4-1

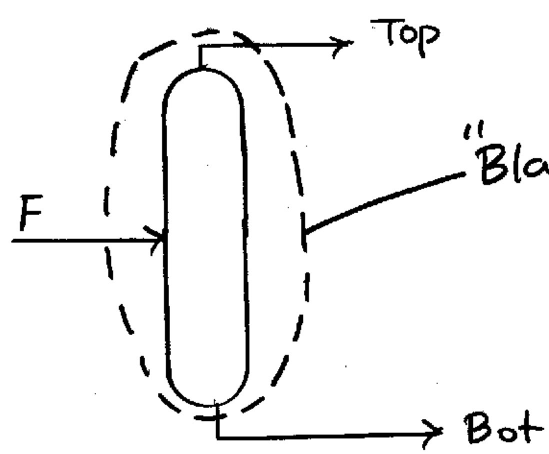
Distillation Cascades (stages)

A cascade consists of two basic operations

(1) Mixing dissimilar materials (to allow for "heat exchange"
"mass exchange"
"elimination of numerous intermediate product streams"

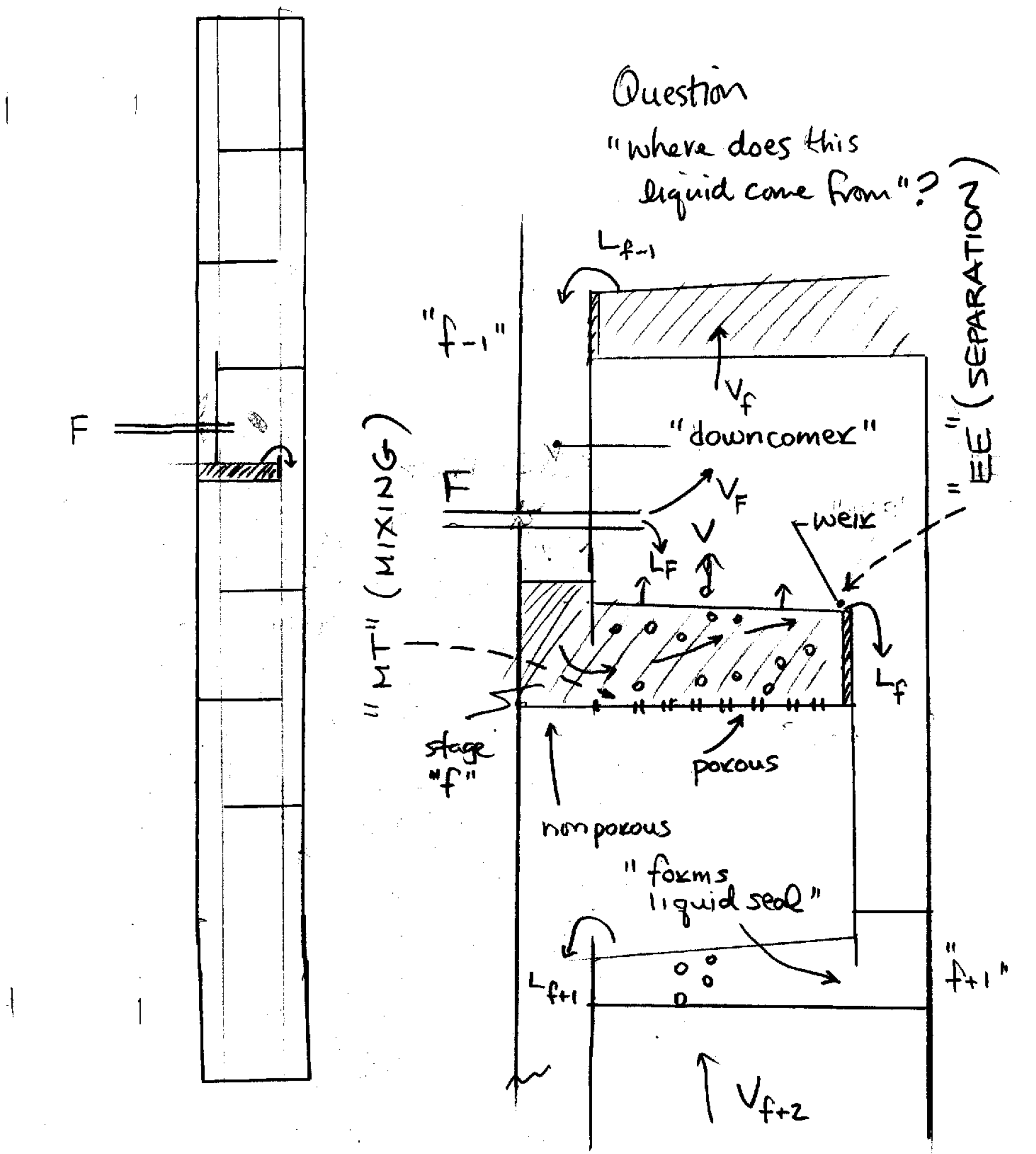
(2) Separating equilibrium materials (usually via gravity)

The exact pattern of these various mixing & separating operations is essential to the effective separation of the process feed into the process products.



4-2

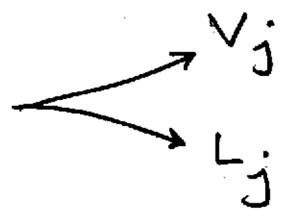
Looking inside the "box"



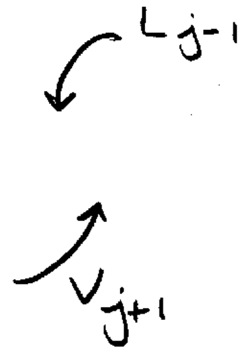
Question
"where does this vapor come from"?

4-3

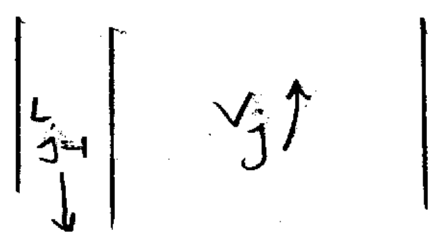
~~EE~~:
on jth
stage



MIXING:
on jth
stage



PASSING
(Non contacting)
j^{th} stage



When the stages have no significant heat exchange (stage heater, stage cooler) we have adiabatic operation as per Figure 5.13 (p 248) [4-3a]

Typically there are 5 zones (different sets of equations) F 5.14 (p249) [4-3b]

4-4

Also discuss

Fig 6.3	4.4a
Fig 6.5	4.4b
Fig 4-7 (Wankat)	4.4c

Distillation columns come in several "standard types" (see Table 5.2 p259, Table 5.2 p 260) and an infinite number of "special configurations" (see Fig 5.18, p 261).

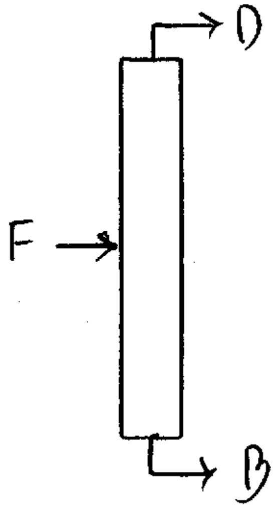
Table 5.2 (4.4d)
Fig 5.18 (4.4e)

4-5

p 359

McCabe Thiele Graphical Method

See (4-5a) for Nomenclature.



External Balances (Overall Column)

TMB: $F = B + D$

MVC MB: $Fz = Bx_B + Dx_D$

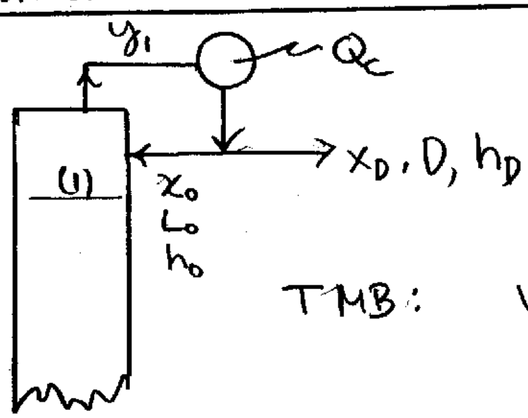
$\therefore$ if x_B & x_D are known we can find B & D (product rates)

for example

$$D = \left(\frac{z - x_B}{x_D - x_B}\right) F \qquad \text{(p 362)}$$

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

Consider a total condenser (TC) See 4-5C



Note $R = \frac{L_0}{D}$

TMB: $V_1 = L_0 + D$

$= \frac{L_0}{D}(D) + D = \left(1 + \frac{L_0}{D}\right) D$

EB: $V_1 h_1 + Q_c = D h_D + L_0 h_0$

but $h_0 = h_D$ & $x_0 = x_D$

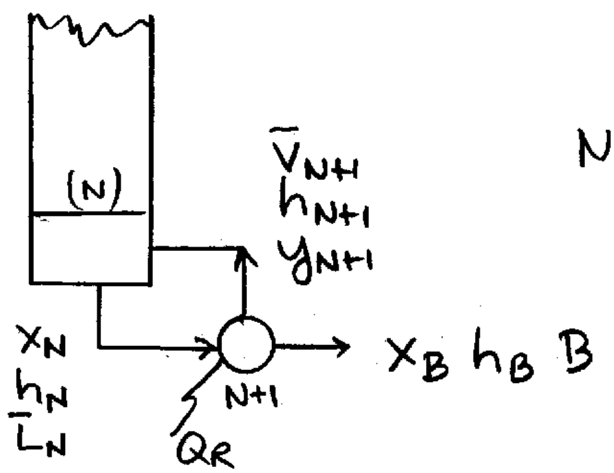
4-6

$\therefore Q_C = h_D(D+L_0) - V_1 h_1$

$Q_C = V_1(h_0 - h_1) = V_1 \lambda$

Consider a partial reboiler (PR)

See 4-6 a

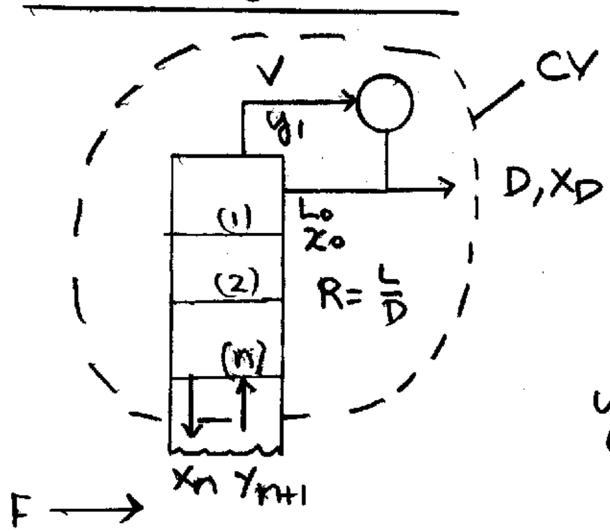


Note $V_B = \frac{\bar{V}}{B}$

TMB: $\bar{L}_N = \bar{V}_{N+1} + B$

EB: $\bar{L}_N h_N + Q_R = \bar{V}_{N+1} h_{N+1} + B h_B$

Rectifying section (above feed) 4-5c



MVC MB:

$$V_{n+1} y_{n+1} = L_n x_n + D x_n \qquad (7\text{-}4)$$

$$\therefore y_{n+1} = \frac{L_n}{V_{n+1}} x_n + \frac{D}{V_{n+1}} x_D \qquad (7\text{-}5)$$

4-7

If we can assume

$$L_0 = L_1 = L_2 = L_n = L_{n+1} \; \ldots \; = L$$
$$V_1 = V_2 = V_3 = V_n = V_{n+1} \; \ldots \; = V$$

Then $y = \frac{L}{V} x + \frac{D}{V} x_D$ (7-6)

"TOL" (top op line)

with slope, y-int, x-int

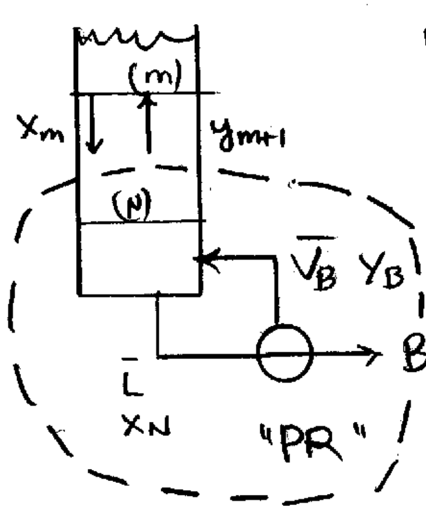
and $x = y = x_D$

Note: $\frac{L}{V} = \frac{L}{L+D} = \frac{L/D}{L/D + D/D} = \frac{R}{R+1}$ (7-7)

and $\frac{D}{V} = \frac{D}{L+D} = \frac{1}{R+1}$ (7-8)

$\therefore \; y = \left(\frac{R}{R+1}\right) x + \left(\frac{1}{R+1}\right) x_D$ (7-9)

Stripping section (below feed) 4-6 a



MVC MB: $\bar{L} x_m = \bar{V} y_{m+1} + B x_B$ (7-10)

$\therefore \; y_{m+1} = \frac{\bar{L}}{\bar{V}} x_m - \frac{B}{\bar{V}} x_B$ (7-11)

$y = \frac{\bar{L}}{\bar{V}} x - \frac{B}{V} x_B$ (7-11b)

4-8 Also

$$y = \left(\frac{V_B+1}{V_B}\right)x + \left(\frac{1}{V_B}\right)x_B \quad (7\text{-}14)$$

"BOL" (Bottom op line)

Taken as a whole, we have

Figure 7.4 4-8a

Consideration of the Feed Stage

5 possible feed states exist

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

or $q = 1 + \frac{\bar{V}-V}{F}$

$q > 1$ Subcooled liquid

$q = 1$ Sat'd "

$0 < q < 1$ mixture V & L

$q = 0$ Sat'd Vapor

$q < 0$ superheated Vapor

see Fig 7.7 4-8b

Fig 7.8 4-8c

4-9

McCabe Thiele Method (cont)

Note also

$$q = \frac{h_V - h_F}{h_V - h_L} \qquad (7\text{-}20)$$

where h_V = enthalpy of feed if vapor
h_L = " " " " liquid

If one makes a MB (MVC) for the feed stage (f) itself, we can show

$$y = \left(\frac{q}{q-1}\right)x - \left(\frac{z_F}{q-1}\right) \qquad 7\text{-}26$$

(FOL) feed op line

Again, viewing 4-8a Fig 7-4, note all three op lines intersect at a common point.

Determination of N (number equilibrium stages) and N_F (optimum feed stage location).

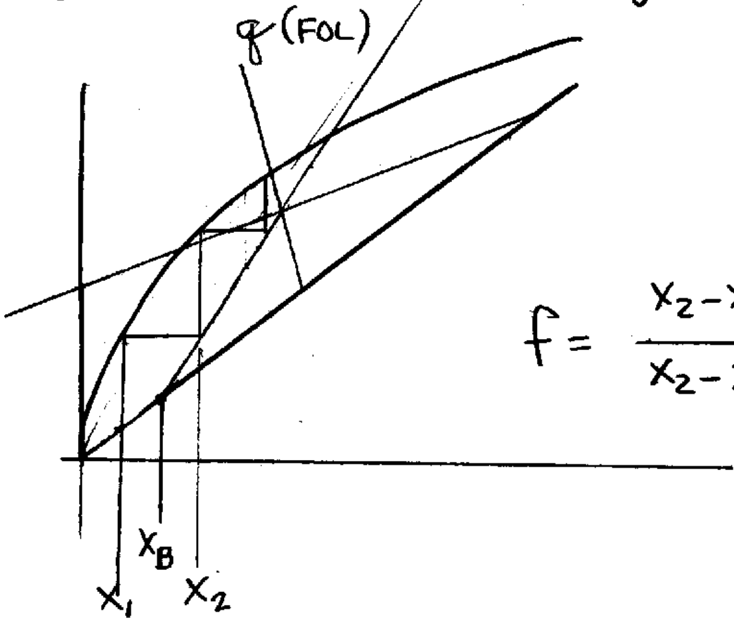
(p 369)

1. Step down from x_D to x_B (switching at N_f)

4-10

2. Step up, starting at x_B to x_D (switching at N_f)

In either case, one will probably <u>not</u> use an integral (whole) number of stages, (Estimate the last stage as a fraction)



$$f = \frac{x_2 - x_B}{x_2 - x_1}$$

known