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Optimizing the Design of Splitter Towers

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The abundance of affordable natural gas and continued growth in the utilization of ethylene and propylene derivatives are key drivers that are leading to the construction of large olefin plants. As is the case for most plants, the trend is to build ever larger olefin plants. To handle the capacity of these mega plants, large diameter splitter towers have to be designed and built. Novel trays and tray support structures were developed to meet these challenges. With these novel approaches, it was possible to build towers of more than 10 m in diameter without having the support structures interfering with the tray operation. Overall tray efficiency values in the range of 92 – 100 % were obtained in these splitter towers. This allowed the companies to minimize reflux ratios and maximize production rates.

1. Introduction

The diameters of mega towers in world-scale olefins plants (DOW, 2016) challenge the state-of-the-art tray designs and tray support mechanisms. Some of the challenges that need to be addressed in these large towers are:

- How do you support the trays with devices that do not interfere with the hydraulic and separation performance?
- Can the deflection of the trays and support structures be limited to where it does not influence the tray performance?
- What is the optimal tray arrangement to minimize the tower diameter and to effectively deal with the high liquid rates?
- Is it possible to achieve high tray efficiencies in these large towers that will allow a reduced number of trays to minimize the tower height?
- Can high tray efficiencies be realized that would reduce the tower pressure drop and reduce the energy consumption of the heat pump compressor?
- Can the tray spacing be optimized without major work in the tower? Can welding be avoided?

Additionally, many existing producers have reconfigured their plants to utilize lower cost feed stocks and taken advantage of the opportunity to make incremental improvements to the plant capacity, requiring improved performance from the distillation equipment. This has required the development of new revamp strategies to optimally reconfigure the fractionation tower internals in a timely manner.

2. Novel Support Structures

To address the challenges highlighted in the introduction Koch-Glitsch has developed a number of novel solutions (US8485504B2).

- SECTIONALIZED BEAM support mechanism (Figure 1): This patented support structure was developed to enable supporting devices in large diameter towers without negatively affecting the hydraulic performance. The support structure is split into 2 parts that can be passed through a manway. The 2 pieces are bolted together inside the tower without welding being required. The load is transferred between the two pieces by large pins that are welded to one of the pieces. The bolts are simply holding the 2 pieces together without having to transfer the load. The SECTIONALIZED BEAM can be pre-cambered to allow the trays to be flat and level under operating loads. More details of a SECTIONALIZED BEAM arrangement are shown in Figure 1.

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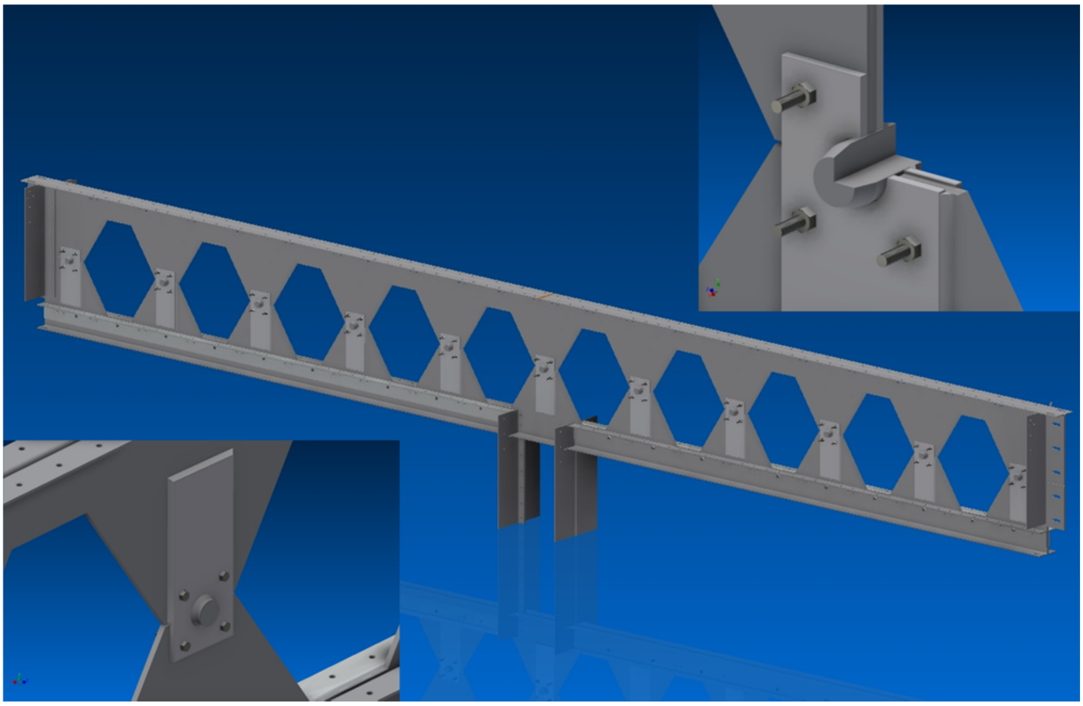

Figure 1: SECTIONALIZED-BEAM support structure

- PINNED-TRUSS support mechanism (Figure 2): This patented support structure was also developed to enable supporting devices in large diameter towers without negatively affecting the hydraulic performance. The support structure is split into many parts that can be passed through a manway. The pieces are bolted together inside the tower without welding being required. The load is transferred between the bolted pieces by large pins that are welded to one of the pieces. The bolts are simply holding the 2 together without having to transfer the load. The PINNED TRUSS can be pre-cambered to allow the trays to be flat and level under operating loads. The 6-pass SUPERFRAC trays used in case study 4.3 are shown supported by PINNED TRUSS support beams in Figure 2.

Figure 2: PINNED-TRUSS support structure

- The OMNI-FIT technology from Koch-Glitsch can be used to install trays without having to weld to the tower shell. This technology can be used in conjunction with the support technologies described above. This technology includes, amongst other, items such as:
    - Downcomer adapters to change the size and shape of downcomers while re-using existing tower attachments.

- Boxed downcomers that allows the number, location and size of downcomers to be altered without having to do welding to the tower shell.
- FLEXILOCK tray construction that allows panels to be snapped together, saving installation time and still creating a rigid assembly.

OMNI-FIT technology was used in the installations covered in the case studies.

3. Tray Optimization

In the design of trays for large diameter splitters there are a number of challenges that need to be addressed;

- High liquid rates require an increase in the number of flow passes. The number of passes influence the capacity and efficiency of the tray. The challenge is to maximize both the efficiency and the capacity. The tray configuration, downcomer shape and valve type play a role in the performance.
- Feed, reflux and reboiler return arrangements can significantly affect the performance of the tower and have to be optimized for the particular tray design. CFD studies are used to do these optimizations.

Optimized downcomer arrangements and tray layouts were developed for SUPERFRAC trays, and combined with optimized valve selections and layouts, to maximize the capacity and efficiency. These new trays were tested in the 1.67 m diameter tower in the Koch-Glitsch test facility. The performance of an optimized tray is shown in Figure 3.

Optimized tray designs were used in the splitters covered in the case studies, yielding tray efficiencies of 90 – 100%. These high efficiencies have been used to achieve combinations of the following benefits:

- Reducing the number of trays, which would reduce the tower height.
- For a fixed number of trays, the reflux can be reduced. This will lower the energy consumption, including that of the heat pump compressor. The reduced reflux will yield a smaller diameter tower, or for a fixed diameter, the capacity can be increased.
- By reducing the number of trays, the overall pressure drop of the tower can be reduced. This will reduce the energy consumption of the heat pump compressor.

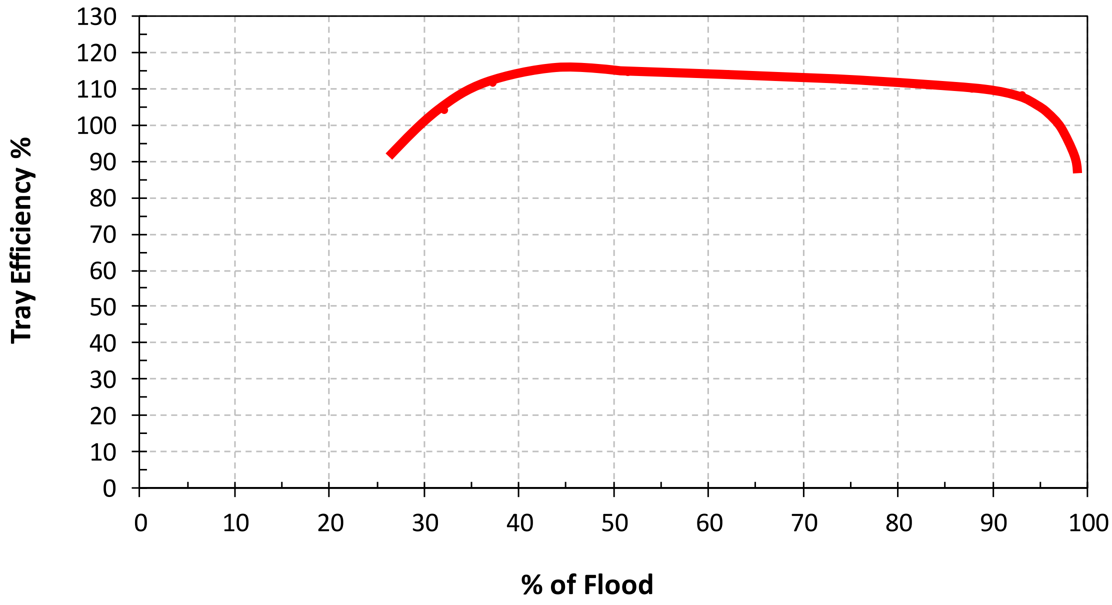

Figure 3: Performance of an optimized SUPERFRAC tray with fixed valves. Data taken in 1.67m diameter Koch-Glitsch test tower with C6 isomer system at 7 barA.

4. Case Studies

4.1 Revamp of a C2 splitter

This tower was producing only 76% of the desired ethylene production rate (Nieuwoudt, 2011). When the tower was pushed higher the ethylene purity and recovery suffered. It was clear that both the capacity and efficiency of the trays were limiting the economics of this plant. The engineering company/licensor considered several alternatives, including trays with a large number of downcomers at a lower tray spacing. Due to the lower efficiency of such trays (Summers et al., 1995) the number of trays would have had to be increased by 23%. The trays would have had to exhibit an increased capacity that would overcome a 23% reduction in tray spacing and give the customer the extra 24% capacity they were targeting. The amount of worked needed to reduce the trays spacing would also have raised hot work issues and would have extended the shutdown.
The owner of the plant decided to use optimized SUPERFRAC trays for this revamp. Koch-Glitsch used a tray layout and valve selection that would maximize the efficiency. The number of trays and tray spacing in the different zones of the tower were adjusted to achieve the maximum capacity and recovery given the purity constraints. This study showed that a 1-for-1 tray replacement with optimized trays would meet the objectives. Changes in downcomer arrangements could be accommodated using the OMNI-FIT technology. This approach removed the need for welding and significantly reduced the duration of the shutdown. The following features were used on these trays: (a) Downcomer shapes and sizes that would maximize the downcomer capacity; (b) Valves and valve arrangements that would maximize the entrainment flood capacity; (c) Features to regulate the froth flow pattern and froth heights to maximize the tray efficiency; (d) Optimizing the feed arrangement, reboiler return, side reboiler draw and return and reflux distribution. Based on Koch-Glitsch calculations the new tower arrangement would increase the ethylene production to 25% above the target set by the operating company. At that point the capacity would be limited by the reboilers, condenser and the pumps, and not the trays.
The tray installation and piping modifications were successfully completed well within the allotted turnaround time. The tower was started up without any issues and the product purity and recovery was reached quickly. Test runs were conducted to assess the separation performance and capacity of the revamped tower. At 96% of the desired rate the upstream units reached their maximum capacity and it was not possible to push the tower to its limit. Even with the limitation of the upstream units the plant was able to increase its ethylene production capacity by 26%. Over the whole operating range of the tests the overall tray efficiency of the SUPERFRAC trays was higher than 96%.

4.2 Revamp of a C3 splitter

Due to an increase in the demand for polymer grade propylene, the operating company embarked on a program to increase their propylene production capacity (Nieuwoudt, 2009). They wanted the maximum possible capacity while maintaining recovery and purity specifications. The tower was equipped with 4-pass valve trays. Koch-Glitsch analysed the plant data and concluded that the trays were limited by jet flood and downcomer flood limitations. In an un-flooded state these 4-pass valve trays were giving efficiency values around 98%.
The operating company evaluated several alternatives before deciding on revamping the tower with SUPERFRAC trays. To maximize the capacity, Koch-Glitsch decided to use 6-pass SUPERFRAC trays. The challenge was to get the same or better tray efficiency with trays that had flow path lengths that were approximately 33% shorter. To address this, the following features were used on these trays: (a) Downcomer shapes and sizes that would maximize the downcomer capacity; (b) Valves and valve arrangements that would maximize the entrainment flood capacity and efficiency; (c) Features to regulate the forth flow pattern and froth heights to maximize the tray efficiency. Changes in the number of downcomers and the downcomer sizes could be accommodated using the OMNI-FIT technology.
The operating company wanted to do the revamp in two phases. The bottom section of the tower was revamped first. When the tower started up the operating company reported flooding issues, an increase in pressure drop and a decrease in product purity. Tower scans showed that bottom of the tower was full of liquid while the reboiler was running at maximum load. It was found that a faulty level sensor led to this problem. The tower was opened and it was found that several of the bottom trays were severely damaged. The damaged trays were replaced, the bottom tray and the sump arrangement was modified and the new SUPERFRAC trays in the top section of the tower (phase 2) were installed. The level measurement system that led to the problem was also upgraded. The tower was started up successfully. Upon ramping up rates it was found that the capacity was limited by upstream units and by the condenser capacity. In winter the condenser capacity was higher due to the lower ambient and coolant temperatures. Given these two limitations, the tower could produce 24% more propylene in summer and 9% more in winter than what it could prior to the revamp. There was not enough condenser capacity and feed to push the tower to the capacity

limit of the SUPERFRAC trays. The propylene purity and recovery was maintained at these increased rates. Over the whole operating range of the tests the overall tray efficiency of the SUPERFRAC trays was 100%.

4.3 Revamp of a C3 splitter

This 8.5m diameter tower was originally designed with 4-pass fixed valve trays and commissioned in 2010. On initial start-up the tray efficiency was poor, generating too few stages to allow the splitter to produce polymer grade propylene product (Kister et al,, 2014). Despite one attempted fix the trays were still plagued by low tray efficiencies, resulting in a significant shortfall in polymer grade propylene production. The plant eventually installed a prefractionation tower to make up for the deficit in stages being provided in the main propylene product splitter.

Following successful commissioning of the prefractionator tower, market conditions were favourable for another increase in capacity. The owner targeted a revamp solution that would ensure 100% of the propylene product to be polymer grade at a 25% higher feed rate. Though Koch-Glitsch did not supply the original equipment, given the history of poor tray performance in the C3 splitter, an extensive review of the tray technology to be used in the revamp was made by the plant engineering staff together with an independent third-party consultant. The review included a demonstration in Koch-Glitsch's 1.67m hydrocarbon pilot plant distillation tower, which closely reproduced the hydraulic design conditions for the revamp – see table 1. Following this review a 6-pass SUPERFRAC tray design was selected for this revamp. Several of the features discussed above were included in this design. This included extensive use of OMNI-FIT technology that allowed the flow path length and downcomer widths to be changed without having to weld directly to the tower shell.

Table 1: Comparison of operating conditions in the 1.67m diameter Koch-Glitsch test tower with the commercial propylene splitter

		Pilot Plant	Commercial Splitter
Vapor density	kg/m³	16.92	16.85
Liquid density	kg/m³	549	529
Liquid viscosity	cP	0.15	0.11
Surface tension	mN/m	7.3	7.6
Vapor diffusivity	m²/s	1.15 x 10-4	1.26 x 10-4
Relative volatility	[-]	1.11	1.20

Using innovative techniques, the 160 existing 4-pass trays were removed and replaced by 158 SUPERFRAC trays plus two dedicated distributor trays and new feed pipes at the reflux and feed entry points. The installation work was completed safely and on time. From the initial tower entry to begin removing the existing trays until completion of the new tray installation took a total of only 38 working days. Such a compact schedule was only possible through a close "one source" working relationship between the Koch-Glitsch equipment design team and the Koch Specialty Plant Services installation project team. The installation team made several key inputs during the detailed design phase that helped to shape the final equipment scope, ensuring it would allow rapid and safe installation while working on multiple levels in the tower. During the installation work in the field, the design team was constantly available to assist with timely resolution of any issues that arose.

Following the revamp with SUPERFRAC trays in 2017 the overall tray efficiency went from approximately 78% to 94%. The tower is now meeting the product purity goal at the higher feed rate. Propylene in the bottom product recycle is less than 50% of the design slippage, allowing the energy consumption (including heat pump compressor duty) to be optimized by reducing the reflux ratio. The new trays also have a lower pressure drop, which further reduces the energy consumption in the heat pump compressor.

The propylene production rate is now almost 50% higher than the original plant design rate and is currently limited by the reboiler capacity - there is no indication that the trays are at their operational limit.

4.4 Grassroots C3 splitter

This grass-roots Propane Dehydrogenation (PDH) plant has a capacity that called for a one of the largest diameter C3 splitters in the world at just over 10 metres in diameter and over 100 metres tall. The plant owner selected SUPERFRAC trays based on criteria including; proven performance, minimum tower size and ease of accessibility. Minimizing the pressure drop was also an important factor since the splitter has a heat pumped reboiler driven by the compressed overhead vapours. The reliably high tray efficiency developed by SUPERFRAC trays allowed fewer trays to be specified resulting in not only a shorter vessel height, but also lower pressure drop requiring less compressor horsepower.

Koch-Glitsch worked closely with the owner's subject matter experts and their engineering contractor to define the scope of the splitter tower internals. An 8-pass SUPERFRAC tray design with several of the features discussed above was selected for this application. With this being a new tower, the tray design, tower diameter and tray spacing could be optimized. Sectionalized beams were used to support the tray decks, with tray levelness being an important factor to ensure that the maximum performance would be achieved.

To minimize fit up errors OMNI-FIT technology was used to significantly simplify the design of the supporting tower attachments that had to be welded inside the tower by the vessel fabricator. This provided greater flexibility to the tray installer to ensure an accurate installation was achieved. Even with the much-simplified tower attachment scope, several deficiencies in the fabrication of the tower had to be overcome during the installation.

On all towers the support rings must be levelled within a manufacturer specified tolerance. The larger the vessel diameter, the more challenging it is for the vessel fabricator to maintain the specified tolerance. The support ring level should ideally be checked at the vessel shop before customer acceptance. Another reality when dealing with such large towers is that it is often impractical to transport them to the plant site in a single piece. When a very tall, large diameter vessel is welded together in the field this creates an opportunity that one or more sections will result to be slightly tilted. The perfectly levelled support rings that were verified at the vessel shop are now sloping, which can impact the tray efficiency, capacity and flexibility. Worse still, the impact is most significant when the rings are all tilted in the same direction. A final check of the support rings should be made prior to beginning installation of the trays. If any of the rings exceed the specified tolerance for level, the tray manufacturer should be contacted immediately to agree a plan for rectification. This may include the use of shims, to shore up the low points of the support ring or in rare cases, repositioning of the support ring. For the PDH splitter Koch-Glitsch sent a tray tower expert to the site to verify the tray installation and he and his project team worked with the tray installers to ensure a quality outcome.

The PDH unit started up in November 2015 and by February 2016, it was running at full capacity, delivering polymer-grade quality propylene from the initial start-up without any issues (DOW, 2016). The tower is meeting all capacity, purity and recovery expectations. The overall tray efficiency is above 90%, which is higher than assumed by the engineering company during the design phase. This allows the owners to adjust the reflux ratio to optimize the production and minimize the energy consumption.

5. Conclusions

The mega splitter towers in modern world scale olefins plants are pushing the boundaries of tray technology. To address the challenges in these towers, novel support mechanisms and tray arrangements were developed. These novel support mechanisms were employed in a number of large towers where it reduced cost and installation time, without impacting the tray performance, and the new tray arrangements were used to maximize the tower capacity and efficiency.

The case studies presented in this paper show that high tray efficiencies and capacities can be obtained with optimized SUPERFRAC trays. In C2 and C3 splitters efficiencies of 92 – 100 % have been obtained. This allows debottlenecking of existing splitters or a reduction in diameter and height for grassroots splitters. It also allows the energy consumption of these mega towers to be minimized. In the case of heat-pump splitters if also minimized the energy consumption and size of the heat-pump system. It is not necessary to find a trade-off between capacity and efficiency.

References

DOW Press release, DOW PDH Unit Completes Performance Test, March 07, 2016, https://www.dow.com/en-us/news/press-releases/dow-pdh-unit-completes-performance-test

Kister H.Z., Clancy-Jundt B., Miller R., Summers D.R., Troubleshooting and Rectification of a Giant C3 Splitter Tower Problem, AIChE Spring meeting, New Orleans, LA, USA, March 30 – April 3, 2014, 1 – 25.

Nieuwoudt I., Tray efficiency of SUPERFRAC high-performance trays in C2 splitter service, Hydrocarbon Asia, April-June 2011, 64 - 68.

Nieuwoudt I. Karpilovskiy O., Lockett M.J., Revamp and Retune, Hydrocarbon Engineering, July 2009, 56 – 60.

Summers D. R., McGuire P.J., Graves C.E. Harper S.E., Angelino S.J., High capacity trays debottleneck C3 splitter, Oil & Gas Journal, November 1995, 45.

US84855504B2, US Patent, Apparatus for supporting internals within a mass transfer column and process involving same.