Achieve Challenging Targets in Propylene Yield using Ultra System Fractionation Trays

Peter Wilkinson, Shell Global Solutions International BV, Amsterdam, NL

Waldo DeVilliers, Shell Global Solutions Inc, Houston, US

E-mail: Peter.Wilkinson@Shell.Com & Waldo.Devilliers@Shell.Com

Giuseppe Mosca, Loris Tonon, Sulzer Chemtech, Winterthur, CH

E-mail: Giuseppe.Mosca@Sulzer.Com & Loris.Tonon@Sulzer.Com

ABSTRACT

The Shell ConSep tray is an ultra high capacity tray that can operate beyond the 'system limit' as demonstrated at FRI [1],[2]. Since the first commercial application of ConSep trays for a revamp of a debutanizer in an NGL plant in 1995 ConSep has been applied in a low pressure hydrocracker main fractionator [3] in high pressure cat cracker debutanizers and in a catcracker depropanizer. The focus of this paper is on recent ConSep applications in catcracker work-up sections which have enabled significant increases in the yield of valuable products such as propylene and gasoline. In addition the first part of this paper is focused on explaining the ConSep technology in more detail.

ConSep technology

Distillation columns equipped with conventional trays can be significantly debottlenecked by applying high capacity trays. For example case studies focused on improving propylene production with high performance trays have been reported in the 2004 ERTC meeting [4]. For columns which are already equipped with high capacity trays the options for further debottlenecking are much more limited, and will often lead to the decision that columns need to be replaced by larger ones, or by adding new columns. In the last decade new developments have focused on "ultra high capacity trays" [5] which are preliminary intended for debottlenecking (up to 50%) columns which are already equipped with high capacity trays. Within Shell there are several applications using the ConSep (ultra high capacity) tray for debottlenecking high capacity trays. The "operating mechanism" of a ConSep tray is illustrated in Figure 1 below.

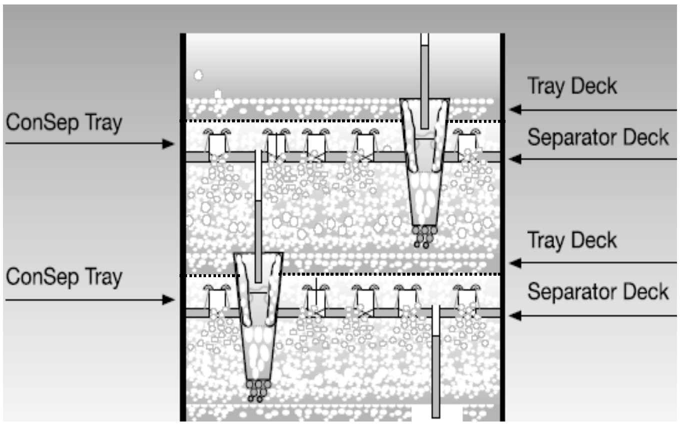

Figure 1. Schematic drawing of ConSep tray, showing separator deck for 'catching' entrained liquid and small separator downcomers which redirects the entrained liquid into the main tray downcomer.

This picture shows that the ConSep tray is basically just a 'normal' Contacting tray combined with a high capacity Separator which uses 'centrifugal forces'. The primary function of the separator is to allow operation of the tray under conditions where vapour loads are so high that a large part of the liquid on the tray is entrained with the vapour. For 'normal' trays flooding can be caused by three mechanisms:

1. Jet-flood limitations
2. Downcomer choking limitation
3. Downcomer back-up limitations

The use of the ConSep separator influences all three mechanisms:

1. The 'normal' jet flood limitation is no longer a concern as the entrained liquid is efficiently separated from the vapour to prevent carry-over of liquid to the tray above.
2. The liquid entering the main downcomer is largely coming from the 'separator' deck where it has been separated from the vapour. Due to the fact that this is relatively "well–degassed' liquid (as shown in Figure 2) the downcomer liquid handling capacity is substantially increased (factor 2-3 higher relative to the downcomer capacity of a normal tray based on our research data for iC4/nC4 at 11bara).
3. With choking and jet-flood limitations largely removed the downcomer back-up is the prime flooding mechanism for ConSep trays. Therefore these ConSep trays are typically designed with a relatively high open area and also the separator deck uses special low pressure drop swirl devices designed with a high open area.

Figure 2. Photo of ConSep Separator deck (ambient air/water test conditions).

In the Shell research facilities in Amsterdam the ConSep trays have recently been studied using very detailed γ-scanning techniques to make 'contour' plots to measure the gas/liquid distribution in the tray (Figure 3).

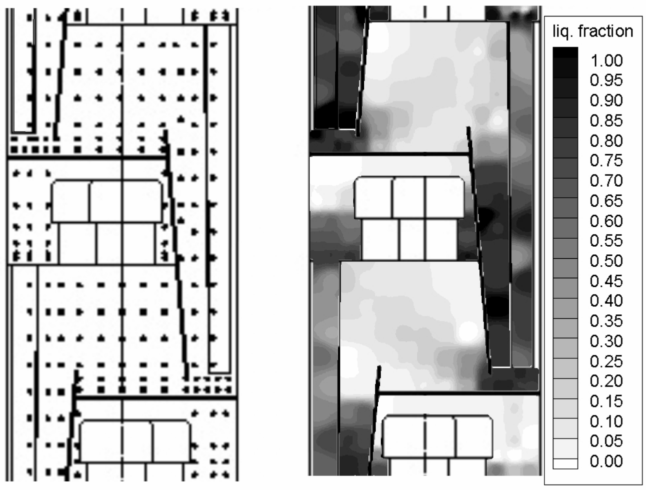

Figure 3. Gamma-scans for iC4/nC4 mixture at 11bar, tray spacing = 450 mm under total reflux conditions. Points in picture on the left show 'scan points'. The vapour load shown is for Cs=0.12 m/s near flooding conditions (Cs = capacity factor based on total column cross sectional area).

The γ-scan results clearly confirm the aforementioned flooding mechanism where downcomer back-up is the main capacity constraint for a ConSep tray. In the layout shown the tray spacing is only 450 mm (from sieve deck to sieve deck). Despite the low tray spacing the capacity measured was very close to the capacity measured for ConSep at FRI (Figure 4) on a larger tray spacing (600 mm) and is still well beyond the 'system limit'. Main reason for the small impact of tray spacing on capacity for these two cases is that the layout shown in Figure 3 was further optimized for downcomer back-up capacity by using a conventional downcomer instead of a relatively short truncated downcomer. This example illustrates that the capacity of ConSep as tested at FRI (figure 4 below) can still be further increased by making changes focused on reducing downcomer back-up. Options to achieve this are:

- Extending the downcomers as much as possible (by using 'conventional downcomers' instead of truncated downcomers).
- Increase number of swirl tubes on the separator deck to reduce pressure drop.
- By increasing the open area of the contacting tray and thus reducing the tray pressure drop (at the expense of turn-down performance).

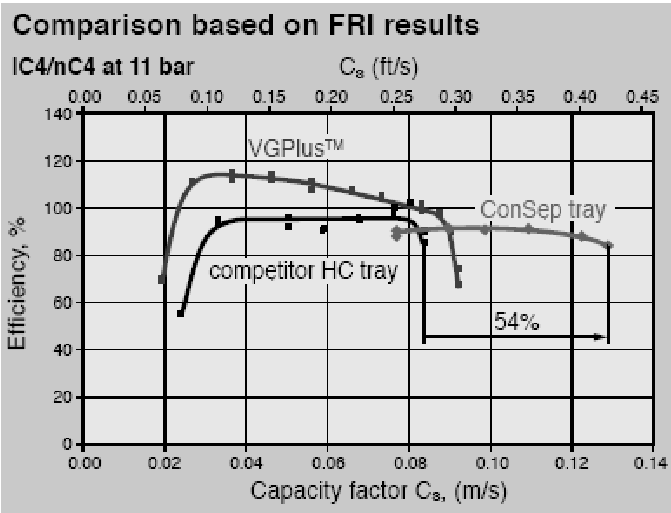

Figure 4. Performance of two path tray with ConSep technology compared to a single path high capacity tray from Sulzer and other tray manufacturer.

When ConSep trays are considered for revamping it is typically found that only part of the potential capacity enhancement is required. When capacity increases beyond 20-30% are being considered usually several other constraints such as reboiler/condenser limitation need to be resolved. Within Shell the columns which have been debottlenecked with ConSep trays are now all no longer limited by flooding, but limited by other factors such as availability of feed and/or constraints on auxiliary equipment (see Table 1).

As a consequence current developments for ConSep are not focussed on achieving even higher capacities. Instead the area of development is more focussed on ways to increase efficiency. As shown in Figure 4 the tray efficiency for a ConSep tray tends to be lower than for a high capacity tray with longer flow path length as the degree of cross flow achievable on a ConSep tray is limited. One way to enhance the overall efficiency or number of stages/m column height is to reduce the tray spacing. This has been successfully applied in research and will also be further tested at FRI in 2006. Other areas for development are to assess the performance of ConSep trays at very high pressures. Until now ConSep has been successfully applied at pressures up to 20 bar at which the liquid density is only about a factor 10 higher than the gas density (and the density difference between gas and liquid is about 400 kg/m^3). When the pressure becomes even higher the separation between liquid and gas will become more difficult. In the near future ConSep will be tested at FRI at even higher pressures aiming to test the performance under conditions where the liquid density is only about a factor 5 higher than the gas density (and the density difference between gas and liquid is as small as 300 kg/m^3). This is mainly of interest for potential ConSep applications in very high pressure columns such as demethanizers.

ConSep applications for catcracker work-up sections

Since the first application of ConSep in 1995 for a debutanizer gas plant [2] these trays have been successfully applied for debottlenecking covering a wide range of applications as shown below in Table 1.

Table 1. Overview of ConSep applications.

Plant	Operating Pressure (Bar)	Year	Max capacity increase achieved(1)
NGL Debutanizer	3-5	1995	22%(2)
FCCU Debutanizer	8-12	1996	30%(3)
HCU Main fractionator	3-4	1999	50%(3)
NGL Debutanizer	3-5	1999&2000	15%(2)
FCCU Debutanizer	8-12	2000	20%(2)
FCCU Debutanizer	8-12	2006	10% (4)
FCCU Depropanizer	18-20	2006	(4)

(1) Capacity achieved in excess of the existing high capacity trays.

(2) Limited by reboiler capacity.

(3) Limited by feed to the column.

(4) Has only just started up, no constraints observed yet.

Apart from the catcracker work-up section applications all other ConSep applications have been reported in the open literature [2][3]. Therefore this paper now focuses on the ConSep applications in FCC work-up sections where capacity increase will normally lead to significant margin improvements.

ConSep Case Study: FCC Gas Plant Depropanizer

Previously an article was written dealing with potential applications of ConSep for depropanizers and even C2-splitters [2]. Meanwhile the first commercial application of ConSep trays in a depropanizer application has recently been completed. The 44 tray, 2.3m diameter column operates in the 18-20 bara range. Prior to the revamp the column had non-Shell high capacity trays at 610mm tray spacing with a liquid feed on tray 26 from the top. A future-operating scenario would have the rectification section operating in the 95 to 105% of maximum useful capacity range (close to flooding limitations). This was unacceptable from an operating flexibility point of view. By replacing the 25 high capacity trays in the rectification section with ConSep trays the column would have sufficient capacity to comfortably handle the future case without exceeding the capacity of the reboilers, condenser and reflux pump. The strategy here was not to make full use of the ConSep capacity but to eliminate the bottleneck and provide the operating flexibility required with no additional capital investment beyond that for the column internals. As a result the revamp targeted just 15% additional capacity over that of the previous high capacity trays in the rectification section.

A third party field services outfit with no prior exposure to ConSep trays installed the 25 trays (each consisting of a HiFi tray and associated separator deck) within a 5-day period. The total installation effort including feed pipes and a collector tray, post-weld heat treatment and quality assurance was completed within a 2-week period. Figure 5 represents a view inside the column after completion of a tray assembly. The top of the swirl tubes can be seen through the perforations of the HiFi tray deck.

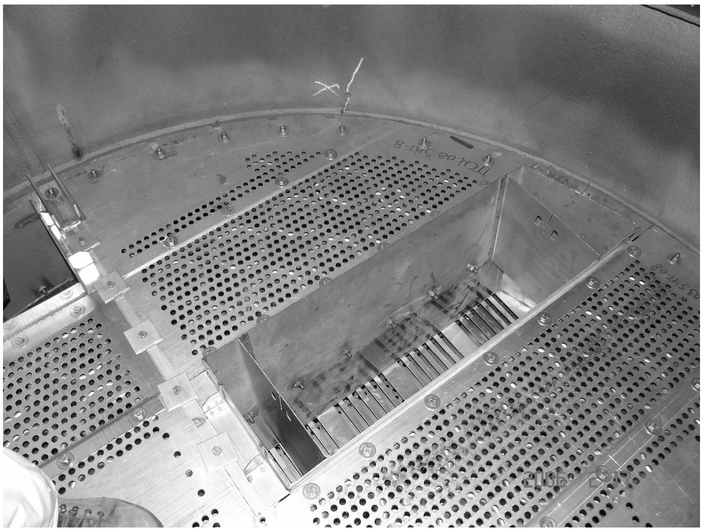

Figure 5. Picture taken during installation of ConSep tray internals for depropanizer.

The column started up without any problems. The highest throughput recorded to date has been 80% of the design loadings. The full design feed will only be available once the upstream cat cracker has been fully converted to the new operating scenario. The total pressure drop across the column has increased by some 15% at a given throughput due to the presence of the swirl decks. The overall column efficiency at this (highest load) operating point has been determined to be in excess of 85% for both the stripping and rectification sections. At these conditions the overhead C3 product typically has less than 10 ppmv C4s. The reflux to feed ratio was approx. 70% of the design value.

These results highlight one of the unique benefits of ConSep tray technology, which is the relatively good efficiencies that can be maintained at conditions that would have flooded high capacity trays. This is due to cross-flow enhancement provided by the contacting tray and the efficient de-entrainment in the swirl tubes.

ConSep Case Study: FCC Debutanizer

In 2006 the 3rd FCC debutanizer application within Shell for ConSep was realized. In addition there has been a 4th design made for a refinery outside Shell. Typically the main drivers for debottlenecking FCC debutanizers are:

- FCC through-put increase, or operating with higher severity to increase gasoline/propylene production.
- Changes to more severe gasoline RVP specifications (related to lowering LCCG endpoint specifications).

In 2002 a Shell operated FCC unit was debottlenecked to achieve a feed rate increase of 30% relative to the original design. After the implementation of the project the debutanizer and the mainfractionator were operating close to flooding (as expected). In 2005 a project was executed which showed that the FCC work-up section could be further debottlenecked using Shell grid trays in the desuperheating section of the mainfractionator and ConSep trays in the debutanizer stripping section. An alternative solution considered was to install a larger feed-preheater for the debutanizer to off-load the stripping section, while shifting load to the column top section which was not operating close to flooding conditions. The disadvantage of this approach was that process simulations indicated a substantial increase of the required reflux ratio and this could lead to constraints on the condenser. This together with a cost comparison (larger heat exchanger versus cost of ConSep trays) showed that the use of ConSep trays was by far to be preferred.

Meanwhile the recommended modifications to the main fractionator and debutanizer have been implemented in May 2006. Similarly to the aforementioned depropanizer application the installation and start-up of the unit went smoothly. Currently the through-put of the FCC unit has been increased by 10% in line with expectations and with all columns running without any signs of flooding. For the debutanizer the reflux ratio has remained constant when comparing the conditions before and after the ConSep tray installation. This indicates that the tray efficiency is comparable to the tray efficiency of the high capacity trays previously installed.

Conclusions

A limited number of ultra-high capacity trays are now available on the market which target debottlenecking of columns already equipped with high capacity trays. This paper has focussed on the ConSep tray which have now been applied in Shell units for just over a decade. All ConSep trays installed since 1995 are still in operation and have lead to considerable capacity increases (up to 50%) relative to the capacities achieved with the high capacity trays they replaced. Based on data from FRI and on the basis of field data for an FCC depropanizer it shows that tray efficiencies for ConSep can be as high as 85-90%, and are often close to or only slightly lower than the efficiency achieved with more conventional high capacity trays. Therefore it may be safely concluded that ConSep trays provide a robust and safe debottlenecking option for columns which are already equipped with high capacity trays such as the Shell HiFi trays [4]. Most likely it is only a matter of time that even large superfractionators will be debottlenecked using Shell ConSep trays [2].

LITERATURE CITED

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