TIME FOR A COLUMN CHECK-UP

Martin Rizo, Alessandro Ferrari, and Neil Sandford, Koch-Glitsch, and Panos D. Dimitriadis, Motor Oil (Hellas), Corinth Refineries S.A., describe the revamping of a naphtha splitter through the installation of new trays.

A project was conducted by a large engineering company to revamp the naphtha splitter in the hydrotreater unit (HDT) at a Motor Oil (Hellas), Corinth Refineries S.A. (MOH) facility in Greece. The original intent was to increase the feed rate to the tower by 21%, from 95 tph up to 115 tph. The naphtha splitter was designed to split the feed into light virgin naphtha (LVN) overhead and heavy virgin naphtha (HVN) in the bottoms of the tower. During the initial study it was determined that the trays in the rectifying section of the tower needed to be replaced with high capacity trays because the original trays would have been severely jet flooded at the increased feed rate. The existing trays in the stripping section would operate within acceptable limits.

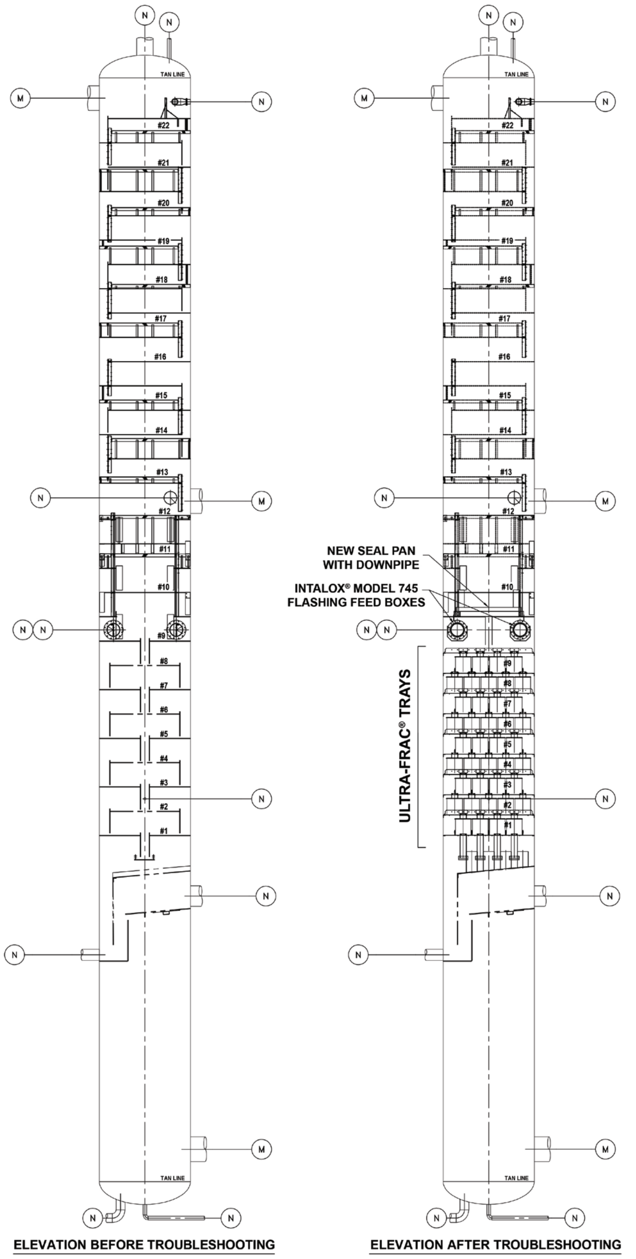

Figure 1. Column elevation after revamp 1Q19 vs column elevation after troubleshooting.

Prior to the revamp, the naphtha splitter was equipped with 30 conventional moveable valve trays, 1-pass above the feed and 2-pass below the feed, with a typical tray spacing of 600 mm. The feed inlet was above tray 14, with trays numbered from bottom to top.

MOH decided to proceed with the revamp of the naphtha splitter with an emphasis on meeting an LVN specification of less than 2.5% by weight of C7+ product, as imposed by the downstream isomerisation unit. In order to achieve the intent of the original project, the feed location was required to be lowered in the tower with more efficient trays installed, and the tray spacing increased in the rectifying section of the tower. The feed was relocated from tray 14 to tray 9 and the trays in the top section were changed to SUPERFRAC® trays, with their tray spacing increased from 600 mm to 950 mm. The trays in the stripping section of the tower were also changed to MINIVALVE® trays to handle the design loads under the new column arrangement (Figure 1, tower on the left). Even though there were fewer trays in the tower (22 trays overall vs 30 trays originally), the tower was still expected to meet the LVN specification due to a better tray hydraulic design coupled with the use of more efficient trays. The content of C6 hydrocarbons in the HVN was only marginally improved by this revamp because of the very limited number of trays in the stripping section, but it was still found to be sustainable by MOH because of the existing refinery scheme downstream of the reforming unit. The hydraulic design of the internals was based on the third-party initial study work.

Troubleshooting

The new trays were installed in 1Q19 with the assistance of Koch-Glitsch certified tower specialists. Shortly after the start-up, MOH performed a test run and the tower did not meet the desired results. At this point, the TOWER DOCTOR™ troubleshooting team was engaged to help assist in determining the cause of the poor performance of the tower. The initial analysis of the tower internals showed that the existing trays were properly designed based on the hydraulic data that was provided to Koch-Glitsch, which performed a simulation of the tower to verify tray hydraulics and efficiency. Plant operations showed that the tower pressure drop (DP) was 0.5 kg/cm^2 – which was an indication of flooding for a tower with 22 trays – and the C7+ content was above 7% by weight, which was an indication of poor separation in the tower. It was concluded that the trays were operating with a very low efficiency and the LVN specification would not be met at current tower operating conditions. Since the tower was flooding, the reboiler steam consumption was limited to 10.5 tph, further exacerbating the fractionation performance of the unit. In addition, the feed to the tower was operating at 109°C, approximately 13°C cooler than the design temperature. This required the reboiler to provide the additional heat to generate the required reflux. Once the trays were analysed with the new reboiler conditions, Koch-Glitsch determined that the existing stripping trays could not work properly because they would flood by both excessive jet flood and downcomer choke flood mechanisms due to the much higher internal vapour/liquid loadings profile. There were also major concerns over fouling in the tower. During the start-up of the unit, the stripper tower upstream of the naphtha splitter was severely fouled and there were concerns that fouling material may have reached the naphtha splitter.

At this point, MOH stopped the tower and completed a mechanical inspection to rule out any potential damage and fouling to the tower. There was also a discrepancy between the troubleshooting team and the third-party design simulation results. Based on the original hydraulic rates in the third-party design

Table 1. Process summary table of column operation during troubleshooting study

Parameter	Unit	Test run data executed after revamp 1Q19	Modelling of test run executed after revamp 1Q19	Plant data during gamma scan at incipient flood conditions	Modelling of plant data during gamma scan at incipient flood conditions
Feed flowrate	tph	113.5	113.5	101.3	101.3
Feed temperature	°C	109	109	108	108
Column pressure drop	kg/cm^2	0.5	0.5	0.3	0.3
Reflux flowrate	tph	55	55	45	45
Reflux temperature	°C	26	26	26	26
LVN flowrate	tph	37	37	32.6	32.6
C7+ content in LVN	%wt	7.2	7.4	2.02	1.97
ASTM D86 95% vol.	°C	83.7	76.1	70	71.8
ASTM D86 EP	°C	102.7	103.7	82	82.5
HN flowrate	tph	76.5	76.5	68.7	68.7
ASTM D86 IP	°C	-	86.3	90	89
ASTM D86 5% vol.	°C	-	88.1	99	98
GAP HVN D86 T5 – LVN D86 T95	°C	-	12	29	26.2
GAP HVN D86 IBP – LVN D86 FBP	°C	-	-17.4	8	6.5
Rectification trays hydraulics	Max. jet flood (%)	-	74	-	67
	Max. downcomer flood (%)	-	78	-	70
Stripping trays hydraulics	Max. jet flood (%)	-	94	-	88
	Max. downcomer flood (%)	-	106	-	97

study, the new trays that were installed should have worked properly and met the goals of the project to increase capacity and maintain product specification for the LVN. The Koch-Glitsch study showed that the existing trays would flood because of the different loading profile, mainly in the stripping section of the tower. The main operating parameters and qualities of the column operation observed during this troubleshooting phase are shown in Table 1 along with process and hydraulic outcomes. The inspection of the tower showed that the trays were in good mechanical condition and there was no evidence of fouling. During tower entry it was decided to make minor modifications to the feed distributor to minimise the risk of liquid entrainment, and to help liquid transition from the 1-pass trays above the feed to the 2-pass trays below.

Gamma scans

The tower was restarted and still did not achieve the desired performance. The tower DP was measured at 0.55 kg/cm^2, which still indicated flooding. Once again, the hydraulic design was verified using the data from the engineering company and no problems were noticed with the design of the trays. There was still concern due to the simulation that showed different internal vapour and liquid traffic in the tower, and Koch-Glitsch requested MOH to perform a gamma scan of the tower while providing guidance on the proper scan lines. There was also concern with the feed inlet area of the tower and the reboiler return area of the tower. Work was carried out in conjunction with process diagnostic specialist company Tracerco to provide proper interpretation of the scans along with the hydraulic analysis of the internals to MOH.

The gamma scans were performed at different operating conditions and the clearest results were shown when comparing the scan results between 78 tph and 116 tph feed throughput vs the original design of 115 tph. Figure 2 shows the scanlines between tray 8 and tray 10 in correspondence of the feed inlet location. The first scan has been taken at turndown feed throughput of 78 tph with the column not in flood conditions, whilst the second has been taken with the column at incipient flood conditions. The scans showed that liquid from the feed would flood the downcomer of tray 9, i.e. the first tray below the feed inlet. This would cause liquid to build up on tray 9 until the seal pan of tray 10 was flooded, which would cause the top of the tower to flood. The simulation was then adjusted to match the actual tower operations at the time of the gamma scans. The new simulation showed very different internal vapour and liquid traffic when compared to the original third-party study. The new hydraulics showed that the stripping section now had an increase of 77% in liquid traffic and the vapour traffic had increased by 32% when compared to the initial design loads provided.

During the gamma scanning test, it had been possible to set the column operating conditions and feed throughput, resulting in column operation at incipient flood condition of the stripping section trays, which had

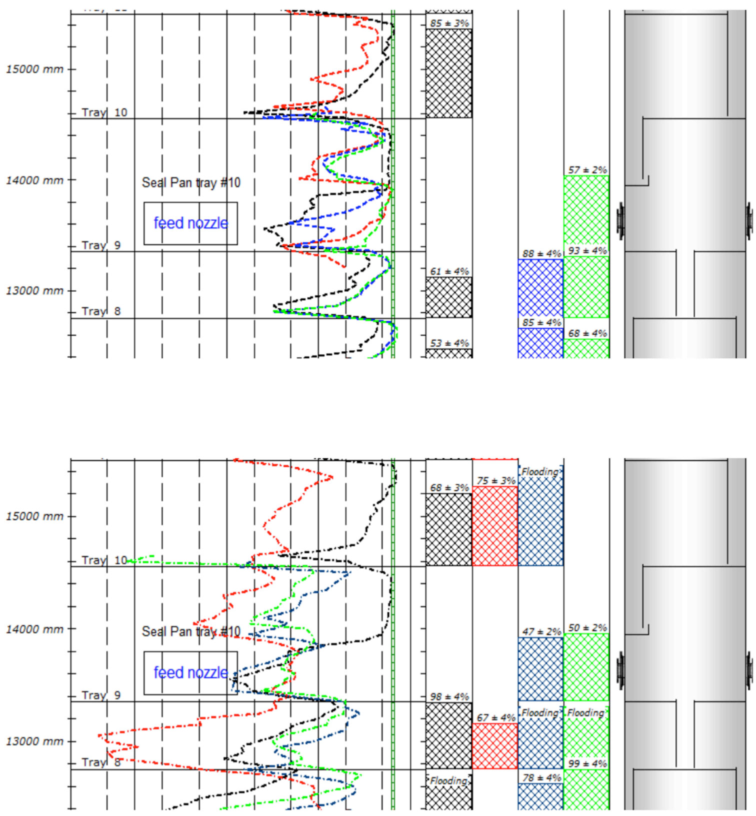

Figure 2. Gamma scans of the tower (courtesy of Tracerco).

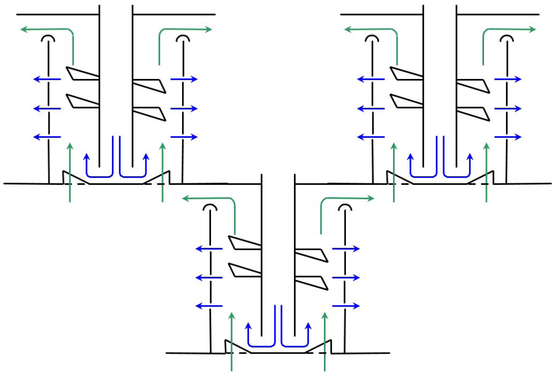

Figure 3. ULTRA-FRAC tray operation.

been suspected by Koch-Glitsch's independent process study. Due to the high accuracy of current Koch-Glitsch hydraulic correlations (regressed from intensive testing in pilot plants, including a 1.7 m [5.5 ft] dia. hydrocarbons distillation tower), the calculated hydraulic ratings were found to be consistent with the scanlines profiles. The field data and results of modelling of the column operation during this gamma scan test have been summarised in Table 1. This observation supported the original theory that the stripping section trays were designed based on an internal vapour/liquid loadings profile that was not aligned with the current operation of the column.

Tray modification

The troubleshooting team recommended that the trays in the stripping section be modified to handle the increase in liquid and vapour traffic. Upon a detailed hydraulic analysis, it was concluded that ULTRA-FRAC® tray technology could provide the requested hydraulic capacity and fractionation efficiency required to meet the product specifications.

The tray uses circular elements that are responsible for both the vapour/liquid contact and separation. Figure 3 shows how each contacting element functions (the vapour path is shown in green and the liquid path in blue). Liquid enters the contacting element from the tray above via a circular pipe downcomer. Vapour enters from the tray below into the annular zone between the pipe downcomer and the circular contacting element. Devices inside the contacting element cause the vapour and liquid to rotate in co-current flow. After exiting from the contacting zone the liquid is forced to the inner circumference of the contacting elements, from which it exits via a series of apertures. The liquid then drops down on to the tray deck where it flows towards the nearest pipe downcomer to feed the next tray down. Vapour, free of entrained liquid, exits from the top of the contacting elements and enters the next tray above.

A detailed understanding of both the capacity and efficiency characteristics of these devices is crucial to ensuring a satisfactory outcome when revamping existing distillation towers.[1,2]

The existing SUPERFRAC trays in the rectification section were able to handle the updated rates as long as the flooding from tray 9 was relieved. The ULTRA-FRAC trays would require a respacing of the existing trays from 600 mm to 500 mm to maintain the same number of trays and allow a proper transition between the different tray technologies inside the column. A new flashing feed gallery was installed to minimise the disturbance of liquid and ensure almost completely deaerated liquid is fed to the ULTRA-FRAC trays. The seal pan of tray 10 was also modified to minimise interaction with the feed vapour and liquid. A chimney tray was installed at the bottom of the tower to properly send liquid to the sump partition baffle feeding the reboiler and ensure uniform vapour distribution to the bottom tray. Figure 1 shows the arrangement of the revised stripping section (tower on the right) recommended by the troubleshooting team, compared to the first revamp elevation developed using the original third-party study (tower on the left).

Table 2. **Process summary table of column operation after troubleshooting with ULTRA-FRAC trays**

Parameter	Unit	Modelling of column operation with ULTRA-FRAC trays in the stripping section (at conditions closest to 1st set of plant data after revamp)	1st set of plant data after troubleshooting with ULTRA-FRAC trays in the stripping section	2nd set of plant data after troubleshooting with ULTRA-FRAC trays in the stripping section (with max. reflux ratio)
Feed flowrate	tph	116.5	115	112.4
Feed temperature	°C	108	110.5	109
Column pressure drop	kg/cm^2	0.26 (including margin)	0.17	0.18
Reflux flowrate	tph	65	65	65
Reflux temperature	°C	40	37.5	24
LVN flowrate	tph	37.4	37	32.1
C7+ content in LVN	%wt	< 1	-	0.93
ASTM D86 95% vol.	°C	70	66	68
ASTM D86 EP	°C	< 82	68	72
HN flowrate	tph	79.1	78	80.3
ASTM D86 IP	°C	91	87	92
ASTM D86 5% vol.	°C	99	95	99
GAP HVN D86 T5 – LVN D86 T95	°C	29	29	31
GAP HVN D86 IBP – LVN D86 FBP	°C	> 9	19	20

MOH requested that Koch-Glitsch guarantee the hydraulic and performance and product qualities for the new internals. Moreover, the new trays and existing reused equipment were to be designed with enough flexibility for the refinery operation and economics in terms of different operating conditions: feed throughput and temperature, and reflux flowrate and temperature. The trays were required to meet specifications for all the analysed operating modes of C7+ less than 1% weight in the LVN and ASTM D86 FBP of LVN less than 82°C.

Tray installation

The new ULTRA-FRAC trays were installed in late 2019 using OMNI-FIT® technology to reduce the installation time. This technology comprises mechanical design techniques that have been specifically developed to allow the rapid and accurate installation of new higher performance devices. Changes of the tray type, the number of flow passes, increasing or decreasing of the tray spacing, and even conversion from packed internals to trays have all been accomplished using the technology without welding directly on the vessel shell.

The proposed modification and trays (now based on Koch-Glitsch simulation results) were installed in six days with the assistance of certified tower specialists onsite to oversee their correct installation. The tower was restarted and now meets the design criteria set out by MOH.

Table 2 shows the main operating parameters and product qualities after the troubleshooting implementation. The design modelling of column operation with ULTRA-FRAC trays in the stripping section, at conditions closest to the plant operation after the revamp, has also been included for better comparison.

It may also be noted that, by taking advantage of the enhanced capacity of the new tray technology, it has been possible to operate the column at a higher reflux ratio, which can be conducive to maintaining the product quality with varying feed characterisation. The installation of the trays allowed MOH to increase the reboiler steam consumption from 10.5 tph to 15.5 tph and therefore operate the column at a stable and sustainable reflux of 65 tph.

As a result of the higher boilup and reflux, the LVN flowrate is maintained at elevated values with an on spec C7 content (average 0.98 %wt). The differential pressure of the column is stable at reduced levels of approximately 0.18 kg/cm^2. The downstream DIP/TIP units have benefited as the upgraded feed compositions favour normal paraffins conversion, product RON increase and isomerate yield increase. Reducing the C7 content of the TIP feed can be beneficial for the performance of the unit, as cracking of the C7 components in the reaction section is limited.

The troubleshooting team was able to quickly identify the problem with the original revamp design of the naphtha splitter by providing an updated simulation that matched actual tower operations. They were able to devise a plan to scan the tower and provide a detailed scan interpretation with hydraulic data analysis to match the gamma scan results. MOH was, in turn, able to make a change in internals to ensure the tower could meet the specified design goals of the revamp.

References

1. REMESAT, D., MAROIS, F., SICONOLFI, M., and WEILAND, R., ‘Debottlenecking a Depropanizer with ULTRA-FRAC® trays’, paper presented at the Distillation Symposium of the 2003 Spring AIChE Meeting.
2. FERRARI, A., NIEUWOUDT, I., and SANDFORD, N., ‘Picking the right workhorse’, *Hydrocarbon Engineering* (April 2020), pp. 24 – 28.