Mass Transfer-I

Mass Transfer Equipment (Continue…)

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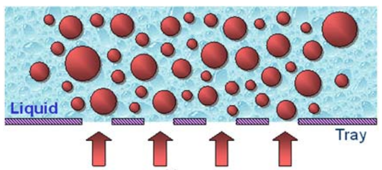
Mass Transfer Equipment (Continue…)

Sieve Tray Column

Sieve trays are simply metal plates with holes in them. Vapour passes straight upward through the liquid on the plate. The arrangement, number and size of the holes are design parameters.

- The "Sieve tray" is a perforated plate type tray, with holes punched into the deck-plate that typically measure from 3/16" up through 1" in diameter.
- Vapor comes out of the holes which in turn, keeps the liquid from weeping through.
- The vapor and liquid then, create a mix on the tray deck.
- The liquid will then leave the tray, via the down-comer. As the vapor continues to the tray above.



http://www.wermac.org/equipment/distillation_part2.html

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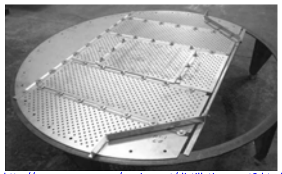

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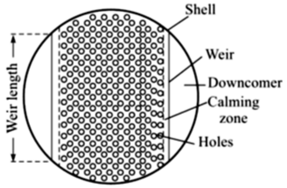

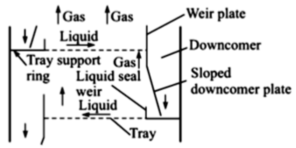

- A sieve tray has a higher entrainment than a standard valve type tray.
- For efficient operation, hole velocity must be sufficient in order to balance the head of the liquid on the tray.
- It is used when turndown is limited to 2:1 and fouling is not a concern.
- The sieve tray is and remains, one of the most economical trays because it does not contain separate valve assemblies.

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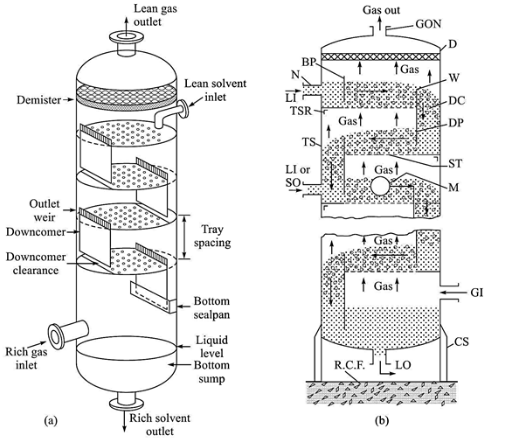

Figure 5.1 (a) Schematic of a 'sieve tray' column and (b) sectional sketch of a 'sieve tray' column [BP: baffle plate; CS: column support; D: demister; DC: downcomer; DP: downcomer plate; GI: gas inlet; GON: gas outlet nozzle; LI: liquid inlet; LI or SO: liquid inlet or side-stream outlet; M: manhole; N: nozzle; RCF: reinforced concrete foundation; ST: sieve tray; TS: tower shell; TSR: tray-support ring; W: weir].

Bubble-cap tray column

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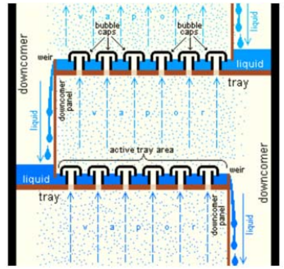
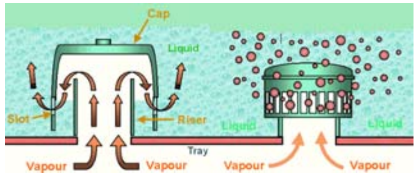
- This is the oldest type of tray.
- A bubble cap tray has riser or chimney fitted over each hole, and a cap that covers the riser.
- The cap is mounted so that there is a space between riser and cap to allow the passage of vapour.
- Vapour rises through the chimney and is directed downward by the cap, finally discharging through slots in the cap, and finally bubbling through the liquid on the tray.





http://mtl-us.com/bubble-cap-tray-distillation-column.php

https://www.facebook.com/CEL4U/photos/a.180956 2052634256/1961411057449354/?type=3&theater

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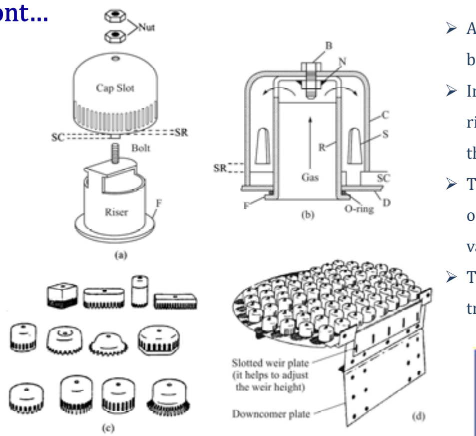
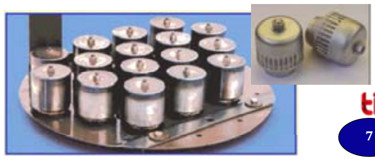


Figure 5.2 Bubble caps and a bubble-cap tray: (a) an exploded view of a bubble cap and (b) sectional diagram of a bubble cap [B: bolt; C: cap; D: tray deck; F: flared bottom of the riser; N: nut; R: riser; S: slot; SC: skirt clearance; SR: shroud ring] Courtesy: ACS Industries, USA; (c) different types of bubble-caps and (d) a bubble-cap tray

- A bubble-cap consists of two major components –a bell-shaped 'cap' and a 'riser'.
- In this figure shows a typical bubble cap design. The riser is inserted through a hole on the tray floor and the bell shaped cap is bolted to it.
- The riser or chimney is a piece of tube with a flared or expanded bottom end. In fact, the riser acts as the vapour passage and also hold the cap.
- The shape of the slots may be rectangular, triangular, trapezoidal, or saw-tooth type.



Valve tray

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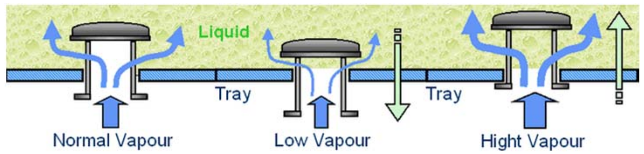
- In valve trays, perforations are covered by liftable caps.
- Vapour flows lifts the caps, thus self creating a flow area for the passage of vapour.
- The lifting cap directs the vapour to flow horizontally into the liquid, thus providing better mixing than is possible in sieve trays.

http://www.wermac.org/equipment/distillation_part2.html

This FLEXITRAY™ valve tray is a steel sheet on which liftable valves are mounted. They are much more efficient than sieve trays.

Picture of Koch-Glitsch, LP.



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- The valve tray provides variable area for the gas or vapour flow depending upon the flow rate or 'throughput'. This is way it is called **'valve tray'**
- A common valve tray has sufficiently large punched holes on the tray floor, each fitted with a movable disk, generally circular.
- A disk has guides that can slide vertically up or down along the thickness of the tray floor. The opening for the gas flow changes in this way, but the disk is always held in the same vertical line.
- As the gas flow rate increases, the disk is automatically raised. It settles down at a low vapour rate to prevent **'weeping'.**
- A few problem common to all kinds of valve trays are
  - (i) Mechanical wear and corrosion because of continuous movement of the valve legs.
  - (ii) Sticking of the disk on the tray if there is sticky deposition on the tray.
- Excessive opening of the valve at a low gas rate cause sweeping and valves should therefore be heavy enough to prevent this. On the other hand, heavy valves incur a greater pressure drop.

Efficiencies for a Tray Column

The overall column efficiency for a tray column may be defined by:

Where:
N_{EQ} is the number of equilibrium stages
N_{actual} is the number of actual trays in the column.

$$E_o = N_{EQ} / N_{actual}$$

Murphree tray efficiency is the most widely used efficiency in separation process calculations:

$$E_{i,j}^{MV} = \frac{y_{i,j} - y_{i,j+1}}{y_{i,j}^{*} - y_{i,j+1}}$$

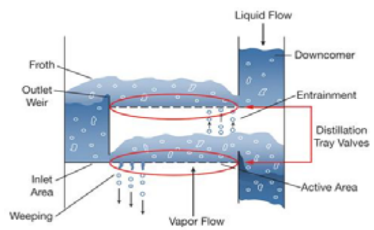
Where,
$E_{i,j}^{MV}$ is the **Murphree tray efficiency** for component i on stage j
$y_{i,j}$ is the composition of the vapor in equilibrium with the liquid leaving the tray

Problems related to tray tower

Entrainment

Entrainment refers to the liquid carried by vapour up to the tray above and is again caused by high vapour flow rates. It is detrimental because tray efficiency is reduced: lower volatile material is carried to a plate holding liquid of higher volatility. It could also contaminate high purity distillate. Excessive entrainment can lead to flooding.

Entrainment is the phenomena in which liquid droplets are carried by vapor/gas to the tray above. Therefore, the less volatile liquid components from bottom tray are mixed with liquid having relatively more volatile materials on the overhead tray. It counteracts the desired mass transfer operation and the plate efficiency decreases. Entrainment increases with vapor velocity.



https://www.aiche.org/resources/publications/cep/2016/may/consider-moving-fixed-valves

https://www.rccostello.com/distil/distilop.htm#:~:text=Entrainment%20refers%20to%20the%20liquid,holding%20liquid%20of%20higher%20volatility.&text=Excessive%20entrainment%20can%20lead%20to%20flooding.

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The fractional entrainment (Ψ) is defined as follows

$$\left(\Psi = \frac{\text{kg}}{\text{kg gross liquid flow}}\right)$$

A sieve tray has a higher entrainment than a standard valve type tray. For efficient operation, hole velocity must be sufficient in order to balance the head of the liquid on the tray.

The fractional entrainment (Ψ) can predicted using Fair's correlation in terms of the flow parameter and actual flooding velocity

$$\left[F_{LG} = \frac{L}{V}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\right]$$

Effect of Ψ on Murphree plate efficiency can be estimated using Colburn equation

$$E_a = \frac{E_{mv}}{1+\frac{\Psi E_{mv}}{1-\Psi}}$$

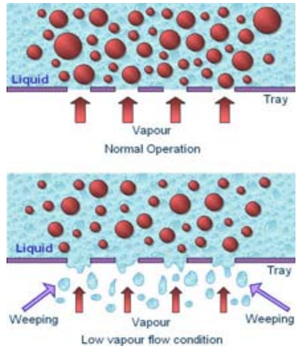
E_{mv} = Murphree vapor efficiency

E_a = Corrected Murphree vapor efficiency for liquid entrainment

Weeping

This phenomenon is caused by low vapour flow. The pressure exerted by the vapour is insufficient to hold up the liquid on the tray. Therefore, liquid starts to leak through perforations. Excessive weeping will lead to dumping. That is the liquid on all trays will crash (dump) through to the base of the column (via a domino effect) and the column will have to be re-started. Weeping is indicated by a sharp pressure drop in the column and reduced separation efficiency.

Weeping occurs at low vapor/gas flow rates. The upward vapor flow through the plate perforations prevents the liquid from leaking through the tray perforation. At low vapor flow rates, liquid start to leak/rain through the perforation (called weeping). When none of the liquid reaches the down-comer at extreme weeping condition at very low vapor flow rate, it is called dumping. The weeping tendency increases with increasing fractional hole area and liquid flow rates.



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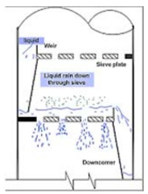
The vapor velocity at the weep point (where liquid leakage through holes starts) is the minimum value for stable operation. For a chosen hole area, the minimum operating vapor flow velocity ($U_{min,op}$) at minimum flow rate for stable operation should be above weep point vapor velocity. The minimum vapor velocity ($U_{\min}$) at the weep point is calculated through following correlation



http://enggyd.blogspot.com/2009/09/effect-in-towers_09.html

$$U_{\min} = \frac{K_2 - 0.9(25.4 - d_h)}{{\rho_v}^{1/2}}$$

Actual operating minimum vapor velocity ($U_{min,op}$):

$$U_{min,op} = \frac{\text{minimum vapor flow rate}}{\text{hole area}}[\text{m/s}]$$

Where,

d_h= hole diameter, mm,

ρ_v = vapor density, kg/m3 (maximum value of vapor density)

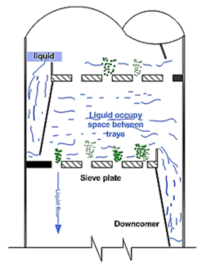
K_2 = constant (K_2) of weep-point correlation depends on the depth of clear liquid (weir crest + weir height) on the plate

To avoid weeping: $U_{min,op} > U_{\min}$.

Flooding

Flooding is brought about by excessive vapour flow, causing liquid to be entrained in the vapour up the column. The increased pressure from excessive vapour also backs up the liquid in the downcomer, causing an increase in liquid holdup on the plate above. Depending on the degree of flooding, the maximum capacity of the column may be severely reduced. Flooding is detected by sharp increases in column differential pressure and significant decrease in separation efficiency.

Excessive liquid buildup inside the column leads to column flooding condition. The nature of flooding depends on the column operating pressure and the liquid to vapor flow ratio. It may be down-comer backup, spray entrainment or froth entrainment type floodings. Higher tray pressure drop due to excessive vapor flow rates holds up the liquid in the down-comer, increases the liquid level on the plate and leads to downcomer flooding situation.



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The column flooding conditions sets the upper limit of vapor velocity for steady operation. Gas velocity through the net area at flooding condition can be estimated using Fair's correlation

$$U_{nf} = C_{sbf}\left(\frac{\sigma}{20}\right)^{0.2}\left(\frac{\rho_l-\rho_v}{\rho_v}\right)^{0.5} \quad \text{[m/s]}$$

ρ_v = vapor density, kg/m3
ρ_l = liquid density, kg/m3
σ = liquid surface tension, mN/m (dyn/cm)
C_{sbf} = capacity parameter (m/s)

Capacity parameter (C_{sbf}) can be calculated in terms of plate spacing and flow parameter

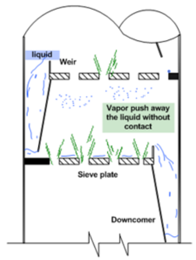
$$F_{LG} = \frac{L}{V}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}$$

L=liquid flow rate, kg/s
V=vpor flow rate, kg/s

The design gas velocities (U_n) is generally 80-85% of U_{nf} for non-foaming liquids and 75% or less for foaming liquids subject to acceptable entrainment and plate pressure drop.

Coning

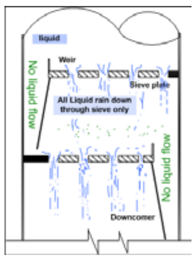
Coning in a tray tower occurs due to low liquid flow rate when compared to gas which results in pushing of the liquid away from the tray opening.



http://enggyd.blogspot.com/2009/09/effect-in-towers_09.html

Dumping

When the gas flow rate is very low, in comparison to liquid flow rate, liquid flows from a tray opening without entering in to down-comer. This phenomenon is called **'Dumping'**.



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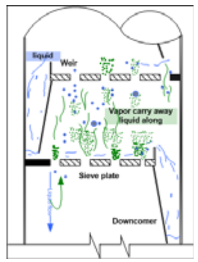
Priming

Priming is an exaggerated condition of liquid entrainment. Due to high gas flow rate, liquid from the bottom trays are carried away along with the gas to the top tray. This phenomenon is called **'Priming'**.



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References

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Mass Transfer

Theories for Mass Transfer Coefficients

Lecture 9, 15.11.2017, Dr. K. Wegner

MASS TRANSFER OPERATIONS: ABSORPTION AND EXTRACTION

José Coca, Salvador Ordóñez, and Eva Díaz

7. Short introductions to: Mass transfer; Separation processes; Particulate technology & multi-phase flow

- Lecture notes/ppt of Dr. Yahya Banat (**ybanat@qu.edu.qa**)

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