BEST *of both*

I. Nieuwoudt and J. Penciak, Koch-Glitsch, USA, explore how high performance trays can deliver the best capacity and efficiency.

Around 1810 the French inventor Cellier-Blumenthal was already using sieve trays that were not too different from the present day sieve trays. In an 1815 patent Cellier-Blumenthal disclosed the use of bubble cap trays. Again, these bubble caps were not too different from the bubble caps that are being used today. In a distillation process patented in 1832, Anneas Coffey mentions the use of trays that have sieve holes and movable valves. The movable valves were to only open once the vapour rate exceeded a certain value. This dual valve arrangement was clearly an attempt to extend the operating window of the trays. For approximately 120 years bubble cap, sieve and valve tray technology remained virtually unchanged. During this period the bubble cap tray was considered the weapon of choice. Poorly designed sieve trays, resulting in bad weep characteristics, made process engineers wary of switching from the tried and trusted bubble cap trays.

It is thus not surprising that when Fractionation Research Inc. (FRI) started its test work in 1954, the first two trays that were subjected to distillation tests were bubble cap devices. In the 1950s the performance of crossflow trays was improved by using large movable valves and segmental sloped downcomers. In 1956, the FLEXITRAY® device from Koch became the third tray to be subjected to distillation tests at FRI. Interestingly, this tray, with large movable valves,

Table 1. Influence of tray efficiency and capacity on the costs of new installations							
Scenario	**Tower**	**Trays**	**Foundations and structures**	**Heat exchangers**	**Auxiliary equipment**	**Energy consumption**	**Overall costs**
Low tray efficiency: increase number of trays to compensate	↑ Increase in tower height due to increased number of trays	↑ Increase in number of trays due to efficiency shortfall	↑ Increase in weight of equipment and height of structure	≈	≈ Slight increase in cost of pumps and piping	≈	↑ Depending on the size of the tower, the cost increase can be quite significant
Low tray efficiency: increase reflux ratio (or solvent rate) to compensate	↑ Increase in tower diameter and size of reflux drum	↑ Increase in tray diameter	↑ Increase in weight of equipment	↑ Increase in size of all heat exchangers	↑ Pumps and line sizes to be increased	↑ Increase in energy consumption is proportional to increase in reflux rate	↑ The capital and operating cost increase of this option could be dramatic
Tray with good efficiency but reduced capacity	↑ Increase in tower diameter	↑ Increase in tray diameter	↑ Increase in weight of equipment	≈	≈	≈	↑ Increase in capital cost

Table 2. Influence of tray efficiency and capacity on the costs of revamps							
Scenario	**Capacity/ product purity**	**Tower modifications**	**Trays**	**Heat exchangers**	**Auxiliary equipment**	**Energy consumption**	**Overall costs**
More capacity required. Same product purity required. Tray with increased capacity but reduced efficiency. One for one tray replacement Increase reflux ratio.	↑ A significant portion of the capacity increase of the tray is consumed by the higher reflux rate, reducing the net capacity gain	≈	≈	↑ Higher reflux ratio will cause increase in duty requirements. Exchanger revamp/ replacement may be needed	↑ Increase in flowrates due to higher reflux rate. More equipment may need to be replaced	↑ Significant increases in energy consumption due to increase in reflux ratio. This could have a dramatic impact on operating costs	↑ A significant increase in the energy consumption could have a dramatic impact on the economics of the process. The energy consumption can be reduced and the capacity increased by using trays with high capacity and high efficiency
Higher purity products required Minimise the impact on capacity Increase number of trays	↑ Lower tray spacing reduces the tower capacity. This increases the unit cost of the products	↑ Major mechanical modifications are needed to accomodate more trays	↑ Large number of trays increases costs	≈	≈	↑ Reduction in capacity increases the energy consumption per unit of production	↑ The reduction in capacity caused by the lower tray spacing increases the unit cost of the product. This cost increase and capacity reduction can be negated by installing trays with high capacity and efficiency at a higher tray spacing

outperformed the bubble cap tray in capacity and efficiency. For performance and economic reasons the valve tray quickly became the standard. This remained the state of the art in tray technology for approximately 30 years. In the 1970s and 1980s new random packing and the advent of structured packing made serious inroads on the crossflow tray domain. Atmospheric and vacuum applications were taken over by structured packing, and random packing made serious inroads in the medium to high pressure market. The packing products ensured low pressure drop, high capacity and good efficiency. However, since the 1990s trays have been on the rebound. The developments and economic benefits that led to the renewed interest in trays are covered in this article.

High performance crossflow trays

Although the 1956 FRI tests showed that the capacity and efficiency of the movable valve FLEXITRAY® tray exceeded that of the bubble cap tray by a handsome margin, the cost of both of these devices prompted tray developers to continue looking for alternatives. In the late 1960s and early 1970s trays with large fixed valves were tested at FRI. These early tests showed that:

- The efficiency of a tray with large, round, fixed valves is only marginally lower than that of a tray with large, round, moving valves.

- The entrainment flood capacity (on a bubbling area basis) of a tray with large, round, fixed valves is only marginally lower than that of a tray with large, round, moving valves.
- The efficiency of a tray with round, fixed valves is measurably better than that of a tray with rectangular shaped valves.

Although the performance of these fixed valve trays was marginally below that of moving valve trays, its development was a breakthrough in bringing down the fabrication time and cost of trays.

Subsequent research showed that small diameter valves have a higher entrainment flood capacity and higher efficiency than large diameter valves. This led to the introduction of the patented MINIVALVE® tray technology by Koch-Glitsch[1,2]. The fixed valve version is called VG-0, and the movable valve version is called MV-1. The shape and dimensions of these valves have been tailored to ensure good liquid/vapour mixing without imparting excessive directionality to the froth flow. VG-0 fixed valves were recently used on the SUPERFRAC® high performance tray that was tested at FRI using the i-C4/n-C4 test system at 165 psia. This tray showed unsurpassed efficiency over the whole operating range, even at operating conditions very close to the flood point. These test results confirm that the

Figure 1. Photograph of a two pass SUPERFRAC® tray showing some of the available features.

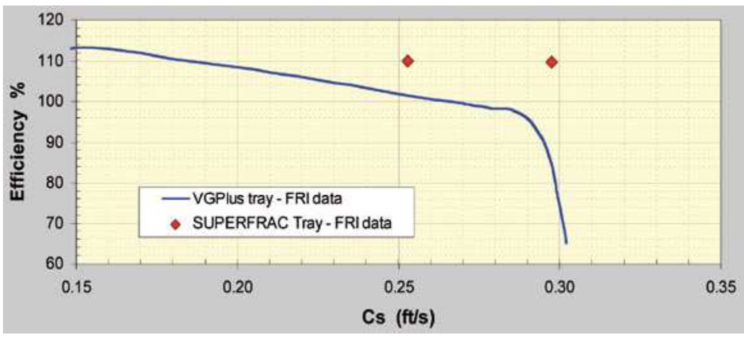

Figure 2. Performance of SUPERFRAC® tray in F.R.I test (i-C4/n-C4, 165 psia, total reflux). VGPlus tray data taken from reference

MINIVALVE tray technology by Koch-Glitsch can be used on high performance trays to obtain good tray efficiency.

Good valve performance alone does not ensure good tray performance. In order to maximise the capacity of a crossflow tray, it is imperative to make the downcomer only as big as it needs to be. Oversizing the downcomer reduces the bubbling area and disengagement area of the tray. Koch-Glitsch patented several 'semi-conical vapour tunnel' downcomers characterised by a downcomer bottom edge that consists of a multitude of straight lines[3,4]. This multitude of straight lines follows the contour of the tower wall and frees up bubbling area and disengagement area that would otherwise have been inside the downcomer. Even more bubbling area can be freed up by truncating the vapour tunnel downcomer, and populating the area underneath the truncation plate with bubbling devices[5,6]. However, bubbling area is only effective if bubbling actually takes place. An inlet weir and bubble promotors are used to ensure that the liquid from the downcomer starts bubbling right away, and that the active area gained by the vapour tunnel, or truncated vapour tunnel downcomer is fully utilised[2].

In the case of truncated downcomers, it is important to give special attention to how the liquid exits the downcomer. Koch-Glitsch has patented several downcomer outlet arrangements[5,7,8] where the liquid exits at the back of the truncation plate, between the downcomer apron and the truncation plate, or through louvers in the truncation plate. An additional benefit of the vapour tunnel downcomer, and in particular the truncated vapour tunnel downcomer, is that it maximises the liquid flow path length. This maximises the crossflow effect, which increases tray efficiency. The downcomer design of choice, as well as the relative dimensions, depend on the particular application.

To maximise tray efficiency, it is also very important to maximise the plug flow effect by eliminating stagnant zones and retrograde flow. This is done by strategically placing proprietary push valves and other proprietary directional devices on the tray deck. However, too much push will reduce tray efficiency. This is confirmed by the fact that the VG-0 valves on the SUPERFRAC tray tested at FRI demonstrated a higher efficiency than other FRI tested trays that imparted more push on the froth.

The SUPERFRAC tray technology can also be used in fouling services. A larger version of the patented fixed valve, called VG-10, which has a larger escape area per valve, or the patented PROVALVE® high net rise fixed valve[9] can be used in conjunction with special hardware and special beam and downcomer designs to deal with the fouling tendency of the system.

It is evident that the SUPERFRAC tray technology should be seen as a proprietary toolbox of:

- High capacity and high efficiency valves available in different sizes.
- Vapour tunnel or truncated vapour tunnel downcomers with various downcomer outlet shapes to maximise tray capacity and efficiency.
- Inlet weir and bubble promoters.
- Push valves and other directional devices.
- Multi-pass arrangements.
- Special features to deal with fouling.
- Mechanical innovations to simplify installation.

In designing an optimal SUPERFRAC tray, Koch-Glitsch selects the features that best fits the capacity and efficiency requirements of the application.

Tables 1 and 2 show that using trays with reduced efficiency and capacity can have quite detrimental effects on the economics of the process, both in new installations and revamps. It should be clear that significant economic rewards could be reaped by using trays with good capacity and efficiency, and not just one or the other.

In the case studies and design studies below it is shown how SUPERFRAC tray features have been combined to ensure superior capacity and efficiency.

Case studies

The recurring theme in the case studies presented below is that the good efficiency and capacity of the SUPERFRAC tray can be used to increase throughput and product purity and to reduce capital and operating costs.

FRI tests

In 2005 the SUPERFRAC tray was tested at FRI The features used on the tray were designed to give good capacity and efficiency.

FRI data taken on the VGPlus tray in the i-butane/n-butane system at 165 psia were recently reported by Mosca et al[12]. In Figure 2 the VGPlus performance data are compared with FRI data taken on the SUPERFRAC tray at exactly the same conditions. Based on the test results it is evident that the SUPERFRAC tray has 10% efficiency and 7% useful capacity advantage over the VGPlus tray.

The SUPERFRAC tray has the highest combined efficiency and capacity of all conventional crossflow trays tested at the FRI.

Propylene splitter revamp

A significant revamp of a C3 splitter unit was completed in 2000 to obtain additional capacity over first generation high capacity trays. Due to the number of stages involved in this propylene/propane separation, the splitter is actually two columns. The feed is located in the middle of the lower column, which has both a stripping and a rectifying section. The upper column contains additional rectifying trays. Figure 3 is a simplified process flow diagram of the unit. The tray design changes included SUPERFRAC style downcomers to maximise active area, push valves, fixed MINIVALVE units, higher open area, reduced weir height, number of passes increased to six, and tray space increased below the feed. OMNI-FIT® revamp techniques were used to change the number of passes and tray spacing without welding to the column shells. In addition, the feed inlet nozzle was relocated to a higher position on the column. The results of this revamp are summarised in Table 3. Even with the six pass design and reduced flow path length, the measured overall tray efficiency was still 95%. Importantly, the efficiency of the SUPERFRAC trays was so much better than the trays it replaced that the same product purity could be obtained with fewer trays and a lower reflux ratio. The benefits of the increased efficiency plus the higher capacity of the SUPERFRAC trays allowed the tower to produce 15% more propylene than was possible before.

Depropaniser revamp

In 1990, the sieve trays in the rectifying section were upgraded and the stripping section trays were replaced with INTALOX® structured packing to increase the capacity from 4000 bpd to 6000 bpd. In 2000, the operator wanted to increase the capacity again. At that point the limitation was the sieve trays in the rectification section. The sieve trays were replaced with SUPERFRAC trays with vapour tunnel downcomers and truncated downcomers. The revamp layouts are shown in Figure 4. The upstream equipment now limits the tower feed rate to 7100 bpd. The next limitation in the column will most likely be the structured packing. An 18% increase in capacity was obtained and the SUPERFRAC trays are nowhere near capacity limit. A post revamp performance test indicates that the SUPERFRAC trays in the rectifying section are operating at a tray efficiency of above 100%.

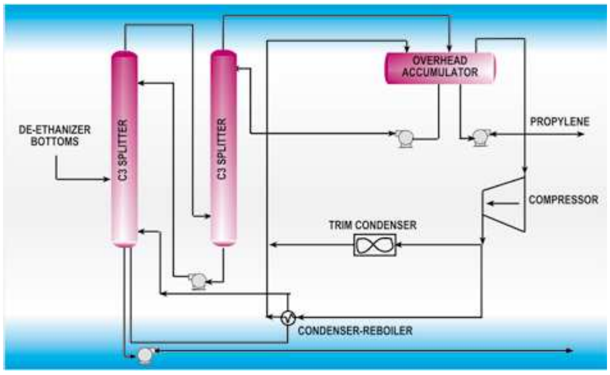

Figure 3. C3 splitter simplified process flow diagram.

Table 3. Summary of C3 splitter results

	Before	After
Diameter, ft	16	16
Tray configuration	4 pass	6 pass
Tray type	1st generation high capacity trays	Multi-chordal SUPERFRAC® trays
Valve type	Movable valves	VG-0 valves
Above feed		
Number of trays	196	178
Tray spacing (in.)	22	22
Below feed		
Number of trays	44	49
Tray spacing (in.)	22	27.5
Propylene rate (million lb/yr)	850	958
Max wt% propane overhead	0.4%	0.4%
Max lv% propylene bottoms	5%	5%

Design example

Mosca et al[12] recently reported on the revamp of a deisobutaniser to achieve more capacity. VGPlus trays were used to debottleneck the tower. The operating conditions and stream compositions of this deisobutaniser tower are very similar to that of the FRI i-butane/n-butane tests. This similarity means that the FRI test results can be used to optimise the tray designs for this application. Based on the SUPERFRAC tray used in the FRI test, SUPERFRAC tray features were carefully chosen and the geometric parameters optimised to give the best combined efficiency and capacity for this application. Using the higher capacity and superior efficiency of SUPERFRAC trays, the tower performance was simulated using the SRK model in PRO/II. The results of this study are summarised in Table 4.

The following conclusions can be drawn from Table 4:

- At the same feed rate, the superior efficiency of SUPERFRAC trays reduces energy consumption by 17% over that of the VGPlus trays.
- If no additional energy is available, SUPERFRAC trays would give 23% higher throughput than the VGPlus trays, at the same product purities.
- If the refiner is able to supply an additional 7% of energy to the tower, SUPERFRAC trays will have 30% higher throughput than the VGPlus trays, at the same product purities.

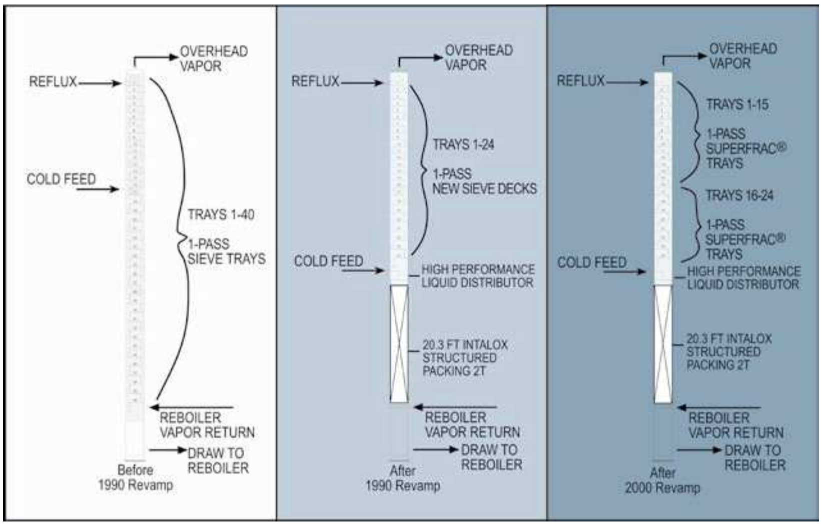

Figure 4. Depropaniser column layouts before and after revamps.

Table 4. Deisobutaniser design example

	VGPlus trays (Table 4 in reference 12)	SUPERFRAC® trays at the same tower feed rate as VGPlus trays	Optimised design using SUPERFRAC® trays
Feed rate	100%	100%	130%
Liquid rate (below feed)	100%	83%	107%
Vapour rate (below feed)	100%	83%	107%
Reboiler duty	100%	83%	107%
Jet flood	86%	65%	85%
Downcomer flood	89%	67%	88%
Pressure drop (mBar)	6.55	5.22	7.50
Tray efficiency	93%	103%	103%

It is evident that using a SUPERFRAC tray design that is optimised for efficiency and capacity can yield a spectacular reduction in energy consumption and increase in throughput. Reduced efficiency drives up the energy cost of a distillation tower because more reflux is needed to achieve the desired separation. This additional reflux also reduces the capacity of the tower since it consumes part of the tray capacity. At the current level of energy costs the influence of tray efficiency cannot be disregarded.

The influence of tray efficiency on the economics of a distillation operation is particularly pronounced for trays with a large number of downcomers and short flow path lengths. The efficiency of these trays are in the 70 - 75% range. The tray spacing can be reduced to counter the loss in tray efficiency. This not only drives up the cost of the trays and creates installation issues, but the capacity of the trays is also reduced by the reduction in tray spacing. The only solution is to use trays that have high efficiency and capacity instead.

Conclusion

The superior efficiency and capacity of high performance SUPERFRAC trays can be used to extend the efficient capacity of towers to well beyond that of other high performance trays. The features used on these trays must be carefully selected to achieve the right balance between performance and cost. Given the current cost of equipment and energy, it makes sense to pay special attention to the performance of trays in distillation towers.

Notes

References

1. US patent No. 5120474.
2. US patent No. 5147584.
3. US patent No. 5895608.
4. US patent No. 6003847.
5. US patent No. 5453222.
6. US patent No. 5213719.
7. US patent No. 5480595.
8. US patent No. 5632935.
9. US patent No. 5762834.
10. SUMMERS, D.R., et al. 'High-capacity trays debottleneck Texas C3 splitter', *Oil & Gas Journal*, Nov 6, 1995, pp 45 - 50.
11. DE VILLIERS, W., et al. 'Further advances in light hydrocarbon fractionation', *PTQ*, Summer 2004, pp 129-133.
12. MOSCA, G et al. 'Increasing deisobutanizer capacity', *PTQ*, 2006 Revamps, pp 27 - 33.