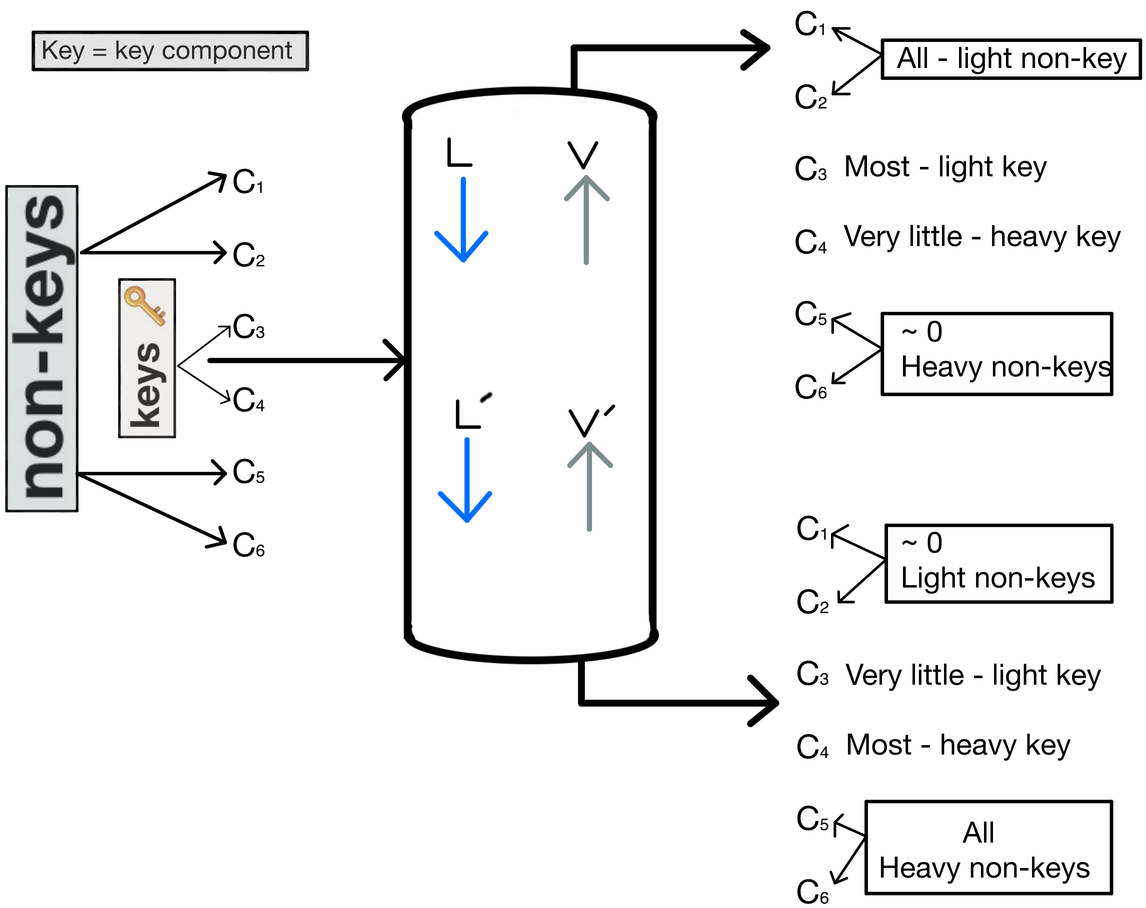
Chapter 8

Multicomponent Distillation - The Design Problem

Consider on a qualitative basis the distillation of a hydrocarbon mixture (C_1-C_6) designed to separate the mixture between C_3 and C_4



Degree of Freedom Analysis:

Compared to the binary case, there is an extra degree of freedom for each additional component

$$DOF = \underbrace{R}_{\text{\# of feed components}} + 8$$

Specify the Design Problem:

R + 7 {
- R feed flows
- Feed enthalpy (counts as two: T_f and Q_f)
- Column pressure and feed pressure
- Reflux ratio (r)
- Two specifications related to the desired separation
  ex: % recovery of light key in distillate and % recovery of heavy key in bottom product.

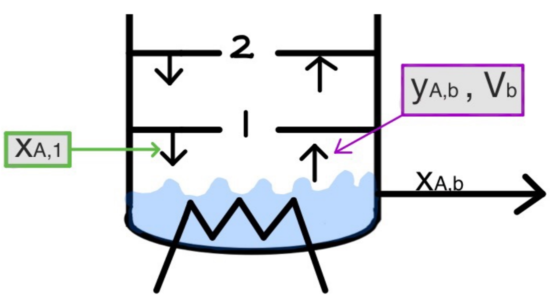
Objective: Calculate n and m by adjusting the feed plate location

🚩 Design the column using the remaining DOFs as the independent variables.

> **Nomenclature**
>
> **n** = # of plates above the feed plate including the feed plate.
> **m** = # of plates below the feed plate.
> A figure illustrating n and m can be found in Lecture 7.

Operation at infinite reflux: The Fenske Equation

Consider the bottom of the column for the case of a binary mixture:



Equilibrium in the Reboiler:

$$\left(\frac{y_A}{y_B}\right)_b = \alpha_{AB}\left(\frac{x_A}{x_B}\right)_b$$

Material Balance:

$$V_b\, y_{Ab} = L_1\, x_{A1} - x_{Ab}\, b$$

At infinite reflux b is small and $V_b \approx L_1$

so $y_{A,b} = x_{A1}$ and $\left(\frac{x_A}{x_B}\right)_1 = \alpha_{AB}\left(\frac{x_A}{x_B}\right)_b$

Similarly for Stages 1 and 2: $\left(\frac{x_A}{x_B}\right)_2 = \alpha_{AB}\left(\frac{x_A}{x_B}\right)_1 = \alpha_{AB}^2\left(\frac{x_A}{x_B}\right)_b$

For N Stages: $\left(\frac{x_A}{x_B}\right)_d = (\alpha_{AB})^{N_{min}}\left(\frac{x_A}{x_B}\right)_b$

or $N_{min} = \dfrac{\log\left[\left(\frac{x_A}{x_B}\right)_d \Big/ \left(\frac{x_A}{x_B}\right)_b\right]}{\log(\alpha_{AB})}$

For a multicomponent system, the above equations also apply with A and B taken as the 2 key components

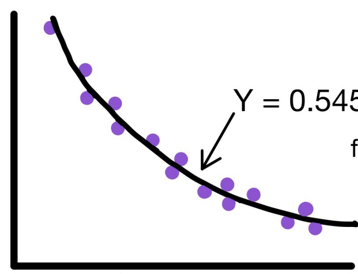
"Short-Cut" methods for a multicomponent distillation column design

See chapter 7 of Wankat for additional details

The Gilliland Correlation:

$$\frac{N - N_{min}}{N+1}$$

(Y)



$$Y = 0.5458 - 0.5914X + \frac{0.002743}{X}$$

for 0.01 < x < 0.9

$$\frac{\left(\frac{L}{D}\right) - \left(\frac{L}{D}\right)_{min}}{\frac{L}{D} + 1}$$

(X)

- N_{min} can be determined from the Fenske Equation
- $\left(\frac{L}{D}\right)_{min}$ can be determined from the Underwood Equation

see Chapter 7.2 of Wankat

When the "non-key" components are entirely in one product or the other

$$V_f = \sum_{i=1}^{N} \frac{\alpha_i F z_i}{\alpha_i - \phi} \quad \text{then} \quad V_{min} = \sum_{i=1}^{N} \frac{\alpha_i D y_{i,D}}{\alpha_i - \phi}$$

solve for value of ϕ between values of the key component

"FUG" interface in ChemSep: