Packed towers

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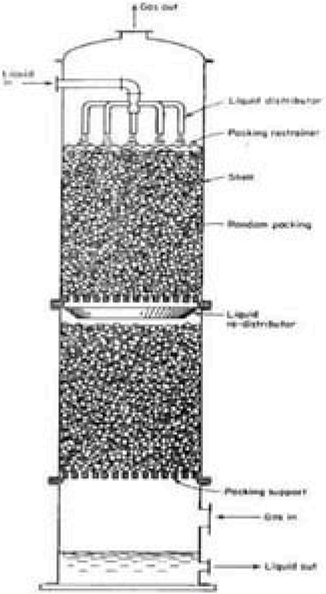
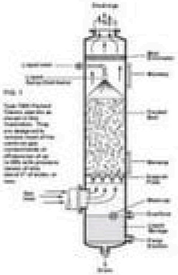
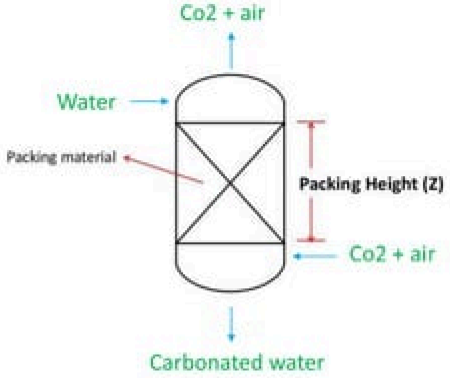
Packed towers-introduction

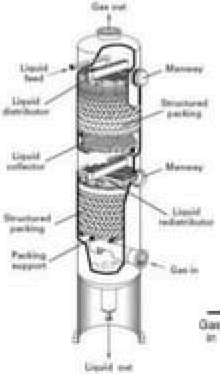
- ✓A common apparatus used in gas absorption, distillation and liq-liq extraction.
- ✓It consists of cylindrical column (tower) equipped with gas inlet and distributing space at the bottom, a liquid inlet and distributor at the top, gas and liquid outlets at top and bottom, and a supported mass of inert solid shapes called tower packing .
- ✓Absorption can be
- ✓A “physical” absorption → process occurs due to solubility and vapour-pressure relationships or,
- ✓A chemical absorption → chemical reactions between absorbed substance and the absorbing medium
- ✓packing increase the area of contact between gas and liquid this results in increased mass transfer between phases

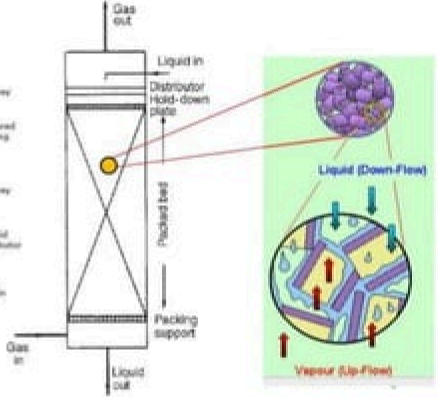

Gas out
Liquid in
Liquid distributor
Packing restrainer
Shell
Random packing
Liquid re-distributor
Packing support
Gas in
Liquid out



REPRESENTATION OF PACKED COLUMN







Design and construction

- The packing support is typically a screen, corrugated to give it strength , with a large open area so that flooding does not occur at the support.

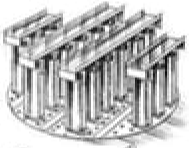
The liquid inlet

- The inlet liquid , which maybe pure solvent or a dilute solution of solute in the solvent and which is called "WEAK LIQUOR" is distributed over the top of the packing by the distributor and, in ideal operation , uniformly wets the surfaces of the packing.

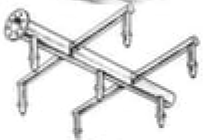
The distributor

- The distributor is a set of perforated pipes.
- In large towers spray nozzles or distributor plates with overflow weirs are more common.

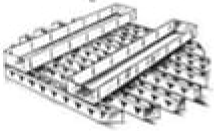
Liquid distributers



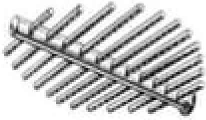
Orifice type



Spray type



Trough type



Pipe type

Notched Chimney Type

The gas inlet

- The solute containing gas or rich gas enters the distributing space below the packing and flows upward through the interstices in the packing counter current to the flow of liquid .

The packing

- The packing provides a large area of contact between the liquid and gas and encourages initimate contact between the phases.

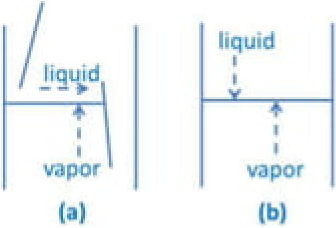
- The solute in the rich gas is absorbed by the fresh liquid entering the tower, and dilute , or lean, gas leaves the top.
- The liquid is enriched in solute as it flows down the tower , and a concentrated liquid , called "STRONG LIQUOR" leaves the bottom of the tower through liquid outlet.

Flow through packed tower

Two types of flow in a column

a. cross flow

b. counter flow



Packed towers are used for continuous Countercurrent contacting of gas and liquid absorption.

Types of tower packings

1. Those that are dumped at random into the tower.
2. Those that are known as structured or ordered packings.

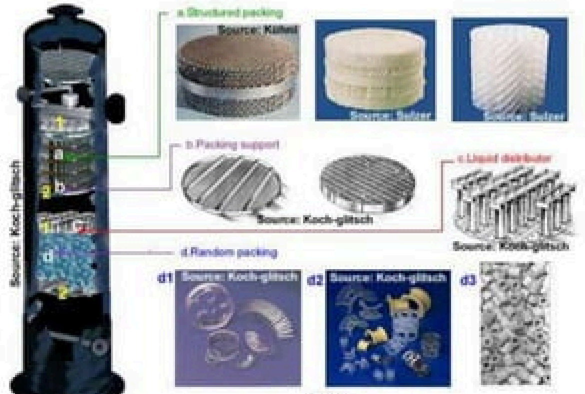
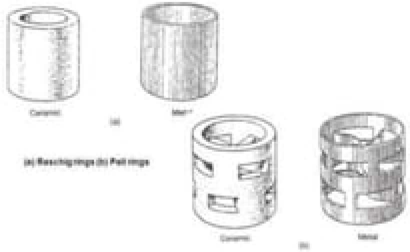


Fig.1

Packing Materials

1. **Ceramic:** superior wettability, corrosion resistance at elevated temperature, bad strength
2. **Metal:** superior strength & good wettability
3. **Plastic:** inexpensive, good strength but may have poor wettability at low liquid rate



DUMPED PACKING or RANDOM PACKING :

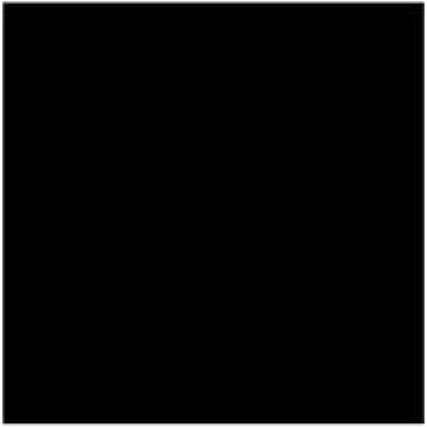
- Dumped packing consists of units 6 to 75mm (1/4 to 3 in) in major dimension.
- Packings smaller than 25mm are used mainly in laboratory or pilot plant columns.
- Dumped tower packings are made of cheap , inert materials such as clay, porcelain , or various plastics .
- Thin walled metal rings of steel or aluminium are sometimes used .
- High void spaces and large passages for the fluids are acheived by making the packing units irregular or hollow , so that they interlock into open structures with the porosity or void fraction of 60 to 90 percent.

- Ceramic berl saddles and raschig rings are older types of packing that are not much used now , although they were big improvement over ceramic spheres or crushed stone when first introduced.
- Intalox saddles are somewhat like berl saddles , but the shapes prevents pieces from nesting closely together , and increases the bed porosity.
- Super intalox saddles are a slight variation with scalloped edges ; they are available in plastic or ceramic form .
- Pall rings are made from thin metal with the portions of the wall bent inward od from plastic with slots in the wall and stiffening ribs inside .
- Hy-pak metal packing and flexirings are similar in shape and performance to metal pall rings.
- Beds of pall rings have over 90 percent void fraction and lower pressure drop than most other packings of the same nominal size.

- In stacked packing the units are 50 to 200mm (2 to 8in) in size.
- They are much less commonly used than dumped packings .

STRUCTURED PACKINGS or ORDERED PACKING:

- Structured packings with ordered geometry evolved from the stedman packing of the late 1930s but they found few industrial uses until the sulzer packing was developed in about 1965.
- Early structured packings were fabricated from wire gauze most current ones are made of sheets perforated corrugated metal,with adjacent sheets arranged so that liquid spreads over their surfaces while vapour flows through channels formed by the corrugated.
- The channels set an angle of 45degree



Types of packing

(a) Raschig rings

(b) Pall rings

(c) Berl saddle ceramic

(d) Intalox saddle ceramic

(e) Metal Hypac

(f) Ceramic, super Intalox

(g) cross partition rings

Raschig Ring

Pall Ring

Ralu Ring

Hiflow

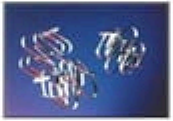
Hypak

Top Pak

Interpack

VSP Rings

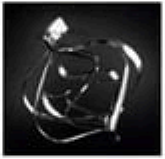
Cascade Mini Ring



Raschig Super Ring

Intalox Sadle

Nutter Rings



Intalox Ultra

PACKING MATERIAL PROPERTIES

Properties of tower packing:

- ✓ Low weight per unit volume
- ✓ Large surface area per unit volume of packing
- ✓ Chemically inert to the fluids being processed
- ✓ Lightweight but strong
- ✓ Good distribution of fluids
- ✓ Good wettability

Packing	Size (in.)	Weight (lb/ft^3)	Surface area, a (ft^2/ft^3 packing volume)	Void fraction (%)	Packing factor, F (ft^2/ft^3)
Raschig rings (ceramic and porcelain)	1/2	52	114	65	580
	1	44	58	70	155
	1 1/2	42	36	72	95
	2	38	28	75	65
	3	34	19	77	37
Raschig rings (steel)	1/2 • 1/32	77	128	84	300
	1 • 1/32	40	63	92	115
	2 • 1/16	38	31	92	57
Berl saddles (ceramic)	1/4	55	274	63	900
	1/2	54	155	64	240
	2	48	79	69	110
		38	32	75	45
Intalox saddles (ceramic)	1/4	54	300	75	725
	1/2	45	190	78	200
	1	44	78	77	98
	2	42	36	79	40
Intalox saddles (plastic)	1	6.00	63	91	30
	2	3.75	33	93	20
	3	3.25	27	94	15
Pall rings (plastic)	5/8	7.0	104	87	97
	1	5.5	63	90	52
	2	4.5	31	92	25
Pall rings (metal)	5/8 • 0.018 thick	38	104	93	73
	1 1/2 • 0.03 thick	24	39	95	28
Tellerettes	1	7.5	55	87	40
	2	3.9	38	93	20
	3	5.0	30	92	15

DESIGN OF PACKED TOWER:

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

Select the type and size of packing.

↓

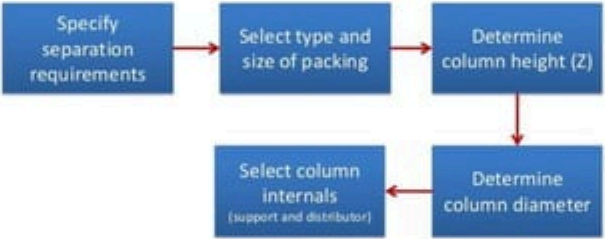
Determine the column height required for the specified separation.

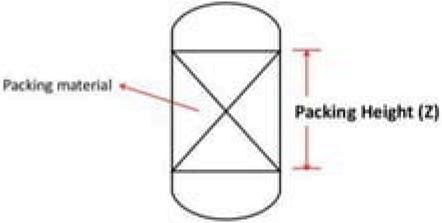
↓

Determine the column diameter (capacity), to handle the liquid and vapour flow rates.

↓

Select and design the column internal features: packing support, liquid distributor, redistributors. Example





Requirements:

The principal requirements of a packing are that it should:

- Provide a large surface area: a high interfacial area between the gas and liquid.
- Have an open structure: low resistance to gas flow.
- Promote uniform liquid distribution on the packing surface.
- Promote uniform vapour gas flow across the column cross-section.
- Packings with a regular geometry: such as stacked rings, grids and proprietary structured packings.
- Random packings: rings, saddles and proprietary shapes.

- The diameter of a packed absorption tower depends on the quantities of gas and liquid handled, their properties, and the ratio of one stream to the other.
- The height of the tower, and hence the total volume of packing, depends on the magnitude of the desired concentration changes and on the rate of mass transfer per unit of packed volume.
- Calculation of the tower height, therefore,rest on

- material balances,
- enthalpy balances, and
- estimates of driving force and mass-transfer coeffcients.

DETERMINATION OF COLUMN OR TOWER HEIGHT:

- NTU (number of transfer units)
- HTU (height of transfer unit)
- HETP (height equivalent to a theoretical plate)

Methods for Packing Height (Z)

2 methods

More common

Equilibrium stage analysis HETP method	**Mass Transfer analysis** HTU method

Equilibrium stage analysis – HETP method

$$Z = \text{HETP} \times \text{N}$$

N = number of theoretical stages obtained from McCabe-Thiele method

HETP

- Height Equivalent to a Theoretical Plate
- Represents the height of packing that gives similar separation to as a theoretical stage.
- HETP values are provided for each type of packing

Mass Transfer analysis – HTU method (more common)

$$Z = \text{HTU} \times \text{NTU}$$

HTU = Height of a Transfer unit

NTU = Number of Transfer Units (obtained by numerical integration)

$$Z = \frac{V}{K_y a\, A_c} \int_{y_{A,in}}^{y_{A,out}} \frac{dy}{(y_A^* - y_A)} \qquad Z = H_{OG} \times N_{OG}$$

$$Z = \frac{L}{K_x a\, A_c} \int_{x_{A,in}}^{x_{A,out}} \frac{d\,x_A}{(x_A - x_A^*)} \qquad Z = H_{OL} \times N_{OL}$$

- HETP is a height equivalent to theoretical plate.

- As we have noted, instead of a tray (plate) column, a packed column can be used for various unit operations such as continuous or batch distillation, or gas absorption.

- With a tray column, the vapours leaving an ideal plate will be richer in the more volatile component than the vapour entering the plate by one equilibrium "step".

- When packings are used instead of trays, the same enrichment of the vapour will occur over a certain height of packings, and this height is termed the height equivalent to a theoretical plate (HETP).

- Therefore, the required height of packings for any operation is given by = HETP × N

- **In industrial practice, the HETP concept is used to convert** empirically the number of theoretical trays to packing height.

- Most data have been derived from small-scale operations and they do not provide a good guide to the values which will be obtained on full-scale plant.

- This method had been largely replaced by the **Method of Transfer Units.**

- In practice, packed columns are often analyzed on the basis of equivalent equilibrium stages using a Height Equivalent to a Theoretical Plate (HETP):

- For a specified operation, in packed tower, the height of packing is to be determined and in tray tower, numbers of ideal trays are determined. The ratio between packing height to number of trays required for the operation is called **height equivalent to theoretical plate (HETP).**

$$\text{HETP} = \frac{packed\ height}{no\ of\ stages} \qquad H = n\text{HETP}$$

- HETP varies with size and type of packing, flow rate of gas and liquid, concentration of solute, physical and transport properties as well as equilibrium relationship and uniformity of liquid and gas distribution.

Height of a packed tower = f(the overall resistance to mass transfer between the gas and liquid phases, the average driving force and interfacial area)

Consider a differential height of the absorber dZ. In height dZ, the rate of mass transfer of species A

$$N_A A(a dZ) = d(G_m y) = A d(G' y)$$

a: interfacial area available to mass transfer per unit volume of the packing

A: cross-sectional area of the tower

$$N_A A(a\,dz) = d(G_m y) = A\,d(G' y)$$

$$K_y a(y_{AG} - y_A^*)\,dz = d(G_m' y)$$

$$dZ = \frac{G_m' dy}{K_y a(y - y^*)} = \frac{G_m' y}{K_G aP(y - y^*)}$$

The equation can be also written for liquid resistance part.

$$dZ = \frac{G_m' \, dy}{K_y a (y - y^*)} = \frac{G_m' \, dy}{K_G a P (y - y^*)}$$

To solve the above equation we can determine the overall value of K_ya (K_ga) based on experimental "pilot plant" operated with a certain packing and gas/liquid rate. The right side of the equation can be integrated from the knowledge of the operating line and equilibrium line chracteristics.

This method can be modified to deal with the "height of a transfer unit" and "the number of transfer units" by modifiying the equation somewhat

Tower Height

The equation can be expressed in terms of height of transfer unit (HTU) and number of transfer units :

$$Z = \frac{G'_m}{K_{OG}aP}\int_{y_2}^{y_1}\frac{dy}{(y - y^*)}$$

HTU or Hoy

NTU or Noy

HTU is reaonably constant through the absorber and has unit of length. NTU is dimensionless.

Evaluating height based on HTU-NTU model

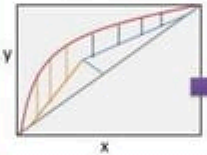
$$Z = \frac{V}{K_y a\, A_c} \int_{y_{A,in}}^{y_{A,out}} \frac{dy}{(y_A^* - y_A)}$$

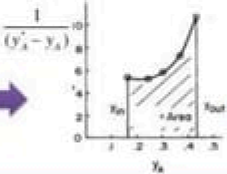
H_{OG}

Substitute values to calculate H_{OG}

Integration = N_{OG}

- N_{OG} is evaluated graphically by numerical integration using the equilibrium and operating lines.
- Draw $1/(y_A^* - y_A)$ (on y-axis) vs. y_A (on x-axis). Area under the curve is the value of integration.

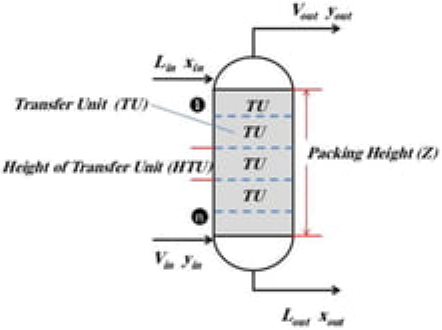




Evaluate area under the curve by numerical integration

Area = N

Packing Height (Z)



Packing Height (Z) = height of transfer unit (HTU) × number of transfer units (n)

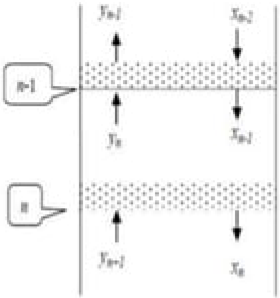
Comparison between HTU / NTU and HETP

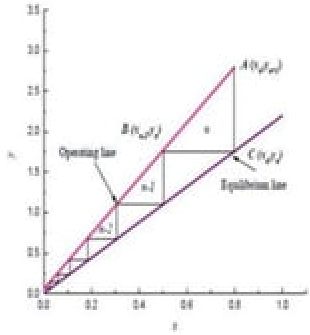
The NTU and the HTU should not be confused with the HETP and the number of theoretical equilibrium stages n, which can be calculated with the Kremser Equation:

Relationship between HTU and HETP

$$\mathrm{HETP} = \frac{\mathbf{H}_{OG} \mathrm{Ln}\left(\frac{mG_m}{L_m}\right)}{\left(\frac{mG_m}{L_m - 1}\right)} \qquad \mathbf{H}_{OG} = \mathbf{H}_G + \left(\frac{mG_m}{L_m}\right)\mathbf{H}_L$$

When the operating and equilibrium lines are not only straight but also parallel, NTU = n and HTU = HETP. Otherwise, the NTU is greater than or less than n.


n-1
n


Operating line
Equilibrium line
n
0.0
0.2
0.4
0.6
0.8
1.0

$$G'(y_{n+1} - y_n) = L'(x_n - x_{n-1}) = \text{Mass transfer rate}$$

- The mass transfer rate for *h height can be expressed as*

$$\text{Mass transfer rate} = K_G\bar{a}P.h(y - y^*)_{av}$$

$$G'(y_{n+1} - y_n) = K_G\bar{a}P.h(y - y^*)_{av}$$

$$h = \frac{G'(y_{n+1} - y_n)}{K_G\bar{a}P(y - y^*)_{av}} \qquad \text{(A)}$$

where,

- $$(y - y^*)_{av} = \frac{(y-y^*)_A - (y-y^*)_B}{ln\frac{(y-y^*)_A}{(y-y^*)_B}} = \frac{(y_{n+1} - y_n) - (y_n - y_{n-1})}{ln\frac{(y_{n+1} - y_n)}{(y_n - y_{n-1})}} \qquad (1)$$

- *as (y-y*)av is taken as log mean gas phase gas phase driving force from A to B across nth tray.*

➢ From the figure,

$$\frac{(y_n - y_{n-1})}{(y_{n+1} - y_n)} = \frac{\frac{(y_n - y_{n-1})}{(x_n - x_{n-1})}}{\frac{(y_{n+1} - y_n)}{(x_n - x_{n-1})}} = \frac{\textit{slope of equilibrium line}}{\textit{slope of operating line}} = \frac{m}{\frac{L'}{G'}} = \frac{mG'}{L'} \qquad (2)$$

$$\left(1 - \frac{mG'}{L'}\right) = \left[1 - \frac{(y_n - y_{n-1})}{(y_{n+1} - y_n)}\right] = \frac{(y_{n+1} - y_n) - (y_n - y_{n-1})}{(y_{n+1} - y_n)} \qquad (3)$$

From equation (1) & (3),

$$(y - y^*)_{av} = \frac{(y_{n+1} - y_n)\left(1 - \frac{mG'}{L'}\right)}{\ln \frac{L'}{mG'}} = \frac{(y_{n+1} - y_n)\left(\frac{mG'}{L'} - 1\right)}{\ln \frac{mG'}{L'}}$$

- From equation (A) we can find the value of H,

$$h = \frac{G'(y_{n+1}-y_n)}{K_G \bar{a} P \frac{(y_{n+1}-y_n)\left(\frac{mG'}{L'}-1\right)}{\ln\frac{mG'}{L'}}} = \frac{G' \ln\frac{mG'}{L'}}{K_G \bar{a} P\left(\frac{mG'}{L'}-1\right)} = H_{toG}\,\frac{\ln\frac{mG'}{L'}}{\left(\frac{mG'}{L'}-1\right)}$$

- Hence, the same separation is achieved for *h height in packed tower and in the nth tray which is equal to HETP.*

$$HETP = H_{toG}\,\frac{\ln\left(\frac{mG'}{L'}\right)}{\left(\frac{mG'}{L'}-1\right)} = H_{toG}\,\frac{\ln \bar{S}}{(\bar{S}-1)}$$

where, H toG is height of overall gas phase transfer unit.
is stripping factor = / /=1 and m is Henry's law constant. HETP is used to characterize packing. A good packing has small HETP.

METHODS OF TRANSFER UNITS:

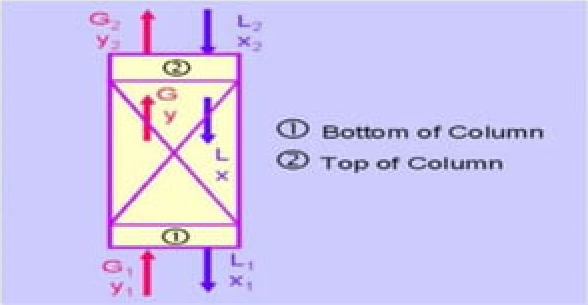
- The **number of transfer units (NTU) required is a** measure of the difficulty of the separation.
- A single transfer unit gives the change of composition of one of the phases equal to the average driving force producing the change.
- The NTU is similar to the number of theoretical trays required for tray column.
- Hence, a larger number of transfer unit will be required for a very high purity product.

- The **height of a transfer unit (HTU) is a measure of** the separation effectiveness of the particular packings for a particular separation process.

- The more efficient the mass transfer (i.e. larger mass transfer coefficient), the smaller the value of HTU.

- The values of HTU can be estimated from empirical correlations or pilot plant tests, but the applications are rather restricted.

The calculation of packing height follows the same nomenclature as before and this is shown in the Figure below



There are two types of basis for determination of packing height.

- Gas phase
- Liquid phase

Gas phase

- For the **Gas-phase, we have:**

  z = NOG x HOG

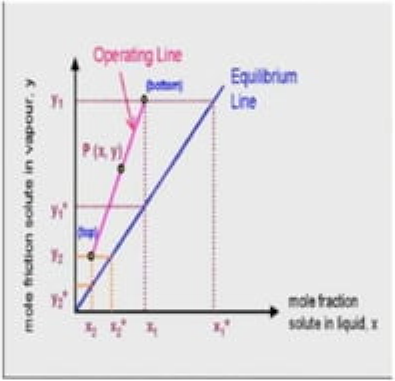
$$N_{OG} = \frac{y_1 - y_2}{(y - y^*)_{LM}}$$

$$(y - y^*)_{LM} = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln\left[\frac{(y_1 - y_1^*)}{(y_2 - y_2^*)}\right]}$$

$$H_{OG} = \frac{G}{K_y a (1-y)^*_{LM}}$$

$$(1-y)^*_{LM} = \frac{(1 - y_1) - (1 - y_1^*)}{\ln\left[\frac{(1 - y_1)}{(1 - y_1^*)}\right]}$$

- The values of y1* and y2* can be obtained from the equilibrium line (y1 - y1*) is the concentration difference driving force for mass transfer in the gas phase at point 1 (bottom of column) and (y2 - y2*) is the concentration difference driving force for mass transfer in the gas phase at point 2 (top of column).



- The values of $y1^*$ and $y2^*$ can be obtained from the equilibrium line.

- Alternatively, equilibrium values $y1^*$ and $y2^*$ can also be calculated using Henry's Law ($y = m x$, where m is the gradient) which is used to represents the equilibrium relationship at dilute conditions.

Thus, we have: $y1^* = m\,x1$; $y2^* = m\,x2$

Liquid Phase

❖ Similarly for the liquid-phase we have:

$z = N_{OL} \times H_{OL}$

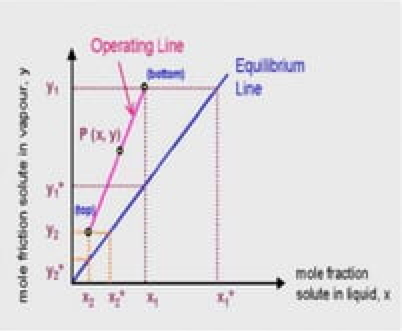
$$N_{OL} = \frac{x_1 - x_2}{(x^* - x)_{LM}}$$

$$(x^* - x)_{LM} = \frac{(x_1^* - x_1) - (x_2^* - x_2)}{\ln\left[\dfrac{(x_1^* - x_1)}{(x_2^* - x_2)}\right]}$$

$$H_{OL} = \frac{L}{K_x a\,(1-x)^*_{LM}}$$

$$(1-x)^*_{LM} = \frac{(1 - x_1) - (1 - x_1^*)}{\ln\left[\dfrac{(1 - x_1)}{(1 - x_1^*)}\right]}$$

- (x1* - x1) is the concentration difference driving force for mass transfer in the liquid phase at point 1 (bottom of column) and (x2* - x2) is the concentration difference driving force for mass transfer in the liquid phase at point 2 (top of column).



$$z = N \times H = N_{OG} \times H_{OG} = N_{OL} \times H_{OL}$$

where

N = number of transfer units (NTU)

H = height of transfer units (HTU)

ADVANTAGES:

1. For corrosive liquids, a packed column will usually be cheaper than the equivalent plate column.
2. The liquid hold-up is lower in a packed column than a plate column. This can be important when the inventory of toxic or flammable liquids needs to be kept as small as possible for safety reasons.
3. Packed columns are more suitable for handling foaming systems.
4. The pressure drop can be lower for packing than plates; and packing should be considered for vacuum columns.
5. Packing should always be considered for small diameter columns, say less than 0.6 m, where plates would be difficult to install, and expensive.

- Amine absorbers use counter-current flow through a trayed or packed tower to provide intimate mixing between the amine solution and the sour gas.
- In packed towers also known as air stripping towers, the contaminated water flows downwards through a packing, counter-current to an air flow which strips the VOCs into the gas phase and discharges them through the top of the tower. The treated water is collected at the bottom of the tower.

THANKYOU

MIST ELIMINATORS
Various types of separation products: wire mesh, Plate-Pak Multi-Pocket Vane MaxCap Mist Eliminator
RANDOM PACKINGS
Various types and sizes: pall rings, saddle rings, raschig rings
ACCUFLOW™ INLET DEVICE
High performance inlet diffuser. Extremely robust device designed for vertical or horizontal vessels
SEMV™ HIGH PERFORMANCE TRAY
Ideal for additional capacity: fixed and floating mini valves, rectangular and push valves
CONVENTIONAL TRAYS
Our technology offers the right tray: floating valve, fixed valve, baffle, cartridge, caged valve, sieve, dual flow, bubble cap
SUPERBLEND 2-PAC™
High performance random packing: multiple combinations and sizes, increased efficiency, increased capacity
MAXSWIRL CYCLONES™
Demisting device: high capacity and high efficiency
DISTRIBUTORS
Multiple types and designs: AKM high performance distributor, orifice riser distributor, V-Notch distributor, Narrow Trough distributor
SUPPORT GRIDS
Various types with wide variety of openings. Support grids for random and structured packing, grating and wedge wire support grids
COLLECTOR TRAYS
Designed for removing liquid from column: chimney tray, Lamella Collector
STRUCTURED PACKINGS
Montz-Pak, high performance types M and type MN packing, wire gauze packing, knitted mesh packing, grid packing
WEDGE WIRE
Robust and versatile products: support grids, outlet baskets, lateral systems, flat screen, water well screen