ENGINEERING THE FUTURE

Emily Ruhl and Michael Krela, Koch-Glitsch, USA, explore the development of distillation tray valve types and consider how operators can best align valve selection with current demands and future challenges.

As the refining and chemical industries evolve, so does the focus on maximising energy efficiency and operational capacity. Distillation accounts for approximately 40% of energy consumption in refining and chemical processing[1] and 6% of total energy use in the US.[2] The design of distillation internals, particularly the selection of tray valve types, is an important decision that can strongly influence the energy efficiency and capacity goals of a plant. A poorly operating tower can significantly increase its energy consumption. Understanding how different valve types perform under varying conditions can simplify valve selection decisions and better align column design with long-term energy and capacity goals.

History of valves

Distillation trays have been used for centuries, with the earliest consisting of simple holes in the deck (sieve trays). Another early design was the 'bubble cap', a large, formed cap patented by Cellier-Blumenthal in 1815.[3] Both devices served the industry for over a century, with the bubble cap tray used in services with a wide operating range. In the 1950s, movable valve trays were developed. These were smaller devices than bubble caps and improved on sieve trays with additional capacity and turndown by providing a cover over the hole. In the early 1990s, valves that are punched directly from the deck material were developed, which enhanced both capacity and reliability. In recent years, valve performance has been further optimised, and several new valve devices have been developed to increase capacity and efficiency compared to earlier generations.

Operating conditions

Valve performance is directly related to the active area performance of the tray. While the valve type has some effect on the downcomer performance, the main impact of valve

Figure 1. Valve types: sieve holes (left), T valves (middle), FLEXIPRO® floating valve (right).

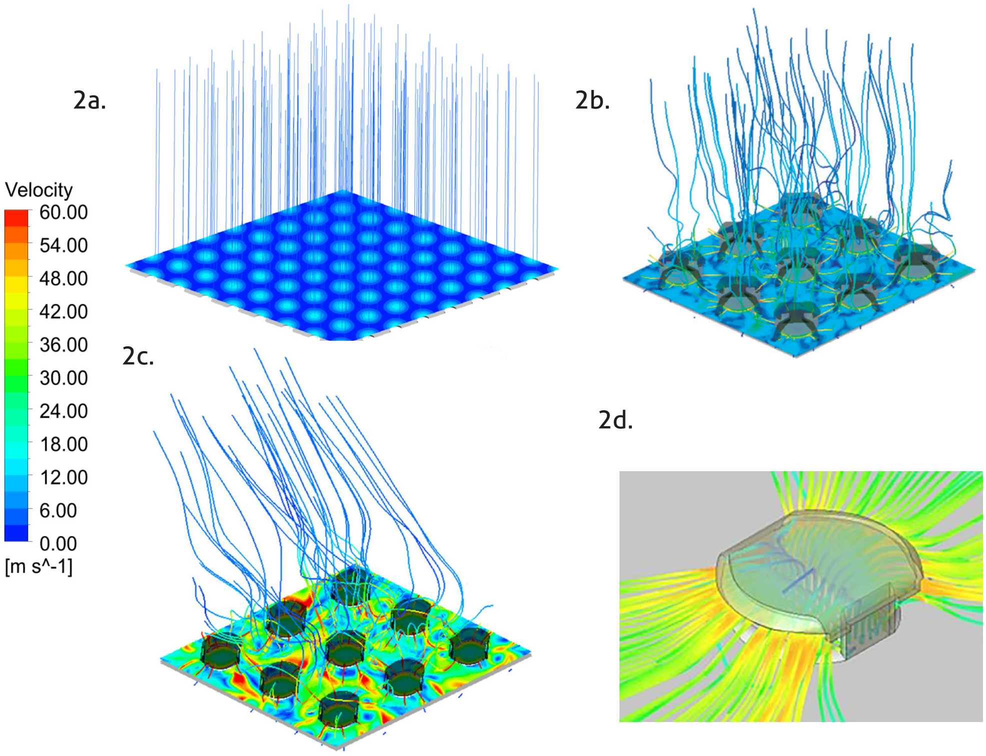

Figure 2. CFD images of sieve holes (2a), T valves (2b), and FLEXIPRO valves (2c and 2d).

performance is on the deck area. Tray efficiency depends on effective vapour and liquid interaction, which is achieved through uniform contact across the tray and thorough mixing at the deck level. Any inefficiencies in vapour and liquid contact across the tray will result in a greater energy requirement to make the separation, leading to energy inefficiency which is counter to plant sustainability goals.

The upper limit of efficient operation is defined by jet flooding, which is where a large percentage of the liquid hits the tray above (entrainment). Eventually, this leads to the column filling with liquid which makes the column inoperable.

Weeping, the lower limit of efficient operation, occurs when there is insufficient vapour pressure and liquid falls down onto the tray below through the openings in the deck, bypassing the contacting area on the tray. Weeping at the inlet of the tray is the worst type since the liquid misses contact on two tray levels, dropping near the downcomer below. This can cause inefficiency at minimum rates where more energy is required to maintain the vapour pressure and keep the efficiency at an operable level.

Valve features

The feature set of an active device will have a direct influence on its performance. By examining the specific features a device has, operators can directly correlate this to the performance in the tower.

The most basic deck device is the sieve hole. This is simply a hole in the deck without any added features to direct vapour flow or prevent liquid from weeping through the opening.

Movable valves, such as type T valves, have a cage and moving valve cap over the deck hole. This gives the hole some protection from liquid weep at low vapour rates and blocks the hole as the valve closes.

The latest generation of valves have a variety of features to enhance efficiency, capacity, and turndown performance. FLEXIPRO® floating valve trays have a shaped cap that directs the vapour flow to leave the valve in a downward fashion. The valve shape, with a narrower downstream leg, helps create a forward pushing action which helps minimise gradients in the froth. The hole is extruded upward, creating a barrier to help prevent liquid from weeping through the hole. The floating valve also includes a moving cap that is able to close at reduced vapour rates to improve vapour distribution and further prevent the liquid from weeping through the cap (Figure 1).

Evaluation of valves using CFD

Computational fluid dynamics (CFD) simulations model fluid behaviour by using numerical methods to solve equations governing fluid flow. CFD techniques have been specifically developed to help analyse valve efficiency and capacity. These techniques can be used to model the valve features that were previously discussed and to provide a visual representation of how the features impact performance.

Vapour velocity vectors leaving the valve correspond to how well the vapour and liquid mix, and are also related to the capacity of the device.

Looking at the basic sieve hole, vapour exiting the hole has an upward only trajectory and no mixing on the deck level. This can be seen in the CFD image of that device in Figure 2a.

Conventional moving valves, like the T valve, have a cover over the deck orifice to help prevent the liquid from weeping when the tray is operating at reduced vapour loads. The trajectory of the vapour is still generally in the upward direction and there is little mixing between the vapour and liquid at the deck level, as seen in the CFD image in Figure 2b, with the lowest vapour velocity (blue zones) witnessed at the deck level. This means there is minimal vapour-liquid contact close to the tray deck.

Moving to the latest generation of valves, the CFD of a FLEXIPRO floating valve tray shows how the downturned cap on the valve directs the vapour to leave the valve downwards (Figure 2d). The downward vapour trajectory reduces the entrainment of liquid to the deck above, which directly translates to greater capacity. The CFD image (Figure 2c) shows that the downward turn also results in more intense mixing at the deck level which enhances the efficiency as shown by the high vapour velocity zones (in red and yellow).

In addition, the forward motion to the vapour as it leaves the valve results in a pushing action, as shown in the CFD image (Figure 2c) by the vapour profile lines pointing in the direction of the liquid flow on the deck. This reduces the amount of entrainment and gradients in the froth profile.

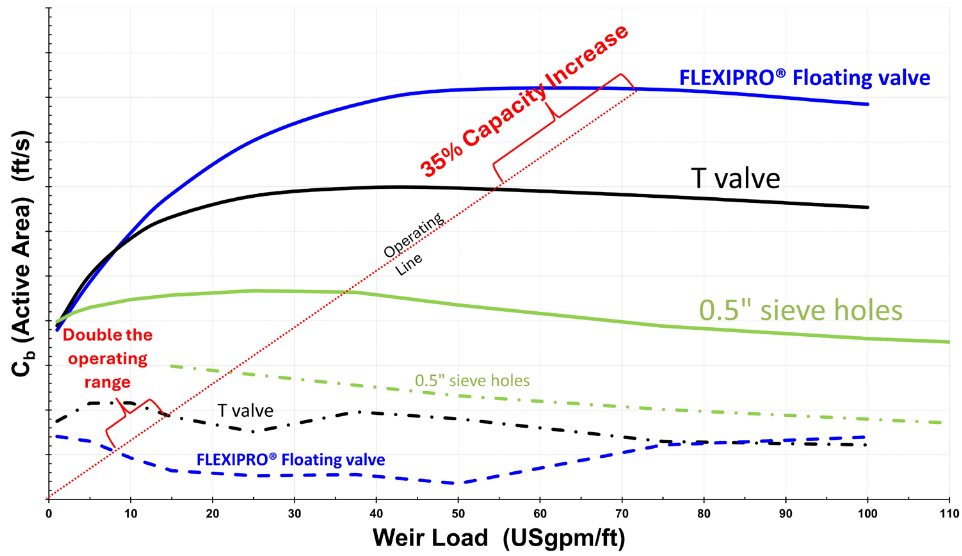

Figure 3. Capacity and entrainment curves for FLEXIPRO Floating valve trays, T valve trays, and sieve trays.

Valve performance

The differences in features can be seen in the data for these valves (Figure 3) in an air/water system comparing sieve holes, the moving T valve, and FLEXIPRO's floating valves. The sieve tray has the lowest capacity and the narrowest operating range. And on the upper end, the floating valve trays have approximately 35% higher capacity than the T valve tray, which is in the middle. The tapered cap and the forward push help contribute to the valve tray's reduced entrainment. The upwards

Figure 4. FLEXIPRO floating valve trays (top) and T valve trays (bottom) operating at high liquid loads (left) and operating at low liquid loads (right).

Table 1. Deisobutaniser sizing comparison

	Sieve trays	Reduced diameter	Reduced height
Valve type	0.5 in. sieve holes	FLEXIPRO floating valve	FLEXIPRO floating valve
Diameter	14 ft - 6 in. ID	12 ft - 0 in. ID	14 ft - 6 in. ID
Height	200 ft	200 ft	140 ft
Tray spacing	24 in.	24 in.	16 in.
Minimum load	60%	15%	20%
Approximate vessel weight	385 000 lb	270 000 lb	285 000 lb
Approximate vessel savings		30%	26%

At a relatively low weir loading of 25 gal./min per ft, some of the turndown enhancement features create a noticeable difference in the froth profile on the tray (Figure 4 right). The T valve tray has no upstream leg protecting it from liquid coming out of the downcomer and the liquid is scooped into the valve opening, particularly at the first row of valves next to the downcomer exit. This inlet weep is detrimental to the efficiency of the tray. The upward trajectory of the vapour creates a clear layer of liquid at the deck level on the T valve tray deck where there is no vapour liquid contact at all. At these conditions, additional energy would be required to maintain the efficiency of the column. The wider upstream leg and extruded orifice protect the floating valve tray from weeping. The contoured cap and pushing action of the valve create a well-mixed, uniform froth across the tray deck and at the deck level. This means that for applications with low liquid load, less vapour is required to maintain the efficiency of the tower, resulting in less energy use.

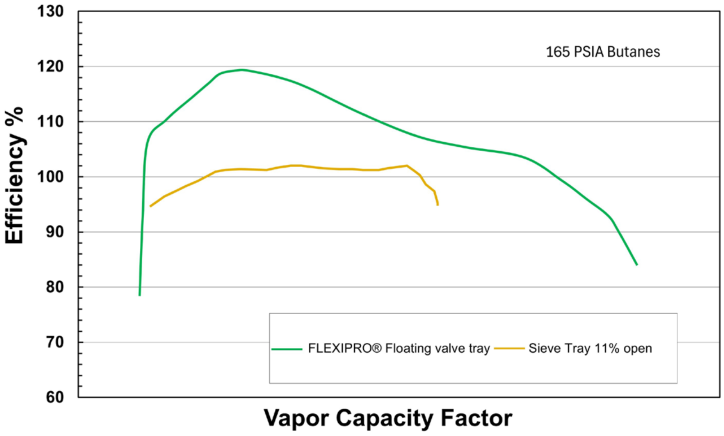

Figure 5. Efficiency curves of FLEXIPRO floating valve trays and sieve trays in a butanes system at 165 psia.

Efficiency

If the efficiency of these devices in a hydrocarbon system is considered, there is a large difference in the efficiency of a simple sieve hole compared to the floating valves (Figure 5). This improved efficiency can directly translate into less energy required for the same separation.

extruded hole results in enhanced turndown performance by preventing liquid from entering the hole.
The floating valve provides double the turndown performance compared to T valves due to its advanced features.

Operational performance

The various valve features can be best compared in an operating pilot column. Koch-Glitsch's air/water test apparatus offers a clear view into the column at various flow conditions. From this, operators can simultaneously see two trays in operation, with the floating valves on the top tray and T valves on the bottom tray. Each tray has the same tray design, with the only difference being valve type. The left image in Figure 4 shows conditions at high vapour rate, where the T valve tray on the bottom level is entraining 10% of the liquid to the tray above, and the floating valve tray on top is in normal operating conditions. The downward turn of the FLEXIPRO valve cap and the push effect of the valve can be seen in the flat froth profile across the flow path. The first few rows of the T valve tray are less active, creating a mountain-like profile that peaks around the middle of the flow path, indicating vapour maldistribution. The disengagement area is less clear above the froth on the T valve deck, which translates to less capacity, while the floating valve tray offers additional capacity. This allows for either a diameter or height reduction for grassroot towers or an increase in capacity for existing columns.

Case study

As shown in the visual analysis, the various features of the latest generation of tray valves translate into better performance. Looking at a deisobutaniser as an example, the vessel size can be reduced, which will result in a large reduction in the capital cost of the tower (Table 1).
In addition, the turndown performance will be enhanced for the valve tray, eliminating the energy inefficiencies that the sieve trays would experience at lower rates.

Conclusions

Decades of tray valve innovation, from early sieve holes to modern floating valve designs, highlight the critical role of advancements in distillation technology. Supported by CFD simulations, test data, and visual observation, these enhanced valve features have been shown to improve energy efficiency, increase capacity, and expand operational flexibility. As the industry continues to prioritise operational excellence and performance, such technologies represent the ongoing evolution of mass transfer equipment to meet current demands and future challenges.

References

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