i. nieuwoudt, o. karpilovskiy and m. j. lockett, koch-glitsch lp, usa,

Revamp & retune

describe the installation of 6-pass trays in a large C3 splitter.

In the recent past, the consumption of polypropylene has grown by more than 30% over a five year period. This growth in consumption pushed producers to add polymer grade propylene capacity. The separation of propane from propylene is typically accomplished in large diameter superfractionators equipped with a high number of trays. One way of adding incremental capacity is to revamp these C3 splitters with higher capacity internals.

This article describes the revamp of a large polymer grade C3 splitter that originally contained 4-pass valve trays. The trays were replaced with 6-pass SUPERFRAC® trays to achieve a significant capacity increase without sacrificing tray efficiency. This case study also highlights that the success of a revamp could hinge on paying special attention to all the peripheral equipment around the tower.

Background

Due to a growth in polymer grade propylene demand, the operating company wanted to increase the capacity of a C3 splitter as part of an olefins plant capacity increase programme. The C3 splitter initially contained 187 4-pass valve trays at 435/460 mm tray spacing, and the column diameter was 4900 mm.

Normally the maximum feed rate was approximately 25 tph, but during a test run in the middle of winter, a feed rate of 28.5 tph was achieved. The company aimed to significantly increase this feed rate by revamping the trays, without sacrificing product purity and recovery.

Koch-Glitsch analysed plant data and performed simulations and hydraulic analyses on the existing valve tray layout. The conclusion was that the feed rate was limited by both jet flood and downcomer limitations. As is usual in any revamp, a number of alternatives were evaluated in order to achieve the required objective in the optimum way. Retraying at reduced tray spacing was considered to increase the number of theoretical stages in the column, thus allowing a lower reflux ratio to be used and thereby unloading the trays. Although the tray capacity is lower at reduced tray spacing, the net result sometimes allows an increase in the column production rate. A disadvantage of this approach is the time and expense of retraying at reduced tray spacing, because normally most

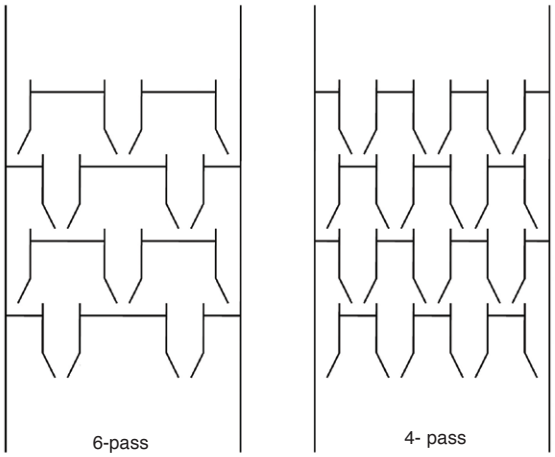

Figure 1. Schematic of original and replacement trays.

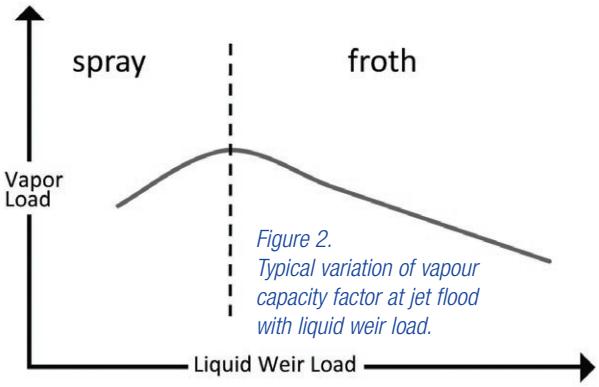

Figure 2. Typical variation of vapour capacity factor at jet flood with liquid weir load.

of the existing tray support rings cannot be reused and new ones have to be installed. Another alternative that was considered was retraying with either 4-pass or 6-pass high performance SUPERFRAC trays.

SUPERFRAC trays

SUPERFRAC tray technology brings together a portfolio of patented features that have been developed over many years by engineers at Koch-Glitsch. The particular features that are incorporated into a given design depend on the application. Some of the features of the technology include:

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

SUPERFRAC trays have been described previously in a number of publications.[1, 2]

Revamp

A noteworthy aspect of the revamp described in this article is the use of 6-pass SUPERFRAC trays. Highly liquid loaded applications, such as high pressure distillation processes, require the use of trays that incorporate multiple downcomers. It has long been recognised that for these applications, multi pass trays have a distinct advantage over other types of multi downcomer trays that utilise downcomers that are arranged at 90° to each other on successive trays. Examples of the latter are multiple downcomer (MD) and enhanced capacity multiple downcomer (ECMD) trays.[3, 4] MD and ECMD trays usually only achieve a tray efficiency in the range of 70 - 75%.[5] In contrast, a multi pass tray takes advantage of the cross flow effect that significantly boosts the tray efficiency. In a recent total reflux distillation test at Fractionation Research Inc. (FRI), the SUPERFRAC tray achieved an efficiency of 109% at Cb = 0.393 ft/s in the i-butane/n-butane system at 165 psia.[2] This SUPERFRAC tray efficiency is 10% higher than values reported for other fixed valve trays tested at FRI. Although the use of 6-pass trays is not common, they are increasingly being used because of the advantages they bring. The relative unfamiliarity of the distillation community with 6-pass trays is one of the reasons for writing this article.

The solution that was finally adopted for this revamp was replacement of the existing 4-pass valve trays with non-truncated downcomer 6-pass SUPERFRAC trays. The revamp was carried out in two phases to coordinate with other modifications that were planned within the ethylene complex. During phase 1, the 65 trays below the feed were replaced. Phase 2 involved replacement of the 122 trays above the feed.

A schematic of the original 4-pass trays and the replacement 6-pass SUPERFRAC trays is shown in Figure 1.

Design of 6-pass SUPERFRAC trays

The principle on which the revamp was based is that the tray vapour capacity factor at jet flood is increased as the liquid weir load is reduced by the addition of flow passes. The vapour capacity factor based on bubbling area (Cb) is defined as $C_b = Q_G / A_b [(\rho_G/(\rho_L-\rho_G)]^{0.5}$, where Q_G is volumetric vapour rate and A_b is the bubbling area.

The liquid weir load is defined as Q_L / W where Q_L is the volumetric liquid rate and W is the outlet weir length.

At very low liquid weir load (USGPM/in. of weir or $m^3/m.s$), the vapour is able to rip the liquid into small droplets and entrain a significant amount to the tray above, even at moderate vapour rates. At very high liquid weir load, the vapour expands the large volume of liquid. The higher the vapour rate, the larger the volume of this expanded mass. As the vapour rate increases, the volume of this expanded mass can 'fill up' the volume between the trays and cause a capacity limit. Based on these observations at high and low liquid weir loads, it is clear that the optimum operating regime is somewhere between these two extremes; this is indeed what is observed in practice. At intermediate liquid weir loads, the vapour rate, at which a certain percent of entrainment occurs, exhibits a maximum. A typical qualitative representation is shown in Figure 2. It is based on numerous published data sets, some of which have been summarised previously.[6] The maximum loosely corresponds to the transition from the spray to the froth regime, with spray occurring to the left of the maximum and froth to the right. Weir loads for high pressure distillation are typically such that the tray

operates in the froth regime to the right of the maximum. Increasing the number of passes, and thereby reducing the liquid weir load, increases capacity as long as the tray continues to operate to the right of the maximum. In this case, increasing the number of passes from four to six moved the design point closer to the maximum as depicted in Figure 2.

The trays were equipped with fixed type VG-0 valves. These patented valves are optimised to give good interaction between the liquid and vapour phase whilst limiting entrainment. VG-0 valves were also used in the FRI total reflux distillation test where a tray efficiency of 109% was achieved at Cb = 0.393 ft/s. Downcomer backup flooding was prevented by judicious selection of the number of valve units on each pass. An important consideration in the design of the 6-pass trays was the importance of balancing the vapour and liquid between each pass. It is well known that maximum tray efficiency is achieved by ensuring that the L/V ratio is the same on each pass. The Koch-Glitsch philosophy on balancing is to use equal flow paths lengths for each pass. Feedback from the field in this and other applications has indicated that equal flow path length gives higher efficiency than the alternative of equal active area for each pass. Tray balancing is only as good as the underlying hydraulic models. Over several decades, Koch-Glitsch has systematically conducted experiments to build tray hydraulic models that capture the influence of geometrical and process parameters.

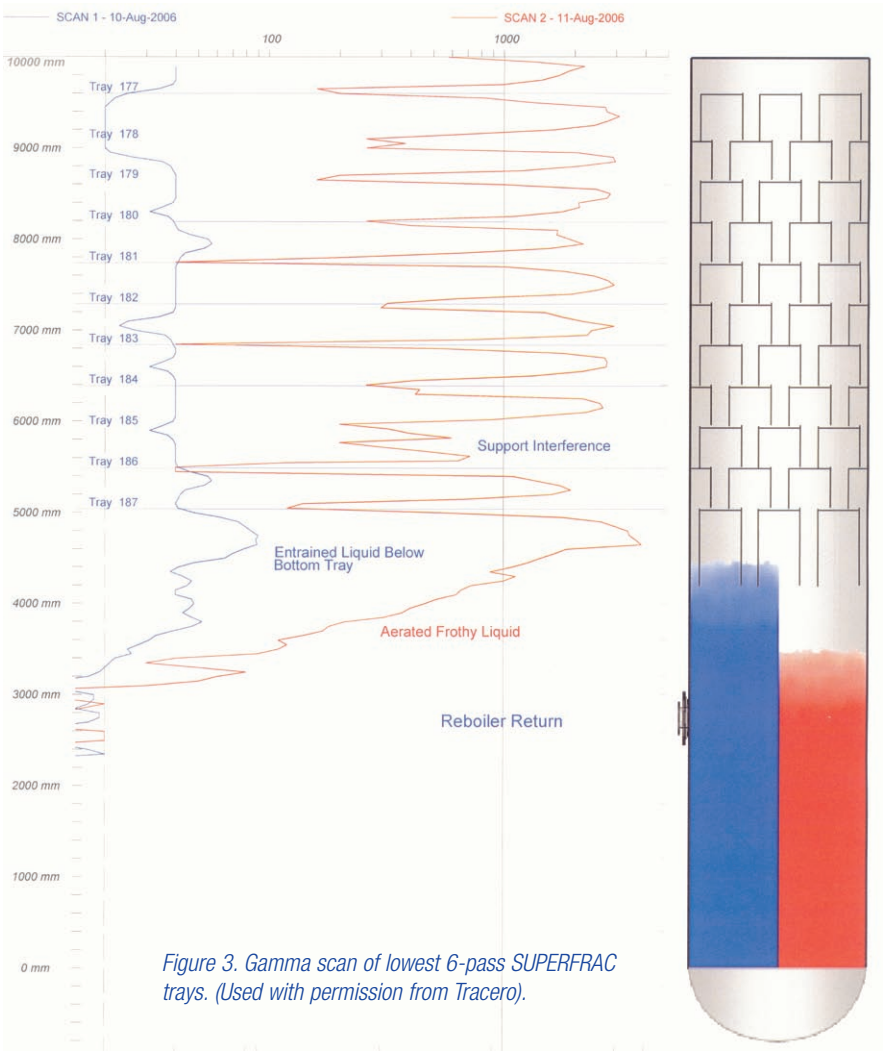

Figure 3. Gamma scan of lowest 6-pass SUPERFRAC trays. (Used with permission from Tracero).

It is also important to pay attention to the feed, reflux and reboiler return piping to ensure that they do not contribute to a lack of symmetry that might compromise tray balancing.

Phase 1 of the revamp

The first phase of the revamp was replacement of the 65 trays below the feed, which was completed uneventfully. However, upon startup, the original maximum capacity could not be achieved. A test run was conducted in the middle of summer and the maximum feed rate that could be achieved was 25 tph.

The customer was relatively unfamiliar with 6-pass SUPERFRAC trays and not surprisingly asked whether flooding of the replacement trays could be the likely cause of the problem. After reviewing the tray design and finding nothing untoward, Koch-Glitsch engineers then conducted a site visit to assist in resolving the problem.

During this investigation, the following came to light:

- The higher the ambient temperature, the higher the tower pressure and the higher the pressure drop.
- The bottoms level reading rose slowly as the feed rate was increased, but never exceeded 80 - 85%.
- The valve on the reboiler heating medium went to the fully open position as the feed rate was increased.

In analysing the problems, the Koch-Glitsch engineers postulated the following:

- Due to an increase in the cooling water temperature (ambient temperature increase), the condensers were not able to drop the top temperature sufficiently. This led to an increase in the tower pressure.
- The increased tower pressure led to an increase in the bottoms temperature.
- The higher bottoms temperature meant that the heat transfer driving force in the reboiler system was reduced.
- With insufficient boilup, material accumulated in the sump. The control system tried to compensate by increasing the flow of heating medium to the reboiler, but the valve went to the fully open position.
- The level indication system on the bottom of the tower did not respond correctly, which led to a liquid level being displayed in the control system that did not match the actual level in the tower sump.
- The liquid level rose to the point where the reboiler return vapour impinged on it. This frothed up the sump material and also entrained material to the bottom trays. This ‘flooded’ the bottom trays.

- The liquid interfering with the reboiler vapour return could have created more back pressure on the reboilers, which could have suppressed the boilup even further.

After consultation with the operating company, it was decided to arrange for a scan of the tower using gamma radiation to gain more insight into the probable cause of the problem. Unfortunately, a local company carrying out gamma scans was not available and due to import/export restrictions it was impossible to bring radioactive sources across the border. Coordination of the scanning procedure by Koch-Glitsch proved to be rather challenging. Agreement and coordination between four companies was required: the customer, the scan provider, the radioactive source provider and the radioactive source carrier. In the end, the scan was conducted without serious difficulties. The relevant part of the scan results is shown in Figure 3. It shows two scans (i) at high pressure drop conditions and (ii) at normal pressure drop conditions for the lower most trays in the column. The low pressure drop scan was carried out at normal operating conditions where the column was running well. The high pressure drop condition was generated by intentionally increasing the tower pressure so as to push the reboiler system to the limit. The high pressure drop scan showed no clear vapour spaces either between the trays or below the bottom tray. The column was clearly flooded. The scan at normal pressure drop conditions, however, showed clear vapour spaces between the trays, indicating that the trays were not flooded. Below the bottom tray, the bottoms liquid level was seen to be located above the reboiler return nozzle. There was a two phase mixture between the reboiler return nozzle and the bottom tray and no clear vapour space existed below the bottom tray. The interpretation is that, because of the high bottoms liquid level, at high flow rates liquid was being entrained up into the bottom tray causing flooding that extended up into the column.

After reviewing the results of the scans and the available operating data, it was concluded that the following factors were the cause of what the customer thought was tray flooding:

- The condensers had too little surface area to cope with higher cooling water temperatures (higher ambient temperatures) at an increased feed rate. This led to an increase in column pressure and temperatures.
- The reboilers had too little surface area to cope with the higher bottoms temperature that resulted from an increase in bottoms temperature (higher column pressure) and the increased feed rate.
- The sump level was run too close to the reboiler return. The accuracy of the sump level reading was also suspect.

It is interesting to note that level problems and reboiler problems rank very high on Kister's list[7] of the reasons for tower malfunctions in the recent past. Although the lack of sufficient area in the condenser could be seen as the root cause for the problems with the tower in this case study, it exposed the problems with the reboiler and sump level. The lesson is that these problems occur again and again because the tendency is to focus on the items in the tower, forgetting that the items around the tower are as important. These problems were fixed during the second phase of the revamp.

Phase 2 of the revamp

The second phase of the revamp entailed replacing the 122 trays above the feed, as well as fixing the problems that were identified in phase 1. Again 4-pass trays were replaced with 6-pass SUPERFRAC trays. The tower was run at a feed rate of 31 tph and the purity specifications were met. At this point, there was not enough feed available to push the tower any further. The 31 tph of feed is 24% higher than the 25 tph they were achieving in summer and 9% higher than the 28.5 tph they were achieving in winter. However, it needs to be borne in mind that at 31 tph of feed, the tower equipped with SUPERFRAC trays was not limited by the tray capacity but by the lack of feed availability. The revamp was a success.

Tray efficiency

Operating data were simulated using the Peng-Robinson equation of state using proprietary Koch-Glitsch parameters. The result was an average tray efficiency of approximately 100% for the 6-pass trays in this service. This average efficiency of 100% for the 6-pass SUPERFRAC tray is approximately the same as that of the original 4-pass valve trays, even though the flow path length of the 6-pass trays was approximately 33% lower than the flow path length of the 4-pass trays. Kister[8] has analysed data provided by FRI and, based on his results, a reduction in tray efficiency of approximately 8% might have been expected in the present revamp because of the reduced flow path length. The explanation is that the FRI data only considers the effect of flow path length, everything else being held constant. In fact many variables were changed, apart from the flow path length, such as valve type, the use of push valves, weir height and updated flow balancing methods. These all contributed to the high efficiency of the 6-pass Superfrac trays reported here.

Conclusion

The following can be concluded from this successful C3 splitter revamp:

- Always carefully evaluate the exchangers, pumps, line sizes, valves and instrumentation when doing a revamp. Splitting the responsibilities between design companies and tower internals vendors can lead to oversight.
- SUPERFRAC trays can simultaneously deliver high capacity and high efficiency.
- 6-pass SUPERFRAC trays can be used to debottleneck highly liquid loaded large diameter towers.
- It is not necessary to sacrifice efficiency to achieve high capacity, not even in 6-pass trays.

References

1. 'SUPERFRAC high performance trays,' Bulletin KGSF-1 2M0406DL, Koch-Glitsch, LP, Wichita, Kansas, 2006.
2. NIEUWOUDT, I. and PENCIAK, J., 'Best of both,' *Hydrocarbon Engineering*, July 2007, pp. 85 - 89.
3. BRUCKERT, W., 'Vapor liquid contact system and method,' US Patent 3,410,540, 1968.
4. RESETARITS, M. R. and LOCKETT, M. J., 'Multiple downcomer fractionation tray with vapor directing slots and extended dowcomer baffles,' US Patent 5382390, 1995.
5. SUMMERS, D. R.; MCGUIRE, P. J.; GRAVES, C. E.; HARPER, S. E. and ANGELINO, S. J., 'High capacity trays debottleneck Texas C3 splitter,' *Oil & Gas Journal*, November, 1995, p. 45.
6. LOCKETT, M. J., 'Distillation tray fundamentals,' Cambridge University Press, 1986.
7. KISTER, H. Z., 'What caused tower malfunctions in the last 50 years,' *Chemical Engineering Research and Design*, Vol. 81, Issue 1, Jan 2003, pp. 5 - 26
8. KISTER, H. Z., 'Effects of design on tray efficiency in commercial towers,' *Chemical Engineering Progress*, June 2008, p. 39.