Multicomponent distillation (A+B+C…)

- Similar to binary distillation (mass balances, heat balances, operating lines, etc.)
- One difference – more towers are needed (**n-1** for complete separation)
  - What to separate first?
  - What is economical vs. fastest?
- Rigorous trial-and-error numerical solutions
  - Feed conditions are known
- Shortcut methods
  - Useful for surveying options, approximating designs, estimating costs

![Diagram of distillation process](image)
1. Equilibrium data (e.g. relative to C in A+B+C)

- Ideal - Raoult’s law:
  \[ y_i = \frac{P_i}{P} = \frac{P_i}{P} \times_i \quad \alpha_i = \frac{P_i}{P_C} \]

- Non-ideal:
  \[ y_i = K_j x_i \quad \alpha_i = \frac{K_i}{K_C} \]

Figure 2.10 Comparison of experimental K-value data and S-R-K correlation.
2. BP and DP trial-and-error calculations
(see Example 11.7-1)

- **BP of liquid and vapor composition** – At T, the following must hold:
  \[ \sum y_i = \sum K_i x_i = K_c \sum \alpha_i x_i = 1.0 \]
  \[ y_i = \frac{\alpha_i x_i}{\sum \alpha_i x_i} \]
  - Liquid composition specified: Assume T, get values for \( \alpha_i \) from \( K_i \) values
  - Calculate \( K_c \) from above, compare T corresponding to this value vs. actual

- **DP of vapor and liquid composition** – At T, the following must hold:
  \[ \sum x_i = \sum \frac{y_i}{K_i} = \frac{1}{K_c} \sum \frac{y_i}{\alpha_i} = 1.0 \]
  \[ y_i = \frac{y_i / \alpha_i}{\sum y_i / \alpha_i} \]
  - Vapor composition specified: follow same procedure
3. Key components (L and H)

- Samples can be collected from any tray, but only 2 components can be separated in a single tower.

- Which 2?
  - Select light key (L) and heavy key (H)
  - E.g. for debutanizer, which is which (Seader & Henley)?

![Figure 9.3 Specifications for debutanizer.](image-url)
3. Key components - # of ideal stages
(see Example 11.7-2)

• Fenske equation still holds for L/H split:

\[ N_w = \frac{\log\left(\frac{x_{LD}}{x_{HD}}\right)\frac{x_{HW}}{x_{LW}}}{\log(\alpha_{L,av})} \]

\[ \alpha_{L,av} = (\alpha_{LD}\alpha_{LW})^{1/2} = \left(\frac{K_{LD}}{K_{HD}}\frac{K_{LW}}{K_{HW}}\right)^{1/2} \]

• Other components:

\[ \frac{x_{iD}D}{x_{iW}W} = (\alpha_{i,av})^N = \frac{x_{HD}D}{x_{HW}W} \]

• Combining information thus far, we can determine:
  – Feed T if given P (or P if given T)
  – Top (D) and bottom (W) T or P
  – Distribution of other products (i’s) in D and W
4. Shortcut methods
(Underwood, see Example 11.7-3)

(1) Minimum reflux ratio \( (R_m) \) – Underwood’s method:

\[
1 - q = \sum \frac{\alpha_{i,av} x_{iF}}{\alpha_{i,av} - \theta}
\]

\[
R_m + 1 = \sum \frac{\alpha_{i,av} x_{iD}}{\alpha_{i,av} - \theta}
\]

- \( \theta \) value is between \( \alpha_{L,av} \) and \( \alpha_{H,av} \) (or 1), solved by trial-and-error
- All components \( (i) \) are included (*need F and D compositions)
- Solve 1-q equation first to obtain \( \theta \)
  - If feed is at BP, LHS \((1-q) = 0\)
- Use \( \theta \) to obtain \( R_m \)
  - If feed is at BP, LHS \((1-q) = 0\)
4. Shortcut methods
(see Example 11.7-3)

(2) # of ideal stages (N) at R – Erbar and Maddox or Gilliland correlations:
- $N_m$ from Fenske equation
- $R_m$ from Underwood method

![Diagram 11.7-3: Erbar-Maddox correlation between reflux ratio and number of stages ($R_m$ based on Underwood method).](image1)

![Diagram 9.10: Comparison of rigorous calculations with Gilliland correlation.](image2)
4. Shortcut methods
(see Example 11.7-3)

(3) Feed tray location – Kirkbride’s method:

\[
\log \frac{N_e \text{ (enriching)}}{N_s \text{ (stripping)}} = 0.206 \log \left[ \frac{x_{HF}}{x_{LF}} \frac{W}{D} \left( \frac{x_{LB}}{x_{HD}} \right)^2 \right]
\]

– Feed tray is \( N_e \) from top (i.e. \( N_e \) trays above, \( N_s \) trays below)
5. Feed tray location

- Kirkbride approximation

\[
\log \frac{N_\infty}{N_s} = 0.206 \log \left[ \left( \frac{x_{MIP}}{x_{LF}} \right) \frac{W}{D} \left( \frac{x_{LW}}{x_{HD}} \right)^2 \right]
\]

\[
N = N_z + N_s
\]