Keeping up with the Times

Neil Sandford, Greg Spencer and Alessandro Ferrari, Koch Engineered Solutions, discuss the development process behind, and applications of, new mass transfer tray technology.

Distillation and absorption research and development is an expensive but necessary endeavour to enable the continued expansion of mass transfer devices' capabilities. The typical development process may involve the following steps:

- Set targets for success.
- Define initial concept.
- Create 3D CAD of concept.
- Test concept with computational fluid dynamics (CFD).
- Create physical prototype.
- Air/water test at small scale, to confirm capacity characteristics.
- Air/water test at larger scale.
- Perform hydrocarbon distillation pilot test to confirm capacity and separation efficiency.
- Proceed with commercialisation.

Inevitably, the development of improved devices often leads to dead ends, where the concept is not a sufficient improvement over current state-of-the-art technology.

In these cases, one crucial aspect is that if an idea is destined to fail, it should fail fast – ideally before a large expenditure of capital. The development process may be halted at any one of the above steps if it becomes clear that the targets are not going to be met. In addition to this, typically there are recycle loops in the early phases, where designs are adjusted and there is a reset before continuing down the development path. The following is an account of the steps taken in the development of the FLEXIPRO® valve.

Setting the targets

Koch-Glitsch, a Koch Engineered Solutions company, recently embarked on the creation of a new tray mass transfer device that is intended to improve upon the FLEXITRAY® valve tray product line. This solution was initially introduced in the 1950s and is still widely applied today. Therefore, lofty ideals were set for the project's success:

- The new valve should have more capacity in order to be capable of expanding the capacity of existing distillation and absorption towers, or reducing the size of new towers.
- The new valve should match or exceed the separation efficiency of its predecessors.
- The new valve should match or exceed the operating range of existing devices.
- Ideally, the new valve should be a fixed, non-moving device.

This last aim was primarily targeted at improving the reliability of the equipment, and would prove to be one of the defining characteristics of the new valve device. In recent years there has been a trend towards the specification of more reliable mass transfer equipment, and this inevitably means that fixed devices are preferable to floating or moving valves.[1] Moving valves were developed to improve the flexibility (defined as the ability to operate a distillation or absorption tower at varying load or feed rate) of sieve trays. In distillation there is often the option to reduce the feed rate to a tower but maintain the design condenser and reboiler duties, in order to keep the tray loading condition within an acceptable range. Doing this, however, results in inefficiency – running at 25% of design feed rate while still maintaining 50% of design reboiler duty means effectively doubling the energy consumption per unit of product.

Except for those rare cases where a plant produces an excess of energy that cannot be used elsewhere, such a trade-off is only acceptable if the tower only needs to function at a reduced production rate for a very limited period each year. When changing plant capacity is a more frequent occurrence, this demands a more flexible mass transfer device that has an extended range of operation, allowing for a reduction in feed rate at a near constant reflux ratio (or solvent/feed ratio, in the case of an absorption service).

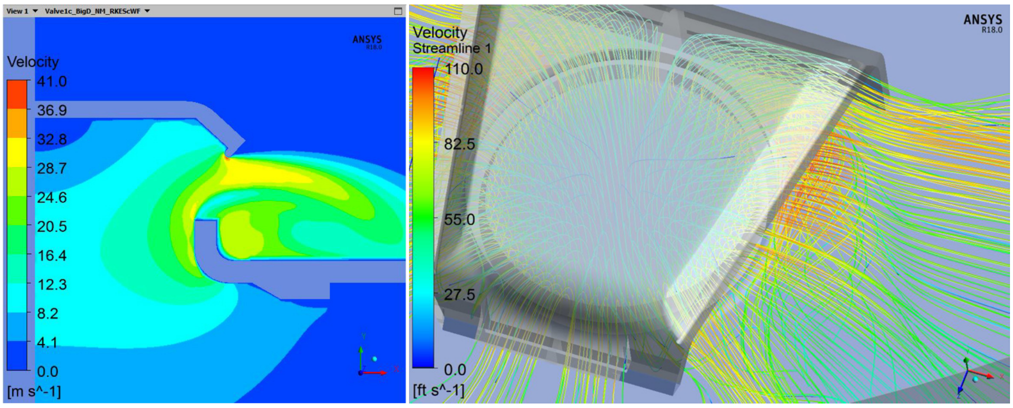

Figure 1. CFD plots of velocity contours and streamlines of vapour exiting from side curtain openings of FLEXIPRO®.

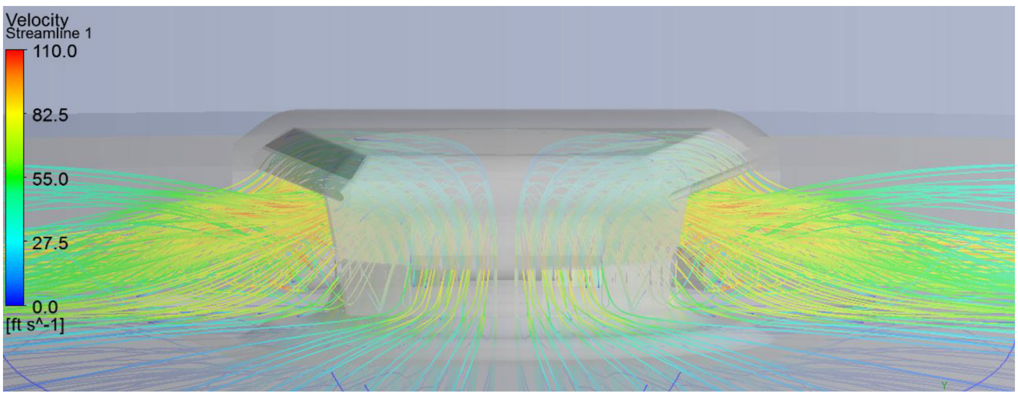

Figure 2. CFD streamlines of vapour leaving FLEXIPRO valve side curtain and added louvered opening

Conceptual design

After setting the targets for the new device, the next step is that the development team brainstorms initial ideas to define the principal features of the new valve. The starting point for one such iteration was the PROVALVE® tray. This is a trapezoidal-shaped, fixed valve which is set above a circular opening in the tray deck. Unlike fixed valves that are punched from the tray deck, the valve cover extends wider than the deck opening, leading to a more horizontal vapour trajectory leaving the valve. The main benefits of this are enhanced capacity, reduced liquid entrainment and, due to the trapezoidal shape, a forward pushing action which helps in sweeping any fouling materials across the tray decks into the downcomers and on down the tower. As a result, PROVALVE trays are used in many of the most severely fouling applications in refineries around the world, such as coker fractionators.[2, 3]

Extrapolating from this experience to develop a new valve device required the creation of several features. To improve the tray capacity and efficiency, the flat profile of the PROVALVE unit was coined downwards near the periphery. CFD analysis confirmed that this change would enhance the turbulence and mixing at the tray deck level (see Figure 1), where the vapour and liquid first interact on the tray. Then, to enhance bubbling and to eliminate a stagnant zone immediately downstream of the valve that was revealed in CFD modelling (see Figure 2), a louvered opening was added in the narrower downstream leg. This addition was expected to be beneficial both for mass transfer efficiency and fouling resistance, by eliminating a zone where fouling materials might otherwise collect.

The final and most novel feature of the new valve is an upwardly extruded deck opening, the purpose of which is perhaps best understood by a simple comparison with the bubble cap tray. In the bubble cap tray, a circular riser extends above a hole in the tray deck. Vapour travels up

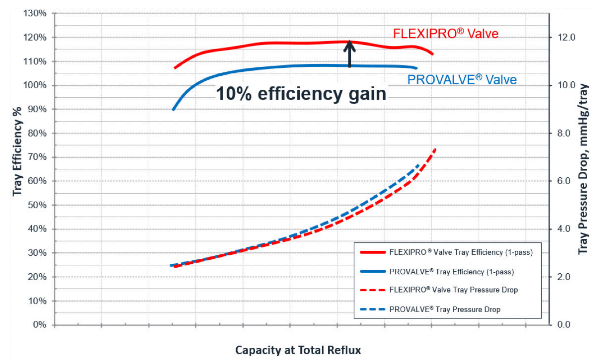

Figure 3. Pilot testing results from Koch-Glitsch 1.7m (5.5 ft) hydrocarbons distillation tower, C6 isomers at 5.7 bara.

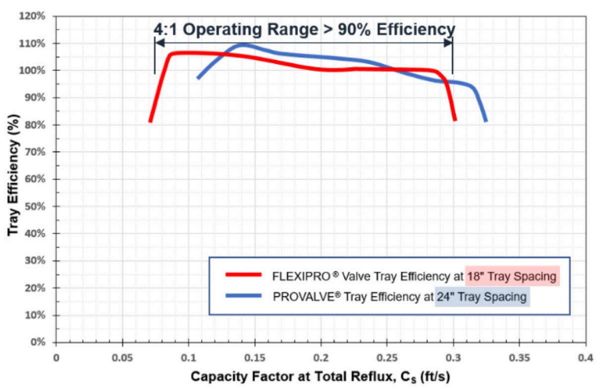

Figure 4. Pilot testing results from FRI 1.2 m (4 ft) hydrocarbons distillation tower, iC4/nC4 at 11.4 bara.

the riser and is then deflected downwards by the circular cap, finally exiting from the bottom edge, or skirt, of the cap (or via a series of vertical slits).

Bubble cap trays are known for their ability to handle a very wide range of vapour rates, because the riser prevents liquid from spilling down when the vapour rate and pressure drop is very low. In the new prototype valve, the vertical extrusion of the deck opening is not nearly as tall as a bubble cap riser, but it does serve the same basic function, making it more difficult for liquid to leak or weep down through the deck openings that are intended for vapour to flow through, and thus extending the useful operating range of the tray.

A secondary effect of the extruded deck opening is the reduction of the head loss or pressure drop of the vapour at that point in its passage through the tray. This counters the slight increase in pressure drop that occurs due to the final downwards exit path from the curtain area of the valve, leading to almost the same pressure drop as the PROVALVE tray (for the same deck open area).

Prototyping

Once the basic design of the new valve device had been defined, the next step is to make prototype parts for initial hydraulic verification in a small-scale air/water pilot plant. Since this only requires moderate operating conditions, it is possible to employ additive manufacturing or 3D printing of plastic prototypes to speed up the production and faithfully maintain the form defined by the 3D CAD model.

It is important, however, to understand how the final commercial parts will be manufactured. While additive manufacturing techniques are improving exponentially, at this point the use of such a method to manufacture large quantities of metal valves for commercial use is not competitive with other techniques. It is therefore necessary to consider that whatever shape of the valve is refined at this stage must be possible to manufacture in various metals by standard die tooling techniques. This constraint may change in the future, at which point the only limitation will be the imagination of the developers.

Pilot testing

Following successful air/water hydraulic testing, the next step was to verify the mass transfer efficiency in Koch-Glitsch's hydrocarbons pilot column. This required a new prototype made from metal for thermal and chemical resistance. The pilot test only required a small quantity of valves so that metal 3D printing could be employed in the generation of the metal prototypes. The prototype trays were installed, and the performance evaluated over a range of operating pressures. Testing with a hydrocarbon system (in this case, C6 isomers) also provides additional useful information on jet flood and downcomer capacities for a lower surface tension system. The hydrocarbons pilot testing confirmed that the tray efficiency was comparable with – or better than – existing devices (see Figure 3).

Recently, the new FLEXIPRO valve was independently demonstrated during a pilot test at Fractionation Research Inc. (FRI) in Stillwater, Oklahoma, US. The FRI membership voted for the FLEXIPRO valve tray to be tested as the 2021

Category 1 (membership supported) tray test. The FRI test used the butanes system at 11.4 bara (165 psia) in their LP 1.2 m (4 ft) dia. distillation column. The demonstrated capacity and tray efficiency at total reflux is shown in Figure 4 for the FLEXIPRO valve tray, and compared with PROVALVE trays that were the subject of an earlier 2009 Category 1 test in the same pilot column, under the same conditions.

At first glance, the performance of the FLEXIPRO valve tray may seem unremarkable, until it is noted that almost the same capacity was achieved using a tray spacing of only 457 mm (18 in.) for the FLEXIPRO valve tray, compared to 610 mm (24 in.) that was used in the PROVALVE tray test. Additionally, an operating range of 4:1 with the tray efficiency exceeding 90% was demonstrated for a fixed valve supported by the same commercially-available OMNI-FIT® technology expansion rings that are frequently used in tower revamps, without the use of any gaskets.

Further, when the data is normalised to the same tray spacing (see Figure 5), the FLEXIPRO valve tray shows a 7% capacity advantage over the PROVALVE tray. And, when compared to traditional round or rectangular moving valves, the capacity advantage increases to 27%.

There are several ways to exploit the improved performance of the valve tray. Depending on the specific needs of the application, the distillation or absorption tower may be reduced in height or diameter. The following examples illustrate how one might improve a vessel design.

Case study 1: a midstream amine contactor

A US midstream oil and gas company required a new amine contactor to be sized for the design conditions listed in Table 1.

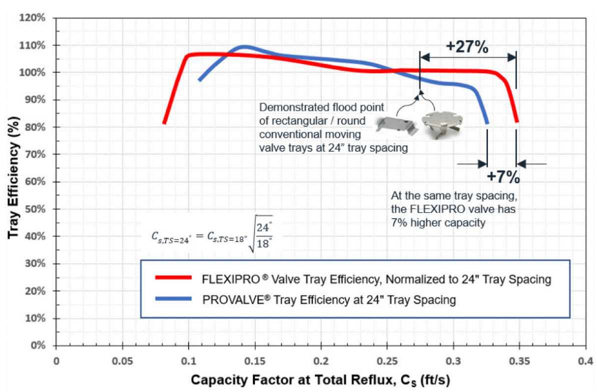

Figure 5. FRI pilot test results normalised to 610 mm (24 in.) tray spacing.

Table 1. Amine contactor design specifications

Gas feed rate	250 million ft³/d	279 x 10³ Nm³/hr
Gas pressure	1000 psig	69 barg
Amine circulation rate	300 gpm	68 m³/hr
Downcomer inlet velocity	0.20 ft/sec	0.06 m/sec
Flexibility required	4:1	-
Design jet flood rating	80% maximum	-

Considering the high operating pressure, a high foaming tendency is likely for this application. A system factor of 0.73 was specified to derate the tray flooding calculations. Additionally, to keep all tray design comparisons on a consistent basis, the downcomers were sized based on a clear liquid inlet velocity of 0.2 ft/sec.[4]

The tower was initially sized using conventional FLEXITRAY valve trays, which resulted in a required tower diameter of 2438 mm (96 in.), and a tray spacing of 610 mm (24 in.). Any savings in vessel height are less interesting for this tower, as the vessel only required 20 trays with an overall height of approximately 18 m (60 ft). The focus was therefore on the reduction of the vessel diameter.

By applying the FLEXIPRO valve trays, Koch-Glitsch was able to reduce the vessel diameter to 2133 mm (84 in.) – a 24% reduction in the cross-sectional area. The vessel wall thickness also reduced by 10%, leading to an overall vessel weight reduction of approximately 20% (which also provides a good indication of the vessel cost reduction, which was one of the main targets set for the new valve).

Case study 2: a superfractionator

Another example is a propane/propylene splitter in an olefins unit. These towers require a large number of theoretical stages to achieve the necessary separation in order to meet a polymer-grade propylene specification. In many cases, this requirement results in the need to divide the separation between two towers in series, with associated piping and pumping of internal reflux.

With a total of 170 trays required, it is possible to size the tower with 550 mm (22 in.) using conventional FLEXITRAY valve tray spacing, resulting in an overall vessel height of 105 m (344 ft) – including approximately 6 m (20 ft) for liquid hold-up below the bottom tray. Alternatively, if the tower is sized using the FLEXIPRO valve trays, tray spacing could be reduced to 406 mm (16 in.), and the overall vessel height to 81.5 m (267 ft) – a reduction of 23.5 m (77 ft), or 22% with no increase in the tower diameter.

Conclusion

The use of modern design and manufacturing techniques such as 3D CAD, CFD and 3D printing are accelerating the research and development process, while allowing time for the evaluation of more variants to enhance performance and bring novel, improved products to the market in less time. The patented FLEXIPRO valve tray is an example of a valve device for the mass transfer industry that, by improving capacity and separation efficiency and extending operating range, leads to reduced energy consumption and improved mechanical reliability for all distillation and absorption applications.[5]

References

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5. U.S. Patent No. 10 258 936