

## **DISTILLATION TRAY VALVE FEATURES – A VISUAL EVALUATION**

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Emily Ruhl  
Koch-Glitsch, LP  
4111 E 37<sup>th</sup> St N  
Wichita, KS 67220

Karly Davison  
Koch-Glitsch, LP  
4111 E 37<sup>th</sup> St N  
Wichita, KS 67220

### **ABSTRACT**

When it comes to distillation tower internals, choosing between improved capacity, improved separation efficiency, extended operating range, reduced energy consumption/lower carbon footprint, and improved mechanical reliability requires engineering decisions that often result in compromises being made. The choice of which valve type to use is an important part of the tray design that will affect how the design goals are met.

Recent developments in tray valves have largely eliminated the need to choose between these goals, with the operator benefiting from both reduced capex and increased energy efficiency. Tray valve performance can be evaluated by using visual tools that have been verified with test data. Computational Fluid Dynamics (CFD) is used to investigate the vapor profile of various valve features. Pilot plant videos showing a side-by-side comparison of the current industry standard moving valves with the newest generation of valves at a variety of operating conditions clearly demonstrate the difference in performance in an operating tower. These visual methods are confirmed by the data collected in pilot testing.

Case studies featuring gas processing applications are also discussed to demonstrate how advanced valve features can lead to improvements in capacity, operating range, and efficiency in both new and existing columns.

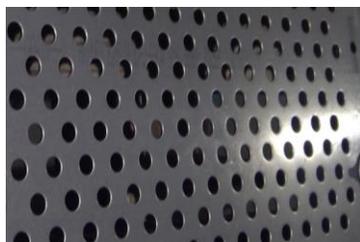
## DISTILLATION TRAY VALVE FEATURES – A VISUAL EVALUATION

*Emily Ruhl, Koch-Glitsch, Wichita, KS*

### Introduction

As the refining and chemical industries continue to advance, the emphasis on achieving optimal energy efficiency and maximizing operational throughput has become increasingly critical. Distillation processes alone account for nearly 40% of the energy consumed within refining and chemical manufacturing sectors<sup>1</sup>, representing approximately 6% of total energy usage across the United States<sup>2</sup>. Distillation internal design parameters, particularly the choice of tray valve type, plays a pivotal role in shaping both the energy profile and capacity objectives of a facility. The configuration and features of these valves directly influence vapor-liquid contact and mass transfer efficiency. Inefficient tower operation can lead to substantial increases in energy consumption. Therefore, a comprehensive understanding of how various valve designs perform under diverse operating conditions is essential. This knowledge streamlines the valve selection process and ensures that column design is aligned with long-term energy and capacity targets.

Distillation trays have been used for centuries. The earliest trays, sieve trays, had simple holes in the deck (Figure 1). Around the same time, Cellier-Blumenthal patented the “bubble cap” in 1815<sup>3</sup>, a large, formed cap that covers a riser from the deck (Figure 2). Both devices served the industry for over a century, with the bubble cap tray preferred in services where a wide operating range was required.



**Figure 1:** Sieve Tray

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<sup>1</sup> Optimize Energy Use in Distillation, Douglas White, Chemical Engineering Progress, March 2012

<sup>2</sup> Reducing Distillation Column Energy Usage, Jim Cahill,

[https://www.emersonautomationexperts.com/2010/industry/downstream-hydrocarbons/reducing\\_distil/](https://www.emersonautomationexperts.com/2010/industry/downstream-hydrocarbons/reducing_distil/)

<sup>3</sup> Best of Both, Nieuwoudt, Penciak, Spencer, Hydrocarbon Engineering, July 2007



**Figure 2:** Bubble Cap Tray

In the 1950's, movable valve trays were developed. These were smaller, movable devices, that had higher capacity than bubble caps and improved on the turndown of sieve trays by providing a cover over the hole (Figure 3). In the early 1990's, valves that are punched directly from the deck material were developed (Figure 4). These improved further on capacity over the movable valves and provided additional reliability. In recent years, valve performance has been further optimized, and several new valve devices with additional features have been developed to increase capacity and efficiency compared to earlier generations.



**Figure 3:** Moving FLEXITRAY<sup>®</sup> Valve Tray (T valve)



**Figure 4:** Punched VG-0 Type MINIVALVE<sup>®</sup> Tray

Because of the wide variety of valve devices introduced over the years, the task of choosing the correct valve for a specific application is not an easy one. Previously, an engineer would have to rely on reported test results from tray vendors and potentially interpret difficult charts to figure out the capacity and turndown capability of the valve type. In many cases, the charts available would not be on the same basis, making comparison even more difficult.

In an effort to make evaluating valve types much easier, Koch-Glitsch has focused on visual analysis of valve performance, allowing the engineer to make a faster, more intuitive evaluation

of how the valve would perform in the column. Computational Fluid Dynamics (CFD) simulations model fluid behavior by using numerical methods to solve equations governing fluid flow. CFD techniques have been specifically developed to help analyze valve efficiency and capacity. These techniques can be used to model the valve features and to provide a visual representation of how the features impact the performance of the valve. Vapor velocity vectors leaving the valve correspond to how well the vapor and liquid mix and are also related to the capacity of the device.

### Operating Conditions

Capacity of a tray can be divided into two different parts of the tray; the active area and the downcomer. The downcomer performance has little to do with the valve choice, so the main parameter of focus is the active area when evaluating valve performance. Tray efficiency depends on effective vapor and liquid interaction, which is achieved through uniform contact across the tray and thorough mixing at the deck level. Any inefficiencies in the vapor and liquid contact, such as uneven flow or segregation between the vapor and liquid, will result in more energy required to make the separation, resulting in an energy inefficiency which is counter to plant sustainability goals.

The upper limit of efficient operation is defined by jet flooding. At this condition, a large amount of liquid entrains to the tray above. This causes the liquid to recycle back to a tray after it has already reached equilibrium, causing the efficiency of the column to decline. As this entrainment increases further, the column fills up with liquid, making the column inoperable.

Weeping occurs at the lower limit of efficient operation. This occurs when there is insufficient vapor pressure drop 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 of weep since the liquid misses contact on two tray levels, dropping near the entrance to the downcomer on the tray below. This can cause inefficiency at minimum rates where more energy is required to maintain the vapor pressure drop and keep the efficiency at an operable level. Weeping at the outlet of the tray, near the outlet weir, is less critical since the liquid has contacted vapor across the tray and is only bypassing the downcomer.

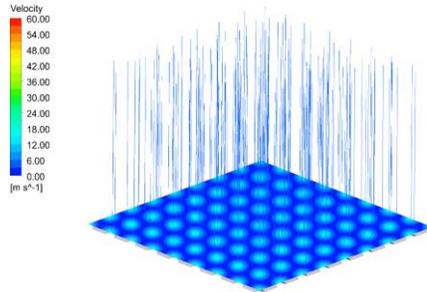
### Valve Features

The features of an active device will have a direct influence on its performance. By examining the specific features of a device, and verifying them with CFD, we 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 vapor flow or prevent liquid from weeping through the opening. Looking at the CFD of a basic sieve hole (Figure 5), the first portion of the CFD analysis shows the vapor path leaving the hole. We can see that the vapor exiting the hole has an upward trajectory with minimal horizontal spreading. Without any protection over the hole, vapor will carry the liquid upward meaning that the capacity limit is reached relatively quickly. The second part of the CFD is of the deck level, showing the vapor velocity close to the deck. This shows areas of blue, indicating large zones of liquid on the deck that does not interact with the vapor. This lack of vapor and liquid mixing will impact the efficiency on the deck.

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**Figure 5:** CFD of a Sieve Tray

If we look at an operating tower with sieve holes (Figure 6), we see this upward trajectory in the froth profile. The vapor is carrying the liquid up in jets off the deck, there is little separation between the “jets” on the deck and the tray above which indicates that the capacity is limited.



**Figure 6:** Sieve Tray in Operation

Bubble caps consist of a riser, often welded to the deck, and a cap that goes over the top. They are still used for low liquid rate applications since there is no hole in the deck for liquid to fall through as the vapor rate decreases. In the CFD image (Figure 7), we see the vapor exit the bubble cap in the downward direction. Although the area taken up by the cap itself means that the vapor and liquid have a limited amount of space to contact, which will limit the capacity.

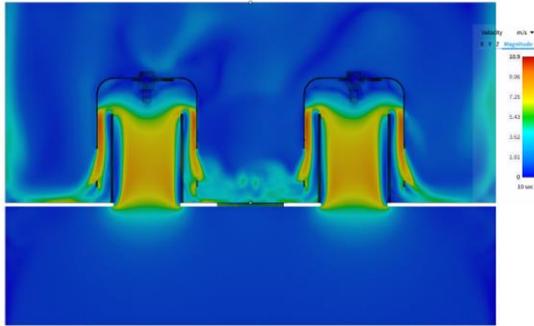


Figure 7: CFD of Bubble Cap

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 vapor rates and blocks the hole as the valve closes. Looking at the CFD of a T valve (Figure 8), the trajectory of the vapor is still generally in the upward direction, carrying the liquid with the vapor directly upward. We also see a good number of blue zones on the CFD, indicating little mixing between the vapor and liquid at the deck level, impacting the efficiency of the tray.

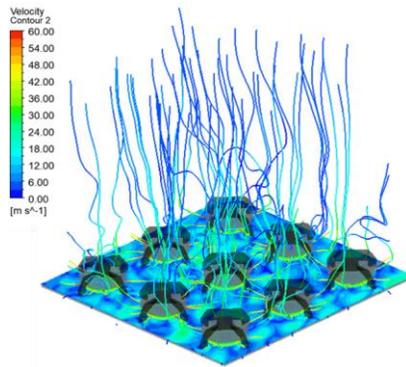


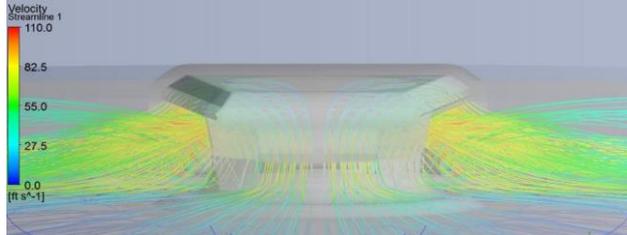
Figure 8: CFD of a T Valve Tray

The latest generation of valves have a variety of features specially designed to enhance efficiency, capacity and turndown performance. FLEXIPRO<sup>®</sup> floating valve trays (Figure 9) have a contoured cap that directs the vapor flow leaving the valve downwards. The valve shape, with a narrower downstream leg, helps create a forward pushing action which helps minimize gradients in the froth. The deck hole is extruded upward, creating a barrier to help prevent liquid from weeping through the hole. The FLEXIPRO<sup>®</sup> floating valve also includes a moving cap that is able to close at reduced vapor rates to improve vapor distribution and further prevent the liquid from weeping through the cap.

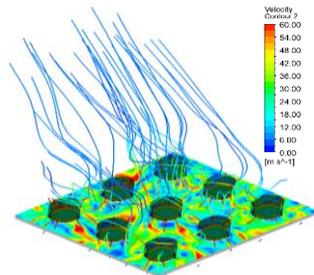


**Figure 9:** FLEXIPRO® Floating Valve

If we look at the CFD of a FLEXIPRO® floating valve tray (Figure 10), the downturned cap on the valve directs the vapor leaving the valve downward. The downward vapor trajectory reduces the entrainment of liquid to the deck above, which directly translates to more capacity. The CFD image (Figure 11) shows that the downward turn also results in more intense mixing at the deck level that enhances the efficiency as shown by the high vapor velocity zones (in red and yellow). In addition, we can see the forward motion to the vapor as it leaves the valve, resulting in a pushing action, as shown in the CFD image (Figure 11) by the vapor profile lines pointing in the direction of the liquid flow on the deck. This reduces the amount of entrainment and reduces gradients in the froth profile.



**Figure 10:** CFD Image of a FLEXIPRO® Valve



**Figure 11:** CFD Image of a FLEXIPRO® Valve Tray Deck

We can compare the different features of the T valve and the FLEXIPRO® floating valve. Koch-Glitsch's air/water test apparatus gives the view of two trays in operation simultaneously, with the FLEXIPRO® Floating valves on the top tray and T valves on the bottom tray (Figure 12). Each tray has the same tray design, with only the valve type differing between the two trays. The first image shows conditions at high vapor rate, where the T valve tray on the bottom level is entraining 10% of the liquid to the tray above and the FLEXIPRO® floating valve tray on top is in normal operating conditions. The downward turn of the FLEXIPRO® floating valve cap and the push effect of the valve can be seen in the froth profile with a flat froth profile across the flow path. The upward trajectory on the T valve creates a mountain-like, non-uniform profile of froth that peaks around the middle of the flow path, indicating vapor maldistribution. We also see less clear disengagement area above the froth on the T valve deck, which translates to less capacity, while the FLEXIPRO® floating valve tray has additional capacity to spare as indicated by the space between the froth and the tray above.

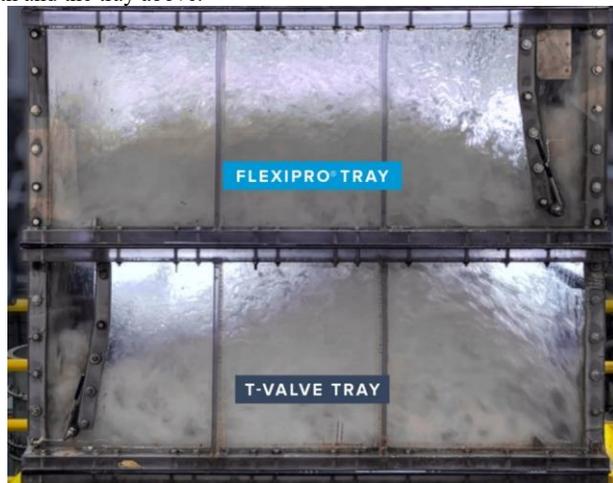


Figure 12: FLEXIPRO® floating valve trays (top) and T valve trays (bottom) operating at high liquid loads

At a relatively low weir loading of 25 gpm/ft, we see some of the turndown enhancement features creating a noticeable difference in the froth profile on the tray (Figure 13). The T valve tray has nothing 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 as the liquid bypasses two trays worth of contact. The upward trajectory of the vapor creates a clear layer of liquid at the deck level on the T valve tray deck where there is no vapor 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 FLEXIPRO® 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 also at the deck level. This means that for applications with low liquid load, less vapor is required to maintain the efficiency of the tower, resulting in less energy use.

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Commented [TY4]: Refer to Figure 12



Figure 13: FLEXIPRO® floating valve trays (top) and T valve trays (bottom) operating at lower liquid loads.

Going down to extreme low liquid rates of 1 gpm/ft weir load, we can still see the difference between the valve types in the operation (Figure 14). This would be similar in operation to a Glycol Contactor or wash trays in an Amine Regenerator. The T valve tray has dry zones on the deck where the vapor has carried the liquid up into a spray above the deck which is not ideal for efficient mass transfer. On the FLEXIPRO® valve tray, the downward turn on the cap, the extruded orifice and the moving valve means we still see a froth level on the deck where the vapor and liquid are mixing efficiently.

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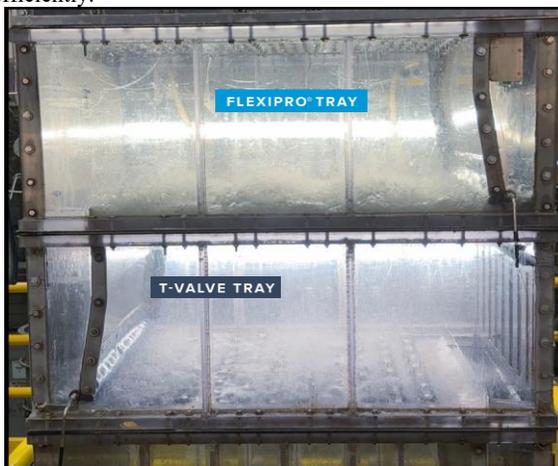
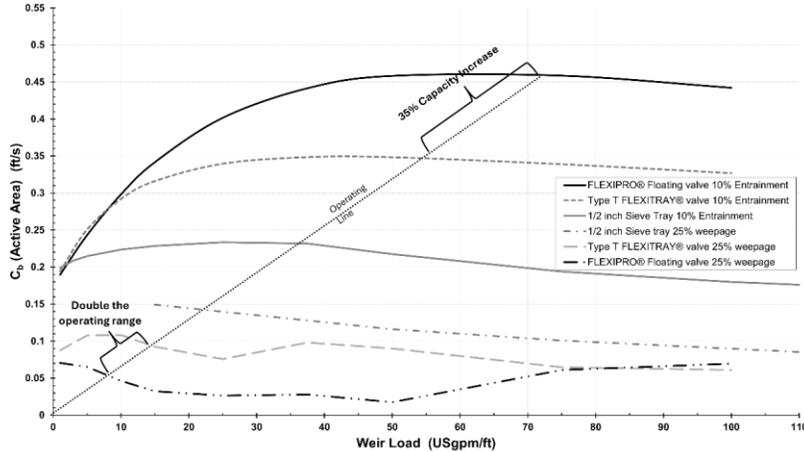


Figure 14: FLEXIPRO® floating valve trays (top) and T valve trays (bottom) operating at extreme low liquid loads

## Capacity Curves of Different Valve Types

These visual observational methods are also supported by the operational data. In the same air/water system used in the pilot column, we can compare the capacity curves of sieve trays, T valves and FLEXIPRO® valve trays (Figure 15). Unsurprisingly, based on the CFD images and view of the operational column, the sieve tray has the lowest capacity and also starts to weep first. On the upper end, FLEXIPRO® valve trays have approximately 35% higher capacity than the T valve tray, which is in the middle, showing that the additional valve features that give a better vapor profile translate into additional capacity. On the turndown performance, FLEXIPRO® valve trays with the extruded orifice in the deck, experience less weep than T valves do, doubling the operating range. This measured weep does not even account for the difference in weep location that we are able to see in the operating column.

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**Figure 15:** Capacity curves for FLEXIPRO® floating valve trays, T valve trays and sieve trays at 18'' tray spacing in an air/water test apparatus.

What this difference in capacity means is that in an existing tower that is not downcomer limited, a simple deck replacement which changes older tray valve technology to something with advanced features, can achieve a higher throughput to the column.

## Case Studies

As shown in the visual analysis, the various features of the latest generation of tray valves translate into better performance. Looking at an Amine Contactor 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 can be improved by using FLEXIPRO® valve tray, eliminating the energy inefficiencies that the sieve trays would experience at lower inlet gas rates.

**Table 1: Amine Contactor Sizing Comparison**

	Sieve Trays	Reduced Diameter	Reduced Height
Valve Type	0.5" sieve holes	FLEXIPRO® floating valve	FLEXIPRO® floating valve
Diameter	14'-6" ID	12'-0" ID	14'-6" ID
Height	200 ft	200 ft	140 ft
Tray Spacing	24"	24"	16"
Minimum Load %	60%	15%	20%
Approx. Vessel Weight	385,000 lbs	270,000 lbs	285,000 lbs
Approx. Vessel Savings		30%	26%

Seeing that FLEXIPRO® valve tray's features provide efficient performance at low weir loads, we can apply this valve to a Glycol Contactor in place of bubble cap trays. Sizing a TEG contactor for a gas rate of 80 MMSCFD and a glycol rate of 18 gpm, we see a significant reduction in tower diameter by using a movable valve with turndown features combined with the capacity enhancing features (Table 2).

**Table 2: TEG Contactor Sizing Comparison**

	Bubble Cap Trays	FLEXIPRO® Valve Trays
Diameter	60" ID	48" ID
Height	37 ft	37 ft
Tray Spacing	24"	24"
Minimum Vapor Load Requested %	33%	33%, up to 15% possible
Approx. Vessel Weight	60,000 lbs	40,000 lbs
Approx. Vessel Savings		33%

## Conclusions

Visual methods to evaluate tray valve design and performance have evolved as the valve features have also evolved. As the industry continues to prioritize operational excellence, the adoption of advanced valve features that have been visually validated will be essential for optimizing column performance and meeting the evolving demands of gas processing.