High-capacity tray for debottlenecking a crude distillation unit

Use of ultra-high-capacity trays in the most constrained section of a CDU enabled over a 50% increase in throughput at less cost than other debottlenecking options

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The main fractionator of the crude distillation unit (CDU-1) in the Whangarei refinery of The New Zealand Refining Company (NZRC) was retrofitted with high-capacity internals to increase the unit throughput from 8500 t/d to 13 000 t/d. Ultra-high-capacity Shell ConSep* trays were applied in the most capacity-constrained HGO pumparound (mid circulating reflux) section of the column, as no other first-generation, high-capacity tray was found adequate to debottleneck this section. By the application of these trays, capex savings of the order of $5.5-6 million were achieved compared to other conventional debottlenecking options. This was the first application of ConSep trays in a CDU main fractionator, and the post-revamp test run established realisation of the expected performance.

Whangarei refinery targeted expanding its refining capacity through the Point Forward Project.[1] The project involved increasing the throughput of the CDU-1 from 8500 t/d to 13 000 t/d, thereby increasing the distillate component to downstream processing and generating additional long residue to replace imported long residue for loading the vacuum distiller. Figure 1 shows a simplified process flow diagram of CDU-1.

Shell Global Solutions International (SGSi) carried out the feasibility study for the expansion of CDU-1. Several options were studied to debottleneck the main fractionator:
- Replacement of the existing column internals with high-capacity internals including the ConSep tray for the most capacity-constrained HGO pumparound section
- Installation of a new crude pre-fractionator column to separate off light naphtha and reduce the load to the main fractionator. The capex for this option was found to be $6 million higher than for option 1

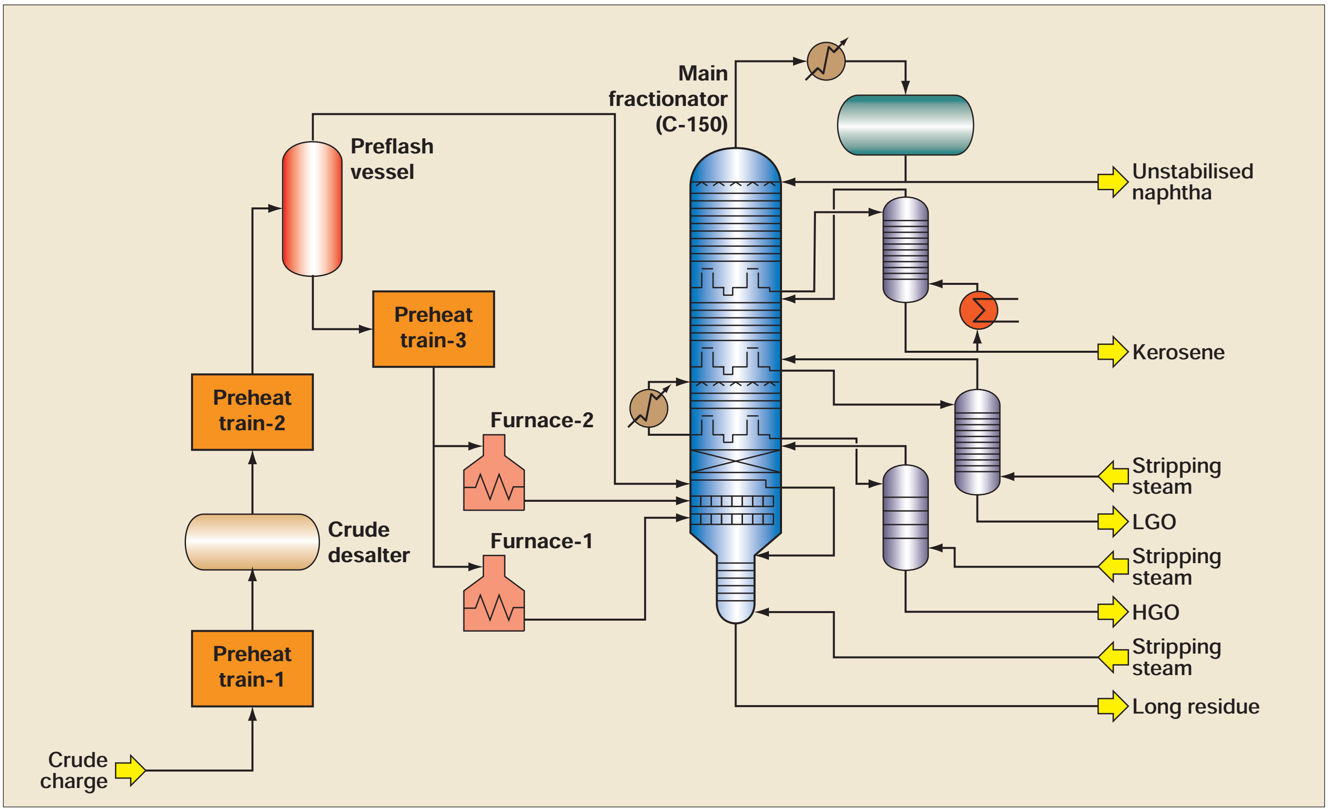

Figure 1 Simplified process flow diagram of CDU-1

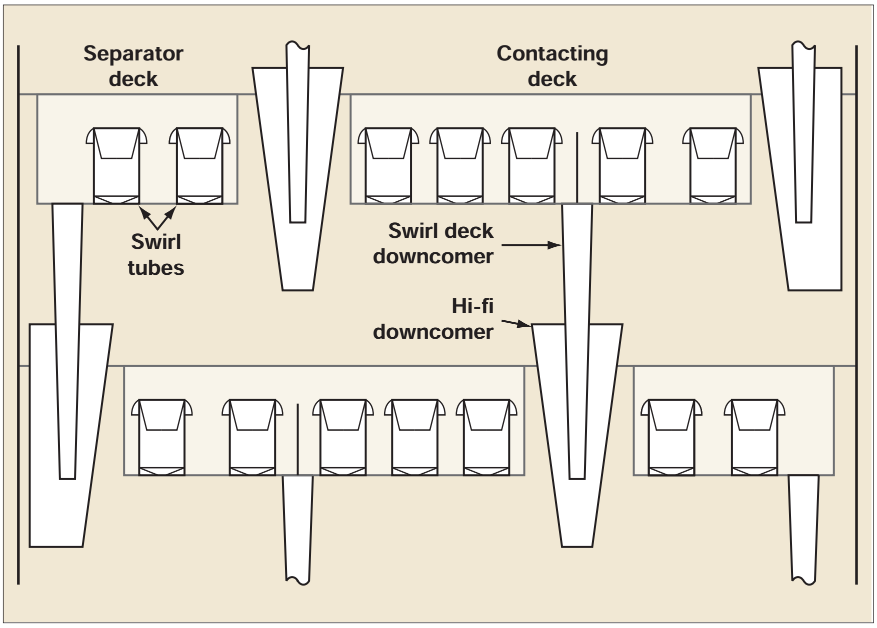

Figure 2 Schematic of ConSep tray

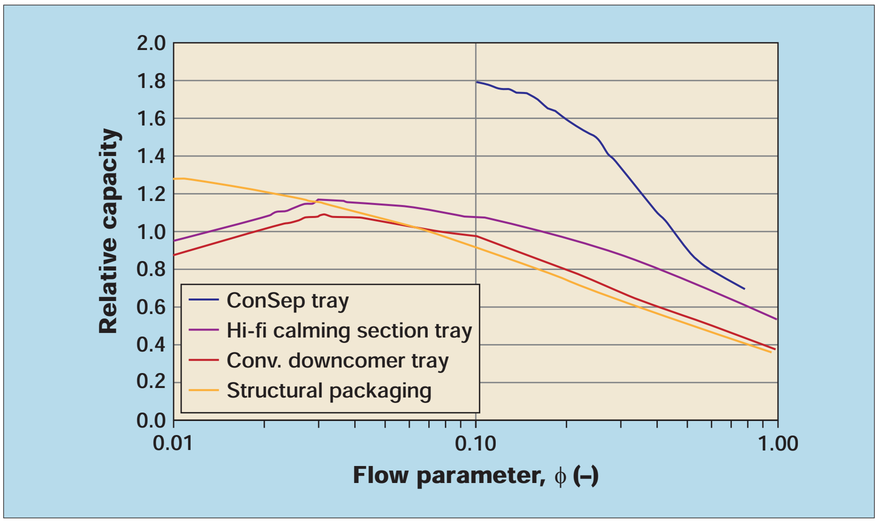

Figure 3 Comparison of column internal capacities

Overview of ConSep tray applications

Location	Diameter	Application	Installed	Capacity increase, %
UK	1.9	NGL debutaniser	1995	22[1]
Australia	1.9	FCCU debutaniser	1996	30[2]
Germany	2.2	HCU main fractionator	1999	50
Australia	1.7	NGL debutaniser	1999	15[1]
Singapore	2.5	FCCU debutaniser	2000	20[1]
Japan	2.1	FCC debutaniser	2006	10
Sweden	2.0	FCC debutaniser	2006	20
Sweden	1.0	C_3/C_4 splitter	2007	50
USA	2.3	C_3/C_4 splitter	2006	12
Canada	1.0	Depropaniser	2007	20
New Zealand	4.6	Crude distillation	2009	22[2]
Singapore	1.8	PO drying column	2011	20[2]
China	3.2	Ethylene fractionator	2011	Target 25%[3]
Japan	2.5	FCC debutaniser	2013 (scheduled)	Target 15%[3]

1 Limited by reboiler capacity   2 Limited by feed to column   3 No data yet

Table 1

- Installation of a new heavy end column to recover the heavy gas oil (HGO) dropped into the long residue due to offload the main fractionator. The capex for this option was found to be \$5.5 million higher than for option 1.

On the basis of a comparison of the revamp options, NZRC decided to proceed with the ConSep tray alternative owing to this option's lowest capex and most favourable economics.

Shell ConSep tray technology

The ConSep tray utilises the principle of de-entrainment by centrifugal forces to remove the gravitational limitation of jet flood. Separation of the entrained liquid before entering the next tray allows very high vapour velocities to be achieved in the column. The tray combines the features of a contacting deck and a separator deck in a single tray. The basic features of the tray are shown in Figure 2. The functioning of the contacting deck, which in fact is a normal tray, is limited by three hydraulic mechanisms: jet flooding, downcomer choking and downcomer backup. The use of a separator deck influences all three mechanisms:[2]

- The jet flooding limit is extended as the entrained liquid is efficiently separated from the vapour to prevent carry-over of liquid to the tray above
- The liquid entering the main downcomer is largely coming from the separator deck, where it is well degassed. As a result, the downcomer liquid handling capacity is substantially increased
- To eliminate downcomer backup limitation, the separator deck is designed with low-pressure drop swirl tubes. The contacting deck is also designed with a relatively high open area.

Figure 3 shows the expected capacity gain of the ConSep tray over conventional trays and packing.[3]

The flow parameter (ϕ) is defined as:

$$\phi = \frac{L}{V}\sqrt{\frac{P_v}{P_L}}$$

where $\frac{L}{V}$ represents the liquid-to-vapour mass flow ratio and $\frac{P_V}{P_L}$

represents the ratio of vapour-to-liquid density.

Typically, the ConSep tray is capable of offering a 40-50% capacity advantage over a wide range of first-generation, high-capacity trays. In most revamps, the column retrofitted with the ConSep tray becomes limited by other factors such as availability of feed and/or constraints on auxiliary equipment, including reboiler, condenser, pumps and so on, even before the full potential of the ConSep tray is realised. Table 1 shows some applications of this tray along with benefits achieved and constraints faced.

Modifications of main fractionator (C-150)

During the feasibility study, the HGO pumparound section of the column was found to be severely limiting for the targeted throughput of 13 000 t/d. This section was already fitted with Shell Calming Section (CS)* trays. Since the first generation of high-capacity internals was found inadequate to debottleneck this section, ultra-high-capacity ConSep trays were selected. The trays were designed to achieve 33% more capacity compared to the CS tray.

The HGO pumparound section consisted of three contacting trays with a tray spacing of 500mm. A one-for-one tray replacement with ConSep trays was selected. Figure 4 shows a schematic drawing of the HGO pumparound section fitted with these trays. For the remaining sections of the column, the following internals were suggested:

- Stripping section: Shell HiFi* trays
- Wash section: MellapakPlus 252Y** packing
- All other sections: Shell CS trays.

As this was the first application of ConSep trays in this service, a detailed study was carried out to address the risks associated with this application and the mitigations were applied in the design. The trays were manufactured by Sulzer Chemtech. To ensure proper performance of the trays in a relatively new application, rigorous quality control steps were followed at the manufacturing site and a detailed mock-up assembly of tray components was carried out at the refinery site prior to installation in the column.

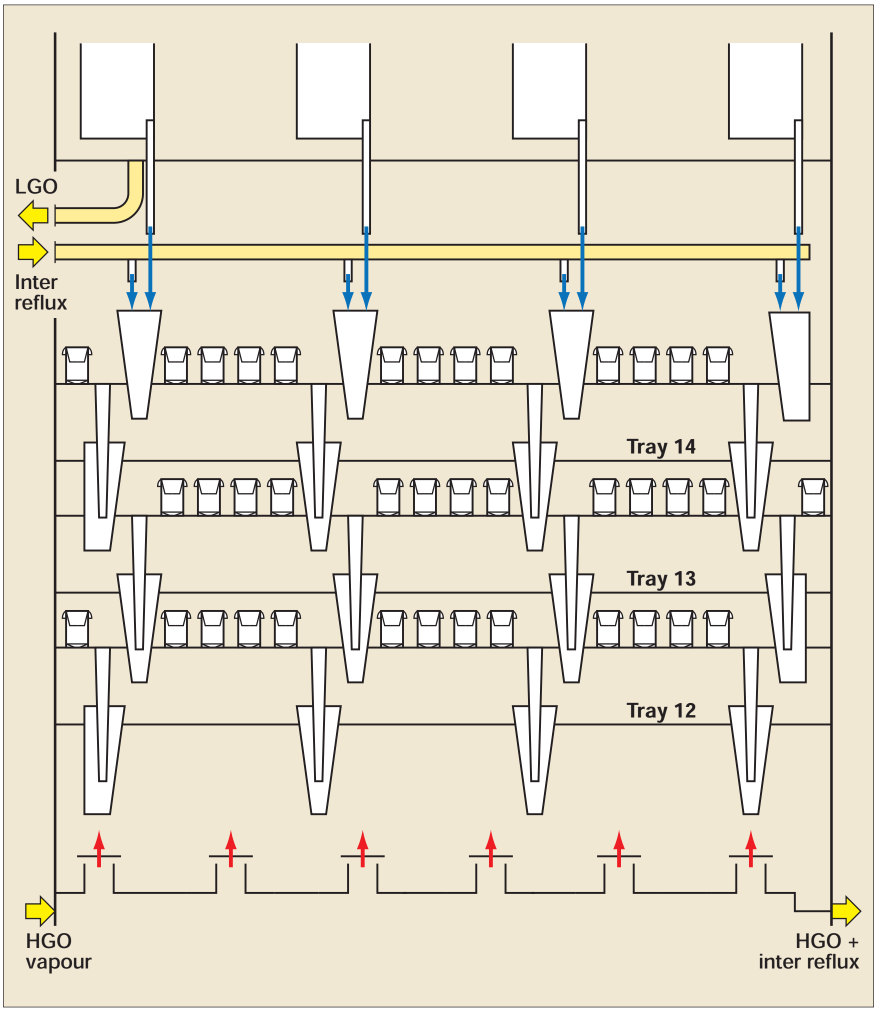

Figure 4 Schematic of HGO pumparound section of C-150

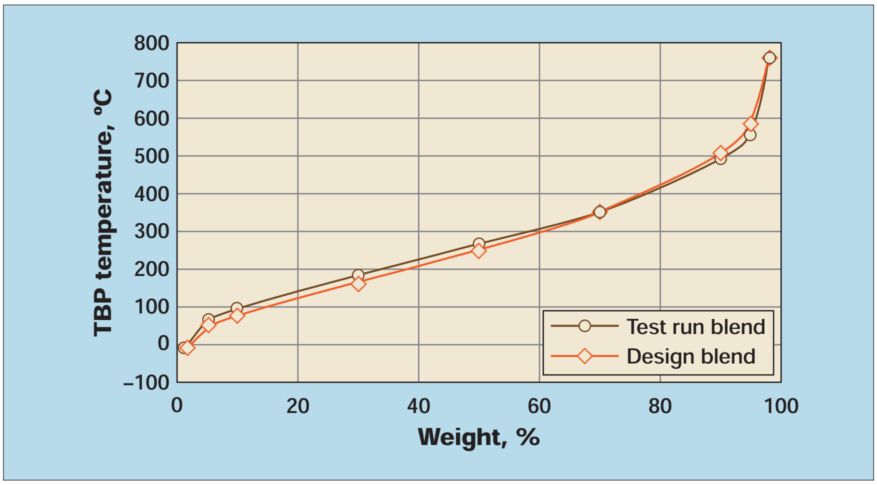

Figure 5 Comparison of design and test run crude TBP

Post-revamp performance

From conception to implementation, the project took four years, and the revamp was implemented during a normal planned shutdown in October 2009 without affecting the unit's availability. The performance test run of CDU-1 was conducted in September 2010. Crude throughput was maintained at 13 000 t/d, although the crude blend used during the test run was marginally heavier than the one considered for the revamp design.

Key design and test run operating conditions of C-150

Parameters	Design	Test run	Parameters	Design	Test run
Crude intake, T/D	13 000	13 077	Flash Zone press, barg	1.90	2.24
Naphtha, T/D	4405.0	3516.4	Feed temp, °C	361.5	345.0
Kerosene, T/D	1498.8	2169.3	Top temp, °C	180.8	175.7
Light gas oil, T/D	1517.0	1116.1	Kero draw temp, °C	216.5	223.4
Heavy gas oil, T/D	2014.5	1731.9	LGO draw temp, °C	244.2	250.1
Long residue, T/D	3573.3	4271.1	HGO draw temp, °C	280.7	278.3
Strip steam, T/D	106.9	149.5	Flash zone temp, °C	343.9	327.3
Top press, barg	1.65	1.95	Bottom temp, °C	333.3	322.061

Table 2

Comparison of the design crude blend and crude blend used during the test run is shown in Figure 5.

Key design conditions and test run operating conditions of C-150 are shown in Table 2. The product quality is compared in Figure 6 (a-e).

C-150 was simulated for the test run conditions to evaluate hydraulic loading of the ConSep trays. In Table 3, the key performance indicators for these trays operating under test run conditions are compared with the design conditions. During the test run, the trays were operating 10-15% lower than design capacity, even at a design intake of 13 000 t/d, due to:
- Heavier feed than in the design case
- Less preheat recovery of the order of 10-12°C due to limitations in the crude preheat train.

Based on a review of operating experience since startup and the

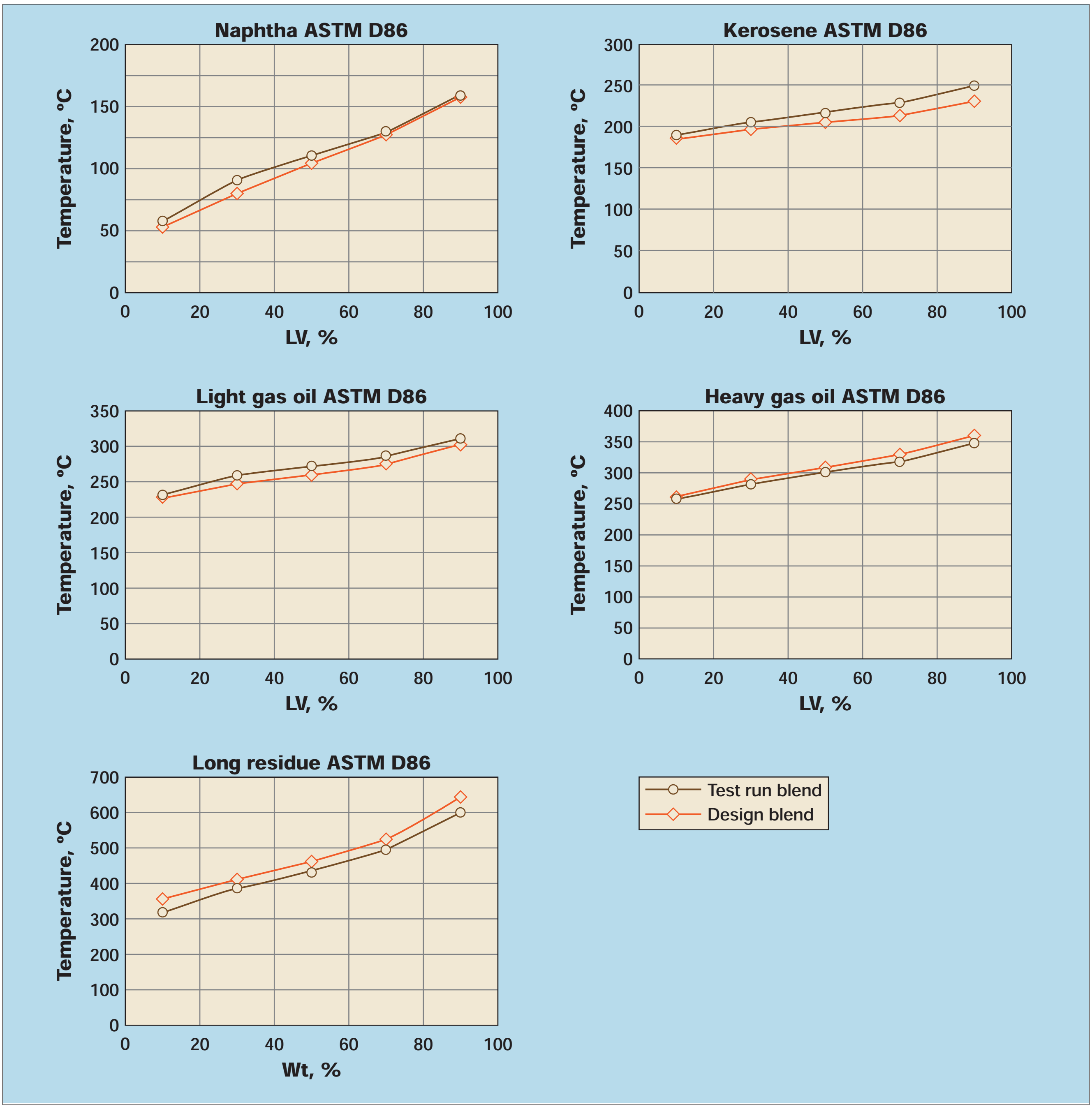

Figure 6(a-e) Comparison of design and test run product quality test run's results, it could be concluded that the revamp targets for the CDU-1 main fractionator (C-150) were achieved. No hydraulic constraint was experienced in achieving the design intake of 13 000 t/d and the required product quality was achieved.

Key performance indicators for ConSep trays		
Parameters	**Design**	**Test run**
Froth backup/CS height, %	68	60
Tray pressure drop, mbar	12.3	9.2
Tube flood , %	73	60
Flow parameter	0.17	0.19
Overall column load factor, m/s	0.12	0.10
Flooding (CS tray), %	133	112

Table 3

Conclusions

The performance of Shell ConSep trays in the HGO pumparound section of the CDU-1 main fractionator met the target of capacity enhancement without any drawback compared to the pre-revamp conditions. During the test run, the trays were operating at 10-15% lower than the design capacity even at the design intake of 13 000 t/d due to heavier crude feed and lower feed temperature. However, the built-in capacity margin enabled stable operation for the trays at much above the capacity limit of the first generation of high-capacity trays.

The options to debottleneck columns already equipped with the first generation of high-capacity trays are limited. ConSep trays provide an attractive solution for such cases. In this revamp project, use of only three of these trays in the most capacity-constrained section of the column made it possible to retrofit the existing column and made the capex option more attractive over the other debottlenecking options.

* Shell ConSep, Shell CS and Shell HiFi are Shell trademarks. ** Mellapak Plus 252Y is a Sulzer Chemtech trademark.

References

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2 Wilkinson P M, De Villiers W E, Mosca G, Tonon L, Achieve challenging targets in propylene yield using ultra system fractionation trays, ERTC 2006.

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