Distillation Trays as Mechanical Equipment

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Presented at the American Institute of Chemical Engineers Webinar
Online, December 14, 2016, 14:00-15:00 EST-USA
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Designers, purchasers, and users of equipment are solely responsible for technical, legal, economic, safety, and all other consequences of the equipment they use.
Distillation Trays

One equipment choice for distillation

Other choices

• Packing
• Exotics
  • Spinning band
  • Spinning disc
  • Fibers

Trays also used in liquid-liquid extraction

Caged-valve tray
Courtesy of RVT Process Equipment
Coverage Today

Conventional cross-flow trays
   With downcomers
   Without downcomers

High-capacity trays
   With hanging downcomers (truncated downcomers)

This is the most common type

Other types available for specific applications
1. What trays need to do
2. Tray flow
3. Tray types
4. Mechanical construction
5. Specification
6. Reliability
1. What trays need to do
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Distillation Requirements

Transfer lightest liquid into the vapor (vaporization)
Transfer heaviest vapor into the liquid (condensation)

Vaporization and condensation require heat transfer and mass transfer

Surface-area required between different phases

Phase separation required to keep benefits of separation
Tray Function

- Heaviest Vapor
- Lightest Liquid
- Mix
- Separate

Liquid

Vapor

Tray
1. What trays need to do
2. Tray flow
3. Tray types
4. Mechanical construction
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6. Reliability
Cross-Flow Trays

- liquid to tray below
- liquid from tray above
- vapor through active areas
- liquid across active area
Tray Functional Zones

1. Active Area
   Vapor-liquid mixing.

2. Open Space
   De-entrain liquid from vapor.

3. Downcomer
   De-gas vapor from liquid.
1. What trays need to do
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6. Reliability
The Naming of Trays

Downcomers
- With and without
- Conventional and hanging (truncated)

Passes
- Defined by flow paths available for liquid

Devices
- Defined by equipment in active area
Downcomers
Trays with Downcomers

Most common type

Reliable, flexible, and predictable operation

Segregated area for:

• Liquid degassing
• Accumulating liquid height for pressure balance

Downcomer may be straight (vertical) or sloped
Conventional Downcomers

Area under downcomer solid, no vapor flow

Outlet weir usually holds a liquid level on the tray
(zero or positive seal)
Example Downcomer Tray

Sieve tray, Two-Pass
Courtesy of RVT Process Equipment
Hanging or Truncated Downcomer

Downcomer is short

Orifice plate in downcomer holds a dynamic seal on the liquid in the downcomer

Increases tray capacity

Decreases downcomer rate flexibility (reduces downcomer height and volume)

From USA Patent 4,504,426
Example Hanging Downcomer Tray
Trays Without Downcomers

Liquid and vapor flow through same hole on tray

High capacity, Low flexibility

Lower efficiency

Usually reserved for very fouling services

Some other applications
Example Trays Without Downcomers

From USA Patent 2,750,174

From USA Patent 2,767,967
Passes
Tray Passes

Paths for liquid flow

The more paths for liquid flow, the higher the liquid handling capacity

Liquid flow paths change pressure balance, multiple flow paths can increase vapor capacity as well

1, 2, 4 paths common

3 used occasionally

5+ not common

The more passes, the larger the tower minimum diameter

The active area should be a minimum width to allow for manways
One-Pass and Two-Pass
Three-Pass and Four-Pass
Two-Pass Tray, In Service
Devices
Active Area Devices: 1

Mix vapor and liquid

Valves most common
  Help keep liquid on the tray, increase operating flexibility
  More expensive
  Directional valves, help push liquid
  Fixed valves, reduce fouling problems
Active Area Devices: 2

Sieve holes (perforated trays)
- Cheapest
- Reasonable flexibility

Bubble caps
- More expensive
- Maximum flexibility
- When used properly, suitable for very low liquid rates

Other options less common
Valves

Valve
Courtesy of Sulzer Chemtech

Caged Valve
Courtesy of RVT Process Equipment
Sieve (Perforated) and Bubble-Caps

Sieve
Courtesy of RVT Process Equipment

Bubble Cap
Courtesy of RVT Process Equipment
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Modern Trays

Constructed in panels

Panels have integral trusses

Some components may be beams or stand-alone beams may be included

  Example: use a downcomer panel as a beam

Tray ring holds tray edge in place

Bolts, clamps, and washers hold tray in place: friction fit

  Allows for fabrication, installation, out-of-round tolerances
Component Schematic

- Tray panel with truss
- Downcomer panel as beam
- Downcomer inlet panel as beam
- Downcomer Spacer
- Outlet weir
  Non-Structural
- Downcomer panel
  Non-Structural
- Tray ring
Tray Clamps

- Truss
- Active Panel
- Tray Ring
- Tray clamp
- No overlap with ring
Washers and Seals

Outlet weir

Sealing strips

Caged Valves

Washers
Underside: Trusses Do Not Overlap or Connect
1. What trays need to do
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Mechanical Specifications Often Assumed

60 psf (lb/ft²) distributed load (at operating conditions) [0.030 kg/cm²]
or
30 psf (lb/ft²) distributed load for light duty [0.015 kg/cm²]

250-300 lb point load (at operating conditions) [0.122-0.146 kg/cm²]
1 % vessel out of roundness maximum (ASME BPC VIII-1 UG-80)

Bolting not to be critical-slip
Install with vessel in vertical position
Manway opening from top only
Beams and trusses all underneath active area
Hole punch direction down
Mechanical to Specify, Common

Components

- Metal thickness for tray decks, panels, and devices
- Beam thicknesses (minimums)
- Average thickness or minimum thickness

Load requirements

Materials of construction

Size of manhole to pass pieces through

Manway opening from top and bottom

If out-of-roundness needs to be worse than 1%

Hardware extra pieces (5 to 10%)

Include tower attachments (weld-in components) or not
# Common Specifications: Components

<table>
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<tr>
<th>Component Type</th>
<th>Gage</th>
<th>Inch*</th>
<th>mm*</th>
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<tbody>
<tr>
<td>Major support beams</td>
<td>7</td>
<td>0.1793</td>
<td>4.5</td>
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<tr>
<td>Minor support beam</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alloy and non-ferrous</td>
<td>12</td>
<td>0.1046</td>
<td>2.5</td>
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<tr>
<td>Carbon steel</td>
<td>10</td>
<td>0.1345</td>
<td>3.5</td>
</tr>
<tr>
<td>General components</td>
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<td></td>
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</tr>
<tr>
<td>Alloy and non-ferrous</td>
<td>14</td>
<td>0.0747</td>
<td>2.0</td>
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<tr>
<td>Carbon steel</td>
<td>10</td>
<td>0.1345</td>
<td>3.5</td>
</tr>
</tbody>
</table>

* Approximate equivalents
Mechanical to Specify, Less Common

Deflection under load, often not specified, should be 1/8” or 3 mm

Uplift resistance, often not specified

Supported from ring only or split support (from above)

If to be installed while vessel horizontal

Leak rates

Leak tests
1. What trays need to do
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Trays Leak

Always some leaks (unless fully seal welded)

Seal plates used to close gaps in tray

Gaps in downcomer seal area more of a problem than in the tray deck

- Head of liquid in downcomer increase leak
- Liquid bypasses tray completely
- Vapor flow on tray reduces active area leaks
Major Damage, Trays Fail...

Corrosion, pick the right materials
Installation, understand and follow procedures

The “Big 4”
Pressure surges, water entering hot systems (or other sudden vaporization)
Level upsets in tower bottoms
Vibration (rare)
Pressure surges, PSV releases
Pressure Surge Tray Damage
Best Approach

Reduce the number and size of upsets

**Pressure Surges**
Keep violently flashing streams out of the system
Keep level controllers working
Avoid PSV releases

**Vibration**
Inherent in operating conditions
Mechanical solution required
Make tray stiffer and change mechanical layout
Specifications to Add

Higher distributed load
Specify an uplift resistance
Make components thicker
Additional features
   Truss lugs, to prevent trays from being pushed down
   Shear clips, to prevent trays from being pushed up
   Through bolting, requires field fit and drilling
Specified number and type of major beams
Welding installation (allow for thermal expansion)

Pressure relief options
Relative Cost: Making Trays Stronger

Through-Bolting Adds Strength

Through-Bolted on Truss

Friction-Fastened on Truss (Standard Washer)

Friction-Fastened on Truss (Heavy Washer)
Lugs and Clips: Panel-to-Ring

End View

Side View
Through-Bolted Rings

Through-bolting requires field fit and drilled holes

Rings are thick

Side View

Truss

Tray Ring
Alternative: Pressure Relief

Add a trap-door to handle pressure relief

Deals with pressure surges, not with level induced damage or vibration damage
Trap-Door Tray

Fig. 3.

From USA Patent 4,133,852
Trap-Door Tray
One Final Caution

Don’t make the trays stronger than the vessel.
Conclusions
Today’s Take-Away

Mechanical requirements add to process requirements

Understand cost, delivery time, installation time consequences of requirements

Basic requirements outlined

Many complex trays with special features
Further Reading


What We Do

**Consulting and Engineering in Economics**

- Market analysis
- Strategic consulting

**Operational Excellence**

- Performance gap analysis
- Performance improvement

**Refining, Petrochemicals, Chemicals**

- Conceptual design
- Technology selection
- Value-chain integration
- Safety and environment

**Sulfur and Gas Treating**

- Oxygen enrichment
- Gas treating solvents

**Infrastructure and Environmental**

- Water
- Materials handling

**Management, Economics, and Business Operations**