Developments in Splitter Revamps

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Abstract: This presentation will focus on developments in ethylene plant fractionator revamps. It will discuss the use of high capacity distillation trays to increase capacity in fixed tower sizes. It will present an overview of Shell high capacity mass transfer technology including the HiFi Plus† and ConSep† trays. Additionally it will present revamp case studies and performance data illustrating the potential of these devices.

Ethylene plant distillation trains

An ethylene plant makes extensive use of distillation, especially in the cold section illustrated in figure 1. Any revamp project will also need to consider the required column internals for the columns shown below to allow the desired throughput.

![Ethylene Plant Cold Section Diagram]

Figure 1: Ethylene Plant Cold Section

† Shell Group trademarks
Principles of High Capacity trays

Revamps of high pressure distillation columns such as those found in the cold section of ethylene plants can effectively make use of high capacity tray technology. Features of high capacity trays are:

- Truncated downcomers that maximize the bubbling area
- Low entrainment bubblers such as Sulzer MVG\textsuperscript{††} valves
- Long weir lengths providing high liquid handling capacity
- Good tray efficiency ensured by providing adequate flow path length and avoiding stagnant areas through good liquid distribution
- Ability to function at low tray spacing
- Devices at the inlet of downcomers that produce a lower and more uniform froth height

The Shell family of high capacity devices such as the Calming Section Plus\textsuperscript{†} (CS Plus) and HiFi Plus trays make use of these features. Figure 2 illustrates the expected capacity and range of application of these devices relative to conventional trays and packing. The design principle is that for every flow parameter $\phi$ there is an optimal tray layout – one that maximizes vapor capacity whilst maintaining an acceptable efficiency. At high system pressures downcomer choking may occur resulting in increased froth height and an earlier limitation on tray capacity. Hence the maximum useful capacity is really that determined by the minimum of jet flood, downcomer choking and downcomer inlet velocity restrictions. The concept of "maximum useful capacity" (MUC) rather than a hydraulic flood is used to indicate the maximum tray capacity. The column may still be operable beyond 100% of MUC but the efficiency will be severely degraded.

![Figure 2: Comparison of column internal capacities](image)

\textsuperscript{††} Sulzer Chemtech trademarks
The flow parameter is defined as: \( \phi = \frac{L}{V} \sqrt{\frac{\rho_g}{\rho_l}} \), where \( L/V \) represents the liquid to vapor mass flow ratio. The density correction factor is the ratio of vapor to liquid density.

Sulzer MVG valves (see figure 3) are utilized in Calming Section Plus and HiFi Plus trays to offer increased vapor capacity and reduced entrainment. The lateral discharge of the vapor jets helps to collapse the froth and reduce entrainment. The directional nature of the valves help to sweep liquid across the tray deck. Turndown capability is between that of sieve and moving valves. MVG tray panels are mechanically more robust than sieve or moving valve tray panels.

Figure 3: MVG valves

In the case of the HiFi Plus tray, use can also be made of a special downcomer inlet device, called a Crown Inlet Device\(^\dagger\) (CID), to provide additional downcomer liquid handling capacity for high pressure columns.

Typical tray layouts are illustrated in figures 4 and 5.
Calming Section† (CS) trays are typically used for flow parameters below 0.2 such as Main Fractionators, De-isobutanizers, C6/C7/C8 fractionations, atmospheric and mild vacuum chemical columns and in general any place where entrainment is a concern. A single tray design is required for odd and even trays.
HiFi trays are typically used for flow parameters above 0.1 such as Deethanizers, Depropanizers, Debutanizers, Rectified Absorbers, C2 and C3 splitters, pump-around sections in fractionators and in general any place where liquid capacity is a concern. Again a single tray design is required for odd and even trays.

Since the 1980s, there have been more than 2000 applications of Shell Calming Section and HiFi trays world-wide.

**Minimize installation time and effort**

When revamping C2 and other splitters the downtime required to install new internals can often become the critical path. The length of the shutdown can have a significant impact on the revamp economics. Techniques that reduce installation effort are therefore of particular interest. Shell high capacity trays use envelope downcomers that are fully supported by the tray deck. The downcomers are 'dropped' into place with no need for modifications to downcomer bolting bars. Missing support ring segments can be filled in using expansion rings thus avoiding welding to the vessel wall.

Shell Global Solutions has formed an alliance with Sulzer Chemtech to market and sell the Shell mass transfer technology world-wide. Sulzer Chemtech has developed a number of time and cost saving techniques that can be utilized with Shell high capacity trays [1]. These are summarized below.

The Lip-slot panel connection (fig. 6) eliminates the need for bolting at panel overlaps. This reduces the time required to fasten panels to each other dramatically. Only the last panel is required to be bolted or connected with wedge type connections. Split-wedge tray support ring and downcomer connections further reduce the need for bolting. After installation the wedges are secured by bending them outwards.

Figure 6: Lip-slot and Split-wedge type connections

Existing support rings can be used to support new expansion rings with vertical struts and lattice beams to avoid having to weld to the column wall. This practice (fig. 7 left hand) eliminates the need for post welded heat treatment or pressure testing after the work has been completed. In addition up to two HiFi trays can be supported by a single lattice beam at low tray spacings (fig. 7 right hand).
The use of expansion rings, vertical bars and lattice beams combined with Lip-Slot panel connections may save up to 35% of the installation time, resulting in a significant money savings over conventional methods.

**Debottlenecking opportunities**

Table 1 illustrates the Shell internals that can be considered for revamping ethylene plant columns (mostly cold-side).

<table>
<thead>
<tr>
<th>Column</th>
<th>Pressure [bar abs]</th>
<th>High Capacity Internals</th>
<th>Super-high Capacity Internals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic Scrubber</td>
<td>&gt; 30</td>
<td>CS</td>
<td></td>
</tr>
<tr>
<td>Demethanizer</td>
<td>&gt; 40</td>
<td>CS/HiFi</td>
<td>ConSep</td>
</tr>
<tr>
<td>Deethanizer</td>
<td>&gt; 30</td>
<td>CS/HiFi</td>
<td>ConSep</td>
</tr>
<tr>
<td>Depropanizer</td>
<td>&gt; 20</td>
<td>CS/HiFi</td>
<td>ConSep</td>
</tr>
<tr>
<td>Debutanizer</td>
<td>&gt; 10</td>
<td>CS/HiFi</td>
<td>ConSep</td>
</tr>
<tr>
<td>C2 Splitter *</td>
<td>10-40</td>
<td>HiFi</td>
<td>ConSep</td>
</tr>
<tr>
<td>C3 Splitter</td>
<td>10-40</td>
<td>HiFi</td>
<td></td>
</tr>
</tbody>
</table>

(* Non heat-pumped)

The ConSep tray is a relatively new device offering extremely high capacity. It will be described in more detail later on.

**Splitter Revamps**

Bravo, Sikkenk and Roza [1] reported on the relationships between operating pressure, relative volatility, number of stages and required reflux ratio for a given set of feed and product specifications for low (heat-pumped) and high pressure C2 Splitters. For low pressure C2 Splitters the ability to increase reflux is often limited by heat pump or refrigeration limits. They indicated that lower pressure in C2 Splitters yields lower reflux
requirements however that is offset by the increase in vapor velocities due to the lower vapor density. The revamp then becomes a trade-off between the effects of pressure reduction on relative volatility (beneficial) and tray vapor capacity (negative). In such cases the use of high capacity trays is of great benefit. For high pressure C2 Splitters the detrimental effect of higher pressure on volatility dominates and there is a clear preference for lower pressure.

Two case studies covering a C2 and C3 Splitter revamp for a Shell lower-olefins facility in Europe are described below. The C2 splitter revamp involved a 1 for 1 retray of 4-pass conventional trays by 130 HiFi sieve trays (tray spacing 18 inch). The column was a high pressure C2 Splitter operating at 20 barg with a diameter of 4.4m. The throughput of the Splitter before and after the revamp is shown in figure 8. A capacity increase of approximately 45% was witnessed. Figure 9 illustrates the required reflux to feed ratio before and after the revamp confirming that the tray efficiency remained the same. A reduction in pressure drop of approximately 30% was also observed.

Figure 8: C2 Splitter capacity before and after revamp
The C3 Splitter revamp involved the replacement of 150 conventional 4-pass trays at 18 inch tray spacing with 211 HiFi sieve trays at 12 inch tray spacing. The column is a high pressure C3 Splitter operating between 11-18 bara (due to environmental fluctuations) with a diameter of 6.0m. The throughput of the Splitter before and after the revamp is shown in figure 10. A capacity increase of approximately 30% was witnessed.
Moving beyond High Capacity Trays

FRI defines the 'Ultimate Capacity' of a column to be the vapor load at which liquid would be entrained upwards independent of the column hardware. The Shell ConSep tray is designed to operate at or beyond the FRI ultimate capacity. It combines a conventional contacting deck that operates under conditions of severe entrainment with a separation deck utilizing centrifugal force to separate the entrained liquid from the vapor. The entrained liquid is returned to the tray below. See Figure 11.

The ConSep tray represents an enhancement of the HiFi tray in that it allows operation above the jet flood point, but permits normal downcomer flow as well. It is the highest capacity device in the Shell family of fractionation devices. It offers increased capacity over conventional trays of approximately 50-80% and 30-50% over CS or HiFi trays. It maximizes jet flood and liquid handling capacity. It can be retrofitted to existing towers utilizing tray spacings of 18-32 inches and provides comparable efficiency to conventional trays.

Table 2 provides a summary of ConSep applications in various services. Note that the Shell Calming Section/HiFi trays that were replaced already achieved a capacity increase of 10-40% over conventional multipass trays [2].

Table 2: Applications of Shell ConSep trays to replace existing HiFi/CS trays

<table>
<thead>
<tr>
<th>Country</th>
<th>Plant</th>
<th>Column diameter, m</th>
<th>Year</th>
<th>Max capacity increase achieved¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>NGL debutanizer</td>
<td>1.9</td>
<td>1995</td>
<td>22%²</td>
</tr>
<tr>
<td>Australia</td>
<td>FCCU debutanizer</td>
<td>1.9</td>
<td>1996</td>
<td>30%³</td>
</tr>
<tr>
<td>Germany</td>
<td>HCU main fractionator</td>
<td>2.2</td>
<td>1999</td>
<td>50%</td>
</tr>
<tr>
<td>Australia</td>
<td>NGL debutanizer</td>
<td>1.7</td>
<td>1999</td>
<td>15%³</td>
</tr>
<tr>
<td>Singapore</td>
<td>FCCU debutanizer</td>
<td>2.5</td>
<td>2000</td>
<td>- ⁴</td>
</tr>
</tbody>
</table>

¹ Post startup performance testrun - capacity achieved on top of the existing HiFi/CS trays.
² Limited by reboiler duty.
³ Limited by feed to the column.
⁴ No test run data available.
A Main Fractionator at the Godorf Refinery was retrofitted with ConSep trays to realize a capacity gain opportunity offered by an optimized process [2]. Previously the top section of the main fractionator had been the bottleneck of the hydrocracker. Startup was trouble-free and the new design capacity was met and exceeded in quick time. Figure 12 illustrates the increase in throughput that was achieved as a result of the revamp.

Figure 12: Production increase after revamping with ConSep™ trays

A second ConSep case study involves a NGL debutanizer revamp. In this Shell plant there were two identical debutanizers both receiving the same feed from a depropanizer. In 1995 one of these debutanizers was revamped with ConSep trays (1 for 1 tray replacement of all trays). This has increased the capacity by more than 20% (relative to high capacity Shell Calming Section valve trays). At the highest reboiler duty shown in figure 13 the calculated maximum column load factor is 0.12 m/s. Operating at even higher loads is not possible due to reboiler constraints (the reboiler has not been revamped).
Reboiler duty (Mwatt)

Average pressure drop / tray (mbar)

Shell-ConSep trays
Shell Calming Section trays

Figure 13: Comparison between debutanizer with and without ConSep trays.

Conclusions
1. The use of high capacity trays with sensible mechanical design and installation features offer an attractive means of revamping ethylene plant splitters and other fractionation columns.
2. Shell Calming Section and HiFi trays offer an attractive combination of performance enhancing features to maximize jet flood and liquid handling capacities with over 2000 documented installations.
3. Shell ConSep trays represent a breakthrough in distillation tray technology offering exceptional debottlenecking potential.

References
[2] "The Shell ConSep tray technology provides unparalleled distillation capacity" presented by C. Groenendaal, B. Trautrims, K. Kusters and J.L. Bravo at the EFChE-Conference April 2001 in Bamberg, Germany

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