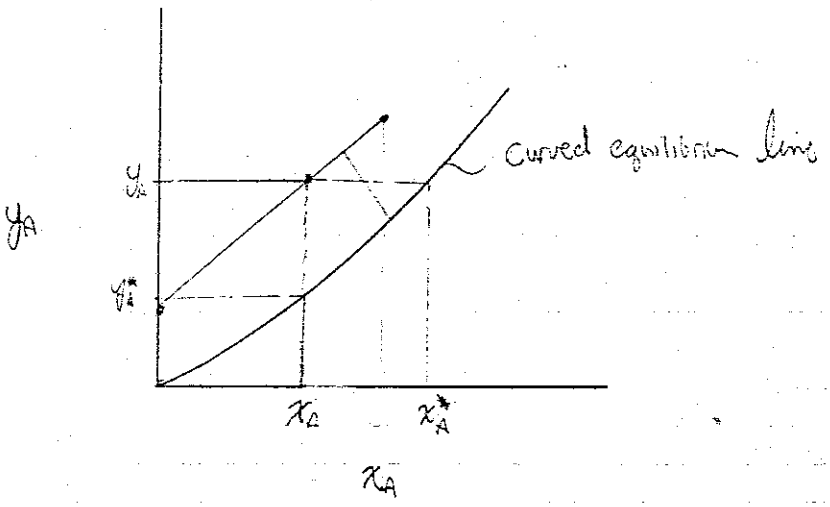
$$Z_T = H_{oy} N_{oy}$$

(H_{oy}: height to overall transfer unit; N_{oy}: number of overall transfer units)

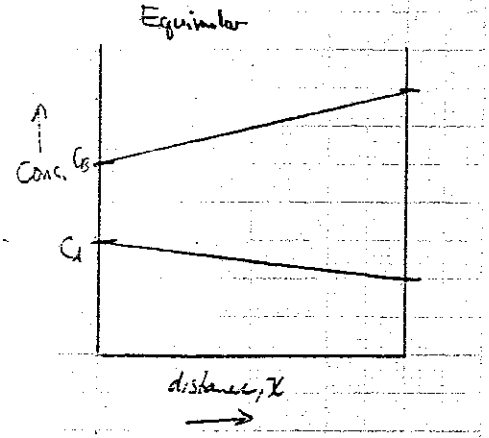
$$H_{oy} = \frac{V/S}{K_y a} \sim \frac{\text{cross sectional}}{\text{Area}}$$

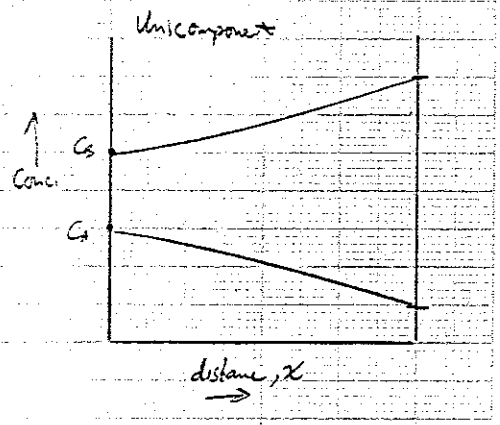
$$\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{H}{k_x a}$$

Actual System



Conc. profile in reactor





$$H_{oy} = \frac{V/S}{K_y a} \qquad N_{oy} = \int \frac{dy}{y - y^*}$$

$$H_{ox} = \frac{L/S}{K_x a} \qquad N_{ox} = \int \frac{dx}{x^* - x}$$

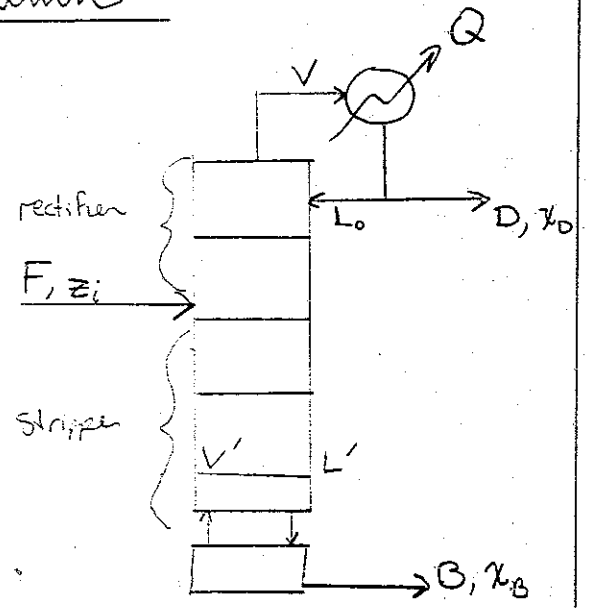
$$Z_T = H_{oy} N_{oy}$$

Absorption with Chemical Rxn:

Used to scrub NH_3 & other acid gases

the advantage is that you maintain a very high driving force.

Distillation Column



Overall mass Balance:

$$F = D + B$$

Component Mass Balance:

$$Fz_i = Dx_D + Bx_B$$

$R = \frac{L_o}{D}$ ← reflux ratio

$$\frac{L}{V} = \frac{R}{R+1} \qquad R = \frac{L/V}{1 - L/V}$$

↑ internal reflux ratio

$$V' = L' - B$$

$$L' = L + qF$$

$$V' = V - (1-q)F$$

$$q = \frac{L}{F} = \frac{H^V - h_F}{H^V - h_L}$$

R_{min} ⇒ occurs at intersection of TOL, EL, FL

Bottom operating line:

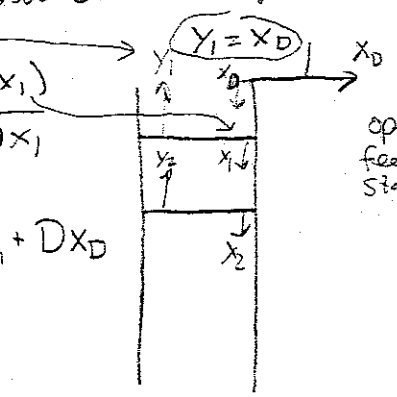
$\frac{L'}{V'}$ if boilup ratio is given you can solve for this

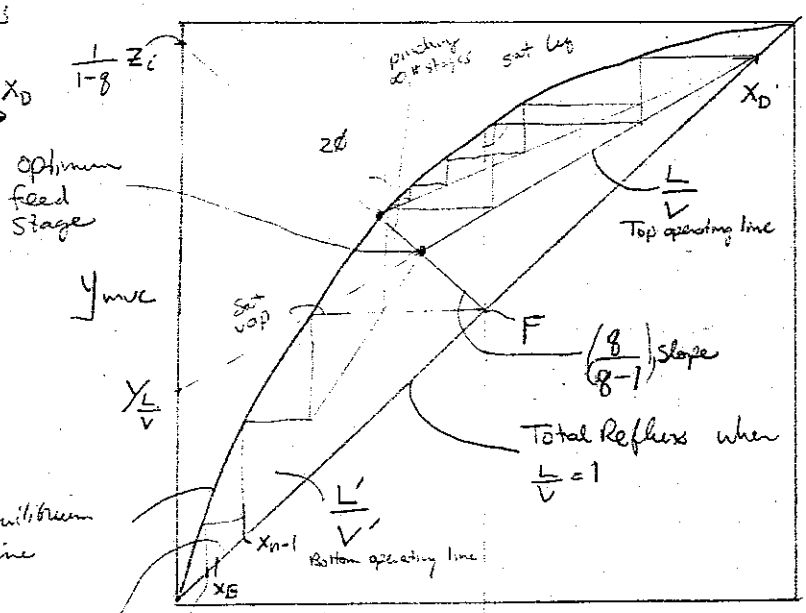
equilibrium → find compositions streams

$$\alpha_{12} = \frac{y_1}{x_1}\frac{(1-x_1)}{(1-y_1)}$$

TOL →

$$y_{n+1} = \left(\frac{L}{V}\right)x_n + Dx_D$$





$$\text{Frac} = \frac{\text{dist. op. Line to } x_B}{\text{dist. op. Line to EL}} = \frac{x_B - x_{n-1}}{x_n - x_{n-1}}$$ Pg. 160

$$\frac{L}{V} = \frac{x_D - y_{L/V}}{x_D}$$

Column Troubleshooting

An existing distillation column is being used to fractionate a feed. Predict the effect of each of the following changes on the purity of the distillate and bottoms, other independent column variables remaining unchanged. What variable could you change (in which direction) to keep the tops and bottoms composition constant? Assume that the stage efficiency never changes.

(a) the relative volatility of the feed is lowered

$\alpha = \frac{K_{more}}{K_{less}}$

purity will decrease

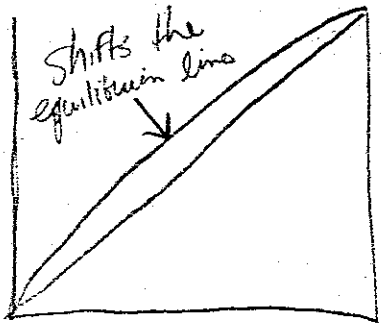
require more stages

q = decrease

Increase Boilup

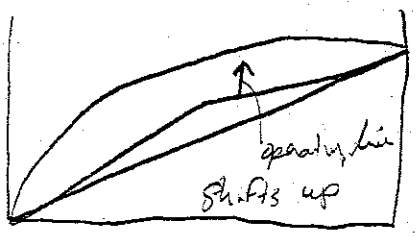
decrease Reflux temp

to give more liquid



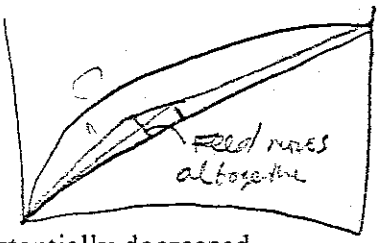
(b) cooling water become warmed in flowing to the condenser

Less liquid / Less period



(c) the concentration of the more volatile component in the feed is reduced

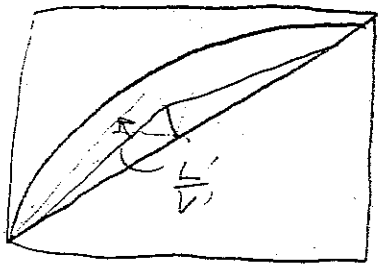
purity is reduced



(d) the reboiler becomes fouled and the heat it can supply is substantially decreased

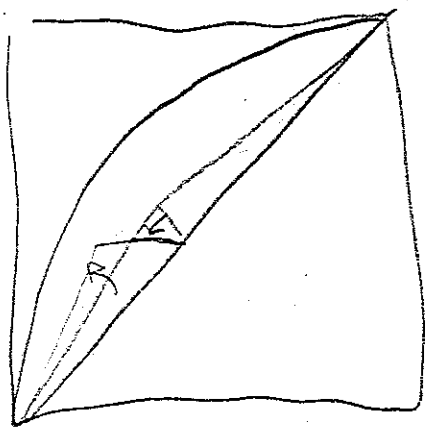
decreased purity ⇒ liquid increases

Slope $\frac{L'}{V'}$ increases shifts up

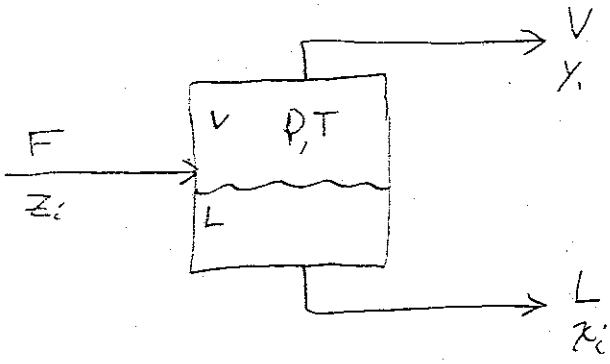


(e) the feed (formerly a liquid) is now fed in as a vapor

purity is reduced



Flash Drum



Need dew point & bubble point to see if flashing even needs to be done.

Can use depreister charts

DP $\Rightarrow \sum \frac{y_i}{K_i} = 1$ ← iterate until this is true

BP $\Rightarrow \sum K_i x_i = 1$

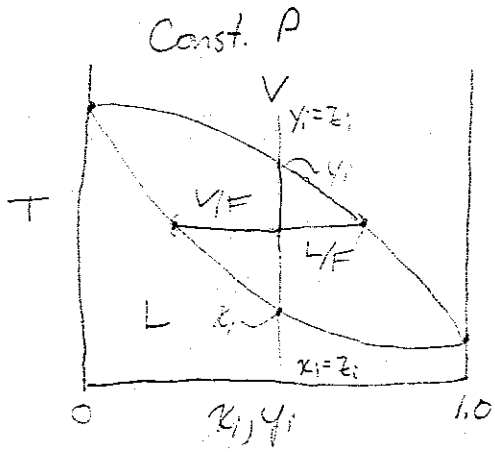
Mass Balance

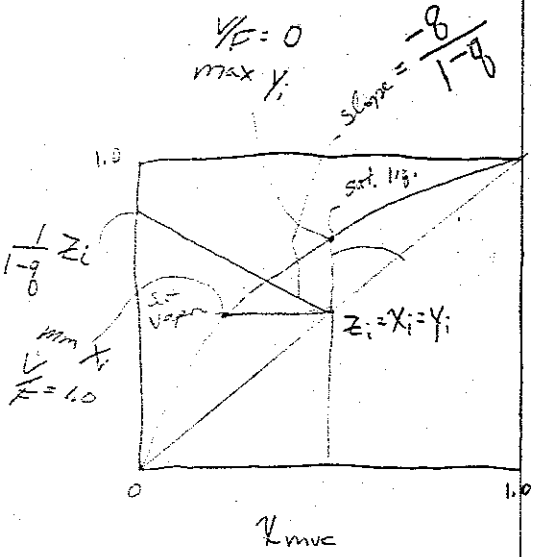
$F = L + V$ Basis: $F = 1$ so, $1 = V + L$

$F z_i = V y_i + L x_i$

$1(z_i) = V y_i + (1-V) x_i$

$\frac{V}{F} = \frac{z_i - x_i}{y_i - x_i}$ ⇐ reverse lever Rule





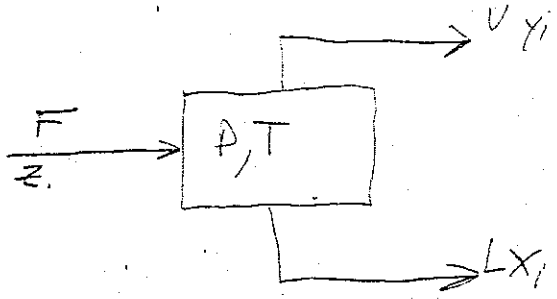
Feed fraction vaporized = $f = V/F$

Feed fraction remaining liquid = $q = L/F$

$y = -\frac{L}{V} x + \frac{F}{V} z$ $\quad \frac{L}{V} = \frac{q}{1-q}$ $\quad \frac{F}{V} = \frac{1}{1-q}$

use graph to find x_i & y_i for a given V/F

For Flash drum: Find flow rates & compositions



find K_i from depression Charts

given F & z_i

use Rachford-Rice equation to find V/F using trial and error. eqn. (3-29)

find x_i from eqn. (3-25)

find $y_i = K_i x_i$

Newton-Raphson method for better V/F

Rachford Rice equation –

$$f\left(\frac{V}{F}\right) = \sum_{i=1}^{c} \frac{(K_i - 1) z_i}{1 + (K_i - 1)\frac{V}{F}} = 0 \qquad \frac{df}{d(V/F)} = -\sum_{i=1}^{c} \frac{(K_i - 1)^2 z_i}{[1 + (K_i - 1) V/F]^2}$$

$$\left(\frac{V}{F}\right)_{new} = \left(\frac{V}{F}\right)_{old} + \frac{f(\frac{V}{F})}{df/d(V/F)}$$

$$\left(\frac{V}{F}\right)_{new} = \left(\frac{V}{F}\right)_{old} + \frac{\sum\left[\frac{(K_i - 1) z_i}{1 + (K_i - 1) V/F}\right]}{\sum\left[\frac{z_i (K_i - 1)^2}{[1 + (K_i - 1) V/F]^2}\right]}$$

Same approach is use for TBP

Multicomponent Distillation:

Four equations for CMO

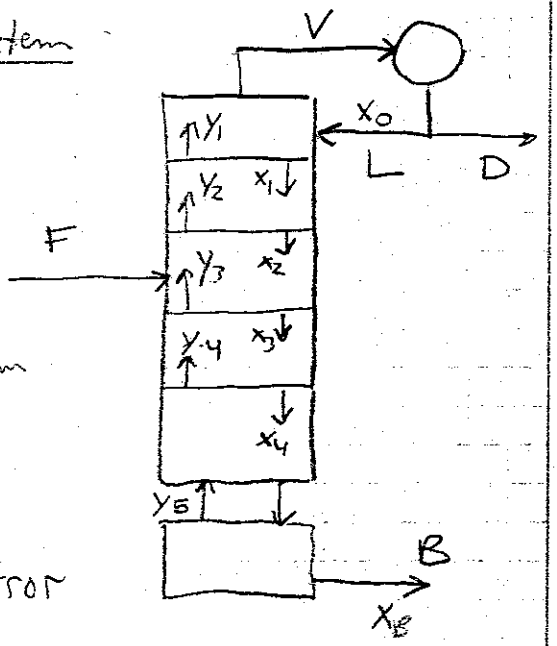
(1) Mass balance on each stage
(2) equilibrium K relation
(3) total liquid on each stage is saturated $\Sigma y_i = 1.0$
(4) Enthalpy balance on each stage

Steps for CMO Multicomponent System

(1) Get traffic in column
(2) Guess T on every stage
(3) Calculate k_i on every stage $k_i = (T, P)$
(4) Write CMB for Component 1 on each stage
(5) Solve for x_i for component 1 using Matrix Method

$$\begin{bmatrix} & \end{bmatrix}\begin{bmatrix} \end{bmatrix} = \begin{bmatrix} \end{bmatrix}$$ Thomas Algorithm

(6) solve for all components
(7) See if $\Sigma x_i = 1.0$ & $\Sigma y_i = 0$
(8) if $T \neq T_{act}$ use Newtons Method with error functions to correct T



Short Cut Method: (Good Starting point for more rigorous approach)

Step 1: (determine R_{min} by the Underwood equation)

(a) Define light & heavy key as the most & least volatile components present in appreciable amounts in both Distillate & Bottoms

Ex: C_6H_6 C_6H_5Cl $pC_6H_4Cl_2$ $oC_6H_4Cl_2$

for this system C_6H_6 = Lk (Light key)

C_6H_5Cl = HK (heavy key)

b) define relative volatilities α_j, base upon heavy key

$$\alpha_j = K_j/K_{hk} = \frac{P_j^\circ/P}{P_{hk}^\circ/P} = \frac{P_j^\circ}{P_{hk}^\circ}$$

P_j° & P_{hk}° are Estimated at T_{avg}

Bubble point calculation on distillate $\sum y_i = 1.0$ $BP = T_D$
Bubble point calculation on bottoms $BP = T_B$

$$T_{avg} = (T_D + T_B)/2$$

(C) Solve equation (48) for ϕ & use ϕ in eq. (49)

$$\sum_j (\alpha_j z_{jF} F)/(\alpha_j - \phi) = F(1-q)$$

Should only be one value for ϕ if no components exist between light & heavy key components

Use $$\sum_{j=lk}^{hk} \frac{\alpha_j x_{jD} D}{\alpha_j - \phi} = D(R_{m+1})$$ (underwood Equation)

Solve for R_{min}

2) Determine Minimum # of Trays using The Fenske Equation

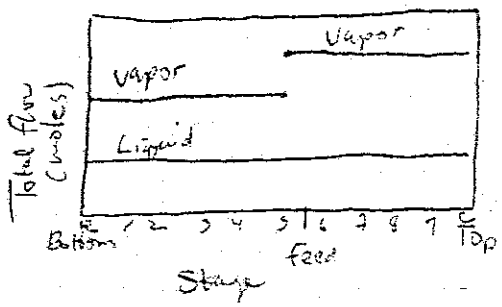
$$N_{m+1} = \frac{\ln\left[\left(\frac{x_{lk} D}{x_{hk} D}\right)\left(\frac{x_{hk} B}{x_{lk} B}\right)\right]}{\ln \alpha_{lk\,AV}}$$

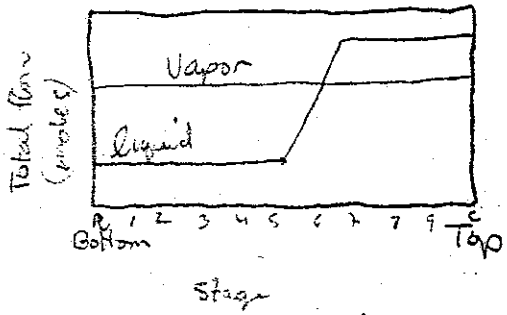
$$\alpha_{lk\,av} = \left(\alpha_{lk}^{top}\ \alpha_{lk}^{Bottom}\right)^{0.5}$$ ← temp will vary @ to & bottom so use this equation

3) Estimate a realistic reflux ratio $1.25 \times R_{min}$

4) Use Gilliland's Correlation to estimate actual # of plates (Figure 5) of Short cut Method handout

Multi Component Distillation Graphs

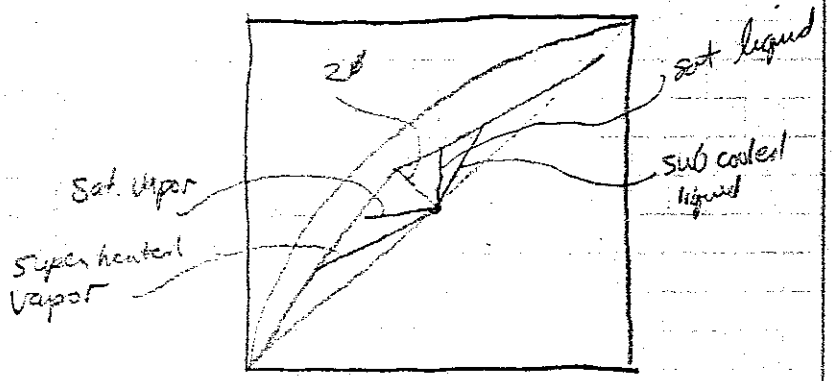




Sat. Vapor Feed

Sat. liquid Feed

if 2Ø liquid will decrease & vapor will increase



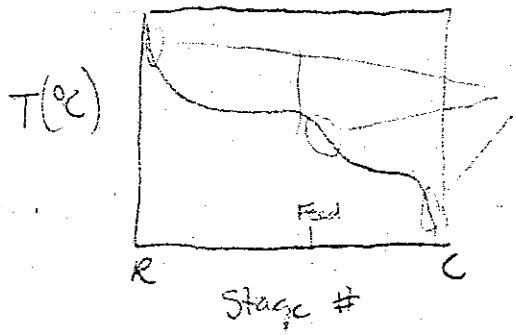
Feed lines for McCabe Thiele

$$\text{Slope} = \left(\frac{q}{q-1}\right)$$

$$q = \frac{L}{F}$$

lower enthalpy is always better

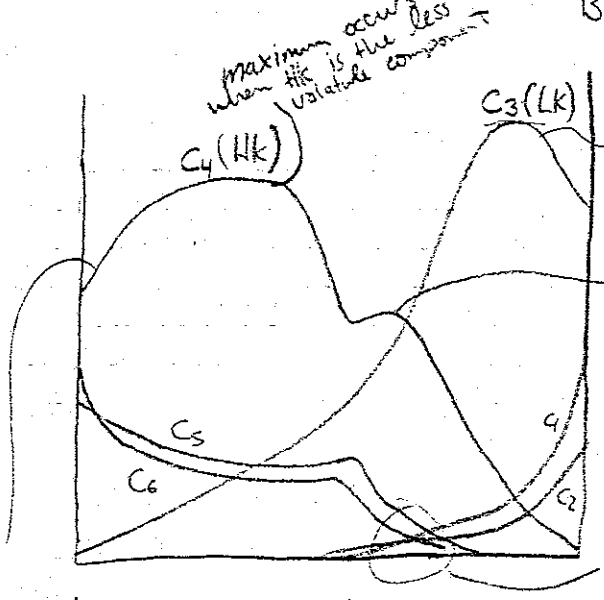
Multicomponent Distillation Graphs Cont.



largest composition changes

Composition Changes:

Mutticomponent: 1) Top 2) Bottom 3) Feed
Binary: 1) Rectifier 2) Stripper



max occurs just before both LNK's increase rapidly in concentration

new max is because heavy key components are dropping fast

HNK don't go directly to zero because of Feed

Heavy key increases because it is more volatile than C_5 & C_6

Pages 225-227