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# Kolmetz Handbook Of Process Equipment Design

# Distillation Column Packing Hydraulics Selection, Sizing And Troubleshooting

(ENGINEERING DESIGN GUIDELINES)


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## INTRODUCTION

### Scope

This design guideline covers the basic element of packed hydraulics in sufficient detail to allow an engineer to design a packed column with the suitable size, material and hydraulic characteristic of packed. The selection of type, material, and hydraulic characteristic of packing should be considered on surface area because it is essentially for heat and mass transfer.

The choice of packing and distributor design is crucial to maintain the reliability of a fouling service column. The performance of a packed column is dependent on the maintenance of good liquid and vapor distribution throughout the packed bed and it is important consideration in packed column design. The internal fittings in a packed column are simpler than those in a plate column but must be carefully designed to ensure good performance.

The materials of the available internals are very different and fort the selection the resistance and costs is essential, and it has to be calculated carefully. A good material packed has longer life time and which its affects are temperature, chemical composition, contact time and stress factors to the material.

For good performance of packed also influenced by the hydraulic which take apart in internals. The hydraulic characteristic is influenced by the maximum of liquid-vapor loading. In this section will calculated the flooding, wetting characteristic, number of theoretical unit (NTU), height of transfer unit (HTU), height equivalent of theoretical plate (HETP).

The design of packed hydraulic may be influenced by factors, including process requirements, economics and safety. In this section, there are tables that assist in making these factored calculations from the vary reference sources.

The theories used in this guideline are commonly used in industrial such as GPDC, Leva, Mersman and Deixlar. The application of the packed hydraulic theory with the example will make the engineer easier to study for the packed hydraulic and the ready to perform the actual design of the packed column.

Include in this guideline is an example data sheet which is generally used in industrial and a calculation spreadsheet for the engineering design.

## Type of Packed Column

The packing should have a large open area to reduce fouling potential, but with adequate mass transfer capabilities. Packed column is divided by Random, Structured and Grid Packed Columns which is generate a mass transfer area by providing a large surface area over (50%) which the liquid can transfer heat and mass to the vapor. The specific surface area is a rough indicator of packing efficiency. The higher surface area, the more efficiency packing. Packing factors are indicators of capacity. The lower packing factors, the higher capacity.

1. Random Packed Column

   Random packing is packing of specific geometrical shapes which are dumped into the tower and orient themselves randomly. The capacity, efficiency and pressure drop characteristics vary with packing size and type. Random packing has more risk than structured packing and less ability to handle maldistributed liquid. There some type of random packing.

   a. Raschig rings are the oldest, cheapest types of random packed and still use. The height of the rings is equal to its diameter. Their evolved are Pall rings. Pall rings have openings which have been made by folding strips of the surface into the ring that will increase the free area and improves wetting and the liquid distribution.

   b. Berl saddles which were developed to give improved liquid distribution compared to Raschig rings. They have smaller free gas space than Raschig rings. Their aerodynamic shape is better and giving a loer pressure drop and higher capacity. The evolved of Berl saddles are Intalox saddle which is easier manufacture than Berl saddles. The shape of Intalox give adjacent elements do not blank off thus avoiding stagnant pools of liquid, trapping gas bubbles and violent changes in the direction of the gas that result a higher capacity, efficiency and lower pressure drop.

c. Hypac and Super Intalox are the evolved of Pall rings and Intalox saddles. Super Intalox have smooth scalloped edges and holes that changes promote drainage of liquid, eliminate stagnant pockets and provide more open area for vapor rise. Super Intalox have higher capacity and efficiency than Intalox saddle. Hypac has more tongues in an effort to improve the spread of surface area.

(a)

(b)

(c)

(d) (e) (f)

Figure 1: Type of Random Packing: (a). Rascig rings, (b). Pall rings, (c). Berl saddles, (d) Intalox saddles, (e) Hy-pak, (f). Super Intalox

2. Structured Packed Column

Structure Packed column is crimped layers or corrugated sheets which is stacked in the column. Each layer is oriented at 70° to 90° to the layer below. The surface of corrugated sheets can be grooved, lanced, textured, or smooth, maybe perforated or imperforated. The material is folded and arranged with a regular geometry to give a high surface area with a high void fraction. Structured packed offers 30% capacities higher than random packed for equal efficiency up to 50% higher at the same capacity. Structured packed have low HETP typically less than 0.5 m and low pressure drop (100 Pa/m). The cost of structured packed per cubic meter will be significantly higher than random packed, but this is offset by their higher efficiency.

Structured Packings are supplied by many vendors. One is made of perforated wire mesh sheet which a special contoured pattern and are arranged vertically. Adjacent sections are rotated 90°. One is a corrugated structured, has grooved and perforated surfaces. The crimp angle is 45° and the crimp apex is sharp. The develop of second generation of structured packing which is designed to avoid premature flooding in any region of packing. They are available in metal, plastic and stone ware.

Structured packed used in the following:

- Difficult separations which requiring many stages such as isomers separation
- High vacuum distillation
- In the column revamps structured is use to increase capacity and reduce reflux ratio requirements.
- Used in absorption, in application where high efficiency and pressure drop are needed.

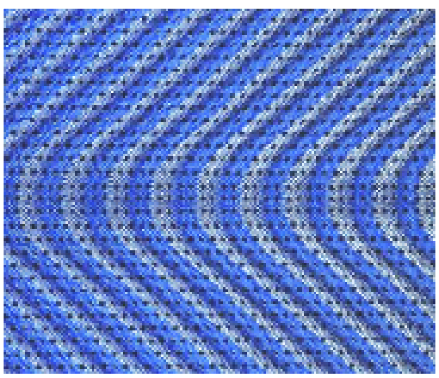

Figure 2 : Structured Packing

3. Grid Packed Column

Grid packed column is systematically arranged packing use an open-lattice structure. This device is composed of panels that contain vertical, sloped, and horizontal surfaces that promote mass transfer and enhance entrainment removal. They have high open area, resulting in high capacity, low pressure drop, and high tolerance to fouling and plugging. The amount of surface area per unit volume is much less than that of a random packing and thus the grid's efficiency is only about 1/2 that of 2 in (50 mm) Pall rings. Grid surfaces are designed to be self draining, avoiding areas where sediment may trap or hot liquid may polymerize.

The low pressure drop keeps liquid holdup at a minimum, which reduces the residence time in the heated zone. The high open area and rugged construction give grids a strong resistance to pressure surges. Due to their layered structure, grid are easy to install remove, inspect, and maintain. The efficiencies are considerably lower than random and structured packed. Grids are primarily used in direct-contact heat transfer, scrubbing, heavy hydrocarbon and deentraining services.

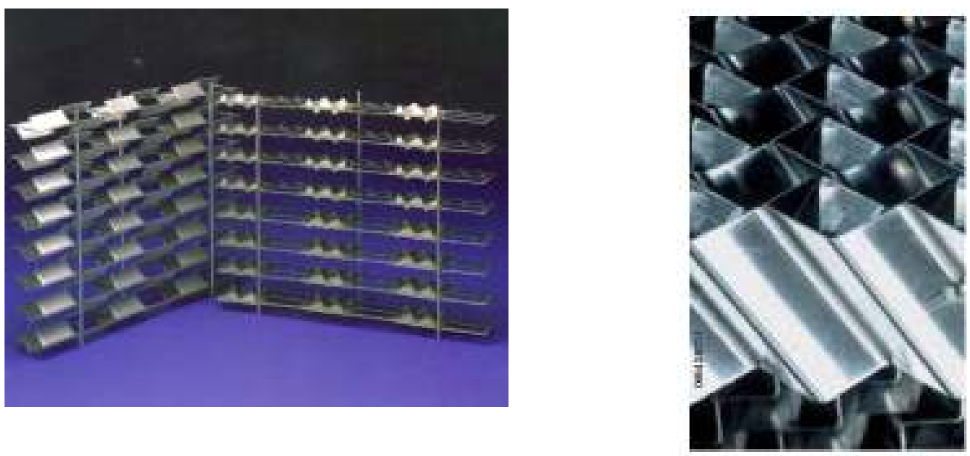

Figure 3: Grid Packed

Various vendors have developed many types of grids. Fouling can reduced heat transfer in the column, increased pressure drop, reduced capacity, and reduced run time. For high fouling service like in ethylene plant.

## General Design Consideration

A packed hydraulic design is normally divided into two main steps, a process design followed by a mechanical design. The purpose of the process design is to calculate the flooding, wetting characteristic, number of theoretical unit (NTU), height of transfer unit (HTU), height equivalent of theoretical plate (HETP). On the other hand, the mechanical design focuses on the packed design.

In designing packed there are many factor have to be considered for the suitability of the hydraulic such as the safety, environmental requirements, packed performance, economics of the design and other parameters, which may constrain the work.

Packed column may be used for many vapor liquid contacting operations. A process engineer can use the following guideline in making preliminary selection on whether use packed column for particular application. The rules of thumb for selecting packing are:

1) the compounds are temperature sensitive
2) pressure drop is important (vacuum service)
3) liquid loads are low
4) towers are small in diameter
5) highly corrosive service (use plastic or carbon)
6) the system is foaming
7) the ratio of tower diameter to random packing is greater than 10

The design of a packed column will involve the following steps:

1. Select the type and size of packing.
2. Determine the column height required for the specified separation.
3. Determine the column diameter (capacity) to handle the liquid and vapor flow rates.
4. Select and design the column internal features: packing support, liquid distributor, redistributors.
5. Check for pressure drop, liquid holdup, and flooding

The internals should have high separation efficiency at lowest pressure drop as it possible. Efficiency and pressure drop increase with decreasing diameter of internals but the operation area is reduced. The selection criteria of internals as follow:

1. Chemical, mechanical and thermal resistance.
2. Long lifetime behavior
3. Large hydraulic capacity, low pressure drop, wet ability
4. Ability for balancing of irregular phase distribution
5. Mass transfer behavior
6. Low costs

To optimization of the packing work, there’s some factor should be considerate.

1. maximizing theoretical stages per height of section or column,
2. minimizing pressure drop per theoretical stage of separation, and
3. maximizing the operating range of the column that results in reasonable performance often requires the column to operate at the extremes of the stable operating range. Therefore, an understanding of the phenomena that control each of the three regions: poor wetting, stable operation, and heavy entrainment

**Packed hydraulic operation**

Packed column performs well at low pressure, low liquid and vapor loading that make packed column have the most efficient in these terms. At high flow parameters the capacity and efficiency can significantly reduce, also in heavy fouling applications and corrosive condition. Packed will enhance whatever mal-distribution is developed by the vapor-liquid feed. Packed column has less pressure drop than tray column and it reduce foaming since generates thin films instead of fine droplets for mass and heat transfer.

Packed tower operated under vapor-liquid counter current conditions and becoming increasingly important in environmental protection technologies. Among these, packing has received the greatest attention owing to their good performance. That why the knowledge of the hydraulic characteristic are essential for design of packing tower to get the best optimizing performance of packing for maximizing theoretical stages per height of column, minimizing pressure drop per theoretical stage of separation, and maximizing the operating range of the column.

The operation area of packing is limited by the maximum loading which depend on the characteristic of phase, the type and geometry of the internal. Figure 4 shows the operating area of packed column.

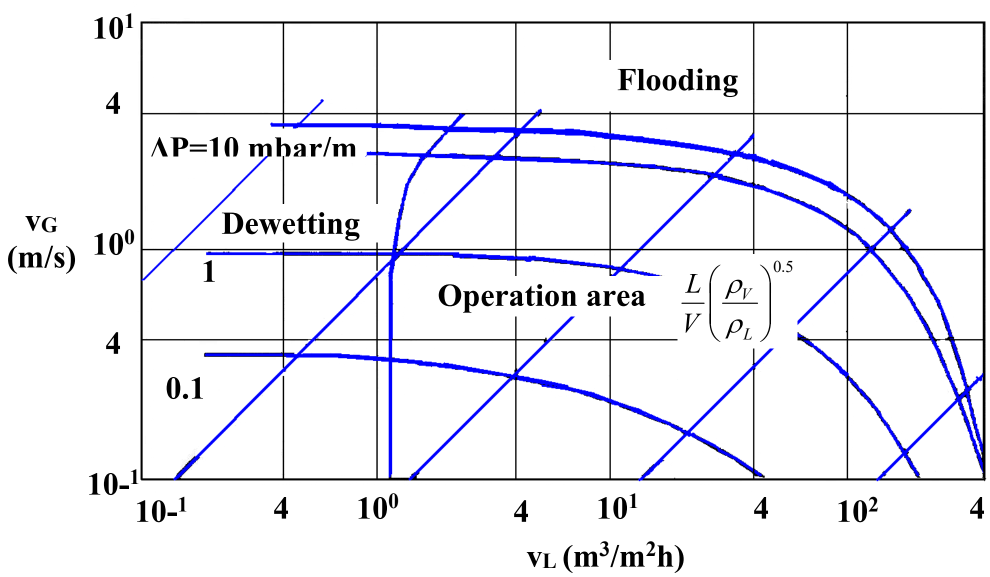


Figure 4; operating area of packed column

The upper limit is called flooding point and the lower limit dewetting point. Reaching the loading point, the down flowing liquid phases holdback by the up flowing gas phase result a higher liquid in the bulk and increase the gas pressure drop then gives the flooding point. It makes the liquid can not flow downwards. While in the other side the vapor passes as single phase without contact to the liquid on the column. A strong segregation of the phases and a rapid increase of the pressure drop. Furthermore increase the loading and decrease of the efficiency

The area between loading point and flooding point is the operation area. The vapor can not pass the column without contact with liquid. Where the vapor is dispersed, some liquid is hold back. Because of high turbulence of both phases result a good mass transfer and high separation efficiency.

The lower limit is the minimum liquid flow or limit of wetting of the internals. With decreasing wetting of the internal, the mass transfer is reduced and separation efficiency of the column decreases. The lower limit is influenced by physical properties of the mixture to be separated as well as from material and geometry of the internals.

The tower diameter should be chosen to minimize total investment while insuring operation under satisfactory hydraulic conditions. To control packed operating area limitations is used hydraulic mechanism. The study on hydraulic on packing included the pressure drop over the dry and wetted (irrigated) packing as well as dynamic (free draining) liquid hold up.

1. The pressure drop is entirely by frictional losses through a series of opening and therefore is proportional to the square of the gas flow rate. In random packing, the opening are randomly sized and located, and pressure drop is due to expansion, contraction, and changes of direction. In structured packing, the openings are regular and uniform size and pressure drop is due to changes in direction.

   If a packed with gas flow is wetted on the surface of the internal liquid films are produced. The downflowing liquid reduced the relative voids volume, the free are for passing vapor is reduced and the vapor pressure drop is increases. Increasing wetting density will increase the liquid below loading zone which independent from vapor velocity.

2. The liquid holdup is the fraction of liquid held up in packed column. The volume of liquid holdup volume is often needed for calculating packed bed support beam loadings as well as for determining how much liquid drains to the bottom of a tower when the vapor rate is stopped.

3. At lower liquid rates, irrigation to the bed is poor result poor efficiency. When liquid is well distributed in the column result the minimum wetting rate of the packing. Below minimum wetting the falling liquid film breaks up, some of the packing surface unwets, and the efficiency drops. When liquid distributor is poor, it will take more liquid to wet the entire packing bed.

4. When vapor rate increases, column operation moves into the loading region. Efficiency improves because of the greater liquid holdup, but this improvement is short-lived. As the flood point is approached, the efficiency passes through the maximum and the drops because of excessive entrainment. When vapor rate decreases, it will decrease pressure drop per theoretical stage, but will increase column diameter.

The packed tower design concepts are listed below:

1. Packed towers almost always have lower pressure drop compared to tray towers.

2. Packing is often retrofitted into existing tray towers to increase capacity or separation.

3. Packed diameter is less 1/8$^{th}$ column diameter. Use too large size in a small column can cause poor liquid distribution. Design packed size recommended as follows

Table 1: Packed size in different column diameter

| Column Diameter<br>m (ft) | Packed size<br>mm (in) |
|---|---|
| < 0.3 (1) | < 25 (1) |
| 0.3 to 0.9 (1 to 3) | 25 to 38 (1 to 1.5) |
| > 0.9 (3) | 50 to 75 (2 to 3) |

4. The thickness of random packed is recommended 0.012 to 0.028 in (0.3 to 0.7 mm) and for structured packed is 0.006 to 0.008 in (0.15 to 0.20 mm) to reduce costs.

5. The ratio of design vapor load to the ultimate capacity vapor load must be kept below 85%.

6. For gas flow rates of 500 $ft^3$/min (14.2 $m^3$/min), use 1 in (2.5 cm) packing, for gas flows of 2000 $ft^3$/min (56.6 $m^3$/min) or more, use 2 in (5 cm) packing.

7. A wide trough distributor or an orifice pan may required If liquid rate is above 30 gpm/$ft^2$ (20 $dm^3/s/m^2$) but it is not recommended if liquid rate is less than 10 gpm/$ft^2$ (6.7 $dm^3/s/m^2$).

8. Ratio of tower diameter to packing diameter should usually be at least 15

9. Due to the possibility of deformation, plastic packing should be limited to an unsupported depth of 10-15 ft (3-4 m) while metal packing can withstand 20-25 ft (6-7.6 m).

10. Liquid distributor should be placed every 5-10 tower diameters (along the length) for pall rings and every 20 ft (6.5 m) for other types of random packing.

11. For redistribution, there should be 8-12 streams per sq. foot of tower area for towers larger than three feet in diameter. They should be even more numerous in smaller towers.

12. Packed columns should operate near 70% flooding.

13. Height Equivalent to Theoretical Stage (HETS) for vapor-liquid contacting is 1.3-1.8 ft (0.4-0.56 m) for 1 in pall rings and 2.5-3.0 ft (0.76-0.90 m) for 2 in pall rings.

14. In Grid packed, for vacuum pipestill wash zones, the minimum allowable nozzle size is 3/4 in. (18 mm) with pressure drop between 3 and 20 psia.

15. Grid tier is rotated 45$^o$ horizontally to insure good vapor and liquid distribution.

16. Random packed should be installed across the entire cross section of the tower to ensure a uniform density through out the bed.

17. Pressure drop less than 1.2 in water/ft height of packed. Design pressure drops should be as follows:

Table 2: Pressure drop in difference services

| Service | Pressure drop (in water/ft packing) |
|---|---|
| **Absorbers and Regenerators**<br>Non-Foaming Systems<br>Moderate Foaming Systems | 0.25 - 0.40<br>0.15 - 0.25 |
| **Fume Scrubbers**<br>Water Absorbent<br>Chemical Absorbent | 0.40 - 0.60<br>0.25 - 0.40 |
| **Atmospheric or Pressure Distillation** | 0.40 - 0.80 |
| **Vacuum Distillation** | 0.15 - 0.40 |
| **Maximum for Any System** | 1.0 |

**Internals Packing**

The internals packed should be choice carefully to ensure the desired efficiency and capacity. Support packed and internal distributor of liquid and vapor must be carefully designed for good performance. Bellow is discussed each internals packed.

1. Packing support or bed limiter is used to carry the weight of the wet packing while allowing free passage of the gas and liquid. Gas inlets are provided above the level where the liquid flows from the bed. Although support packed can not improve capacity but it is to provide sufficient open area so that it do not reduce tower capacity. Supported bed limiters should be attached to relatively small wall clips instead of full-circumference support rings and it rest on 360$^o$ circumferential support rings . Keep the width of minor support beams to 2 in (50 mm) or less.

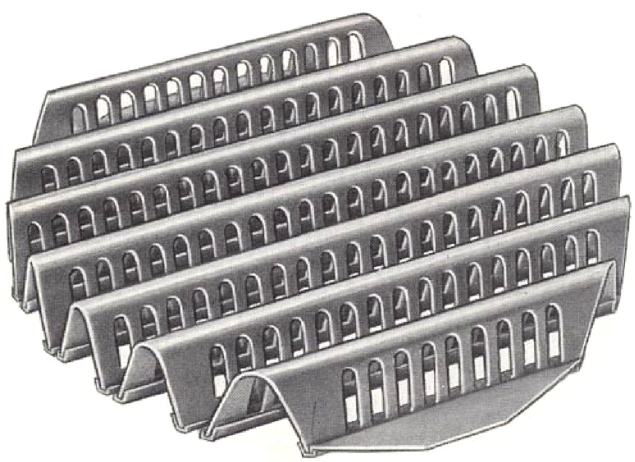

Figure 5: Type of Support Packed

To restrict packed bed movement in service, a suitably designed grid or screen should be fitted to the top of each packed bed. The levelling beams of the liquid distributor can be designed to prevent the movement of structured packing. Beds of random packing require separate structure consisting of a suitably sized wire screen attached to grid or frame. This must be secured to the vessel wall immediately above the packed bed to ensure that the top of the packing remains level.

2. Liquid distributor is used to maintaining a uniform flow of liquid throughout the column. The distributors should be designed to allow distribution of the fouling service liquid without accumulating fouling material. For small diameter columns, a central open feed pipe or one fitted with a spray nozzle may well be adequate. The liquid distributor type which use depends on column size, packed type, liquid rate the amount of fractionation and system fouling tendency. The liquid distributor should optimizing design parameters such as drip point density and distribution, distributor orifice size and elevation, and liquid level.

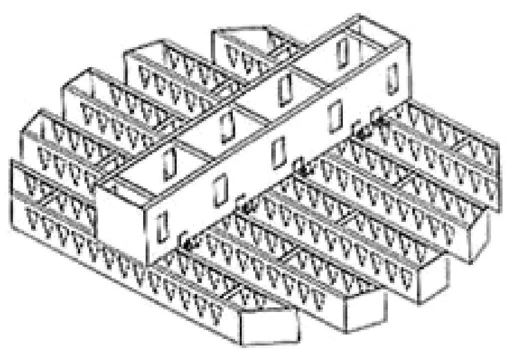

Figure 6: liquid distributor

In high vapor rate systems, liquid distributors fitted with drip tubes to guide the liquid onto the surface of the packing should be specified to avoid entrainment and vapor induced maldistribution. In addition to the gravity distributor range. Good quality liquid distribution is provided over a maximum turndown range of 2:1 through holes punched on the pan floor on with the standard giving 150 points/m2 on an 80mm square pitch.

3. Liquid redistributors
   Redistributors are used to collect liquid that has migrated to the column walls and redistribute it evenly over the packing and also out any mal-distribution. Redistributors reduce the free column area result the hydraulic loading and the pressure drop increases further flooding point might be reached. A liquid redistributors should be used between adjacent beds. For Raschig rings redistribution should provided at each 2.5 to 3 column diameters, for Intalox and Berl Saddles 5 to 8 column diameters, and for Pall rings should be 5 to 10 column diameters.

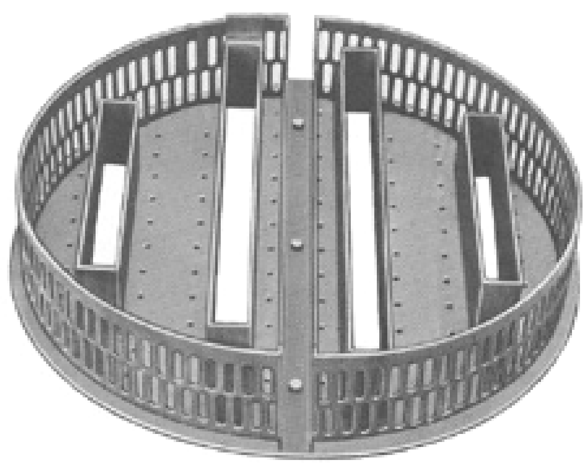

Figure 7: Liquid redistributors

4. Hold down plate
   Hold down plates are used where flow conditions and the packing characters might be such that the packing would move about with possible injurious effects like at high vapor rate or surging occurs through misoperation so the top layers of packing can be fluidized. This condition can make ceramic packed break up, metal and plastic packed can be blown out of the column. The openings in hold down plates

should small enough to retain the packed but should not restrict the vapor and liquid flow.

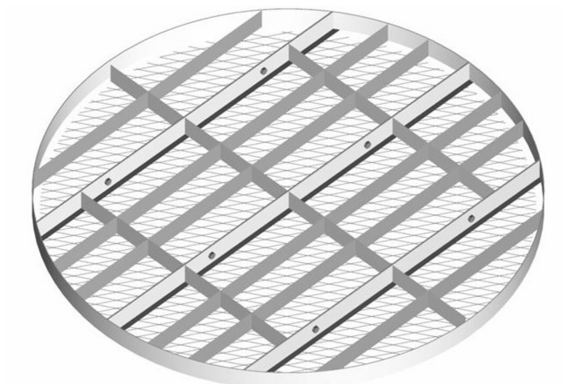

Figure 8: Hold Down Plates

**Material of Packing**

The material for packed should be selected carefully based on chemical composition, thermal, contact time and stress factor. The materials which have long time life become plus value, but it makes higher costs. The materials which commonly use are metal, ceramic and plastic. Below is discussed each materials.

1. Metal
   Stainless steel and other alloy beside carbon steel are usually required because of their corrosion resistance. They have the highest capacity and efficiency, wider range geometries, higher turndown, and unbreakable compared with other material.

2. Ceramic
   Ceramic materials are good in chemical resistance against organic and inorganic except hot caustic and hydrofluoric acid. They have 10 years or more life time if the tower runs properly and thermal resistance up to 1800$^O$ C. Ceramic may breakage, plugging and require packed replacement if there's vapor surges or

severe temperature changes. After startup with new packed some attritions may occur and producing fine ceramic particles.

3. Plastic
   Polypropylene is standard use for plastic material and has limited temperature less than 125$^{O}$ C but not for condensed hydrocarbons. They have good corrosion resistance, high capacity, high efficiency, lower density, high viscosity and low coefficient of elasticity. The disadvantage for plastic material are low thermal stability and aging, poor wettability.

For all those materials discusses, it can be concluded that ceramic packing will be the first choice for corrosive liquids, but ceramics are unsuitable for use with strong alkalis. Plastic packing are attacked by some organic solvents and can only be used up to moderate temperatures, so are unsuitable for distillation columns. Where the column operation is likely to be unstable, metal rings should be specified, as ceramic packing is easily broken.

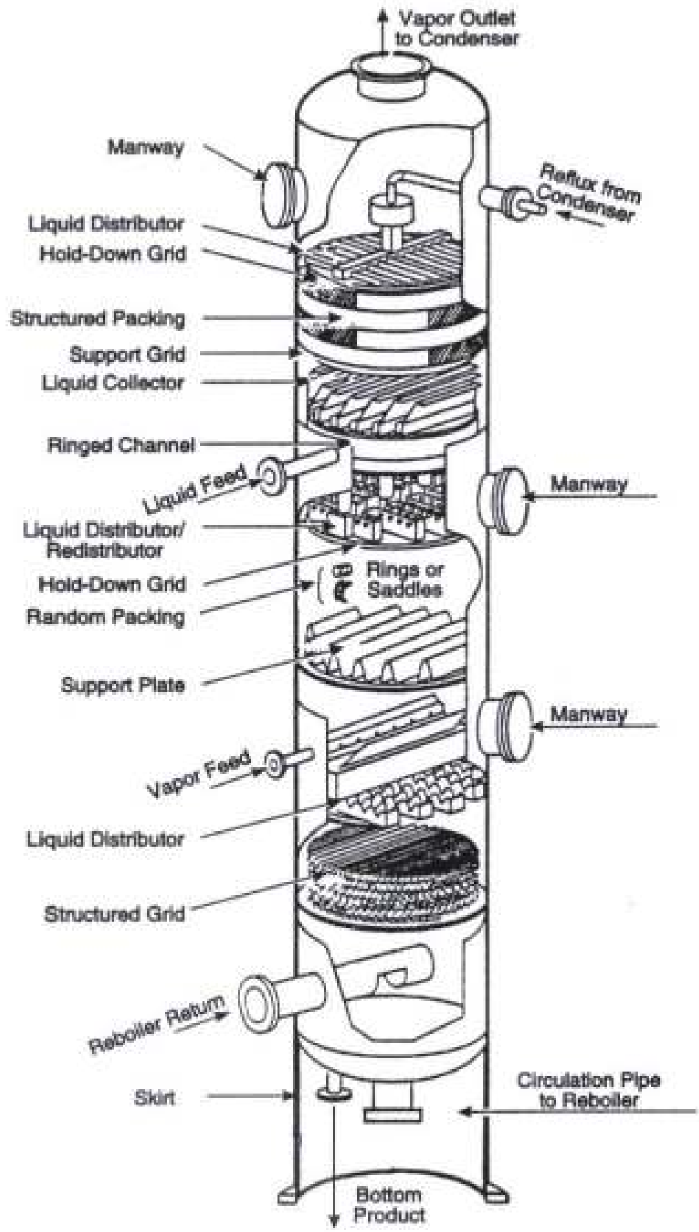


Figure 9 : Internal Column of Packing

## DEFINITIONS

**Dewetting point** - The lower limit in operating range of packed column, fixed by the minimum liquid flow.

**Flooding point** – The upper limit in operating range of packed column. Increases of loading gives the flooding point

**Grid packing -** Systematically arranged packing use an open-lattice structure.

**Height equivalent to a theoretical plate (HETP)** - the height of packing that will give the same separation as an equilibrium stage.

**Height of transfer unit (HTU)** – The height of packing that gives composition changed equal with one transfer unit.

**Hold down plates** - Equipment in packing column is used where flow conditions and the packing characters might be such that the packing would move about with possible injurious effects

**Liquid distributor** – Equipment in packing column to maintaining a uniform flow of liquid throughout the column.

**Liquid holdup** - The fraction of liquid held up in packed column.

**Liquid redistributors** - Equipment in packing column to collect liquid that has migrated to the column walls and redistribute it evenly over the packing and also out any mal-distribution

**Mal-distribution** – Fault distribution of vapor liquid in packing column. Maldistribution can affect in efficiency column.

**Mass transfer** - The relative motion of species in a mixture due to concentration gradients.

**Number of transfer unit (NTU)** – The level of difficulty separation.

**Operating area** - The range of vapor and liquid rates over which the packing will operate satisfactorily (the stable operating range).

**Packing factor** – An empirical factor in packing. Each type of packing have different packing factor.

**Packing support or bed limiter** - Equipment in packing column to carry the weight of the wet packing while allowing free passage of the gas and liquid.

**Pressure drop** - A function of vapor and liquid rates as well as the packing shape and size.

**Random packing** - Packing of specific geometrical shapes which are dumped into the tower and orient themselves randomly

**Structure Packing** - Crimped layers or corrugated sheets which is stacked in the column.

**Turndown** - The ratio of the highest to the lowest flow rates

## NOMENCLATURES

| | |
|---|---|
| A | The effective mass transfer area, $m^2$ |
| $A_s$ | Cross sectional area, $ft^2$ |
| $a_p$ | specific surface area, $ft^2/ft^3$ |
| $\Delta C_A$ | The driving force concentration difference, $mol/m^3$ |
| $D_G$ | Vapor molecular diffusity , $cm^2/s$ |
| $f_p$ | HETP prorating factor, dimensionless |
| $F_p$ | Packing factor based on table, $ft^{-1}$ |
| $G_m$ | Molar gas flow rate, mol/s |
| $H_D$ | Transfer height due to vapor phase axial mixing, in |
| $H_G$ | Mass transfer of vapor, in |
| $H_L$ | A mass transfer unit of liquid, in |
| $h_L$ | Liquid holdup |
| Kc | The mass transfer coefficient, $mol/m^3$ or m/s |
| $L_m$ | Molar liquid flow rate, mol/s |
| $L_S$ | Liquid velocity based on cross section area, ft/s |
| m | The slope of the operating line |
| $n_A$ | The mass transfer rate, mol/s |
| $V_s$ | Vapor velocity based on tower cross-sectional area, ft/s |
| $\Delta P$ | Pressure drop, Pa |
| $\Delta P_{flood}$ | Pressure drop at flood, in $H_2O$/ ft packing |
| $Q_L$ | Liquid rate, gpm |
| $q_L$ | Liquid rate, $ft^3/s$ |
| $q_v$ | Vapor rate, $ft^3/s$ |
| $Sc_v$ | Schmidt number of vapor, dimensionless |
| v | Kinematics viscosity, centistokes |
| x | Mole fraction of light key in liquid phase |
| y | Mole fraction of light key in vapor phase |
| Z | Column height, ft |

## Greek Letters

| | |
|---|---|
| μ | Viscosity, cP |
| ρ | Density, $lb/ft^3$ |

## Superscript

| | |
|---|---|
| HETP | Height equivalent of a theoretical plate, in |
| HTU | Height of transfer unit, in |
| L | liquid phase |
| NTU | Number of transfer unit |
| V | vapor phase |