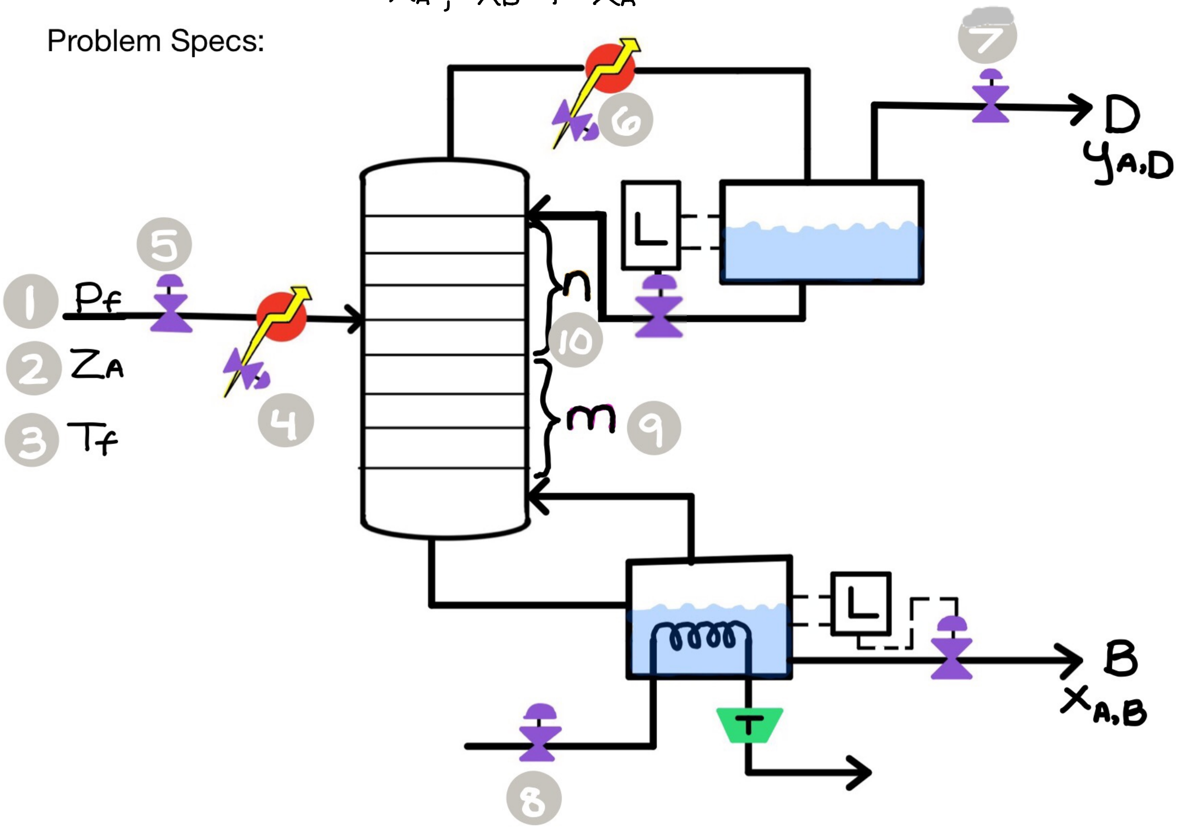
Chapter 7

Binary Multistage Distillation: The McCabe-Thiele Method

Binary implies that there is one independent composition variable

x_A ; $x_B = 1 - x_A$

Problem Specs:



Description Rule: DOF= number of variables set by construction and controlled by operation by independent means.

Variables:

• P_f	• Z_A	• T_f	• n	• m
• valve 4	• valve 5	• valve 6	• valve 7	• valve 8
↑	↑	↑	↑	↑
Control loop for Q_f	Feed flow rate	Control loop for Q_c	Control loop for P	Control loop for Q_R

Conclusion: DOF=10

More commonly the feed variables and the column pressure are fixed (P, Q_f, T_f, P_f, F, z_A) so that four degrees of freedom are left.

Simulation Problem

D
Reflux ratio (reflux flow/D)
m
n

Calculate: $x_{A,D}$, $x_{A,b}$

determine the separation achieved

Design Problem

Specify desired separation – $x_{A,D}$, $x_{A,b}$

Reflux ratio

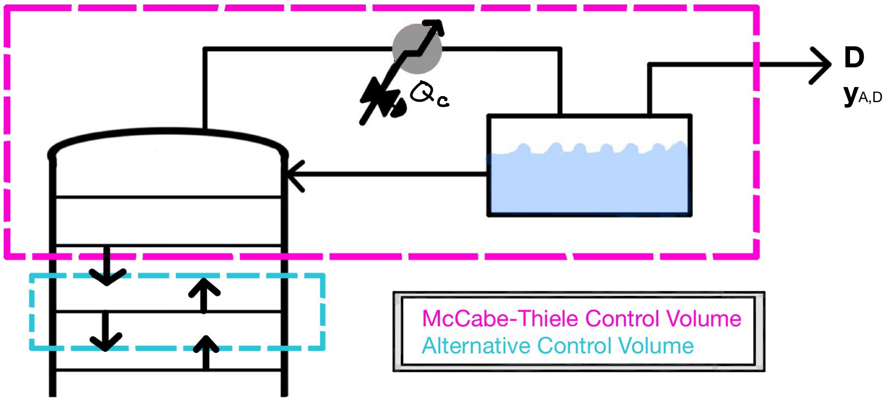
3 variables are specified

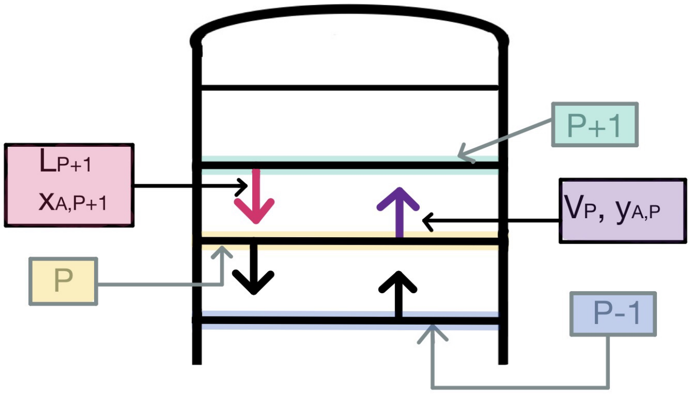
Vary feed late location to minimize n + m

Design the column

Variables and control volume used in McCabe-Thiele method:

Top of column





The subscripts on the variables denote the source of the quantity.

Overall material balance:

$$V_p = L_{p+1} + D$$

Component material balance:

$$V_p\, y_{A,p} = L_{p+1}\, x_{A,p+1} + D\, y_{A,D}$$

Enthalpy balance:

$$V_p \underset{\boxed{\text{vapor enthalpy}}}{\underset{\uparrow}{H_p}} = L_{p+1} \underset{\boxed{\text{liquid enthalpy}}}{\underset{\nwarrow}{h_{p+1}}} + H_D\, D + Q_c$$

Assume "constant molar overflow" which implies

$$L_{p+1} = L_p = \ldots \equiv L$$

$$V_{p+1} = V_p = \ldots \equiv V$$

<u>Operating Line</u>: Line on y-x diagram formed by composition of streams passing each other.

👉🏽A graph with an example of a related type of operating line can be found on page 2 of Lecture 5

For the rectifying section of the column (the top section), the plate number subscripts can be dropped to yield:

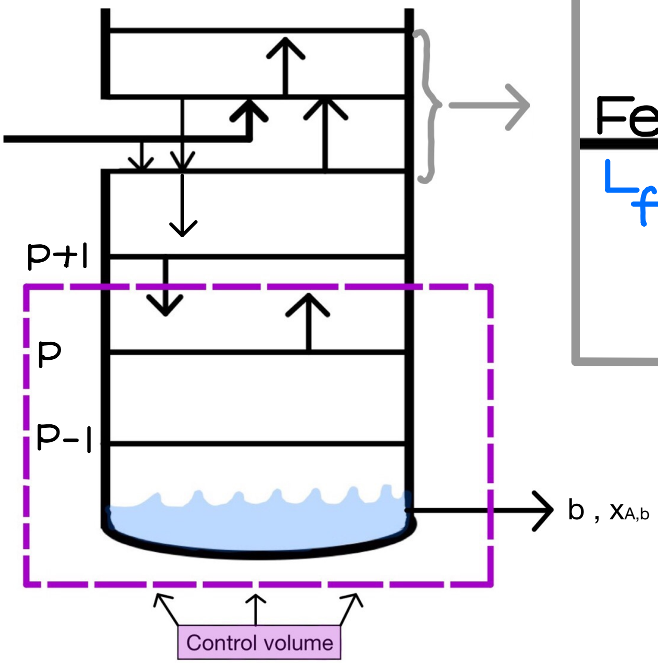
$$y_{A.} = \underbrace{\left(\frac{L}{V}\right)}_{\substack{\uparrow \\ \boxed{\text{Slope}}}} x_{A,} + \underbrace{\left(\frac{D}{V}\right) y_{A,D}}_{\substack{\uparrow \\ \boxed{\text{Intercept}}}}$$

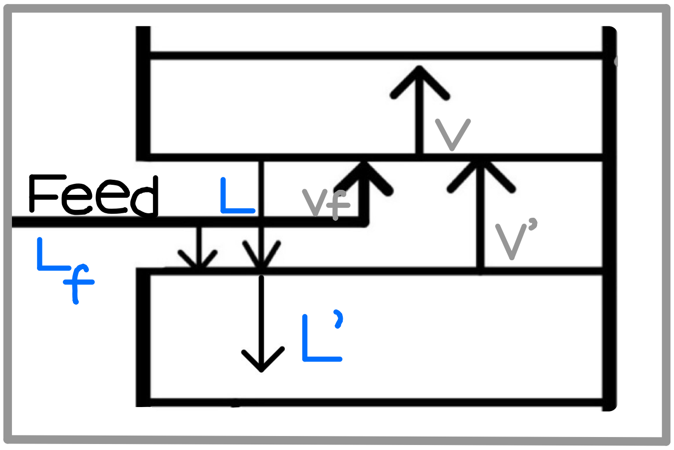
Intersection with the 45% line

$$y_A = \left(\frac{L}{V}\right) y_A + \left(\frac{D}{V}\right) y_{A,D}$$

$$\left(1-\frac{L}{V}\right) y_A = \left(\frac{D}{V}\right) y_{A,D} \Rightarrow y_A = x_A = y_{A,D}$$

Stripping section- the bottom section of the column





📖 $\bar{L}$ in Wankat → $L' = L + L_F$

$V = V' + V_F$

Operating line:

$$y_A = \underbrace{\left(\frac{L'}{V'}\right)}_{\boxed{\text{Slope}}} x_A - \underbrace{x_{A,b}}_{\boxed{\text{Intersection with 45° line}}} \left(\frac{b}{V}\right)$$

Intersection of operating lines:
Subtract the two equations for the operating lines to obtain an equation which holds for the intersection.

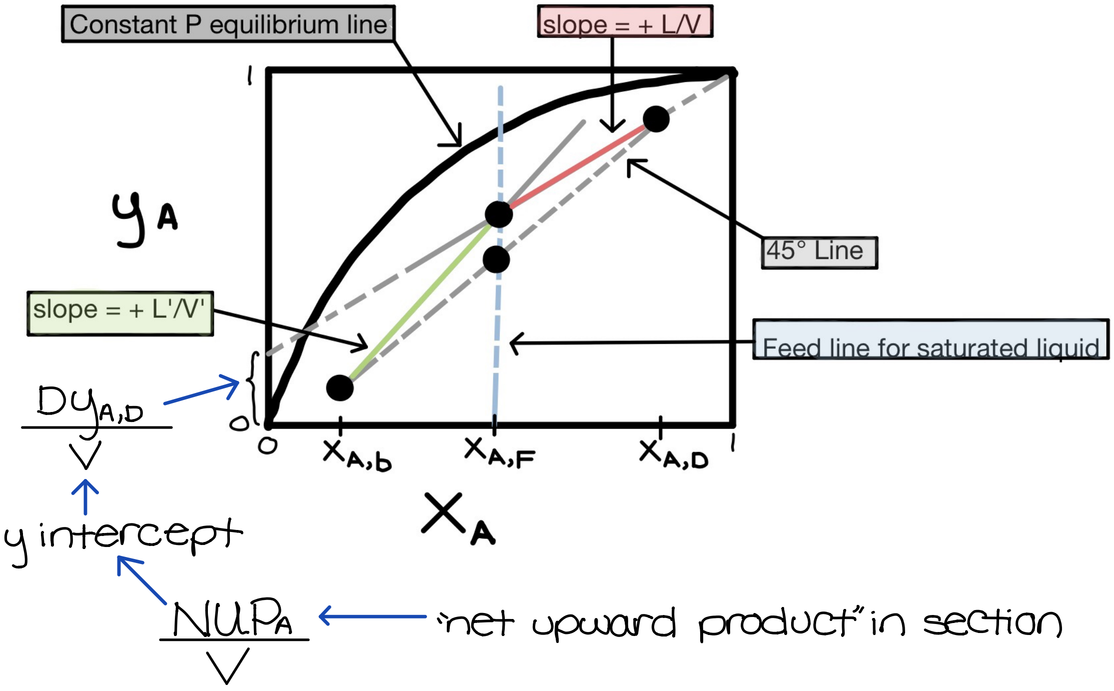
$$\underbrace{(V - V')}_{\boxed{V_F}} y_A = \underbrace{(L - L')}_{\boxed{-L_F}} x_A + \underbrace{D y_{A,D} + b x_{A,b}}_{\boxed{F\ z_A}}$$

Properties

Slope: $-\frac{L_f}{V_f}$

Intersection with 45° line: z_A

Summary:


Constant P equilibrium line
slope = + L/V
1
y_A
45° Line
slope = + L'/V'
Feed line for saturated liquid
$\frac{Dy_{A,D}}{V}$
0
0
$x_{A,b}$
$x_{A,F}$
$x_{A,D}$
1
x_A
y intercept
$\frac{NUP_A}{V}$
"net upward product" in section