EXPAND PLANT’S CAPACITY WITH HIGH PERFORMCE TRAYS

Giuseppe Mosca, Loris Tonon, Sulzer Chemtech, Winterthur, CH
Daniel Efremov, Sulzer Chemtech, Russia
Peter Wilkinson, Shell Global Solutions International, Amsterdam, NL

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ABSTRACT
Increasing capacity in major existing equipment, without compromising efficiency, is a key factor to economically meet revamp targets.
When expanding plants throughput, one of the major key equipment to look at is the distillation column. Most of the equipment being used, such as pumps, exchangers, coolers, valves, piping, can be modified or replaced by bigger size with minor impact on the available layout space of the plant. For some other equipment i.e. fired heaters, reactors and distillation columns, the replacement could be very difficult, economically unattractive, or even impossible; they are in fact the true bottleneck of the potential capacity expansion of an existing running plant. It clearly appears the reason why, in the last 20 years, a lot of effort and research work have been done to develop new features, enhancing capacity and efficiency of the mass transfer components, with the scope of pushing the distillation columns to their ultimate limit set by vessel diameter.
The purpose of this paper is to give an overview of the most advanced fractionation trays available in the petrochemical and chemical industries, such as Sulzer VGPlus™ High Performance Trays and Shell HiFi™ trays. Two successful commercial revamp experiences will be discussed in detail, where the use of the appropriate type of High Performance Trays yields to the most cost effective revamp solution for a De-Butanizer and a C3 Splitter.
1) Conventional Trays
A conventional tray consists of a bubbling area where liquid and vapor are in contact for mass-transfer. A downcomer receiving the mixed phase or froth, where the liquid separates from the vapor and moves down to the tray below; and an empty space, between adjacent trays, where vapor-liquid disengagement takes places and clear vapor moves to the tray above. Capacity limitation may occur basically with two mechanisms: the inter-space between adjacent trays is not enough for vapor disengagement, and massive entrainment is carried up to the tray above: Jet Flooding.
Capacity may be limited also by excessive froth flow from the tray deck to the mouth of the downcomer. The vapor cannot separate from the liquid, causing excessive downcomer backup, and consequent froth accumulation backward to the bubbling area: Downcomer Flooding.
When reaching the flooding condition the pressure drop start to increase drastically and the tower becomes inoperable.

2) High Performance Trays
The High Performance Trays (HPT) are more often found in the industrial applications, as the operating targets become more and more challenging.
The HPT are normally used in revamps with following two scenarios:
1. Increase the tower capacity by means of one-for-one replacement;
2. Increase the number of theoretical stages by installing more actual trays at reduced tray spacing; either to improve product ‘s recovery, or product ‘s purity, or minimize operating cost by reducing reflux ratio.

HPT are also used in grassroots applications either to minimize tower diameter or column height, with the goal of minimizing investment cost. This is the case of Super-Fractionators requiring a high number of trays i.e. C3 and C2 Splitters and isomers Splitters.
It has to be underlined that there is not a HPT suitable for all possible services.
There are several factors to be checked: the type of applications, the required operating duties, the ratio of liquid over vapor, the geometrical dimensions of the columns, mechanical/structural concerns etc. Only after a deep analysis of such aspects, a given type of HPT can be selected as the best fit, either for a performance and/or cost points of view.
With Sulzer Chemtech is actually available one of the largest HPT portfolio of the market, to satisfy the highest demanding Customers for any type of applications and duties.
It ranges from the proprietary chordal downcomer VGPlus™, to the multi-downcomer Shell HiFi™ trays, and to the ultra system limit Shell ConSep™ trays (out of the scope of this paper).

2.1) VGPlus™ Trays
With extensive research work, testing facilities, and the use of new technologies like Computational Fluid Dynamic (CFD) analysis (Figure 1), Sulzer Chemtech has recently developed the highest performance fractionation tray ever tested at the FRI (Fractionation Research, Inc. USA). FRI is an independent consortium qualified and worldwide recognized for testing mass transfer components either for capacity and efficiency.

Several features have been used to enhance the capacity of a conventional tray and deliver the Sulzer Chemtech proprietary VGPlus™ trays.

MVG Openings: the unique design and orientation of this fixed valve provides with:

- Horizontal vapor dispersion as it leaves the lateral slots, thus less jetting and less entrainment (Figure 2).
- No liquid blown upstream, thus less back mixing, less hydraulic gradient along with the flow path.
- Directional shape of the valves helps to sweep the liquid across the tray.
- Higher capacity than movable round valves (Figure 3).
- Lower pressure-drop per theoretical stage than movable round valves (Figure 4).
- Good turndown capability, slightly less than movable valves, definitely higher than sieve or any other fixed valves.
- No moving parts, no mechanical wear, thus more robust, and longer life than movable valves or sieve trays.
- More suitable for fouling services than movable valves.

Truncated Downcomer: (Figure 5) the conventional downcomer is modified so that the lower outlet edge ends some 100 to 150mm above the tray deck.

The area beneath the downcomer is therefore gained for extra bubbling activity and disengagement zone, resulting in higher capacity without adversely affecting the mass transfer efficiency.
Redirecting Devices: (Figure 6) A further improvement has been achieved at the downcomer inlet area by means of redirecting devices, bubble enhancers and push valves. These special features provide with:

- Aeration enhancement of the liquid coming from the downcomer to increase the bubbling activity and the mass transfer efficiency.
- Uniform froth distribution over the active area, stagnant zone is eliminated, liquid gradient along with the flow path is reduced, and vapor cross flow channeling is minimized.

VGPlus™ HPT provide with the following advantages (Figure 7):

1. Up to 30% higher capacity than conventional trays.
2. Up to 10% higher capacity than competitor chordal downcomer HPT.
3. Up to 15% higher efficiency than competitor chordal downcomer HPT.

For atmospheric to medium-high pressure applications Sulzer can offer the best cost effective solution based on either the VGPlus™ tray or the Shell CS™ tray. This includes CDU, FCCU, HDT, Main Fractionators, Naphtha Stabilizers, Naphtha Splitters, Debutanizer, C3/C4 Splitters, Iso-C4/Normal-C4 Splitter, Aromatics separations. For the medium pressure applications there is an overlap with the Shell HiFi™ trays. For the optimum tray selection (VGPlus™, Shell CS™, Shell HiFi™) the design must be carefully evaluated to hit the best device.

2.1) Shell HiFi™ Trays

These trays are made up of several downcomers properly located offset to the cross section centreline, supported by a major beam and a 360° support ring (Figure 8). Downcomer bolting bar are not needed. The downcomer outlet is located at 100 to 150mm above the tray deck, so that the area beneath the downcomer is gained for extra bubbling activity and disengagement zone for capacity maximization.

Within the alliance agreement with Shell Global Solution, they are now available in the Sulzer Chemtech HPT portfolio.

The major unique advantage is that the downcomers provide with an outlet weir length double or triple than chordal downcomer trays. This lowers the liquid loading per length of weir by a factor of 2 to 3, and subsequently the crest height over the weir, and the total pressure drop per tray, resulting in a significant capacity boosting over conventional trays.
More over since there is no obstruction between the several compartments of the tray, the vapor distribution underneath the bubbling area is very uniform: it is the only hydraulically self-balancing multi-downcomer tray ever built in the market.

HiFi™ trays can be fitted with sieve holes, movable or fixed valves. In combination with fixed valves MVG™ (=Shell HiFi Plus™ trays) they provide with the highest performance, therefore are recommended when the required capacity approaches the system limit. HiFi™ trays provide with following features and performances:

1. Largest downcomer area per given column diameter
2. Longest weir length per given column diameter
3. Largest capacity at high liquid loading
4. Lowest pressure drop per tray at high liquid loading
5. Lowest tower height per theoretical stage (tray spacing as low as 300mm)
6. Up to 40% higher capacity than conventional trays
7. Up to 10% higher efficiency than competitor multi downcomer trays

Medium to high-pressure applications are the best fit for such trays. In some cases, where a high number of trays is required, the use of these devices allow for an effective economical solution, because they can be installed at very low tray spacing, with consequent minimization of tower height. The typical applications are: C2 Splitter, C3 Splitter, Xylene isomers Splitter, Super-Fractionator in general, Demethanizer and Deethanizer in Ethylene and Gas plants.

3) Case Story 1: De-bottlenecking a De-Butanizer

A major Refinery wanted to increase the throughput of a De-Butanizer by 25%, and simultaneously improve the quality of the LPG and of the stabilized Gasoline.

3.1) Process Description (Figure 9)

The feed to the tower is composed of two streams: the major one is coming from the second condensation stage of the Crude Distillation Unit. A second portion is added before entering the column; actually the revamping was needed to process also this stream.

In the column the LPG is separated from the Stabilized Naphtha, a part of it is sent to the Hydrotreater and the rest directly to the Gasoline pool.

3.2) Scope of the Revamping
Due to the high demand of Gasoline, there was the need to increase the capacity of the De-Butanizer from 163 to 204 tons/h. A better product’s quality was also required, in particular the Reid Vapor Pressure of the Gasoline had to be consistently reduced to comply with the market requirement, in particular during Summer time; as well as the C5 plus in the LPG to be not more than 0.4 %Vol. (See Table 3.2.1).

Table 3.2.1: Case Story 1, De-Butanizer Revamp Design Data

<table>
<thead>
<tr>
<th></th>
<th>Pre-Revamp</th>
<th>Post-Revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate (tons / h)</td>
<td>163</td>
<td>204</td>
</tr>
<tr>
<td>Gasoline RVP (psi)</td>
<td>8</td>
<td>7.1</td>
</tr>
<tr>
<td>C5 in LPG (% Liq. Vol.)</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Max. Column Press. Drop (Kg/cm2)</td>
<td>0.3</td>
<td>0.35</td>
</tr>
</tbody>
</table>

3.3) The Solution
Sulzer Chemtech provided technical support to determine the ultimate capacity based on the existing vessel diameter. Several process simulations with PRO2 from SIMSCI, and hydraulic calculations with proprietary programs, were performed to select the most appropriate HPT to meet such challenging targets. The process study was performed within the constraints specified by the Client i.e. condenser & reboiler duty, Pumps & Exchangers data sheet, mechanical limitation of the column, time frame for project implementation at site.

The 36 existing two-pass valve trays were replaced with VGPlus High Performance Trays, same number of flow path. Due to the big difference in liquid traffic through the column, the downcomers had to be resized, and consistently enlarged. To avoid massive welding to the tower wall, tailored design features (downcomer adaptors) have been used to fit the new trays with the existing tower attachments.

Feed & top reflux nozzles were maintained, however new distributors were needed.
Sulzer Chemtech personnel supervised the installation activity and finally inspected the tower internals. The job was implemented in 12 working days, slightly ahead than scheduled.

3.4) Post Revamp Results
The unit is running since more than 6 months at a capacity close to the revamp target, very smoothly with no problems, nor at the column, nor at the other equipment. The quality of
Gasoline as well as LPG is even higher than expected. The pressure drop across the column is close to the maximum allowable. The trays are providing mass transfer efficiency above any optimistic expectation: over 85%.

4) Case Story 2: De-bottlenecking a C3 Splitter

Due to the high demand of Propylene the Client decided to increase the capacity of the C3 Splitter as well as improve the recovery.

4.1) Process Description

This C3 Splitter is located in the cold section of an Ethylene Plant. The cracked gas from the last compressor stage is sub-cooled and separated in a liquid and a gas stream. The liquid phase passes through a Coalescer and a De-Hydrator before entering the high pressure Depropanizer. The gas as well is de-hydrated before entering the same column few trays above. The overhead goes to the Demethanizer Pre-Fractionator upon hydrogenation. The bottom of the HP Depropanizer goes to a Cooling water, and before entering the low pressure Depropanizer, a polymerisation inhibitor is added. The bottom is fed to the DeButanizer, where LPG is separated from the Pyrolysis Gasoline. The overhead of the LP Depropanizer pass through an arsine guard, mixes with the bottom of the Deethanizer, pass through a COS/MeOH guard and is further hydrogenated to convert methyl acetylene and propadiene (MAPD).

The treated C3s is fed to the C3 Splitter (see Figure 10). The unit consists of two columns in series: C-1 and C-2. The first column receive the feed; the bottom product is predominantly propane with some propylene and some C4s, it can be recycled back the low pressure Depropanizer or to the furnaces. The quench water coming from the Quench Tower provides the duty to the reboiler. The overhead gas of the column C1 is fed to the bottom of the second column C2. The bottom liquid coming from C2 is pumped to the top tower C1. The propylene stream is drawn off few trays below the top tower C1, allowing a pasteurising section for the removal of the un-condensable components such as hydrogen, methane, and C2s. Cooling water is used to generate the top reflux. It is a high-pressure C3 Splitter working at a pressure of 19 Barg, producing polymer grade propylene over 99.5% wt.

4.2) Scope of Revamping
The Unit had to be revamped to increase the capacity by 18% while maximizing the propylene recovery. The major revamp design data is shown in the hereafter Table 4.2.1.

Table 4.2.1: Case Story 2, C3 Splitter Revamp Design Data

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent</th>
<th>FEED</th>
<th>OVHD</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>% Wt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>% Wt</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2 ‘s</td>
<td>% Wt</td>
<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Propylene</td>
<td>% Wt</td>
<td>83.23</td>
<td>99.58</td>
<td>4.95</td>
</tr>
<tr>
<td>Propane</td>
<td>% Wt</td>
<td>16.53</td>
<td>0.40</td>
<td>93.83</td>
</tr>
<tr>
<td>Iso-Butane</td>
<td>% Wt</td>
<td>0.02</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>Nor-Butane</td>
<td>% Wt</td>
<td>0.01</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Iso-Butene</td>
<td>% Wt</td>
<td>0.07</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>1-Butene</td>
<td>% Wt</td>
<td>0.08</td>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td>Butadiene</td>
<td>% Wt</td>
<td>0.02</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>C5 ‘s</td>
<td>% Wt</td>
<td>0.01</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>% Wt</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>Kg/h</td>
<td>35000</td>
<td>28955</td>
<td>6045</td>
</tr>
<tr>
<td>Pressure</td>
<td>Barg</td>
<td>24</td>
<td>19.3</td>
<td>21.1</td>
</tr>
<tr>
<td>Temperature</td>
<td>ºC</td>
<td>35</td>
<td>41</td>
<td>60</td>
</tr>
</tbody>
</table>

Several process simulations have been performed to find out the optimum revamp solutions. Two major cases were investigated:

1. **One-by-one tray replacement:** this option was the easiest to implement in terms of tower internals modifications, but was requiring a reboiler duty 16% higher than available.

2. **5 for 4 trays replacement:** with this option a higher number of fractionation stages could have been possible to achieve, so that the required reboiler duty was consistently reduced down to the available from the existing equipment.

Option 2 was selected, beside the trays and the feed and reflux distributors, no other equipments were modified nor replaced.

4.3) Tower Internals Modification
In both the columns, the existing Dual Flow trays were replaced with Shell HiFi trays at lower tray spacing, with the exception of the pasteurising section where the one by one solution was preferred.

This is a very critical path of the whole project; it requires extensive work, and can have a huge impact on the profitability of the revamp. A detailed bar schedule of the activities at each level of the column with manhole access, and coordination of the several crews working in parallel is mandatory to minimize the shutdown time.

Since a higher number of trays were foreseen, new tower supports were also needed. This would have required a lot of welding to the tower wall, if conventional tower attachments were being used, with consequent post welding heat treatments; a very high time consuming and risky activity.

Sulzer Chemtech has developed a number of techniques to minimize cost and installation time. Existing support rings can be used to hold the new expansion ring by mean of vertical struts, thus direct welding to tower wall is not anymore needed. Moreover a single lattice beam can support two HiFi trays (Figure 11).

The unique Lip-Slot™ panel connection eliminates the need for bolting of adjacent tray panels. Only the last panel and the tray man-way are bolted or connected with the Split wedge type of connection (Figure 12).

The use of the expansion rings, vertical struts, and lattice beams, combined with the Lip-Slot panel connection allowed for a saving up to 35% of the installation time. The job was executed in 21 working days as planned.

4.4) Post revamp results

The unit is running since more than two years providing satisfactory performances. The additional Propylene production is consistently higher than before revamp, so that the pay back of the project was counted in only few months.

4.5) Conclusions

1) While revamping Units, it is mandatory a fully understanding of the major equipment being used; among these the distillation columns, which represent in many cases the bottleneck of the expansion capacity of a plant.

2) The High Performance Trays provide the Petrochemical Industry with a great mean to maximize plant ‘s capacity without compromising the efficiency.
3) There are several types of HPT: Chordal Downcomer i.e. Sulzer VGPlus\textsuperscript{TM}; Multi Downcomer i.e. Shell HiFi\textsuperscript{TM}; ultra-System Limit i.e. Shell ConSep\textsuperscript{TM}. Each one has got its best fit of application.

4) For any projects and or service, the most suitable HPT shall be selected to achieve challenging targets with minimum investment cost.

REFERENCES
1) G. Mosca, E. Tacchini, G. Scribano, “High Performance Trays for Distillation Columns” Presented at the 1\textsuperscript{st} CHEM ARAB Conference, Beirut, Lebanon (January 2001).
11) C. Groenendaal, B. Trautrim, K. Kusters and J.L. Bravo, “The Shell ConSep\textsuperscript{TM} tray technology provides unparallel distillation capacity”, presented at the EFChE Conference, Bamberg, Germany, (April 2001); 
Figure 1: CFD Study:
Lower row shows how redirecting devices create a more uniform fluid distribution

Figure 2: MVG trays
Froth collapses due to later vapor discharge
FRI Test: Total Reflux, C6 / C7

Figure 2: Performance comparison MVG versus Round Valve

Figure 4: Performance comparison MVG versus Round Valve
Figure 5: VGPlus Tray

Figure 6: Redirecting Devices and Push Valves
FRI Test Data
FRI tower ID 1.2m, 11 bar i-C4/n-C4, total reflux, tray spacing 24"

Figure 7: Performance comparison: VGPlus versus Nye Trays

Figure 8: Shell HiFi™ Plus Tray
Figure 9: Case Story 1: De-Butanizer Process Flow Diagram
Figure 10: Case Story 2: C3 Splitter Process Flow Diagram
Figure 11: Expansion rings, vertical struts and lattice beams

Figure 12: Lip-Slot and Split-wedge type connections