If ideal,

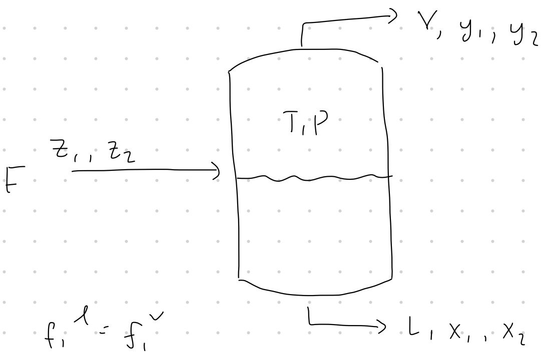
what method = how to calculate K value

$x_1 P_1^* = y_1 P \qquad K_1 = y_1 / x_1 = P_1^* / P$

$\gamma_1 x_1 P_1^* = y_1 P \qquad K_1 = y_1/x_1 = \dfrac{\gamma_1 P_1^*}{P}$

$x_1 \bar{Q}^l = y_1 \bar{Q}^v \qquad K_1 = \bar{Q}_i^l / \bar{Q}_i^v$

$\gamma_1 x_1 P_1^* = \bar{Q}_i^v P \qquad K_1 = \dfrac{\gamma_1 P_1^*}{\bar{Q}_i^v P}$



$f_1^l = f_1^v$

$f_v^l = f_2^v$

?

$x_1 P_1^* = y_1 P \qquad K_1 = P_1^*$

$x_2 P_2^* = y_2 P \qquad K_2 = P_2^*/P$

$z_1 = x_1 L + y_1 V$

$z_2 = x_2 L + y_2 V$

$x_1 + x_2 = 1.0$

$y_1 + y_2 = 1.0$

$K_1 = y_1 / x_i \quad \therefore \quad y_1 = K_1 x_1$

$z_1 = x_1 [L + K_1(1-L)]$

$z_2 = x_2 L + K_2 x_2 (1-L)$

$x_1 + x_2 = 1.0$

$y_1 + y_2 = 1.0$

$\therefore \quad x_1 = \dfrac{z_1}{L + K_1(1-L)}$

$x_2 = \dfrac{z_2}{L + K_2(1-L)}$

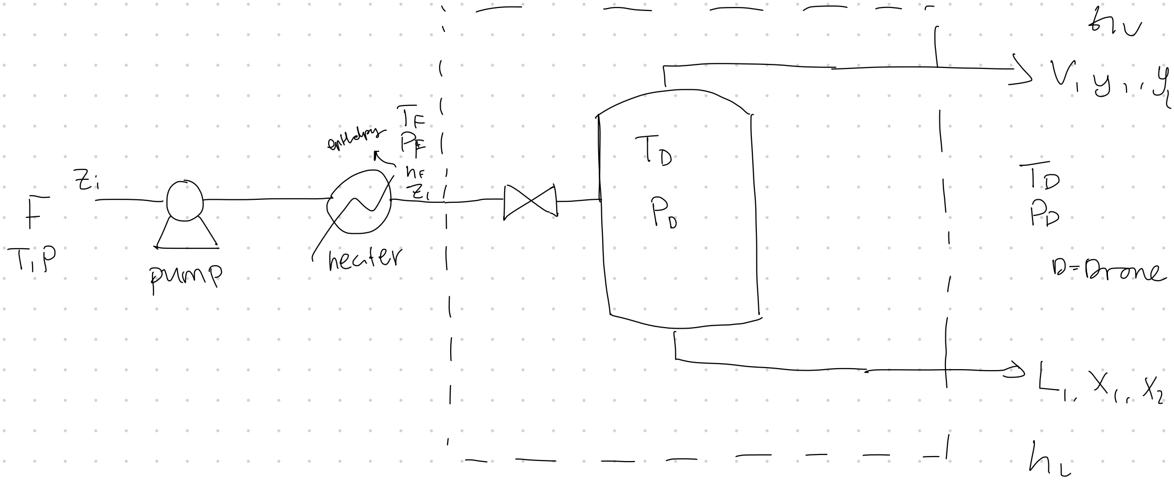
$x_1 + x_2 = 1.0$

$y_1 + y_2 = 1.0$

$\sum \dfrac{z_i}{L + K_i(1-L)} = 1.0$

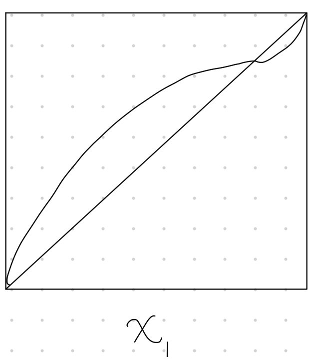
$\sum \dfrac{K_i z_i}{L + K_i(1-L)} = 1.0$

$\sum \dfrac{(1-K_i)}{L + K_i(1-L)} = 0.0 \quad F(L) = 0$

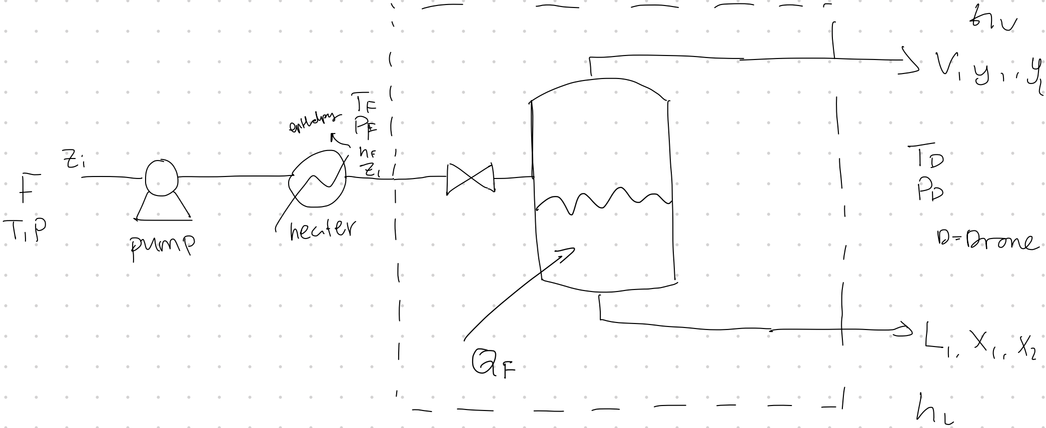


at P: 1 atm

$X_{F,EtOH}$	Y_{EtOH}	T
0.0	0.0	100
0.8943	0.8943	78.15
1.0	1.0	78.3

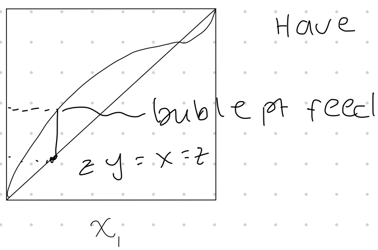


fu 08/27



$F = L + V$

$z = xL + yV$



Have data

$$y = -\frac{L}{V}x + \frac{F}{V}z \qquad \text{operating line}$$

@ $y = x = z$

$$y = \frac{1-f}{f}x + \frac{z}{f}$$

$$y = \left(\frac{-\varepsilon}{q+1}\right) + \left(\frac{1}{1-\varepsilon}\right)z$$

(quality)

f = fraction vaporized

$f = \frac{V}{F}$

q = $\underbrace{\text{fraction liquid}}_{\varepsilon\text{-bal.}}$ $\frac{L}{F}$

Bubble pt feed $V = 0$ $L = 1$

$$\frac{V}{F} = 0 \qquad \frac{L}{V} = \frac{F}{0} = \infty$$

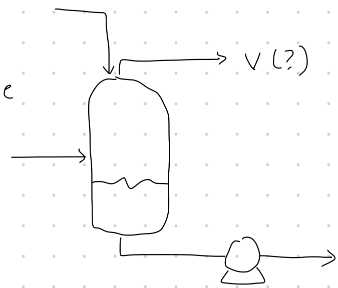
Assignment #1 08/30

From Thermo 2, solve flash problem use ASPEN

V, L

- Size vessel
- Din ~ vapor traffic
  max vapor velocity

Gives us molar flow rate



Can determine u (max velocity) in the drone.

$$u = K_{drum} \sqrt{\frac{\rho - \rho_v}{\rho_v}} \quad (ft/s)$$

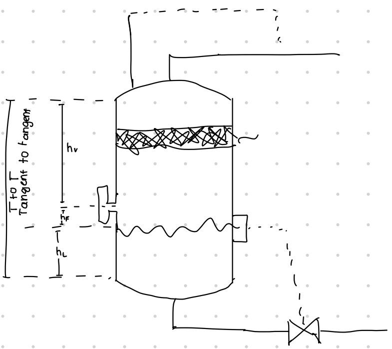
↳ empirically determine

$$K_{drum} = \exp\left[A + D \ln F_{1v} + C(\ln F_{1v})^2 + D(\ln F_{1v})^3 + E(\ln F_{1v})^4\right]$$

$$F_{lv} = \frac{\omega_L}{\omega_V}\sqrt{\frac{\rho l}{\rho v}} \qquad W: \text{mass flow rate}$$

gives ≃ 5% entraintment (carries over liquid)

Use rebuty? u (ft/sec) and V (ft^3/sec)



Area of drum (din)

V (ft^3/s) u = ft/s

$$A = \frac{V}{u} = ft$$

$$D = \sqrt{\frac{4A}{\pi}}$$

Din from vap. vel

height??

rule of thumb

[Typical $L/D \approx 4-5$]

TtT
$$\begin{cases} h_v = 3' + \frac{1}{2} Din & \text{minimum} \\ h_f = 1' + \frac{1}{2} Din & \\ h_L = \text{from liquid} & 3.5 \end{cases}$$

b. of drum - up

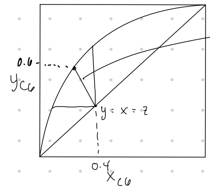
' foot

check L/D if it's 4-5

Work out Ex 2-4 Pg 47!

Use ASPEN!

Watch some tutorials



09/01

ASPEN HW

1) Calc L, V from flash

$L \equiv$ mole/hr $\Rightarrow ft^3/s$
$V \equiv$ mole/hr $\Rightarrow ft^3/s$

2) Cal max velocity $u = K_{drum}\sqrt{\frac{\rho - \rho_v}{\rho_v}}$ ft/sec

3) calc area of drum $\equiv \frac{V\ (ft^3/sec)}{u\ (ft/sec)}$ = area (ft^2)

$D_{in} \Rightarrow ft$

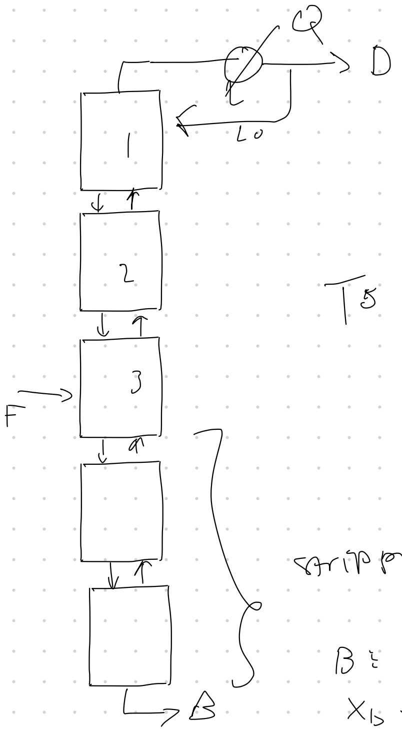
4) $h = h_v + h_f + h_L$

$h_v = 3' + \frac{1}{2} D_{in}$
$h_f = 1' + \frac{1}{2} D_{in}$
h_L = from liquid b of drum - up

$\therefore \frac{h}{D} \approx 4 - 5$

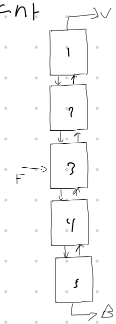
09/01

C.3 ish



D = distillate product

constant P

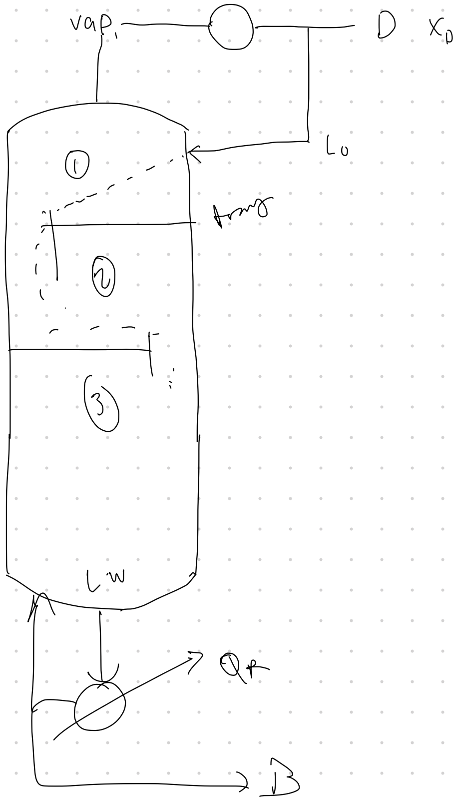


$T_5 > T_4 > \dots T_1$

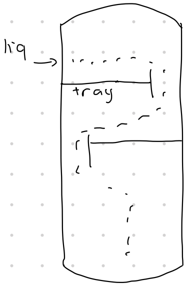
stripping action

B = bottom product

x_B = bottom y composition

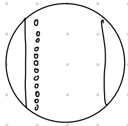

vap,
D x_D
L_0
1
trays
2
3
Lw
Q_R
B

09/03



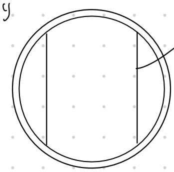
Tray

sieve-tray (cheapest) → not best

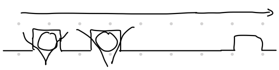


diameter/number of holes based on vapor traffic (volum. flow, velocity)

Tray

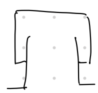


valve tray



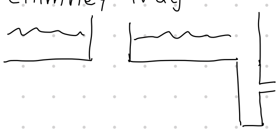
not the most efficient

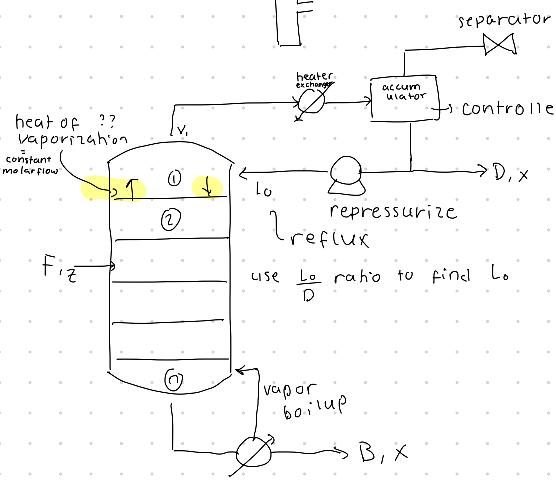
cap tray



distance is imp. for velocity

Chimney tray





controlled P, but it's low

use $\frac{L_0}{D}$ ratio to find L_0

D = distillate

X_D = distillate component

B = bottoms

B_x = bottoms composition

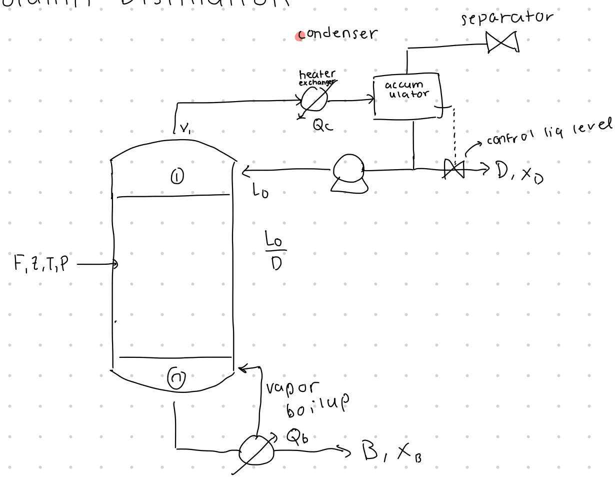
L/D = reflux ratio

L_0 = reflux

$Q = UA(T_1 - T_2)$

Column Distillation

09/08



In Designing Column Specify:

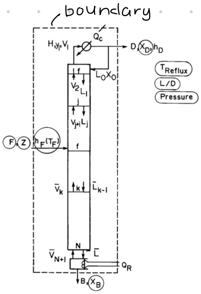
- Pressure of the column   ✩constant✩
- Feed conditions   ex: sat'd liq, sat'd vap
- reflux L_0 (condition: usually sat'd)
  reflux amt, so L_0/D
- x_D, x_B
- Feed location - at the optimum tray (continue to find the optimum tray)
  - economic analysis

Then, calculate: $D, B, Q_c, Q_b, N, N_{feed}$, column diameter

To simulate, specify:

- N
- Feed plate
- Column diameter
- duty Q_c, Q_b
- specify x_D or x_B
- calc L_0/D to set x_D specify to calc ; recalc when needed
- check $L/D \Rightarrow V$
  check column diam. sufficient for V

3.4 External Column Balance



Mass Balance

$$F = D + B \quad \text{(overall MB)}$$

The more volatile component mass balance:

$$zF = F_z = Bx_B + Dx_D$$

$$D = \left(\frac{z - x_B}{x_D - x_B}\right) F$$

$$B = F - D = \left(\frac{x_D - z}{x_D - x_B}\right) F$$

specified D, x_D, sat'd; T_D, Q_c

Energy Balance:
(around the entire column)

$$Fh_F + \underbrace{Q_c + Q_R}_{\text{unknowns}} = Dh_D + Bh_B$$

Condenser

$y_1 = x_D = x_0$ composition is unchanged

Condenser MB: $V_1 = L_0 + D$

L/D specified .... L_0

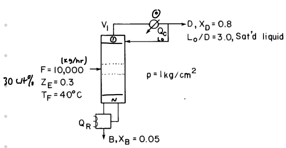
$\therefore$ condenser EB

$$V_1 H_1 + Q_c = (D + L_0) h_D = V_1 h_D$$

$$Q_c = V_1 (h_D - H_1)$$

back to overall EB to calc Q_R

Example 3-1 Ext balances for binary distillation 09/10



Calc D, B, Q_c, Q_R

$F = D + B$

$0.3F = 0.80D + 0.05B$

$D = 3333 \quad B = 6667$

$D = F\dfrac{(z - x_B)}{(x_D - x_B)} = 10{,}000\left[\dfrac{0.3 - 0.05}{0.8 - 0.05}\right] = 3333$ kg/hr

$B = 1000 - 3333 = 6667$ kg/hr

$h_F\ (z = 0.3, 40°C) = 30$ kcal/kg
h_D @ 0.8 sat'd liq = 60 kcal/kg
h_B @ 0.05 sat'd liq = 90 kcal/kg
$h_1\ (y_1 = x_0 = 0.8$, sat'd vap$) = 330$ kcal/kg

} Fig 2-4

$$Q_c = \left(1 + \frac{L_0}{D}\right) D (h_D - h_1) = (1 + 3)\left(3333 \frac{\cancel{kg}}{hr}\right)(60 - 330)\frac{kcal}{\cancel{kg}}$$

$$= -3{,}559{,}640 \text{ kcal/hr}$$

Total energy balance

Q_R: 4099 650 kcal/hr

$Q_R = Dh_D + Bh_B - Fh_F - Q_c$
$= (3333)(60) + 6667(90) - 1000(30) - (-3559640)$
$= 4099\ 650$ kcal/hr

Sat'd liq

$h_F = 80$ kcal/hr

$Q_C = -3559,640$ kcal/hr

$Q_R = 3599650$ kcal/hr

Sat'd vapor

$h_F = 375$ kcal/hr

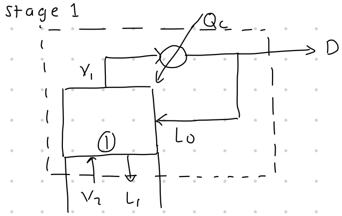
$Q_C = -3559640$ kcal/hr

$Q_R = 649,650$ kcal/hr

09/10

Chapter 4

Internal Stage by stage Balance



Overall mass balance:

$V_2 = L_1 + D$

more volatile component mass balance:

$L_1 x_1 + D x_D = V_1 y_2$

Energy balance (well-insulated, adiabatic column)

$V_2 H_2 + Q_C = L_1 h_1 + D h_D$

Degrees of freedom f:

$f = C + 2 - P$

$= 2 + 2 - 2$

$= 2$

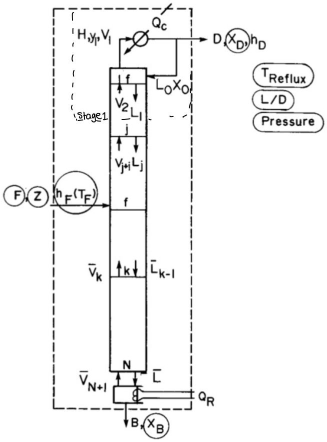
If $P = 1$ atm $f = 1$

sat'd ovhd product

$\therefore f = 0$ calc everything

☆ Assume that each stage is at eqm.

→ liq, vap leaving the stage are at eqm

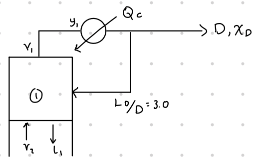


h_F, h_D, h_B, H from data

$h(x_1)$ $H(y_1)$

$y = K(x_1)$

Internal Column Balance

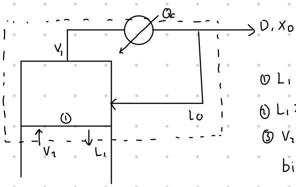


know: $V_1 = L_0 + D$

$y_1 = x_D$

x_1 from data

stage N $x_B = 0.05$



① $L_1 = V_2 + D$ overall mass balance

② $L_1 x_1 + D x_D = V_2 y_2$ more volatile comp. MB

③ $V_2 H_2 + Q_c = L_1 h_1 + D h_D$ EB (well-insulated, adiabatic column)

binary $C = 2$ $P = 2$ $\therefore f = 2$ (degrees of freedom)

↳ specify column pressure

④ $y_1 = K(x_1)$

⑤ $h = h(x_1)$

⑥ $H = H(y_1)$

6 eqns unknown 1st stage

solve then go to the stage below

Stage 2 EB

$V_3 = L_2 + D$

$V_3 y_3 = L_2 x_2 + D x_D$

$Q_c + V_3 H_3 = L_2 h_2 + D h_D$

$h_2 = h(x_2)$

$y_2 = K(x_2)$

$H_3 = H(y_3)$

$V_{j+1} = L_j + D$

$V_{j+1} y_{j+1} = L_j x_j + D x_D$

$Q_c + V_{j+1} H_{j+1} = L_j h_j + D h_D$

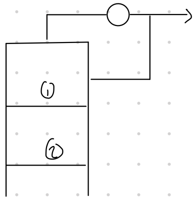
$h_j = h_j(x_j)$ $H_{j+1} = H_{j+1}(y_{j+1})$ $x_j = x_j(y_j)$

j down to feed stage

when conditions "match" stage $j+1$

@ feed stage, new mat'l balance

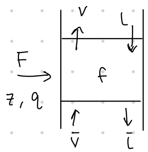
new energy balance eqns



$$V_{j+1} = L_j + D$$
$$V_{j+1} y_{j+1} = L_j x_j + D x_D$$
$$Q_C + V_{j+1} H_{j+1} = L_j h_j + D h_D$$

$$h_j = h(x_j)$$
$$H_{j+1} = H(y_{j+1})$$
$$x_j = x(y_j)$$

@ Feed stage mat'l balance / energy balance change



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

q: sat'd liq
↳ $\bar{L} = L + F$
$\bar{V} = V$
$q = 1$

if q = sat'd vapor
$V = \bar{V} + F$
$\bar{L} = L$
$q = 0$

subcooled liq $q > 1$
superheated vap $q < 1$

Stripping section (bottom of the column)

$$\bar{V}_K = \bar{L}_{K-1} - B$$
$$\bar{V}_K y_K = \bar{L}_{K-1} x_{K-1} - B x_B$$
$$\bar{V} H_K = \bar{L}_{K-1} h_{K-1} - B h_B + Q_R$$

$$h_{K-1} = h(x_{K-1})$$
$$H_K = H(y_K)$$
$$x_{K-1} = x(y_{K-1})$$

Lewis Method
$L \equiv$ nearly constant
$V \equiv$ nearly constant
$\bar{L}$ = constant
$\bar{V}$ = constant

1. Column is adiabatic
2. Sensible heat "small" relates to the latent heat
3. Heat of vaporization is constant
4. Constant molal overflow (CMO)

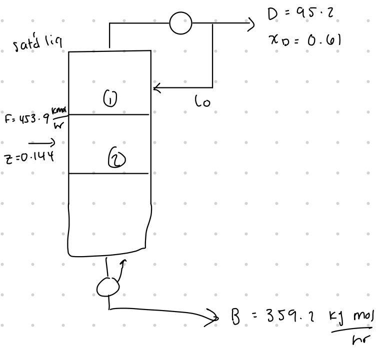
$$\therefore V_{j+1} y_{j+1} = L_j x_j + (V_{j+1} - L_j) x_D$$
$$V y_{j+1} = L x_j + D x_D$$
$$y_{j+1} = \frac{L_j}{V_{j+1}} x_j + \left(1 - \frac{L_j}{V_{j+1}}\right) x_D$$

$$y_{j+1} = \frac{L}{V} x_j + \left(1 - \frac{L}{V}\right) x_D$$

→ always w/ equilibrium
→ top operating eqn

$$y_K = \frac{\bar{L}_{K-1}}{\bar{V}_K} x_{K-1} - \left(\frac{\bar{L}_{K-1}}{\bar{V}_K} - 1\right) x_B$$

w/ CMO $y_K = \left(\frac{\bar{L}}{\bar{V}}\right) x_{K-1} - \left(\frac{\bar{L}}{\bar{V}} - 1\right) x_B$



$L/D = 3$

how many stages? $x_B = 0.02$

$$L = \frac{L}{D}\cancel{D} = 3(95.23) = 285.7 \ \frac{kgmol}{hr}$$

$$V = L_0 + D = 285.7 + 95.2 = 380.9$$

$$\frac{L}{V} = \frac{285.7}{380.9} = 0.75$$

$$y_{j+1} = \frac{L}{V} x_j + \left(1 - \frac{L}{V}\right) x_B$$

$$= \frac{285}{380} x_j + \left(1 - \frac{285}{380}\right) x_B$$

$$= 0.95 x_j + (1 - 0.25) x_B$$

---

stripping section

sat'd liq

$$\bar{L} = L + F \qquad \bar{V} = V$$

$$= 285 + 453.9$$

$$= 739.6$$

$$y_K = \left(\frac{\bar{L}}{\bar{V}}\right) x_{K-1} - \left(\frac{\bar{L}}{\bar{V}} - 1\right) x_D$$

$$= 1.94 x_{K-1} - 0.942 x_B$$

① Top of column
$y_1 = x_D = 0.61$

$x_1 =$ from quality $= 0.4$

② $y_2 = 0.75\, x_1 + 0.25\,(x_D) = 0.453$

from quality
$x_2 = 0.11$

③ $y_3 = 1.942\, x_2 + (-0.942)\, x_B$
$= 0.195$

$x_3 = x_B$
$= 0.02$

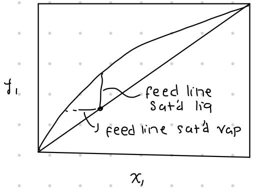
09/17

Lewis Method

CMO, adiabatic

$y = \frac{L}{V}x + \left(1 - \frac{L}{V}\right)x_D$

$y = K(x)$

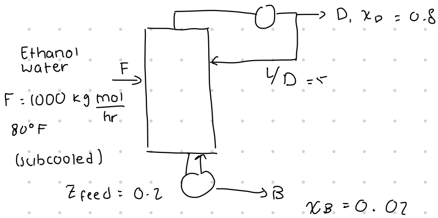


$y = \frac{L}{V}x + \frac{F}{V}t$

quality $q = \frac{H - h_f}{H - h}$

slope of feed line $\frac{L}{V} = \frac{q}{q-1}$

McCabe-Thiele Method (solve this w/ ASPEN)



Find feed plate location!

N stages?

Feed subcooled

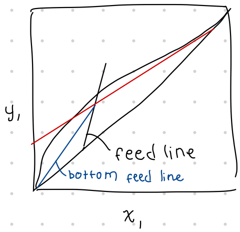
$h_F = 25$ Btu/lb

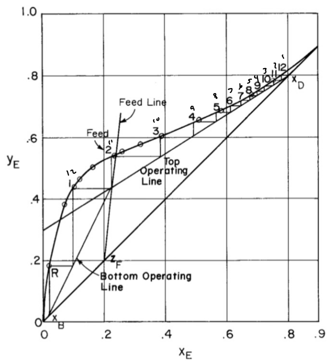
$H_v = 880$ Btu/lb

$h = 125$ Btu/lb

$q = \frac{880 - 25}{880 - 125} = 1.13$

$y = x = z$





Top operating line

$y = \frac{L}{V}x + \left(1 - \frac{L}{V}\right)x_D$

$\frac{L}{V} = \frac{L/D}{1 + L/D} = \frac{5/3}{1 + 5/3} = 5/8$ (slope)

$x = 0$ $y = 0.3$

y intercept $= \left(1 - \frac{L}{V}\right)x_D = (3/8)(0.8) = 0.3$

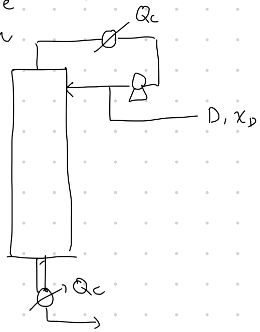
Bottom operating line

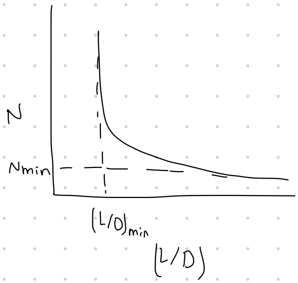
$y = \frac{\bar{L}}{\bar{V}}x - \left(\frac{\bar{L}}{\bar{V}} - 1\right)x_B$

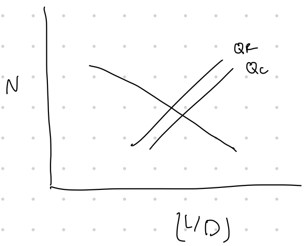
calc slope from mat'l balance

add these to HW!

What we can do on ASPEN

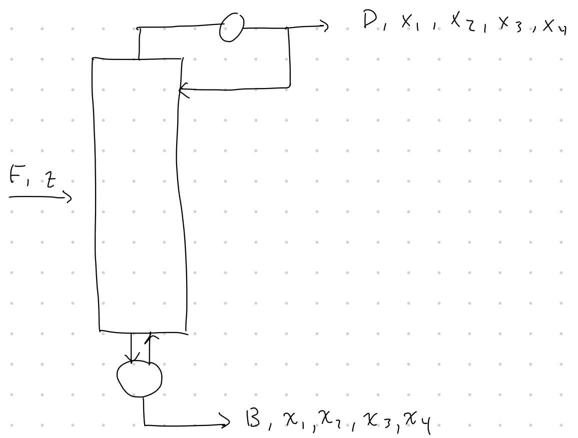






N @ 1.5 $(L/D)_{min}$
2 $(L/D)_{min}$
3 $(L/D)_{min}$

Hw 3 Example 5-1 pg. 164
using Radfrac/ Peng Robinson



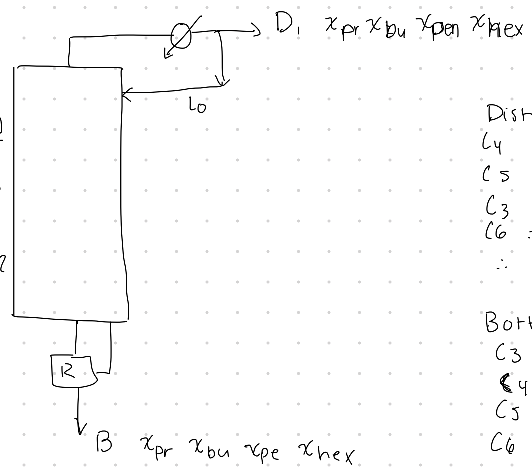
- Calculate D and B
- Specify L_0
- Calc mat'l balance condenser
- Stage 1, calc
- Stage 2, calc

Can't specify $x_{distillate}$ anymore
Typically specify key component in distillate
- light key (most volatile)
- heavy key (least volatile)

- light nonkey - if a nonkey is more volatile (lighter) than the light key.
- heavy non key - if it is less volatile (heavier) than the heavy key.

Example 5-1

99.4% C4



$F = 2000 \frac{kgmol}{hr}$

$z_{prop} = 0.056$ (C3)
$z_{but} = 0.321$ (C4)
$z_{pent} = 0.482$ (C6)
$z_{hex} = 0.141$ (C5)

$C_3 = 112 \frac{mol}{hr}$
$C_4 = 642$
$C_5 = 964$
$C_6 = 282$

99.7% C5 recovered

Distillate
C_4 $(0.9940)(2000)(0.321) = 638.5$
C_5 $(0.003)(2000)(0.482) = 2.89$
C_3 $(2000)(0.056) = 112$ +
C_6 : 0
$\therefore$ D = 753

Bottom
$C_3 = 0$
C_4 3.85
$C_5 = 961$
$C_6 = 282$
1250