Performance Enhancement of Distillation Column by Optimizing the Geometry of Bubble Cap Trays

1Mr. Nilesh P. Patil, 2Dr. V. S. Patil
1Ph.D (Engineering & Technology) (Pursuing), M.Tech (Chemical Engineering), AIE, AMIChE, Assistant Professor - Chemical Engineering, Division of Chemical Engineering, University Institute of Chemical Technology, N.M.U., Jalgaon.
Email – nileshppatil_21@yahoo.co.in
2Ph.D (Engineering & Technology), M.Tech (Chemical Engineering), MIE, DBM Professor, Chemical Engineering, Division of Chemical Engineering, University Institute of Chemical Technology, N.M.U., Jalgaon.

Abstract:
Distillation is by far the most important separation process in the petroleum and chemical industries. It is the separation of key components in a mixture by the difference in their relative volatility, or boiling points. In most cases, distillation is the most economical separating method for liquid mixtures. However, it can be energy intensive. Distillation can consume more than 50% of a plant’s operating energy cost. There are alternatives to distillation process such as solvent extraction, membrane separation or adsorption process. On the other hand, these processes often have higher investment costs. Therefore, distillation remains the main choice in the industry, especially in large-scale applications.

In designing a distillation column, the sizing of the column is most important it includes understanding of thermodynamics of the vapor and liquid phases. The vapor-liquid equilibrium (VLE) determines the minimum number of stages required to achieve the degree of separation needed. The selection of column internals is very critical in distillation column design. There is a wide variety of trays and packing in the market. Each design has its strengths and weaknesses. First of all the process engineer has to decide which type of internals has to be opted & it solely depends on the fluids to which the column is going to be subjected.

The paper in detail elaborates the factors governing the performance of distillation column. The objective of the paper is to enhance the performance of distillation column by optimizing the geometry of bubble cap trays.

Introduction:
As far as distillation is concerned it is the most important separation process in the petroleum refineries and chemical industries. It is the separation of key components in a mixture by the difference in their relative volatility, or boiling points. Besides energy intensive process, in most cases distillation is the most economical separating method for liquid mixtures as compared to other separation methods. Being such a vibrant process, it is quite essential for us to look into the energy optimization of the column. There are various factors governing the performance of the distillation column. Even then the column internals / trays adopted in the column are the most influential factor governing the performance of distillation column. The parameters like pressure drop may vary because of the alteration of the type of trays employed.

Conventional fractionating trays consist of vapour / liquid contacting trays with segmented liquid down flow areas. Columns can contain any number of trays installed vertically above each other. Each set of trays needs to be individually designed for the specific process and mechanical requirements anticipated within the column. There are different types of trays such as sieve trays, valve trays, bubble cap trays etc. each of them has its own advantages & disadvantages. The performance of the column can be evaluated in terms of purity of the product obtained against energy consumption. Bubble cap trays are found to be the best performer amongst the available configurations of trays. The only disadvantage of the bubble cap trays is pressure drop. The attempt of minimizing this drawback of the bubble cap tray is done in the article.

Function of Trays:
Mass transfer columns in general operate with countercurrent vapour and liquid flow with the tray decks used to provide stagewise contact between the vapour and liquid resulting in light component as overhead product and heavy component as bottom product. The basic flow pattern on a cross-flow tray is liquid phase continuous and vapour phase dispersed through the liquid. This ensures maximum vapour contact with
the liquid but at the expense of creating a barrier to vapour flow that can result in a substantial pressure drop across the tray.

The sketch shown in Fig.1 illustrates the operating principle of conventional 1-pass and 2-pass fractionating trays. In each case, clear liquid enters the tray deck area from under the downcomer apron. Simultaneously, vapour from the tray below passes through the open area (perforations, valves or bubble caps) where it must bubble through the liquid forming a 2-phase froth in which mass transfer takes place whilst the froth moves horizontally across the tray deck. Vapour continuously disengages from the froth and flows to the tray above. The froth discharges over the outlet weir into the tray downcomer which acts as a settling zone where vapour disengagement takes place thus allowing clear liquid to flow to the tray below.

Proper and efficient functioning of trays for each specific service requires a unique design configuration based on a careful balance and optimization of a number of interrelated and often opposing factors which in turn requires an accurate and reliable profile of the flowrates and properties of the internal column traffic.

**Tray Configuration:**

Listed below are the key tray design parameters which impact on column operation:

- **Active Area / Bubble Area** - is the deck area of the tray which may either be perforated or fitted with valves or bubble caps and is the area available for vapour/liquid contacting. The vapour handling capacity of a tray is proportional to the active area (i.e. inversely proportional to the approach to Jet Flood).

- **Downcomer Area** - is the area available for the transport of liquid from one tray to the next tray below. Also a very important function of the
downcomers is to allow for the disengagement of vapour from the liquid which is a function of both residence time of the liquid in the downcomer. Undersized downcomers will result in downcomer flood.

**Open Area / Hole Area** - is the aggregate area available for vapour passage through the tray deck via perforations or valve and bubble cap slots. This is a critical factor in the tray operating range since high vapour velocity through the open area (hole velocity) will induce heavy liquid entrainment (as well as high pressure drop), but low hole velocity may allow liquid to "weep" or even "dump" through the tray deck to the tray below. The influence of open area on pressure drop also impacts on the liquid back-up in the downcomer.

**Tray Spacing** - is the vertical distance between adjacent tray decks. This effects both the height of spray that may be generated on the tray deck before liquid carryover and also the allowable head of liquid in the downcomers.

**Downcomer Clearance** - is the space below the downcomer apron allowing liquid to flow from the downcomer to the tray deck below. This must be sized to provide a balance between the minimum head loss required for good liquid distribution across the tray deck and avoiding excessive downcomer back-up.

**Outlet Weir Height** - The outlet weir is used to maintain a head of liquid on the tray deck as well as to ensure a positive vapour seal to the bottom of the downcomer.

**Flow Path Length** - is the span of tray deck between the downcomer inlet and the outlet weir and is the shortest path that the liquid takes in crossing the active area from one downcomer to the next. Particularly in small columns, it has a big influence on tray efficiency.

**Number of Flow Paths** - Larger diameter trays may be fitted with multiple downcomers to reduce the liquid load across each active area section. This reduces the weir load and liquid head on the tray deck resulting in higher vapour capacity, lower pressure drop and improved operating turndown range.

**Tray Feeds & Draws:**

All columns in commercial operations will have process streams feeding to the column as well as product draw points. However any interference with the normal vapour and liquid flows on well designed trays can easily cause tray malfunction so the location and configuration of column feeds and draws is critical to overall column performance. Tray feeds may be liquid, vapour or mixed. The generally preferred arrangement for liquid feed between trays is a perforated pipe which directs liquid onto the vapour side of the downcomer apron so that the feed liquid mixes with the reflux from the tray above at the downcomer outlet. If the feed liquid is hotter than the liquid on the tray, an insulation baffle (or target plate) should be fitted to the vapour side of the downcomer apron to prevent vaporization of liquid in the downcomer. A good rule-of-thumb (except for large size feed pipes) is that the perforated pipe should have a 200mm clearance above the tray deck and a 50mm clearance from the downcomer apron.

The preferred arrangement for liquid feed to the top tray is to feed into a "false downcomer". Typically the false downcomer would be 300mm high with half the normal downcomer clearance (minimum 25mm) to ensure sufficient head in the downcomer for good lateral distribution of liquid across the tray deck. Alternatively, an inlet weir may be installed in place of the "false downcomer". In most cases an open nozzle is adequate for vapour feeds between trays which should be located to provide at least 400mm disengagement space from the tray above (therefore increase tray space by at least 50%) and oriented perpendicular to the liquid flow on the tray deck.

The reboiler return should be located at least 300mm above the liquid level and must also avoid any interference with liquid flowing from the bottom tray seal pan. Side draw liquid product is drawn from trays by locating draw nozzles in tray draw sumps normally placed below downcomers. Both the draw nozzle and sump must be sized to avoid drawing vapour. Typically the draw nozzle would be sized to restrict liquid velocity to below 1m/s and the depth of the draw sump would exceed 2.5 x nozzle diameter with the draw nozzle flush with the sump floor. The depth of the draw sump should not exceed 30% of normal tray spacing. Large volume draws and total draws may require chimney trays. A draw pan located below a seal pan may be used to draw liquid from below the bottom tray.

**Tray Operating Limits:**

The tray operating envelope shown in Fig. 2 illustrates the relationship between liquid and vapour rates and the normal tray operating limits. The absolute locations of the envelope boundaries are a function of the tray layout and so each tray design will result in a unique set of operating limits. Ideal tray designs have the full range of expected column operation located within the envelope.
The normal tray operating limits are defined as follows:-

**Entrainment Limit** - is reached when the velocity of vapour through the tray open area is high enough to project liquid droplets to the tray above.

**Jet Flood** - is the criteria used to predict the point at which massive liquid carryover will occur due to the height of spray on the tray deck exceeding the available tray space. It is normal practice to limit tray design to a maximum of 80% of jet flood to allow a safety margin on tower control, possible discrepancies of VLE data and also the limitations of the flooding correlation used.

**Weeping** - occurs when the velocity of the vapour through the tray open area is too low to prevent liquid from leaking through the open area thus bypassing contact area to the tray below. Most valve and sieve trays will weep in normal operation. Weeping is considered excessive when it is sufficient to cause loss of efficiency - usually 10 to 20%.

**Blowing Flood** - occurs at low liquid rates at which the tray operates in the spray regime resulting in massive entrainment of liquid to the tray above to the extent that the tray deck is essentially blown dry.

**Downcomer Flood** - occurs at high liquid loads when the downcomers are too small to allow effective vapour disengagement (either because the downward velocity or "inlet velocity" of the liquid is too high or else insufficient residence time) causing vapour entrainment to the tray below. The resulting increased aeration of the liquid in the downcomer may also cause premature downcomer back-up flood.

**Downcomer Back-up Flood** - occurs when the head of liquid in the downcomer backs up onto the tray deck. The head of clear liquid in the downcomer is a balance of the pressure drop across the tray plus the head loss through the downcomer clearance. However an aeration factor must be applied to estimate the actual height of aerated liquid in the downcomer.

**Tray Pressure Drop** - may also be limiting criteria particularly in low pressure services. The operating tray pressure drop is the sum of the dry pressure drop caused by the resistance to vapour flow through the tray open area and the head of clear liquid on the tray deck. The head of clear liquid on the tray deck is a function of weir height and weir length (as well as liquid and vapour rates and physical properties) and so pressure drop may be reduced by increasing the number of flow paths in high liquid rate services.

**Process Design:**
The proper design of the trays is essential to ensure that all tray design parameters can be fully evaluated to ensure optimum performance over the complete range of anticipated operation. Input data should preferably be generated from a commercial column simulation package that should include stage-by-stage liquid and vapour loads, densities and transport properties. This is essential to ensure that the tray design takes account of the full range of loads across the each set of trays.

The following parameters must be considered whilst tray design:
- Jet flood
- Entrainment limits
- Pressure drop
- Downcomer back-up
- Downcomer inlet velocity
- Weir loadings
- Downcomer residence time
- Weeping

In addition, flagging of tray design parameters such as flow path length and balanced designs in trays with multiple flow paths ensure a tray design which is efficient and practical.

**Design Input:**
Accurate prediction of column internal traffic is essential to the evaluation of tray design layout and prediction of tray performance. The following is the minimum data required for tray design and evaluation:
- Vapour & liquid flowrates
- Vapour & liquid densities
- Liquid viscosities & surface tensions.

This information should be generated on a stage-by-stage (or tray-by-tray) basis using a commercial column simulation package (e.g. Process, Hysim or Aspen).

If an evaluation of existing trays is required then the following additional information should be provided either in the existing tray arrangement drawings or in tabulated form:
- Tray diameter
- Tray spacing
- Downcomer inlet and outlet widths
- Weir heights and downcomer clearances.
- Number and type of valves or perforations.
Tray Design – Mechanical:

The CAD/CAM system for tray design and manufacture is necessary to ensure good fit up of all tray parts. An added benefit from the accuracy of this system is that it allows for tray design with through-bolted panel joints that results in a more rigid structure than can be achieved by clamping tray panels together with friction washers. Trays drawings are produced from computer generated three-dimensional models of trays assembled in the vessel and include tray attachments and internal piping where relevant. The CAD models are subsequently used to program CNC machines for accurate fabrication of individual components.

Tray Installation:

To minimize installation time, trays are designed using the minimum number of individual panels that can be installed through the vessel man way and other access (and mass transfer) limitations. Fractionating trays are supplied in "completely knocked down" (CKD) form in crates for final assembly inside the column. Therefore it only becomes a proper functioning fractionating tray when it has been properly assembled. No matter how well a tray has been designed and manufactured, sloppy installation will result in a tray which does not conform to the design specification and which may therefore not perform. The following are just a few common installation faults that would impact adversely on tray performance:

- Incorrect panel location - e.g. similar shape panels with wrong number of valves
- Poor panel fit-up / adjustment - possible large gaps in panel joints
- Incomplete or insecure bolting
- Incorrect use of peripheral ledge clamps - not properly overlapping tray ring
- Missing seal plates
- Trays decks not installed level
- Incorrect downcomer clearances - could result in premature downcomer flood
- Incorrect weir heights

Types of Trays:

1. Sieve Trays: Sieve trays have tray deck areas uniformly perforated with round holes. Vapour flow through the tray deck to contact the liquid is controlled by the number and size of the perforations. For efficient operation, the hole velocity must be sufficient to balance the head of liquid on the tray deck and thus prevent liquid from passing through the perforations to the tray below. On the other hand high hole velocities may cause severe liquid entrainment to the tray above. Consequently Sieve Trays have a narrow operating range, no more than 2:1.
2. Valve Trays:

Valve trays have perforated tray decks fitted with moveable discs (valves) to vary the tray open area with changing vapour load. There are numerous valve types which may either have legs fitted to the valve disc to restrict upwards movement or alternatively the valve disc movement is restricted by a "cage" fitted to the tray deck. At very low vapour rates, the valve discs rest on the tray deck to almost close off completely the tray deck perforations thus minimizing tray open area. As the vapour rate rises, the valve discs are lifted from the tray deck which increases the open area for vapour flow between the valve disc and the tray deck. The effective operating range of valve trays is dependent on specific service conditions as well as pressure drop limitations and can be as high as 10:1.

3. Fixed Valve Trays:

Fixed valve trays are manufactured by punching and forming integral valves over the tray deck. By punching the fixed slots in a parallel to liquid flow arrangement, the fixed valve tray gives higher capacity than the sieve tray with a greater availability for turndown.

4. Bubble Cap Trays:

Bubble cap trays consists of bell shaped caps fixed to cylindrical risers through which the vapour passes the tray deck. The caps divert the vapour flow below the level of liquid on the tray deck where it is jetted into the liquid either through slots at the bottom of the cap or else between the skirt of the cap and the tray deck.

Conclusion:

Considering all the facts associated with performance enhancement of the column, it is found that the geometry of the trays plays a major role. Besides having a higher pressure drop, bubble cap trays are found to be the most reliable, promising & offers a better vapour liquid contact which results into the desired separation than any other type of trays.

References

