Overview

• Questions on homework??
• McCabe-Thiele graphical technique (binary systems)
  • Condensers
  • Reboilers
• Binary Shortcut Methods
• AspenPlus:
  o Shortcut methods: DSTWU
  o Rigorous method: RADFRAC
• Efficiencies
• Introduction to multicomponent distillation
McCabe Thiele: Reboilers

Figure 7.21 Reboilers for plant-size distillation columns: (a) kettle-type reboiler; (b) vertical thermosyphon-type reboiler, reboiler liquid withdrawn from bottom sump; (c) vertical thermosyphon-type reboiler, reboiler liquid withdrawn from bottom-tray downcomer.
Effect of Different Reflux Ratios

- Before we saw that...
  - increasing reflux resulted in an enrichment of vapor stream in the “lighter” component

For constant $N$

- Now if keep $X_0$ constant and change $R$, see effect on $N$.
Effect of Different Reflux Ratios

- Increase R --- cost effect??

![Graph showing the relationship between reflux ratio (R/Rmin) and costs]

- Steam Costs [$/yr; 1991]
  - $0
  - $20,000
  - $40,000
  - $60,000
  - $80,000
  - $100,000
  - $120,000
  - $140,000
  - $160,000
  - $180,000
  - $200,000

- Cooling Water Costs [$/yr; 1991]
  - $0
  - $5,000
  - $10,000
  - $15,000
  - $20,000
  - $25,000
  - $30,000

- $ steam
- $ water

R/Rmin: 1 1.2 1.4 1.6 1.8
Effect of Different Reflux Ratios

\[ R_{\text{min}} < R_{\text{opt}} < R_{\infty} \]

\[ R = \text{factor} \times R_{\text{min}} \]

\[ 1.05 < \frac{R_{\text{opt}}}{R_{\text{min}}} < 1.50 \]

Seader & Henley, 2006
Tie Together

- Found using McCabe-Thiele (knowing \(x_D\), \(x_B\), & feed condition):
  - \(N_{\text{min}}\) (at total reflux)
  - \(R_{\text{min}}\) (at infinite number of stages)

- If given actual \(R\) (or choose by \(R = \text{factor} \times R_{\text{min}}\)) can find:
  - \(N\)
  - \(N_F\) (optimum feed stage number)

Suggests there is a relation between \(N\), \(N_{\text{min}}\), and \(R_{\text{min}}\).
Gilliland Correlation

61 Data points over ranges:

1. No. components: 2 to 11
2. $q$: 0.28 to 1.42
3. $P$: vacuum to 42.4 bar
4. $\alpha$: 1.11 to 4.05
5. $R_{\text{min}}$: 0.53 to 9.09
6. $N_{\text{min}}$: 3.4 to 60.3

Molokanov Eqn:

$$Y = 1 - \exp\left[\left(\frac{1+54.4X}{11+117.2X}\right)\left(\frac{X-1}{X^{0.5}}\right)\right]$$

Seader & Henley, 2006
Binary Shortcut Methods

McCabe-Thiele is good at showing procedure and helping explain concepts for binary distillation. It can be extended to multiple feeds and side draws (Wankat).

When consider multicomponent mixtures, McCabe-Thiele is not quite as useful. However, having some shortcut methods to aid in final column design is useful.

Minimum number of stages: Fenske Equation

\[
N_{\text{min}} = \ln \left[ \frac{x_D \left( 1 - x_B \right)}{1 - x_D} \right] \frac{1 - x_B}{x_B} \ln \alpha
\]

- binary; total condenser; \( \alpha \sim \text{constant} \)

\[
\bar{\alpha} = \sqrt{\alpha_{\text{Dist}} \alpha_{\text{Bot}}} \quad \text{or} \quad \left( \alpha_{\text{Dist}} \alpha_{\text{Feed}} \alpha_{\text{Bot}} \right)^{\frac{1}{3}}
\]

\[x_i = \frac{y_i}{y^*} \]

\[x_{ij} = \frac{P_{i*}}{P_{j*}}\]
Binary Shortcut Methods

Minimum reflux ratio: **Underwood Equation**

\[
\frac{L_{\text{min}}}{F} = \left[ \frac{Dx_D - \alpha D(1 - x_D)}{Fz_F - F(1 - z_F)} \right] \frac{1}{\alpha - 1}
\]

- binary; assumes rectifying line intersects eq. line at feed line; \( \alpha \sim \text{constant} \)

\[
R_{\text{min}} = \frac{L_{\text{min}}}{D}
\]

\( R = \text{factor} \times R_{\text{min}} \)

Approximate number of equilibrium stages \((N)\): **Gilliland correlation**

\[
N \sim 2.5 \, N_{\text{min}}
\]
Binary Shortcut Methods

Optimum feed stage location ($N_F$): Kirkbride Equation

$$\frac{N_R}{N_S} = \left[ \left( \frac{1 - z_F}{z_F} \right) \left( \frac{x_B}{(1 - x_D)} \right)^2 \frac{B}{D} \right]^{0.206}$$

- binary; approximate result
Binary Shortcut Methods

Y = X line
Summary Binary Shortcut Methods (FUG)

**Fenske Equation**

\[
N_{\text{min}} = \ln \left[ \frac{x_D}{1-x_D} \frac{1-x_B}{x_B} \right] \ln \bar{\alpha}
\]

\[
\bar{\alpha} = \sqrt{\alpha_{\text{Dist}} \alpha_{\text{Bot}}} \quad \text{or} \quad \left(\alpha_{\text{Dist}} \alpha_{\text{Feed}} \alpha_{\text{Bot}}\right)^{\frac{1}{3}}
\]

**Underwood Equation**

\[
R_{\text{min}} = \frac{L_{\text{min}}}{D}
\]

\[
L_{\text{min}} = \frac{Dx_D}{Fz_F} - \bar{\alpha} \frac{D(1-x_D)}{F(1-z_F)}, \quad \bar{\alpha} - 1
\]

\[
R = \text{factor} \times R_{\text{min}}
\]

**Gilliland correlation** \((N_{\text{equil}})\)

**Kirkbride Equation** \((N_{F(\text{opt})})\)
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AspenPlus: DSTWU

Isooctane
Potential

Recover 95% butane
5% isobutylene

$\hat{F} = 100 \text{ kmol/h}$

$X_{\text{butane}} = 0.4$

$\hat{G} = 1$

$R = 1.2 R_{\text{min}}$

$X_D = 0.95$

$X_B = 0.05$
Questions?