DISTILLATION TECHNOLOGY & TOWER SIMULATION

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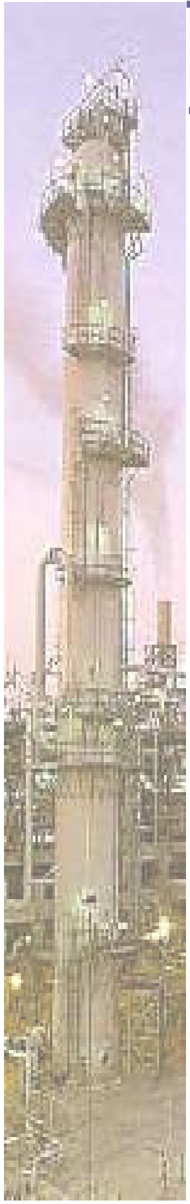


Task Checklist

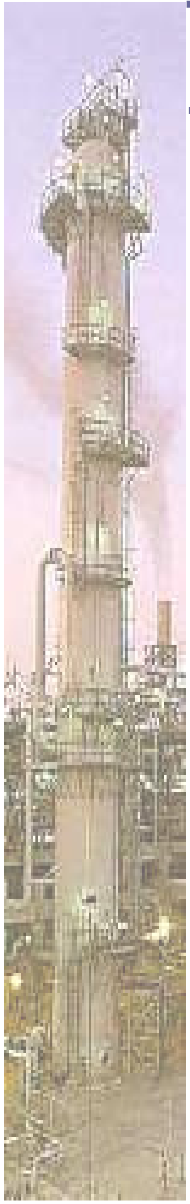
▶ **Introduction**

DISTILLATION / TOWER SIMULATION

- ▷ Basic Concepts
- ▷ Specifications

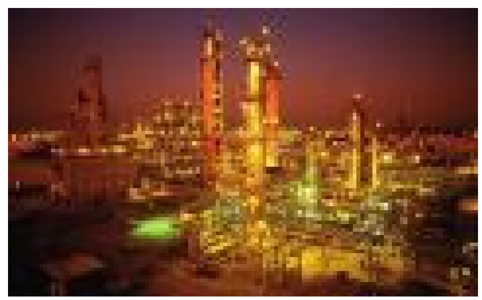
DEVICE SELECTION

- ▷ Contacting Devices
- ▷ Tray Hardware Definitions
- ▷ Tray Hydraulics
- ▷ Packing Hydraulics
- ▷ Other Process Considerations
- ▷ Other Tower Internals
- ▷ Tower Revamps



Did You Know?

- Oldest and most important petrochemical manufacturing process
  - Prepares feed for other refining processes
  - Separates products from other refining processes
- Equipment accounts for 30% of all investments today
- Consumes 70% of all energy at plant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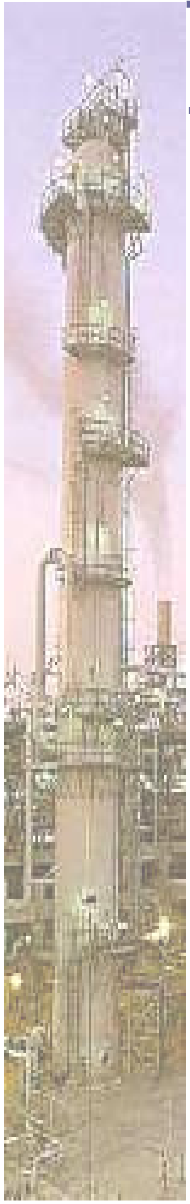
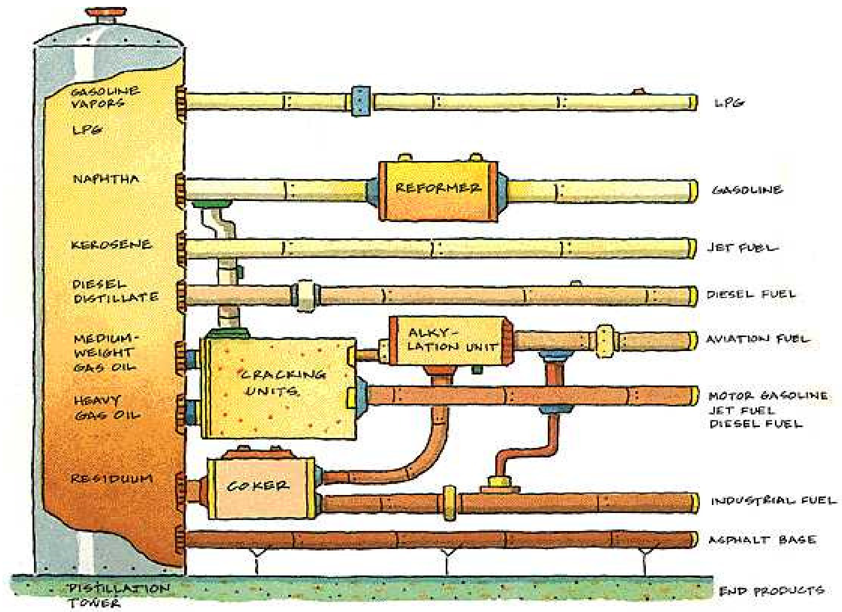
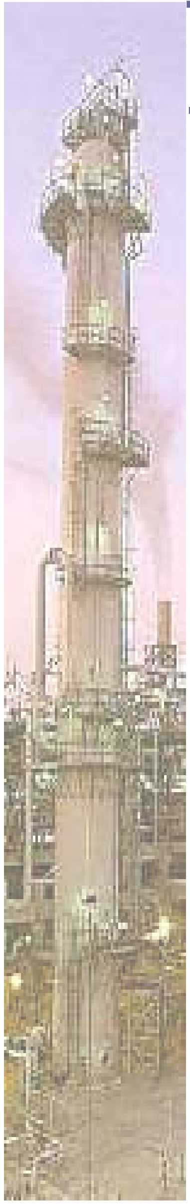
More on Fractionation



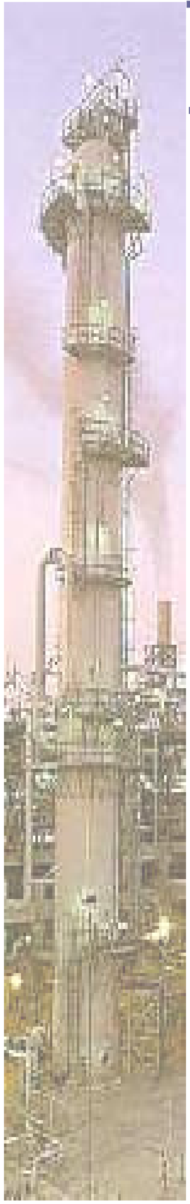
- Separate feed into products according to boiling point
- Products sent to finished product tank or further processed by other units
- Multiple products and feeds common





Objective Questions

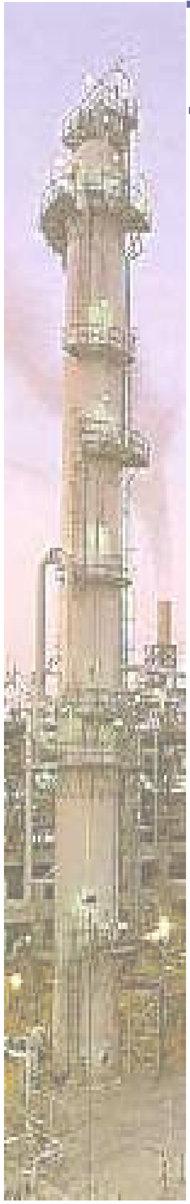
- How can you improve separation efficiency?
- How do you decide on the optimum number of trays for a new tower?
- What sets a tower's operating pressure?
- What are my options to increase a tower's vapor / liquid handling capacity?



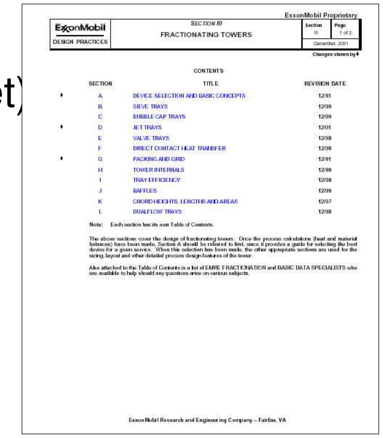
Designer's Role

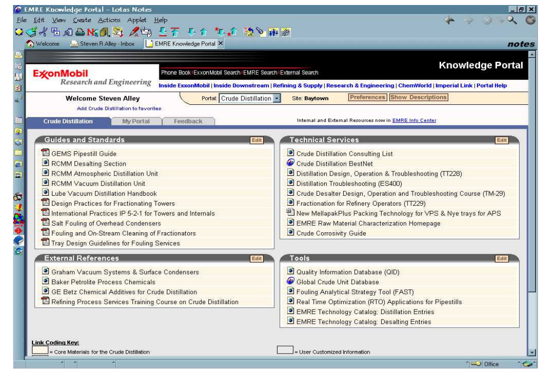
- Perform HMB calculations to develop tower loadings
- New Towers
  - Select optimum tower size, contacting device, and internals to meet process requirements
- Existing Towers
  - Select optimum contacting device and internals to improve performance or expand capacity
  - Screening - Apply Concepts to Troubleshoot Problems
- Prepare Design Package (Consult with Specialist)

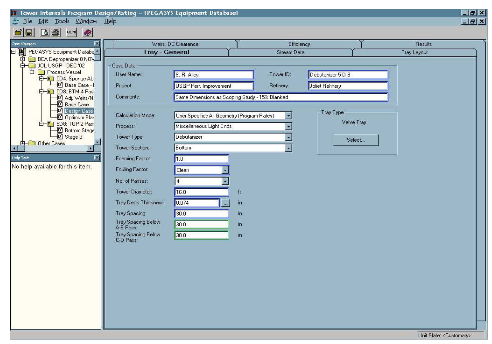
Engineer's Toolbox

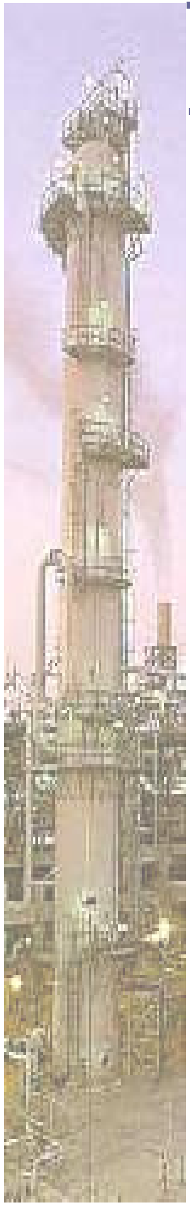


- XOM DP Section III (Intranet)
- ProII / Provision
- Pegasys **E**xxon**M**obil **T**ower **I**nternals **P**rogram - EMoTIP
- EMRE Knowledge Portal
- Fractionation Specialists









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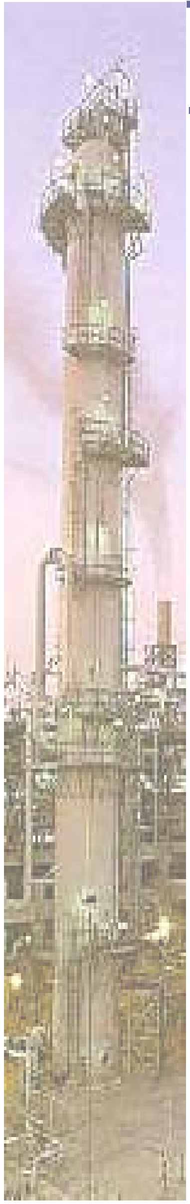
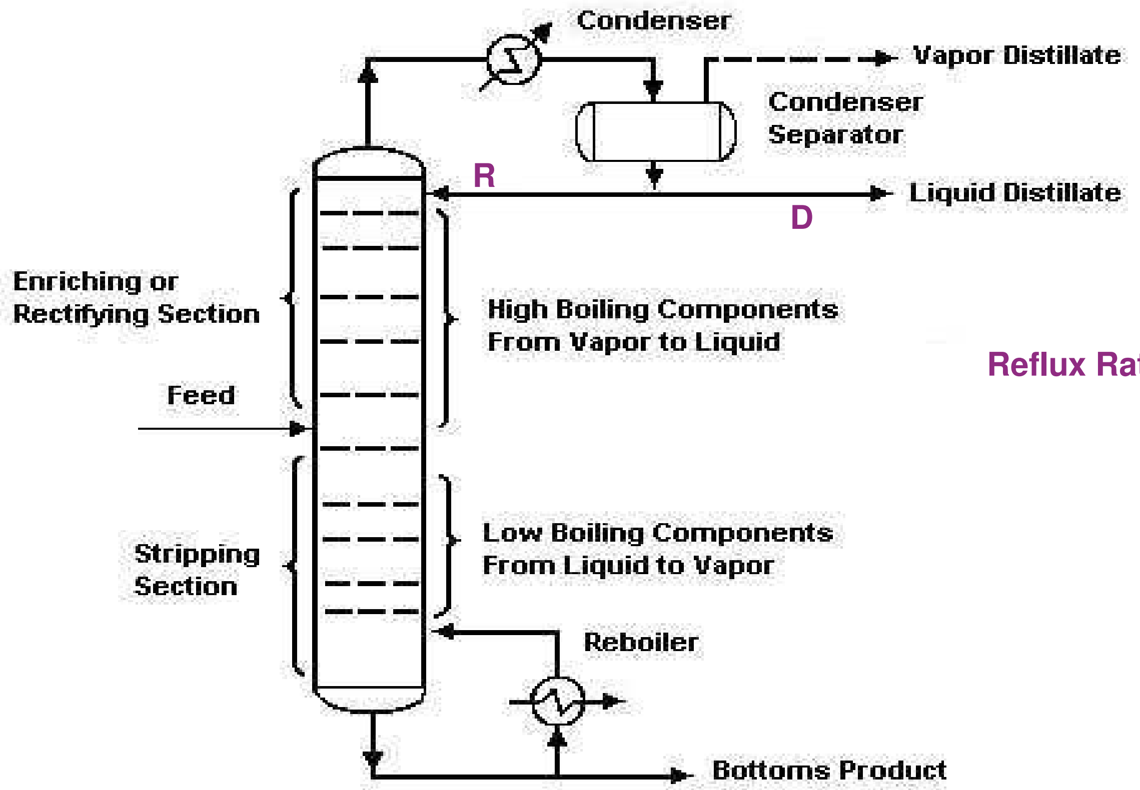


Conventional Tower



Reflux Ratio = R / D

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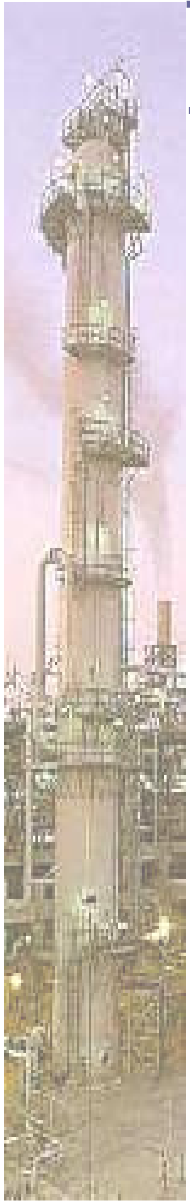
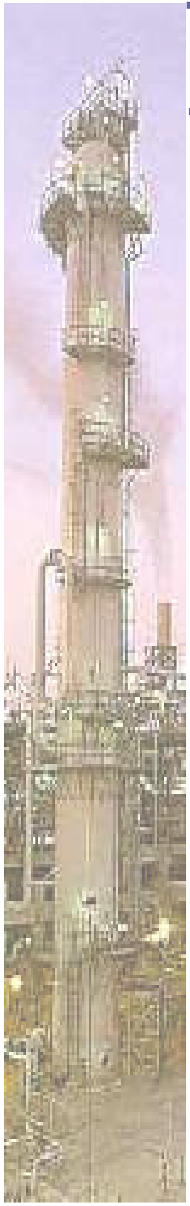


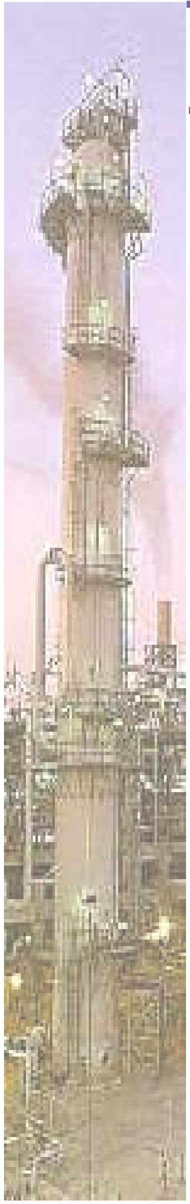
DISTILLATION COLUMN TERMS

- Rectifying section: Section of tower above the feed point. Heavy components are condensed out of the vapor in this section
- Stripping section: Section of tower below the feed point. Light components are stripped out of the liquid in this section
- Reflux: Liquid from the overhead condenser that is returned to the top of the tower. The reflux ratio is the reflux rate divided by the overhead product rate



COMPONENT DEFINITIONS

- Key Components: Major feed components between which a desired split is to be made.
  - Light Key: Least volatile major component whose concentration increases up the tower
  - Heavy Key: Most volatile major component whose concentration increases down the tower
- Other Components:
  - Light Non-Key: Components more volatile than the light key component which end up almost exclusively in the overhead product
  - Heavy Non-Key: Components less volatile than the heavy key component which end up almost exclusively in the bottoms product
  - Intermediate Key: Components whose relative volatility are intermediate between the light and heavy keys and distribute between the top and bottom products

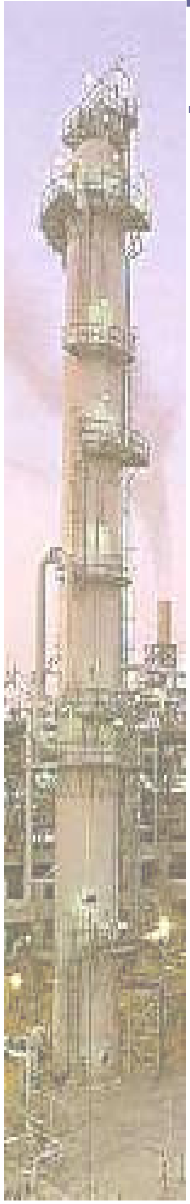


RELATIVE VOLATILITY

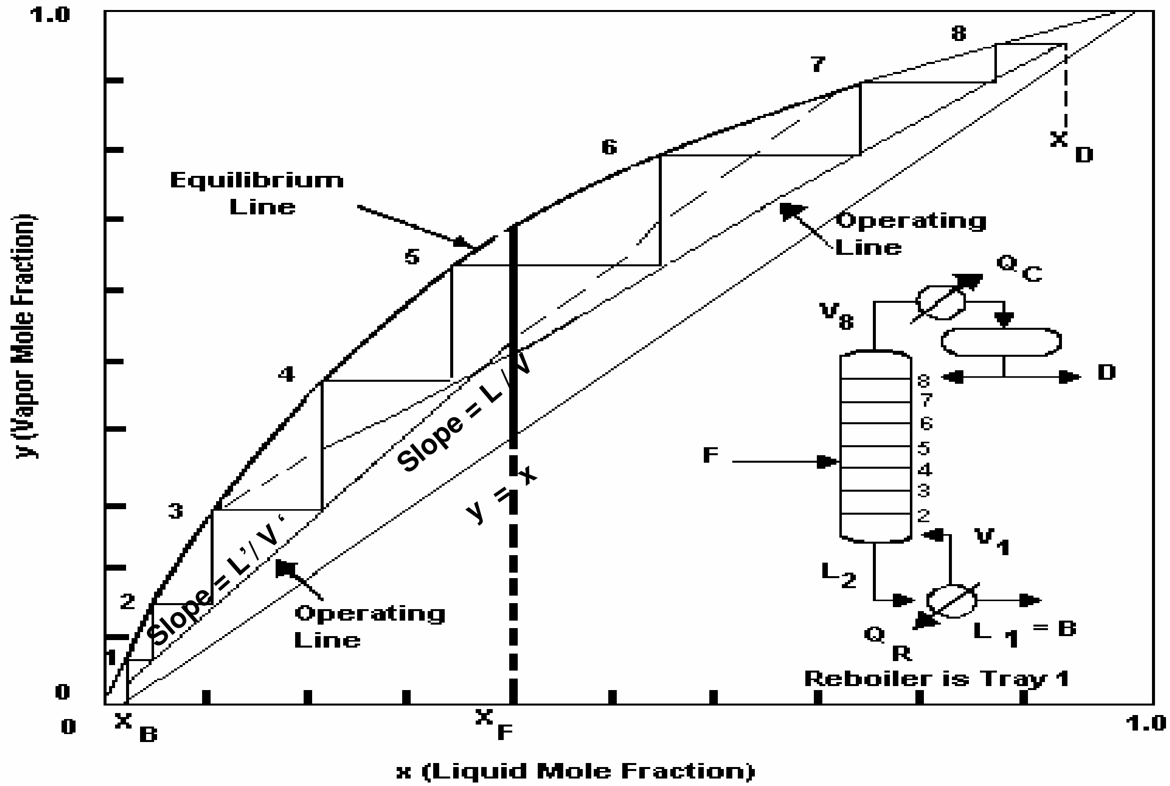
- Separation by distillation takes place by virtue of inequalities in volatilities. Relative volatily α is used to express this inequality.

	Component	K_i	$\alpha = K_i / K_C$
	A	K_A	K_A / K_C
	B	K_B	K_B / K_C
Key Component	C	K_C	1.0
	D	K_D	K_D / K_C

$$\alpha_{AC} = \frac{K_A}{K_C} \cong \frac{P_A/\pi}{P_C/\pi} \cong P_A/P_C \cong \frac{\text{Vapor Pressure Component A}}{\text{Vapor Pressure Component C}}$$



MCCABE - THIELE DIAGRAM



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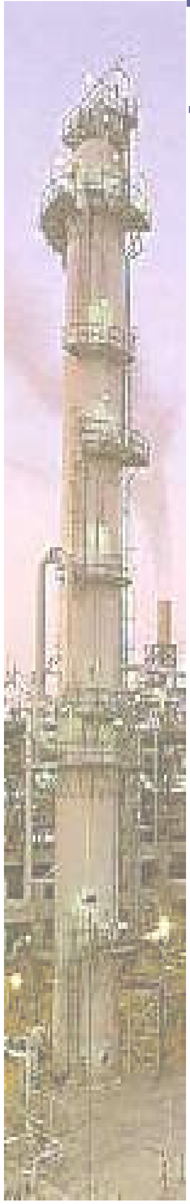
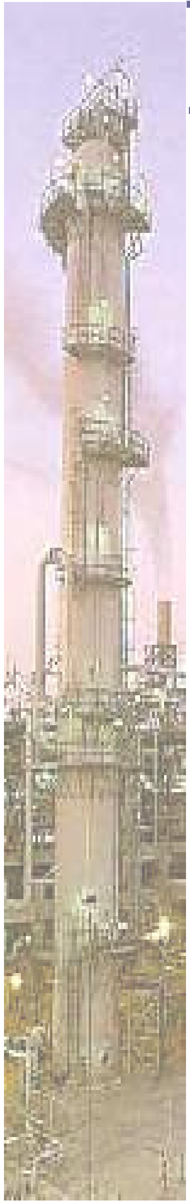


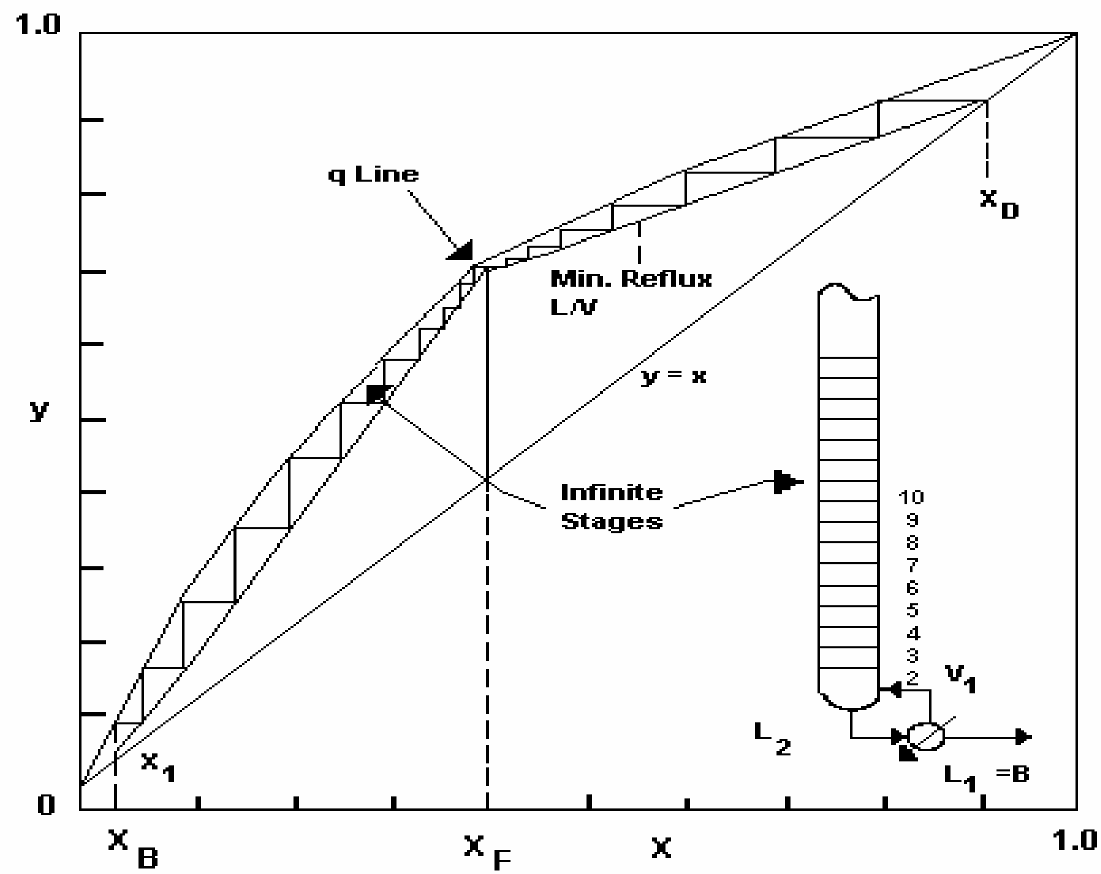
Rules of Thumb

- More Reflux
- More Trays
- Lower Pressure

→ More Separation



MINIMUM REFLUX - INFINITE STAGES



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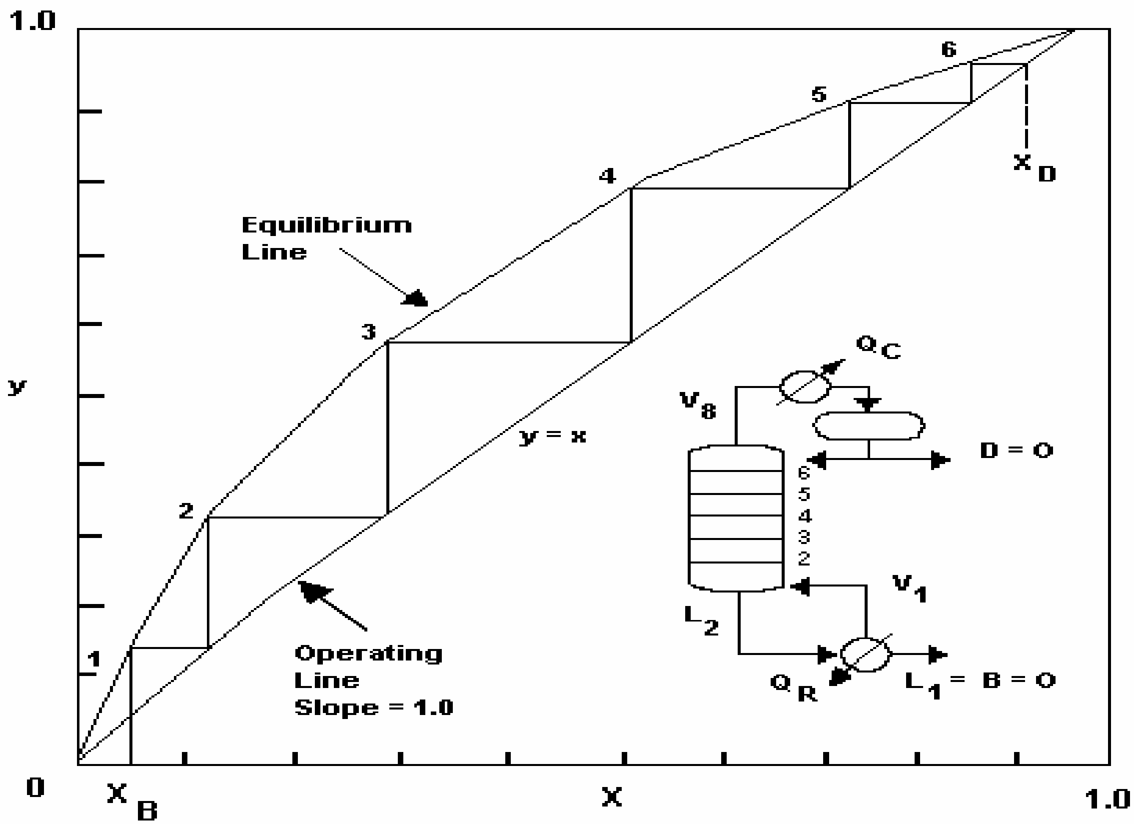
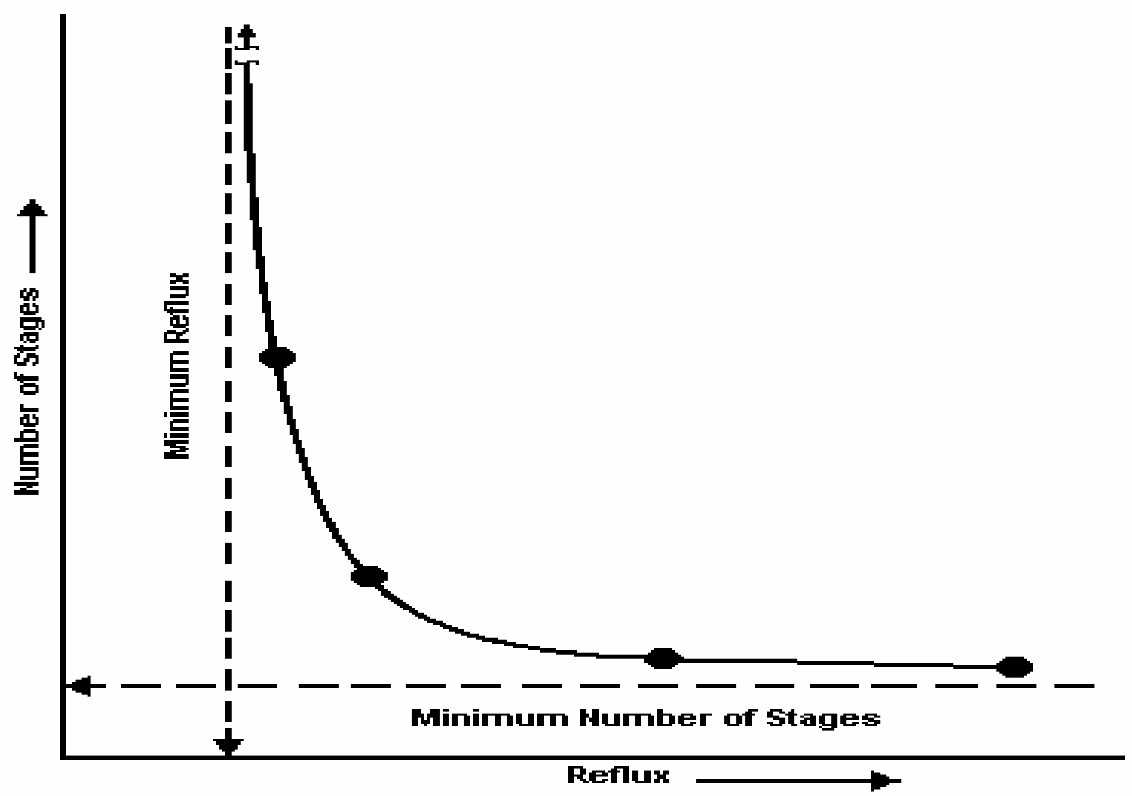
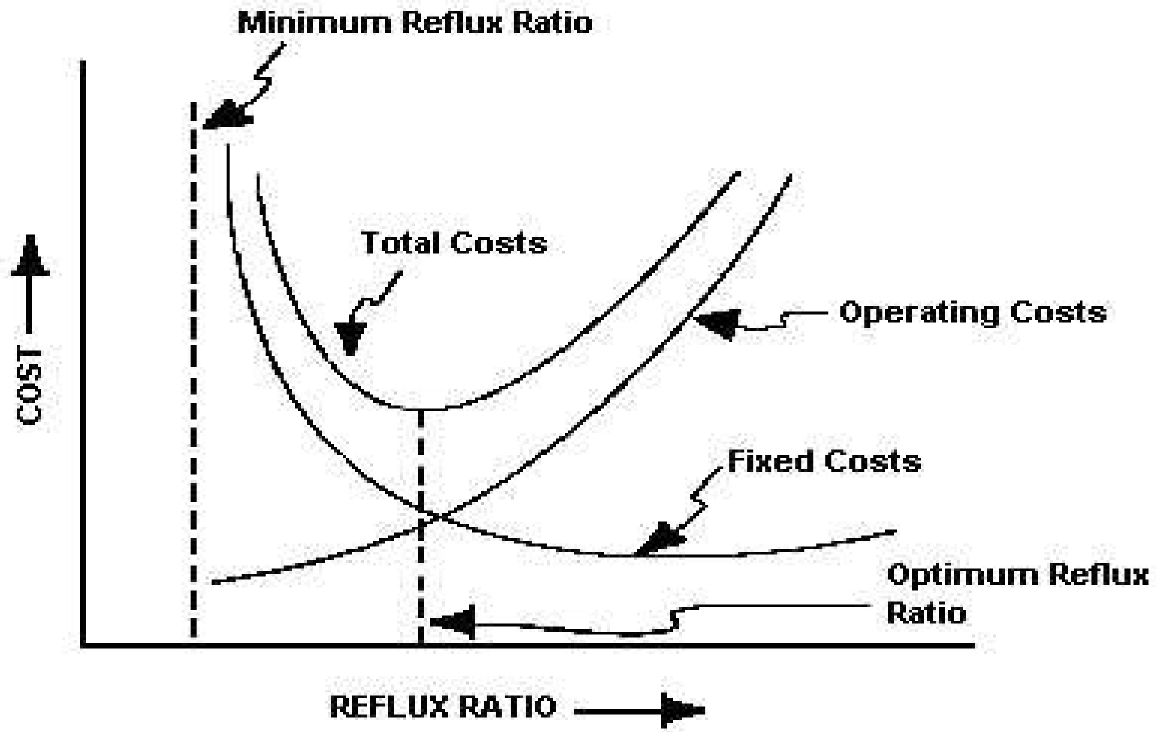
TOTAL REFLUX - MINIMUM STAGES



Stages Versus Reflux



Optimum Reflux Ratio



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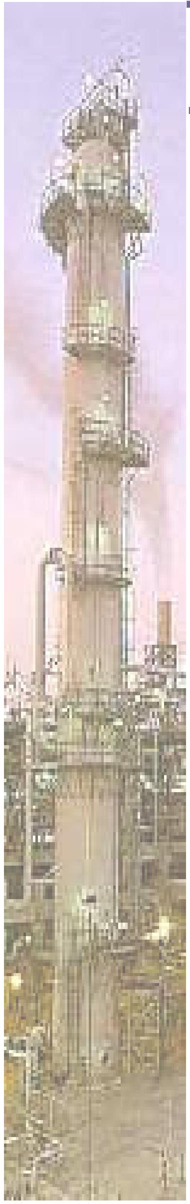

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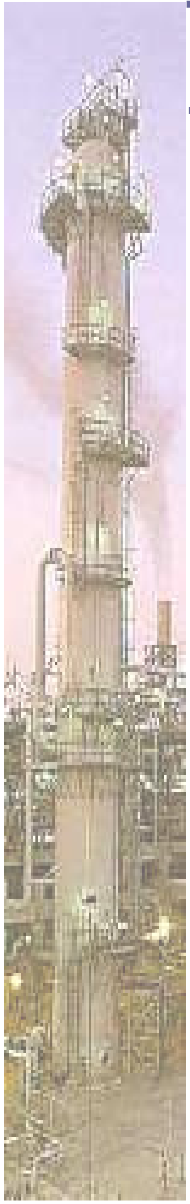
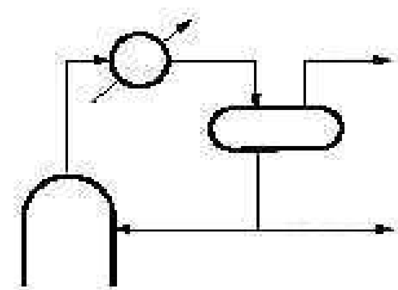
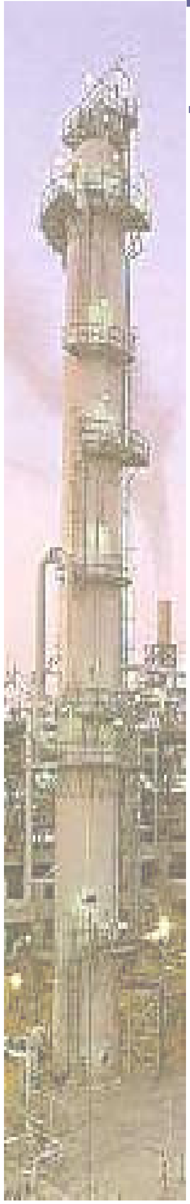


Operating Pressure

- Factors to consider:
  - Temperature of available condensing fluid (air, water, etc.)
  - Where's the overhead product go?
  - Is the overhead totally condensed?
  - Possible Limitations:
    - Bottoms temperature (cracking / color)
    - Reboiler
    - Critical Point (poor separation)
  - How much pressure drop is acceptable?

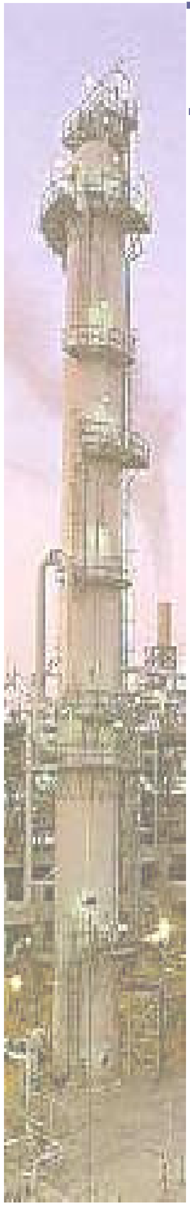




Operating Temperature

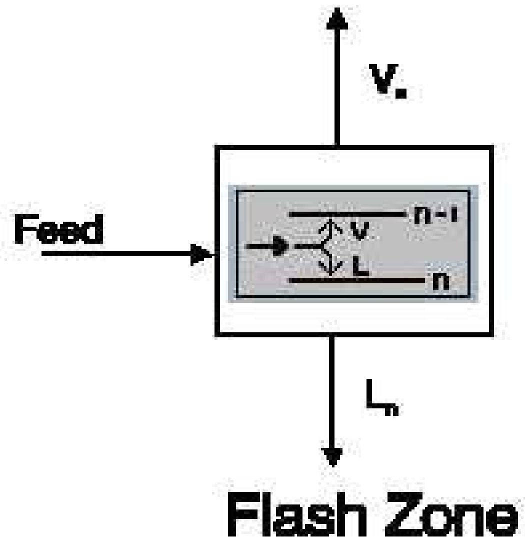
- Fixed once product specifications and pressure are set
- Dew Point Calculation
  - Overhead temp.
- Bubble Point Calculations
  - Bottoms temp.
- Flash Calculations
  - Reflux temp.

2 Degrees of Freedom

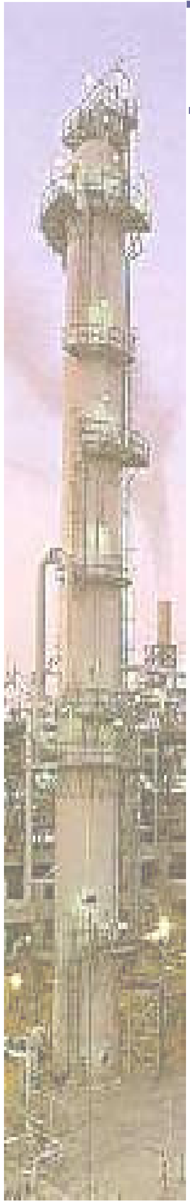


Feed Condition

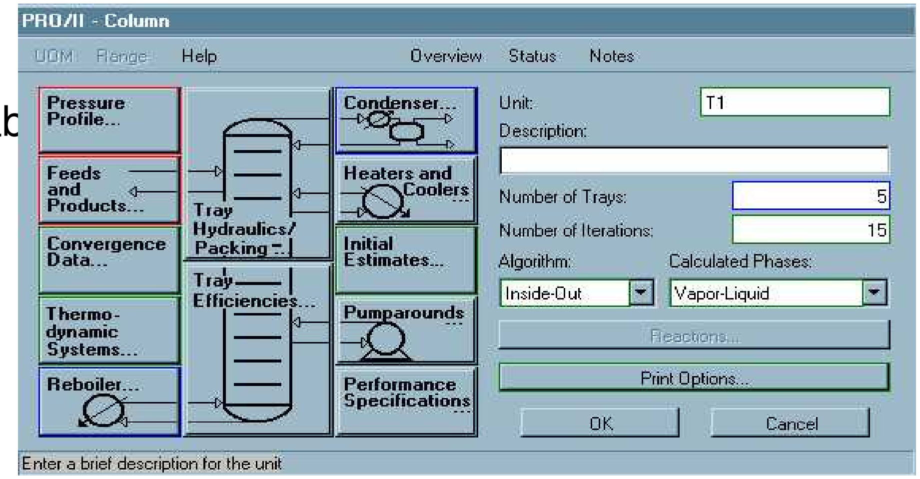
- If not specified, start with bubble point feed - Then optimize.
- Adjust temp. to balance tower loading
- Other Considerations:
  - Reflux vs. Reboiler Duty / Costs
  - Quenching



Simulation Inputs



- Feed Rate and Composition
- VLE Data Method
- Specifications & Control Variab
- Operating Pressure
- Initial Guess (If Required)
- For Rating:
  - Plant Test Data
    - Pressure, Temperature Profile
    - Lab Data (Complete Set of Samples)
- Tray Efficiencies
  - See DP III-I Table 2; Estimates from Past Designs



23 **Specifications**

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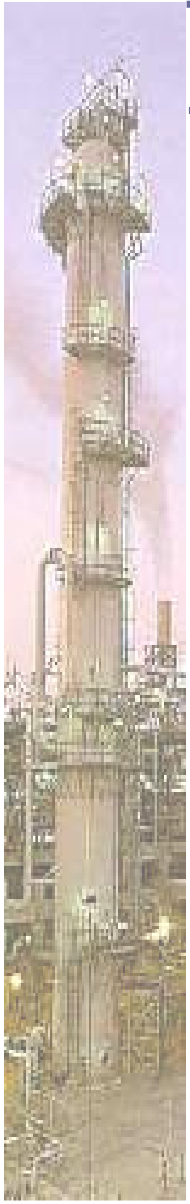
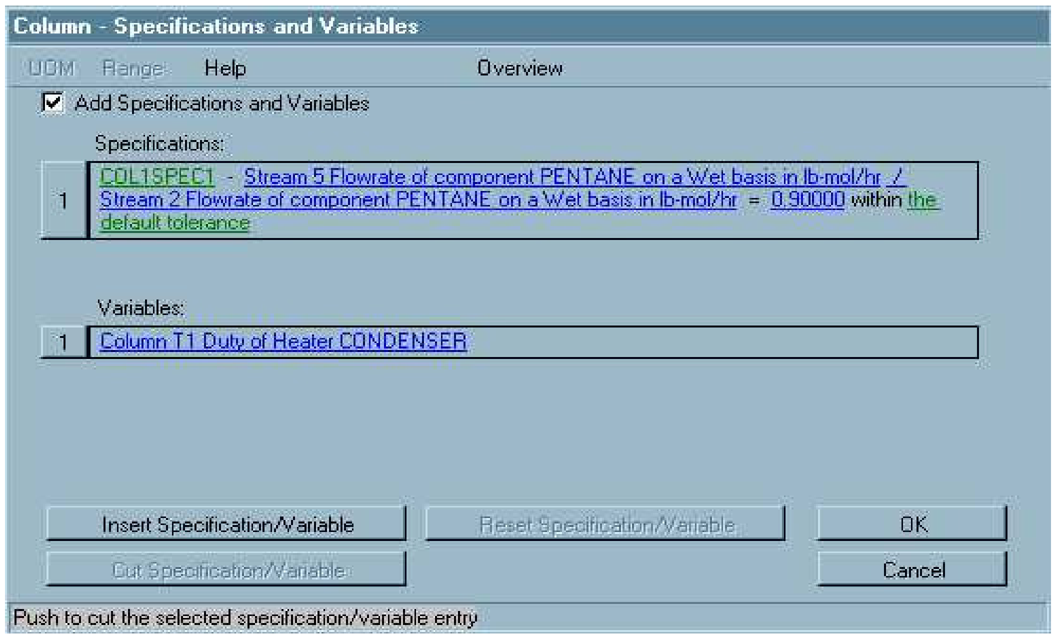
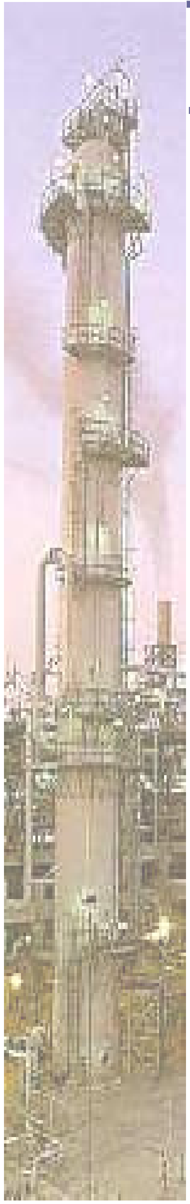


Tower Specifications

- Specifications: usually on product quality
  - Can be mathematical
- Variables: usually condenser / reboiler duty





Proll Condensers

- Stage 1, if present
- 5 Different Types (see PROII Keyword Manual)

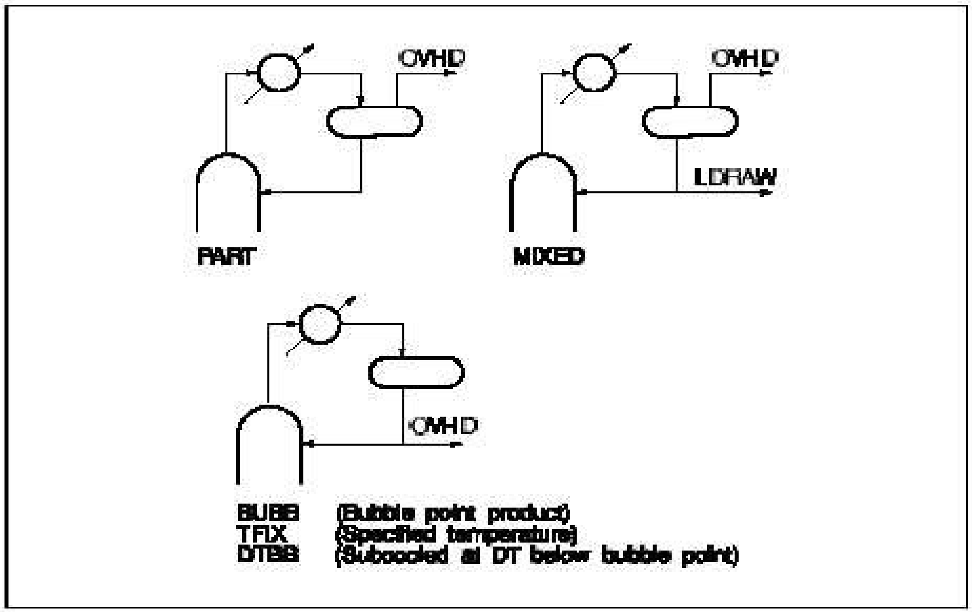
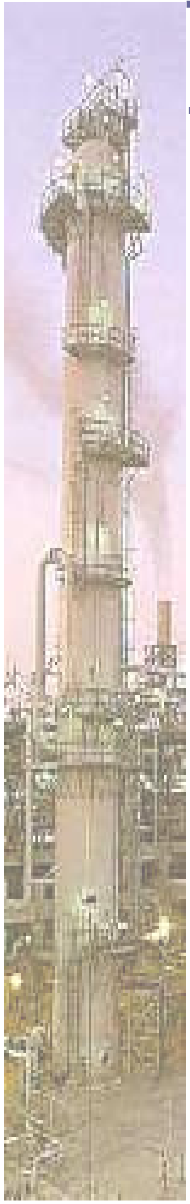


Figure 71.2. Condenser Types



Proll Reboilers

- Last Stage(s)
- Kettle or Thermosiphon
  - Kettle: One Stage
  - Thermosiphon: Two Stages

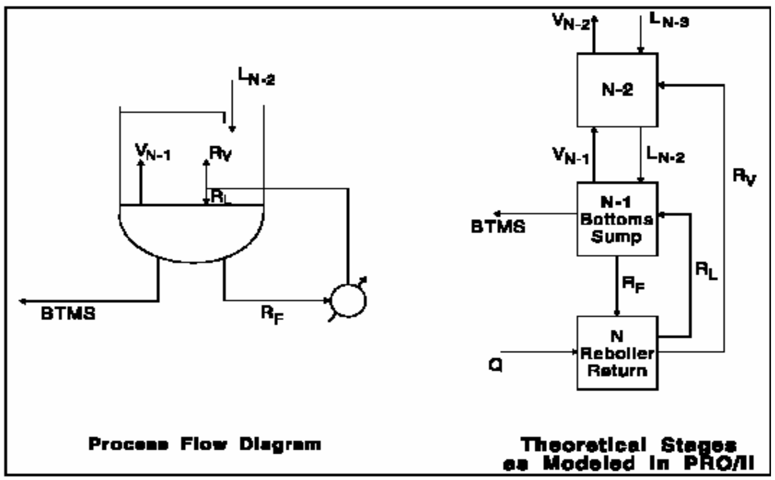


Figure 71.3 Thermosiphon Reboiler, BAFFLE=NO

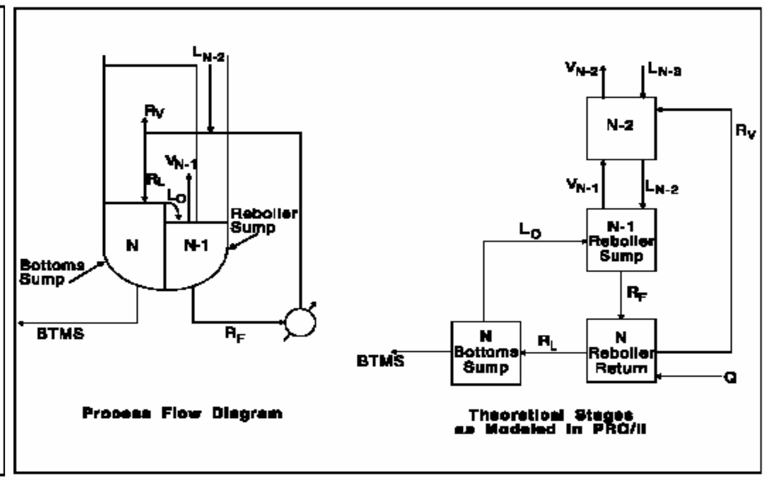
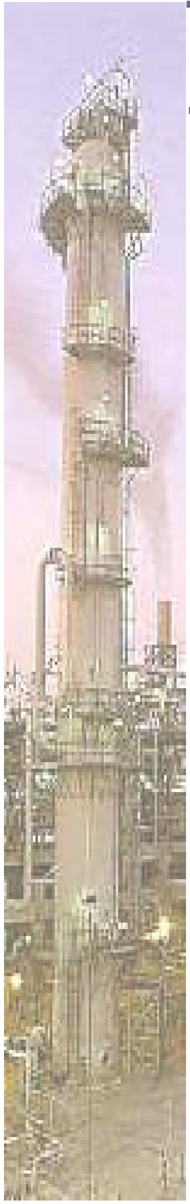
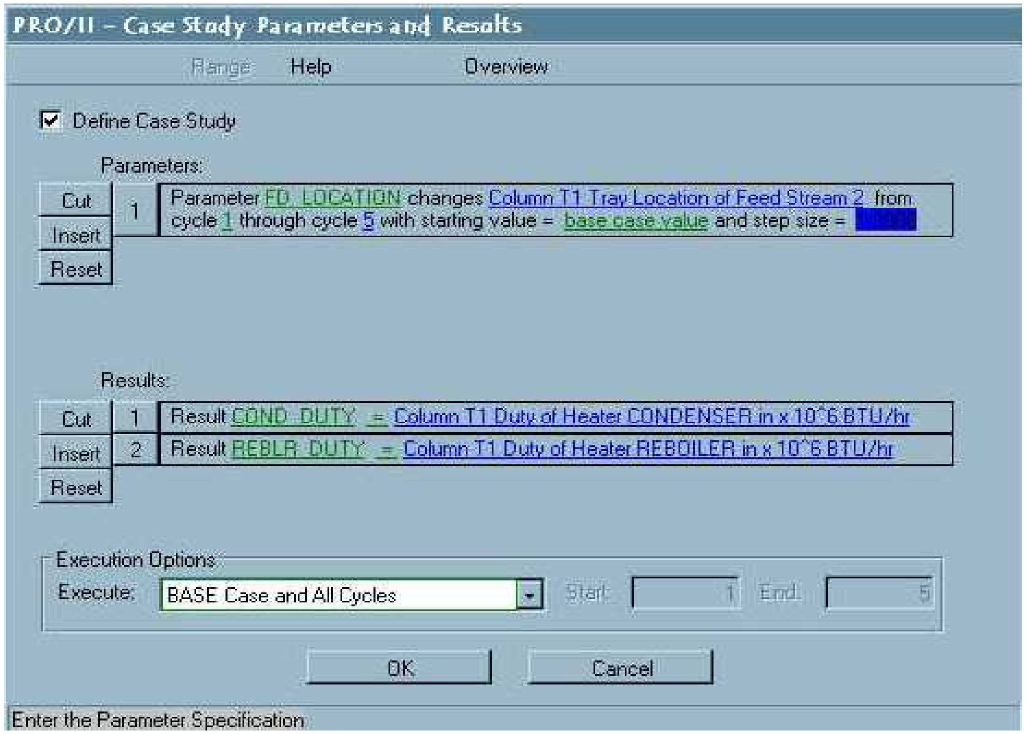


Figure 71.4 Thermosiphon Reboiler, BAFFLE=YES

Simulation Strategy



- Optimize Reflux Ratio, Stages, Feed Condition, and Feed Location



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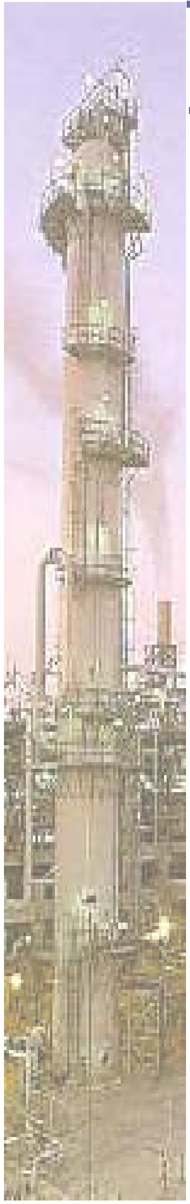
Simulation Pitfalls



- Save / Backup Provision cases often.
- Viscosity, other properties may need to be verified.
- Don’t use ProII to generate pseudocomponents
- Others?

Reactions and Separations

Can We Believe the Simulation Results?

Henry Z. Kister,
Fluor Daniel

Be careful of these key issues that may generate differences between a distillation-tower computer simulation and its actual performance. Simulations do not always square with nuts-and-bolts reality.

Previous surveys (1, 2) collected case histories of tower malfunctions from the open literature. Many reports described simulations that did not reflect what a tower was actually doing. Often, the problem was with the simulation. Sometimes, the problem was that the tower did something unexpected: the simulation was actually correct, based on the data fed to it. Finally, there were instances where both mishaps took place — the simulation had some serious problems, but there were aspects of tower behavior that were not fully understood initially and the simulation helped to explain.

This article focuses on instances where problems were found in the simulation or where the simulation was instrumental in identifying a previously misunderstood problem (see table).

The cases were extracted from surveys in Refs. 1 and 2 and have been updated with some recently reported cases. The original numbering for each case has been retained, so that the reader may easily locate the cases in the previously referred to articles.

The number of examples presented here is by no means a large enough sample for performing a statistical analysis of the main problems in troubleshooting distillation simulations. Nonetheless, the cases provide guidance on what to look for when troubleshooting a distillation simulation — and what to watch out for when carrying out the next simulation.

Three major findings

This survey revealed three major issues that require attention in using simulations:

1. correctly predicting vapor/liquid equilibrium (VLE)
2. having the simulation match plant data
3. applying graphical techniques to troubleshoot simulations.

These three issues are present in about two-thirds of the reported cases. In about 20% of the remaining cases, the process chemistry and hardware efficiency did not match what was true in an actual tower. Other items — correctly modeling feeds, obtaining the true vapor and liquid loads, reliably predicting the hydraulic behavior, and finding and squelching bugs in the simulations — were found to be problematic, but to a lesser degree.

Problems with VLE data and predictions

Most case studies falling into this category involve close-boiling components. The problems can be with two chemicals of similar vapor pressure (e.g., hydrocarbons), or due to a non-ideality that pushes the volatilities of a pair close to a pinch. Correctly estimating non-idealities is another trouble-spot when it comes to VLE predictions. A third dilemma is characterizing heavy components in crude-oil distillation. This is a key problem in simulating refinery vacuum towers. Few reports were made regarding other situations. It seems that VLE prediction for pairs of components that have reasonably high volatilities, for example, methanol/ethanol, is not often troublesome.

52 CEP

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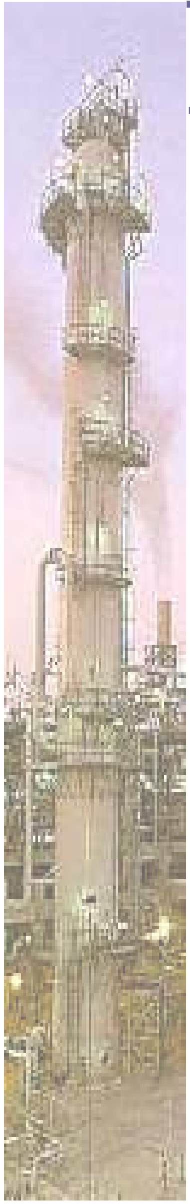
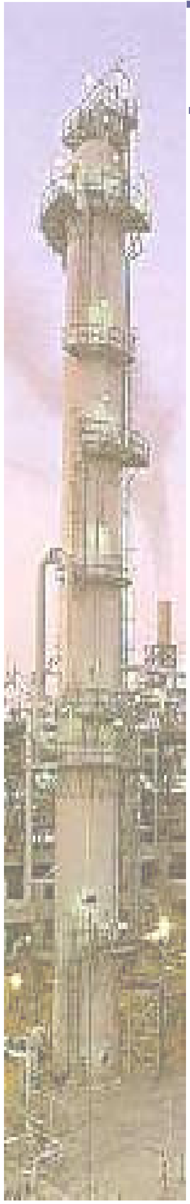


PROBLEM 3
SIMULATION PROBLEM



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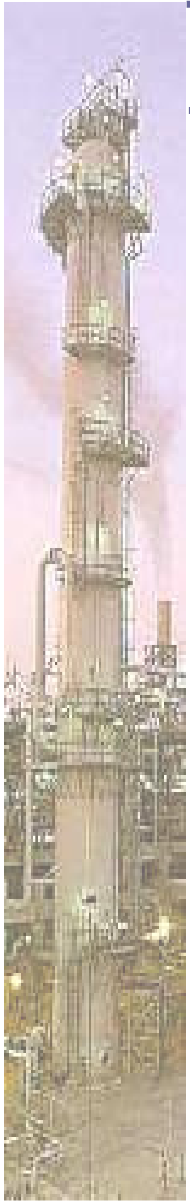
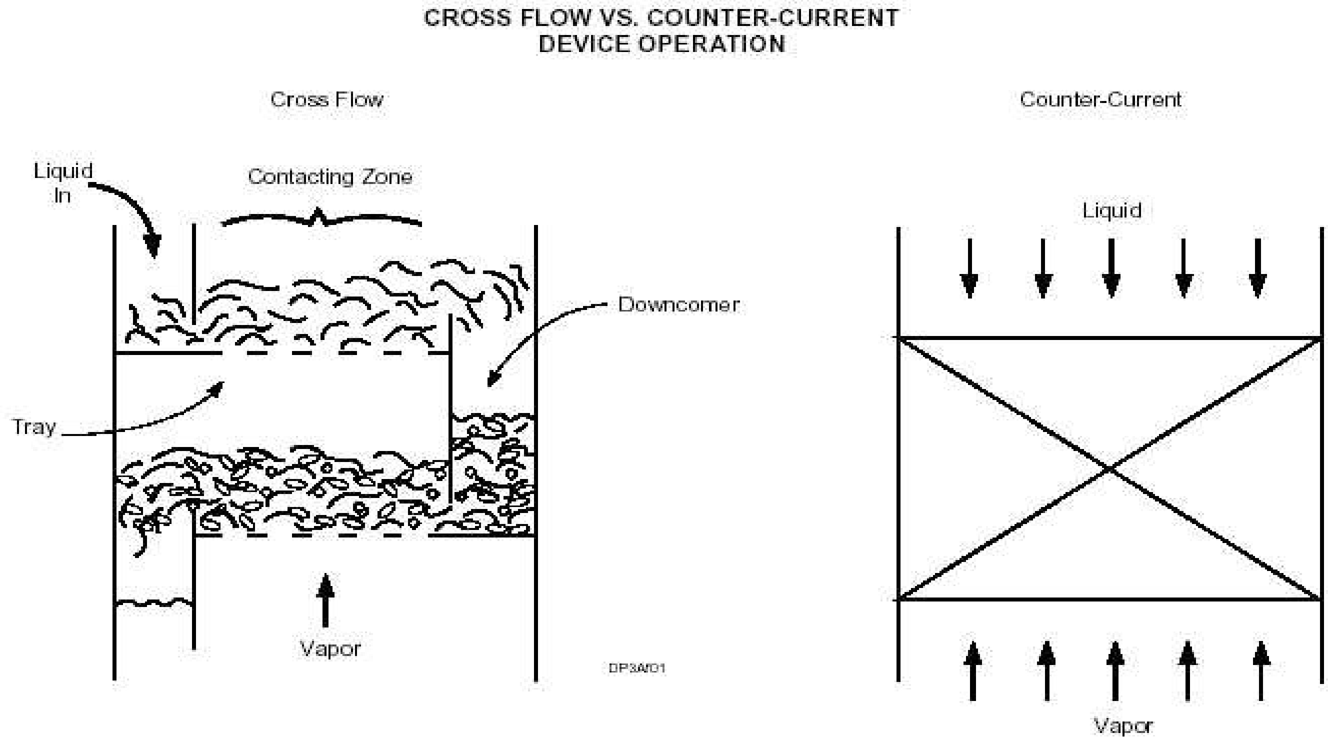


Device Categories



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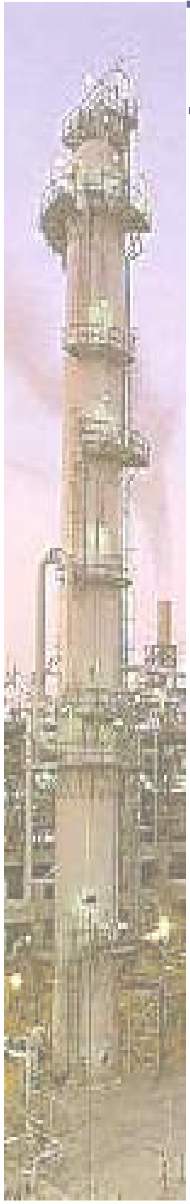


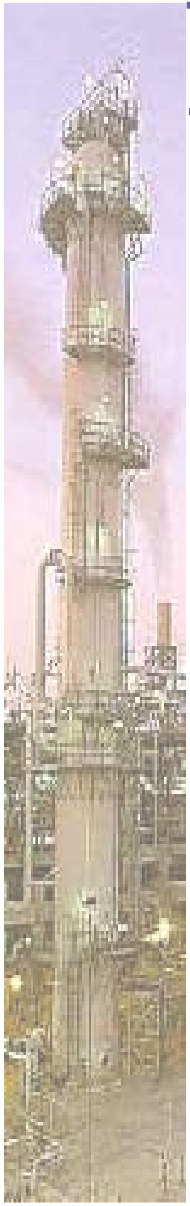
Device Subcategories

Cross Flow

- Conventional Trays
- High Capacity Trays
(Proprietary)

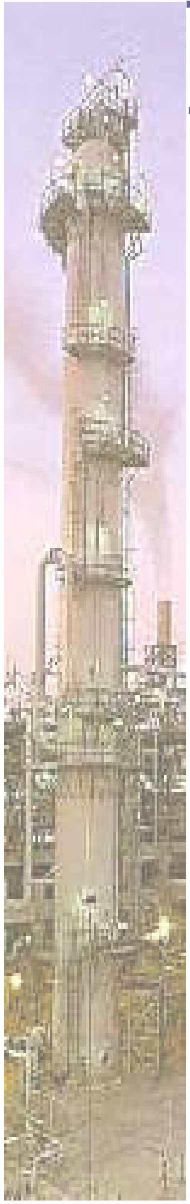
Counter-current Flow

- Random Packing
- Structured Packing
- Baffles, Sheds, and Grid



CONTACTING DEVICE SELECTION

- Reduce investment cost
- Debottleneck throughput or improve product specification
- Save energy via lower pressure drop or higher efficiency
- Improve flexibility or turndown
- Provide reliable construction / easy maintenance

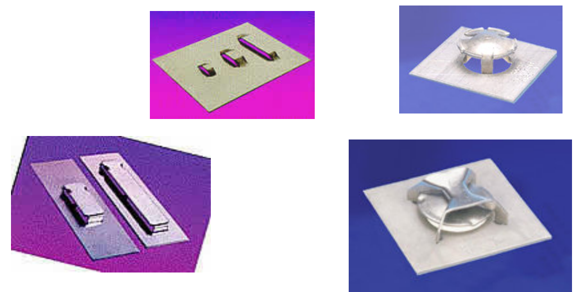


Conventional Trays

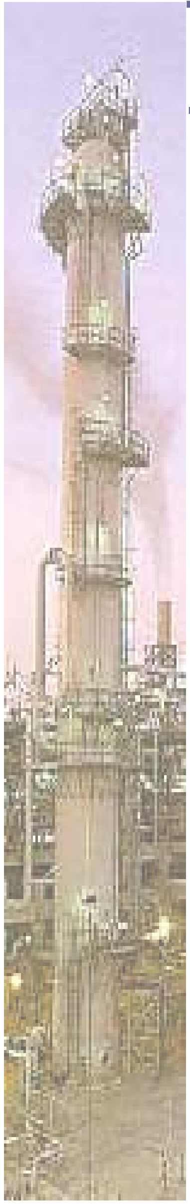
- Sieve
  - Most Widely Used
  - 2:1 Turndown
  - Low Cost (Nonproprietary)

- Bubble Cap
  - Standard until 1950s
  - High Cost
  - Maintenance / Inspection Difficult
  - Excellent Turndown

- Valve
  - Up to 5:1 Turndown
  - 5-10% better capacity over sieve
  - Marginally higher cost
  - Not recommended for fouling services



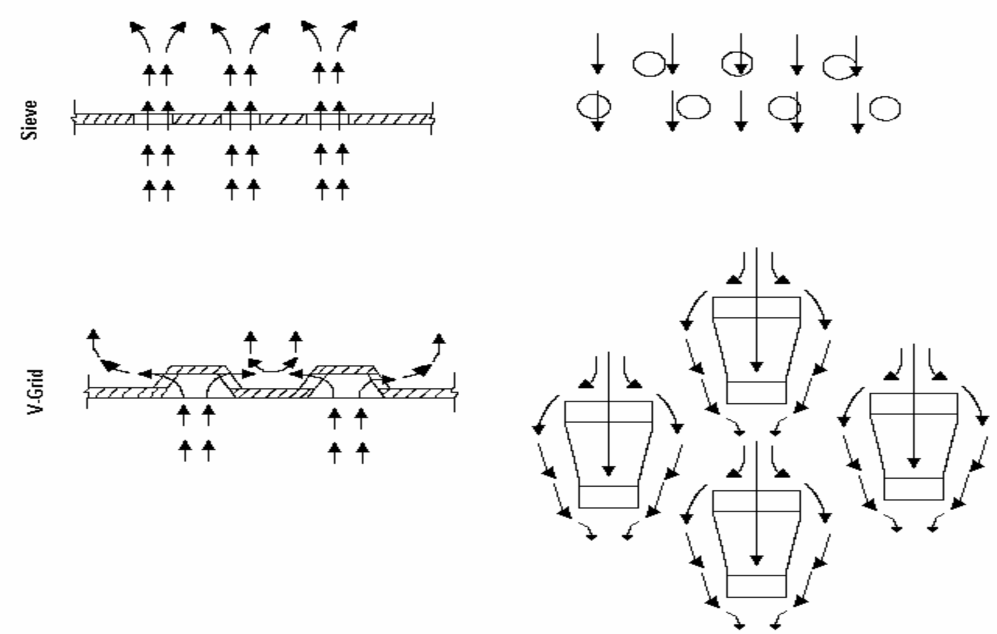
- Jet
  - hExxon Design for High Liquid Loads
  - Efficiency ~20% less than sieve

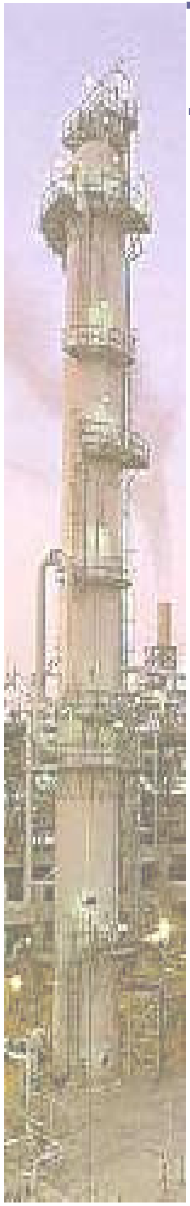


VAPOR AND LIQUID FLOW PATTERNS THROUGH SIEVE AND V-GRID TRAYS

Vapor Flow **(Side View)**

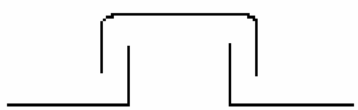
Liquid Flow **(Top View)**



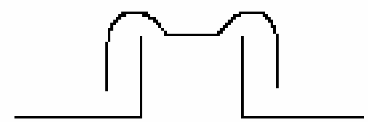


BUBBLE CAP TRAYS

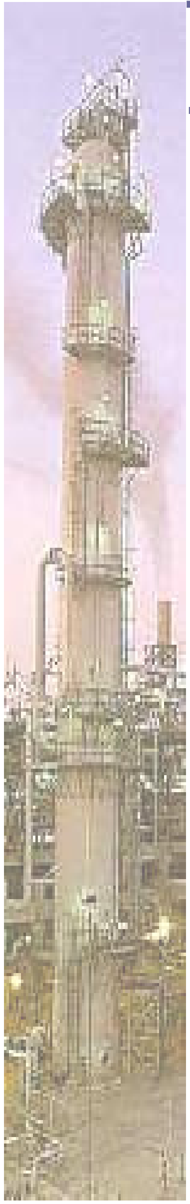
Vapor Flow Through Bubble Caps



Standard Cap



Vacuum Cap



High Capacity Trays

- High Performance Fixed Valves (Increase vapor handling capacity)
  - Koch-Glitsch
    - VG-0
  - Sulzer
    - MVG

- Directional effect reduces fouling and vapor jetting/entrainment
- 10-15% jet flood capacity advantage to 1/2” sieve trays

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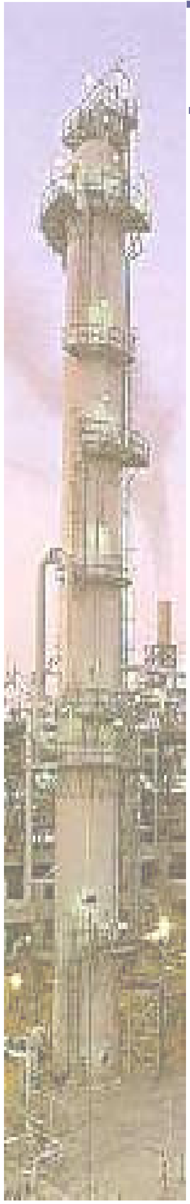
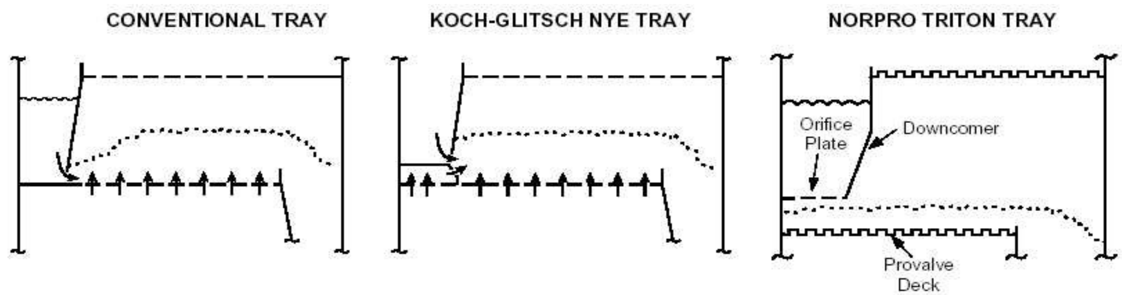
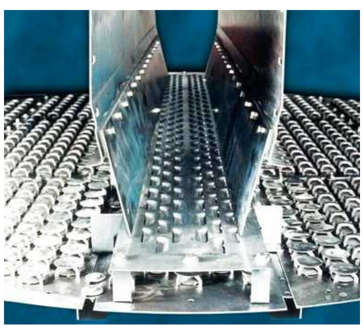


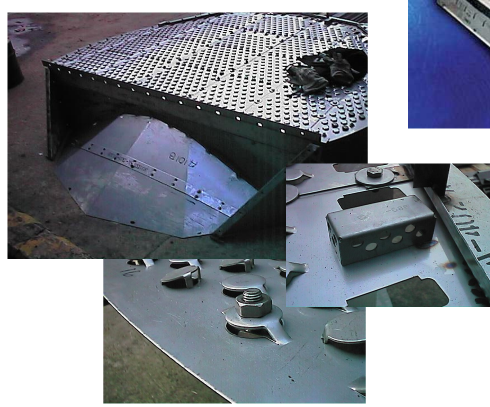
High Capacity Trays (Cont.)

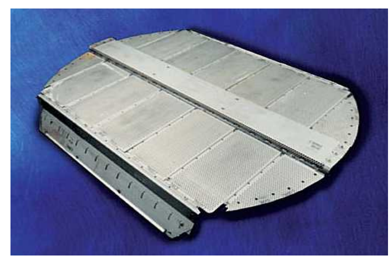
Enhanced Downcomer (Increase vapor handling capacity)

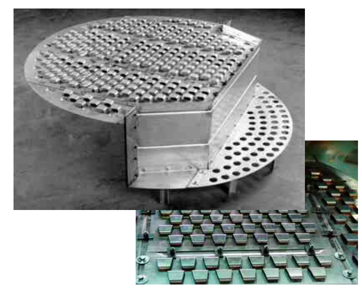
- Koch-Glitsch
  - Nye
  - MaxFrac
  - SuperFrac
  - Triton
- Sulzer
  - MVG-T
    (not shown)











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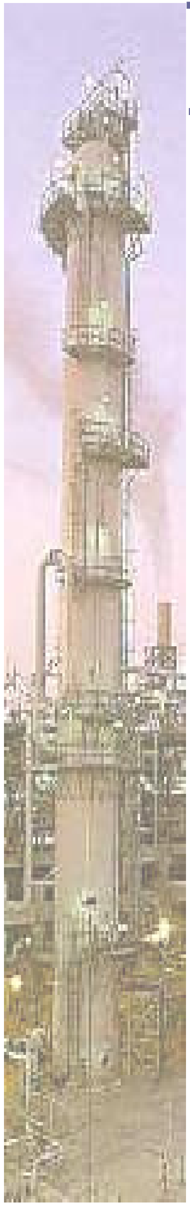
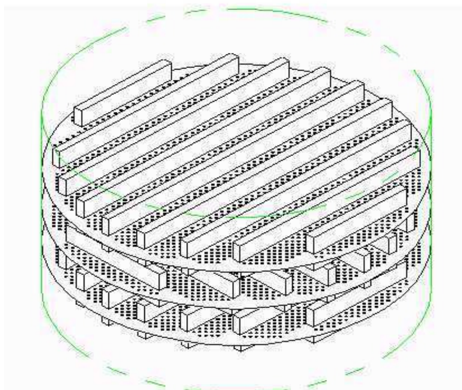
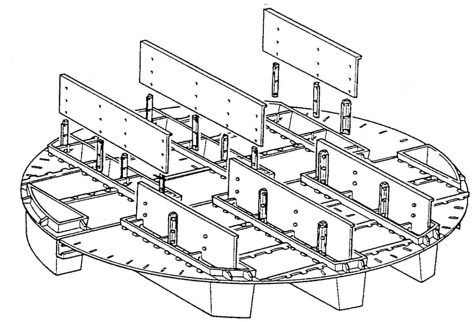


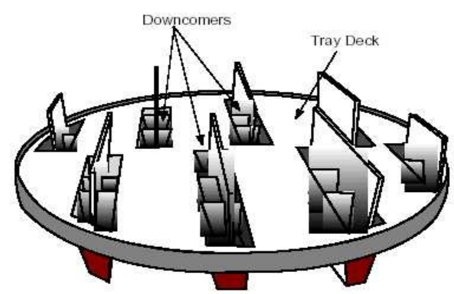
High Capacity Trays (Cont.)

- Multiple Downcomers
  - UOP
    - MD and ECMD



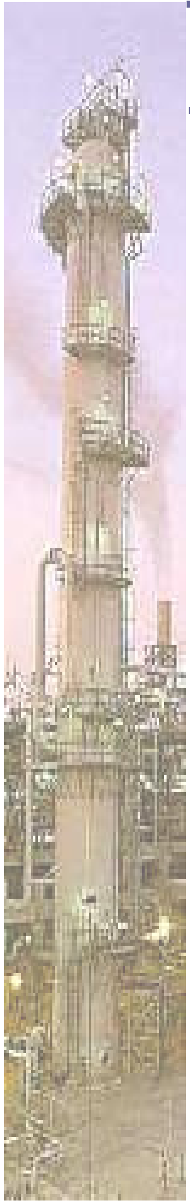
  - Sulzer
    - Shell HiFi





- ~20% higher capacity, but lower efficiency than conventional sieve tray

- Limited access; not recommended for fouling
  (Very difficult to clean / inspect)



TRAYS - SUMMARY OF CHARACTERISTICS

Tray Type	Capacity	Efficiency	Cost Per Unit Area	Flexibility*	Remarks
Sieve	Medium to high.	High. Equal to or better than other tray types.	Lowest of all trays with downcomers.	Medium. 3/1 can usually be achieved.	First choice for most applications; extensive design data available
Valve	Medium to high; as good as sieve trays.	High. As good as sieve trays.	Medium. About 10% greater than sieve trays.	High. Possibly up to 5/1.	Not recommended for moderate to severe fouling services.
Nutter V-Grid	Medium to high; as good as sieve trays.	High. As good as sieve trays	About the same as sieve trays.	Medium. Slightly higher than sieve trays.	Good alternative to sieve trays. Increases run lengths in fouling services.
Jet	Highest at low pressure and high liquid rates	Low to medium.	Low to medium. About 5 % higher than sieve trays.	Low. 1.5 or 2/1.	Consider only when liquid rate exceeds 4.0 gpm/in. of diameter per pass.
Bubble Cap	Medium to high, except low to medium at high liquid rate.	Medium to high.	High. At least twice the cost of sieve trays.	Medium to high 5/1 or slightly higher.	Use for high flexibility where fouling of valve trays may be a problem.
UOP MD, ECMD	Very High.	Low to Medium	High. Paying for proprietary know-how.	Low. (<2/1)	Can be installed on very low tray spacings. Consider for revamps where no other device is acceptable. Not recommended for fouling services.

*Ratio of maximum to minimum vapor loads at which tray efficiency remains above about 90% of its design value.

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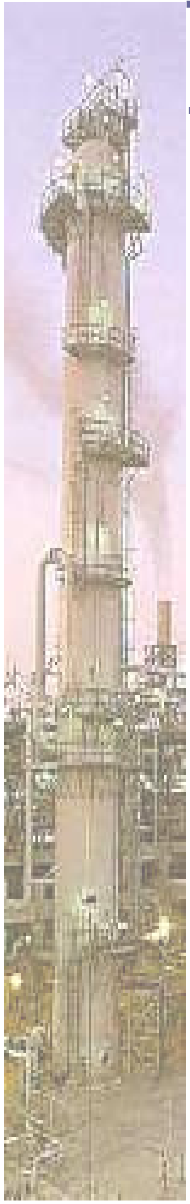
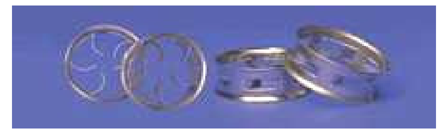
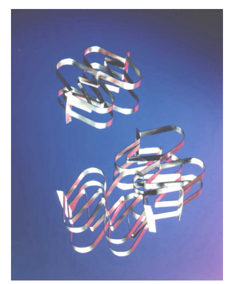
Random Packing



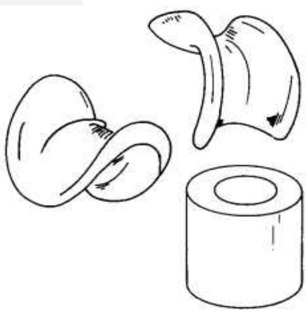
- **3RD Generation**
  - CMR
  - IMTP
  - Nutter Ring
  - Rashig Super-Ring

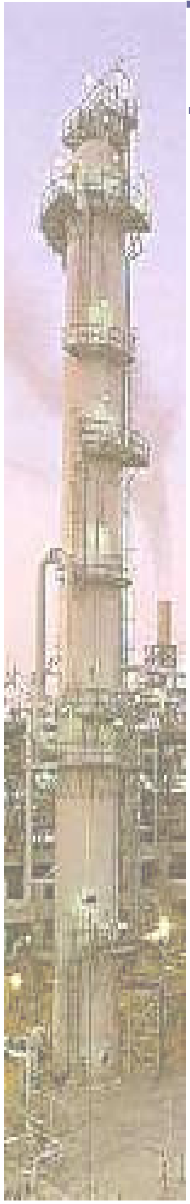




- **2ND Generation**
  - Pall Ring
  - Flexirings
  - Ballast Rings
  - Slotted Rings

- **1ST Generation**
  - Berl Saddle
  - Intalox Saddle
  - Rashig Ring

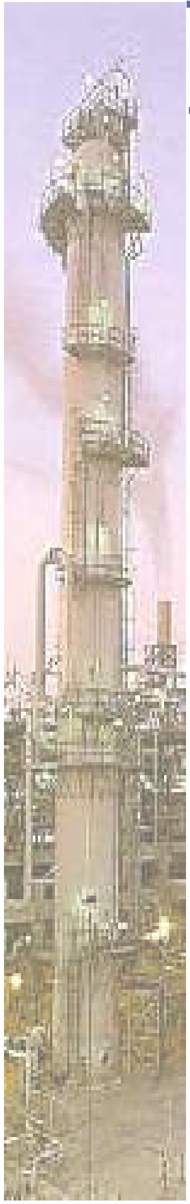




Random Packing (Cont.)

- Packing can usually provide higher capacity and better efficiency than trays.
- As size increases, the capacity increases while the pressure drop, cost, and efficiency decrease.
- Usually not considered for new designs

- Considered for:
  - Low [critical] pressure drop applications (*i.e.* vacuum distillation, etc.)
  - Revamps where acceptable tray design cannot be achieved
  - See DP III-A, p. 34 for others applications

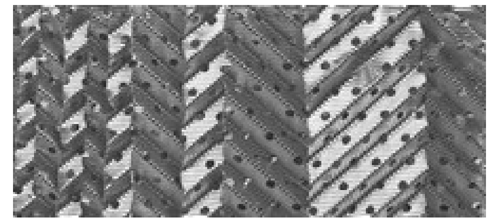


Structured Packing

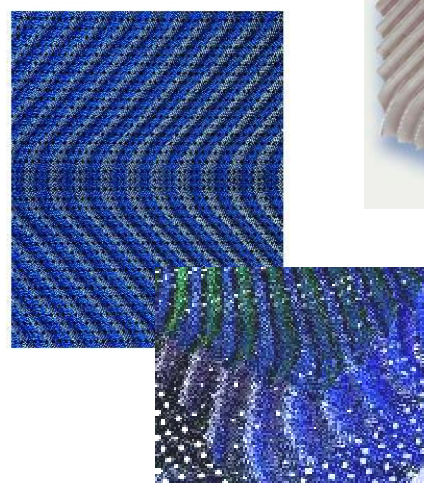
- Conventional
  - Koch-Glitsch: Flexipac, Intalox
  - Sulzer: Mellapak
  - Montz: Montz-Pak Type B1

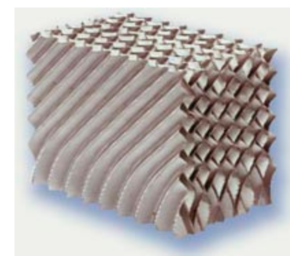
Mellapak

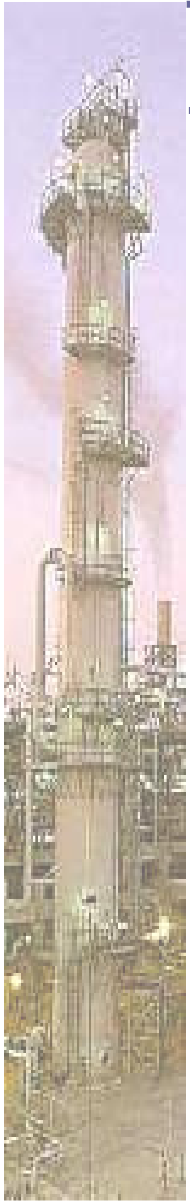
- High Capacity
  - Koch-Glitsch: Flexipac HC, Intalox
  - Sulzer: Mellapak Plus
  - Montz: Montz-Pak Type M



MellapakPlus



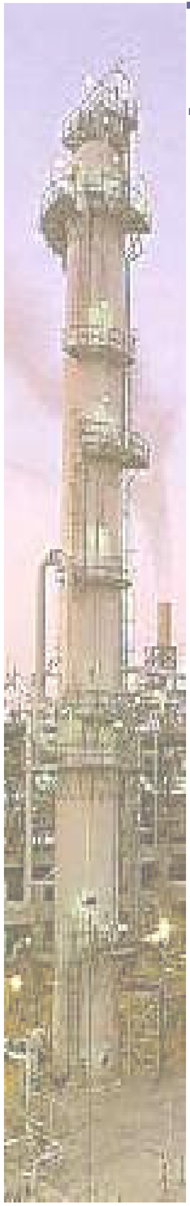




Structured Packing (Cont.)

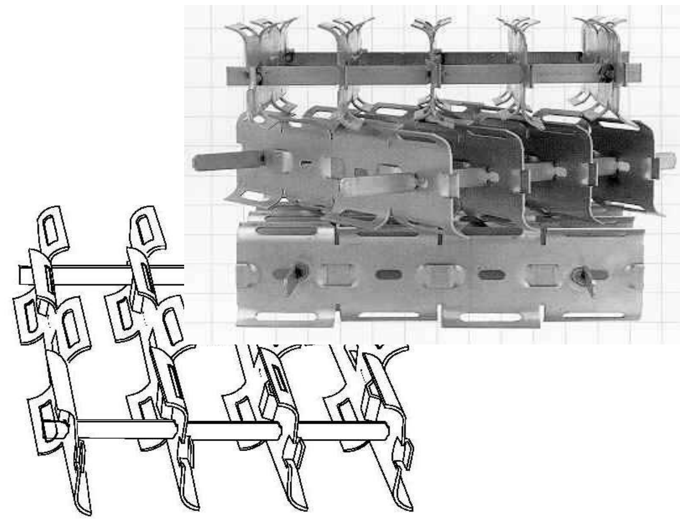
- *Why Structured Packing?*
  - Lowest pressure drop per stage
  - Best capacity / efficiency combination device
  - Less sensitive to liquid maldistribution than random packing
  - Recently, cost is much more competitive with random packing

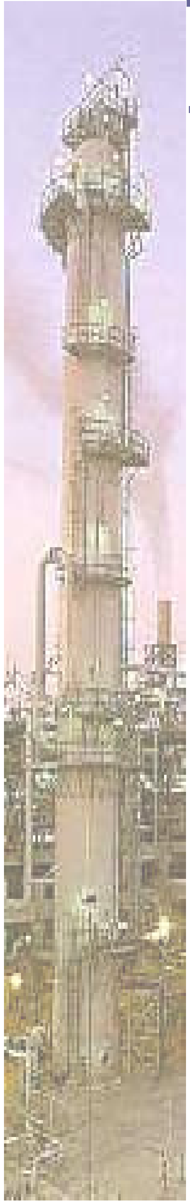
- *Why **<u>Not</u>** Structured Packing?*
  - Not recommended for high pressure towers (poor FRI test results) or where liquid rate exceeds 20 gpm/ft^2 unless application is high pressure aqueous system.



Grid

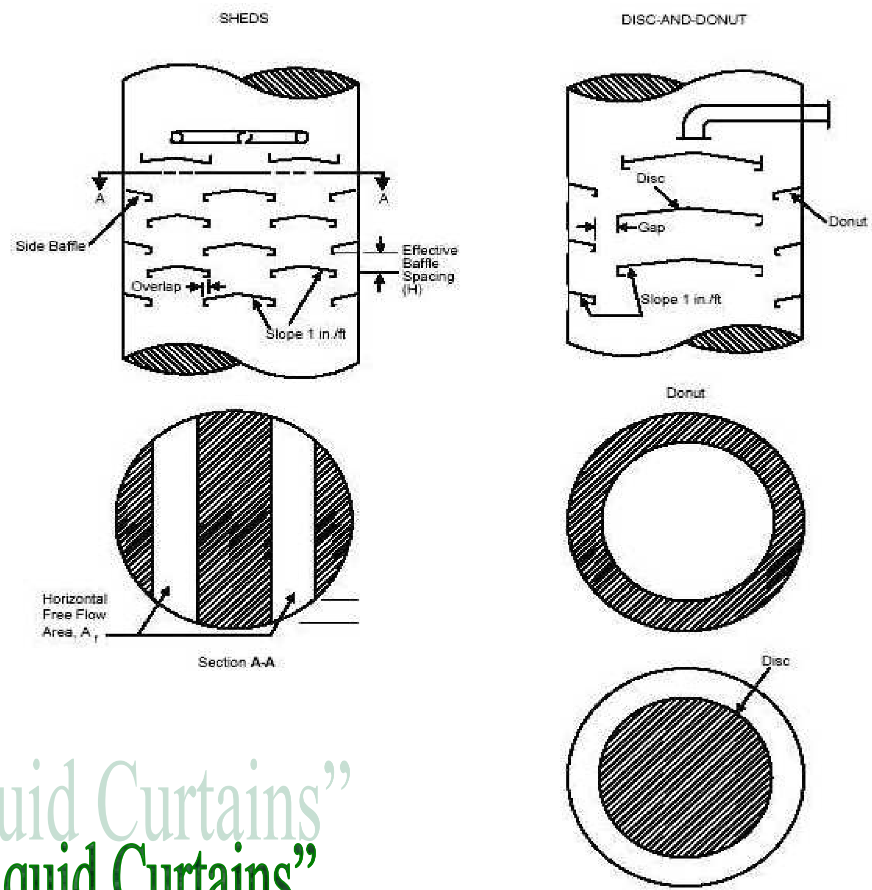
- Used for entrainment removal where fouling is too severe for CWMS
- High Open Area
  - Prevents plugging
- Low Surface Area
  - Low efficiency



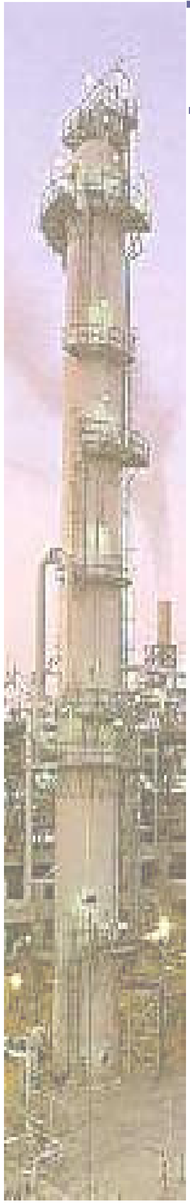


Baffles

- Large Open Area
  - Prevents plugging
- Low Liquid Residence Time
  - Prevents coking

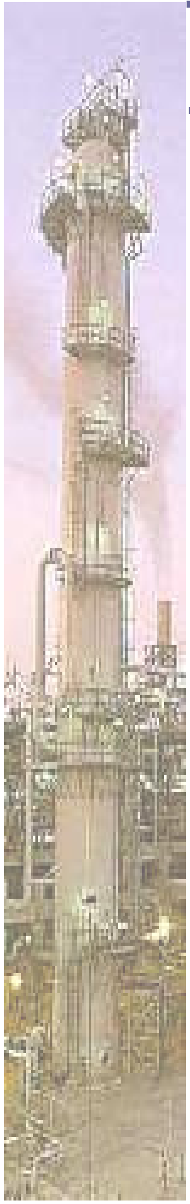


"Liquid Curtains"
"Liquid Curtains"



COUNTERCURRENT DEVICES - SUMMARY OF CHARACTERISTICS

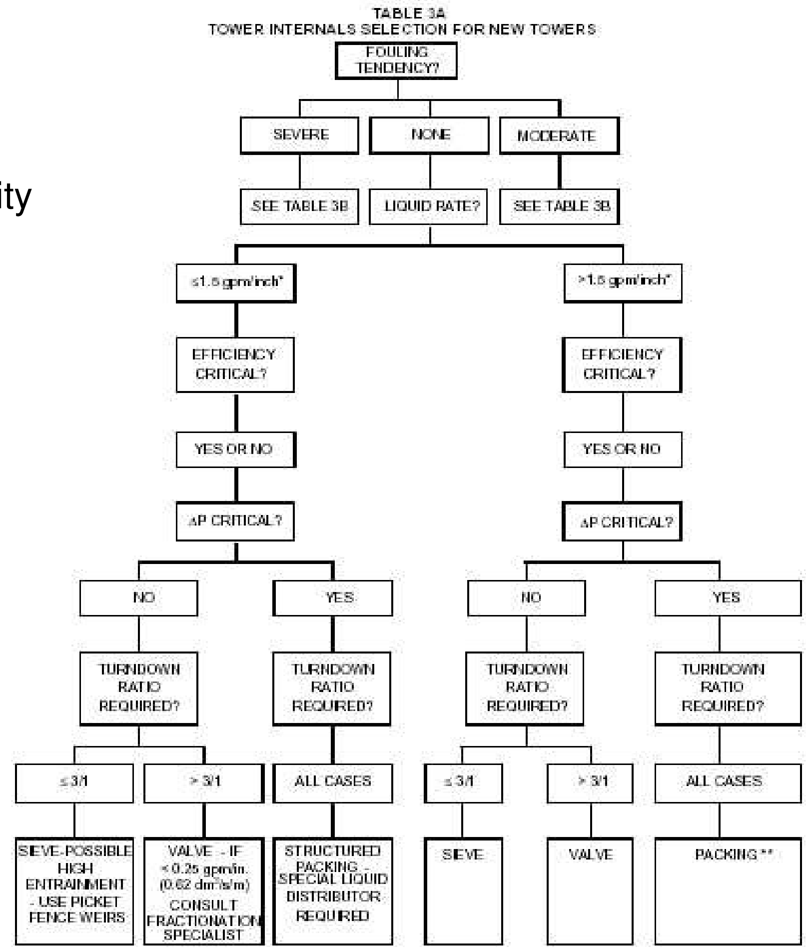
Device	Capacity	Efficiency	Cost Per Unit Area	Flexibility	Remarks
Packing (Pall Rings, Metal Intalox, Nutter Rings.)	Medium.	Medium to High.	Medium to low, depending on material of construction.	> 3/1	Good for ΔP Service. Mainly used in vacuum pipestills and in various high liquid rate absorbers.
Structured Packing Flexipac; Montz, Gempak; Mellapak, Intalox – Structured.	Medium to very high depending on size	Medium to very high depending on size used.	High – at least two times dumped packing cost.	>3/1	Best efficiency per unit of ΔP.
Glitsch Grid Flexigrid Snapgrid	Very high	Poor as fractionation device. Good for entrainment removal and heat transfer	Medium to high.	Low: less than 2/1	Good for high vapor-low liquid service to minimize effect of entrainment. Used in wash zones of heavy hydrocarbon fractionators where moderate coking occurs.
Sheds and Disc and Donuts	Very high.	Poor as fractionation device.	Medium	Low >1.5/1	Used in severe fouling service; e.g. slurry pumparound in cat fractionator.



Device Selection Criteria

- Fouling Tendency
- Good Liquid & Vapor Handling Capacity
- Good Contacting efficiency
- Acceptable Pressure Drop
- Predictable Turndown Characteristics
- Economical

See DP III-A Tables 3-5



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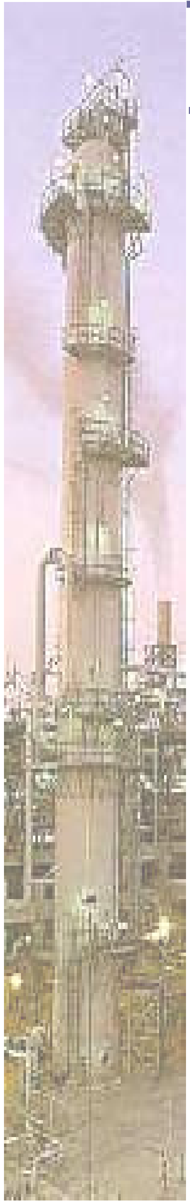

Device Selection Procedure

New Design

- Start with trays, unless pressure drop is critical. If need low dP, consider 2” random packing.
- Calculate optimum tray spacing, diameter, and layout (*i.e.* bubble area and downcomer dimensions) by trial and error to avoid downcomer and jet flood limitations.
  (Use Pegasys / EMoTIP)
- Then select best device type based on Device Selection Criteria.
  (See DP III-A Tables 3&5 Decision Trees)
- Don’t consider High Capacity Trays for new towers - Instead Increase Diameter, etc.

Revamp

- Rate existing contacting device to identify potential limitations (*i.e.* downcomer, jet flood, etc.)
  (See Table 1 ‘Design Principles’ in appropriate DP III Section)
- Identify new layout and device where all design parameters are satisfied
  (Use Pegasys / EMoTIP)
- Consider:
  - Multi-pass Conventional Trays
  - High Performance Fixed Valves
  - Enhanced Downcomer Trays
  - Multiple Downcomer Trays
  - Packing

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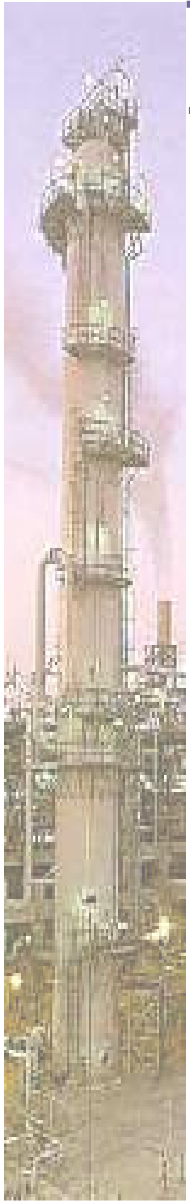


Task Checklist

- ▶ Introduction

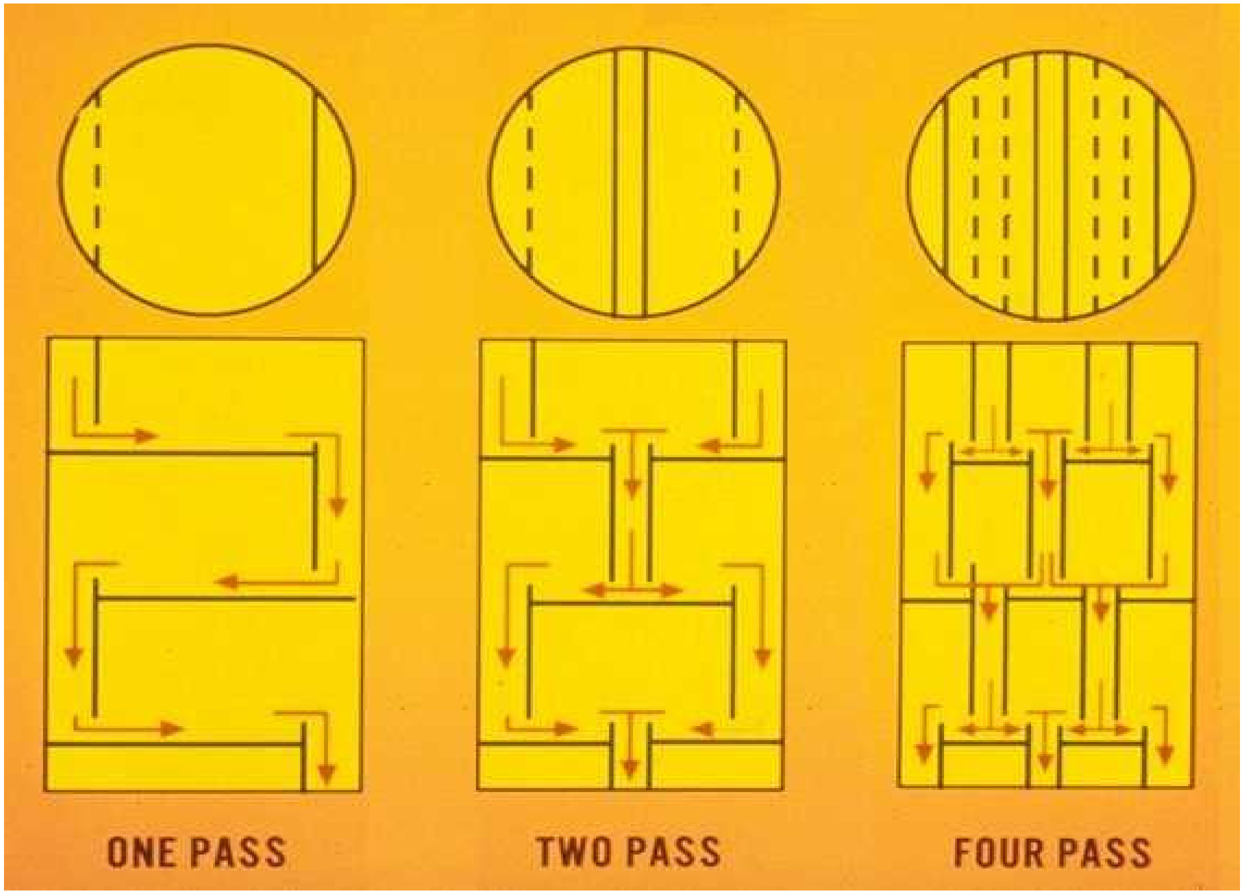
TOWER SIMULATION

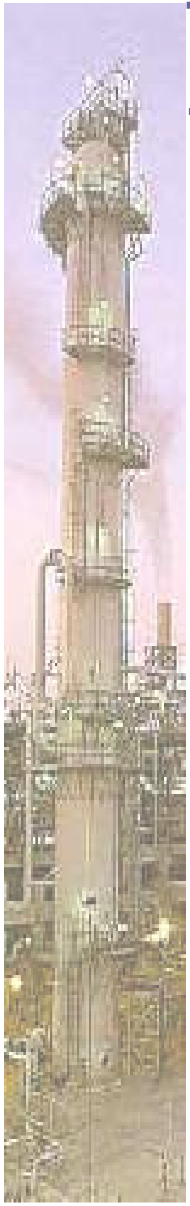
- ▶ Basic Concepts
- ▶ Specifications

DEVICE SELECTION

- ▶ Contacting Devices
- **▶ Tray Hardware Definitions**
- ▷ Tray Hydraulics
- ▷ Packing Hydraulics
- ▷ Other Process Considerations
- ▷ Other Tower Internals
- ▷ Tower Revamps

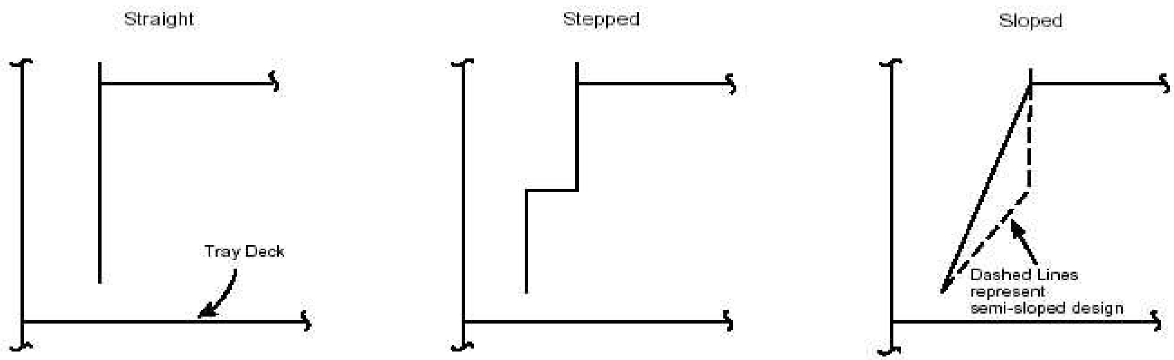
Common Pass Arrangements



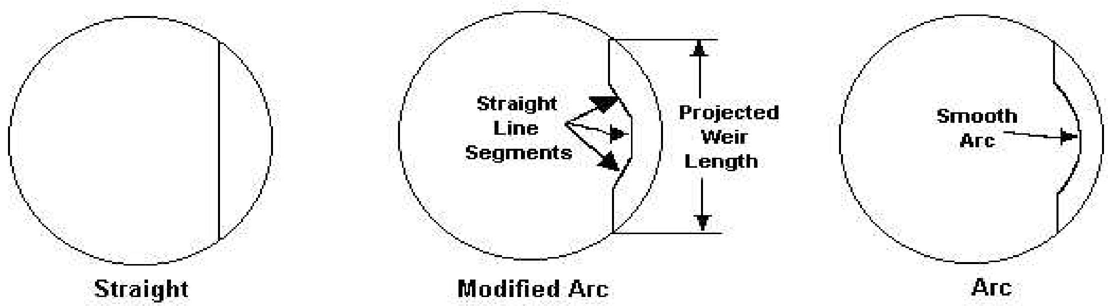


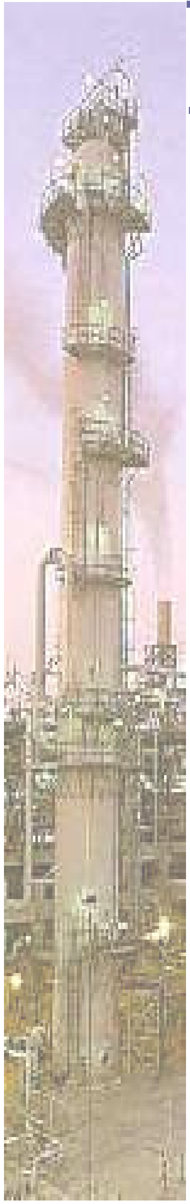
Downcomer Types

- **Stepped / Sloped:** Provide sufficient DC inlet area for adequate vapor / froth disengagement while maximizing bubble area



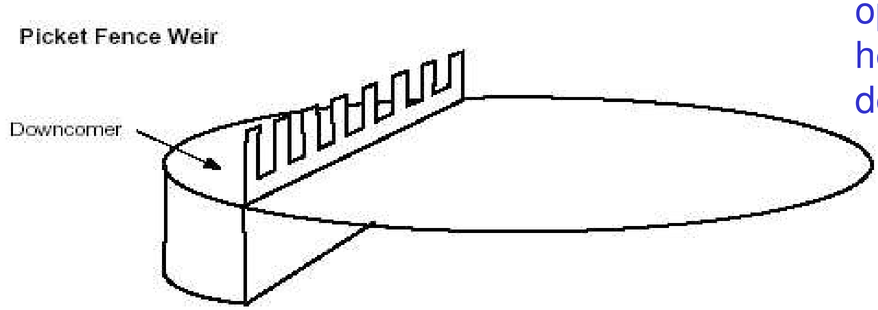
- **Modified Arc:** Used to achieve more evenly distributed liquid flow across a tray (*i.e.* good efficiency); Enables a reduction in DC area

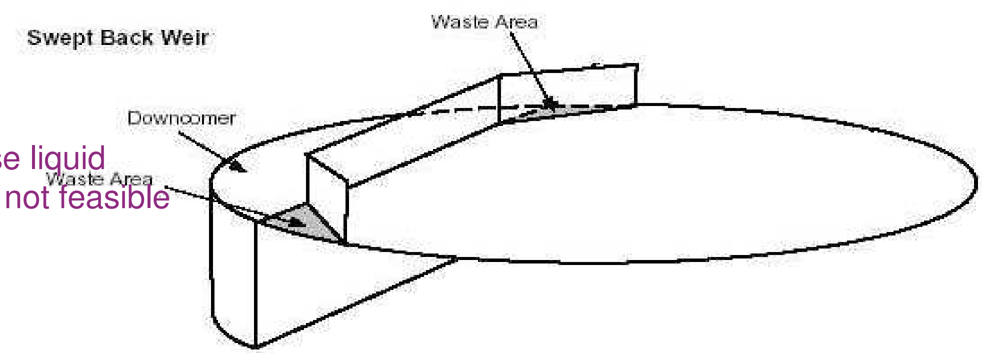




Weir Types

- **Picketing**: Can reduce spray regime operation by increasing effective liquid height; Also used to balance multipass designs





- **Swept Back**: Can slightly increase liquid handling capacity where mod arc not feasible

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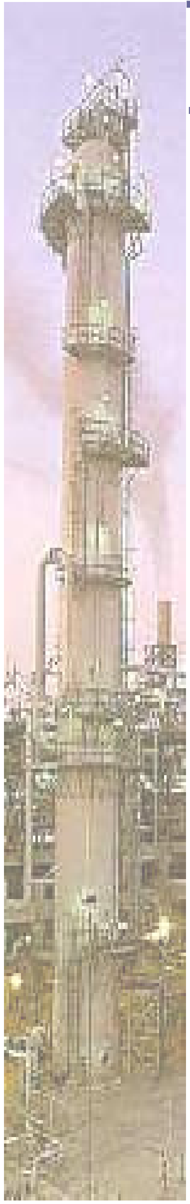
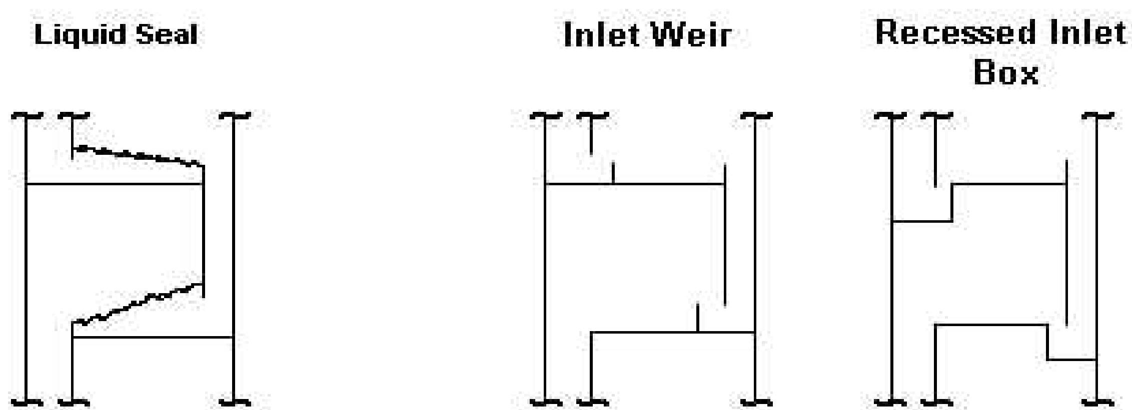


Downcomer Seal Techniques

- Design should ensure vapor cannot bypass a tray by flowing upward through the DC resulting in poor efficiency.

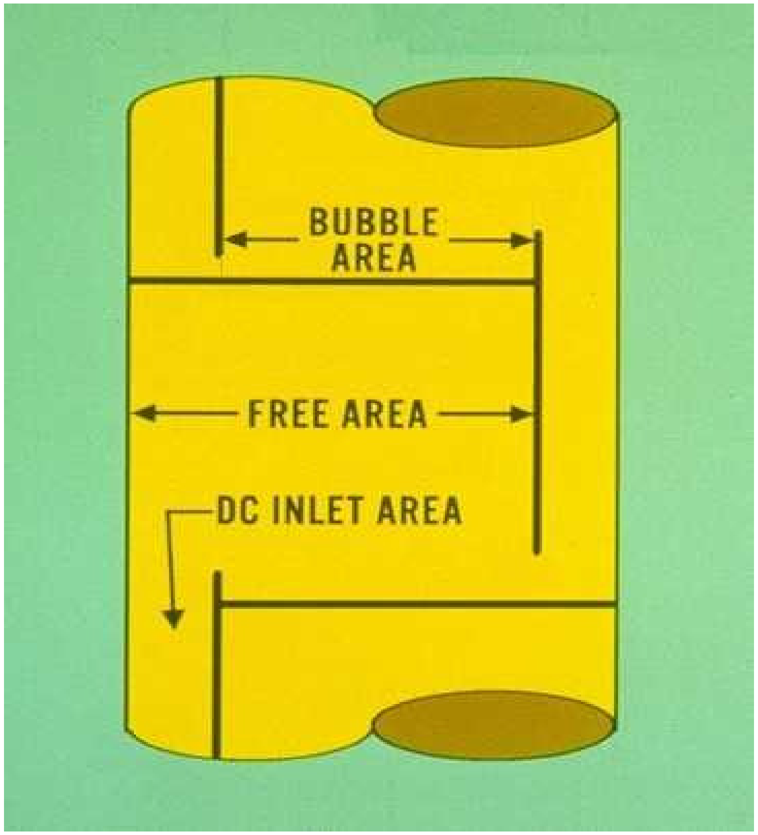


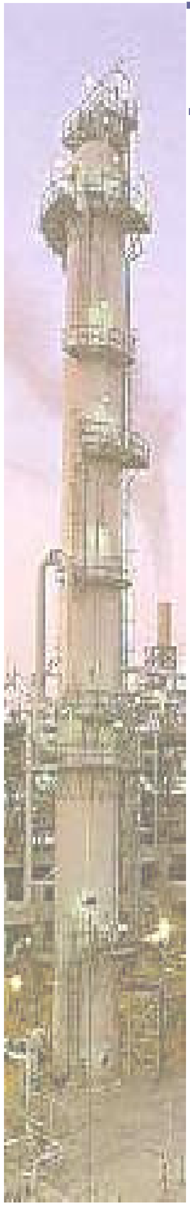
Process Seal

Mechanical Seals

Area Definitions

- Also see DP III-A, Figures 12-13





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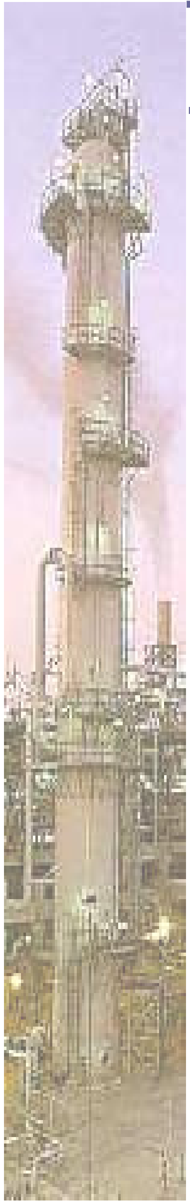


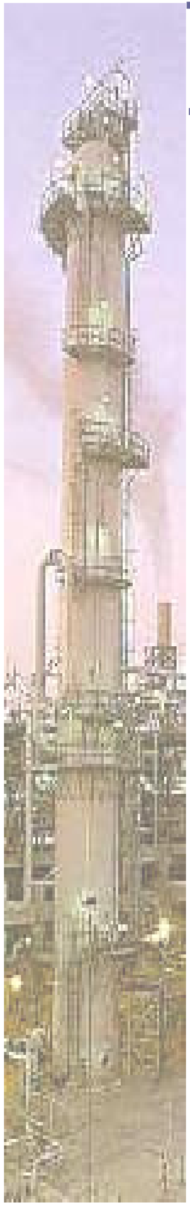
Hydraulic Limitations

VAPOR

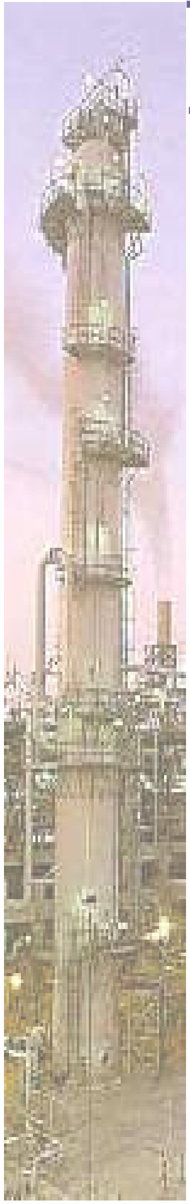
- Jet Flooding
- Ultimate Capacity
- Flow Regimes
- Entrainment

LIQUID

- Downcomer Backup
- Secondary Limitations:
  - Liquid Rate per Inch of Weir
  - Downcomer Choking
  - Velocity Under the Downcomer
  - Downcomer Seal



FRI VIDEO



Jet Flooding

- At high vapor rates, liquid is "jetted" to tray above

JET FLOODING

EFFECT: CARRYOVER OF LIQUID

CAUSE: EXCESSIVE GAS RATE ALTHOUGH SOME LIQUID IS DROPPING OUT

- Vapor handling limitation; sets design in most cases
- Expressed as Percent; Rigorously Calculated
  (See DP III-B / Use Pegasys)
- Related to vapor velocity through the free area
- Strong function of:
  - Tower Diameter
  - Tray Spacing

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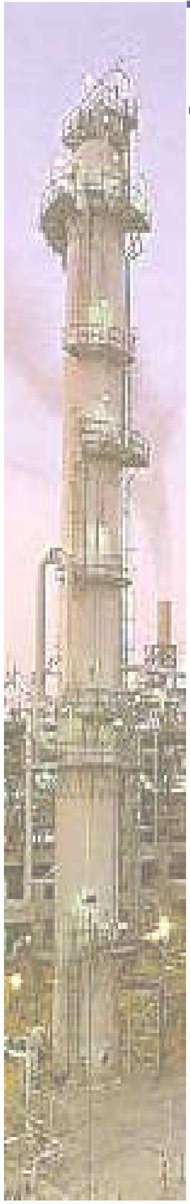
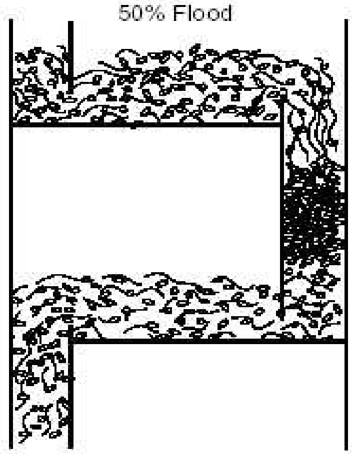
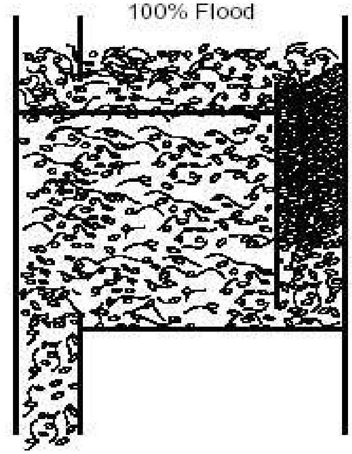
Jet Flooding and Efficiency

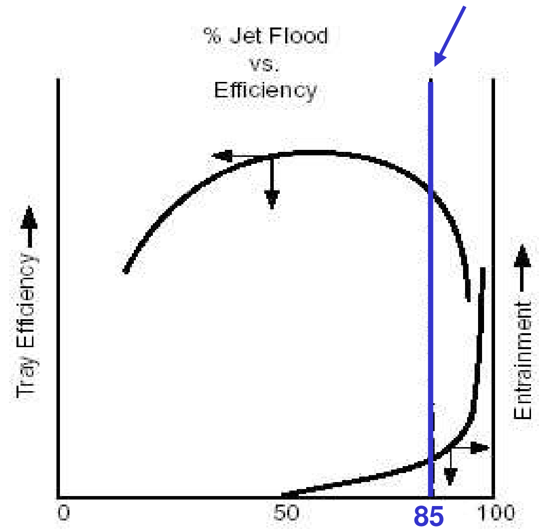


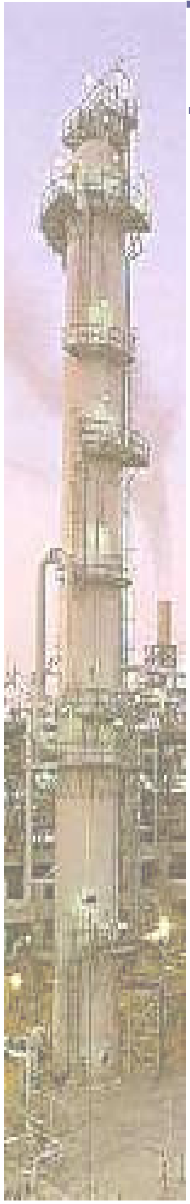


Inter-Tray Space
and Downcomer
Operating Normally



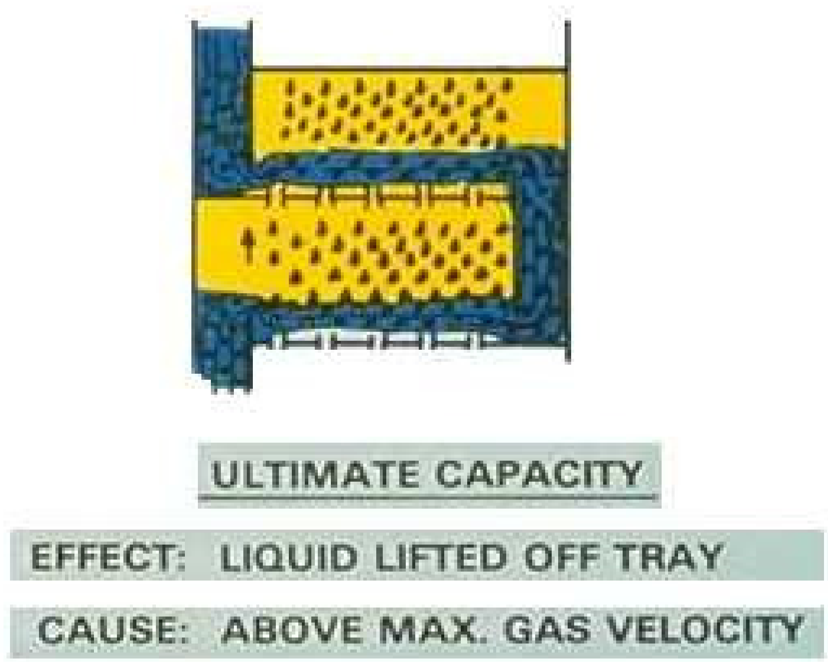
Inter-Tray Space
and Downcomer
Full (Flooded)





Ultimate Capacity

- Highest vapor rate tower can handle -- Stokes Law
- Cannot be increased by hardware changes; only way to increase it is by increasing the tower diameter



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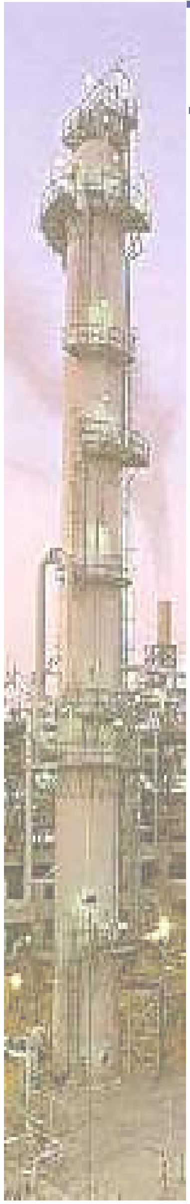
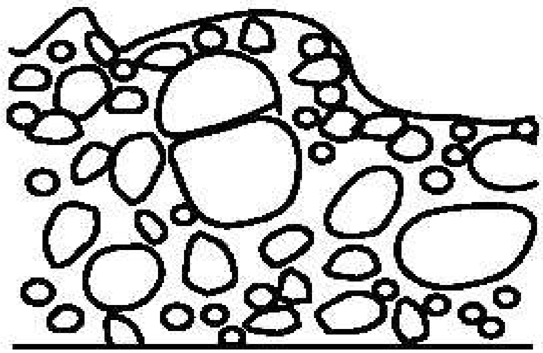
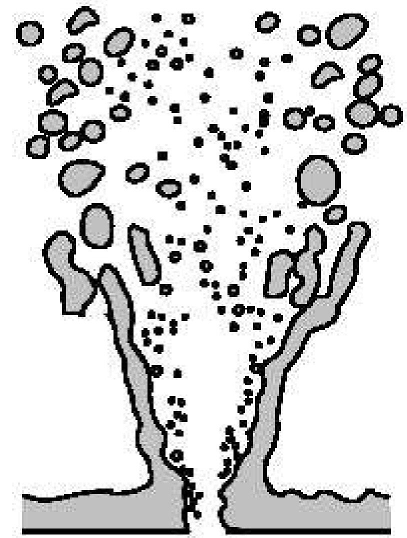


Flow Regimes

Froth

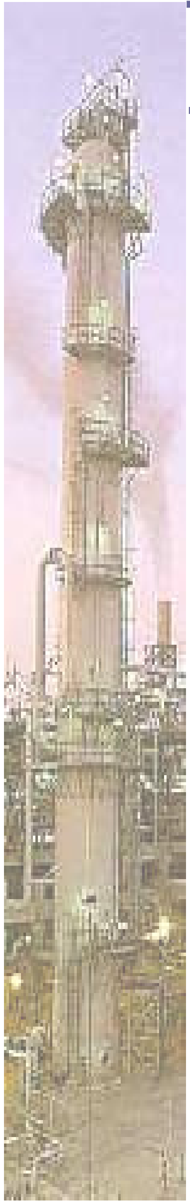


Spray



To Eliminate Spray Regime:

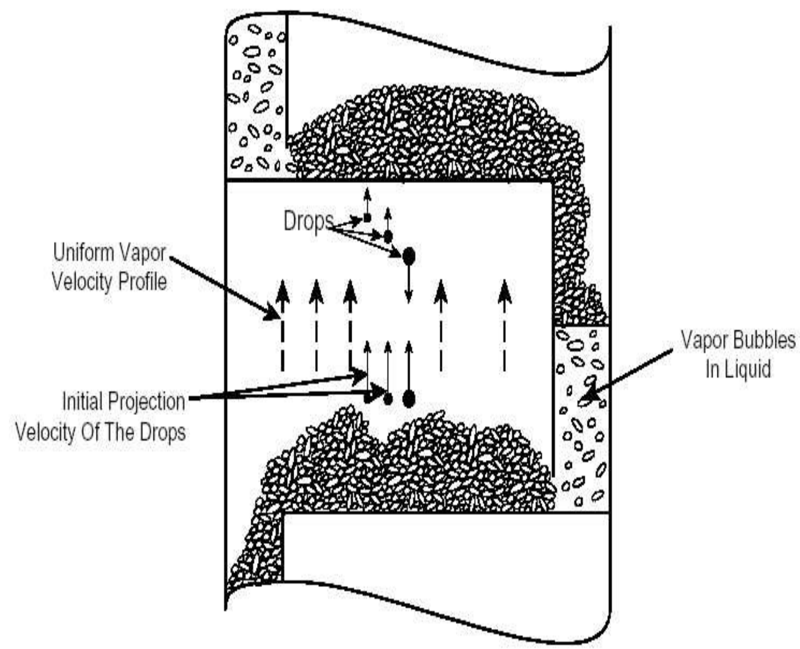
- Use Picket Fence Weirs
- Increase Open Area
- Use Smaller Sized Orifices
- Use Valve Trays

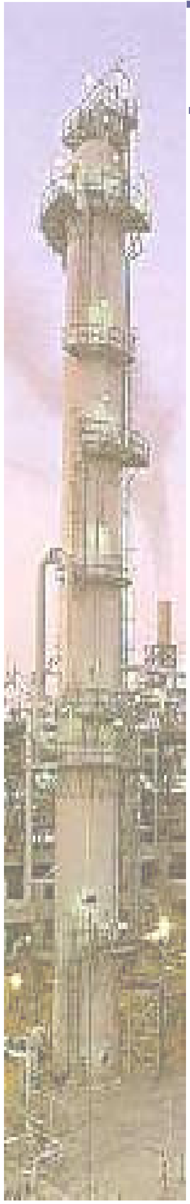


Entrainment

- Liquid [drops] carried by the vapor to the tray above
- Design should limit entrainment to 10% of the tray liquid rate
- Function of:
  - Vapor Rate
  - Liquid Rate
  - Tray Spacing
  - Other Hardware Parameters

GENERATING ENTRAINMENT

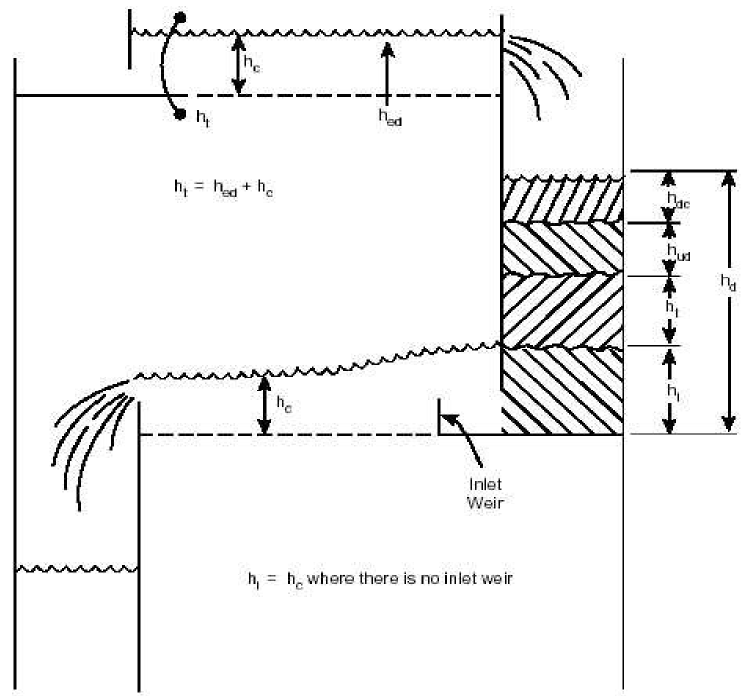




Downcomer Backup

- DC froth height expressed as percent of tray spacing plus the weir height

- DC Filling Components:
  - h_i = inlet head; *f*(inlet & outlet weir)
  - h_t = total tray dP
  - h_{ud} = head loss under DC; *f*(DC Clearance)
  - h_{dc} = head loss due to two-phase flow in DC



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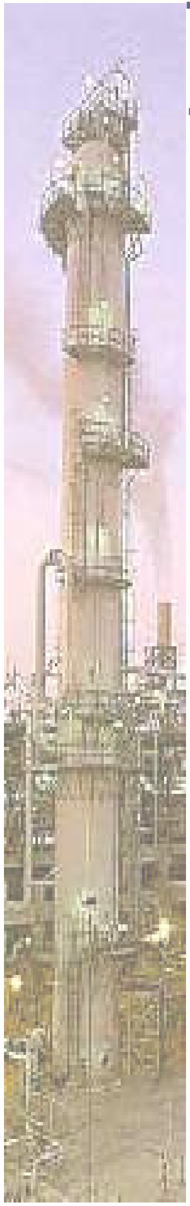
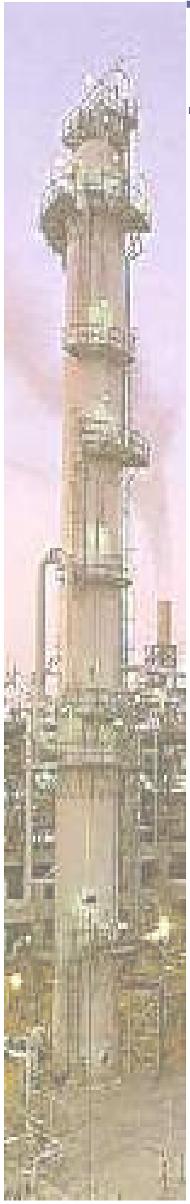


Percent Downcomer Flood

- Performance criteria to see how close a tower is to flooding as a result of excessive froth height in the downcomer
- Represents actual vapor / liquid rates as a percent of the rates which cause 100% DC Backup
- Rigorously Calculated

  (See DP III / Use Pegasys)



Flooding Symptoms

Jet Flooding

- Tower unstable
- Liquid entrainment into overhead system; sharp increase in reflux rate with <u>no</u> separation improvement
- Pressure drop increases sharply with a small incremental increase in vapor rate
- Separation efficiency gradually decreases

Downcomer Flooding

- Tower unstable, surging
- High pressure drop with a small increase in either vapor or liquid rate
- Separation efficiency suddenly decreases
- Loss of tower bottoms liquid level

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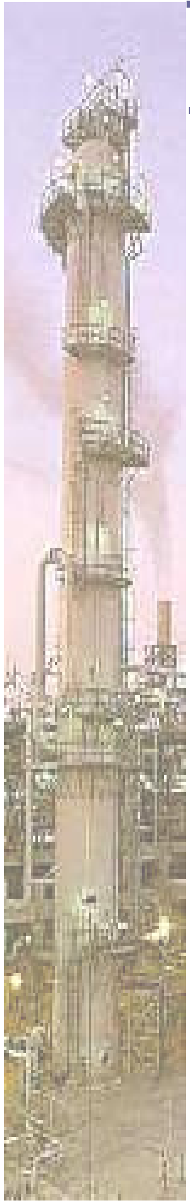


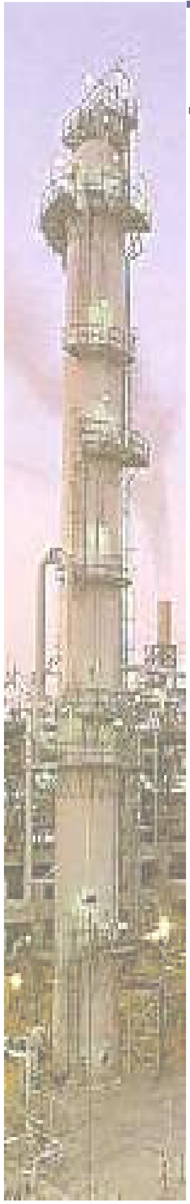
Secondary Liquid Hydraulic Limitations

- Liquid Rate per Inch of Weir
  - The accuracy of the Jet flood and DC Flood correlations can only be ensured within the range of liquid rates used to develop them.

- Downcomer Choking results when the DC inlet area is too small.

- Velocity Under the Downcomer
  - If too high, can produce channeling effect leading to vapor / liquid maldistribution on the tray.

- Downcomer Seal
  - If not sealed, vapor can bypass the tray and flow upward through the downcomer resulting in reduced efficiency.
  - Two types:
    - Mechanical [Static]
    - Process [Dynamic]



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- ▶ Basic Concepts
- ▶ Specifications

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- ▶ Contacting Devices
- ▶ Tray Hardware Definitions
- ▶ Tray Hydraulics
- ▶ **Packing Hydraulics**
- ▷ Other Process Considerations
- ▷ Other Tower Internals
- ▷ Tower Revamps

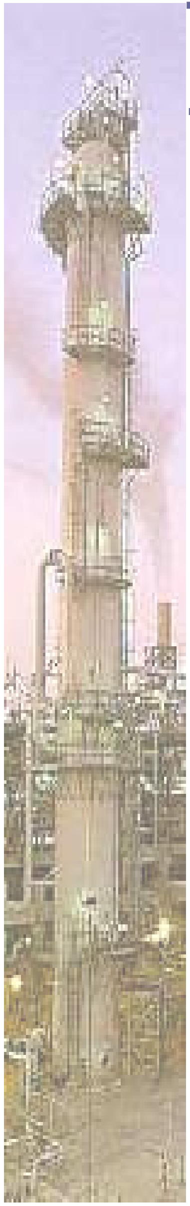
Packing Hydraulics

Flooding -- (Use Pegasys)

- Harder to define than tray hydraulics (*i.e.* no tray spacing or downcomer to fill with liquid)
- As vapor rate increases, liquid accumulates and the pressure drop begins to rise more sharply.
- With further increases in vapor rate, the pressure drop rises almost vertically and liquid stacks up on top of the packing.

Ultimate Capacity -- (Use Pegasys)

- Similar to tray hydraulics



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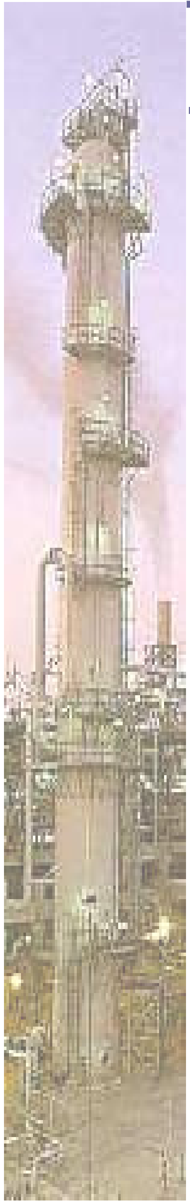


Tray Efficiency

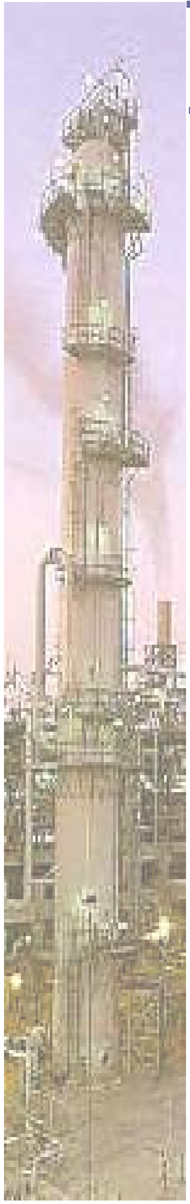
- *Overall Efficiency*, E_O, is a measure of the effectiveness of an entire tower or tower section.
- Allows designer to determine the number of actual trays to provide and sets the tower height.

$$\textit{Actual Trays} = \textit{Theoretical Stages} / E_O$$

- *C*alculated Rigorously - Use Pegasys

  (See DP III-I)

- Factors affecting E_O:
  - Weir Height
  - Flow Path Length and Number of Passes *(i.e. Residence Time)*
  - Weeping or Vapor Recycle
  - VLE Properties and Tower Loading



Packing Height

- To specify correct packing height, designer must calculate height equivalent to a theoretical plate *(HETP)*

$$\text{Packing Height} = \text{Theoretical Stages} \times \text{HETP}$$

- *HETP* must be calculated rigorously - Use Pegasys

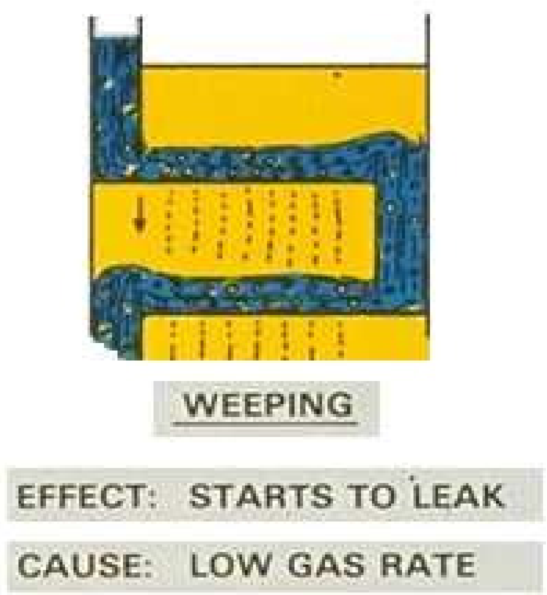
  (See DP III-G)

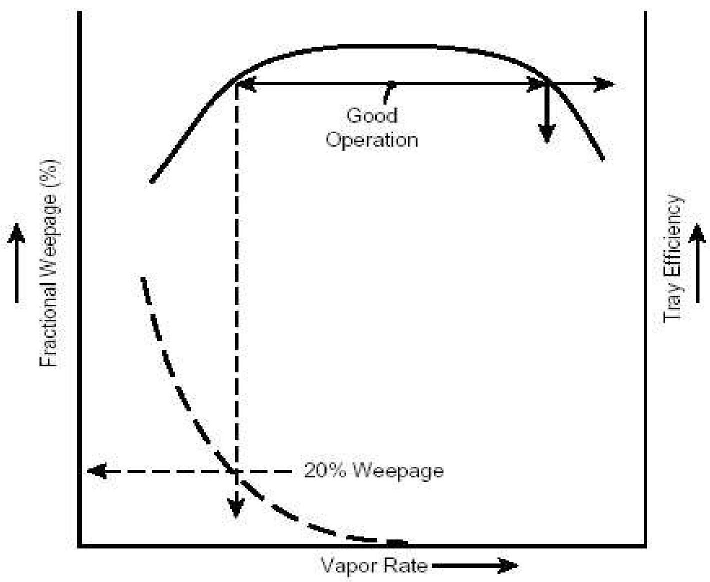
- Other methods for packing efficiency exist, but *HETP* applies to most systems

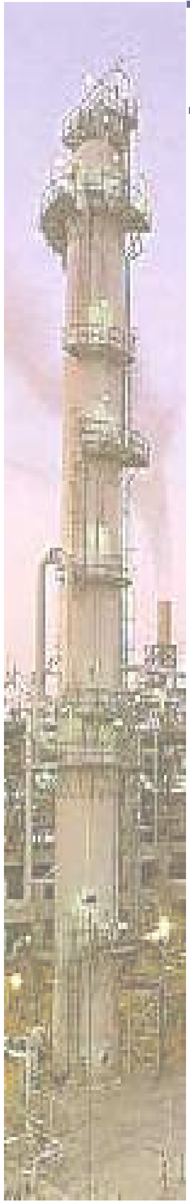
- Factors affecting *HETP*:
  - Distributor Design
  - Packing Size / Geometry
  - VLE Properties and Tower Loading

Turndown

- Defines range of loadings for acceptable device performance
- Excessive ***Weeping*** Decreases Efficiency







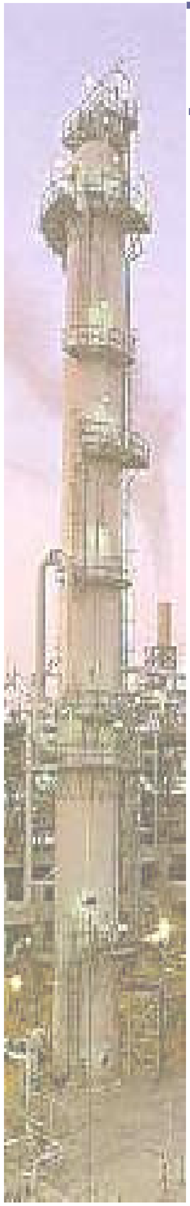
Dry Tray Pressure Drop, h_{ed}

- Dry tray dP is important because:
  - If its too high --- Entrainment
  - If its too low --- weeping at turndown

- Calculated based on vapor flow through device with no liquid present

$$h_{ed} \propto (\text{Vapor Velocity})^2$$

- Function of:
  - Vapor Rate
  - Open Area / Device



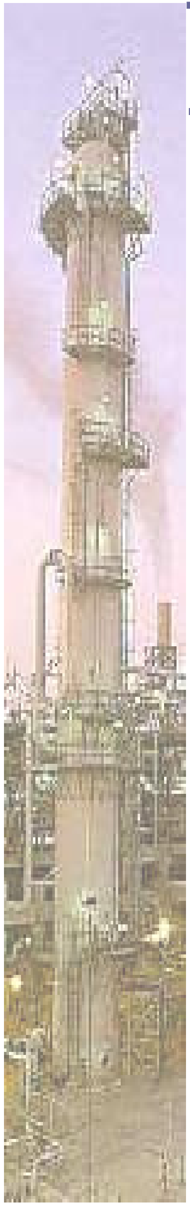
Foaming

- Foaming Mechanisms:
  - Presence of surface active materials or solids
  - HC entrainment or condensation in aqueous systems

- Compensate design by using:
  - Lower percent of Jet and Downcomer Flood
  - Low dry tray dP
  - Low DC entrance velocity and filling
  - Radius tip and large DC clearance
  - Provide antifoam injection facilities

  *(Since degree of foaminess varies and is generally unpredictable, experience in similar towers may be used instead - **Contact a Fractionation Specialist**)*

- Known “Foamers”
  - Amine and Glycol Absorbers
  - Caustic Towers
  - Ethylene Demethanizers
  - Sour Water Strippers

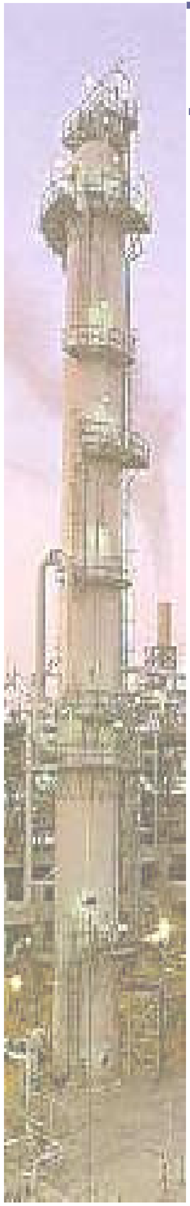


Design Contingency

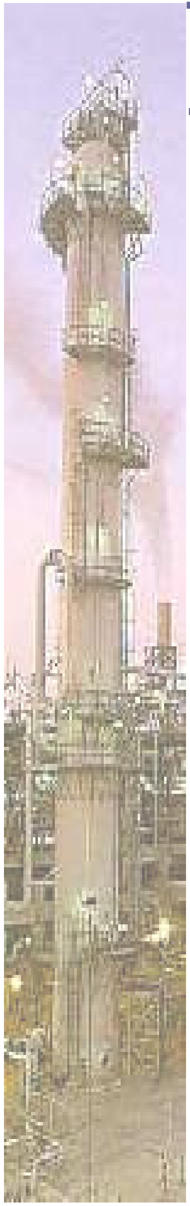
- To insure 90% chance of successful operation, safety margins should be adhered to and are built into EMoTIP.

- Examples

– Jet Flooding (Trays)	80-90% of predicted
– Downcomer Filling	35-50%
– Packing Flooding	80-85% of predicted
– Tray efficiency	Point efficiency debited 10%
– Packing HETP	Predicted divided by 0.85



PROBLEM 4
CONTACTING DEVICE PROBLEM



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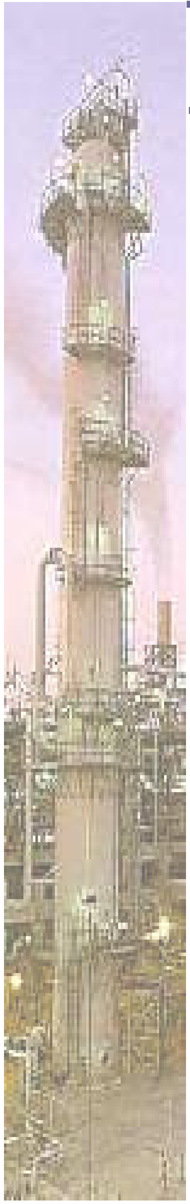
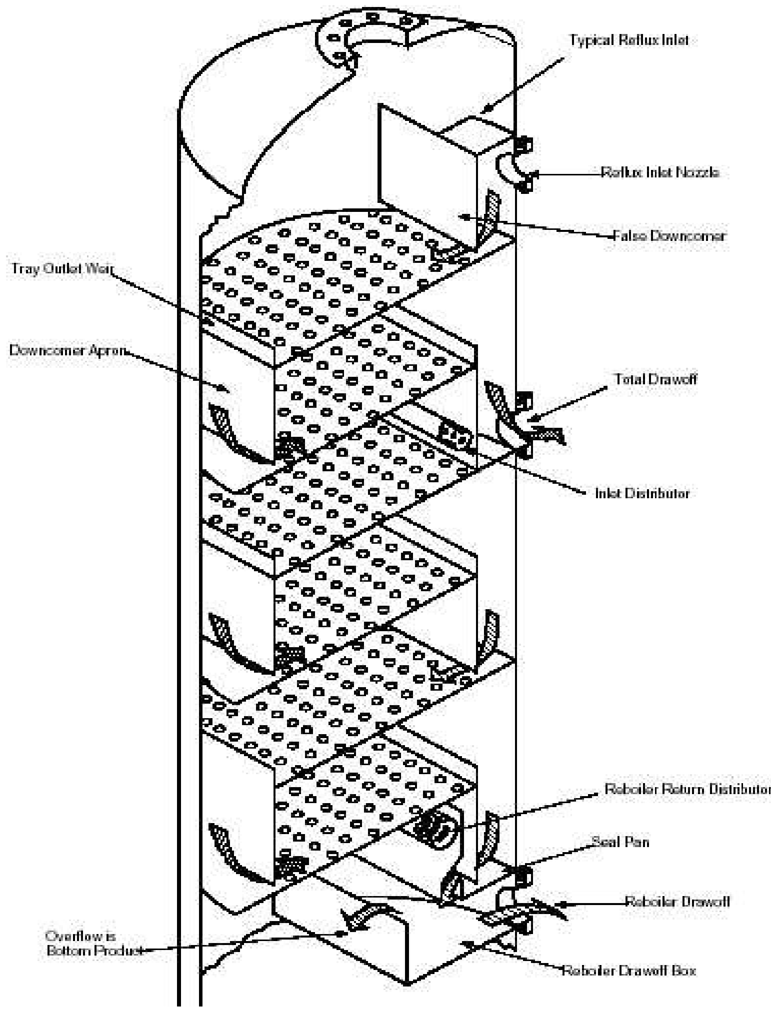
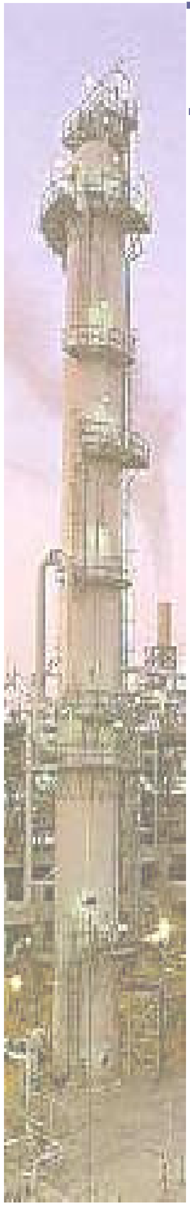
- ▷ Tower Revamps

Tray Internals

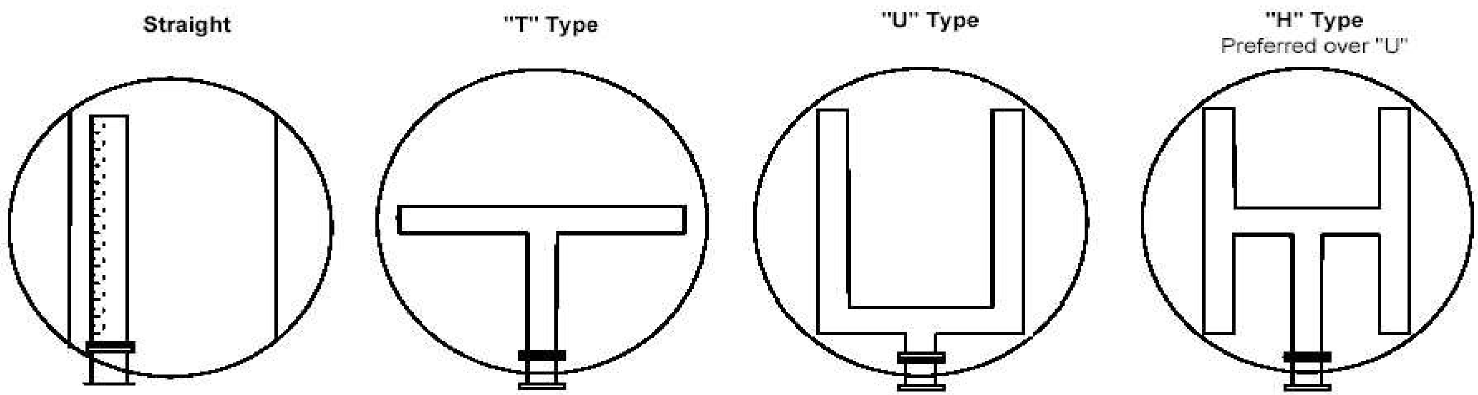




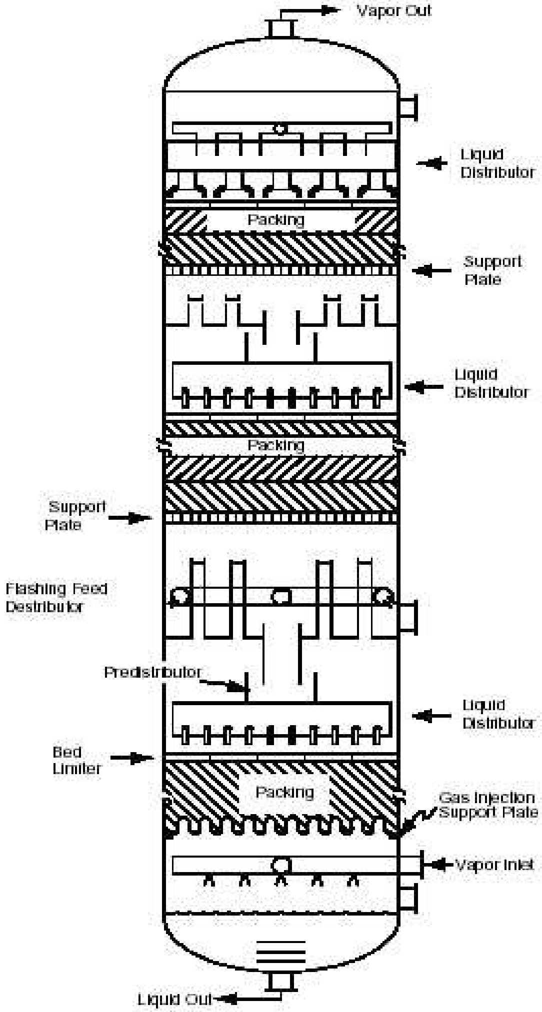


Perforated Pipe Distributors

- Usually directed against a downcomer
- Hole/Slot Area should give 0.25-0.5 psi pressure drop
  (See Fluid Flow Equations, DP III-H)
- Four common types:



Packing Internals



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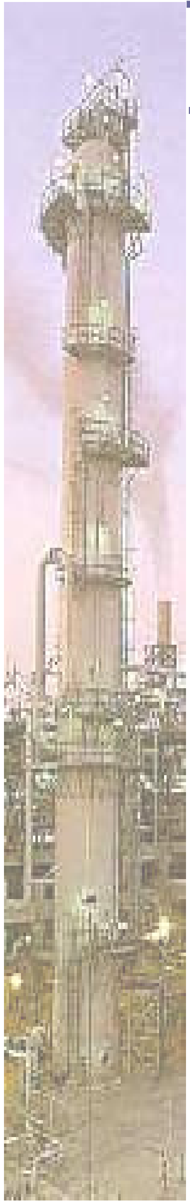
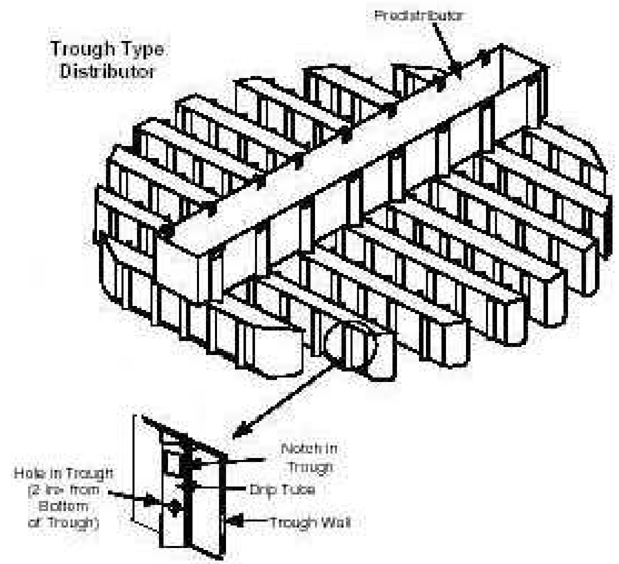
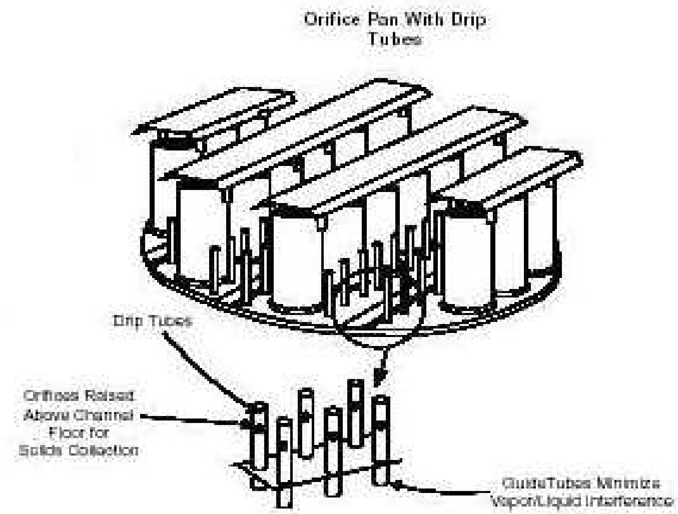


Packing Liquid Distributors

Gravity Type

- Most important packing internal
- Trough type preferred, but high cost
- Design details by vendor but must meet DP III-G, Appendix A criteria
- Must be installed level





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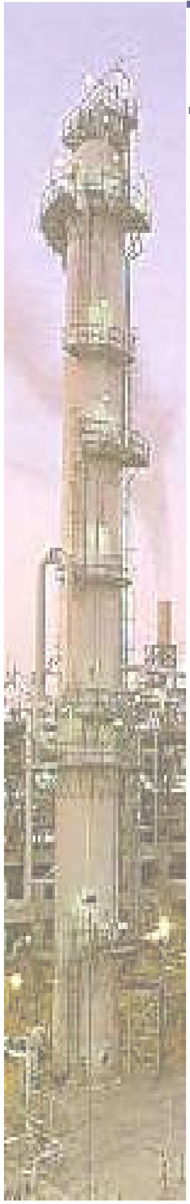
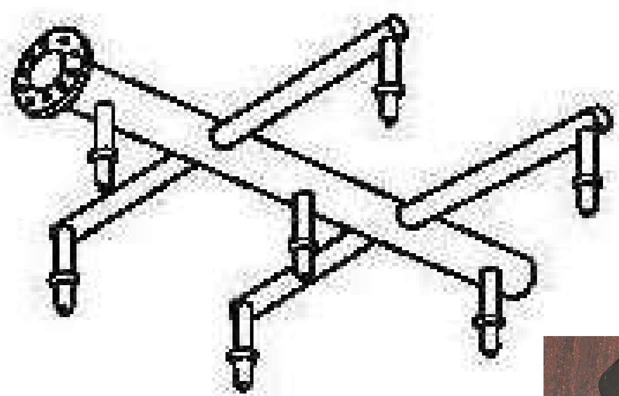
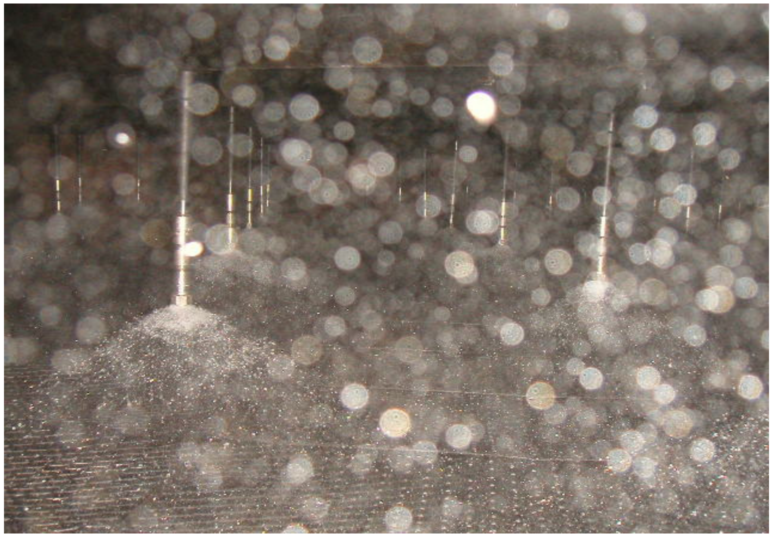


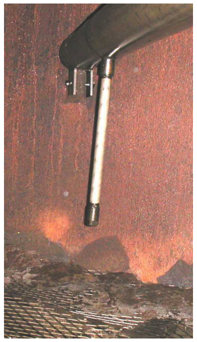
Packing Spray Nozzles

- Provide poor liquid distribution
- Plug easily; strainers required upstream
- Low cost, but often require demister above





- Sprays in action: Water Test of BTRF PS 8 VPS Wash Oil Distributor at Turndown Rate - 2003



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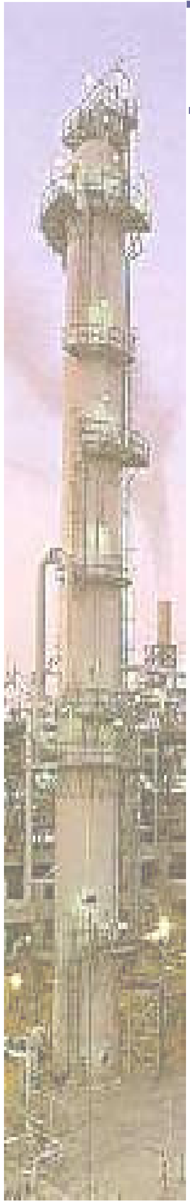
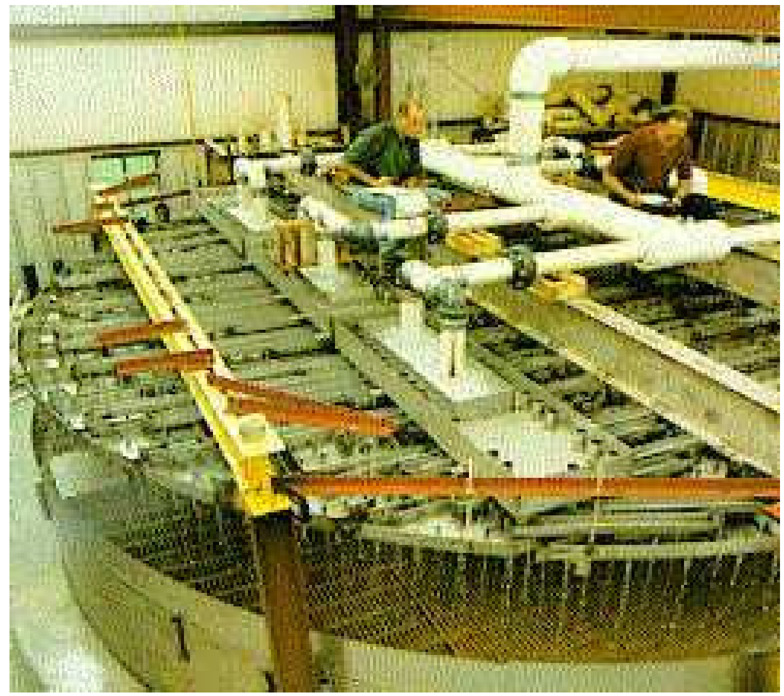


Distribution Quality

- All packing distributors should be tested at vendor shop
- Distributor should be fully assembled during test
- Area samples and individual random sample are compiled to verify performance



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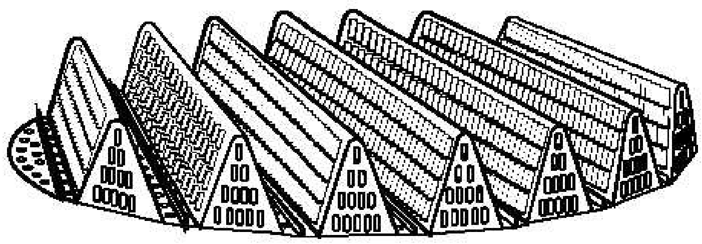
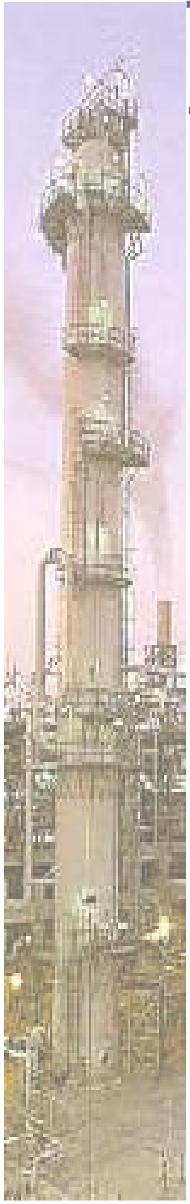
Packing Supports

- Located at bottom of packed bed
- Open Area sized for at least 100% of tower cross section to
- Design details by vendor

Random Packing
Support Plate

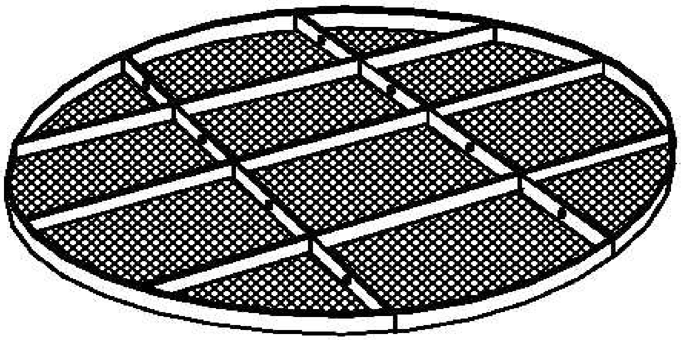


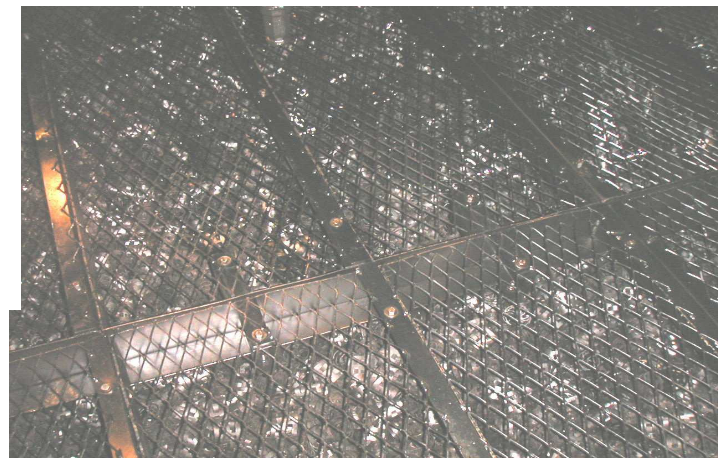


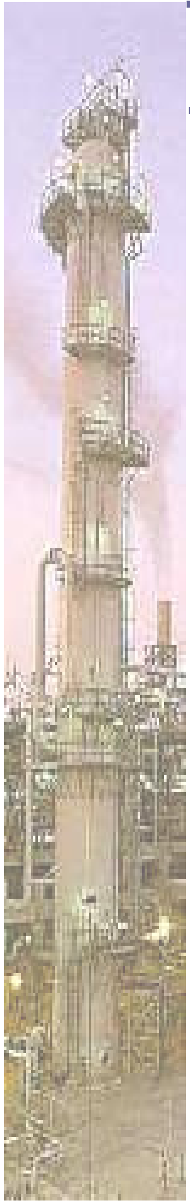
Bed Limiters

- Restrain packing during upsets - keep out of draw nozzles, etc.
- Fastened to clips welded to shell or suspended from distributor

Random Packing
Bed Limiter

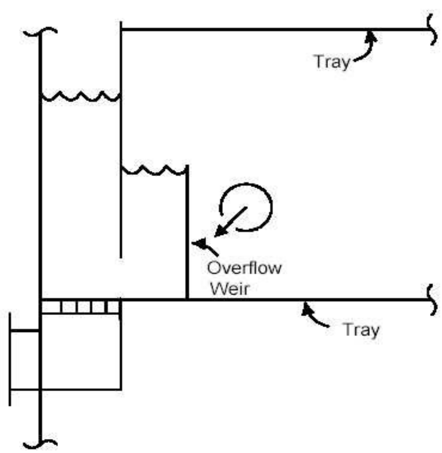


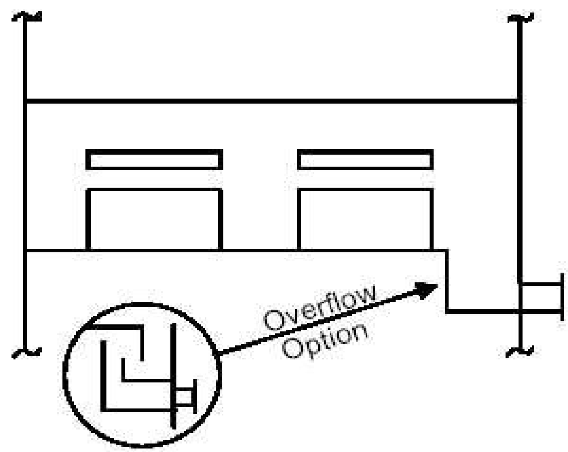


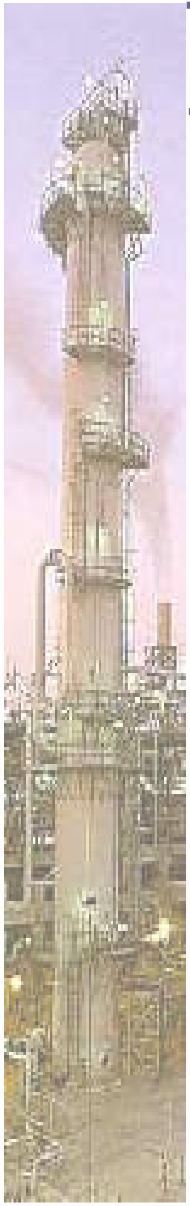


Liquid Draws - Trays and Packing

- Two types:
  - Downcomer (Sump)
  - Chimney Tray
- Either type may be a partial or total draw
- Reboiler Draws are unique (see DP III-H)







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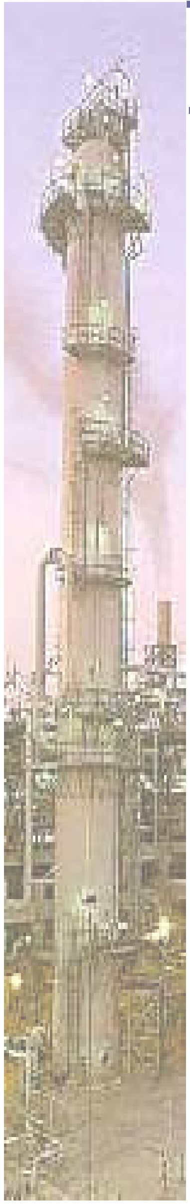
▶ **Tower Revamps**



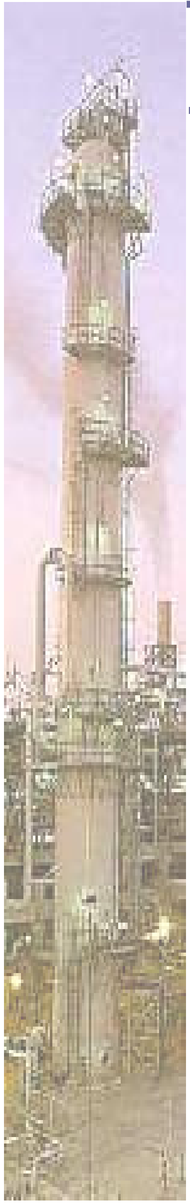
Tower Revamps

- Always consider process alternatives first!!!
  (e.g. increase tower pressure, etc.)

- <u>Revamp Strategy</u>: Rate existing tower to identify limitations
  – Vapor Handling Limitation?
  – Liquid Handling Limitation?
  – Poor Separation Efficiency?
  – Different Service?

- Explore high capacity tray options discussed previously before considering packing

- Fundamental design concepts remain the same. However, sometimes design criteria are too conservative - consult with a Fractionation Specialist.



Revamp Decision Trees

- What's the revamp objective?

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ExxonMobil DESIGN PRACTICES	*FRACTIONATING TOWERS* DEVICE SELECTION AND BASIC CONCEPTS	Section III-A	Page 47 of 60
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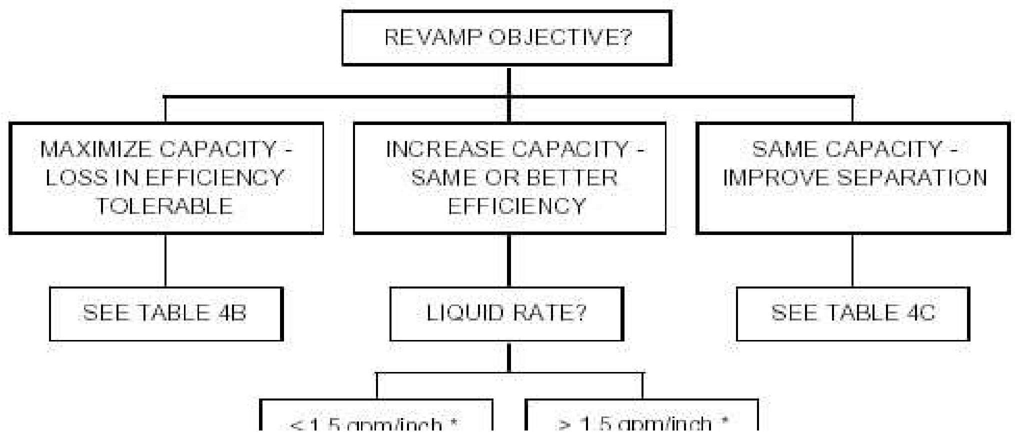
TABLE 4
TOWER INTERNALS SELECTION FOR REVAMPS



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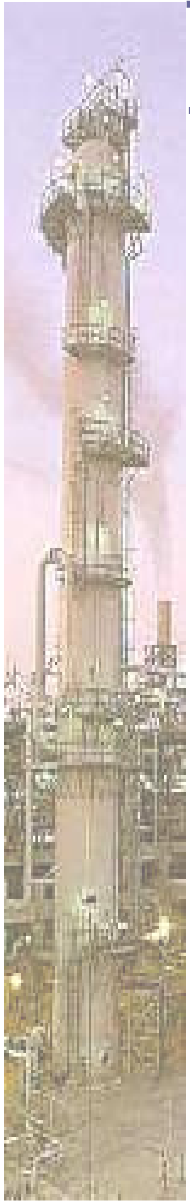
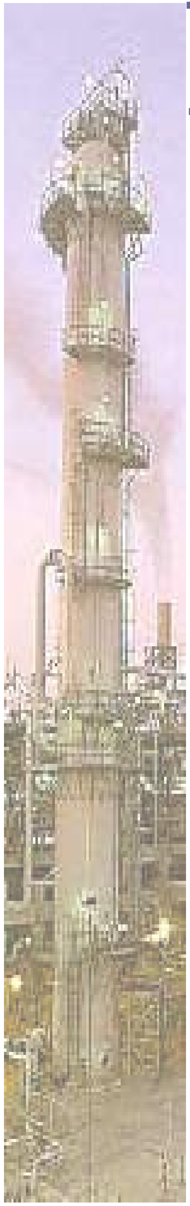


Options Guide

- <u>Revamp Objective</u>: Increased capacity at constant separation efficiency

(XOM DP III-A Table 4A)

PRESSURE		RELATIVE CAPACITY INCREASE @ CONSTANT SEPARATION EFFICIENCY (3)			
		0 - 10%	10 - 20%	20 - 30%	30% +
Low	Under 50 psia (345 kPa)	• MVG • ProValve • SuperFrac (6) •2-Pass Nye (4) •2-Pass Trays • Random Packing • Structured Packing	• Triton • 2-Pass MVG • 2-Pass SuperFrac (6) • 2 Pass Nye (4) • Random Packing • Structured Packing	• Structured Packing	• Structured Packing
Moderate	50 psia (345 kPa) to 165 psia (1140 kPa)	• Nye (4) • ProValve • 2-Pass Trays • MD Trays • Random Packing • Structured Packing (5)	• 2-Pass Nye & Superfrac Trays (6) • Triton • 4-Pass Trays • MD Trays • Random Packing • Structured Packing (5)	• MD Trays • Hi-fi Trays • ECMD Trays • Structured Packing (5)	• Hi-fi Trays • ECMD Trays
High	Above 165 psia (1140 kPa)	• Nye (4) • ProValve • 2-Pass Trays • MD Trays • Random Packing (5)	• 2-Pass Nye & SuperFrac Trays (6) • 4-Pass Trays • MD Trays • Random Packing (5)	• 4-Pass Nye & Superfrac Trays (6) • MD Trays • ECMD Trays • Hi-fi Trays	• Hi-fi Trays • ECMD Trays



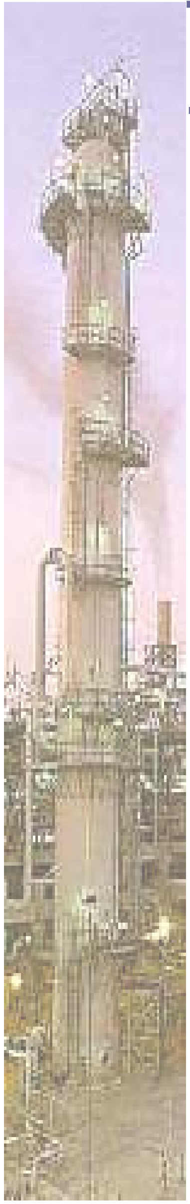
Debottleneck Examples

Cheap

- Operational changes
- Reduce weir height, increase DC clearance or add a shaped lip to lower DC filling
- Change tray decks
- Packed Towers:
  - Increase Packing Size
  - Install Structured Packing
  - Replace liquid distributor(s)

Expensive

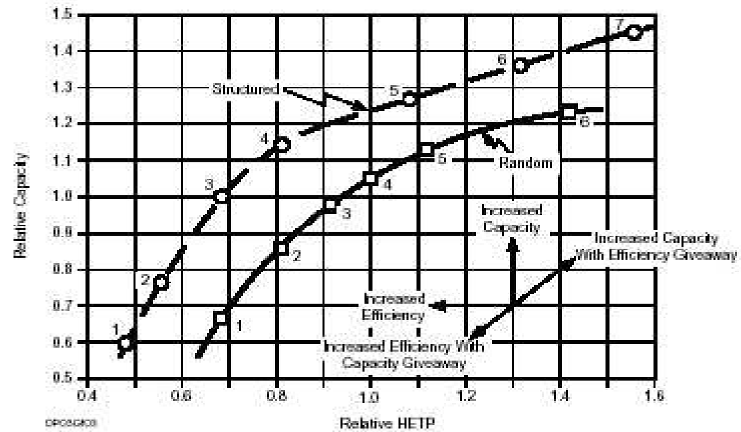
- Install sloped or mod. arc downcomers
- Increase number of liquid passes
- Install high capacity trays
- Changing tray spacing
- Install packing



Packing Selection

- Can easily compare different packing types using this chart

(see DP III-G, Figure 3)



RANDOM PACKINGS

Pt. No.	Packing Types
1.	1 in. Pall Ring #25 IMTP #1.5 CMR
2.	1.5 in. Pall Ring #40 IMTP #1 Nutter Ring #2 CMR
3.	#1.5 Nutter Ring #2.5 CMR
4.	2 in. Pall Ring #50 IMTP #2 Nutter Ring #3 CMR } Base
5.	#2.5 Nutter Ring
6.	#70 IMTP #3 Nutter Ring #4 CMR

STRUCTURED PACKINGS

Pt. No.	Packing Types	Pt. No.	Packing Types
1.	FLEXIPAC 1Y MELLAPAK 500Y	6.	FLEXIPAC 3Y MELLAPAK 125Y INTALOX Structured 5T MONTZ B1-100
2.	MELLAPAK 350Y MONTZ B1-300 FLEXIPAC 1.4Y FLEXIPAC 1.6Y INTALOX Structured 1T	7.	FLEXIPAC 4Y
3.	FLEXIPAC 2Y MELLAPAK 250Y MONTZ B1-250		
4.	INTALOX Structured 2T MONTZ B1-200		
5.	INTALOX Structured 3T MONTZ B1-125 INTALOX Structured 4T		

Notes:

(1) Similar packing types have been grouped for convenience only. They are NOT identical. Within a given grouping, each type should be evaluated on its own merits for a given design since their capacity, HETP, pressure drop, etc. differ.

(2) See text SELECTION OF PACKING for further details on how to use this figure.

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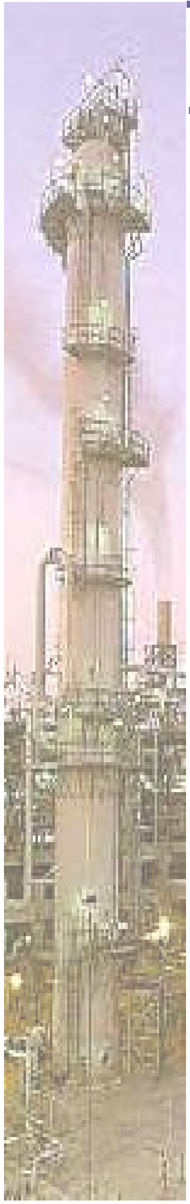

GLOSSARY

Active area — The tray deck area where the liquid-vapor contacts take place.

Antijump baffle — Tower internal device placed over the inlet of an inboard downcomer in order to prevent liquid from one side from jumping to the other side. See figure in the text.

Arc downcomer — A type of downcomer. See figure in downcomer configuration section.

Baffle sections — Horizontal or low-angle contacting devices creating cascades of liquid for contact with rising vapor. There are two basic types of baffle sections: sheds, and disks and donuts. See the figures in the text.

Blank tray — Tray used to collect liquid from higher trays or packing. Blank trays do not provide vapor-liquid contact. A synonymous term is chimney tray.

Bubble cap tray — A type of tray. The vapor goes through risers and inverted caps making contact with the liquid when leaving the caps. See the figures in the text.

Cartridge tray — Prefabricated tray and downcomer assembly. See figure in text.

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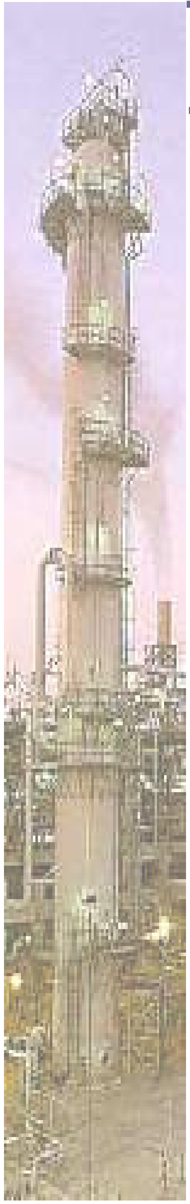

GLOSSARY (CONTINUED)

Chimney tray	Tray used to collect liquid from higher trays or packing. Chimney trays do not provide vapor-liquid contact. A synonymous term is *blank tray.*
Choking	Accumulation of froth bridged over the inlet of a downcomer, slowing down the transfer of liquid to the trays below.
Chordal downcomer section.	Vertical straight downcomer across a chord of the cross tower. Synonymous with *straight downcomer*. See Figure Downcomer Configuration section
Column	A vertical vessel containing contacting devices such as trays or packing, used to perform separations such as distillation or extraction. A synonymous term is *tower.*
Counter-current	Devices in which the liquid flow is truly countercurrent devices to the vapor flow.
Cross-flow devices	Devices in which liquid flows horizontally across a flat plate.
Debottlenecking	Removal of a process or equipment constraint.
Demisting	Elimination of entrained liquid droplets at the top of a packed bed or a trayed tower.

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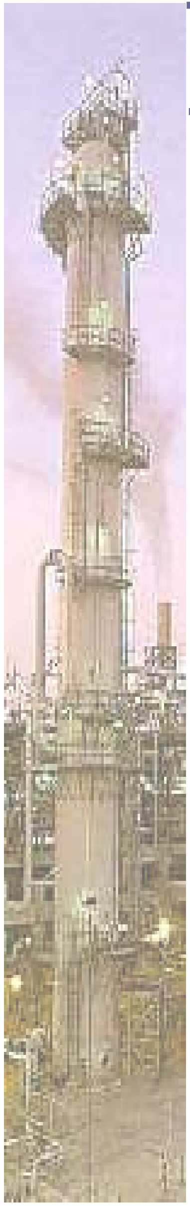
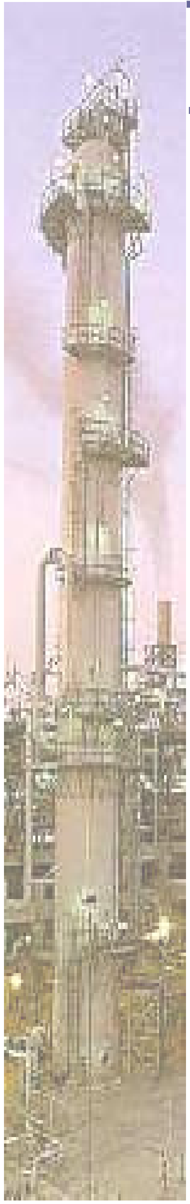


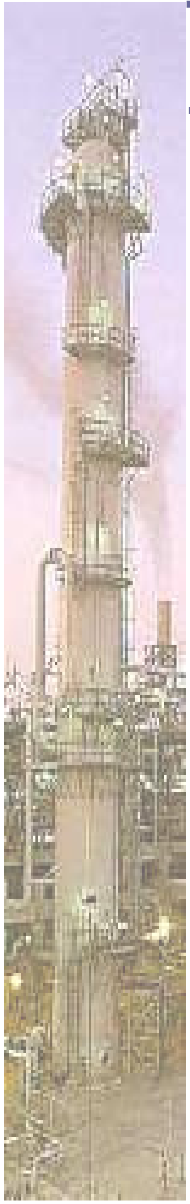
GLOSSARY (CONTINUED)

Disc & donuts	A type of baffle section. See the figures in the text.
Downcomer area	The cross-sectional area of downcomers.
Downcomer clearance	The vertical distance between the bottom of the downcomer and the tray deck.
Downcomer contraction	Pressure drop of the liquid passing under the pressure drop downcomer.
Downcomer filling	Height of liquid in the downcomer. It is often expressed in inches of clear liquid or a percent (clear liquid) of the tray spacing.
Downcomer flooding	Overloading of the tray interspace with liquid, caused by high downcomer filling.
Downcomer rise	The horizontal radial distance between the center of the chord of a straight outboard downcomer and the vessel wall.
Downcomer seal	Hydraulic seal of the downcomer outlet. See figures in the text.



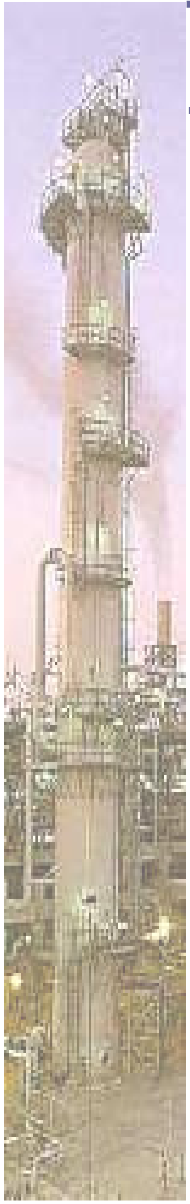
GLOSSARY (CONTINUED)

Downcomers	Tower internals that allow the tray liquid to pass to the tray below.
Dry tray pressure drop	Part of the pressure drop that is not related to the presence of the liquid on the tray, that is, the pressure of the vapor through the contacting device.
Dumped Packing	Packing type, consisting of small (2-in. is typical) devices with large open space, placed in the tower (dumped) in random orientation. A synonymous term is *random packing.*
Dumping	Weeping of all the liquid, so that no liquid flows over the weir.
Entrainment	Liquid carryover by the vapor to the tray above.
Flexibility	Refers to capacity related flexibility. See Turndown.
Flooding	Overloading of the tray interspace with liquid. Frequently, the term refers to jet flooding.
Flow regimes	The movement of liquid and vapor on a tray.



GLOSSARY (CONTINUED)

Free area	The tray cross-sectional area available for vapor flow.
Froth	A flow regime in which vapor passes through a liquid on the tray as discrete bubbles of irregular shape.
Grids	Countercurrent contacting devices fabricated in panels and installed in an ordered manner. In contrast to structured packing, grids provide wide clearances. See the figures in the text.
Hole area	The open area provided within the bubble area to permit vapor to enter, contact and pass through the liquid on the tray.
Inboard downcomer	Downcomer positioned by the vessel wall.
Jet Flooding	Overloading of the tray interspace with liquid, cause by excessive entrainment.
Modified arc downcomer	A type of downcomer. See Figure in Downcomer Configuration section.
Multiple downcomer tray	Proprietary type of tray. See Figure in Downcomer Configuration section.



GLOSSARY (CONTINUED)

Outboard downcomer	Downcomer positioned by the vessel wall.
Packing	Devices that provide countercurrent vapor-liquid contact in distillation columns.
Percent jet flood	The ratio, expressed as a percent, of the vapor velocity (%flood) between the trays. V, divided by the maximum vapor velocity that will not cause flooding.
Plates	Contact points of all the vapor and liquid in a column, such as it occurs on column trays. The term *theoretical plates* is used to indicate that equilibrium is reached at the contact point between all the vapor and all the liquid. The actual plates reflect the obtained tray efficiency. A synonymous term is stages.
Pumparound	Heat removal from a stream pumped from a tray to a higher tray.
Random packing	Packing type, consisting of small (2-in. is typical) devices with large open space, placed in the tower (dumped) in random orientation. A synonymous term is *dumped packing.*

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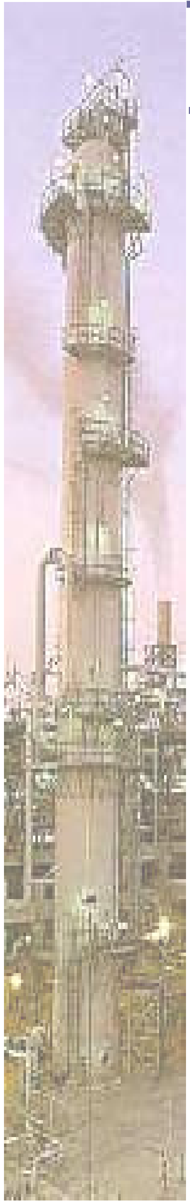
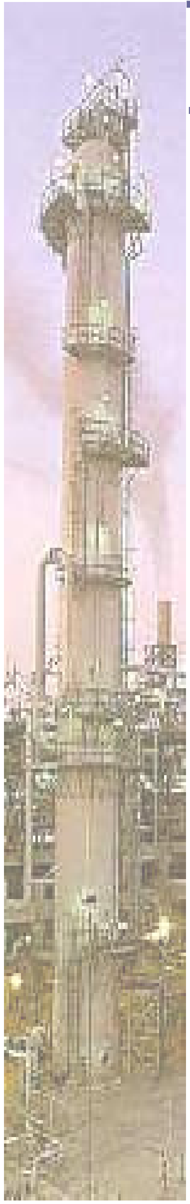


GLOSSARY (CONTINUED)

Seal pan	Tower internal device placed over the inlet of an inboard downcomer in order to prevent liquid from one side from jumping to the other side. See figure in the text.
Sheds	A type of baffle section. See Figure in the text.
Sieve tray	A perforated plate type of tray.
Sloped downcomer	A type of downcomer. See Figure in Downcomer Configuration section.
Spray	A flow regime in which a gas get issuing from the orifice shatters some liquid into droplets.
Stages	Contact points of all the vapor and liquid in a column, such as occurs on column trays. The term ***theoretical stages*** is used to indicate that equilibrium is reached at the contact point between. The actual stages reflect the obtained tray efficiency. A synonymous term is ***plates.***
Stepped downcomer	A type of downcomer. See Figure in Downcomer Configuration section.



GLOSSARY (CONTINUED)

Straight downcomer	**Vertical straight downcomer across a chord of the tower cross section. Synonymous with *chordal downcomer.* See Figure in Downcomer Configuration Section.**
Structured packing	**Countercurrent contacting devices fabricated from thin crimped sheets of metal and installed in layers having a fixed orientation. See the figures in the text.**
Superficial velocity	**Velocity based on the tower diameter rather than the cross-sectional area available for flow.**
Support ring	**Horizontal ring welded to the tower walls that are used to support a tray.**
Tower	**See *column*.**
Tray loadings	**Tray vapor and liquid rates.**
Tray pass number	**The number of individual paths of liquid on a tray.**
Tray spacing	**The vertical distance between two trays.**
Tray turndown	**The ration of maximum to minimum tray loadings in a range over which acceptable performance is achieved.**

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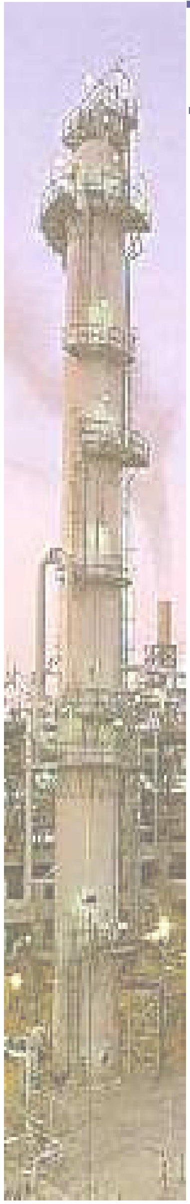

GLOSSARY (CONTINUED)

Truss	**Tray support beam.**
Turndown	**Operation at reduced capacity.**
Ultimate capacity	**The largest vapor load a tower can handle, as predicted by the Stokes law on droplet entrainment.**
Valve tray	**A type of tray with contacting devices that can be opened and closed. See the figures in text.**
Waste area	**Any area in the active area that is farther than 3 in. from the edge of a contacting device.**
Weeping	**Liquid flow through the tray openings.**
Weir	**A vertical strip at the inlet or outlet of a tray used to maintain liquid height on the tray or a liquid seal at the outlet of the downcomer. See figure in text.**

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