CBE 417
“Unit Operations”

Lecture: 9

22 Sep 2010
Overview

• Flash Unit Operation
• Staged systems
• Review Homework
• McCabe-Thiele
Feed Stage

Depending on Feed “condition” will get changes to vapor and liquid flowrates…

Define $q$ = Moles of liquid flow in Stripping section that result from one mole of feed.

\[ q = \frac{\overline{L} - L}{F} \]

Suppose:
- $q = 1$
  \[ \bar{F} = 1 \]
  \[ b = 1 \Rightarrow \overline{L} = L + 1 \]
  \[ \text{Sat’d Liq} \]
- $q = 0$
  \[ \text{Sat’d Vap} \]
Feed Stage Operating Line

Rectifying section

\[ y_{N+1} = \left( \frac{L}{V} \right) x_N + \left( \frac{D}{V} x_D \right) \]

Stripping section

\[ y_{m+1} = \left( \frac{L}{V} \right) x_m - \left( \frac{B}{V} x_B \right) \]

Feed stage & overall column MBs:

\[ \begin{align*}
\bar{V} y_{m+1} &= \bar{L} x_m - B x_B \\
V y_{N+1} &= L x_N + D x_D \\
y(\bar{V} - V) &= x(\bar{L} - L) - (D x_D + B x_B)
\end{align*} \]

\[ \begin{align*}
\bar{V} - V &= \bar{L} - L - F \\
y(\bar{L} - L - F) &= x(\bar{L} - L) - F z_F \\
y\left( \frac{\bar{L} - L}{F} - 1 \right) &= x\left( \frac{\bar{L} - L}{F} \right) - z_F \\
y &= \frac{q}{q-1} x - \left( \frac{z_F}{q-1} \right)
\end{align*} \]
\[ y = \frac{q}{q-1} x - \left( \frac{z_F}{q-1} \right) \]

### Feed Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>( q )</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>sat’d liquid</td>
<td>1</td>
<td>( \infty )</td>
</tr>
<tr>
<td>sat’d vapor</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>mixed V &amp; L</td>
<td>( 0 &lt; q &lt; 1 )</td>
<td>neg. (-)</td>
</tr>
<tr>
<td>subcooled L</td>
<td>( q &gt; 1 )</td>
<td>pos. (+)</td>
</tr>
<tr>
<td>superheated V</td>
<td>( q &lt; 0 )</td>
<td>pos. (+)</td>
</tr>
</tbody>
</table>

### Diagram

- subcooled
- partial \( V \& L \), \( 0 < q < 1 \)
- sat’d liq., \( q = 1 \)
- liq., \( q > 1 \)

### Notes

- Let's put all three lines together:
  - rectifying section
  - stripping section
  - feed line
Operating Lines (McCabe-Thiele)

q is constant

Rectifying & stripping lines must intersect at the same point on the feed line.

Consider limits:
- \( R = \infty \)
- \( R \) where rectifying line intersects the equil. curve
Operating Lines (McCabe-Thiele)

R is constant

Rectifying & stripping lines must intersect at the same point on the feed line.
**McCabe-Thiele Graphical Method**

**Binary Distillation**

\[ \{g_j, x_D, x_B, z_F, \alpha, R \} \]

“step off” equilibrium stages on the XY diagram.

**Total Condenser**

Feed stage location: point where switch from rectifying operating line to the stripping operating line.
McCabe-Thiele Graphical Method

Binary Distillation

“step off” equilibrium stages on the XY diagram.

Feed stage location: point where switch from rectifying operating line to the stripping operating line.

Optimum feed stage location: switching point to obtain smallest number of stages. Switch when intersection of 3 operating lines is first crossed.
McCabe-Thiele Graphical Method

Binary Distillation

Minimum Number of Stages

Total reflux: so $D =$ ?
and $R =$ ??

$R = \infty$

$F = \emptyset$
McCabe-Thiele Graphical Method

Binary Distillation

Minimum Reflux Ratio

\[ N = \infty \]

One or both operating lines intersect the equilibrium line.

**Result:** infinite number of stages.
McCabe-Thiele Graphical Method

Binary Distillation

Minimum Reflux Ratio

One or both operating lines intersect the equilibrium line.

Result: infinite number of stages.
McCabe-Thiele Graphical Method (binary)

Used to simplify analysis of binary distillation (ease of understanding)

**Assumptions:**
- Pure components $a$, $b$ have equal latent heats of vaporization / mole ($\lambda_i$) and they stay constant.
- $\lambda_i$ are much larger than
  - Sensible heat changes
  - Heats of mixing
- Column is adiabatic (well – insulated)
- Constant pressure (P) throughout the column (i.e. no $\Delta P$ in the column)

Called **Constant Molal Overflow** (CMO)
- Assumes for every 1 mole of light material vaporized that 1 mole of heavy material condenses from the vapor phase
- Net result:
  - Total molar flowrates (i.e. $L$ and $V$) remain constant within that column section (rectifying or stripping, or other)
  - Do not need a stage by stage energy balance

McCabe-Thiele is done with MB and Thermodynamic information.
Problem Solving Exercise

Given a liquid mixture of benzene and toluene to separate in a distillation column at 1.013 bar, pressure. The feed of 100 kmol/h is a subcooled liquid (q = 1.195) containing 45 mol% benzene and enters at 327.6 K.

It is desired to obtain a distillate containing 95 mol% benzene and a bottoms product containing 80 mol% toluene. As a first guess, let’s set the reflux ratio to 4. Below is a chart containing the equilibrium information at 1.013 bar pressure.

Determine the molar flows of the two product streams (distillate and bottoms) and the theoretical number of trays needed.

\[ q = 1.195 \]
\[ R = 4 \]
\[ \frac{8}{6-1} = 1.195 \]
\[ 0.195 \]
Questions?