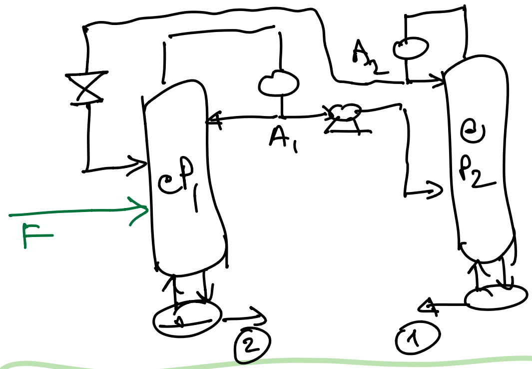
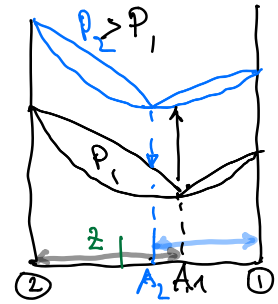
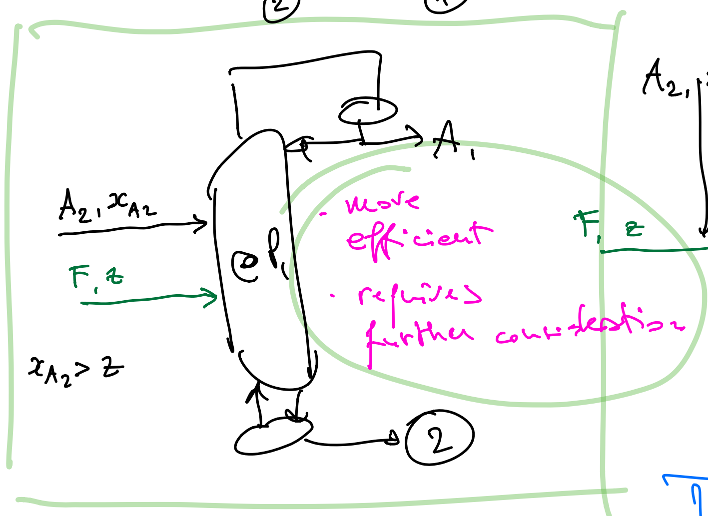
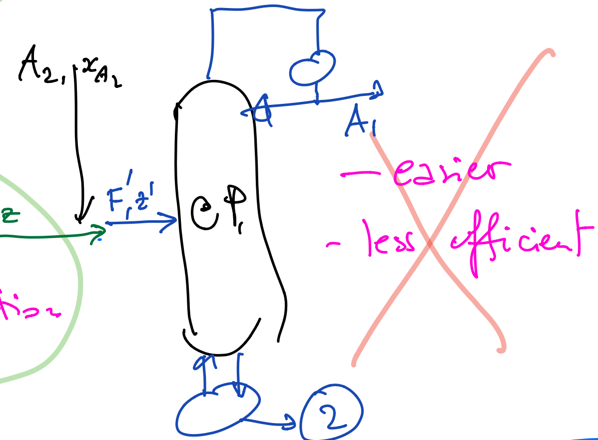
Homogeneous azeotropic distillation

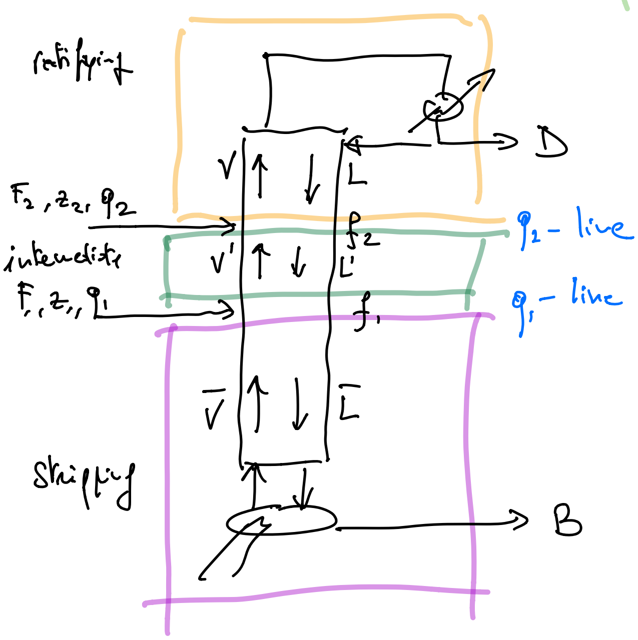


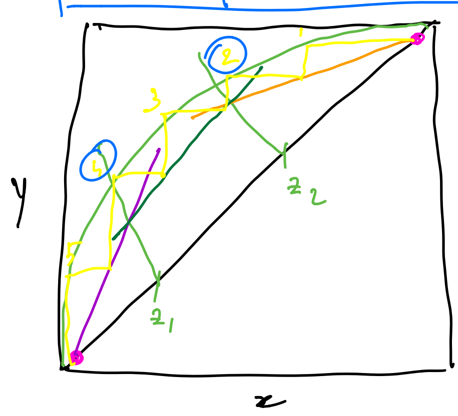






Distillation w/ multiple feeds





Multicomponent distillation

1. From binary to multicomponent
2. Features of multicomponent distillation
3. Introduction to how to calculate N_{min} and R_{min}
4. Fenske method → N_{min} based on $R \to \infty$
5. Underwood method → R_{min} based on $N \to \infty$
6. Gilliland diagram

↳ short-cut design of multicomponent distillation
↳ basis for "Aspen Plus simulation"

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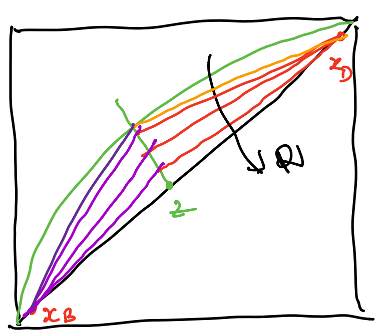
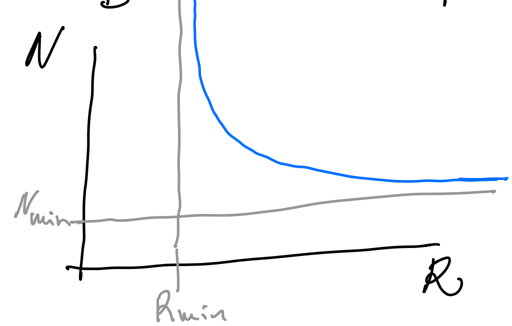
1 The McCabe-Thiele method

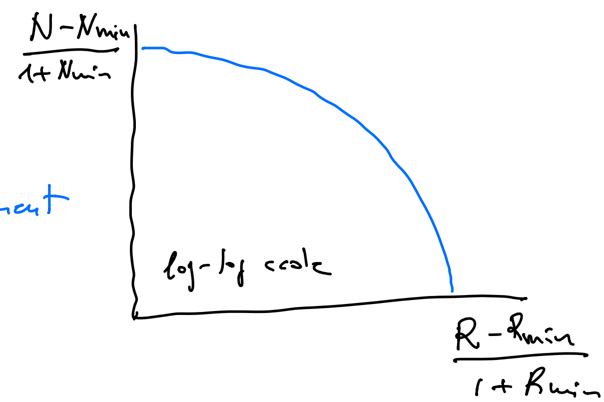


$R = \frac{L}{D}$ → $\frac{L}{V}$: slope of the operating line

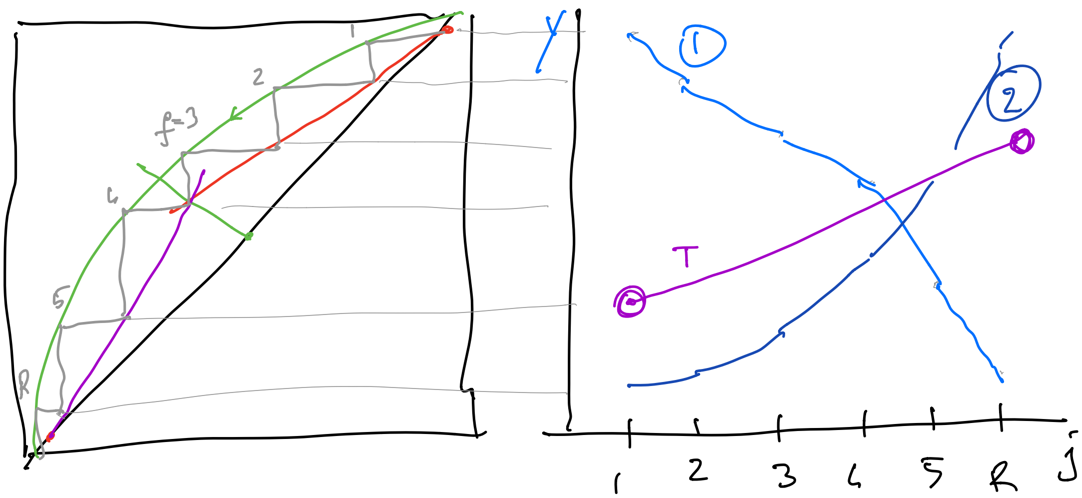


6 Gilliland diagram
↳ { binary, multicomponent

3

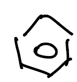
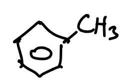
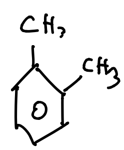
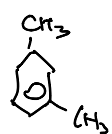
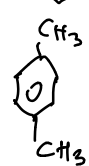
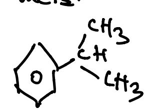


B I N A R Y



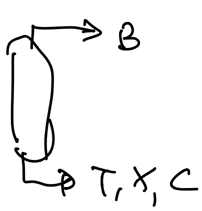
Multicomponent mixture

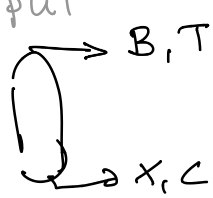
volatility ↑ | T_b ↓

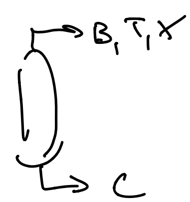
Benzene	C_6H_6		80°C
Toluene	C_7H_8		111°C
Xylene	C_8H_{10}	 ortho-  meta-  para	138°C – 144°C
Cumene (isopropyl benzene)	C_9H_{12}		152°C

B (LK)	B (LNK)	B, T } LNK
T (HK)	T (LK)	X (LK)
X, C } (HNK)	X (HK)	C (HK)
	C (HNK)	

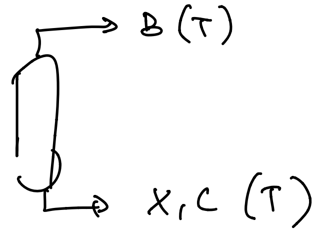
sharp split







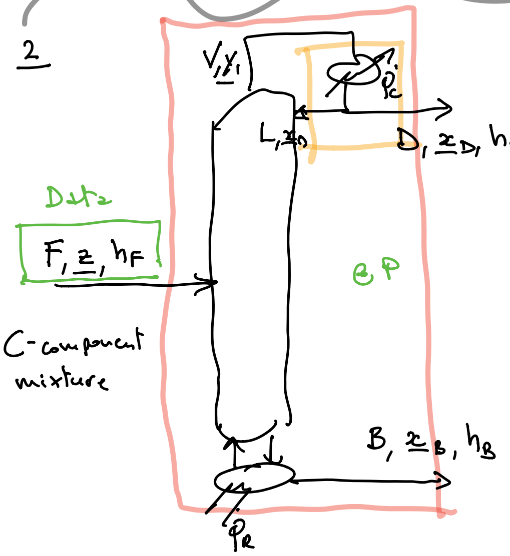
B (LK)
~~T (Intermediate)~~
X (HK)
C (HNK)



intermediate ≡
≡ distributed

non-sharp split

2



Variables

$x_D,\ x_B,\ D,\ B,\ \dot{Q}_R,\ \dot{Q}_C$ — $2C+4$

$y_1,\ V,\ L$ — $C+2$

$\Big\}$ $3C+6$ variables

Balances

$$\left.\begin{aligned} F z_i &= B x_{B,i} + D x_{D,i} \\ \sum_{i=1}^{C} x_{B,i} &= 1 \\ \sum_{j=1}^{C} x_{D,i} &= 1 \\ F h_F + \dot{Q}_R + \dot{Q}_C &= D h_D + B h_B \end{aligned}\right\} C+3$$

$$\left.\begin{aligned} V y_{1,i} &= (D+L)\, x_{D,i} \\ \sum_{i=1}^{C} y_{1,i} &= 1 \\ V H_1 + \dot{Q}_C &= (D+L)\, h_D \end{aligned}\right\} C+2$$

$2C+5$ eqs

$$\text{d.o.f.} = (3C+6) - (2C+5) =$$
$$= C+1$$

Specs: $R = L/D$, $x_{D,LK}$!, $x_{B,HK}$!

3 specs

$C+1-3 = \boxed{C-2 \quad \text{missing conditions}}$

How to assign specs on LK and HK

$$\frac{F z_i = B x_{B,i} + D x_{D,i}}{F z_i} \Longrightarrow 1 = \frac{B x_{B,i}}{F z_i} + \frac{D x_{D,i}}{F z_i}$$

FR : fractional recovery $\qquad 1 = FR_i^B + FR_i^D$

Specs : $R = \frac{L}{D}$, FR_{LK}^D , FR_{HK}^B

sharp split

LNK
LK
HK
HNK

volatility $\qquad T_b$

$FR_{LNK}^D = 1$
$FR_{LK}^D = 0.98$
$FR_{HK}^B = 0.99$
$FR_{HNK}^B = 1$

C components, LK + HK
$\Downarrow$
C-2 NK components

all missing conditions are not missing anymore

non-sharp split

?

LNK
LK
I
HK
HNK

T_b

$FR_{LNK}^D = 1$
$FR_{LK}^D = 0.99$
$FR_I^D = ??$
$FR_{HK}^B = 0.95$
$FR_{HNK}^B = 1$

C-2-N_intermediate

we are still missing conditions!

L.V.E. for C components

$f_i^L = f_i^V$ $\qquad$ iso-fugacity $\qquad$ (ideal gas + nonideal liquid)

$$y_i = \frac{p_i^V(T)\, x_i\, \gamma_i(T, P, \underline{x})}{P} = \frac{p_i^V(T)\, \gamma_i}{P}\, x_i = K_i(T, P, \underline{x})\, x_i$$

$$\boxed{y_i = K_i x_i}$$

relative volatility : $\alpha_{i2} = \dfrac{y_i / x_i}{y_2 / x_2} = \dfrac{K_i(T, P, \underline{x})}{K_2(T, P, \underline{x})}$

$$\boxed{y_i = \alpha_{i2} K_2 x_i}$$

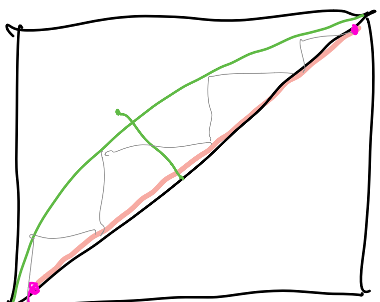
$$\sum_{i=1}^{c} y_i = 1 = K_2 \sum_{i=1}^{c} \alpha_{i2} x_i \Rightarrow K_2 = \frac{1}{\sum_{i=1}^{c} \alpha_{i2} x_i}$$

$$\boxed{y_i = \frac{\alpha_{i2} x_i}{\sum_{i=1}^{c} \alpha_{i2} x_i}}$$

$$\boxed{\alpha_{i2} = \text{constant}}$$

$$\alpha_{i2} = \frac{K_i(T,P,\underline{x})}{K_2(T,P,\underline{x})} = \frac{p_i^v(T)\,\gamma_i}{p_2^v(T)\,\gamma_2} \overset{\gamma_i \approx 1}{=\!=} \frac{p_i^v(T)}{p_2^v(T)} \simeq \text{const.}$$

C.R.V. (relative volatility constant) $\Rightarrow$ $\boxed{y_i = \frac{\alpha_{i2} x_i}{\sum_{i=1}^{c} \alpha_{i2} x_i}}$



Fenske $\Rightarrow N_{min}$

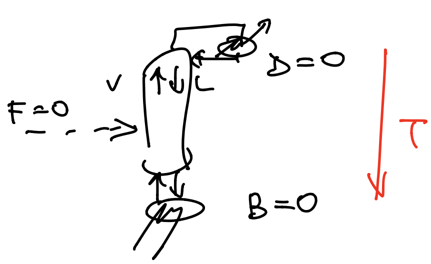
$\Rightarrow R \to \infty$

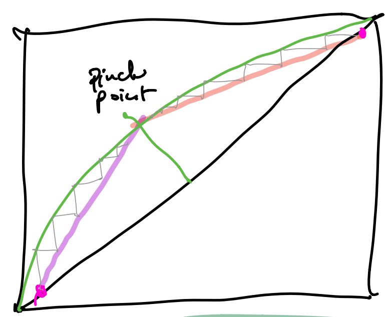
$\Rightarrow \frac{L}{D} \to \infty$ $V = L + D$

$\Rightarrow L = V$

$\Rightarrow \bar{L} = \bar{V}$

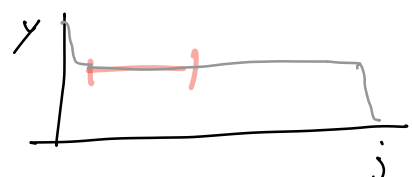
$\left.\begin{matrix} D = 0 \\ B = 0 \end{matrix}\right\} \Rightarrow F = 0$





Underwood $\Rightarrow R_{min}$

$\Rightarrow N \to \infty$



rectifying $y_{j,i} = y_{j+1,i} \ldots$

stripping $y_{k,i} = y_{k+1,i} \ldots$

pinch-point