Unit Operations
Lecture 21 & 22

10 & 12 Nov 2010
Column Internals

- Plate
- Vapor flow

- ~3-13 mm

- Plate
- Vapor flow

- ~25-50 mm

- Plate
- Vapor flow

- ~75-150 mm

<table>
<thead>
<tr>
<th></th>
<th>Sieve Trays</th>
<th>Valve Trays</th>
<th>Bubble-Cap Trays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative cost</td>
<td>1.0</td>
<td>1.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>Lowest</td>
<td>Intermediate</td>
<td>Highest</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Lowest</td>
<td>Highest</td>
<td>Highest</td>
</tr>
<tr>
<td>Vapor capacity</td>
<td>Highest</td>
<td>Highest</td>
<td>Lowest</td>
</tr>
<tr>
<td>Typical turndown ratio</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Turndown Ratio** = Vapor Capacity Flow / Vapor Capacity Column

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coefficients in a ring mean square displacement (MSD) over time. Correlation effects on both components in the mixture. The complete mixture correlation effects is a collective quantity resulting from properties.

α in an equimolar Ar/Kr mixture
## Column Internals

<table>
<thead>
<tr>
<th>Tray Type</th>
<th>Capacity</th>
<th>Efficiency</th>
<th>Turndown</th>
<th>Pressure Drop</th>
<th>Fouling Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve</td>
<td>Medium</td>
<td>Very High</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Moving Valve</td>
<td>Medium</td>
<td>Very High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>High Capacity Valve</td>
<td>High</td>
<td>Very High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Fixed Valve</td>
<td>Medium</td>
<td>Very High</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Bubble Cap</td>
<td>Low</td>
<td>Very High</td>
<td>Very High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Dual Flow</td>
<td>High</td>
<td>Medium</td>
<td>Very Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Baffle</td>
<td>High</td>
<td>Very Low</td>
<td>Medium</td>
<td>Very Low</td>
<td>Very High</td>
</tr>
<tr>
<td>Disc &amp; Donut</td>
<td>High</td>
<td>Very Low</td>
<td>Medium</td>
<td>Very Low</td>
<td>Very High</td>
</tr>
<tr>
<td>NYE</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
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<tr>
<td>EC Technology</td>
<td>Very High</td>
<td>Very High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>CoFlo</td>
<td>Ultra High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
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</tbody>
</table>

Jaeger Product Bull. 400-09
<table>
<thead>
<tr>
<th>RJ-V1</th>
<th>RJ-V4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Piece Moving Valve</td>
<td>RJ-V1 with Venturi Orifice</td>
</tr>
<tr>
<td>RJ-A1</td>
<td>RJ-A4</td>
</tr>
<tr>
<td>3-Piece High Turndown Caged Valve</td>
<td>RJ-A1 with Venturi Orifice</td>
</tr>
<tr>
<td>RJ-A2</td>
<td>RJ-A5</td>
</tr>
<tr>
<td>2-Piece Caged Valve</td>
<td>RJ-A2 with Venturi Orifice</td>
</tr>
<tr>
<td>RJ-A3</td>
<td>RJ-A6</td>
</tr>
<tr>
<td>2-Piece Caged Valve</td>
<td>RJ-A3 with Venturi Orifice</td>
</tr>
<tr>
<td>RJ-MMV</td>
<td>RJ-MV</td>
</tr>
<tr>
<td>High Capacity Mini Valve</td>
<td>High Capacity Fixed Mini Valve</td>
</tr>
<tr>
<td>RJ-SVG</td>
<td>RJ-V0</td>
</tr>
<tr>
<td>Rectangular Fixed Valve</td>
<td>Round Fixed Valve</td>
</tr>
</tbody>
</table>
Valve Trays

Raschig Jaeger offers a vast array of conventional and High Capacity moving and fixed valve types to meet all of our customer's needs. The single piece RJ-V1 is our standard moving valve and is recommended for many applications. The RJ-V1 incorporates tabs to raise the main body of the valve off of the tray floor thereby reducing the chance of sticking. Raschig Jaeger manufactures many types of 1 piece, 2 piece cage and disc (RJ-A2 or RJ-A3), and 3 piece high turndown (RJ-A1) valve units with thickness, material type, and leg lengths as needed to meet any process and mechanical conditions required. Additional variations include extruded tray floor openings to reduce pressure drop and multiple valve weights to permit uniform operation over a wider operating range. See section — for a complete listing and description of our most common styles.

Sieve Trays

Sieve trays began to dominate the CPI's mass and heat transfer applications in the 1950's. Prior to that, bubble cap trays were the industry's workhorse. The sieve tray is a flat perforated plate. If extreme turndown conditions are not required, sieve trays will likely meet your process performance objective. Additionally, sieve trays have better anti-fouling characteristics and lower pressure drop when compared to standard moveable valve trays. Raschig Jaeger has the capability to provide virtually any type of sieve tray. Perforation sizes as small as 1/8" in diameter are offered.

Bubble Cap Trays

Raschig Jaeger designs and provides numerous variations of bubble cap trays. Our most common designs include conventional slotted caps and the standard FRI solid cap (no slots). Standard cap sizes are 3", 4", and 6". Of course, custom designs are available as well. Typical manufacturing methods to secure the riser and cap assembly to the tray floor include extrusion and press fitting, seal welding, and pull-through bolting connections.

Bubble cap trays usually have a lower capacity (10-20 percent) than properly designed valve or sieve trays; however, they are capable of efficient performance over a wider operating range due to their superior leak proof characteristics.

Although some bubble cap tray towers have been retrofitted with the more modern three piece RJ-A1 valve unit, bubble caps still enjoy widespread industrial application in systems where low liquid rates and large variations in vapor loadings are present.
“Packed” Column Internals
Random and Structured Packing

<table>
<thead>
<tr>
<th>Relative cost</th>
<th>Pressure drop</th>
<th>Efficiency</th>
<th>Vapor capacity</th>
<th>Typical turndown ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Fairly high</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>High</td>
<td>Very low</td>
<td>Very high</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>High</td>
<td>Very high</td>
<td>High</td>
<td>High</td>
<td>2</td>
</tr>
</tbody>
</table>
Packed Columns (Distillation)

- Usually for small diameter columns
  - Usually more economical for columns < ~75 cm (2.5 ft)
  - Lower pressure drop than trayed columns
  - Good for vacuum operations
- Wide choice of packing materials (random or structured)
- Watch for safety in “HC” service.

**Figure 10-25.** Generalized flooding and pressure drop correlation for packed columns. Reprinted with permission from Eckert, Chem. Eng. Prog., 66(3), 39 (1970), copyright 1970 AIChE. Reproduced by permission of the American Institute of Chemical Engineers
Column diameter: 0.288 m
Packing height: 2.0 m

Specific pressure drop $\Delta p$ [Pa/m]

Liquid load $u_l$ in [m$^3$/m$^2$ h]

Raschig Super-Ring No. 1.5 made of metal

Gas capacity factor $F_y$ [Pa$^{1/2}$]

Superior performance by design™
Raschig GmbH · Jaeger Products, Inc
Packed Columns (Distillation)

- **Column diameter**
  - \( \frac{D_{\text{col}}}{D_{\text{packing}}} \sim 8 \text{ – } 12 \) (rule of thumb)
  - If \( \frac{D_{\text{col}}}{D_{\text{packing}}} > \sim 40 \), watch for channeling
  - Sized based usually on approach to flooding or acceptable pressure drop

- **Packing height**
  
  \[
  HETP = \frac{H_{\text{packing}}}{N_{TH}} = \frac{\text{packing height}}{\text{number theoretical stages}}
  \]

---

**Figure 10-24.** HETP vs. vapor rate for metal Pall rings; A) Iso-Octane-Toluene, B) acetone-water. Reprinted with permission from “Pall Rings in Mass Transfer Operations,” 1968 courtesy of Norton Chemical Process Products, Akron, Ohio
Trayed Columns (Diameter)

- Chap 10 (p 314, Wankat)  
  "Fair’s Procedure"
  o Considers entrainment flooding (most freq.)
  o Downcomer flooding (sometimes) – need different procedure
  o Downcomer flooding rare if \((1- \eta) \geq 10\%\)
- Used in AspenPlus

\[
\text{Dia} = \text{function} \left[ V^{1/2}, \frac{1}{\eta \text{frac}} \frac{1}{u_{\text{flood}}} \right]
\]

\(\eta \rightarrow \text{tray } A_{cs} \text{ fraction available for vapor flow}\)

\(u_{\text{flood}} \rightarrow \text{flooding vapor velocity } \left[=\right] \frac{ft}{s}\)

\(\text{frac} \rightarrow \text{fractional approach to flooding velocity}\)
Trayed Columns (Diameter)

- Plate spacing (selected for maintenance, performance).
  Typ:
  - 12 – 16” for Dia < 5’
  - 24” larger columns
- Calc Dia & round up to nearest ½ foot (USA)
  - 2.5’ minimum dia.
  - If < 2.5’ consider packed tower

\[ u_{\text{flood}} = C_{sb,f} \left( \frac{\sigma}{20} \right)^{0.2} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \]

\[ \sigma \rightarrow \text{surface tension} \left[= \frac{\text{dyne}}{\text{cm}}\right] \]

\[ C_{sb,f} \rightarrow \text{capacity factor} \]
Overview

• Questions from last week??
• Review rigorous methods / RADFRAC
• Multicomponent systems:
  o Residue curves
  o DSTWU / RADFRAC
  o Rules of thumb
• Complex (Enhanced) distillation
• Column internals

• Batch distillation
Batch (Rayleigh) Distillation

- Usually for small capacity systems
- 1 column handle multi-"campaigns"
- Produce sample new products
- Batch upstream processes
- Feed contains solids/foulants

Material Balance:
leads to Rayleigh Equation

\[
\ln \left( \frac{W}{W_0} \right) = \int_{x_o}^{x} \frac{dx}{y - x}
\]

where:

\[x_o = x_F = \text{mole fraction of initial charge}\]
\[W_0 = F = \text{initial charge}[\text{moles}]\]
Batch (Rayleigh) Distillation

\[ \ln \left( \frac{W}{W_o} \right) = \int_{x_o}^{x} \frac{dx}{y-x} \]

a) \( P = \text{constant}; \ K = f(T) \) only

\[ \ln \left( \frac{W}{W_o} \right) = \frac{1}{K-1} \ln \left( \frac{x}{x_o} \right) \]

b) Binary with \( \alpha = \text{constant} \)

\[ \ln \left( \frac{W_o}{W} \right) = \frac{1}{\alpha-1} \left[ \ln \left( \frac{x_o}{x} \right) + \alpha \ln \left( \frac{1-x}{1-x_o} \right) \right] \]

c) \( y = K \cdot x \); but \( K = f(T,x) \)

Solve graphically or numerically
Multistage Batch Distillation

Modes of operation:
- **Constant reflux rate or ratio**
  - $x_D$ varies with time
  - easily implemented (flow sensors)
  - Relatively simple and cost effective
- **Constant distillate composition**
  - $R$ or $D$ varies with time
  - Requires fast response composition sensors
  - Sensors might not be available or only justified for larger batch systems
- **Optimal control mode**
  - $x_D$ and $R$ varied with time
  - Designed to:
    - Minimize operation time
    - Maximize amount of distillate
    - Maximize profit
  - More complex control scheme

Figure 13.3 Batch rectification. Seader & Henley (2006)
**Multistage Batch Distillation**

**Figure 13.8** Batch stripping.

Removing volatile impurities.

**Figure 13.9** Complex batch distillation.

Flexible, multi-purpose system

Seader & Henley (2006)
Questions?