Mass Transfer I (CH21202)

Outline of the Course

- **Absorption:**
  - Introduction; Solubility, choice of solvent
  - Concept of rate approach and stepwise approach; stage-wise and continuous contact absorbers
  - Rich and lean gases, absorption with chemical reaction
  - Counter and co-current multistage operations; Dilute and concentrate system
  - Process design and Performance evaluation of absorbers
- Distillation:
  - Introduction; Vapour liquid equilibrium, x-y, T-x-y, P-x-y and H-x-y diagrams
  - Henry's, Routh's and Dalton's laws
  - Ideal and non ideal solutions; Azeotropes, relative volatility, flash vaporization
  - Differential distillation, steam distillation, continuous rectification; stage calculation using Ponchon-Savarit and McCabe-Thiele methods
  - Complex/multi-draw configuration; Packed Distillation column, Multicomponent Distillation, Azeotropic and Extractive distillations

Text Books

1. Mass Transfer Operations- Robert E. Treybal
2. Transport processes and Unit Operations – C. J. Geankoplis
3. Chemical Engineering, Volume 2 – J. M. Coulson, J. F. Richardson, J. R. Backhurst and J. H. Harker
4. Unit Operations of Chemical Engineering – W. L. McCabe, J. C. Smith and P. Harriott
5. Principle of Mass Transfer and Separation Processes – B . K. Dutta

Equipment for Gas-Liquid Mass Transfer Operations

Equipments/ devices for interphase mass transfer

1. Gas – Liquid / Vapor – Liquid contacting

   Examples: a) Gas absorption and Striping

   b) Distillation

   c) Humidification or Dehumidification

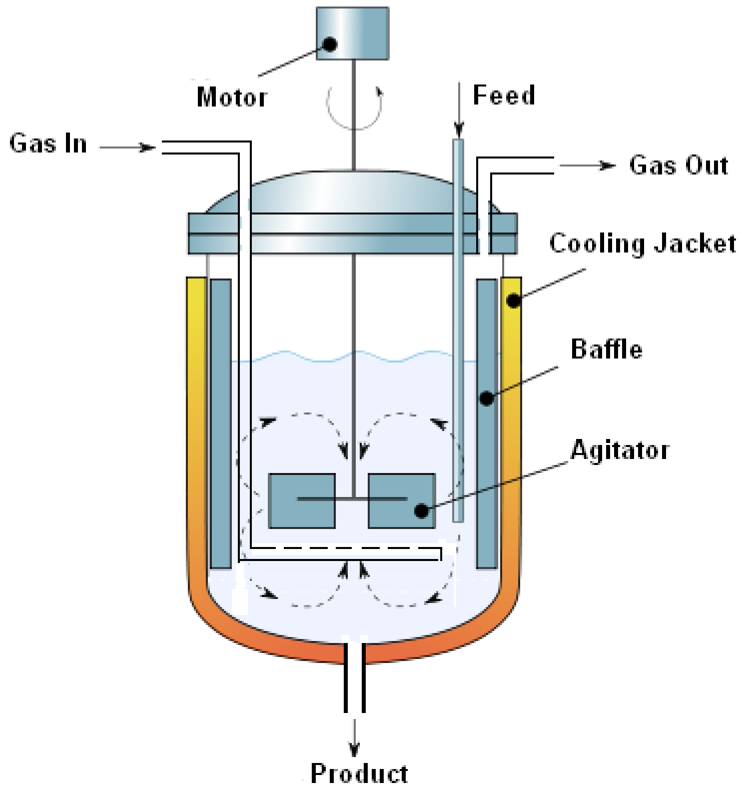
   d) Water cooling

2. Liquid – Liquid contacting (Solvent extraction)
3. Gas – Solid contacting (drying and adsorption)
4. Liquid – Solid contacting (leaching, crystallization and ion exchange)

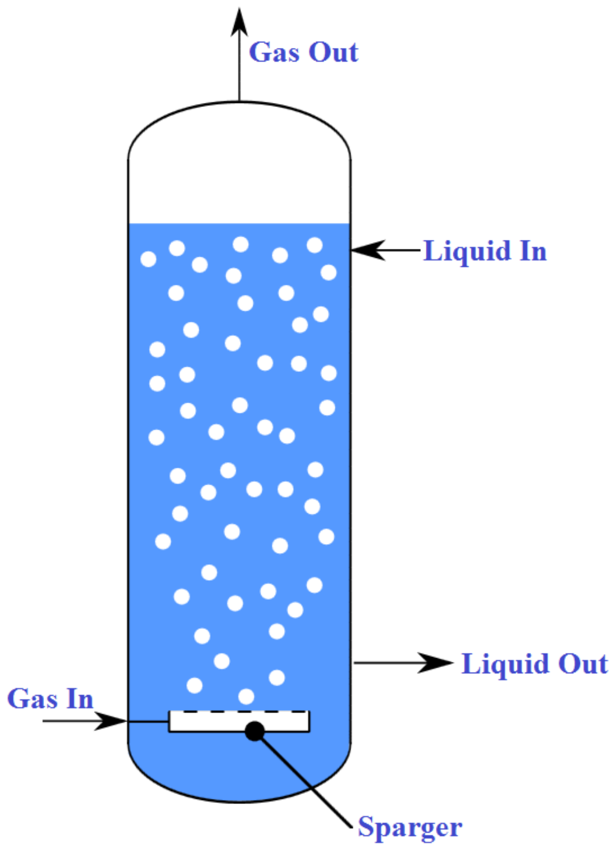
Gas Liquid Contactors

- Gas Dispersed
  - Mechanically Agitated Contractor (MAC)
  - Sparged Vessels (Bubble Columns)
  - Tray Towers
    - Sieve Tray
    - Valve Tray
    - Bubble-cap Tray
- Liquid Dispersed
  - Venturi Scrubber
  - Wetted-wall Towers
  - Spray Towers
  - Packed Towers
    - Randomly Packed
    - Regularly Packed

Agitated Vessels and Sparged Vessels



Mechanically Agitated Contactor (MAC)



Bubble Column

Or, Sparged Vessel

Agitated tanks are preferred where the gas flow rate is low and in the presence of suspended solids, either as a reactant or catalyst.

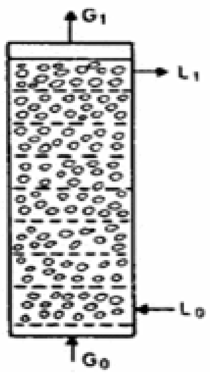
Agitated Vessels and Sparged Vessels

Gas and liquid can conveniently be contacted, with gas dispersed as bubbles, in agitated vessels **whenever multistage counter-current effects are not required.** This is particularly the case when a chemical reaction between the dissolved gas and a constituent of the liquid is required.

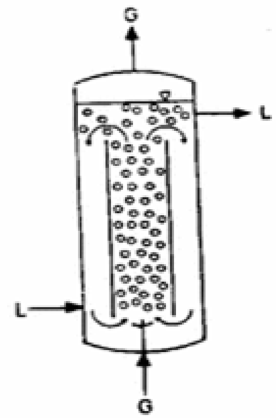
Examples: Carbonation of lime slurry, hydrogenation of vegetable oils, aeration of fermentation broths, as in the production of penicillin, production of citric acid from sugar beat by action of microorganisms, aeration of activated sludge for biological oxidation.

In most of the above processes, solids are suspended in the liquids. As the more complicated counter-current towers have a tendency to clog with such solids, the agitated vessels are usually more successful in such services, because solids can be suspended in the liquids easily.

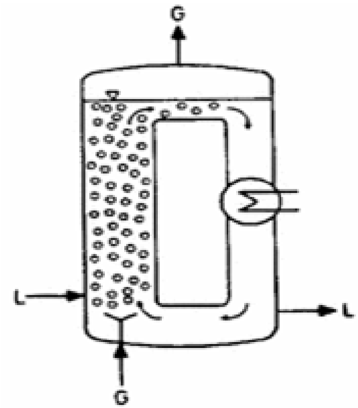
Types of Bubble Column



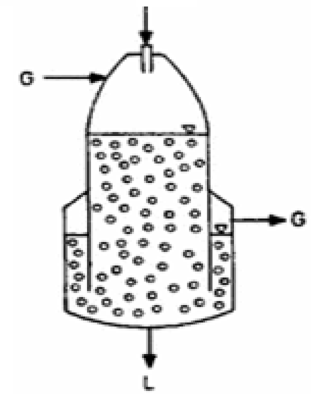
Cascade Bubble Column



Bubble Column with Internal Loop



Bubble Column with External Loop



Downflow Bubble Column

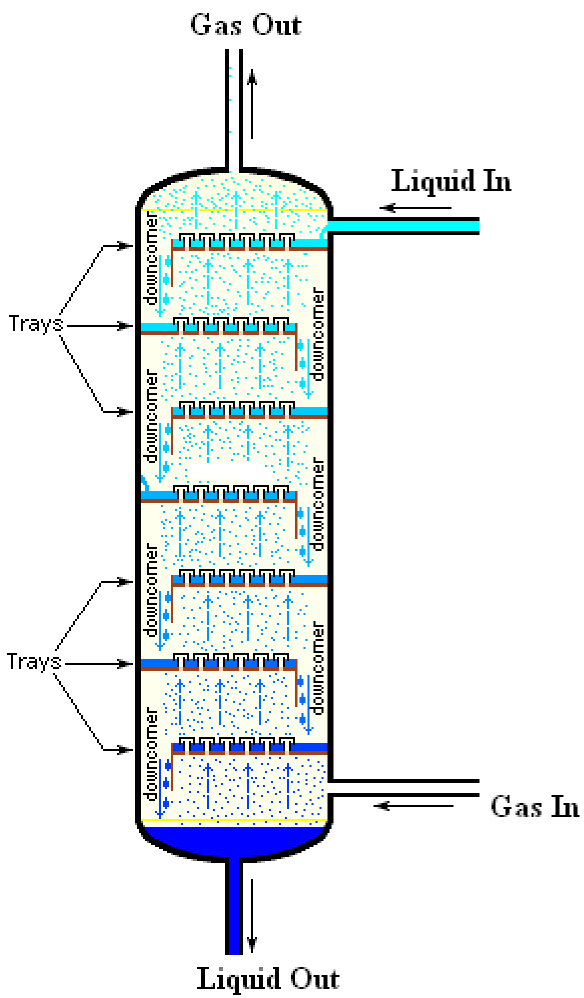
Oxidation of Acetaldehyde to Acetic Acid : Cascade Bubble Column

Biological Wastewater Purification (Aerobic) : Bubble Column with internal loop/ Downflow Bubble Column

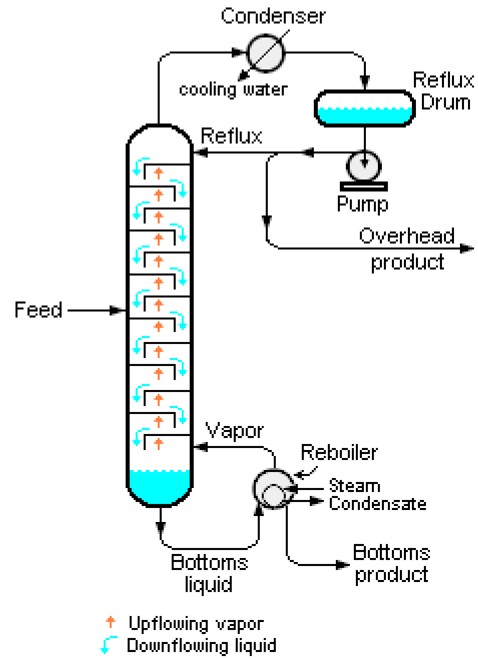
Hydrogenation of Benzene to Cyclohexane : Bubble Column (slurry) with external loop

Fischer-Tropsch Synthesis in Liquid Phase : Slurry Bubble Column

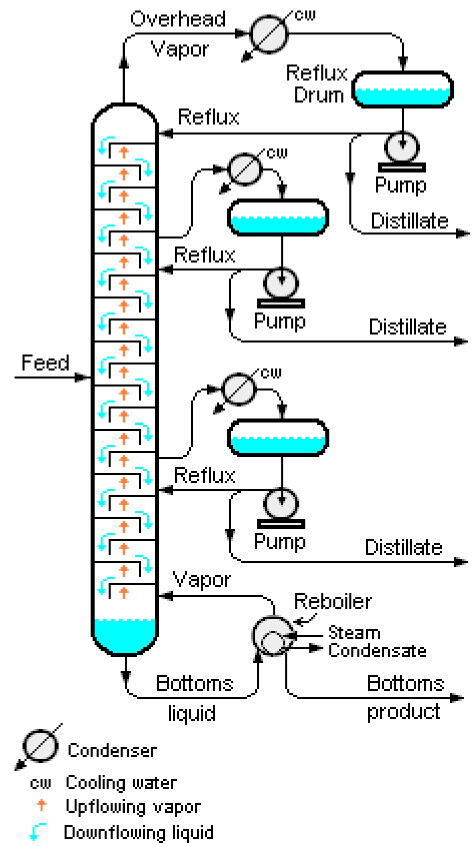
Tray Towers



Absorption Column



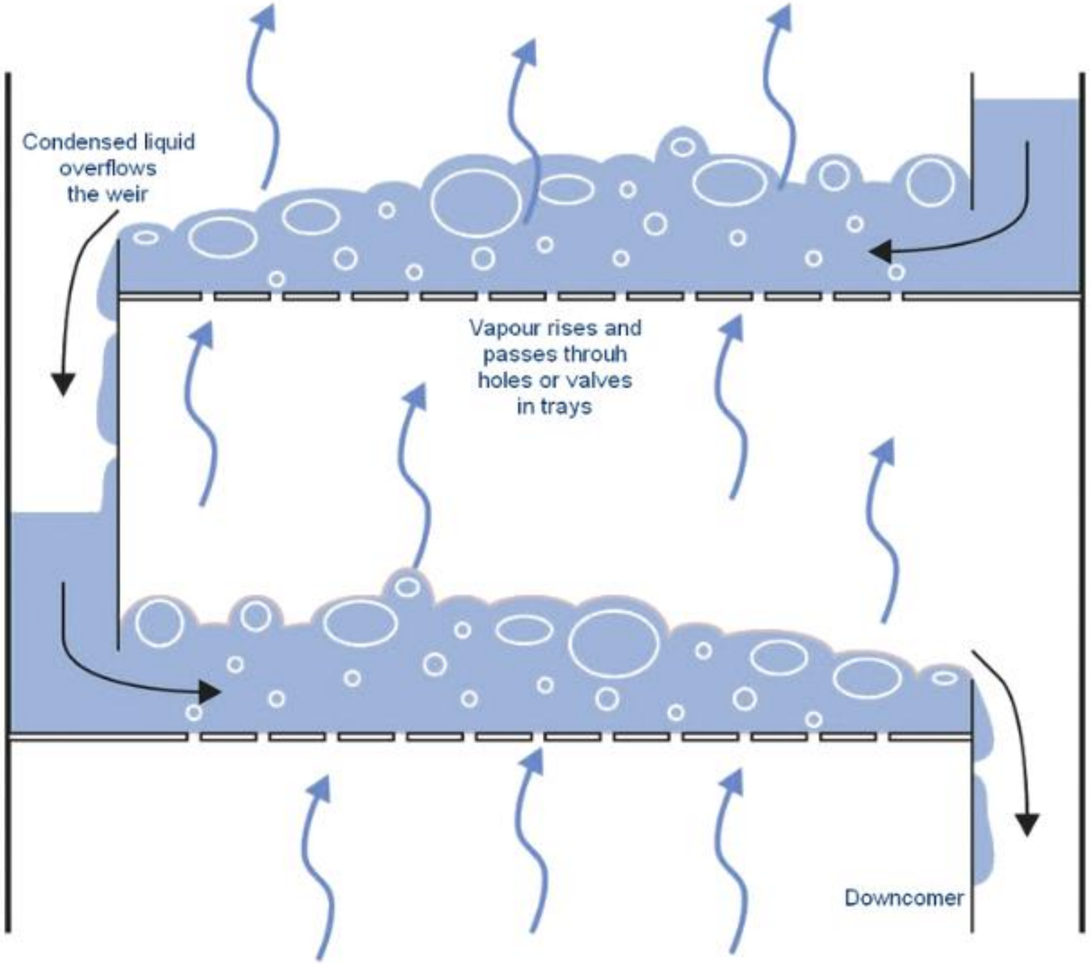
Distillation Column



Distillation Column with Side Draw

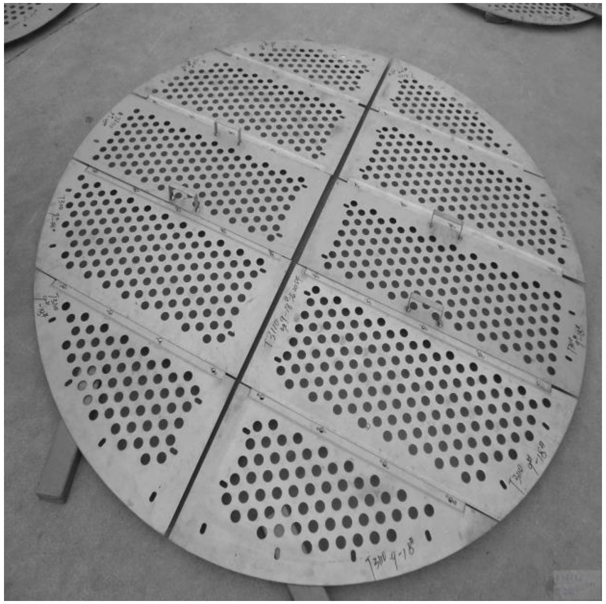
Tray Towers, Downcomers

Tray Towers, Downcomers

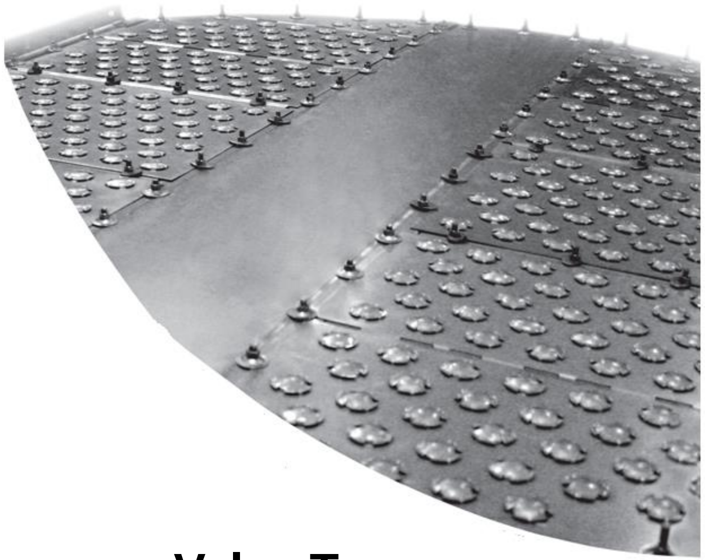


Different types of Trays

Sieve Tray



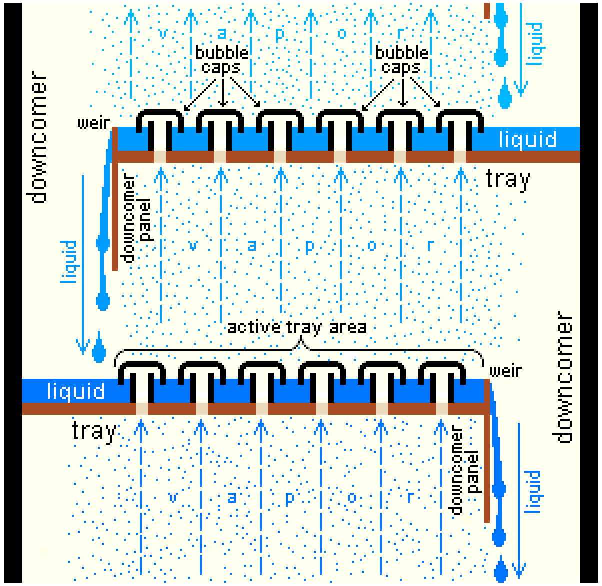
- Hole diameter – 1/8 to ½ inch (3/16 inch common)
- Pitch – $2.5d_H$ to $5\ d_H$
- Free area – 6 to 10%

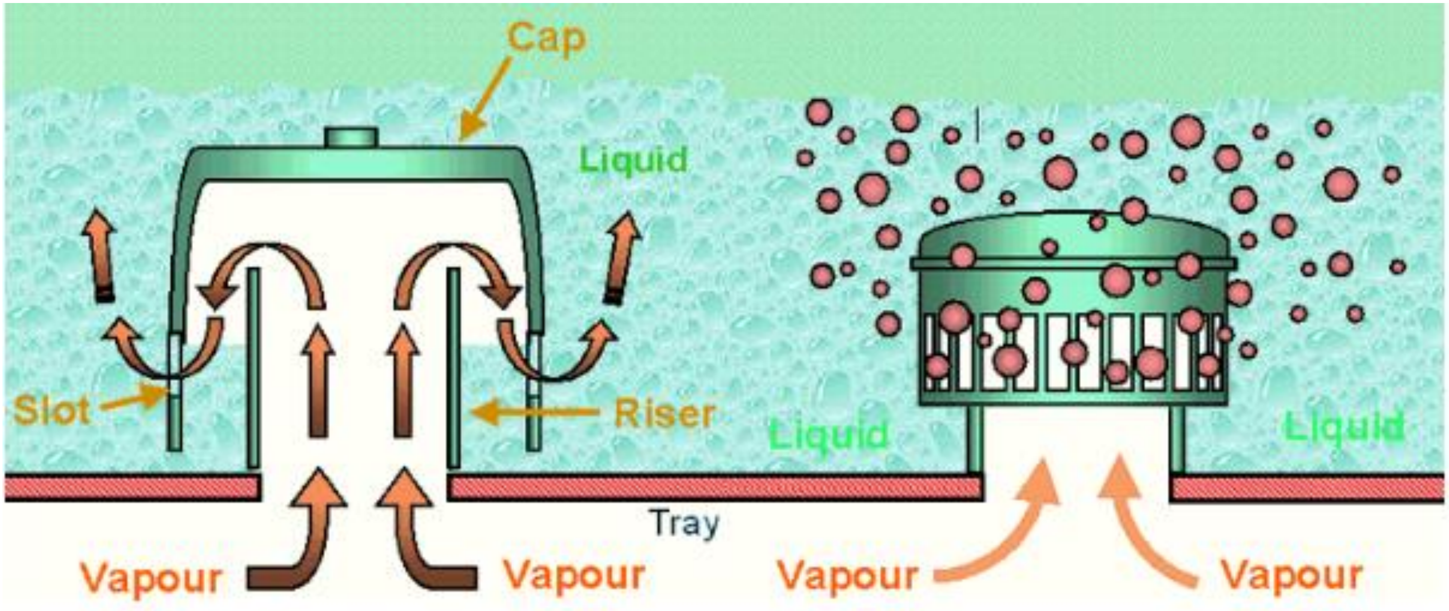


Valve Tray

Bubble-cap Tray

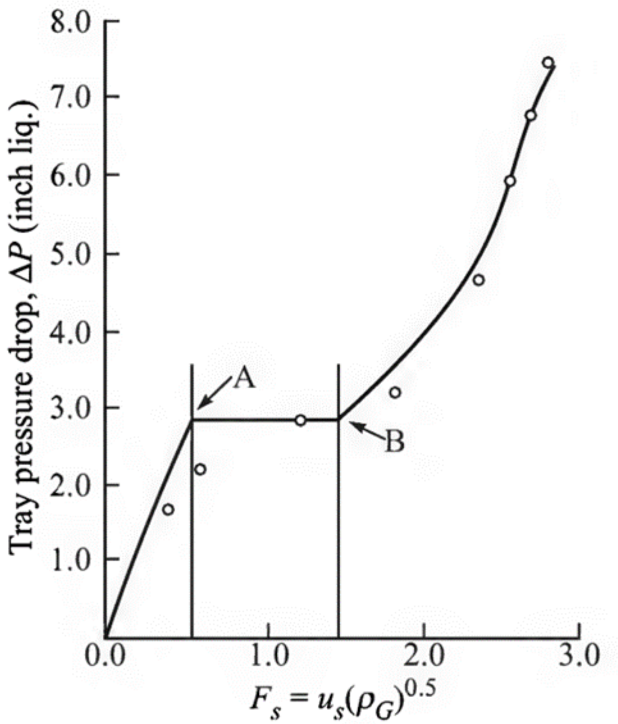
Typical Bubble-cap Design

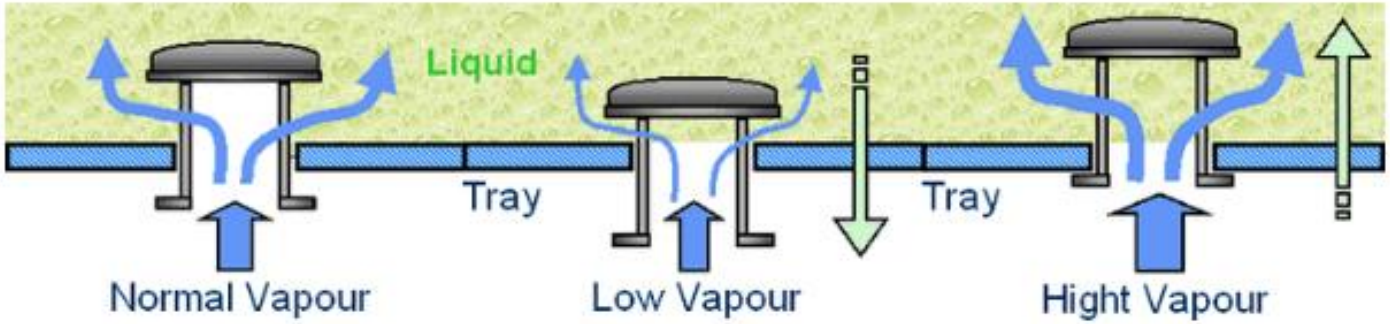




Single Valve

A typical Valve tray pressure drop profile

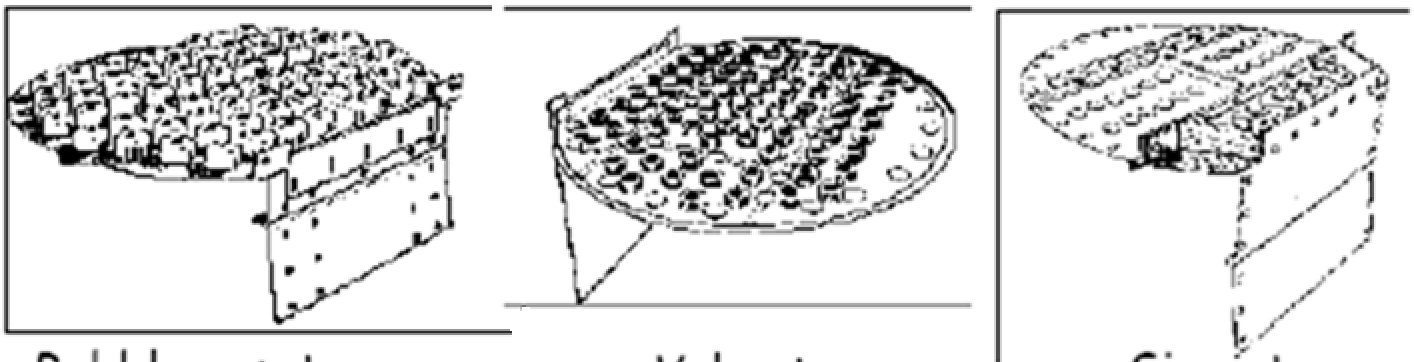




https://www.youtube.com/watch?v=RNWsbrYzPXQ&list=PPSV

Selection of Trays

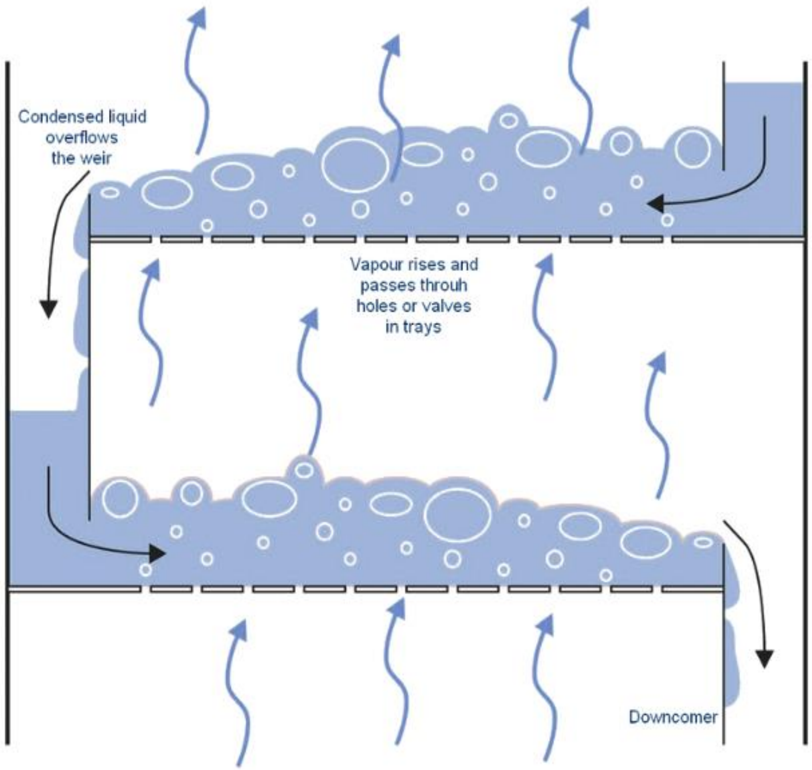
Bubble-caps, Valves or Sieves...



Bubble-cap tray Valve tray Sieve tray

	Bubble-caps	Valves	Sieves
Relative cost	2.0	1.2	1.0
Pressure drop	Highest	Intermediate	Lowest
Efficiency	Highest	Highest	Lowest
Vapor capacity	Lowest	Highest	Highest
Typical turndown ratio	5	4	2

Gas and Liquid Flow in Sieve Tray Tower



Downcomer Residence time: 3 – 5 sec

Liquid velocity: 0.3 – 0.5 ft/sec

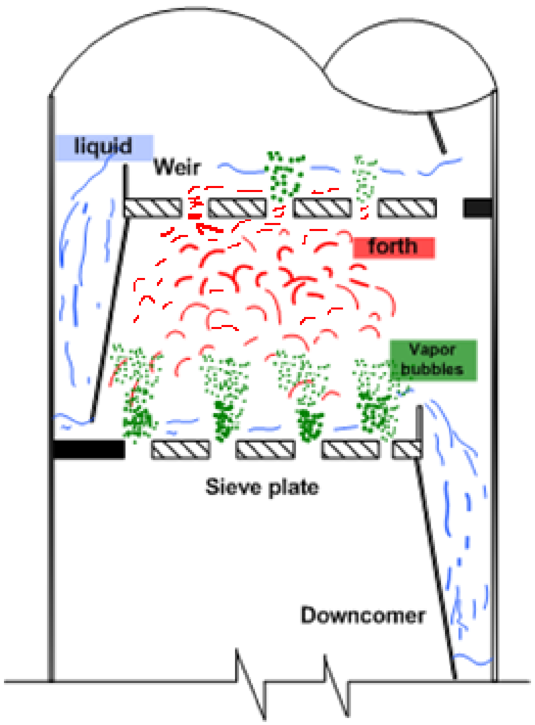
Downcomer plate: straight or inclined

Downcomer clearance: 0.5 – 1 inch

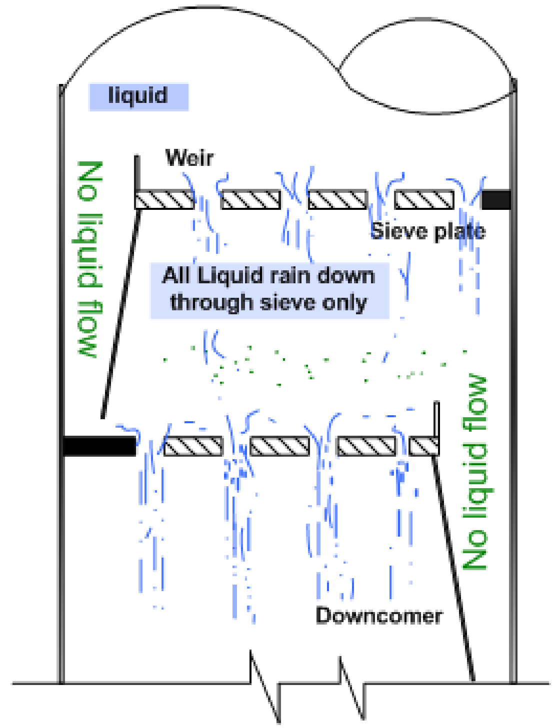
Weir plate: 60 – 80 % tower diameter

Weir height: 1 - 2 inch

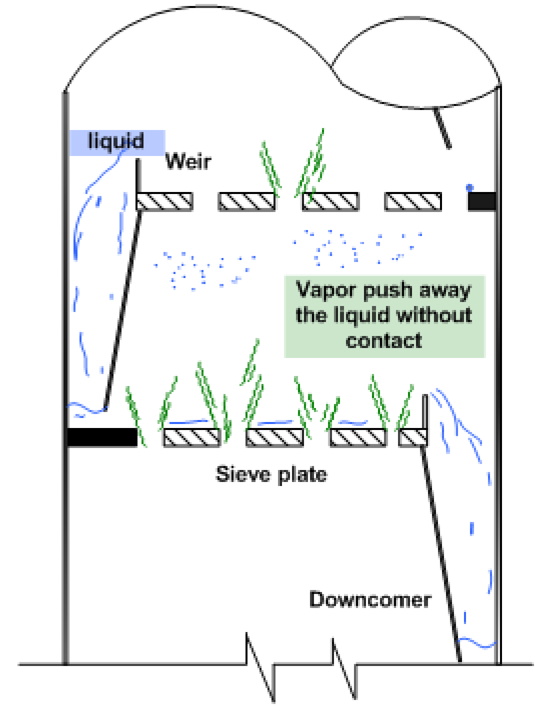
Gas and Liquid Flow in Sieve Tray Tower



Priming



Dumping



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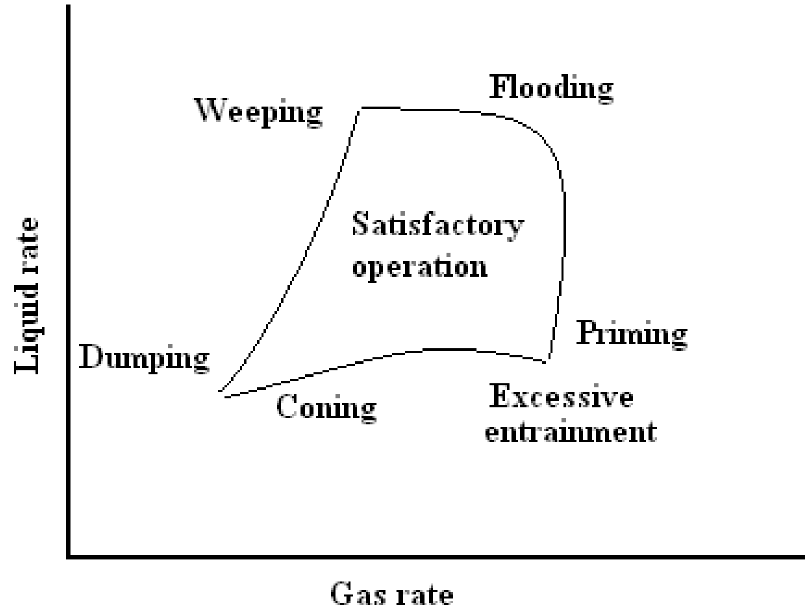
Tray Performance Constraints

Adverse vapor/liquid flow conditions can cause:

- Foaming
- Entrainment
- Flooding
- Weeping/dumping
- Downcomer flooding

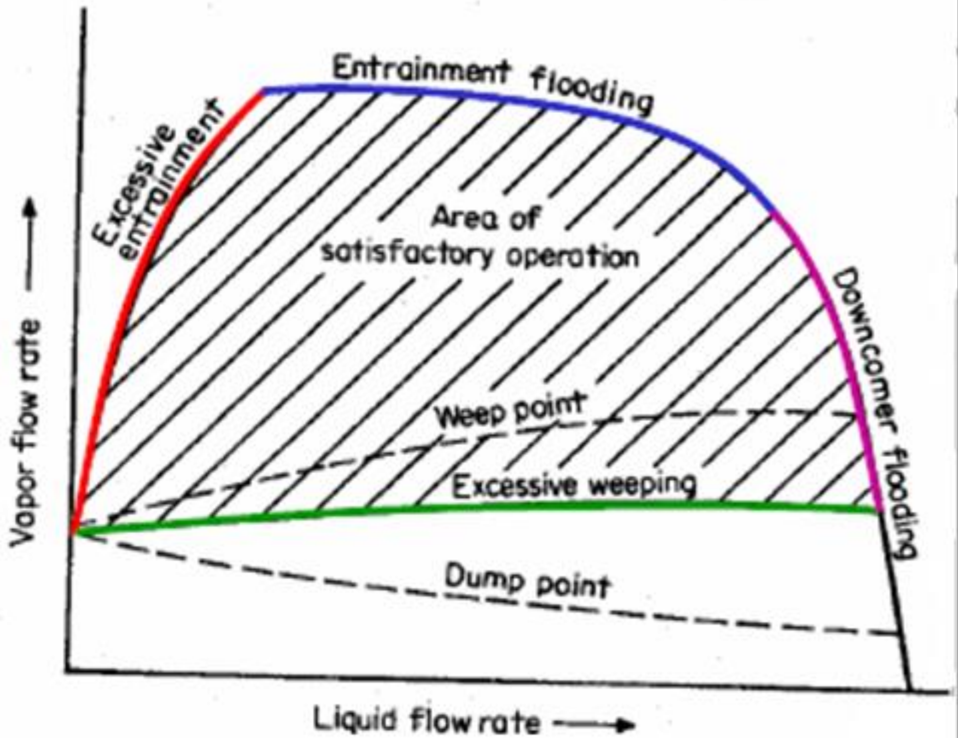


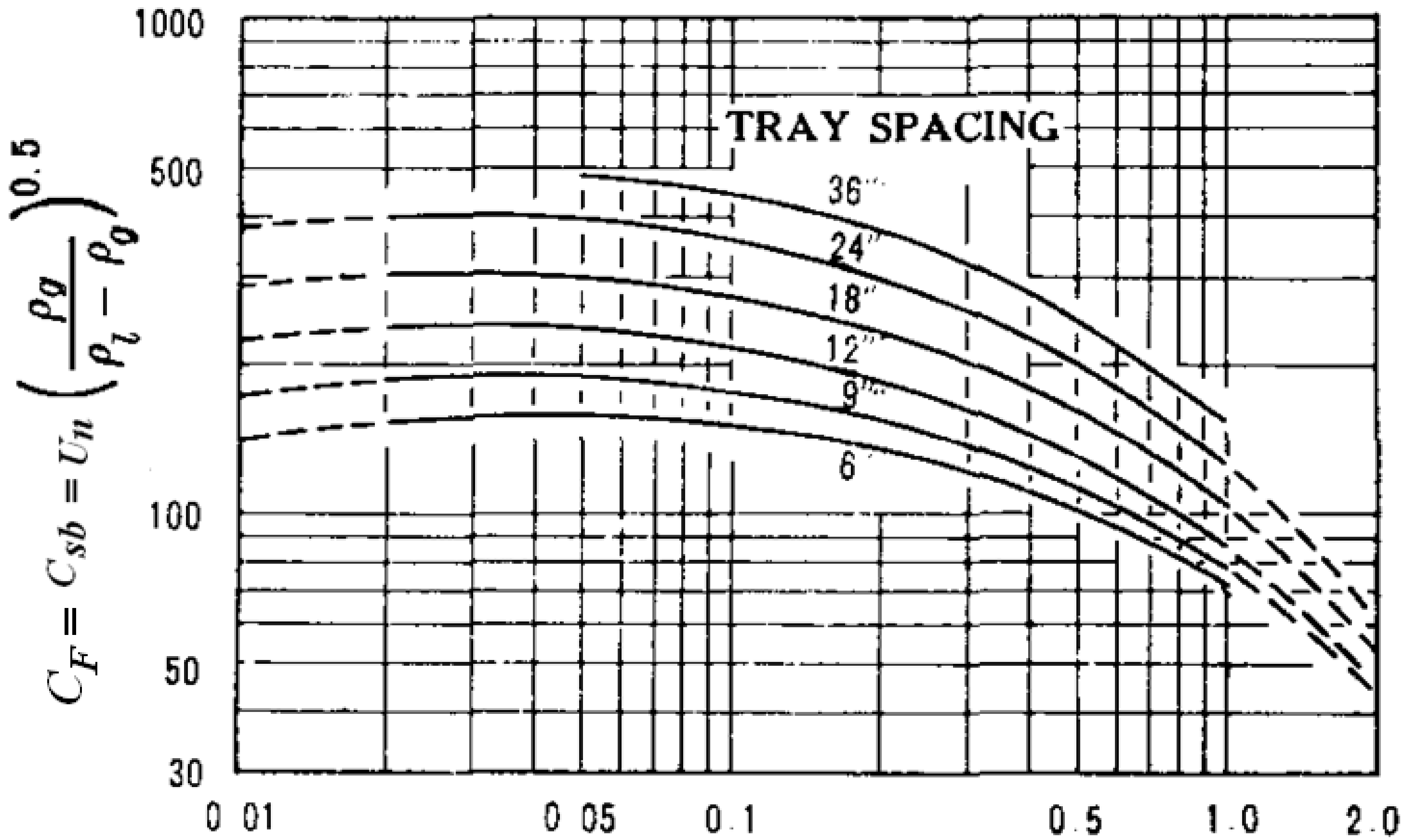
Operating Characteristics of Sieve Tray

Tray Performance Constraints

Adverse vapor/liquid flow conditions can cause:

- Foaming
- Entrainment
- Flooding
- Weeping/dumping
- Downcomer flooding





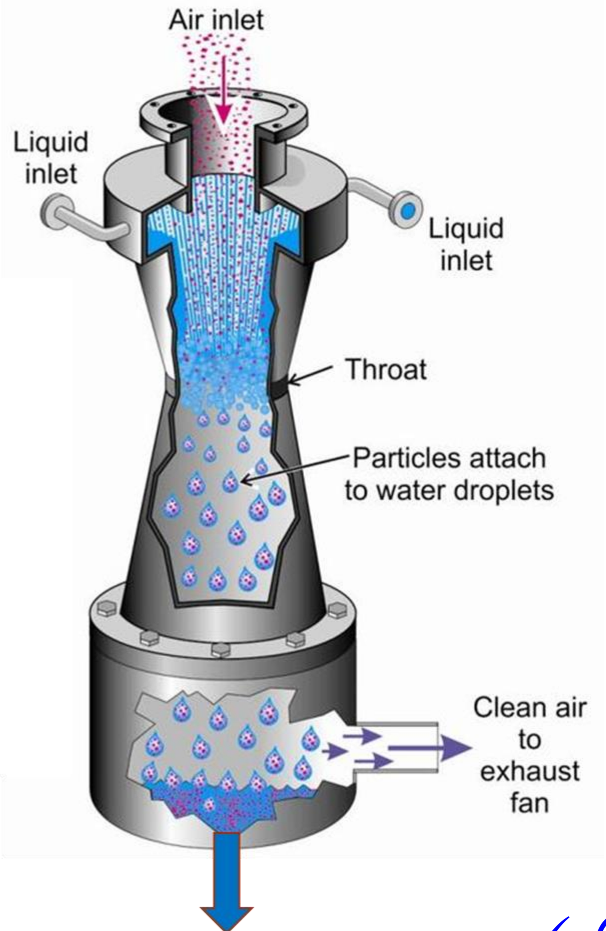
Un= superfacial velocity of the fluid
Csb = Souders-Brown flooding const.
F_{lv} = flow parameter

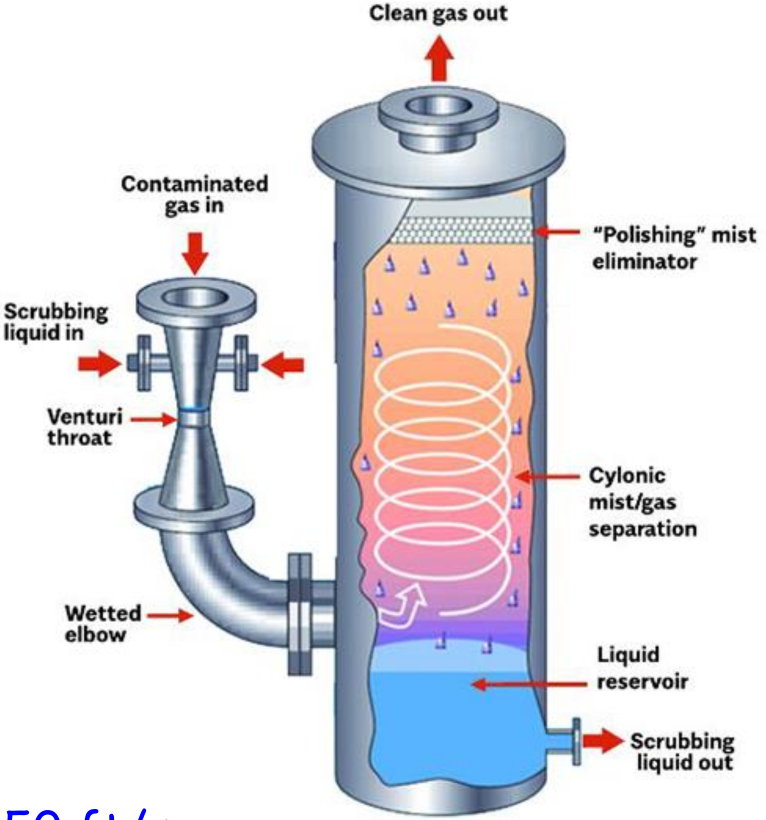
$$F_{lv} = \frac{L}{G}\left(\frac{\rho_g}{\rho_l}\right)^{0.5}$$

Correlation of flooding velocity in bubble-cap column and perforated plate column by Fair and Matthews

Liquid Dispersed Type Gas-Liquid Contactors

Venturi Scrubber

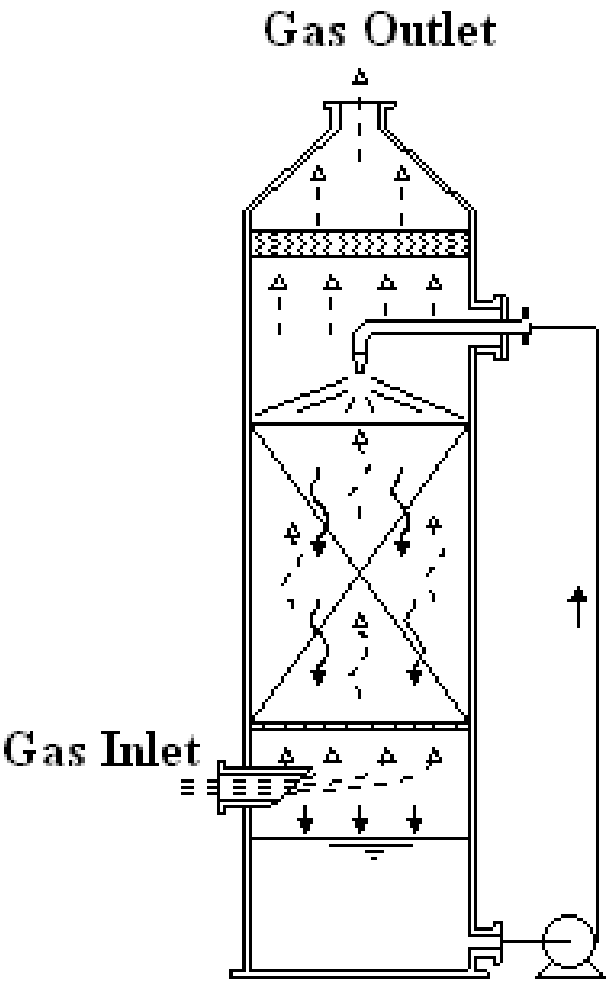




- ✓ *Gas velocity: 250 ft/s*
- ✓ *Corrosive gas-liquid system*

Use: Pulp and paper industry Chemical process industry Food industry Metals processing industry

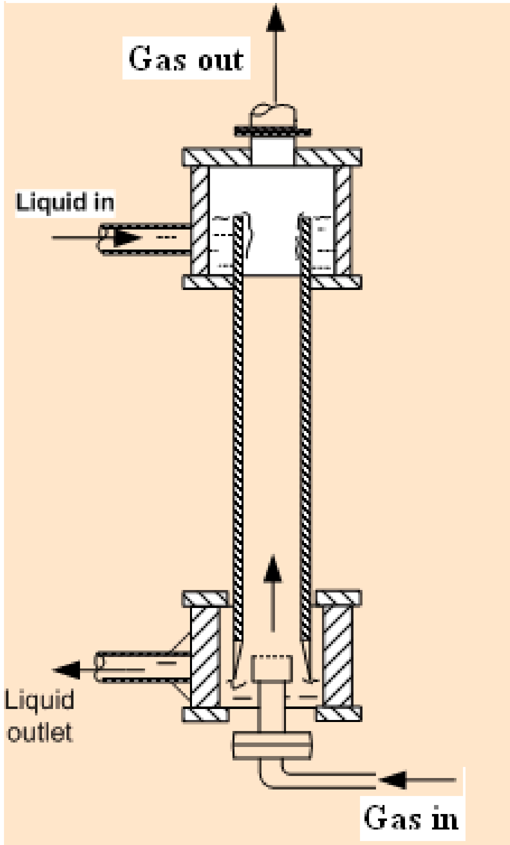
Spray Tower

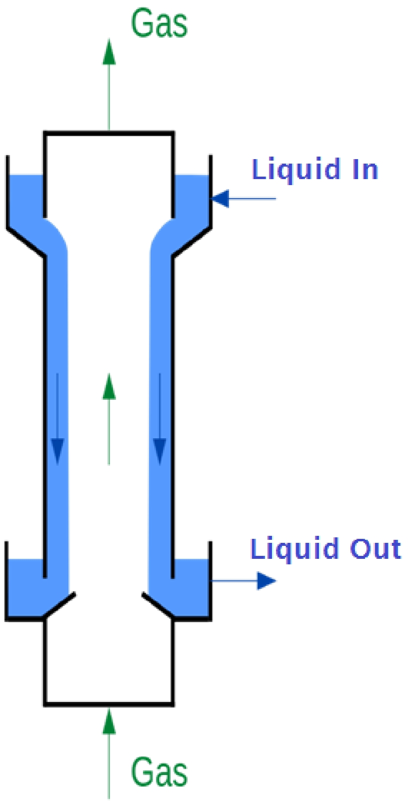


- Handle large volumetric gas flow rate
- Suitable for corrosive liquid and gas
- Liquid/gas containing suspended solids
- Low gas pressure drop application
- Pumping of the liquid to a high pressure to a spray nozzle involve substantial power consumption

Removal of HCl gas from the tail-gas exhaust in manufacturing hydrochloric acid

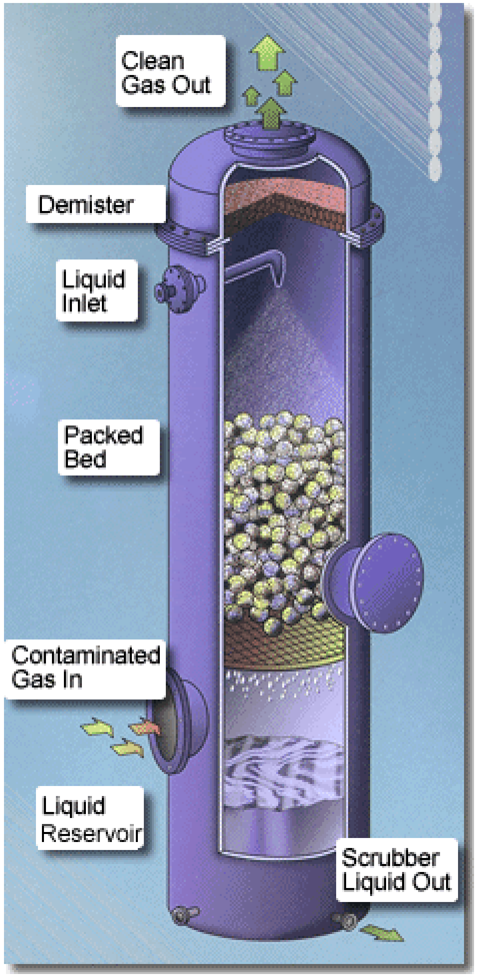
Wetted-wall Column

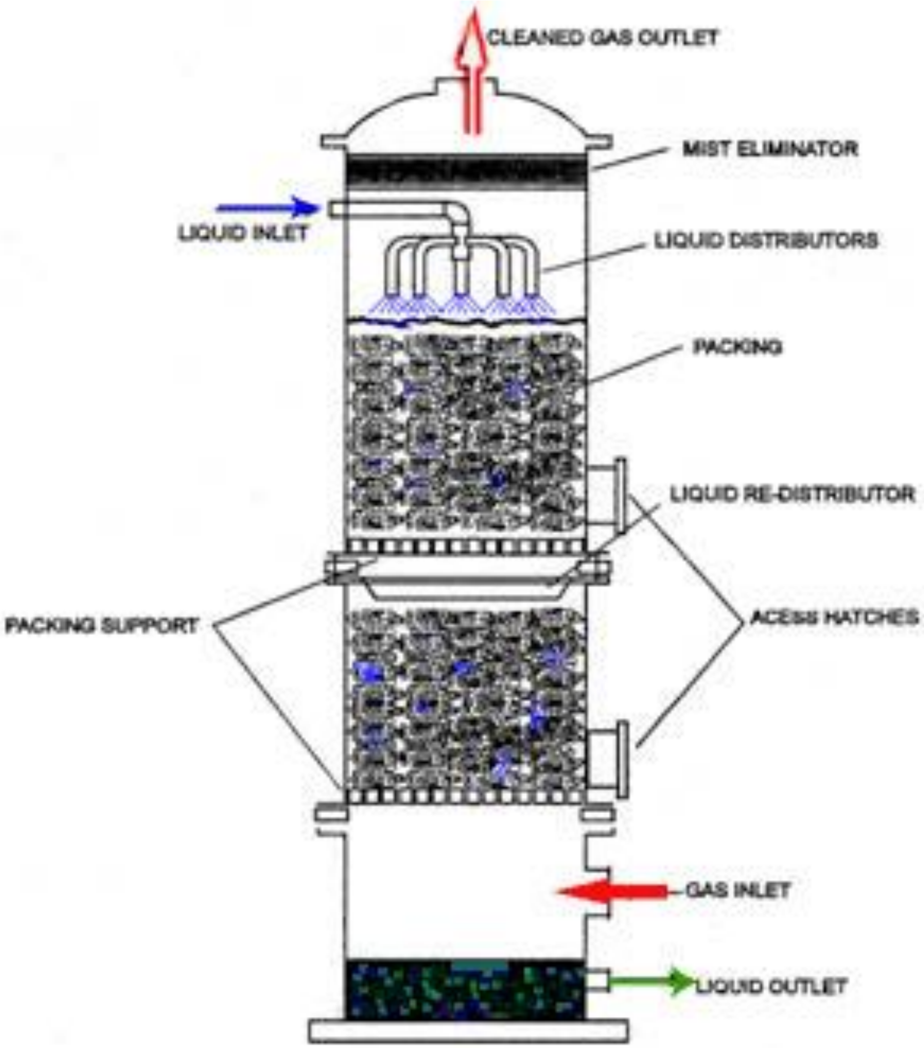




- ❑ Falling-film columns are generally used as laboratory equipment, for example to measure experimentally the values of transport coefficients
- ❑ It is not used at an industrial scale, because it has low surface area and liquid hold-up compared to other gas-liquid contactors

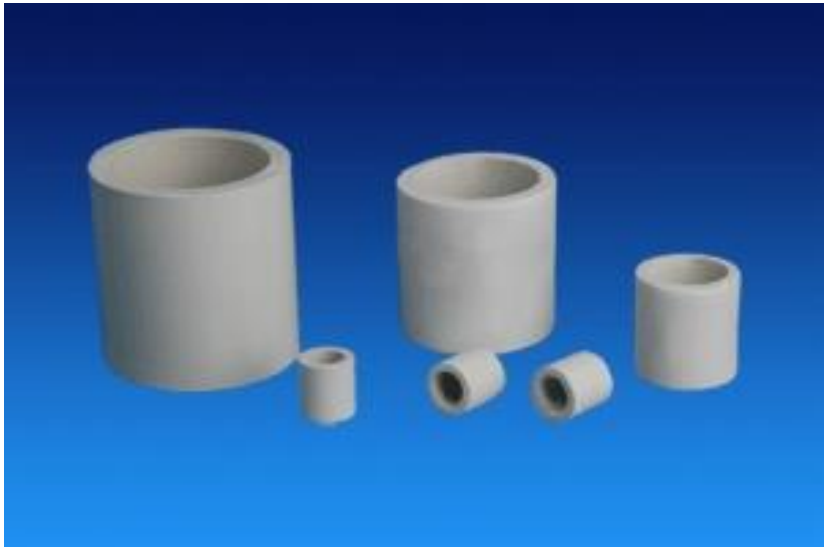
Packed Towers





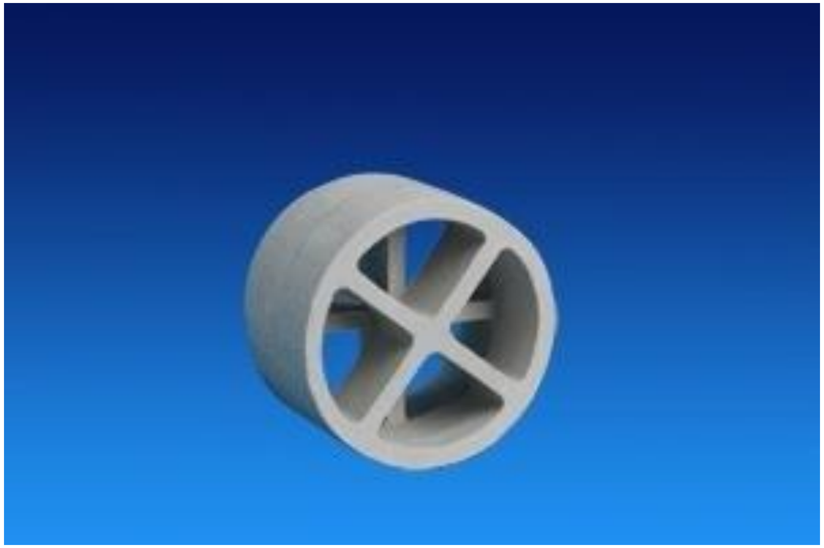
Packed Towers

https://www.youtube.com/watch?v=YM3Giz-wX4Q

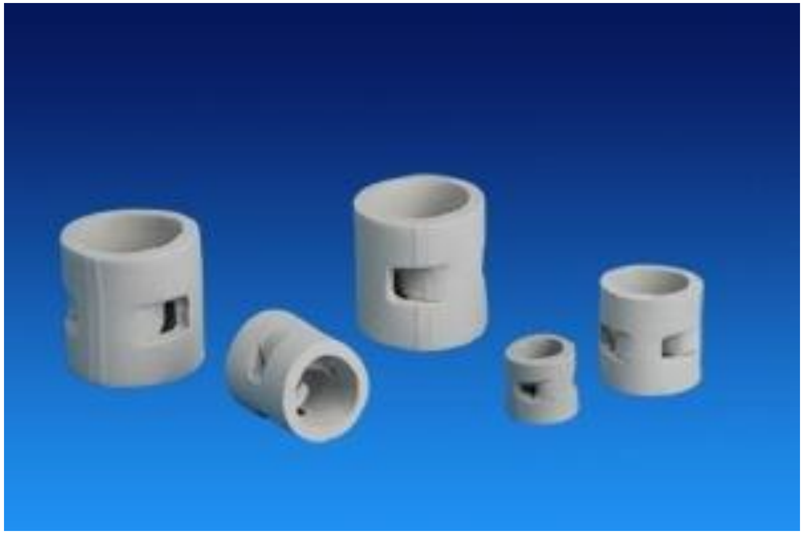


Raschig Ring

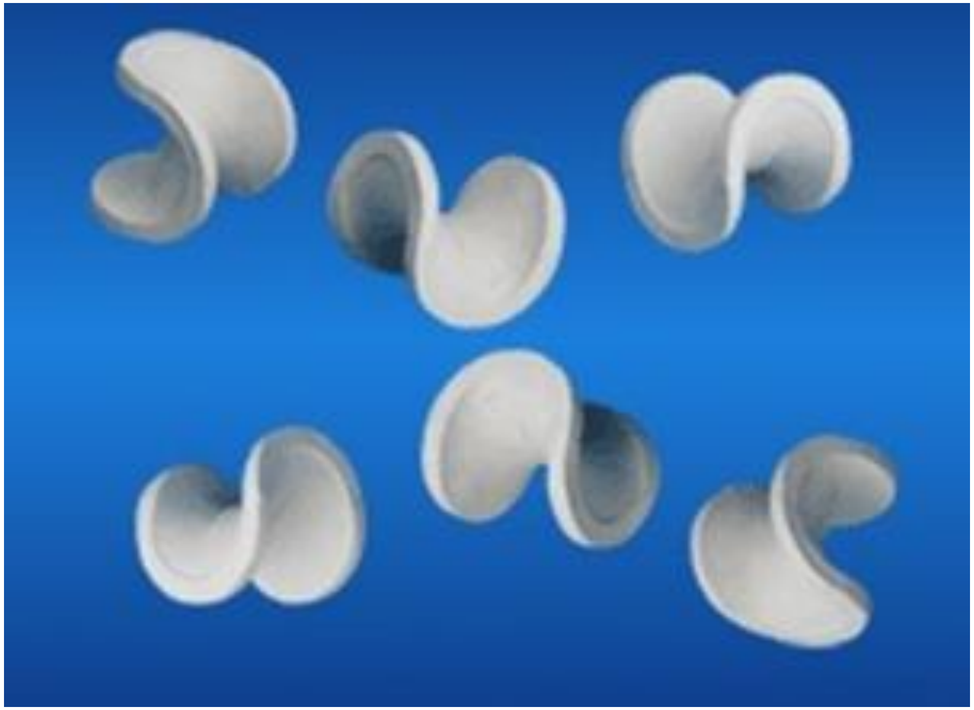
Lessing Ring



Cross Partition Ring

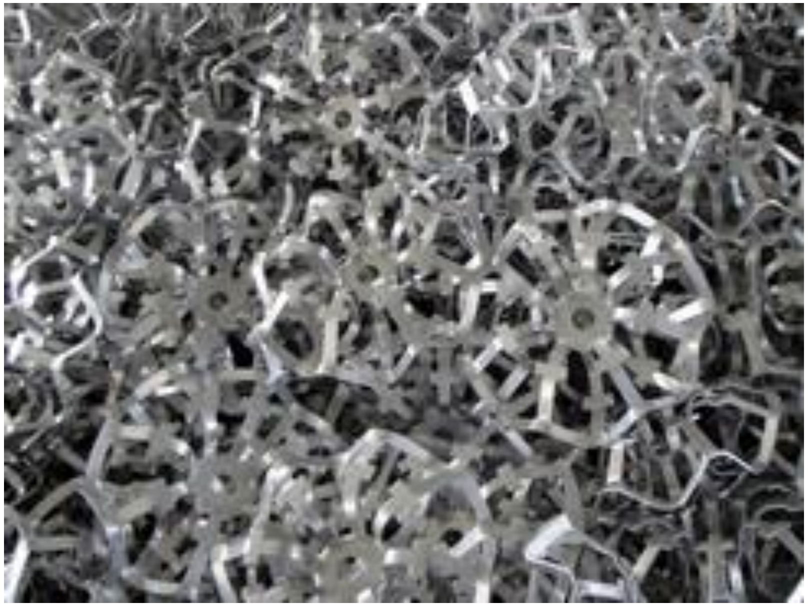


Pall Ring



Berl Saddle

Intalox Saddle



Metal Tellerettes

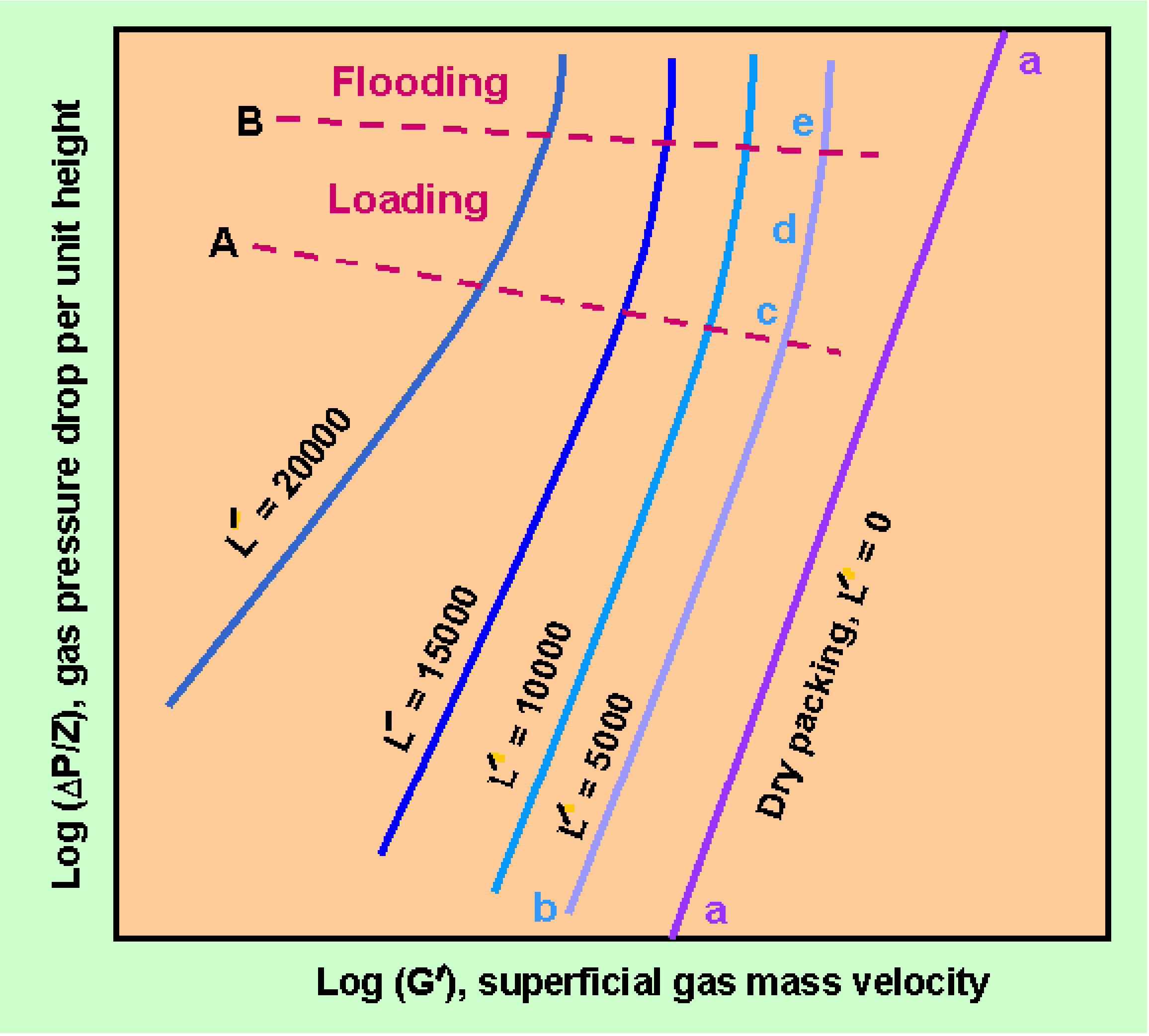
Plastic Tellerettes

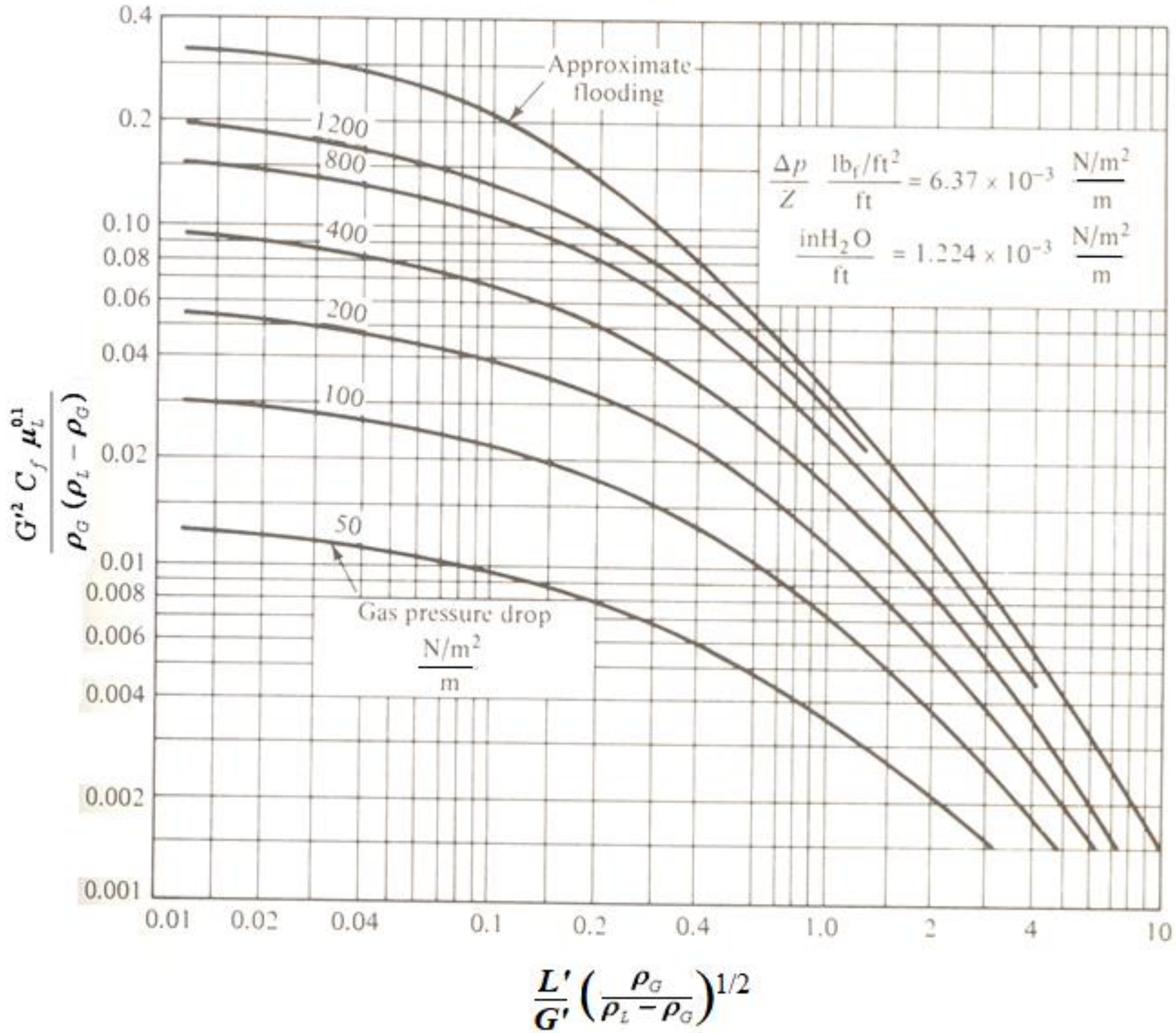
Desirable Characteristics of Packings

A tower packing or fill should possess the following characteristics:

- **Provide large interfacial surface between liquid and gas. The surface of packing per unit volume of packed space (a_p) should be large.**
- **Possess desirable fluid flow characteristics. This ordinarily means that the fractional void volume, ε, or fraction of empty space, in the packed bed should be large.**
- **Be chemically inert to fluids being processed.**
- **Have structural strength to permit easy handling and installation.**
- **Represent low cost.**

Loading and Flooding in Packed Towers



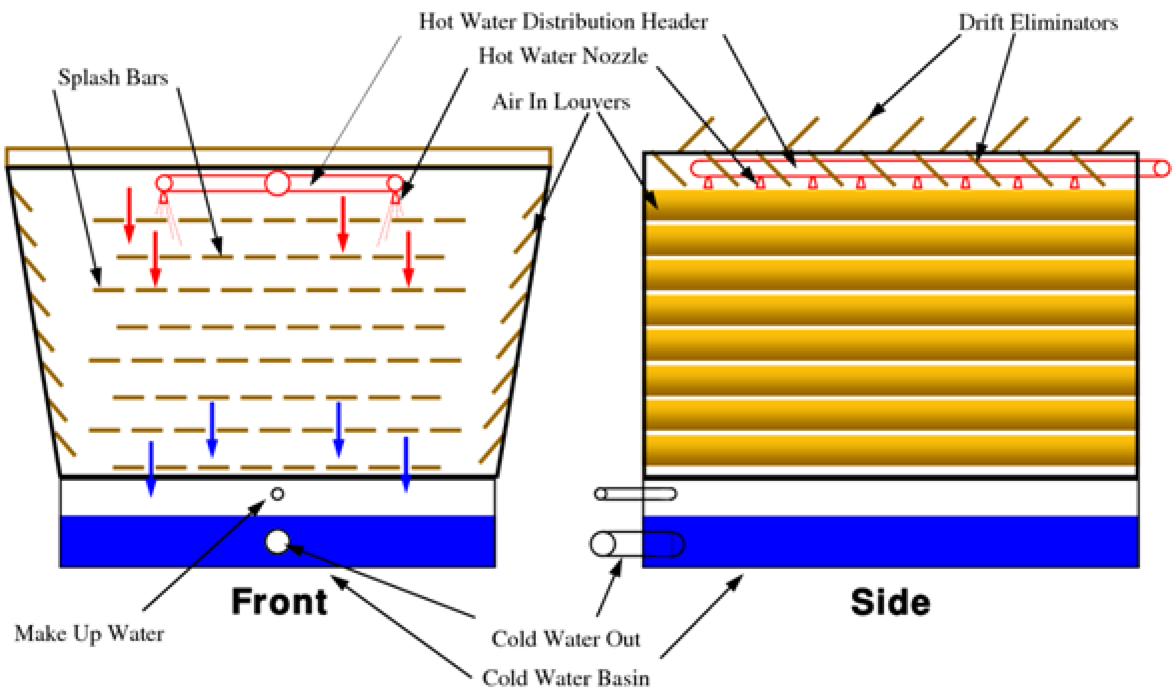


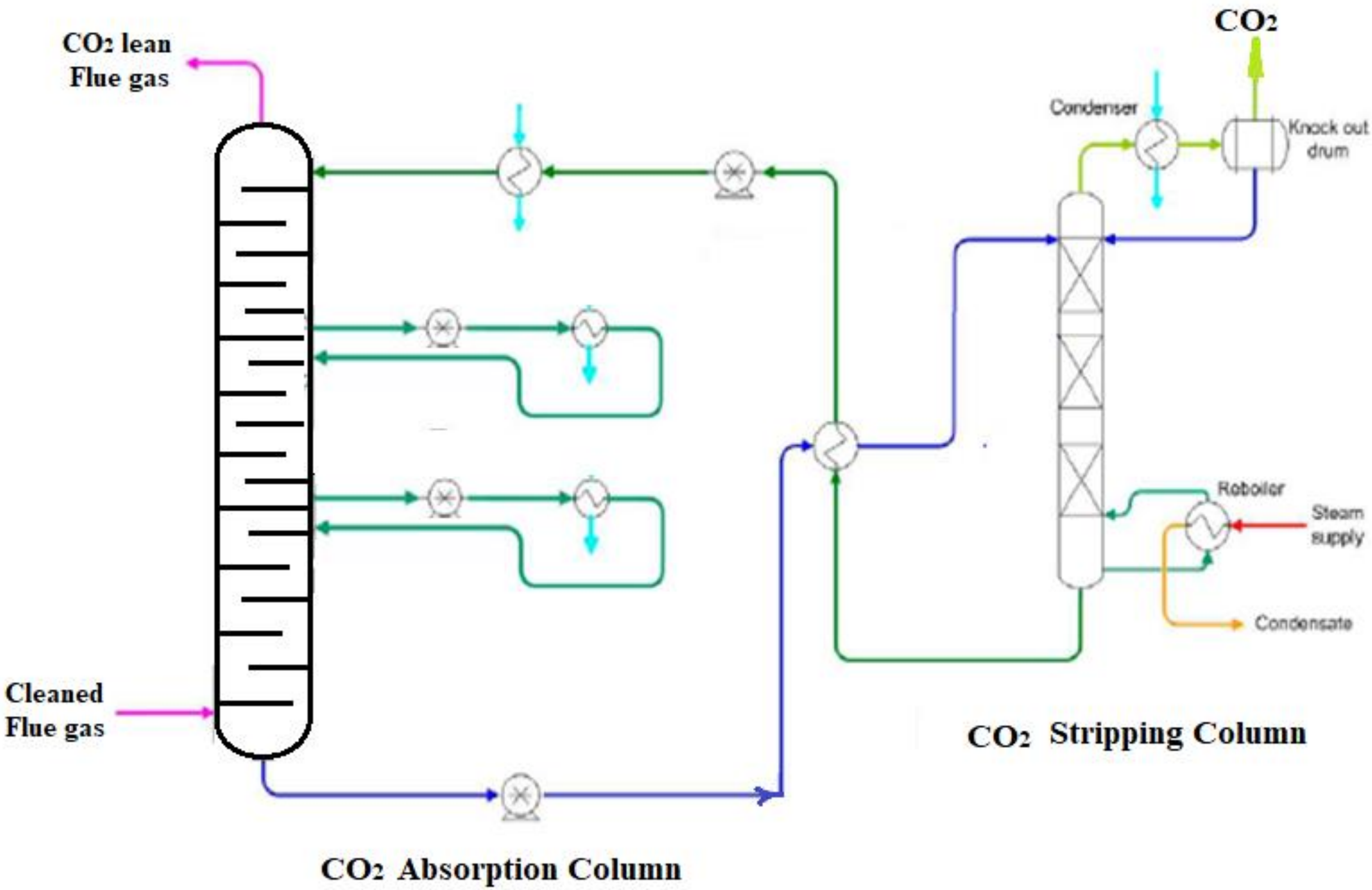
Pressure Drop and Flooding in Random-packed Towers

Tray Towers Vs. Packed Towers

1. Gas Pressure Drop: Packed towers require smaller pressure drop.
2. Liquid hold-up: Packed towers provide substantially smaller liquid hold up.
3. Liquid/Gas ratio: Very low values of L/G ratio are best handled in tray Towers; high values in packed towers.
4. Liquid cooling: Tray towers are suitable.
5. Side streams: More readily removed from tray towers.
6. Foaming systems: Packed towers are more suitable.
7. Corrosion: Packed towers are more suitable.
8. Cleaning : Frequent cleaning is easier with tray towers.

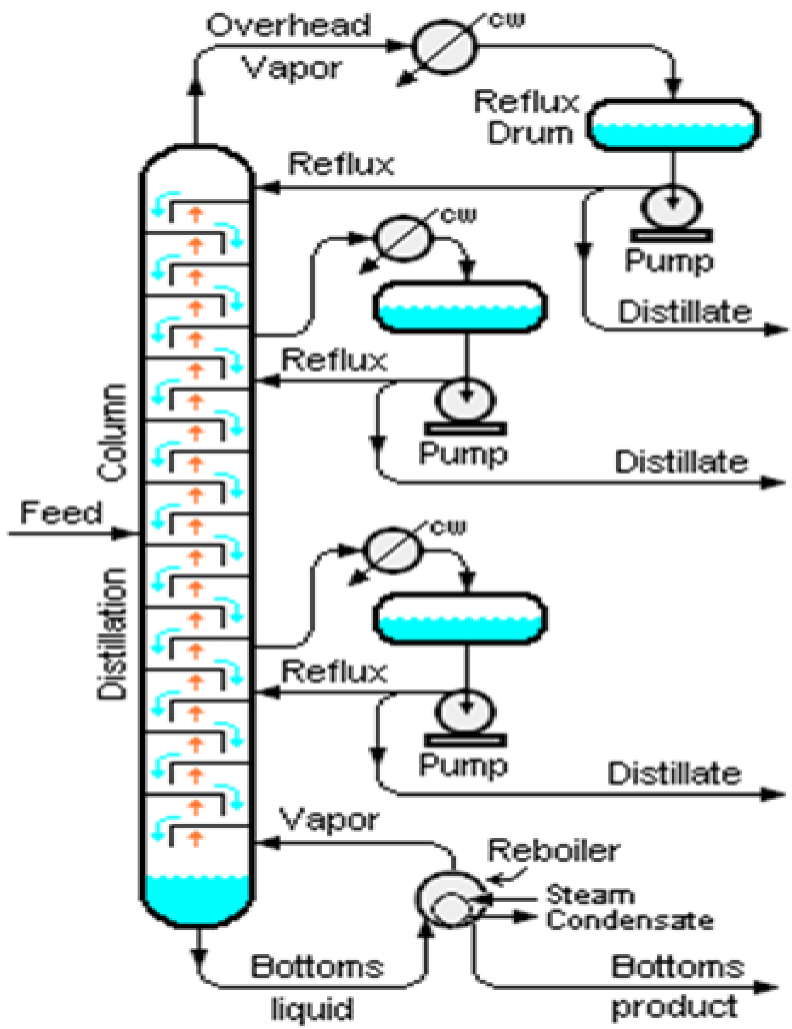
Atmospheric Crossflow Cooling Tower





Tray Tower with inter-tray Liquid Cooling

https://www.youtube.com/watch?v=6Zqe-rHf2v0



Tray Tower with Side Draw

https://www.youtube.com/watch?v=gYnGgre83CI

Thank you