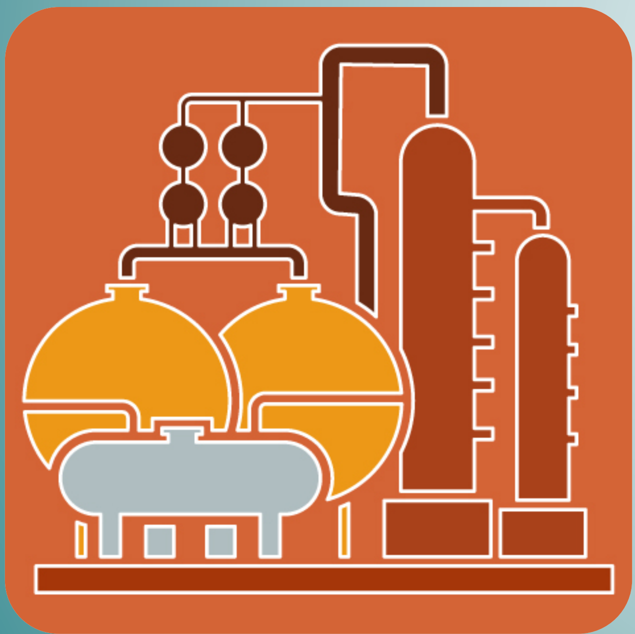
Chemical Process Design / Diseño de Procesos Químicos

Topic 5.4. Distillation and absorption



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Shortcut for Distillation Column Sizing

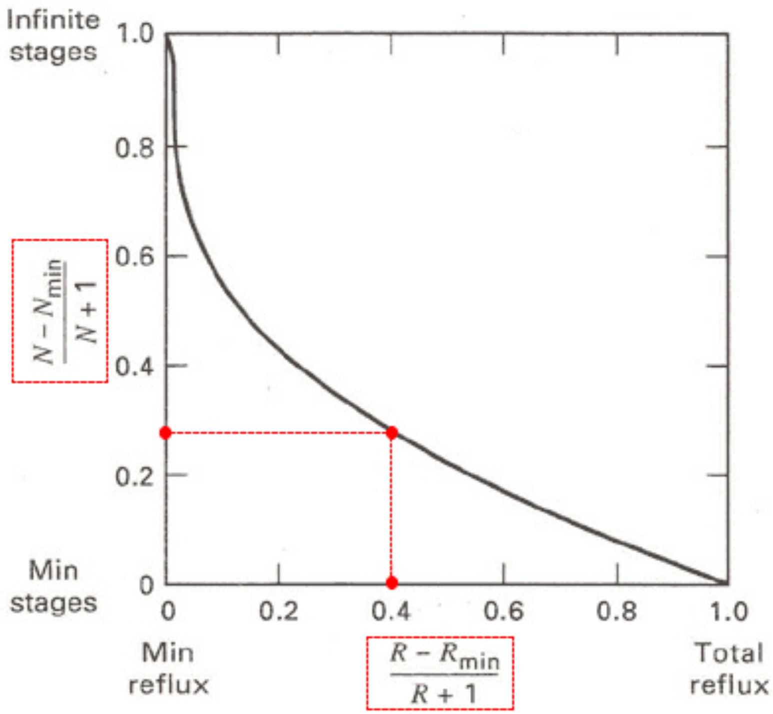
Fenske's equation applies to any two components **"lk or light key"** and **"hk or heavy key"** at infinite reflux and is defined by $\mathbf{N_{min}}$, where α_{ij} is the geometric mean of the α's at the **T** of the feed (**F**), distillate (**D**) and the bottoms (**B**).

$$N_{\min} = \frac{\log\left(\dfrac{x_{Dlk}/x_{Blk}}{x_{Dhk}/x_{Bhk}}\right)}{\log(\overline{\alpha}_{lk/hk})} \qquad \overline{\alpha}_{lk/hk} = \left(\alpha_{D\,lk/hk}\alpha_{F\,lk/hk}\alpha_{B\,lk/hk}\right)^{1/3}$$

$\boldsymbol{R_{min}}$ is given by **Underwood** with two equations that must be solved, where **q** is the liquid fraction in the feed.

$$1 - q = \sum \frac{\alpha_i \, x_{Fi}}{\alpha_i - \phi} \qquad R_{min} + 1 = \sum \frac{\alpha_i \, x_{Di}}{\alpha_i - \phi}$$

Gilliland used an empirical correlation to calculate the final number of stage **N** from the values calculated through the Fenske and Underwood equations ($\mathbf{N_{min}}$, **R**, $\mathbf{R_{min}}$). The procedure uses a diagram; one enters with the abscissa value known, and reads the ordinate of the corresponding point on the Gilliland curve. The only unknown design variable of the ordinate is the number of stage **N**.



Shortcut for Distillation Column Sizing

Simple and direct correlation for (nearly) ideal systems (Westerberg, 1978)

* Determine $\alpha_{lk/hk}$; $\beta_{lk} = \xi_{lk}$; $\beta_{hk} = 1 - \xi_{hk}$

* Calculate tray number Ni and reflux ratio Ri from correlations (i = lk, hk):

Ni = $12.3 / [(\alpha_{lk/hk} - 1)^{2/3} \cdot (1 - \beta_i)^{1/6}]$ **Ri** = $1.38 / [(\alpha_{lk/hk} - 1)^{0.9} \cdot (1 - \beta_i)^{0.1}]$

Nlk, Nhk

Rlk, Rhk

- Theoretical n° of trays $\mathbf{N_T}$ = {0.8 max[Ni] + 0.2 min[Ni]}; **R** = {0.8 max[Ri] + 0.2 min[Ri]}
- Actual n° of trays **N** = N_T / 0.8
- For **H** consider 0.6 m spacing (H = 0.6 N); Maximum H = 60 m → else, 2 columns (*).

* Calculate column diameter, **D**, using internal flowrates (*) and taking into account the vapor fraction of **F**. Internal flowrates used for sizing condenser, reboiler.

Design column at 80% of linear flooding velocity (velocity of the vapor rising through the column at which the liquid on each stage is suspended. The flow of vapor up through the column does not allow the liquid to fall down through the column causing the stages to "flood". The column flooding conditions set the upper limit of vapor velocity for steady operation).

$$U_f = C_{sb}\left[\frac{\rho_L - \rho_G}{\rho_G}\right]^{0.5}\left(\frac{20}{\sigma}\right)^{0.2}$$

Fair's Correlation:

ρ_g, ρ_l: density in kg/m^3

C_{sb}: capacity parameter, m/s

σ: liquid surface tension, in dynes/cm

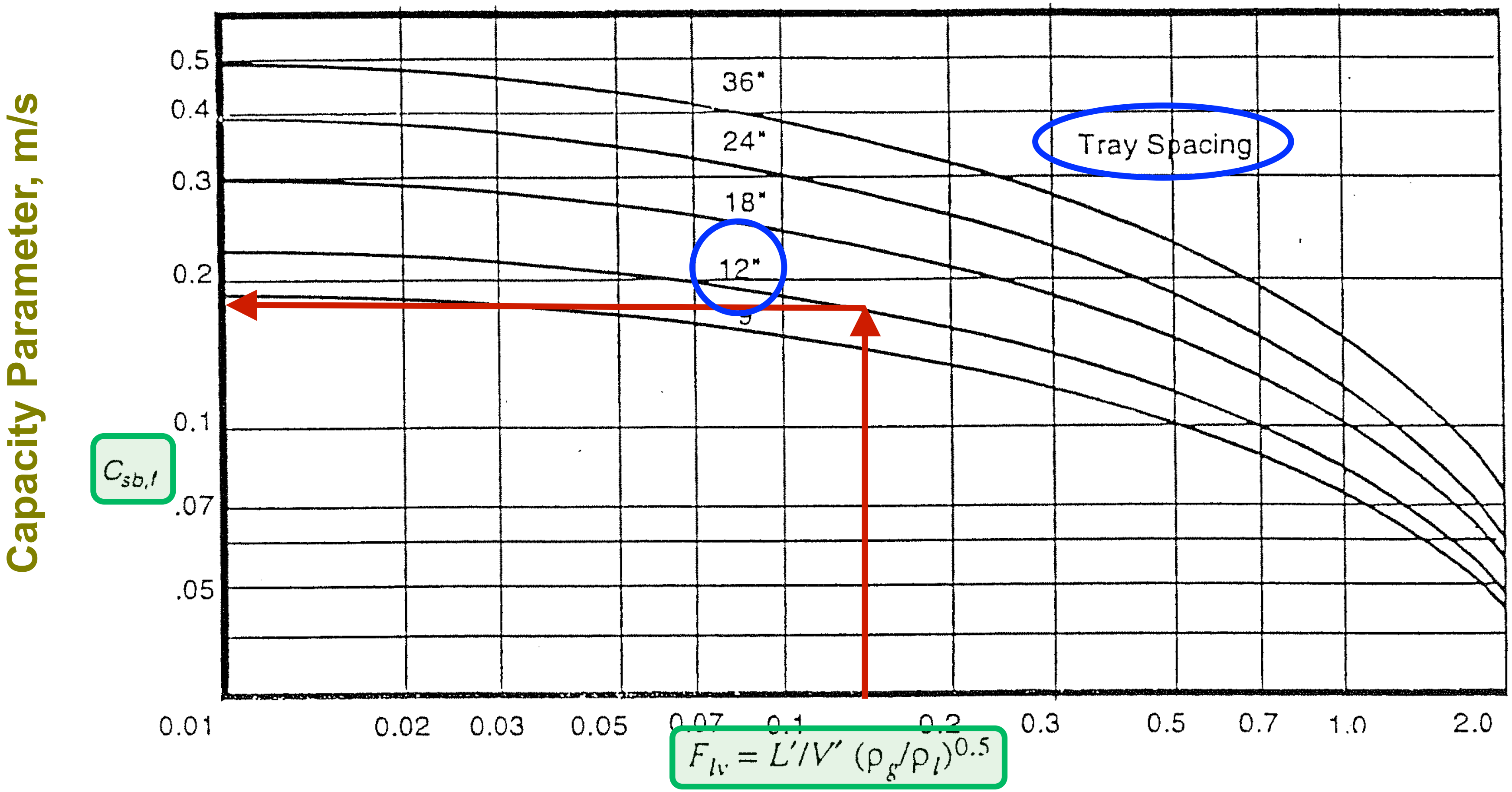


FIGURE 4.4 Flooding limits for bubble cap and perforated trays. L'/V' is the liquid/gas mass ratio at the point of consideration. (Data taken from Fair, 1961.)

L´, V´: mass ratio in Kg/s

ρ_g, ρ_l: density in kg/m^3

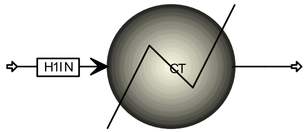
Shortcut for Distillation Column Sizing

From the Continuity equation:

$$A = \frac{\pi D^2}{4} = \left[\frac{\overline{V}}{0.8\, U_f\, \varepsilon\, \rho_G} \right]$$

If D > 3m → Parallel columns.

- Calculate heat duties for reboiler and condenser.



$$Q_{cond} = H_V - H_L = \sum_{k=1}^{n} \left(\mu_D^k + \mu_L^k \right) \Delta H_{vap}^k = \frac{V}{D} \sum_{k=1}^{n} \mu_{dk} \Delta H_{vap}^k \qquad Q_{reb} = V\, \Delta H_{vap}^k$$

- Costing vessel and stack trays (24” spacing).

Distillation Columns

Guthrie MPF for Tray Stacks

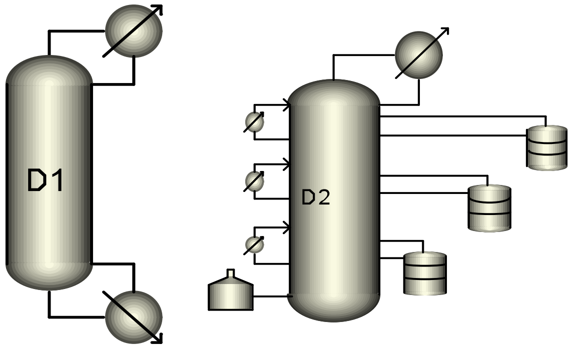
MPF: $F_m + F_s + F_t$

Tray Type,	**F_t**
Grid	0.0
Plate	0.0
Sieve	0.0
Valve o trough	0.4
Bubble Cap	1.8
Koch Kascade	3.9

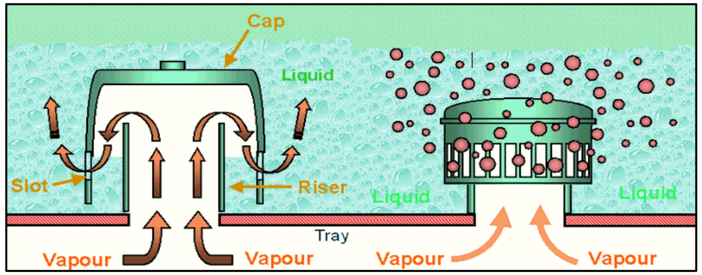
Tray Spacing, F_s

(inch)	24”	18”	12”
Fs	1.0	1.4	2.2

Tray Material,	**F_m**
Carbon Steel	0.0
Stainless Steel	1.7
Monel	8.9



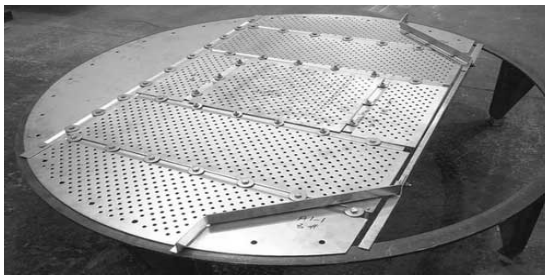
Distillation in Aspen software.



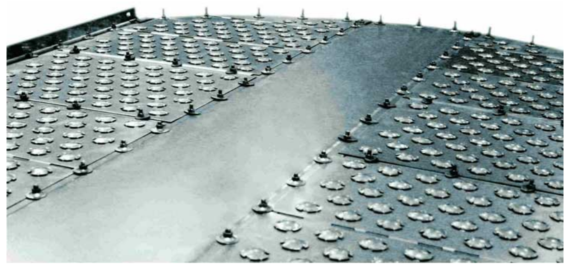
http://www.wermac.org

Bubble Cap Tray:
http://www.wermac.org/

Perforated Tray:
https://www.sulzer.com/



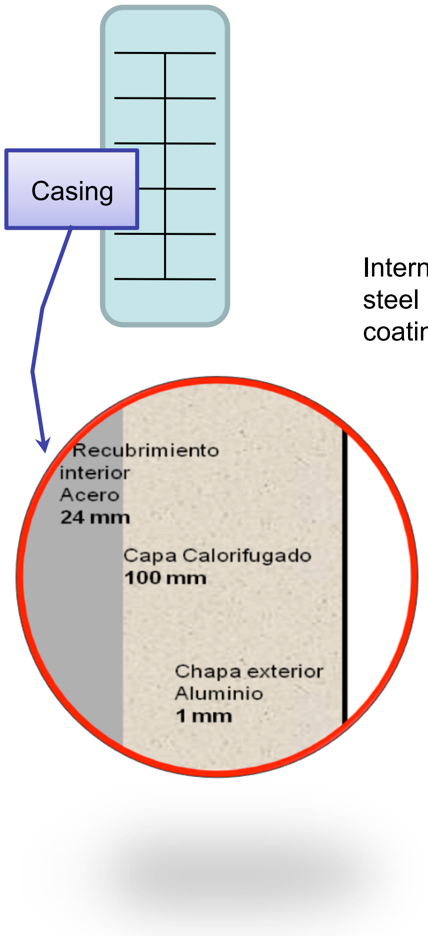
Sieve Tray:
http://www.wermac.org/



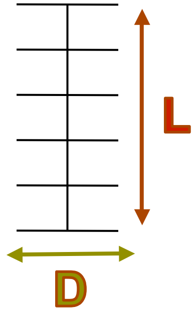
Valve Tray:
http://www.wermac.org/

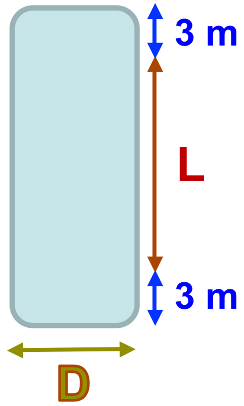
Distillation Columns

Column Cost = Cost of Tray Stack + Cost of pressure vessel (Vertical fabrication)



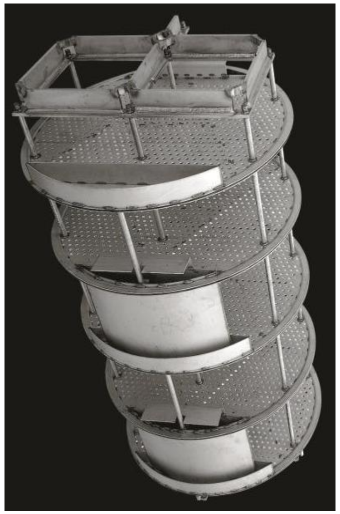
Internal steel coating





Disengaging space.

Enough to serve as a liquid reservoir (5 min).



Tray Stack.
Sulzer Chemtech Ltd., Switzerland.

A vacuum distilation column in a petroleum refinery.
U.K. Association for Scool Science.

$$BMC_{Column} = [UF(BC)\ (MPF + MF - 1)]_{Tray\ Stack} + [UF(BC)\ (MPF + MF - 1)]_{Vessel}$$

Distillation Columns

Equipment Type	C_0 (\$)	L_0(ft)	D_0(ft)	α	β	MF2 / MF4 / MF6 / MF8 / MF10
Vertical fabrication 1 → D → 10 ft; 4 → L → 100 ft	1000	4.0	3.0	0.81	1.05	4.23 / 4.12 / 4.07 / 4.06 / 4.02
Horizontal fabrication 1 → D → 10 ft; 4 → L → 100 ft	690	4.0	3.0	0.78	0.98	3.18 / 3.06 / 3.01 / 2.99 / 2.96
Tray stacks 2 → D → 10 ft; 1 → L → 500 ft	180	10.0	2.0	0.97	1.45	1.0 / 1.0 / 1.0 / 1.0 / 1.0

S ≡ L from equilibrium steps; D from internal mass balance.

$$C = BC = C_0\,(L / L_0)^{\alpha}\,(D / D_0)^{\beta}$$

MF (Module Factor):

- MF 2: If C < 200.000 \$
- MF 4: If C = 200.000 - 400.000 \$
- MF 6: If C = 400.000 - 600.000 \$
- MF 8: If C = 600.000 - 800.000 \$
- MF 10: If C = 800.000 - 1.000.000 \$

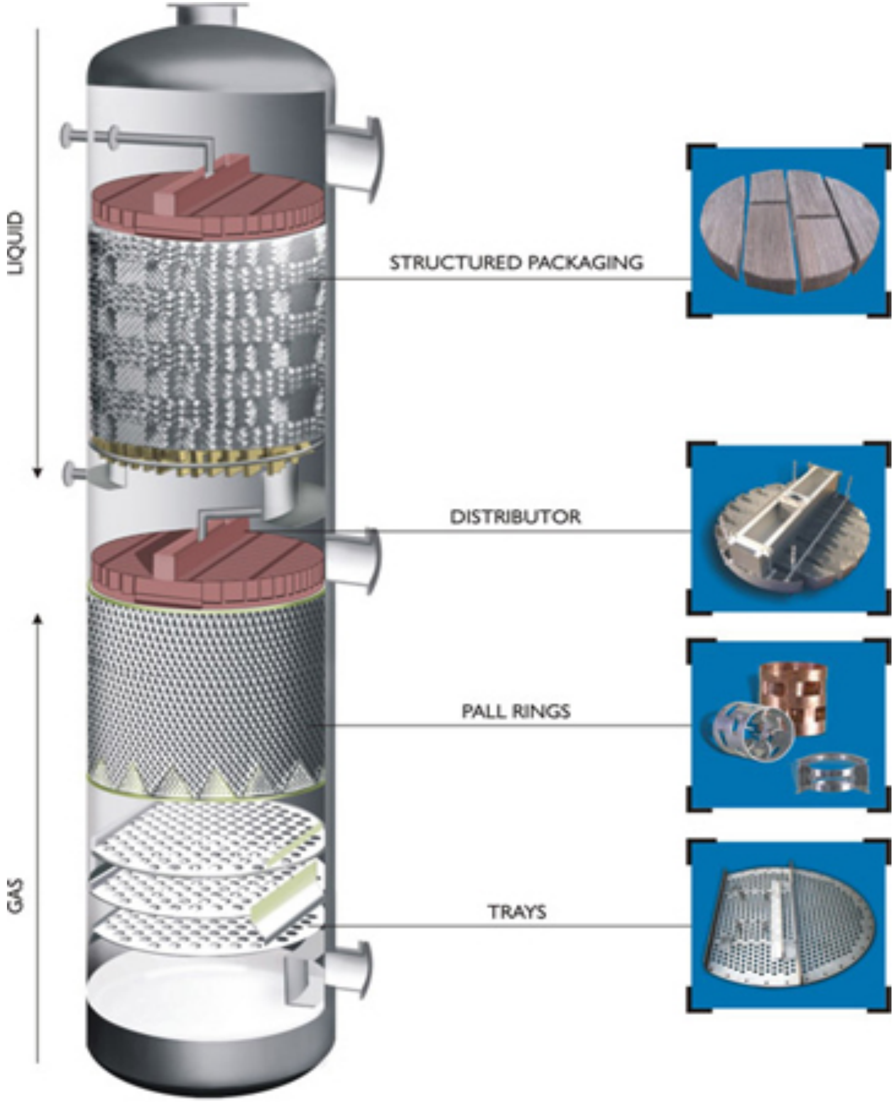
Materials and Pressure correction Factor (Vessels): $MPF = F_m \cdot F_p$

Materials and Pressure correction Factor (Tray Stack): $MPF = F_m + F_s + F_t$

Update Factor UF = Present Cost Index (CI_{actual}) / Base Cost Index (CI_{base})

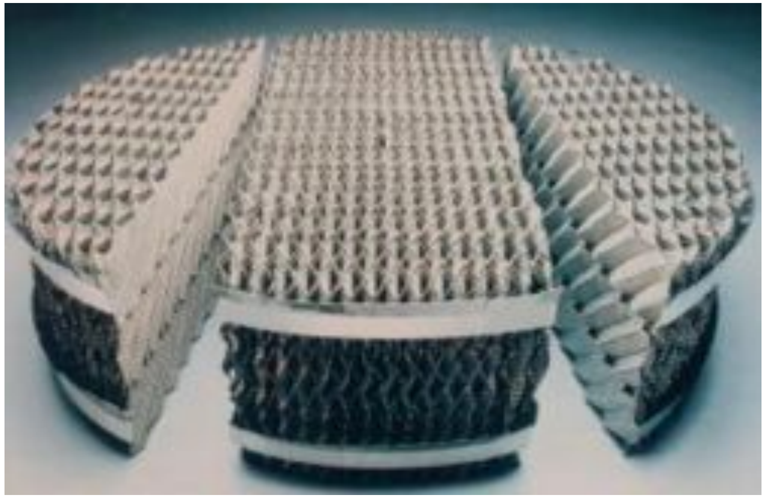
Updated bare (simple) module cost: $BMC = UF(BC)\,(MPF + MF - 1)$

Tray and Packet Bed Distillation Column



https://thermalkinetics.net/distillation-equipment.

Structured packing [CC BY-SA 3.0](CC BY-SA 3.0).



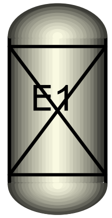
http://en.citizendium.org/wiki/Packed_bed.

Distillation Column

Packed bed distillation column used the in petrochemical industry.

A 40 tray column used for mineral oils.

Shortcut for Absorber Column Sizing



Sizing similar to the distillation columns.

N_T → Kremser equation.

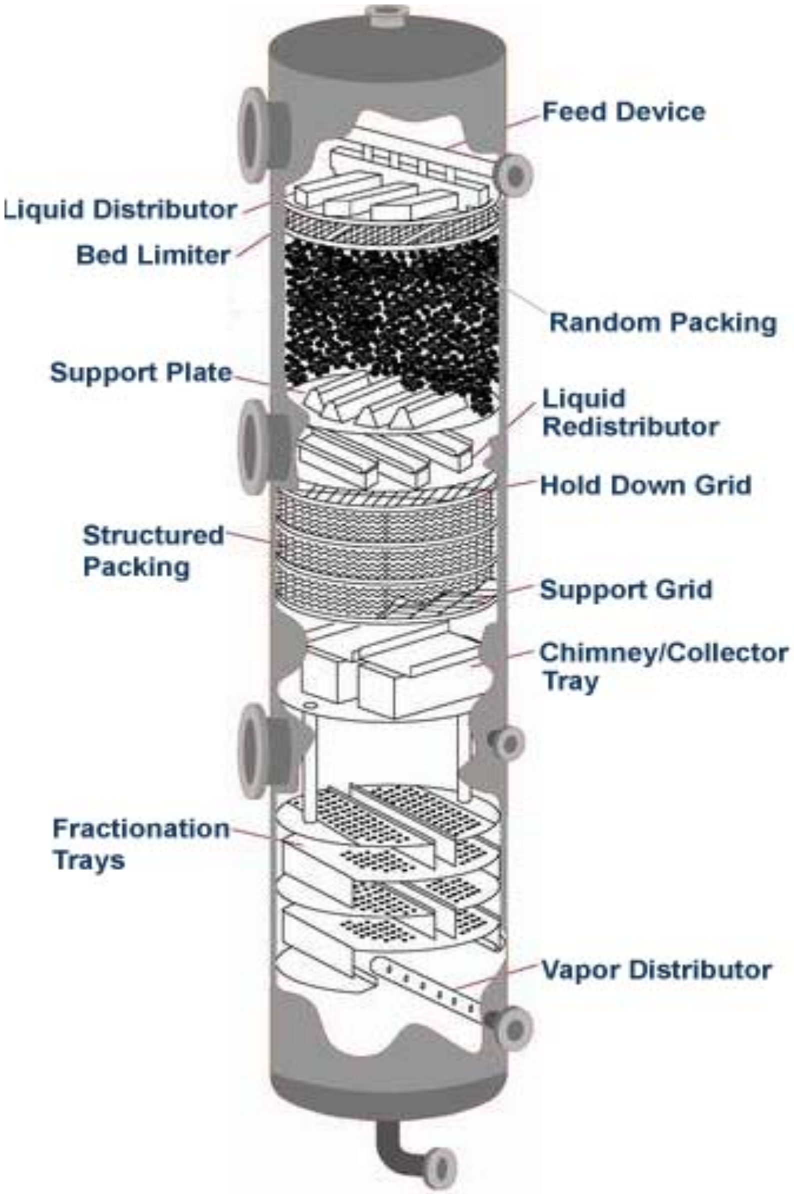
$$N = \ln\left[\frac{l_0^n + (r^n - A_E^n)\, v_{N+1}^n}{l_0^n - A_E^n(1 - r^n) v_{N+1}^n}\right] / \ln(A_E^n)$$

- Assumption: v – l equilibrium → but actually there is mass transfer phenomena (e.g. simulation of CO_2 – MEA absorption) → 20% efficiency in n° trays → **$N = N_T / 0.2$**
- Calculate **H** and **D** for costing vessel and stack trays (24” spacing).
  - **Natural Gas Dehydration video:** https://www.youtube.com/watch?v=ULu3DTmIkV0.

Ammonia stripping in wastewater treatment plant of manure (purines) and additional acid absorption.

http://www.tecnium.es/es/desgasado-tecnium-degas/stripping-tecnium-degas.

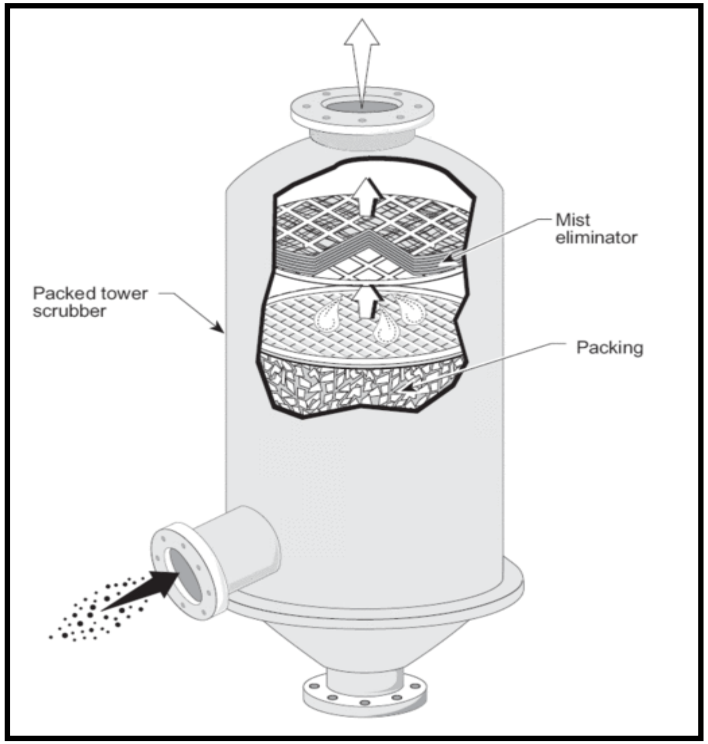
Absorption Column



http://www.industriaquimica.net/.

Absorption column with different types of contact devices:

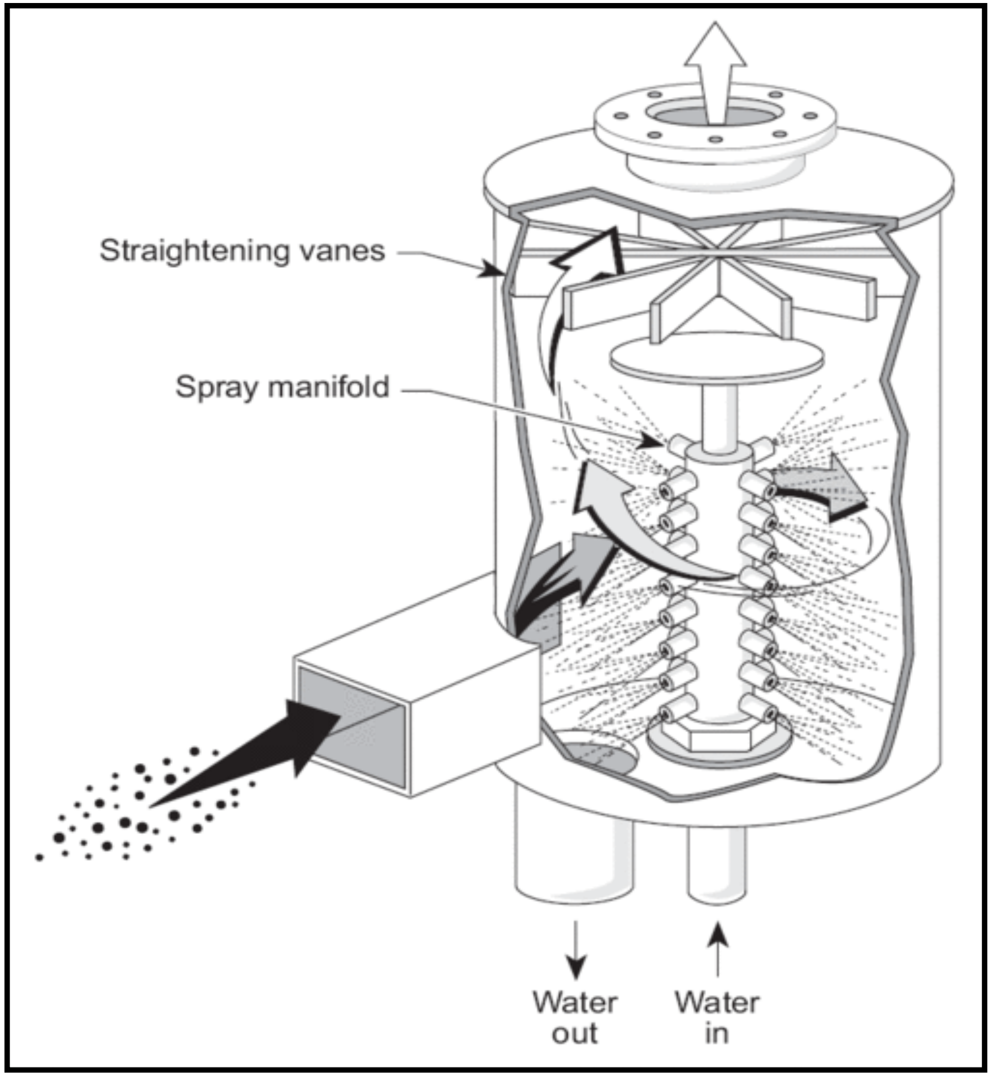
- Random packing.
- Structured packing.
- Trays.



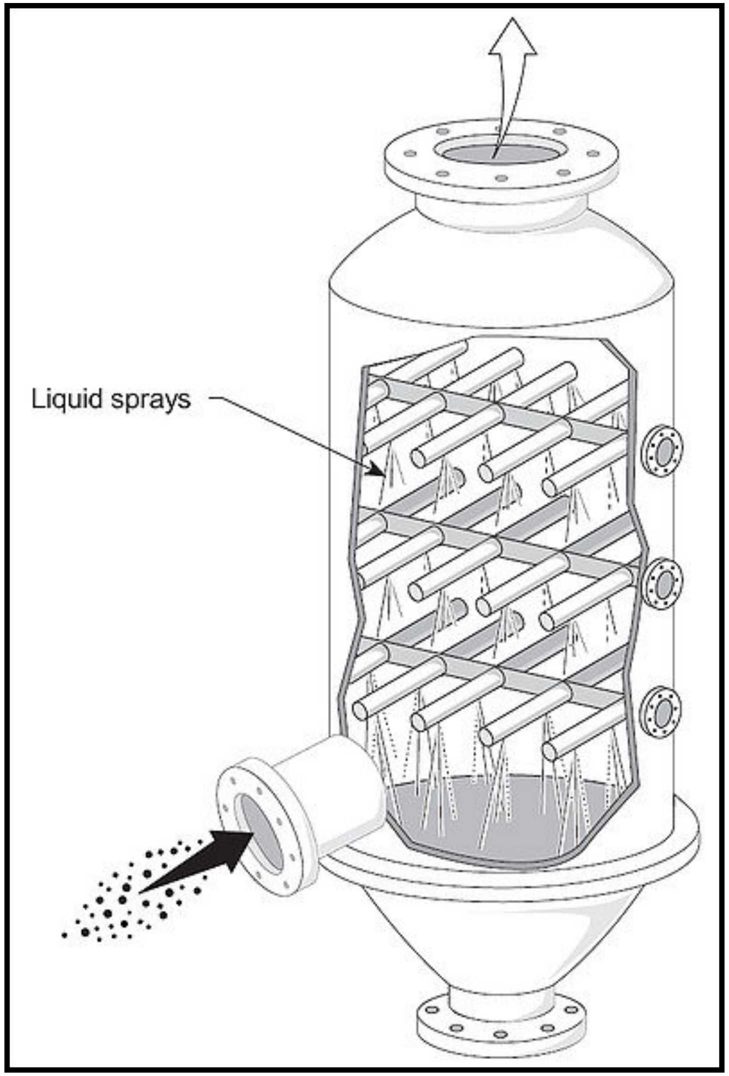
Packed Bed Scrubbers.

http://www.globalspec.com/learnmore/manufacturing_process_equipment/air_quality/scrubbers.

Absorbers

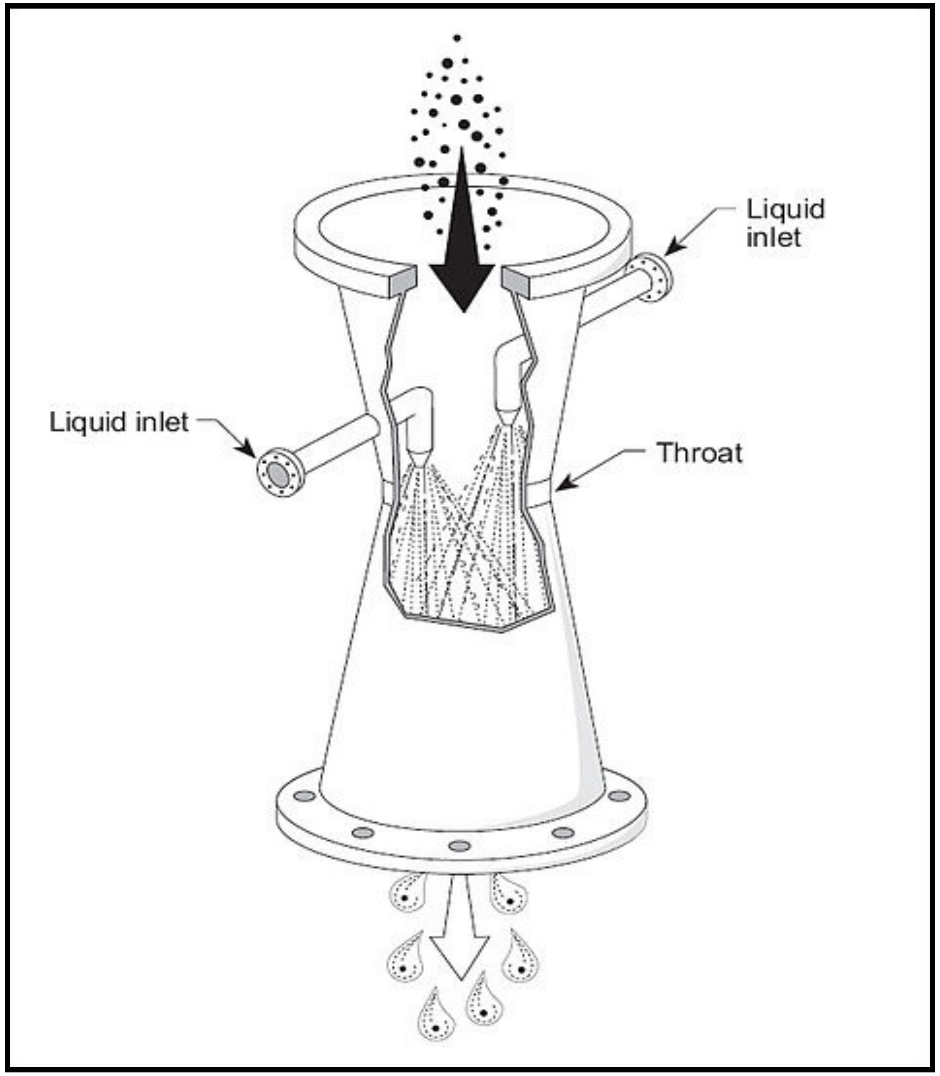


Cyclone Spray Chambers.
US EPA Public Domain.

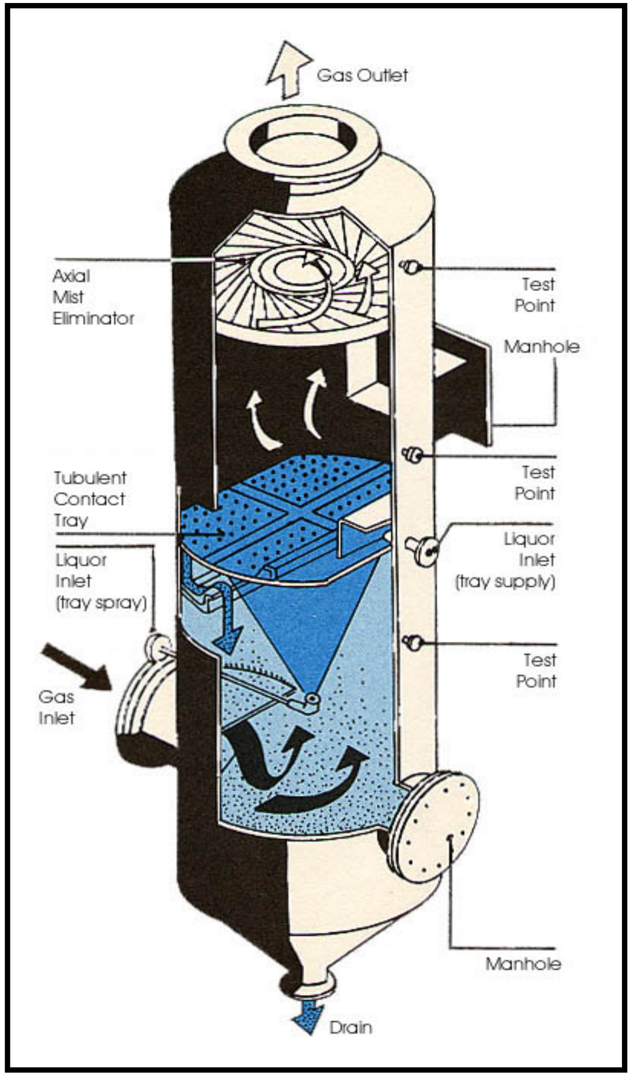


Spray Towers.
US EPA Public Domain.

Absorbers



Venturi Scrubbers.
US EPA Public Domain.



Impingement Scrubbers. Impingement or perforated plate scrubbers.
http://www.globalspec.com/learnmore/manufacturing_process_equipment/air_quality/scrubbers.