Designing High Performance Trays

-The Art Of-

by

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Abstract

What is a tray? Some would only say a panel with perforations that provides a platform for mass transfer; others would add, it is a piece of scientific art. It takes decades of experience to understand the optimum working features of a tray through an understanding of the application/service it is meant to work in, the efficiencies required to achieve the desired output, and the craftsmanship needed to simply produce it. Through a look at the evolution of trays from their simplest designs to their high performance counterparts, 2 case studies will be presented to show the positive impact of high performance trays on process efficiencies and on achieving mega throughputs under more stringent regulations and restrictions.

1. Introduction

When the engineer is faced with a seemingly simple question to describe a tray, very often, the buzzing mind of the same engineer adventures into a paragraph of technical words that would puzzle even the greatest experts about the topic. Trays come in all shapes and sizes with various names such as, sieve, bubble cap, truncated, step-arc, multi-downcomer, mod-arc, reverse flow, disc & donut, shed deck, ripple, etc,. These trays were all invented for specific processes or services. For example we find use for the bubble cap and reverse flow trays in low liquid load services while the disc & donut tray is well suited for highly fouling services where efficiency is expected to be low. Understanding the benefits and working limitations of a tray are key to identify the right internal for the right service, even more so, when constraints such as plot space, lower impurity concentrations, and competition, push the engineer to design better, more efficient, and cost-effective trays.

2. What is a Tray?

A tray is a circular disc, or part of, fixed in a distillation column of a chemical plant and which provides a platform for an ascending vapour stream and a descending liquid stream to interact. Theoretical plates have been established as a measure of separation efficiency in distillation. Via experience, smart modeling, and rigorous calculations, theoretical plates are then physically represented by trays. Trays are then designed and manufactured to bring to the process the desired efficiency and capacity.

3. Tray Types

3.1. Conventional Trays

Among the conventional trays, a baffle tray does well to promote vapour and liquid interaction, but due to its simplistic configuration[Figure 1], separation efficiencies are at the lowest. These trays are thus preferred in heat exchange applications and in fouling services due to their open structure.

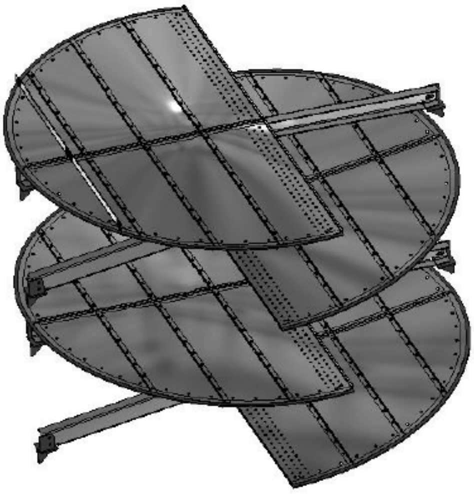


Figure 1 - Baffle Tray

A sieve tray, Figure 2 which consists of a perforated (holes) plate with compartment(s) known as downcomers to accumulate liquid, shows good efficiency.

Figure 2 – Sieve Tray

With the increase in demand of chemical products to the market, plant owners have to continuously adapt their existing designs to suit the market's growing needs. In essence, it implies modifying existing equipment to handle higher throughputs while minimizing the requirement for additional space or bigger equipment on the facilities. Licensors are often under pressure to limit investment costs on new complexes or, in revamp cases, use existing distillation column shells to fit higher performance internals instead of replacing the old with new and bigger columns to handle the demand for extra capacity.

The invention of the V-Grid tray with its tapered, trapezoidal valves extruded from the tray deck and oriented parallel to the liquid flow, allows for 5-10% extra capacity compared to the sieve tray. The lateral vapour release Figure 3 of the V-Grid valves results in a lower froth height than what can be typically observed with sieve holes. This, in turn, allows for more froth, hence higher vapour and liquid loads, to fill up the space between trays before reaching the flooding point.

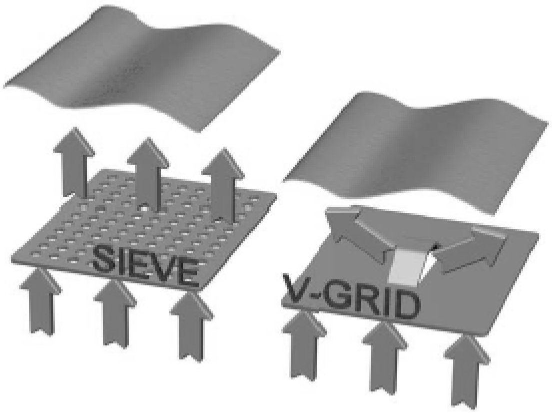


Figure 3 – Lateral Vapour Release

The table below shows the performance of conventional trays for different fields of applications in reference to a sieve tray.

	Sieve	**Fixed Valve**	**Movable Valve**	**Bubble Cap**	**Dual-Flow**	**Baffle, Disc & Donut**
Capacity	Base	Base	Base	Lower	Much Higher	Much Higher
Efficiency	Base	Base	Base	Base	Much Lower	Much Lower
Turndown	2:1	3:1	4:1	8:1	2:1	Not applicable
Entrainment	Base	Lower	Lower	Base	Base	Base
Pressure Drop	Base	Base	Base	Higher	Lower	Much Lower
Maintenance	Base	Base	Higher	Much Higher	Lower	Lower
Fouling Resistance	Base	Higher	Lower	Much Lower	Much Higher	Much Higher
Corrosion Resistance	Base	Base	Lower	Lower	Higher (Scaling)	Higher
Application	Low-High Flow Parameter	Low-High Flow Parameter & Fouling Services	Low-High Flow Parameter with high turndown requirements	Low flow parameter	Fouling Services	Fouling Services

Table 1 Conventional Tray Comparison

3.2. High Performance Trays

A high performance tray displays enhancements on tray decks and/or downcomers. The rule of thumb is higher gas load implies enhanced active area and higher liquid load implies enhanced downcomer area. The fine tuning between active areas and downcomer areas of a high performance tray may at times require ingenuity and creative engineering founded on strong experience when the software simulating the performance of a tray is bound by safe correlations. Figures 4 and 5 below are illustrations of two types of high performance trays, the Shell HiFiPlus tray and the VGPlus tray respectively.

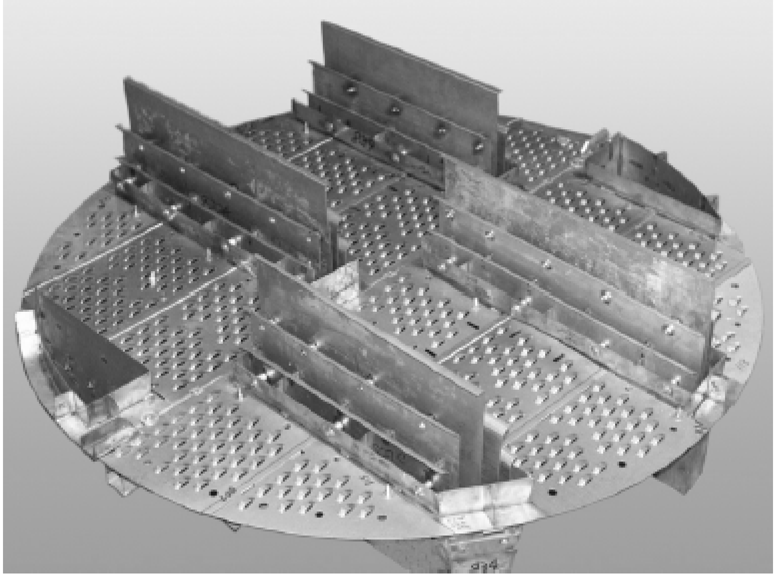


Figure 4 – Shell HiFiPlus Tray

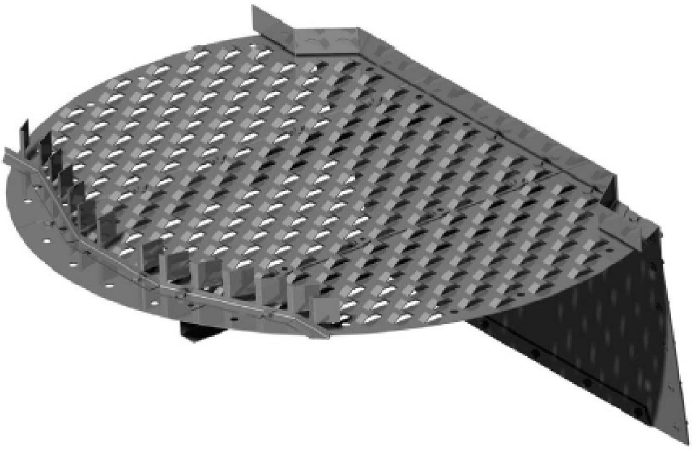


Figure 5 – VGPlus Tray

4. China - C3 Splitter with Shell HiFi Trays

4.1 Background

In 2004, Sulzer delivered to a new petrochemical complex in China a set of Shell HiFiPlus trays to be fitted in a C3 splitter [Figure 6]. The C3 splitter consists of 2 columns operating in series with a side reboiler. The columns operate at high pressure > 20 bar(a) and utilize waste heat (condensate) from the ethylene plant.

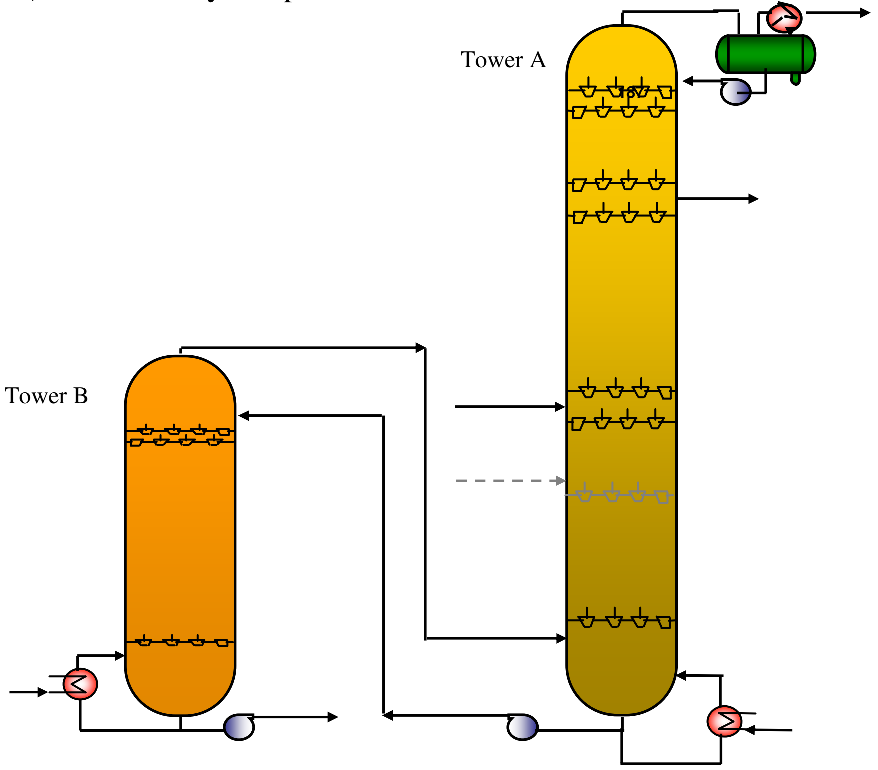


Figure 6 – PFD of C3 Splitter

4.2 Column Configuration

Tower A with an inside diameter of 6,900 mm has 187 Shell HiFiPlus trays and tower B, with an inside diameter of 5,200 mm, has 51 Shell HiFiPlus trays. Due to the high number of theoretical stages (150 – 200 in mega-throughput plants) required to achieve the desired separation, C3 splitters tend to be tall. One goal is thus to minimize column height. This is achieved by keeping tray spacing low although at the expense of comfort for the maintenance crews. A low tray spacing, in turn, implies a reduced hydraulic capacity between two trays since the froth created by the interaction of vapour and liquid has less space to settle in. Tower B has a tray spacing of 400 mm. Tower A has tray spacings of 350 mm and 400 mm at different sections. The feed to tower A is in the liquid phase and comes from two sources; the bottoms of the deethanizer column and the overhead liquid from the Low Pressure Depropanizer column. These two streams are combined before entering the tower.

In August 2006, a test run was carried out on the C3 splitter which operated with 98% feed rate but higher reflux ratio. This brought the hydraulic operation of the column close to design. The test run consisted in monitoring the column under steady state Figure 7 for 48 hours.

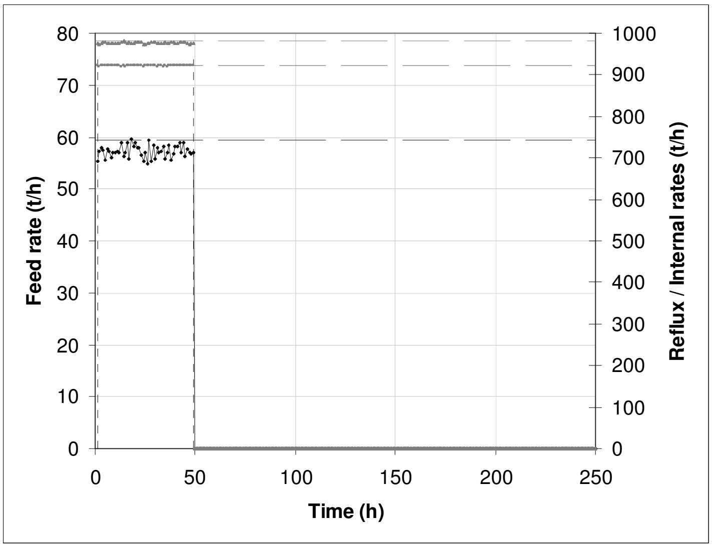


Figure 7 – Steady State Run August 2006

With a feed rate of 60,000 kg/hr for 550 kg/hr as vent and 55,810 kg/hr as product, the material balance seems too perfect. However, this is brought to acceptable levels when considering the standard deviation of 1,840 kg/hr (3%) observed in the product. With the data collected, Sulzer was able to run its own simulations with its proprietary ProII thermodynamic model to determine internal loads and tray efficiency of the tower.

Table 2 below compares the design basis with the results obtained from the test run data collected in August 2006.

	Design Basis	Test Run Results
Propylene Top Purity	> 99.5%	99.83%
Propylene in Bottom	< 3.5%	2.73%
Pressure Drop per tray	5.5 mbar	5.2 mbar
Maximum Useful Capacity	71%	72%
Tray Efficiency	85%	90 – 95%

Table 2 Design basis versus test run results

Key aspects that were considered in the design of the Shell HiFiPlus trays are summarized below:

- Track record of existing C3 splitters equipped with Shell HiFiPlus trays was necessary for consistency and design optimization.
- Minimum tray spacing without sacrificing on useful capacity.
- Setting the optimum net free area based on statistical references of existing C3 splitters with similar operating conditions. Net free area has shown to have an impact on efficiency.
- Flowpath length: With a multi-downcomer tray, flowpath length becomes an important parameter as this affects the efficiency of the tray. Too short a flowpath length can result in loss of efficiency due to too little contact time between vapour and liquid on the active area.

4.3 Conclusion

Although the set of Shell HiFiPlus trays were delivered for a brand new Chinese petrochemical complex, the C3 splitter, which requires a large number of theoretical stages, needed to be equipped with high performance trays to minimize column height and inside diameter while still ensuring useful capacity and process efficiencies were met according to design.

5. Russia - C3 Splitter with VGPlus Trays

5.1 Background

On the 12th December 2006, Sulzer entered into contract with a Russian Olefins producer to revamp their C3 splitter with high performance trays. The objective of the client is to go into a 2-phase upgrade from a 300 KTA plant to step-wise new capacities of 360 KTA and 430 KTA respectively. Accordingly, the C3 splitter would see an increase in feedstock capacity from 20 tons/hour to 30 tons/hour. Furthermore the revamp relating to engineering, delivery and installation was to be carried out over a span of 6 months.

5.2 Column Configuration and description

The C3 splitter $^{\text{Figure 8}}$ consists of two column shells in series (Tower 1 and Tower 2). The two column shells are effectively operating as a single column: overhead vapor from the first column is sent to the bottom of the second column and liquid from the sump of the second column is pumped back to the top of the first column. The overhead pressure of the second column is approximately 9.81 barg. Polymer grade propylene is obtained as overhead vapour from the second column. (Recycle) propane is obtained as bottom liquid from the first column. The reboiler and condenser of the C3 splitter are integrated by means of a heat pump. Overhead propylene vapour is compressed to 15.30 barg and condensed in the internal reboiler/condenser. An auxiliary reboiler and auxiliary condenser are present to account for the net remaining duty. The reflux is sub-cooled by vaporizing the feed to the column. Each column has an inside diameter of 3,400 mm. Tower 1 was equipped with 96 sieve trays and tower 2 with 106 sieve trays and both columns had a tray spacing of 550 mm.

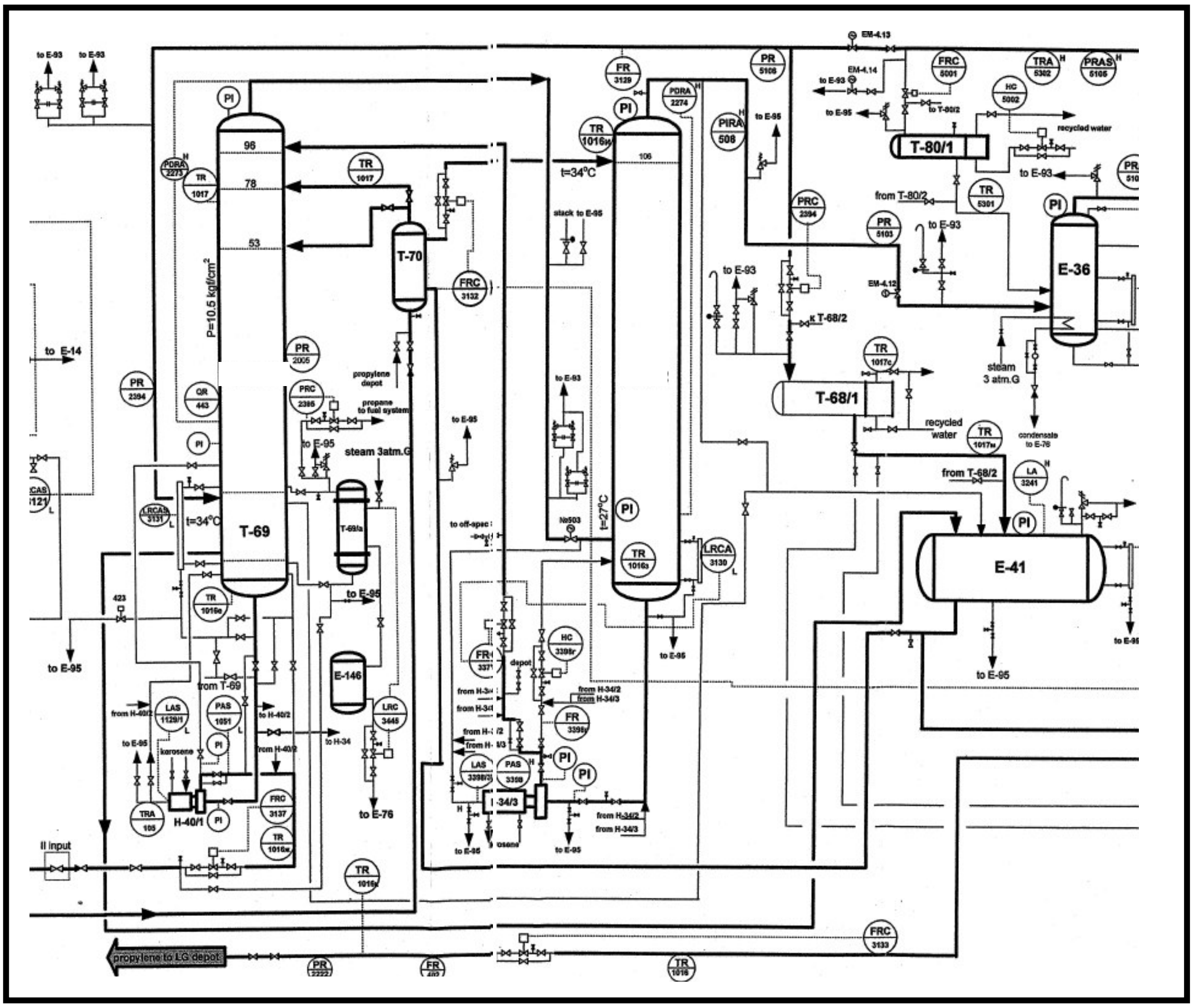
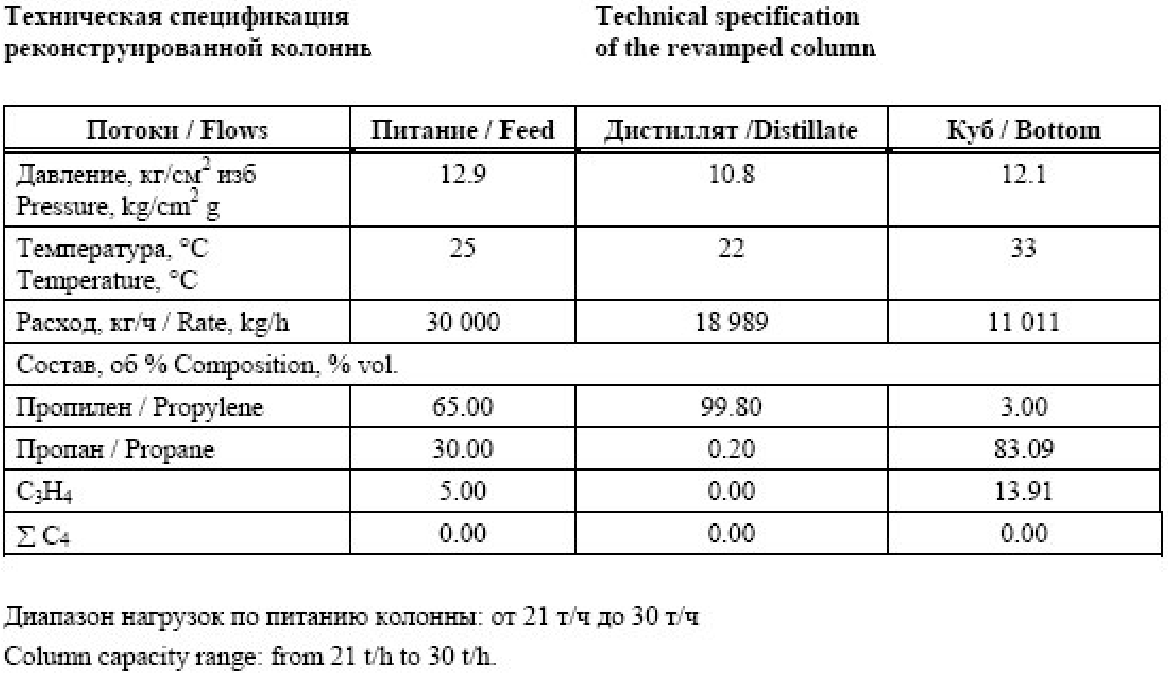


Figure 8 – PFD of existing C3 splitter configuration

Feed rates and design basis were submitted as follows.



Техническая спецификация реконструированной колоннь **Technical specification of the revamped column**

Потоки / Flows	Питание / Feed	Дистиллят /Distillate	Куб / Bottom
Давление, кг/см^2 изб Pressure, kg/cm^2 g	12.9	10.8	12.1
Температура, °C Temperature, °C	25	22	33
Расход, кг/ч / Rate, kg/h	30 000	18 989	11 011
Состав, об % Composition, % vol.			
Пропилен / Propylene	65.00	99.80	3.00
Пропан / Propane	30.00	0.20	83.09
C_3H_4	5.00	0.00	13.91
$\sum C_4$	0.00	0.00	0.00

Диапазон нагрузок по питанию колонны: от 21 т/ч до 30 т/ч
Column capacity range: from 21 t/h to 30 t/h.

Table 3 Technical Specification

Based on the information provided, Sulzer carried out simulations using ProII and its proprietary thermodynamic model. Guarantees were required on top propylene purity, propylene quantity in the bottoms, capacity, pressure drop and mechanical integrity. A sensitivity analysis $^{\text{Figure 9}}$ was essential to decide if more trays should be fitted to increase the number of theoretical stages or whether a 1-for-1 revamp would be sufficient to meet the process and hydraulic requirements. A 1-for-1 revamp also meant re-using existing attachments thereby minimizing installation time. The sensitivity analysis revealed that with the existing condenser, the amount of reflux that could be sent to the column would be sufficient to ensure that a 1-for-1 revamp to high performance trays would achieve the targets.

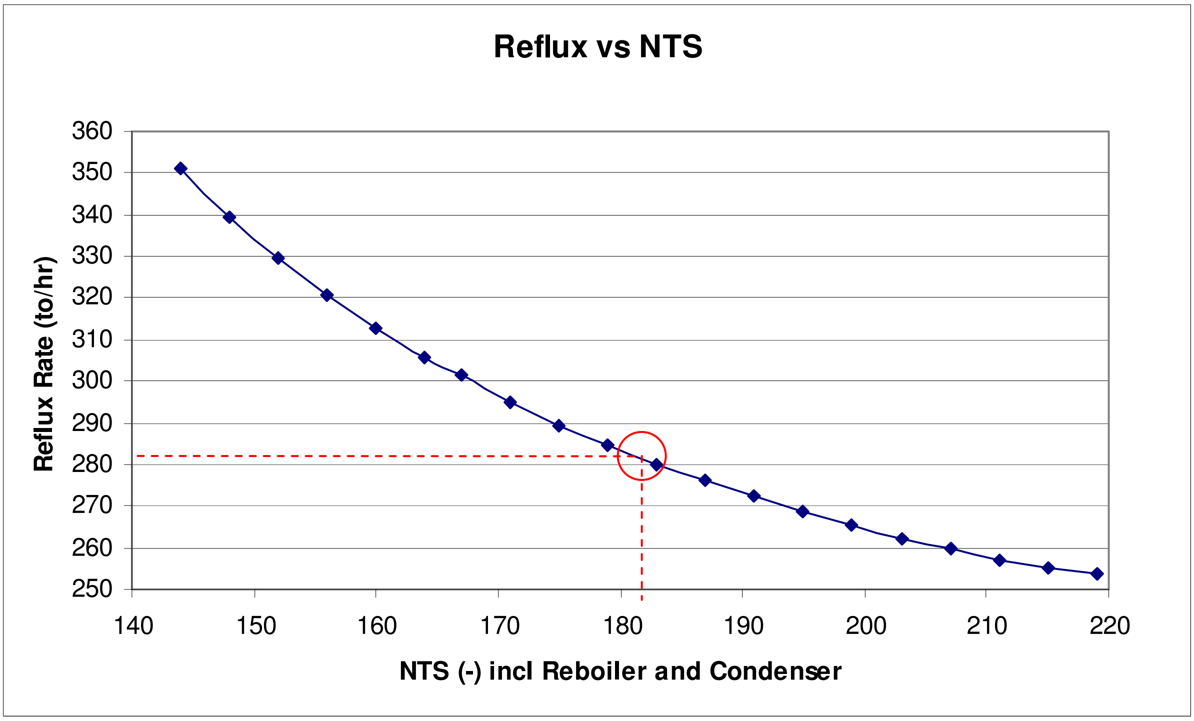


Figure 9 – Sensitivity Analysis

Since there were no requirements to fit additional trays, which implies decreasing tray spacing, the choice of VGPlus trays was deemed suitable for this revamp. It is important to study carefully the requirements of a revamp. Chordal downcomer trays are accepted by the industry to show higher efficiencies than multi downcomer trays due to the longer flowpath lengths available. However, if more trays are required in a column to increase theoretical stages probably due to limitations with the existing reflux condenser, multi-downcomer trays such as the Shell HiFi trays are suitable as they can be fitted for tray spacing as low as 300 mm. With a tray spacing of 550 mm available and a 1-for-1 revamp, a set of VGPlus trays with mod-arc downcomers were adapted to the existing attachments. It should be pointed out that the client did not allow welding to the column wall. As such, centre and off-centre downcomers were enveloped and adapted to the support rings without any welding required to the column wall. The VGPlus trays [Figure 10], after engineering, were presented as "FINAL" to the client as shown below.

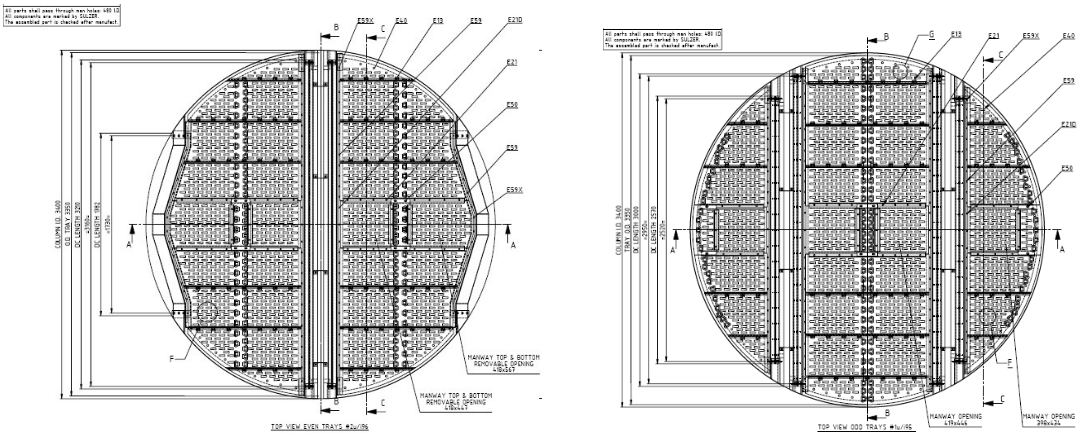


Figure 10 – VGPlus Tray Detailed Drawing

The high performance trays were successfully installed within the shut-down window in June 2007 and in August 2007, the first set of operation data were made available to Sulzer for analysis. Due to high fluctuations in feed quality varying between 60% to 80% propylene and the planned revamp of remaining columns in this plant, the operators are running the C3 splitter at 20 tons per hour of feed. From the operation data submitted after the revamp of this C3 splitter, the following table gives an insight into the results observed with the VGPlus trays.

	Design Basis (30 t/hr feed)	**Test Run Results (20 t/hr feed**
Propylene Top Purity	> 99.8%	99.92%
Propylene in Bottom	< 3.0%	0.86%
Pressure Drop per tray	6.4 mbar	5.5 mbar
Maximum Useful Capacity	88%	70%
Tray Efficiency	93%	~ 95%

Table 4 Design basis versus test run results

5.3 Conclusion

Although the Russian C3 Splitter is not currently running at the capacity for which the trays were designed for, the results obtained from the test run data gives confidence that with the reserves accounted for in the simulation and hydraulic design, the column will perform according to design when switched to maximum capacity. The message to be taken out of this project is that the choice of a higher performance tray is not solely dependent on its ability to meet process requirements but also on indirect factors such as welding constraints on the column shell, shut-down time, auxiliary capacities, and investment levels.

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