DISTILLATION WITH REFLUX

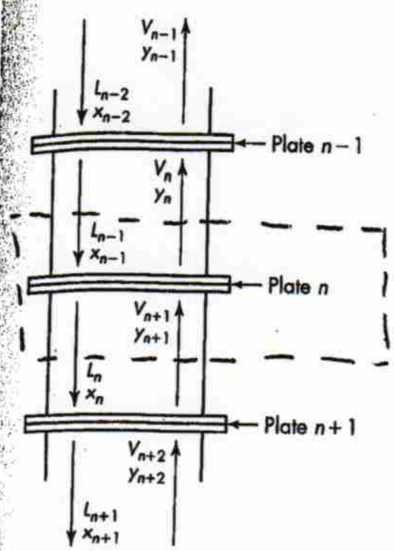


FIGURE 21.3
Material-balance diagram for plate n.

Review of Columns

Around plate n

- Vapor leaving plate y_n
- Liquid leaving plate x_n
- Vapor entering plate y_{n+1}
- Liquid entering plate x_{n-1}

Material balance (Operating Line) : All four streams

EQUILIBRIUM : y_n and x_n

MATERIAL BALANCE CONSIDERS FLOW RATE and COMPOSITION

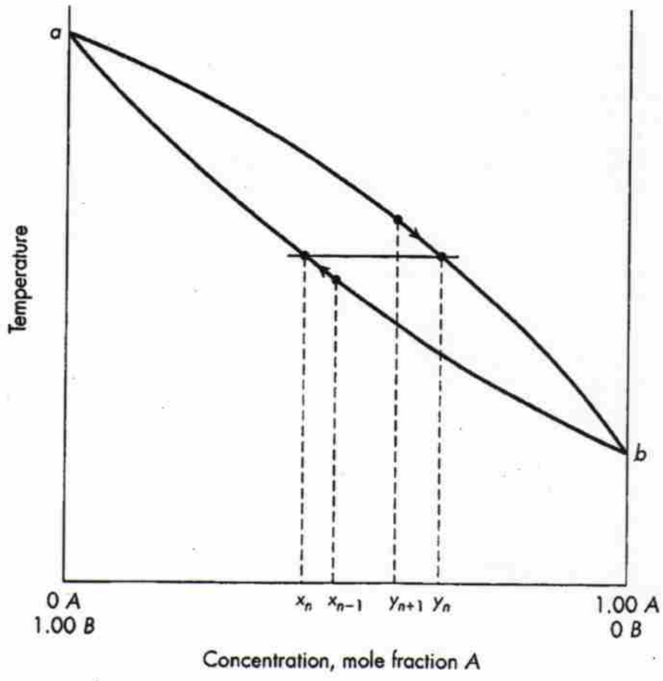


FIGURE 21.4
Boiling-point diagram showing rectification on ideal plate.

As you go up the column:

$T_{n+1} > T_n > T_{n-1}$

TEMPERATURE DROPS

LIGHTER, MORE VOLATILE COMPONENT INCREASES IN MOLE FRACTION

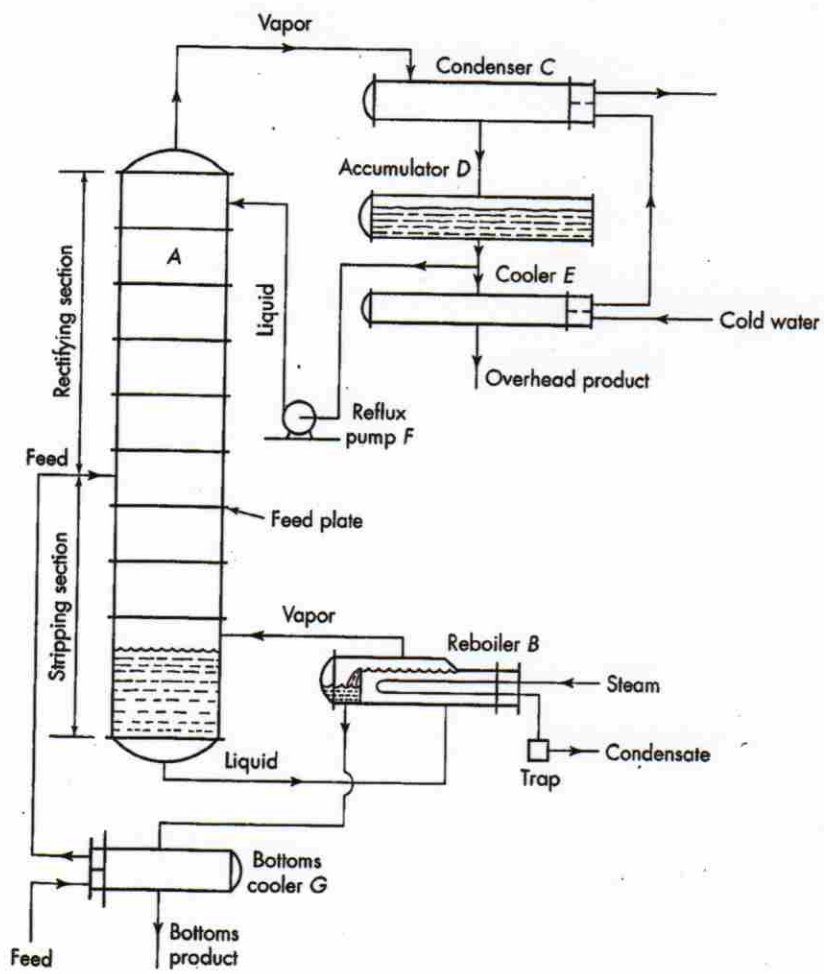


FIGURE 21.5
Continuous fractionating column with rectifying and stripping sections.

- Previously we had a Product stream we wanted to clean and would contaminate another stream to do that.
- Here we have a product feed that we are separating into two valuable streams
- Reboiler creates upward vapor flow
- Condenser creates downward liquid flow
- Above feed plate heavy boiling component is absorbed from vapor into liquid
- Below feed plate light boiling component is stripped from liquid into vapor
- vapor = distillate
- liquid = reflux
- Above feed plate = rectifying
- Below feed plate = stripping

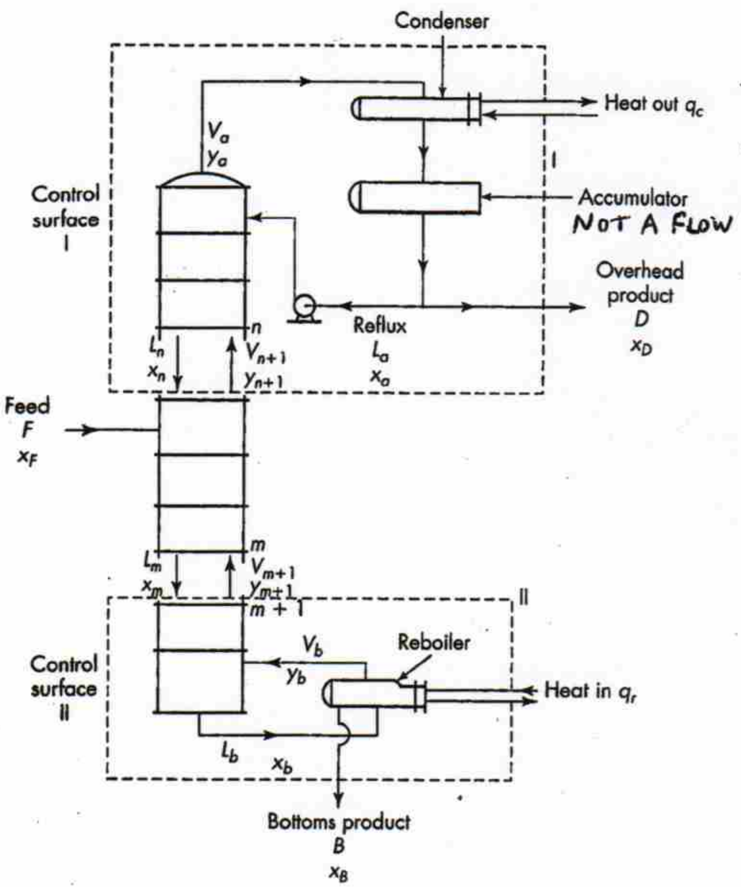


FIGURE 21.6
Material-balance diagram for continuous fractionating column.

MATERIAL BALANCES

ENTIRE PROCESS

Total $F = D + B$

Comp. A $Fx_F = Dx_D + Bx_B$

These combine to give

$$D/F = \frac{x_F - x_B}{x_D - x_B}$$

and

$$\frac{B}{F} = \frac{x_D - x_F}{x_D - x_B}$$

Control Surface I

Just around condenser/accumulator

$$D = V_a - L_a$$

All of Surface I

$$D = V_{n+1} - L_n$$

Component A

$$Dx_D = V_a y_a - L_a x_a$$
$$= V_{n+1} y_{n+1} - L_n x_n$$

D is net flow upward in upper section

D is constant in upper section

Dx_D is constant in upper section

Control Surface II

$$B = L_b - V_b = L_m - V_{m+1}$$

$$Bx_B = L_b x_b - V_b y_b = L_m x_m - V_{m+1} y_{m+1}$$

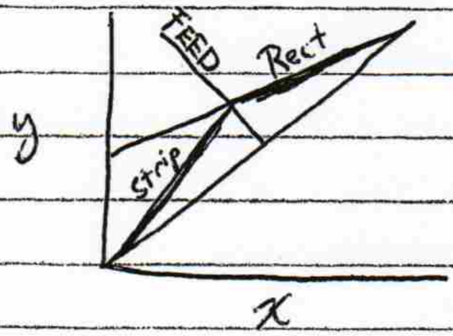
(y_{m+1})

B is net flow downward in lower section

note: in stripping section we use m as plate

B is constant, Bx_B constant in lower section

OPERATING LINES



EACH SECTION HAS IT'S OWN OPERATING LINE!

From the Component A mass balances around each section (see previous page)

Rectifying Op Line

$$y_{n+1} = \frac{L_n}{L_n+D} x_n + \frac{D x_D}{L_n + D}$$

Stripping Op Line

$$y_{m+1} = \frac{L_m}{L_m - B} x_m - \frac{B x_B}{L_m - B}$$

Note: Slope of Rectifying < 1
Slope of Stripping > 1

Constant Molal Overflow

As vapor goes up the column it collects the more volatile component and as liquid goes down column it collects the less volatile component. $L_n \neq L_{n+1}$, etc.

In a fortunate manner the molar heat of vaporization of both components are usually similar. This means the enthalpy lost by condensing the less volatile component is ≈ to the enthalpy gained in vaporizing the more volatile. As a result

$L_{n-1} \approx L_n \approx L_{n+1} \approx L_{n+2} = L$: $L_{m-1} \approx L_m = \bar{L}$: $V_n = V$, $V_m = \bar{V}$

Reflux RATIO

$$R_D = \frac{L}{D} = \frac{V-D}{D} = \frac{\text{Molar Flow of Reflux}}{\text{Molar Flow of Overhead Product}}$$

Divide numerator and Denominator of OP Line by D

$$y_{n+1} = \frac{L_n/D}{L_n/D + D/D} x_n + \frac{D x_D / D}{L_n/D + \frac{D}{D}}$$

$$y_{n+1} = \frac{R_D}{R_D+1} x_n + \frac{x_D}{R_D+1}$$

NOTE: when $x_n = x_D$, $y_{n+1} = \frac{R_D x_D}{R_D+1} + \frac{x_D}{R_D+1}$

$$= \frac{(R_D+1)x_D}{R_D+1} = x_D$$

When $x_n = 0$ $\quad y_{n+1} = \frac{x_D}{R_D+1}$

These two points define the operating line in the rectifying section.

Reflux RATIO IS USED TO DEFINE How the Column will operate!

STRIPPING SECTION HAS ANALOGOUS

$$y_{m+1} = \frac{\bar{L}}{\bar{L}-B} x_m - \frac{B x_B}{\bar{L}-B}$$

Note: this operating line will pass through (x_B, x_B)

Condition of Feed

FEED CAN BE: Below Boiling Point
Saturated Liquid at Boiling Point
Partially Vaporized
etc.

If saturated liquid it all drops to stripping section but does not condense any vapor
If cold, it all drops to stripping section but also condenses some of the vapor stream, etc.

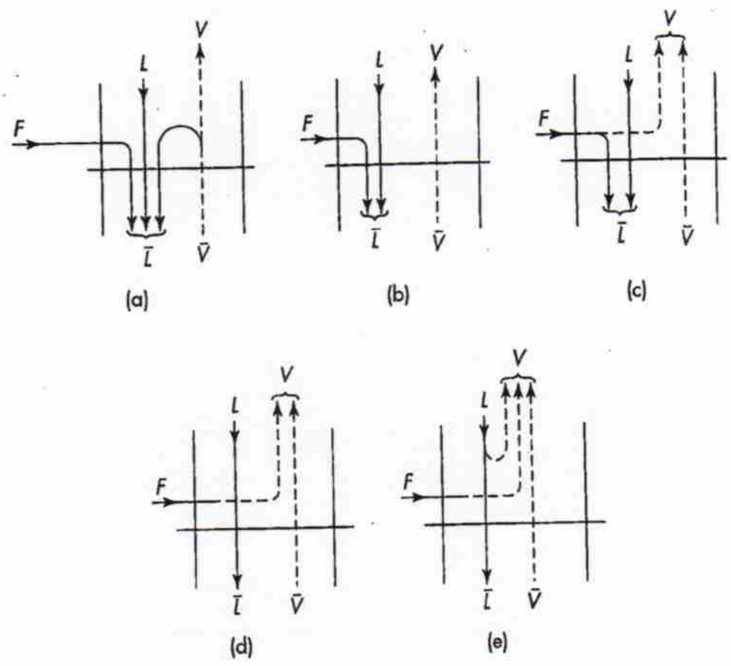


FIGURE 21.11
Flow through feed plate for various feed conditions: (*a*) feed cold liquid; (*b*) feed saturated liquid; (*c*) feed partially vaporized; (*d*) feed saturated vapor; (*e*) feed superheated vapor.

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

q is the moles of liquid flow in stripping section resulting from the introduction of one mole feed.

For Cold liquid $\quad q = 1 + \dfrac{C_{PL}(T_b - T_F)}{\lambda}$

C_{PL} spec heat of liquid
T_F = feed temp
T_b = bubble point
λ = heat of vaporization

FEED LINE

$$\bar{L} = L + qF \qquad V = \bar{V} + (1-q)F$$

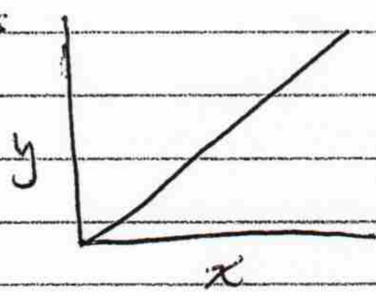
By comparing material balances in stripping and rectifying sections one can derive equation for intersection of the two operating lines

$$y = -\frac{q}{1-q}x + \frac{x_F}{1-q}$$

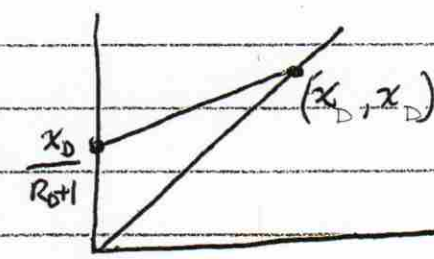
note: when $x = x_F$, $y = x_F$

$\therefore$ Feed line crosses diagonal at (x_F, x_F) and has slope $= -\frac{q}{1-q}$

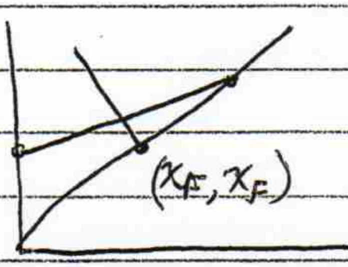
Steps

a) 

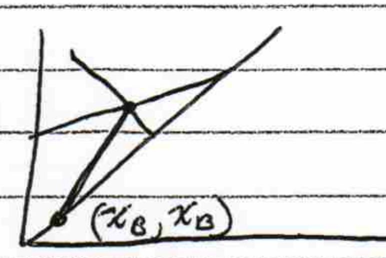
diagonal

b) 

upper op line

c) 

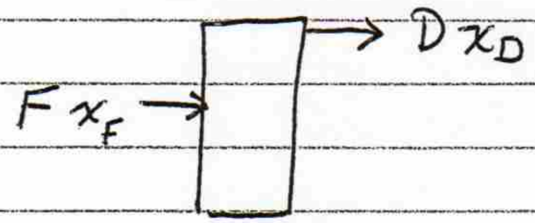
Feed line, slope $= \frac{-q}{1-q}$

d) 

Lower Op Line

PERCENT RECOVERY

Alternate CRITERIA FOR Defining PERFORMANCE



- We have been using mole fractions
- USEFUL for Analysis

CEO of Corporation MAY NOT UNDERSTAND THIS!

THEY WOULD LIKE TO KNOW "How Much of it did I get back"?

$F x_F$ = molar flow rate of Component A in FEED

$D x_D$ = molar flow rate of component A in top

$$\frac{D x_D}{F x_F} \times 100 = \% \text{ RECOVERY}$$

What if $x_D \rightarrow 1.0$ but D is small?