Improving performance through low-cost modification of tower internals

Low-cost revamps of tower internals improve production from existing assets with a payback period of less than a year

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During tough economic times, operators are challenged with increasing margins and decreasing capital expenditures. However, operators can pursue low-cost/high-return opportunities that are within their existing plant capital budgets and will improve product recovery, increase capacity and/or improve reliability (for example, by increasing run length). These projects do not require large-scale engineering support, but can be accomplished with the assistance of knowledgeable professionals who have the skills and experience appropriate to the specific project. Many of these opportunities are uncovered during normal maintenance planning, where justification for the project is based on incremental cost to upgrade tower internals set against the cost to simply replace the internals in kind. As a result, most tower internal revamps can be justified as stand-alone projects (with less than six months' payback time) at the plant level.

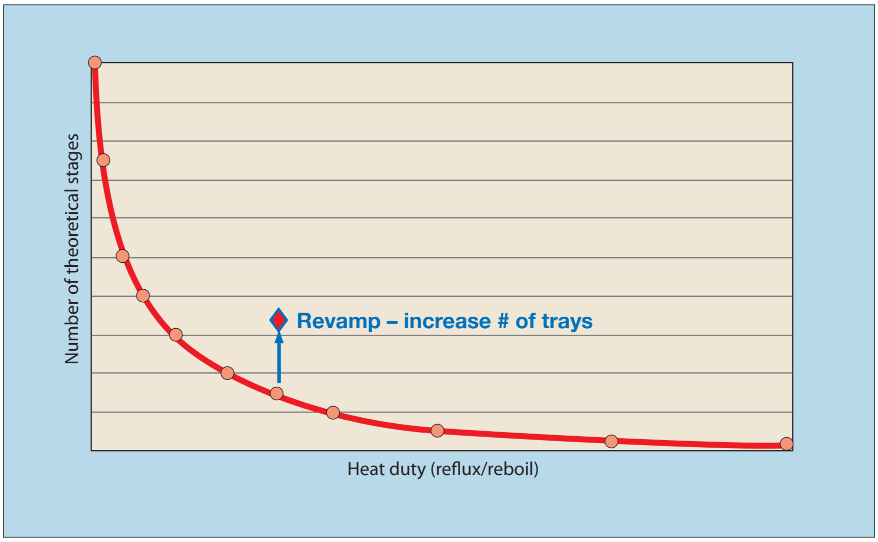

Figure 1 Stage count vs heat duty

General approach

To capture these low-cost/high-return projects, the following tools, tests, data and analyses should be included in the project scope:

- Accurate feed characterisation
- Detailed data from plant operations and test runs
- "Inside-out" design approach[1]
- Up-to-date design guidelines
- Appropriate simulation thermodynamics and topology
- Simulate actual tower internals characteristics
- Simulate actual trays (with tray efficiency) not just theoretical stages
- Computational fluid dynamic (CFD) analysis and/or tower gamma scans where beneficial.

Proper feed characterisation and detailed test run data are essential to obtain an adequate representation in simulation form. They provide the basis for making recommendations on revamps. Data should be compiled, reconciled and regressed to minimise errors between plant data and the subsequent simulation.

Using CFD analysis to model the behaviour of certain tower internals under revamp conditions is crucial in setting an optimal design

Once a satisfactory data set is developed, the simulation strategy needs to be set. The inside-out design approach,[1] together with appropriate thermodynamics and simulation topology, has been used successfully in applying tower internal characteristics into the simulation. This methodology helps to develop a representative model that effectively predicts future tower performance post-revamp and provides detailed operating conditions to design each tower internal. For certain critical separation applications (for instance, vacuum columns, coker and FCC main fractionators), using CFD analysis to model the behaviour of certain tower internals under revamp conditions is crucial in setting an optimal design.

Using an iterative process to modify the equipment's characteristics (tower diameter, heat exchanger

Tray efficiencies used in simulation to represent tower operation		
	Existing tray efficiency,%	Revamp tray efficiency, %, Superfrac trays
Wash section	22	34.5
Stripping section	14	28.8

Table 1

Hydrocracker revamp performance results			
Stage 1 revamp results	**Expected post-revamp**	**Guarantee post-revamp**	**Actual post-revamp**
Feed rate, bpd	75 240	77 400	83 000**
Delta diesel, bpd	190	162	284
$ uplift value per year	1 182 600	1 005 210	1 760 760
Project cost (equipment/install)	500 000	500 000	545 000
Payback (months)	5	6	<4

**not near flood conditions

Table 2

heat duty, control valve opening, pump and compressor capacity) within the simulation and in the tower internals design procedure can help to squeeze as much capacity or increase recovery within the associated equipment's operating envelope. The intent in this exercise is to capture as much improvement in performance from a tower internal modification without requiring expenditure to debottleneck other equipment. In addition, to maintain an overall low project cost for the revamp, the use of mechanical considerations such as minimal (or no) welding, hinged-joint active area panels that reduce bolting requirements, and modular construction can reduce installation time.

Case studies

A simple and cost-effective way to improve recovery (separation) within a distillation column is to increase contact between liquid and vapour by improving the vapour/liquid contact for a given device and/or increasing the number of devices in the separation column.

Figure 1 illustrates the concept of increased stage count to improve separation or to reduce the duty requirements on a column for a given separation. The graph shows that as the number of stages increases, the heat duty for the column decreases. In general, in a revamp for a set heat duty, the amount of separation increases when the number of trays increases (as long as flood point is not reached).

Case study 1: improve hydrocracker fractionator recovery

The operator was replacing tower internals to improve diesel recovery and prepare for future unit flow increases of 15%. The changes to the column were made during the normal maintenance schedule.

The hydrocracker fractionator separates the hydrocracker reactor outlet into light gas (C_4 and lighter), heavy and/or light naphtha, diesel, kerosene and bottoms. During this process, the hydrocarbon is reacted over catalyst in the presence of hydrogen.

To increase diesel recovery and to handle 15% higher flow, the stripping and wash section were revamped with Superfrac trays. Numerous refiners have successfully used this specific revamp design.[2,3]

In the stripping section located below the feed to the column, two trays were added to the existing six trays. The Superfrac trays increased capacity and improved vapour/liquid interaction. Figure 2 illustrates the revamped stripping section. Since the liquid and vapour rates were much lower than the rate needed, the design used a can with an internal diameter 40% that of the full tower diameter. The can arrangement provides much better liquid and vapour contact, as Table 1 indicates. Prior to the revamp, the tray efficiency used to match the stripping section performance was 14% compared to a more typical value of approximately 25%. The difference in efficiency can be attributed to the overly large existing tower diameter. The can arrangement matches the cross-sectional area to the post-revamp flow rates. Also, for this particular case, the can arrangement shortened installation time, because of the modular construction and reduced part handling and bolting needed within the column. Parallel baffles can alternatively be used when the diameter difference between existing and suggested revamp is small.

Due to elevated flow rates in the wash zone, Superfrac trays replaced sieve trays on a one-for-one basis. The improvement in tray efficiency as a result of using the can arrangement and Superfrac trays was 12.5 percentage points per tray — nearly double the existing tray efficiency.

The impact of the tower internal modifications was an improvement in diesel

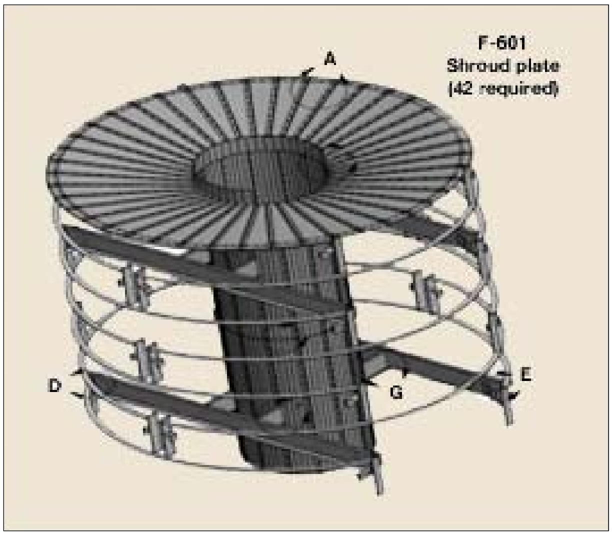

Figure 2 Modified stripping section — HDS fractionator

recovery of over 250 b/d. The internals delivered a jet flood of <70% for the entire column and are well positioned for future increases in feed flow.

Table 2 shows expected and actual diesel recovery from the revamp. The project met all of the product specifications and achieved a payback period of four months. The project's cost was within the accepted 10% margin for a shutdown activity. The additional barrels of diesel above the expected level are likely attributable to the can arrangement, which provided even better liquid/vapour contact than was factored into the design.

Table 2 does not show the effect of increased kerosene recovery, as a result of the change in column compositional profile related to the new internals. Including the increased kerosene recovered (~400 b/d) in the original value proposition would result in a payback period of less than two months.

Expected tray efficiencies for a depropaniser application

Tray efficiency	Industry standard	Superfrac tray revamp study value	Superfrac tray post-revamp value
Above feed	90	97.5	99
Below	70	75.8	78

Table 3

Feed rates to column before and after revamp

Case	Winter, b/d	Summer, b/d
Pre-revamp (1% C_4s overhead)	7150	7580
Design (0.2% C_4s overhead)	8900	6780
Actual revamp (<0.2% C_4s OH)	8980	6805

Table 4

Case study 2: improve recovery of depropaniser

To meet customer requirements, a refiner needed to improve C_4 separation in a depropaniser for both winter and summer cases. The primary objective of the project was to meet new product specifications by modifying only the tower internals. Although the overhead condenser was a design constraint, its revamp would not be considered until the normal lifecycle replacement of the exchange bundle.

The current tower configuration included two beds of structured packing composed of 11 layers of Flexipac 1X packing above the feed and 33 layers of Flexipac 2Y packing below the feed. The packing configuration was a revamp design from the early 1990s that increased capacity over the originally supplied, conventional trays.

The specification for the overhead C_4s was changed to 0.2 mole% from 1.0 mole%, with the bottom C_3 specification remaining at 0.5 mole%. The refiner wanted to maintain the existing feed to the tower because of restrictions in the rest of the plant.

Three main pre-revamp constraints limited the attainment of product specifications and capacity:
- Condenser limitations (cooling water flow)
- Operating pressure
- Tower internals.

The operating pressure was maintained below the maximum of 215 psig (90% of the safety valve setting). The maximum overhead condenser duty for both the summer (7.8 million BTU/h) and winter (11.7 million BTU/h) cases was used accordingly.

The features of the Superfrac tray improve liquid/vapour contact, which translates to higher tray efficiencies

A test run representing typical operation provided the process data for the simulation, which contained proprietary component factors (acentric) and thermodynamic parameters (modified equation of state and interaction parameters). The error between the simulation and plant data was reduced to no more than 7% for any one data point.

The simulation shows that meeting the new product specifications while maintaining the existing duty and pressure limits would require 2.67 times more theoretical stages of separation above the feed and 1.25 times more stages below the feed. Essentially, the feed location was too high for the feed composition in the current configuration.

Designers evaluated high-capacity, structured packings and trays. The packings did not exhibit the ability to handle both the tower liquid/vapour traffic and the desired stages of separations. Superfrac trays provided the necessary separation and could achieve the expected feed rates. This style of crossflow tray provides gains in both capacity and efficiency over conventional and other high-capacity trays.

Table 3 shows the tray efficiencies that were considered for this project. Typically for conventional and industry-standard high-capacity crossflow trays, the tray efficiencies are 90% above the feed and 70% below the feed. The features of the Superfrac tray improve liquid/vapour contact, which translates to higher tray efficiencies.[2] For the revamp study, a comfortable 8% increase in tray efficiency over industry-standard tray efficiencies was expected (97.5% above and 75.8% below feed). Analysing the data after start-up, the trays exhibited a 10% increase in typical tray efficiency, as shown in Table 3.

Table 4 compares the feed rates before the revamp with the less stringent C_4 overhead specifications, the expected design feed rates and the actual demonstrated feed rates. The revamped tower was able to meet the new product specifications while improving the capacity of the column by 35%.

Omni-Fit and Flexilock technologies supported the project economics and the modification of the tower from packing to trays within a tight shutdown schedule. Omni-Fit technology (pedestal tray design) minimised welding and reduced installation time. Flexilock tray construction reduced installation time by up to 20%.[4]

Figure 3 Setup of Ultra-Frac trays

Case study 3: improve capacity of an FCCU deisobutaniser

A refiner was experiencing plant capacity issues due to a bottleneck in the FCCU's gas plant, primarily in the deisobutaniser. RVP specifications for the gasoline were being compromised when the refinery tried to process expected crude slates at design rates. The refiner wanted to lower the RVP of the gasoline and increase the flow to the unit by 50% to meet plant capacity and product requirements. A revamp study proposed installing a new deisobutaniser with an installed cost of $2.75 million. Since the cost of revamp indicated negative project economics, the plant's operators looked for alternatives, which included a small second column in parallel with the existing column and a request to all internals vendors to suggest possibilities.

For such high rates, the Ultra-Frac tray, a co-current liquid/vapour separation device, was the only device seriously evaluated. As Figure 3 shows, the Ultra-Frac tray uses multiple separators that produce co-current flow and create centrifugal action, which essentially breaks the limitations of gravity flow devices. The generated centrifugal forces create intense mixing of liquid and vapour that enables increased flow rates. The Ultra-Frac tray currently is the highest capacity mass transfer device tested at the Fractionation Research Institute.[5]

Table 5 shows the characteristics of column internals before and after revamp, together with the performance parameters. A one-for-one tray change-out was recommended for the entire column. All 48 sieve trays in both the 9.5ft ID rectification and 12ft ID stripping sections were replaced with 48 Ultra-Frac trays on the same tray spacing. For a capacity increase of over 150% of design, the pressure drop increased by only 10%. The column performance benefited from an increase in tray efficiency (65–75%), with the improved tray efficiency reducing the load of the heat duties on the column.

For a capacity increase of over 150% of design, the pressure drop increased by only 10%

The refiner was able to use existing exchangers and spare pumps with some control valve change-outs to handle the increased capacity without compromising product quality. Within the shutdown window, the refiner brought the plant up to design rates and lowered RVP significantly. The overall installed cost was well below the original recommended solution of fabricating a new, larger column, which resulted in a payback period of less than one year.

Case study 4: vacuum column — improve distillation gap

A refiner was operating a vacuum column with a crude mix that was different from its original design specifications. The different crude diminished the recovery of products. In particular, the heavy vacuum gas oil (HVGO) and light vacuum gas oil (LVGO) yields and quality were less than desirable. The refiner wanted to find revamp solutions with a minimum capital investment (payback period of less than four months) that would improve recovery and fit within a planned maintenance schedule.

The vacuum column operated in wet mode (stripping and velocity steam) and contained an enhanced vapour horn, a trayed stripping section and four structured packing pumparound zones — light light vacuum gas oil (LLVGO), LVGO, HVGO and heavy heavy vacuum gas oil (HHVGO) — that used spray headers to apply the return pumparound liquid to the packed bed. Based on the objectives of the potential revamp and the new operating conditions, all the tower internals were evaluated for possible improvement.

Figure 4 shows the internals in the sections that were recommended for the revamp. Replacing the spray headers with trough distributors for the HHVGO and HVGO pumparound zones was suggested. With the chosen crude mix, studies demonstrated that fouling and pressure drop (overhead vacuum ejector had spare capacity) were of limited concern. Replacing spray headers with inherent characteristics of low pressure drop and fouling mitigation with trough distributors was considered an advantage. The trough distributors considered for the revamp provide improved quality of distribution over spray headers and do not produce entrainment at the given conditions. For both the HVGO and LVGO products, entrainment caused by the respective HHVGO and HVGO pumparound spray headers contributed to the less than desired product distillation gaps (recoveries). The entrainment from the spray headers shifts heavier material up the column to the lighter products and reduces overall product separation in the column.

Table 5 shows the product recoveries represented as a 5–95 distillation gap (the difference between the temperature at the 5% vapourisation point for the product above and the temperature at 95% vapourisation for the product below for a given distillation method). A zero or positive gap indicates a good separation between products, while an increasingly negative 5–95 distillation gap indicates a sloppy/poor separation of products. As Table 6 shows, the design of the LVGO-HVGO 9–95 distillation gap was set to -68°C, with the actual operation giving a value of -104°C. The refiner wanted an improvement, and the low-cost change from a spray header to a trough distributor to provide an expected gap value of -85°C (an improvement of 19°C) was approved.

After the revamp, the improvement to the LVGO-HVGO distillation gap was consistently given a value of -76°C, which was better than expected and within 8°C of the initial design on a different crude slate. Overall, for the three product distillation gaps, the values improved between 19°C and 24°C. The revamp was considered a success, with the product recoveries improving well beyond expectations and negligible effect on pressure drop. In addition, the operators were able to easily control changes in feed composition.

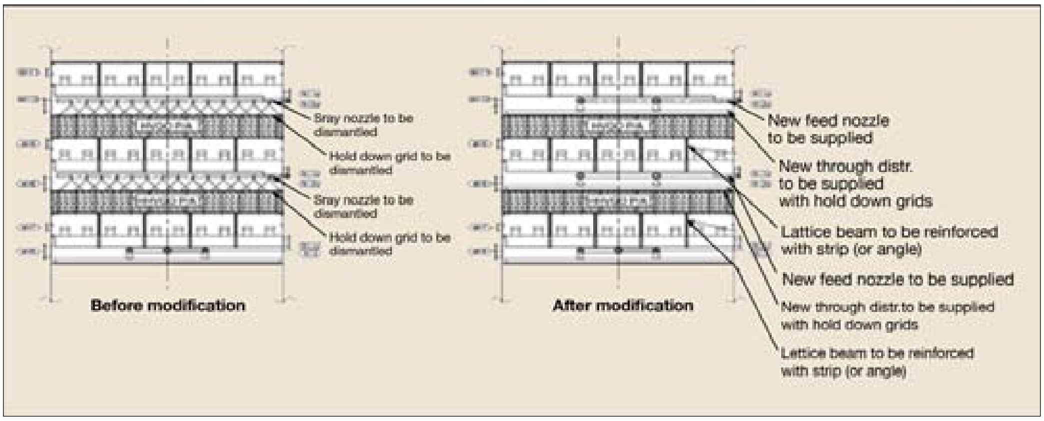

Figure 4 Details of the internals configuration pre- and post-revamp

Summary

The four cases described here provide examples of improving existing production assets using low-cost tower internal revamps. In all cases, the payback period was less than one year and changes were made during regularly scheduled maintenance outages.

SUPERFRAC, ULTRA-FRAC, OMNI-FIT and FLEXILOCK are marks of Koch-Glitsch LP.

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Characteristics and performance of deisobutaniser internals before and after revamp

	Before revamp	After revamp
Column diameter	9.5ft - rectify	12ft - stripping
	9.5ft - rectify	12ft - stripping
Tray type	Sieve	Ultra-Frac
Tray spacing - rectifying	24in	24in
Tray spacing - stripping	30in	30in
Pressure drop, psi	7.1	7.8
Tray efficiency	65%	75%
% of original tray capacity	100%	>150%

Table 5

Product distillation gaps for vacuum column products

Distillation gap (5–95%), °C	Design	Before revamp	Expected revamp	Actual after revamp
LLVGO-LVGO	-49	-19	0	6
LVGO-HVGO	-68	-104	-85	-76
HVGO-HHVGO	-76	-118	-94	-86

Table 6