Troubleshooting premature tower flooding

Thorough analysis of field data and tray hydraulics together with gamma scanning were key factors in the successful troubleshooting of premature flooding in a debutaniser

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Flooding is defined as an operating condition where liquid accumulates in a column. It is the most common cause of capacity limitation of a separation column.[1] The build-up of liquid in a column can initiate from a variety of mechanisms, for instance jet flooding, downcomer choking, and backup flooding. Flooding is usually revealed by a sudden increase in the column differential pressure. Several reasons for column malfunctions have been reported in the literature. Many column malfunctions related to flooding are caused by fouling.[2]

This is a case study of successful troubleshooting of the premature flooding of a debutaniser in a steam cracker unit. The column has been operating well for decades and usually did not have serious problems during the typical five-year turnaround cycle. However, during a recent cycle the column had been in operation for only two and a half years since its last shutdown when flooding was detected.

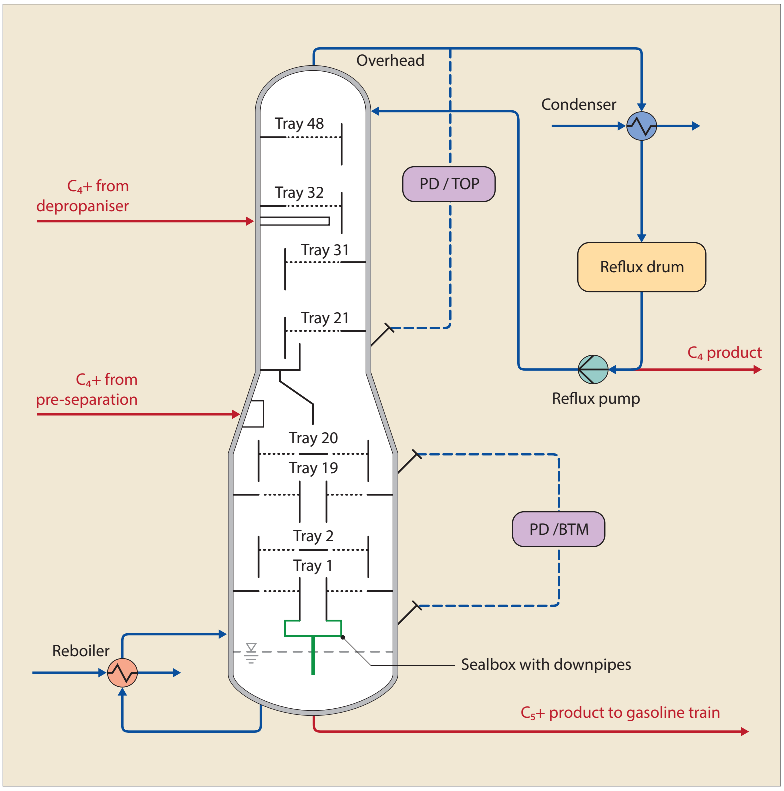

Figure 1 Simplified process scheme of the debutaniser (*courtesy of Linde AG*)

A rapid rise in pressure drop was measured by the plant owner in October 2017. Shortly after that, the bottom product purity deteriorated, followed by the overhead product purity deteriorating and the column operation became unstable. The feed rate to the debutaniser had to be reduced to achieve steady-state operation again. Due to this, the column ultimately became a bottleneck, limiting ethylene production to approximately 80% of plant capacity. Thus, it was necessary to urgently identify the root cause of premature flooding and to develop a solution to overcome the capacity bottleneck.

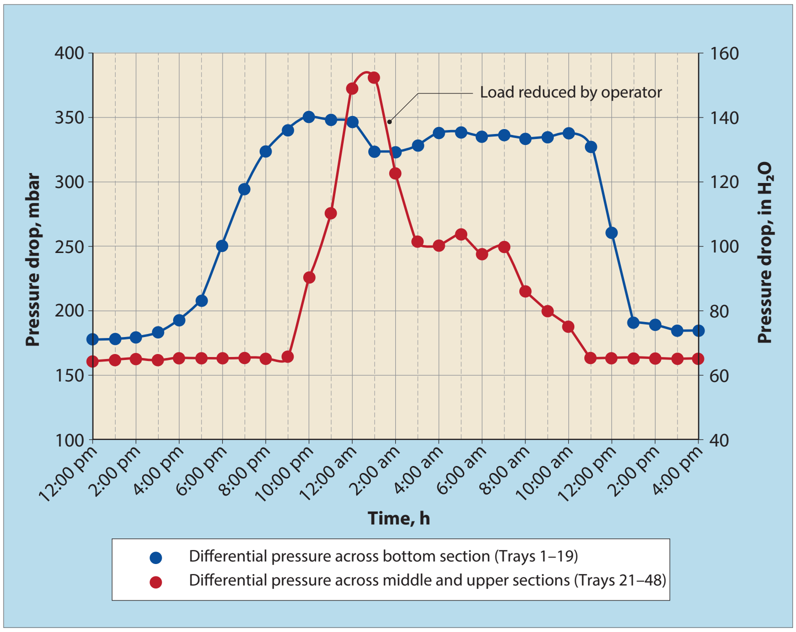

Figure 2 Differential pressure measured 4-6 October 2017 (*courtesy of Linde AG*)

As **Figure 1** shows, the debutaniser is equipped with 20 two-pass standard valve trays in the bottom section below the lower feed inlet, 11 one-pass standard valve trays in the middle section below the upper feed inlet and 17 one-pass standard valve trays in the top section. Each section has straight downcomers on a tray spacing of 600 mm (~24 in).

A C_4+ fraction from an upstream pre-separation column is fed to the debutaniser's lower feed inlet and a C_4+ fraction from an upstream depropaniser is introduced to the debutaniser's upper feed inlet. The feeds are separated into a C_4 overhead product and a C_5+ bottom product. The column is normally operated at an overhead pressure of 4.75 bara (68.9 psia) and a bottom temperature of 105°C (221°F). The debutaniser is instrumented with two differential pressure (ΔP) measurements: one ΔP measurement covering the top trays, Trays 21-48, and the other covering the bottom trays, Trays 1-19. Polymerisation inhibitor is fed to the upstream fractionators to avoid polymer fouling in the debutaniser.

Root cause analysis

First, the plant owner analysed the operational data to better understand the flooding phenomena. A sudden increase of the differential pressure across Trays 1-19 in the bottom section was noticed in October 2017 (see **Figure 2**). Shortly after the bottom pressure drop had established a plateau, the pressure drop across the middle and upper sections, Trays 21-48, started to increase significantly. As **Figure 2** shows, the pressure drop in the bottom section went from 180 mbar to 350 mbar (72 in H_2O to 141 in H_2O), followed by the pressure drop in the middle and upper sections which rose from 160 mbar to 370 mbar (64 in H_2O to 149 in H_2O). After the feed rate to the column was reduced, liquid build-up on the trays appeared to have immediately stopped and then receded. The pressure drop in the middle and upper sections decreased until the initial value was reached again. Shortly afterwards, a reduction in the pressure drop in the bottom section was seen. Steady-state operation and a normal pressure drop were achieved after all the accumulated liquid receded from the trays.

Investigation of the pressure drop data was the first indication that the root cause of the premature flooding was in the bottom section of the column, the reason being that liquid accumulation and hence an increased pressure drop always take place above the liquid flow restriction. The debutaniser is well known for butadiene polymerisation fouling. Hence, this observation was a strong indication that polymer fouling in the bottom section could have caused blockage of the tray active area and/or plugging in the downcomers. Nevertheless, several aspects of the tray design were studied before the entire investigation was focused on flooding caused by fouling.

Second, a hydraulic rating of the trays was performed using plant data from a past high load operation of the column. The results proved that the valve trays have sufficient capacity to accommodate the normal flow rates when no plugging occurs. The calculated overall pressure drop, including the static head and the pressure drop of the overhead nozzle, matched the measured pressure drop of 290 mbar (116 in H_2O) for the high load operation and hence proved the validity of the simulation. It could be concluded that the valve tray design was not limiting the capacity of the column. However, there was still the possibility that the trays were collapsed, which could only be verified by gamma scanning.

Gamma scanning is a non-intrusive investigative technique to diagnose malfunctions of process equipment while it is in operation. During the measurement, a gamma ray emitting radioactive source, along with a radiation detector, are synchronously lowered down opposite sides of the column. The radiation beam passes through the process equipment and its intensity is measured by the radiation detector in terms of a count rate. Interaction of the gamma ray beam with the column shell, internals, and the process fluid cause attenuation of the gamma ray, correlating to the average material density.[3]

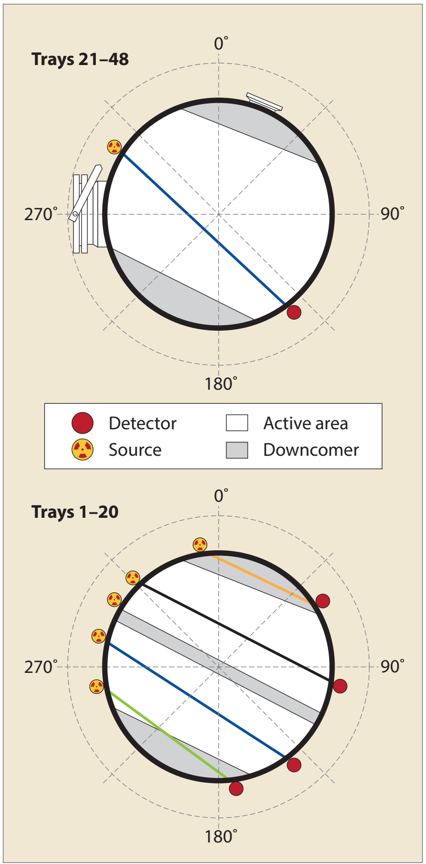

Figure 3 Scanline orientations: August 2017 baseline and December 2017 flooding scan – blue scanline; December 2017 east active area and downcomer scans at normal conditions – black, orange and green scanlines

A baseline scan had already been conducted by Tracerco on behalf of the plant owner under normal operating conditions in August 2017, three months before premature flooding occurred for the first time. All trays were scanned, but only the western active areas of the two-pass trays in the bottom section were scanned. The orientation of the scanline is shown in **Figure 3**.

The results of the baseline scan are shown in **Figure 4**. All 48 trays were holding adequate levels of aerated liquid, hence the good mechanical condition of the trays was confirmed. The one-pass trays in the top section were uniformly loaded, with tray froth levels ranging from 31-48% of the tray spacing. In the lower section, Trays 3 to 20 and Tray 1 were holding uniform froth levels ranging from 33-41% of the tray spacing. But another observation was noticed by Linde AG – a higher froth height was detected on Tray 2 compared to the other surrounding trays, particularly Tray 1. Tray 2 appeared to hold a froth level approximately 66% of the tray spacing. An isolated high or low froth height detected on a single tray is very frequently a result of a measurement anomaly caused by obstructions in the scanline, most typically an external interference such as a support ring, pipe support, weld pad for a manway, or nozzle. However, no notation of potential external interference was made by the scanners in the vicinity of Tray 2. In fact, the same higher froth height on Tray 2 was observed by Linde AG in a previous troubleshooting scan. In this earlier investigation, the cause was physical blockage of Tray 2's downcomer clearance due to fouling causing liquid to stack on the tray active area.

A normal froth height was detected on Tray 1 due to specific sealing of the centre downcomer. A seal box was attached to the centre downcomer of Tray 1 instead of a commonly used seal pan (see **Figure 1**). Downpipes bolted to the seal pan and submerged below the liquid level routed the process fluid into the column sump. Unlike a seal pan, a seal box does not have a clearance under the downcomer. Accumulation of fouling material in the downcomer exits of Tray 1 was not possible since all the solid material was washed away via the downpipes. Therefore downcomer backup flooding would start from Tray 2 or the above trays only. Further gamma scans were performed in December 2017 at flooding conditions to prove the proposed hypothesis. The scan results for this operation are shown in **Figure 5**.

For the December 2017 scan, the scanline orientation used for the baseline scan of the entire column was repeated (blue scanline in **Figure 3**) under flooding conditions. The scan results are shown in **Figure 5**. The blue scan data curve

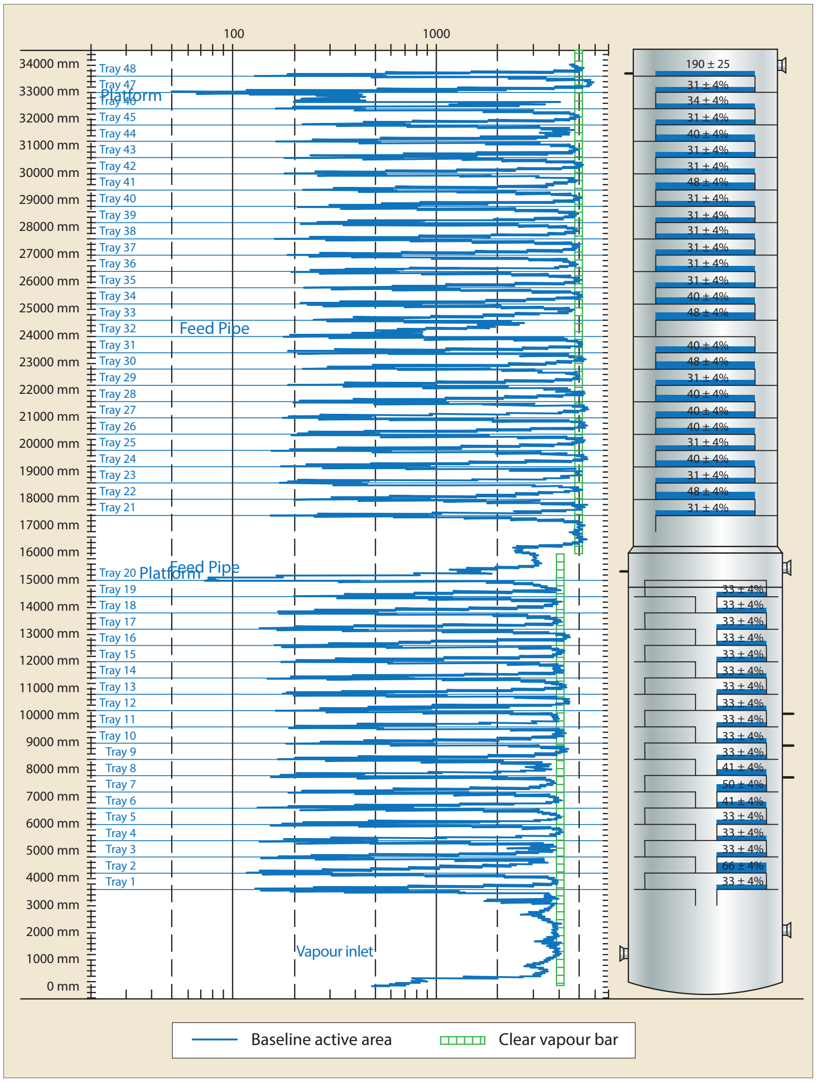

Figure 4 August 2017 baseline scan of tray active areas at normal operating conditions

thus tray damage was not causing the column to flood. As observed in the baseline scan from August 2017 on Tray 2's western active area, an increased froth height was also detected on the eastern active area of Tray 2, approximately 80% of tray spacing.

Additionally, scans were done at normal operating conditions through the outside downcomers in the bottom section. These scanlines are shown in **Figure 3** as the green and orange scanlines. Depicted in **Figure 6** by the green and orange data curves, the downcomer scans showed that the side downcomers of Tray 2 were liquid full, further proof that the flooding was originating at Tray 2. The downcomers from Tray 4 also appeared to have high liquid levels, the east side outside downcomer appearing liquid full; the west side outside downcomer appearing to hold an 80% liquid level. The other outside downcomers in the lower section appeared to hold liquid levels at 50-58% full.

The observations described from these scans provided strong evidence for plugging of the trays and downcomers caused by polymerisation fouling. However, cleaning the trays and downcomers was not a viable option since this would have required a costly shutdown of the entire steam cracker unit. Therefore, the load in the bottom section needed to be reduced. Linde AG and the plant owners decided to investigate a liquid bypass around the problem area.

The relative froth density, the height of the liquid on the tray deck, the pressure drop due to liquid flow under the downcomer, and the total tray pressure drop contribute to the liquid backup in the downcomer.[4] A downcomer backup of 326 mm (13 in or approximately 53%) was calculated for the aerated liquid. This was

represents the baseline scan results while the red scan data curve represents the flooding scan results. The red scanline revealed that the column was flooding, starting from Tray 2. Tray 1 still showed a normal froth height. This conclusively proved that the flooding originated at Tray 2.

Feed rates were reduced to alleviate the flooding. Another gamma scan, but of the eastern active area of the two-pass trays, was performed at normal operating conditions to finally confirm the mechanical integrity of all trays. These scan results are shown with the black data curve in **Figure 6**. The east side active area of Trays 1-20 showed the trays holding adequate froth levels, the observed downcomer liquid load from Trays 6-20, presumably not affected by fouling. The gamma scans showed that the downcomers from Trays 2 through 4 were close to or already full under these loading conditions. In other words, the aerated liquid backup in the downcomers was approaching the 600 mm (~24 in) tray spacing. This meant that increased tray pressure drop contributed only partially to the overall liquid backup in the downcomers. Hence the remaining liquid backup was mainly caused by plugging of the clearance under the downcomer. Reducing the liquid load would reduce the downcomer backup. This was the rationale for installation of a liquid bypass line. A process simulation was conducted by Linde AG to demonstrate that the desired bottom and overhead product specifications could still be achieved, while bypassing a portion of the liquid into the sump.

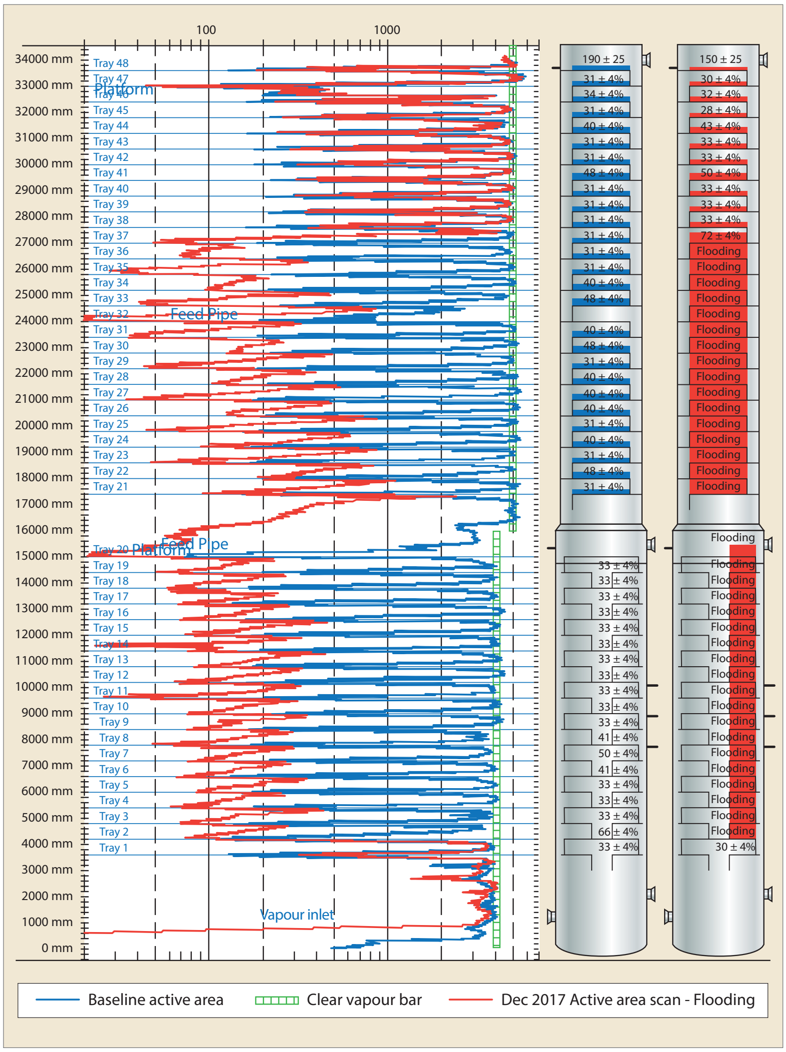

Figure 5 December 2017 scan of tray active areas under flooding operating conditions. Blue curve is the baseline scan; red curve shows flooding started at Tray 2 and had propagated up the column to Tray 38

Solving the flooding problem

The column should be capable of working at desired plant load conditions after installation of the bypass. Therefore, two different actual operating cases of the column were simulated. Case one represented the recent highest load operation of the column. Case two simulated the normal operating conditions of the column at the time of the downcomer gamma scans, just below the flood point. As is typical for a distillation column, the process simulation showed that the highest gas and liquid loads occur in the bottom section, especially on Trays 1 through 5. The liquid load that could not be processed by the column due to plugging of the clearance under the downcomer was determined to be 20.9 m^3/h (92 gal/m). It was necessary to overcome the column bottleneck by bypassing at least this amount of liquid around the affected trays.

Figure 6 shows that at normal operating conditions the outside downcomers of Trays 2 through 4 were liquid full or very near so. The side downcomers of Tray 6 and the above trays were operating at 50-58% downcomer backup. This means that the liquid load on Trays 1 through 5 needed to be reduced. A hot tap in the centre downcomers was not feasible due to poor accessibility and the narrow downcomer width. Therefore, two bypass lines were installed, one in each side downcomer of Tray 8.

A further process simulation proved that the desired bottom and overhead product specification could still be achieved at high load operation when bypassing 20.9 m^3/h (92 gal/m)

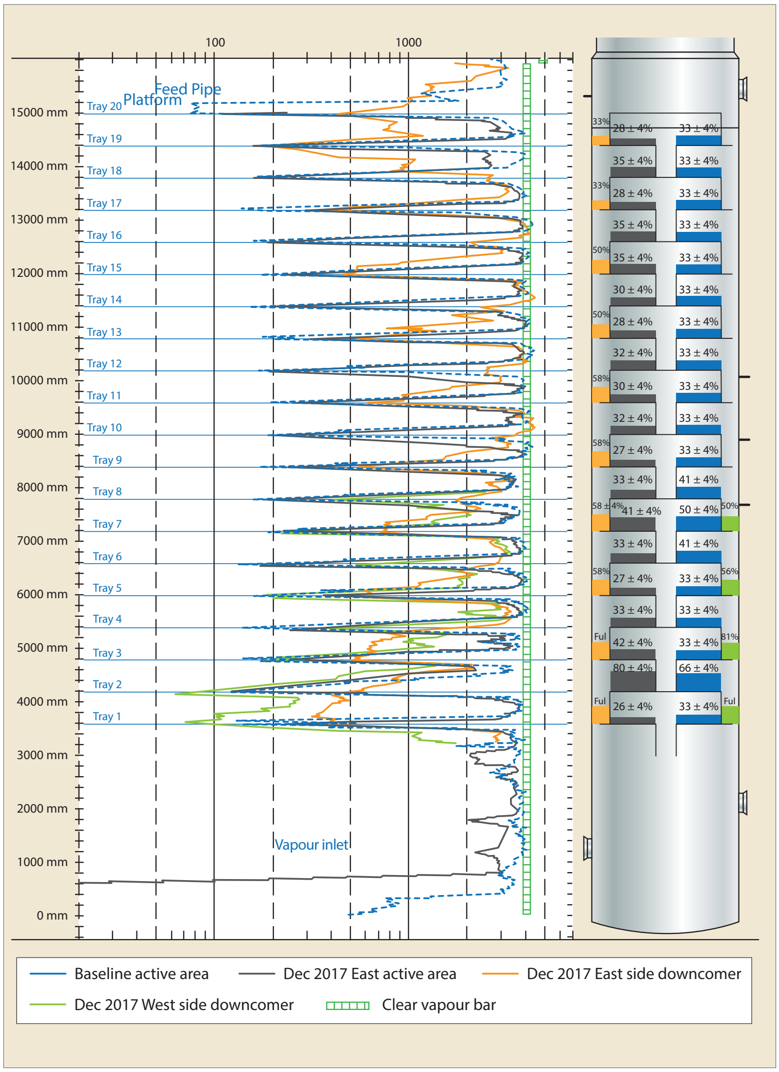

Figure 6 December 2017 scans of two-pass tray eastern active areas (black data curve), east side outside downcomers (green data curve) and west side outside downcomers (orange data curve) at normal operating conditions. Original two-pass western active area baseline scan data shown by dashed blue curve

liquid. Only a minor change of the reboiler and condenser duty of less than 1% was predicted by the process simulation, the reason being that the debutaniser has a relatively big margin in the number of trays and theoretical stages. The slightly increased reflux and reboiler rate could be accommodated by the existing trays.

Bypass lines had to be installed at the bottom of the side downcomers to ensure degassing of the two-phase mixture. However, due to turbulence in the downcomers it was likely that there was no 'clear' liquid at the bottom of the side downcomers. Therefore, sizing of the bypass lines was done to accommodate self-venting. An additional safety margin was considered during the design of the bypass lines in case more liquid than calculated would need to be drawn from the column. The bypass lines needed to be tied in below the column sumps liquid level to prevent vapour bypass. It was necessary to provide a hand valve in each line to control the amount of liquid drawn from the column. The detail engineering, including a risk assessment and the installation of the bypass lines by hot tapping, was done by the plant owner.

Hot tapping is a technique to make a connection to a pressure vessel while it remains in service. An extra gamma scan was performed around Tray 8 in preparation for the hot tapping, to determine the exact orientation of the downcomer bolting bars and the precise elevation of the support ring. In total, four hot taps were installed on the pressure shell, two in the side downcomers of Tray 8 and two below the normal liquid level in the column sump.

The bypass lines were put into operation in mid-2018. The steam cracker unit operating rate could be increased to 97% ethylene production capacity. On-specification overhead and bottom products were produced while the bypass was in operation. The debutaniser was opened in a later turnaround and severe polymerisation fouling was found on the bottom tray active areas and in their downcomers (see **Figure 7**).

Conclusion

In summary, thorough analysis of field data and tray hydraulics together with gamma scanning were key factors for a time- and cost-efficient troubleshooting. Close collaboration between the plant owner, Tracerco scan experts, and engineering company personnel made the troubleshooting discussed here a success.

References

1 Perry R H, Green D W, *Perry's Chemical Engineers' Handbook*, New York, McGraw-Hill, 2008.

2 Kister H Z, What caused tower malfunctions in the last 50 years, *Trans. Inst. Chem. Eng.,* 2003, Vol. 81, 5-26.

3 Pless L, Simon Xu, Distillation tower flooding – more complex than you think, *Chemical Engineering,* Jun 2002.

4 Lockett M J, *Distillation Tray Fundamentals*, Cambridge University Press, Cambridge, 1986.

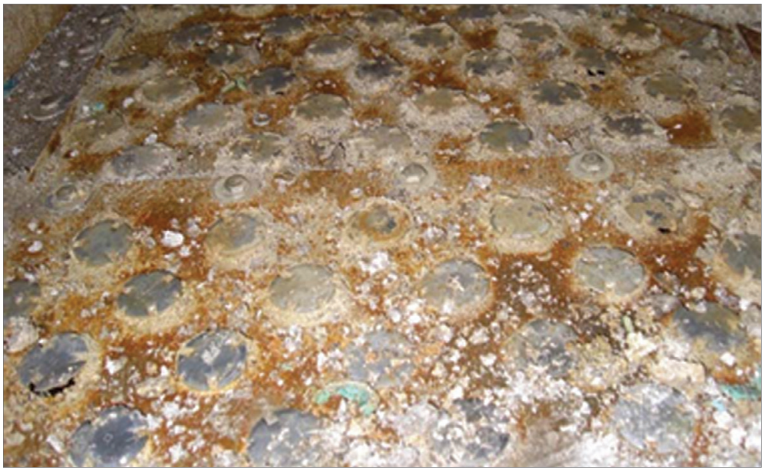

Figure 7 Active area of Tray 1 showing polymer plugging the valve units

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