Distillation Absorption 2010
Lowell Pless, Christopher McKeown, and Simon Xu

DIAGNOSTICS OF HIGH PRESSURE DEPROPANIZER

Lowell Pless[1], Christopher McKeown[2] and Simon Xu[2]
[1] Tracerco, 4106 New West Drive, Pasadena, TX 77507, USA, Email: Lowell.Pless@tracerco.com
[2] Shaw Energy & Chemicals, 1430 Enclave Parkway, Houston, TX 77077, USA, Email: Christopher.Mckeown@shawgrp.com, Simon.Xu@shawgrp.com

Abstract
A Depropanizer tower with a large diameter top section and smaller diameter bottom section was field tested and studied for its root cause of flooding. In the diameter transition zone, a two-phase feed was being introduced. Gamma scans identified that the trays in the top section were flooding and liquid accumulation initiated in the transition zone. A neutron backscatter technique was used to investigate downcomer hydraulics and identify the root-cause of flooding. Coupled with the field troubleshooting, a careful analysis of the design revealed likely causes of the flooding problem. Recommendations for modifications were made and installed.

Keywords: gamma scan, neutron scan, flooding, Depropanizer, tower

1. Troubleshooting

The High Pressure (HP) Depropanizer was a replacement tower as part of a 30% expansion of an ethylene plant. On start-up, plant capacity was limited to 96% of design due to the performance of the HP Depropanizer – C4's in the overhead would go out of specification. As well when the plant approached 96% capacity sharp increases in HP Depropanizer ΔP was observed.

The HP Depropanizer is not a typical distillation tower design as it is part of a heat pump system. As such it does not have the typical overhead reflux arrangement. Instead of the overhead passing through a condenser and part of the liquid used as tower reflux, the HP Depropanizer overhead passes through a feed/effluent heat exchanger, a compressor, reactor train, chillers, condensers and finally to a reflux drum from where some liquid is used as tower reflux and the rest is fed to downstream process. See Figure 1.

The feeds to the HP Depropanizer represent the entire unit ethylene production so the tower being a bottleneck was an extremely troubling problem.

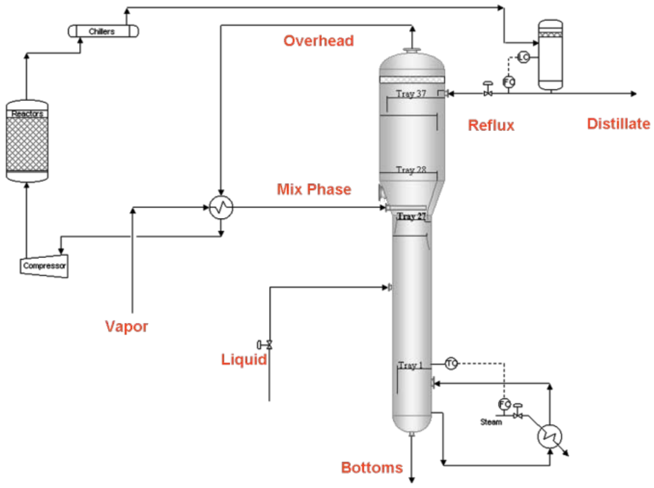

Figure 1. Process Scheme of HP Depropanizer

1.1 Initial Evaluation

The following shows process data concerning the operating problems with the HP Depropanizer:

When the feed load was at 96% of design rate,	ΔP across demister	16 mbar (0.23 psi)
	ΔP across top trays	70 mbar (1 psi)
	Butadiene in overhead	100 to 200 ppm mol
When the feed was increased above 96%,	ΔP across demister	30 mbar (0.43 psi)
	ΔP across top trays	120 mbar (1.8 psi)
	Butadiene in overhead	700+ ppm mol

Based on the process data above it seemed obvious that the top section of trays in the HP Depropanizer was flooding. Rigorous checks of plant operating data versus simulation calculations showed no major deviations from the process design. A gamma scan was performed to confirm the flooding, as well as to see where the flooding was originating. The gamma scan confirmed that the top section of the HP Depropanizer was flooding. As seen in Figure 2 the flooding started at Tray 28 indicating that the downflow liquid from Tray 28 was restricted at the transition zone. However the initial scan could not provide sufficient information to answer the questions on the root cause of flooding:

- Was the flooding from entrainment or downcomer backup?
- What was restricting the flows?
- How to solve the flooding problem?

More field tests and process and hydraulic analysis were required to understand the flooding mechanism and the root causes.

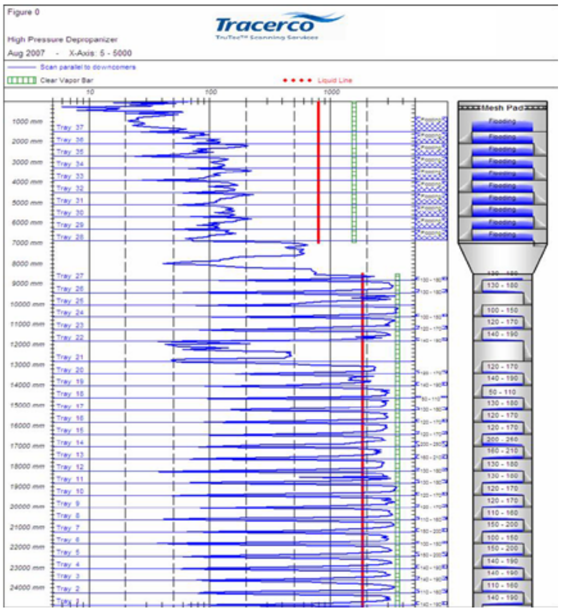

Figure 2. Initial Scan Showed that Flooding Started at Tray 28.

1.2 More Field Tests – Gamma Scans

To investigate the hydraulic abnormalities in the transition zone, two more gamma scans were performed, one for active areas and one for downcomers, as shown in Figure 3. Scan 1 was performed across the active area by scanning parallel to the downcomer; Scan 2 was perpendicular through the downcomer.

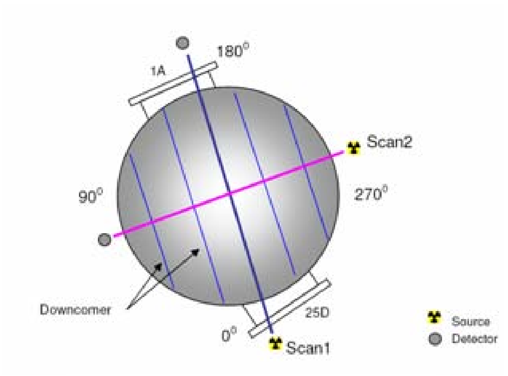

Figure 3. Scan Line Orientations

Figure 4 is an expanded view of the two scans through the transition section. While the orientation of Scan 2 was not perfect for investigating the hydraulic condition of Tray 28's downcomer it did reveal some new information. Scan 1 showed a level of aerated liquid on Tray 27 while Scan 2 showed Tray 27 operating dry, as seen in Figure 4. Within the highlighted area on Figure 4 Scan 1 (the blue curve) showed a response at Tray 27 signifying some dense material (liquid) on the active area of Tray 27. Conversely Scan 2 (red curve) within the highlighted area showed nearly no response at Tray 27. There was no dense material i.e., no liquid holding on Tray 27. Since Tray 27 had been seen holding liquid there was no question that Tray 27 was intact mechanically and capable of holding liquid. Instead during the operation when Scan 2 was performed, while the flooding persisted Tray 27 had gone dry, presumably because liquid downflow from Tray 28 above was severely restricted.

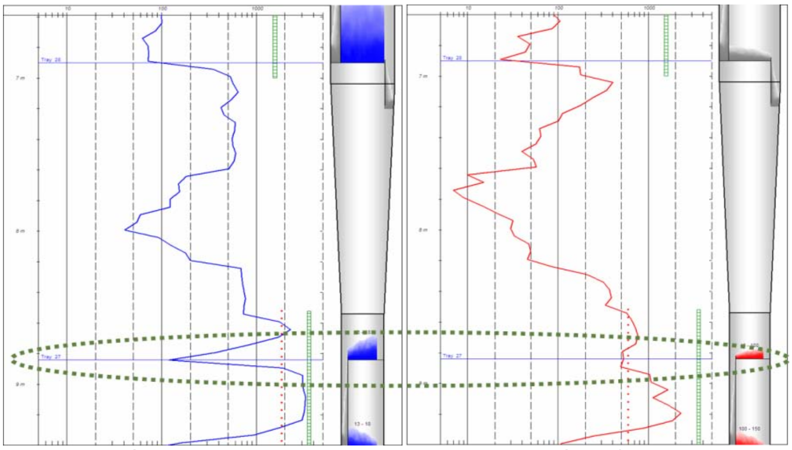
Scan 1 Scan 2

Figure 4. The Liquid Holdup or Froth on Tray 27 Appeared Unsteady During the Scans

Reconciling these results with plant process data (Figure 5) showed that as the pressure drop or flooding severity increased and prolonged, Tray 27 dried up again confirming that the downcomer from Tray 28 was restricted.

1.3 Possibility of Fouling

The possibility of fouling material accumulating in the downcomer outlet was considered. An accumulation of fouling material at the downcomer outlet could restrict the liquid flow and possibly cause the flooding observed.

First, butadiene polymer fouling was considered. However, regarding the potential fouling at the feed point of the HP Depropanizer, the temperatures are too cool to cause butadiene polymer related fouling. The only place in the HP Depropanizer tower where fouling issues are known would be at the bottom, typically in the reboiler itself. Many of these towers are currently in service and have not had issues in the feed location with butadiene polymer fouling.

Second, there was a definite concern that hydrates were present. Formation of stable hydrates is determined by the nature of the compounds, their temperature, and the relative water content.

Potentially hydrates could form and restrict liquid flow from a downcomer or foul tray decks. Methanol injection is a proven method for removing hydrates if present; however, this operator was not willing to inject methanol to prove or disprove this theory. Therefore, the troubleshooting analysis proceeded as if hydrates were not the root cause. Subsequent testing and analysis would prove that hydrates were not the root cause of the flooding.

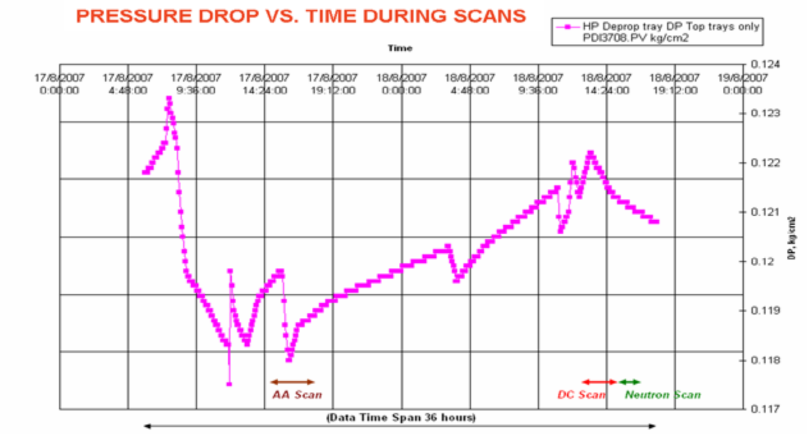

Figure 4. Pressure Drops (Indication of Flooding Severity) during the Scans

1.4 Review of Tower Internals

Several aspects of the design of the HP Depropanizer were studied, focusing on the feed transition area where the flooding initiated. Three items were identified that, listed by relative importance, could be causing the flooding of the HP Depropanizer. Please refer to Figure 6.

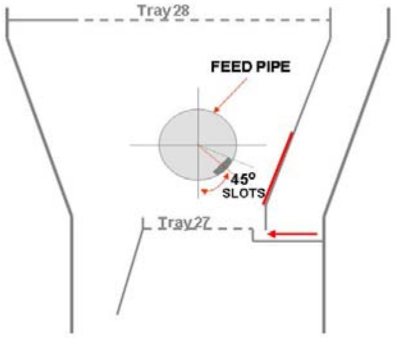

Figure 6. Questionable Tower Internals in the Transition Section

The process simulation showed a mixed phase feed of approximately 93 wt% vapor and 7 wt% liquid (vol% of liquid in the feed < 0.25%). The 2-phase pipe distributor was designed for the exit slots to be centered at an angle of 60° from vertical. Unfortunately some construction drawings showed that the pipe distributor was installed with the exit slots centered 45° from vertical. Therefore, incoming feed was being directed towards the bottom of Tray 28 downcomer. The downcomer from the top section (Tray 28) had been sized based on the liquid load in the middle section of the tower rather than the liquid load coming from the top section. For this reason the downcomer through the transition area was oversized. Because of this the liquid head in the downcomer was lower than expected and gave some concern that the liquid seal could be lost allowing vapor feed to travel up the downcomer. A second goal from the scanning activity was to try to determine if this vapor-bypassing was happening.

An impingement plate is typically used on the downcomer apron to act as a heat insulator to avoid downcomer liquid from being vaporized by the warm feed. In this design the feed temperature was only 3°C (5°F) warmer than the downcomer liquid so the impingement baffle had been left off. In reality the actual temperature profile may not be exactly as predicted by simulation models, as process turbulences could cause temperature deviations. An impingement plate should be installed as an extra precaution.

Evidence was accumulating that vapor flow from the feed was going up the downcomer from Tray 28. At this point everyone involved, especially plant management, wanted “proof-positive” that the hypothesis of vapor-bypassing up Tray 28’s downcomer was actually happening.

1.5 Verifying the Vapor-Bypassing by Neutron Scans

Under most circumstances gamma scanning through tray downcomers is the recommended approach. However there were some extraordinary reasons why this was not the best approach in the circumstance of this HP Depropanizer. The physical structure of the HP Depropanizer, top large diameter and bottom smaller diameter, is challenging for gamma scanning, as shown in Figure 7. As the gamma source and detector travel down through the transition zone, the source and detector are essentially hanging “in the air”, instead of maintaining contact against the walls. Due to limited access through the transition zone this was unavoidable on this tower. Additionally the diameter is constantly changing through the transition zone. Even if one was able to keep the source and detector up against the column wall, for each drop in elevation the radiation counts at the detector will vary based on the constantly changing diameter. It could be possible, even if improbable, that a change in internal process density would be negated or exaggerated by the change in diameter or distance from source to detector.

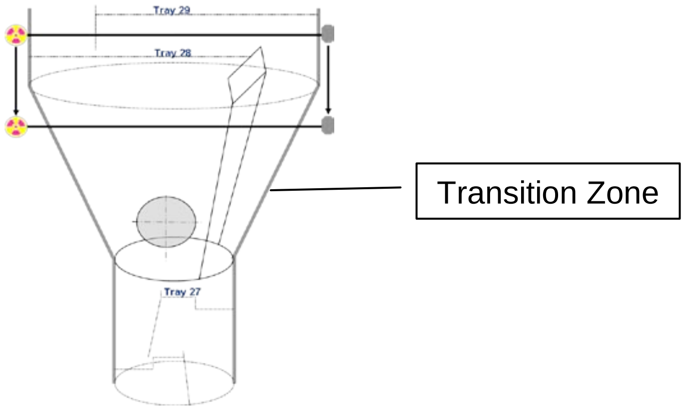

Figure 7. The Transition Section Imposed Challenges to Gamma Scans

Ideally the best way to gamma scan tray downcomers is to scan parallel to the downcomer walls while the radiation beam passes through the middle of the downcomer. Given the physical features discussed above coupled with the relatively narrow downcomer area, a gamma scan was not going to provide the kind of detail information desired about the operating condition of the downcomer through the transition zone.

The best approach to scan through the downcomer in the transition zone would be to scan with neutrons. Neutrons essentially measure the hydrogen concentration of the material in front of the neutron source/detector apparatus. In this case we would expect a large response where hydrocarbon liquid was present and a smaller response where vapor or less liquid was present. The neutron scan started above the opening of Tray 28’s downcomer and proceeded down to below the bottom of this downcomer. The black curve in Figure 8 shows the results from this scan. At the bottom of the downcomer where one would expect liquid the neutron response instead showed vapor. There was a “liquid” response further up in the downcomer, several centimeters from the bottom. The belief is this was a layer of highly aerated liquid or foam suspended in the downcomer by the vapor. Furthermore at the same time neutron readings were taken on the active area of Tray 27 and it was seen to be void of any substantial level of liquid. Thus the neutron scans validated the hypothesis of vapor was blowing back up Tray 28’s downcomer and preventing liquid from down-flowing out of the top section, thus flooding the top of the HP Depropanizer.

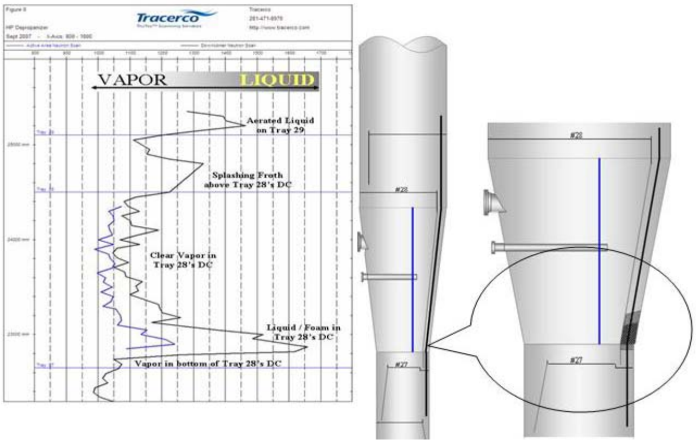

Figure 8. Neutron Scans of the Downcomer in Transition Section
Active Area Scan in BLUE; Downcomer Scan in BLACK

2. Solve the Flooding Problem

With a clear picture on the root cause of flooding in the transition section, several steps were proposed and installed to correct the configuration of the HP Depropanizer feed zone (refer to Figure 9):

- First, the feed pipe slots were modified to be 60° from vertical, reducing the probability of vapor blowing directly onto the downcomer outlet,
- Second, the slot open area was increased to reduce the vapor exit velocity,
- Third, an impingement plate was added to the downcomer apron to provide insulation between the hot vapor and cooler liquid to minimize downcomer liquid vaporizing,
- Fourth, the impingement plate had a ledge added to its bottom edge to further guard against the vapor impinging down onto the liquid leaving the downcomer,
- Fifth, the under downcomer clearance (UDC) was reduced in order to increase the liquid head in the downcomer to secure a liquid seal at the bottom of the downcomer.

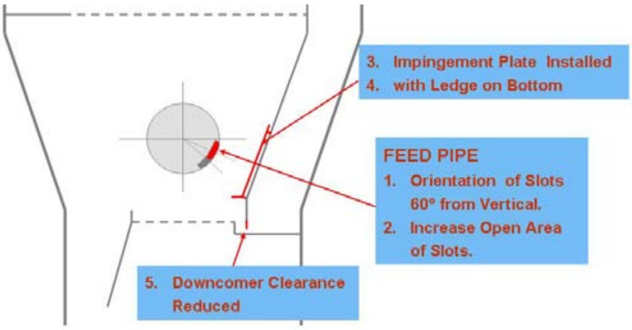

Figure 9. Modifications of the HP Depropanizer Transition Zone

It could be argued that not all of the above design changes were necessary to correct this flooding issue. However, all the changes recommended were low-cost and due to the importance of this tower every opportunity to improve the design was taken to ensure success following the plant shutdown. After these modifications were installed the HP Depropanizer and the unit were restarted. The unit was able to demonstrate design capacity in a successful plant test run with no further symptoms of flooding.