Consider Moving to Fixed Valves

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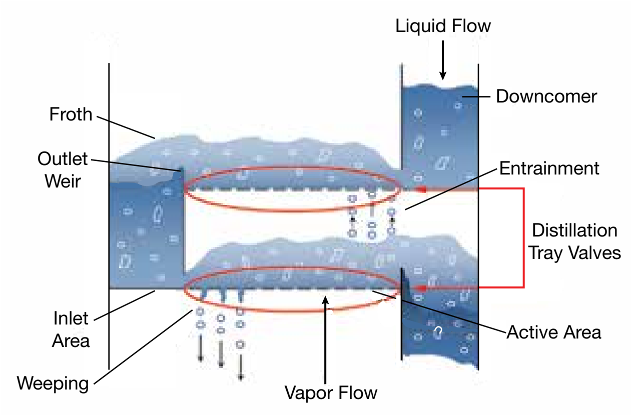
CPI companies are switching to fixed valves despite a slight loss in operational flexibility. Fixed valves offer better reliability, fouling resistance, and more robust valve designs.

Distillation is an essential separation technology for a wide range of applications in the chemical process industries (CPI). Of critical importance to the separation are the mass-transfer devices on distillation trays that create intimate mixing of the liquid and vapor.

The most common types of mass-transfer devices for conventional cross-flow trays (Figure 1) are moving valves and fixed valves. Although moving valves provide operational flexibility, many CPI companies have started selecting fixed valves. They are willing to accept the loss of some operational flexibility to gain benefits provided by fixed valves, including better reliability, fouling resistance, and more robust valve designs that can better withstand operational upsets.

This article discusses moving valves and fixed valves, explains their advantages and disadvantages, and offers guidance on selecting the appropriate valves for distillation trays. The article also includes several examples that illustrate the benefits of fixed valves.

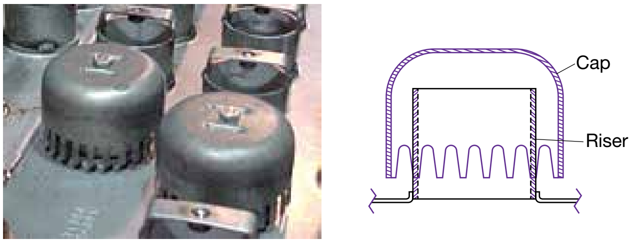


▲ **Figure 1.** In a conventional cross-flow distillation tray, liquid moves down as vapor moves up.

Bubble-cap trays and sieve trays

Before discussing fixed and moving valves, it is important to first discuss two non-valve tray designs — bubble-cap trays (Figure 2) and sieve trays (Figure 3) — that were used in the early days of industrial distillation. These provide a reference point against which to compare other designs.

Bubble-cap trays have been in use since the early 1800s *(1)*. The bubble-cap tray contains holes with a riser on each hole covered by a cap. Vapor passes through the riser as



▲ **Figure 2.** A bubble-cap tray has risers on each hole with caps covering the risers.

▲ **Figure 3.** Sieve trays have round holes punched or drilled into the tray.

it moves upward and is forced downward by the cap, and then it moves back up as it bubbles through the liquid on the tray. Bubble-cap trays require extensive labor and more materials to produce than extruded fixed valves, and therefore are significantly more expensive (by a factor of 2–3). Although very common in older plants, bubble-cap trays have fallen out of favor for general distillation use due to their high cost.

Bubble-cap trays do have advantages and are appropriate for some low-liquid-rate niche applications, as well as applications with widely varying vapor loads. If designed and installed properly, bubble-cap trays do not weep. If weeping occurs on a bubble-cap tray, it is the result of improper design or incorrect installation. A well-sealed bubble-cap tray can have almost infinite vapor turndown (ignoring tray activity, which is discussed later).

Sieve trays, which contain round holes cut or punched through the tray deck, were developed around the same time as bubble-cap trays. In contrast to bubble-cap trays, sieve trays are relatively easy to produce, as production involves simply creating round holes in the tray deck. While sieve trays are inexpensive to produce, they generally do not perform as well — in terms of capacity, flexibility, and fouling resistance — as other mass-transfer devices.

Sieve trays begin to experience entrainment at lower vapor flowrates than fixed-valve or moving-valve trays. Unlike on a valve tray, where vapor is deflected horizontally as it exits a fixed or moving valve, vapor exiting the holes of a sieve tray moves vertically. The vertically directed vapor creates higher froth heights, increasing the potential for entrainment.

This vapor deflection increases the vapor velocity on the tray deck around fixed or moving valves, which helps prevent zones of stagnation where solids can deposit, polymerization can begin, or corrosion can occur. Thus, valve trays offer more fouling resistance than small-hole sieve trays.

Valves

Although bubble-cap and sieve trays are sufficient for certain applications, valve trays have become the most common mass-transfer devices in the CPI. The vapor deflection helps induce more intimate vapor-liquid contacting than is experienced on sieve trays, and valve trays are less expensive than bubble-cap trays.

The valves can be fixed or moving. Fixed valves are permanently open, while moving valves are lifted open by the vapor flowing up through the tray holes.

Moving valves

After its introduction in the early 1950s, the modern moving-valve tray (Figure 4) became a standard for distillation in the chemical industry. Its chief advantage is that its variable vertical movement accommodates a wide operating range. The range of a valve's movement is determined by either the length of the valve legs that protrude through the tray deck orifice (Figure 5, left and right images), or by a cage assembly (Figure 5, center) that restricts vertical movement.

To take advantage of the moving valve's wide operating range, an operator can simply turn up or turn down the vapor flowrate within a certain operating window. Moving valves can generally achieve a nominal turndown (*i.e.*, the ratio of the maximum vapor flowrate to the minimum vapor flowrate) of 4:1.

Turndown ratio is primarily a function of available pressure drop. As the vapor flowrate decreases, so does the pressure drop across the tray. When the tray pressure drop becomes too low, the tray begins to weep, which causes the efficiency of the column to decline. On a moving-valve tray, however, some of the valves begin to close when the vapor flowrate decreases, reducing the effective open area of the tray and limiting the tendency to weep.

Another factor affecting turndown for moving-valve trays is tray activity. As the vapor flowrate decreases, so does the number of valves on the tray actively bubbling vapor. This is particularly important for multipass trays, which typically require a higher vapor flowrate to ensure that all passes are actively bubbling vapor. Tray efficiency declines sharply if one pass becomes inactive. The more flow passes a tray has, the more difficult it is to ensure complete activity on that tray.

One way to improve the turndown performance of moving-valve trays is to install the valves in rows of alternating metal thickness (*e.g.*, alternate 14-gauge and 16-gauge). Using valves of slightly different weights gives the designer control over which valves close first as the vapor flowrate decreases. This design can extend the operating range beyond the 4:1 turndown mentioned previously. Turndown ratios of 10:1 are possible with properly designed moving valves, provided the available pressure drop and tray spacing are reasonable and the system is nonfoaming.

While the standard moveable valves provide a high hydraulic turndown ratio and are more efficient than sieve trays, they also have disadvantages:

• Because they typically have more surface area available

▲ **Figure 4.** A moving-valve tray has valves that move up and down.

▲ **Figure 5.** Moving valves come in several shapes and sizes, including round valves with legs that protrude through the tray orifice (left), caged assemblies (center), and rectangular valves (right).

for the deposition of contaminants, moving valves are more prone to fouling than fixed valves. This is a serious concern for towers operating in severe environments that have a much higher potential for particulate deposition caused by dirt and debris, various forms of corrosion (*e.g.*, from acids), dewpoint salt formation, and, in some cases, polymerization.

- As moving valves open and close, the valve legs can contact the edges of the orifice, which can cause erosion and increase corrosion.
- Fouling or polymer deposition can cause moving valves to stick to the tray deck. To eliminate sticking, most valves are equipped with dimples that prevent complete contact between the valve cap and the tray deck. However, the small escape area provided by the presence of dimples can increase liquid weeping at low vapor flowrates.
- If subjected to an unexpected process upset, moving valves can pop free from their orifices, leaving behind *de facto* sieve holes, which have lower capacity and efficiency than valves.
- Moving valves are more expensive than conventional fixed valves, because more labor and material are required to manufacture them. A general rule of thumb is that moving valves are 10–15% more expensive than conventional fixed valves.
- If trays with moving valves are operated at excessively low vapor flowrates (very high turndown), like fixed valves, they will also experience reduced tray efficiency.

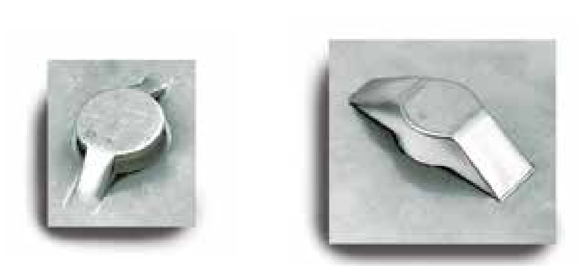
Fixed valves

The simplest fixed valves (Figure 6) are formed from the same piece of metal as the tray deck. Large metal-punching (or stamping) machines impart a tremendous amount of force on a relatively small area of metal sheet to extrude the valve from the tray deck. During this process, the metal is actually stretched from its initial state.

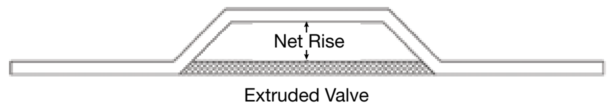
Fixed-valve trays made in this way have no moving parts and are rugged and durable. Thus, they do not suffer from the sticking, popping, and erosion and corrosion associated with moving valves. And, the relatively large opening between the valve and the deck makes extruded fixed valves resistant to fouling. Fixed valves can be manufactured with different heights, and, if necessary, can be made with a higher net rise (Figure 7) to provide more resistance to fouling.

In addition, the hydraulic capacity is inversely proportional to the size of the valve opening — the smaller the opening, the higher the capacity. And, the lower the net rise, the less entrainment that can be expected. Smaller-opening and lower-net-rise extruded fixed-valve trays are often used in heavily loaded tower sections, such as direct-contact heat-transfer pump-around zones.

Another benefit of extruded fixed valves is their ability to withstand process upsets. Due to their durable construction, the mechanical reliability of fixed valves makes them good choices for towers that require an uplift rating to guard against damage. Uplift refers to the forces that the metal internals in a distillation tower are subject to during upset conditions. It can occur, for example, when water is introduced into hot oil and the water rapidly expands as it transforms into steam, when a circulating pump stops working, or when the level of the bottoms liquid becomes so high that it covers reboiler vapor returns.



▲ **Figure 6.** The simplest fixed valve is an extruded hole and cover with small-diameter (left) or large-diameter (right) orifices.



▲ **Figure 7.** The net rise of a fixed valve is the vertical distance from the tray deck to the underside of the valve apex.

Enhanced-fixed-valve designs

As they processed thicker metals and/or metals that could not tolerate as much stretching, mass-transfer equipment suppliers realized that the net rise improvements they could achieve became limited.

One way to address the limitations is a fixed-valve tray that combines large orifices in the deck with separate cover pieces that overhang the openings (Figure 8). The large orifice is similar in size to moving-valve orifices and larger than conventional, high-performance, fixed-valve orifices. The cover pieces have a unique tapered shape that, in effect, pushes the liquid flowing across the tray and prevents the formation of stagnant liquid on the tray deck. This feature also suppresses weeping, since the orifice is well-protected from the momentum of the liquid crossing the tray deck. And, the cover redirects the vapor horizontally from the valve cover, which promotes an even and low froth height, promotes vapor-liquid contacting, and suppresses jet flooding. This unique valve-tray design has excellent fouling resistance and is far superior to moving valves and conventional extruded fixed valves. Unlike extruded fixed valves, the tapered orifice covers cannot be fabricated by extrusion and must be assembled separately.

Mechanical testing showed that this valve construction is very durable and not prone to the problem of dislodging that sometimes occurs with traditional moving valves; in most situations, the tray structure would fail long before the valves could be dislodged. Hence, like trays with extruded fixed valves, the enhanced-fixed-valve tray construction is reliably durable.

Computational fluid dynamics (CFD) modeling was used to compare the predicted vapor flow from an enhanced fixed valve to the vapor flow from a conventional extruded fixed valve (Figure 9). The vapor flow from the enhanced fixed valve is more horizontal than that of the conventional fixed valve; this more horizontal vapor profile enhances mass transfer and aids in preventing fouling material from settling on the tray or around the orifices.

▲ **Figure 8.** An enhanced fixed valve consists of a large orifice in the deck combined with a separate cover piece that overlaps the orifice.

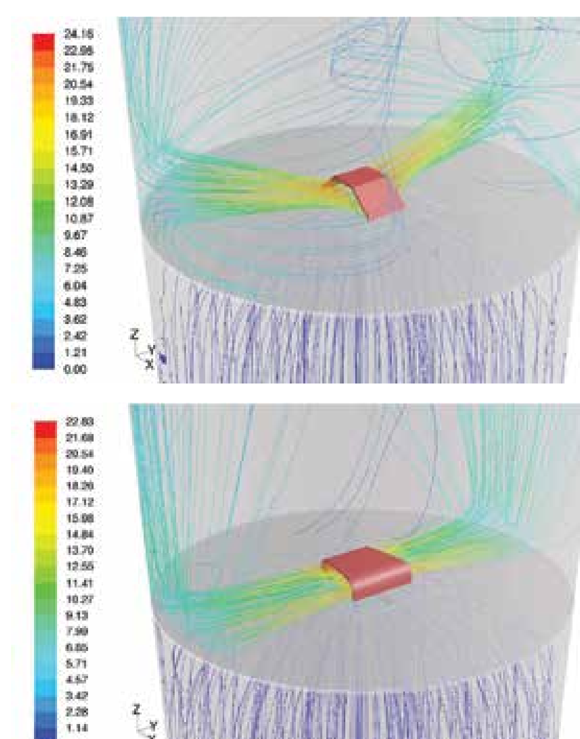
The CFD results show that the enhanced fixed valve eliminates the vertical component of the vapor distribution from a conventional extruded fixed valve. As noted previously, smaller valves tend to have higher capacity, and lower-net-rise valves tend to have less entrainment. The enhanced valve stands out because even though it is a larger valve, it achieves high performance, with a capacity approaching that of a smaller traditional fixed valve. Additional advancements to the enhanced fixed valve have focused on improving vapor-liquid mixing on the tray deck, which reduces liquid entrainment and thus increases tray separation efficiency and capacity.

Enhanced fixed valves are slightly more expensive than extruded fixed valves because their construction process requires the fabrication of the separate cover piece. Their cost is comparable to that of traditional moving valves; however, the benefits of enhanced-valve trays typically justify the incremental cost.

Valve selection

Whether considering distillation tray valves for a new tower or for a revamp, ask these two important questions:

1. Do I need a large operating range for my process?
2. Do I have a severely fouling process?



▲ **Figure 9.** CFD modeling compares the vapor flow through a conventional extruded fixed valve (top) and an enhanced fixed valve (bottom).

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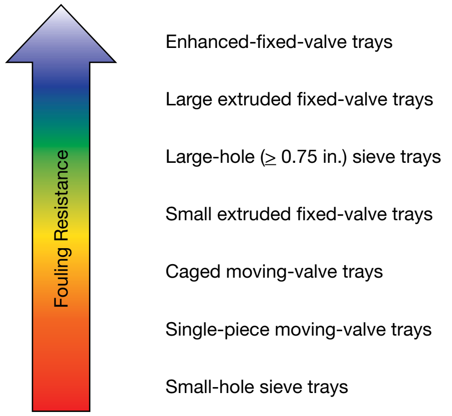
Operating range. In the petroleum refining industry, when profit margins are strong, companies tend to run operating units at full capacity (or beyond design rates, if possible), and not much variance in the hydraulic capacity of the trays is needed. While it may be desirable to run some units at minimum rates during periods of low economic margins or during maintenance on related units, very few units in refineries likely operate at less than 50% of their maximum rate. Changes in market conditions and unique product inventory-management considerations might make it necessary for chemical plants to operate units at rates less than design capacity, but it is unlikely that rates below 50% of design would be sustained for long periods of time.

With this in mind, more companies are shifting toward fixed valves for distillation trays. As a rule of thumb, fixed valves typically have a turndown ratio of 2:1 (although proper design can push the turndown range higher). This turndown on distillation tray hydraulic capacity is close to the hydraulic turndown of other parts of the operating unit (*e.g.,* minimum flowrates of pumps and heaters, control valve sizing, etc.).

Severe fouling. The refining and chemical industries both have severe services, and operating units' run times are often limited by fouling on the distillation trays, which can eventually render some types of valve trays inoperable. Moving valves are more prone to fouling than fixed valves. Thus, when fouling is a problem, moving valves will cause downtime more often. Figure 10 compares the fouling resistance of various mass-transfer devices.

Fouling can occur in many different types of applications. Foulants can be sticky, granular, or film-like. In some processes, the foulants collect on the tops of the trays; in others, the undersides of the tray are affected. In some cases, the foulants enter from an upstream process unit; in others, they are formed inside the trayed tower.



▲ **Figure 10.** Mass-transfer devices provide different levels of fouling resistance. The enhanced-fixed-valve tray provides the most resistance, sieve trays the least.

Here are a few examples of problematic fouling that commonly occurs in the CPI:

• Acrylonitrile (ACN) plants experience fouling in the recovery columns, the head columns, and the drying columns. Polymer fouling can occur from the polymerization of hydrogen cyanide (HCN) and the polymerization of ACN. The use of high-performance fixed valves with directional-flow enhancements (*e.g.*, push valves) combined with the injection of polymer inhibitors help to minimize polymerization and maximize run time.

• In bioethanol plants, the fermentation broth, which contains 10–15% solids, is fed to a beer stripper column that removes the ethanol. The trays in this tower are fouled primarily on the underside but also on the upper side of the trays. Enhanced fixed valves help to mitigate fouling in both areas by reducing the froth heights and driving the foulants across the tray decks.

• The recent substantial increase in light domestic crude oil production in the U.S. is giving oil refiners a readily available alternative feedstock. However, when some of these lighter crude oils are blended with other light crudes or with heavier crude oils, asphaltene — a foulant that will deposit on trays in crude distillation towers — can precipitate *(2)*.

• Olefins plants have several columns that are susceptible to fouling. Ethylene quench columns suffer from fouling by coke fines and by a sticky, oligomer-type foulant. Caustic wash towers can experience the build-up of foulants, typically referred to as red oil, created by aldol-condensation polymerization. Large fixed valves with a high net rise have been successfully used in these towers.

Although fixed valves do offer benefits, they are not as operationally flexible as moving valves. However, this loss of flexibility — a narrower turndown range that precludes running at significantly lower vapor flowrates — is usually a reasonable price to pay to avoid the problems associated with moving valves, such as:

• more fouling than fixed valves, because moving valves have more places for dirt, debris, polymers, and other contaminants to collect

• the potential to stick to the deck, which reduces capacity and tray efficiency

• loss of tray performance if they pop off the deck and entrainment through unrestricted orifices increases

• higher capital expenditures.

Many companies have performed a cost/benefit analysis and determined that the installation of fixed valves with a smaller operating window is adequate for their process and helps avoid some of the disadvantages inherent to moving valves. The following examples illustrate the benefits of switching to fixed valves.

Sour-water stripper

Sour-water strippers *(3)* are often difficult to operate because they process feed streams of widely varying compositions, and they experience severe foaming as well as fouling.

A refinery had two identical sour-water strippers equipped with sieve trays that had 0.5-in. orifices. The towers processed the same sour feed and suffered chronic fouling problems so severe that they required several shutdowns each year for maintenance. The parallel feed arrangement of the two identical sour-water stripper towers presented a unique opportunity to test the performance of new trays under the same conditions as the existing sieve trays.

In the first test, the refiner installed two enhanced-fixed-valve trays in one stripper at a location where the fouling was most severe. After the stripper operated for a typical run length, it was shut down for maintenance and the trays were examined. The two new trays had negligible visual evidence of fouling, while the adjacent sieve trays had considerable fouling and their flow area was reduced by about 90% (Figure 11).

Based on these results, the refiner installed new enhanced-fixed-valve trays throughout the second stripper and then restarted operation. Approximately two weeks later, the first tower was cleaned and restarted, with the existing sieve trays still in place. After a typical run length (130 days), the tower with the sieve trays had to be shut down for cleanout. After the same run time, the sour-water stripper with the new trays was processing sour-water feed at the same rate, yet with no significant increase in pressure drop (Table 1).

A process upset occurred when the sour-water feed was contaminated with caustic, which greatly increased fouling. This provided a third opportunity for testing. At the time of the upset, the sieve-tray tower had been online for 42 days since its last cleanout, while the tower with the enhanced-fixed-valve trays had been online for 191 days. On the eighth day after the upset, the pressure drop of the sieve-tray tower was so high that the feed flowrate was cut in half (Figure 12).

Thirty days after the upset, the sieve-tray tower was taken offline for cleanout. Meanwhile, the tower outfitted with new fixed-valve trays remained online, although the liquid rate was limited to 350–450 gpm. And, 350 days after the upset, the newly trayed tower was still online and processing 350 gpm of sour water. The test results clearly demonstrated the improved performance and fouling resistance of enhanced-fixed-valve trays in sour-water service. The sieve-tray tower was subsequently revamped with new fixed-valve trays.

▲ **Figure 11.** After a sour-water stripper operated for a typical run length, the adjacent sieve (left) and enhanced-fixed-valve (right) trays were examined. The sieve trays had significantly more fouling than the fixed-valve trays.

Solvent-recovery dehydration column

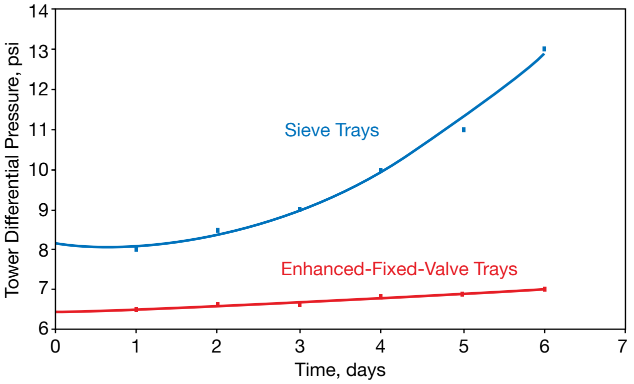
A solvent-recovery dehydration column with sieve trays experienced severe fouling that limited run-length time (Figure 13). Shutdowns were required for cleanout when tower pressure drop became excessive, after approximately 120 days.

The fouling material was a flaky black polymer. To correct the problem, the company installed extruded fixed valves; unfortunately, those fixed valves were too small and the trays had less open area than the sieve trays they replaced. The tower soon became completely fouled; the most severe fouling was toward the bottom of the tower.

The company initially reverted to sieve trays throughout

Table 1. After 130 days of operation, the tower with enhanced-fixed-valve trays was processing more sour-water feed than the tower with sieve trays.

	Tower with 0.5-in. Sieve Trays	Tower with Enhanced-Fixed-Valve Trays
Sour Water Feed, Initial, gpm	480	600
Sour Water Feed after 130 days, gpm	200	550–600
Column Pressure Drop after 130 days	Flooded	No Increase



▲ **Figure 12.** After caustic contaminated the feed, the tower with the sieve trays (blue) experienced a much larger pressure drop than the tower with the enhanced fixed valves (red).

most of the column and enhanced-fixed-valve trays — with the same downcomer area, same weir height, and same downcomer clearance as the sieve trays — in the bottom section. The tower was restarted and achieved a record run length of 197 days (an increase of 65%), and was shut down only for inspection (cleaning was not needed). While the sieve trays in the top section were considerably fouled, the new fixed-valve tray orifices had no signs of fouling, with minimal polymer coating on the tray decks.

Before restarting the column, the operators carefully cleaned the trays in the top section of the column. Ninety days into the run, the tower pressure drop was lower than it was when the column had all sieve trays. The good results of these runs convinced the company to install new enhanced-fixed-valve trays in three identical towers.

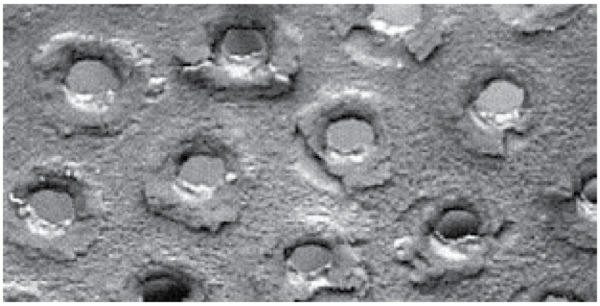
Acryolnitrile production

A European acrylonitrile producer experienced a significant loss in production due to fouling in a recovery column. Fouling was occurring on the active areas of the moving-valve trays; one of the two recovery columns had to be shut down every four months for a lengthy and costly cleanout, during which plant capacity was cut in half.

The company decided to revamp the problem tower to increase the feed flowrate by 10% and to increase its run length. To do this, it replaced the existing moving-valve trays in the active areas with high-performance extruded fixed-valve trays.

After the revamp, the column was started up with no problems. About six months later, reactor problems (unrelated to the recovery column) forced the plant to shut down. The facility's staff took this opportunity to enter and inspect the recovery column — the trays were clean and required no cleanout maintenance whatsoever. After the reactor problems were corrected, the unit started up again and the recovery column operated for more than a year at a 10% higher capacity.

The success of this project prompted the company to revamp the trays in the other recovery column by replacing the moving valves with high-performance extruded fixed valves during the next downtime.



▲ **Figure 13.** Sieve trays in a solvent-recovery dehydration column experienced severe fouling after approximately 120 days in service.

Butadiene plant

A butadiene plant was revamped to increase production. Existing moving valves were replaced with high-performance extruded fixed valves to debottleneck a distillation column. The objectives were to increase column capacity by 15% and eliminate fouling on the trays caused by butadiene polymerization.

Before the revamp, the company had to filter polymer out of the column using dual-strainer filters at the top and bottom of the column. The filters required frequent cleaning, with one filter in service while the other filter was being cleaned.

After the revamp, filter cycling for cleaning was no longer necessary. During a plant shutdown for maintenance, operators inspected the column and found that the trays were clean, with no polymer on the trays. The photos in Figure 14 show the fouled moving-valve trays before the revamp (top) and the clean high-performance extruded fixed-valve trays after operation (bottom).

Tower pressure drop was reduced from about 18 psi before the revamp to about 10 psi after the revamp. In addition, the reflux ratio was reduced from 4.8 to 4.2 while the same product purities were maintained. Energy savings were achieved by a reboiler duty reduction of approximately 9%. The tower capacity was ultimately increased by 32%, which significantly exceeded the target of 15%.

▲ **Figure 14.** Conventional moving-valve trays (top) in a butadiene plant had considerable fouling. The high-performance extruded fixed-valve trays (bottom) remained clean after operation.

▲ **Figure 15.** After operating for one cycle in a coker fractionator, these moving caged valves had considerable fouling.

▲ **Figure 16.** Enhanced fixed valves had little fouling after being in service in a coker fractionator for several years.

Vinyl chloride monomer plant

A VCM producer wanted to debottleneck its ethylene dichloride (EDC) heavy-ends column to increase capacity by 25% and increase run length. The tower experienced frequent shutdowns due to tray fouling.

The company used sieve trays for the EDC heavy-ends column because moving valves were unreliable in this application. A process evaluation indicated that the existing trays were operating at their capacity limits, which was confirmed by a gamma scan. Based on this information and the type of fouling involved, high-performance extruded fixed valves were recommended for the tower revamp.

After the new trays were installed, the unit was started up and a test run was performed to evaluate the effectiveness of the new trays. The unit operated at a 10% higher capacity and the product met the target EDC purity of 99.6%. After two years, the tower was operating at a 24% higher capacity without any problems. The column did not need to be shut down to correct fouling problems. The new trays also proved to be more efficient — the tray spacing in one section of the tower was changed and the revamped tower contained three fewer trays.

Heavy oil service

Fouling is a major consideration in the design of refinery coker fractionators, which process dirty feed in harsh conditions. Figure 15 shows trays from a coker fractionator with moving caged valves after the tower completed one run cycle.

Fixed valves — either large extruded fixed valves or enhanced fixed valves — are strongly recommended for coker fractionator service. The enhanced-fixed-valve tray technology discussed previously has been installed in more than 25 coker fractionators worldwide, in towers ranging in diameter from 6.5 ft to 25 ft. Figure 16 shows trays with these valves after many years of service in a coker fractionator. Notice that while some fouling material accumulated on the valve cover, the orifice and the area around the orifice are virtually clean.

Fixed-valve trays have worked reliably for refinery and chemical plant services, where high temperature, fouling, and corrosion are significant concerns.

Wrapping up

In today's chemical processing world, companies need optimum fractionation efficiency with maximum run times and minimum operating costs. Therefore, choosing the correct distillation valve for new or revamped towers is critical. While moving valves still have their place in many distillation applications, they should generally be reserved for nonfouling services where high turndowns are absolutely necessary. Consequently, the CPI is experiencing a shift from moving valves to fixed valves. Fixed valves offer several key advantages, including higher fouling resistance, durable construction, uplift resistance, higher capacity (in some cases), reasonable turndown ranges, and lower capital costs. Enhanced-fixed-valve trays offer superior fouling resistance and capacity (in moderate to high liquid loads) compared to conventional extruded fixed valves, and are well-suited for extended operation in severe services. CEP

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Literature Cited

1. **Fair, J. R.,** "Historical Development of Distillation Equipment," AIChE Symposium Series, **80** (235), AIChE, New York, NY (1983).
2. **Wiehe, I.,** "Crude Oil Compatibility Testing," www.solublesolutions.com/?page_id=14 (accessed April 10, 2015).
3. **Hauser, R., and T. Kirkey,** "Refinery Tests Demonstrate Fixed Valve Trays Improve Performance in Sour Water Stripper," presented at the 2003 AIChE Spring National Meeting, New Orleans, LA (Mar. 31, 2003).