TROUBLESHOOT PACKING MALDISTRIBUTION UPSET PART 1: TEMPERATURE SURVEYS AND GAMMA SCANS

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This paper describes troubleshooting poor performance of a packed distillation tower and a condition called "upset" in which rapid heating up occurred near the top of the tower. The investigation combined surface temperature surveys, grid, distributor and CAT gamma scans, simulation, and a hydraulic analysis. Part 1 describes the field tests; Part 2 the simulation, hydraulic analysis and fix.

The temperature surveys and gamma scans revealed severe maldistribution in the top bed with vapor flowing in the central regions and liquid in the peripheral regions. Both also showed severe spraying of liquid from the reflux distributor all the way to near the tower tangent line. There were no indications of flooding. The investigation identified the maldistribution of feed and reflux as the major root causes for the poor performance.

KEYWORDS: liquid distributors; packed towers; troubleshooting; gamma scans; temperature surveys; flashing; maldistribution

INTRODUCTION

In a previous paper (1), we demonstrated the value of combining temperature surveys, field tests, and gamma scans to identify and solve packed tower problems. Here we supplement these with simulation and hydraulic analysis. The resulting tool was not only able to identify and solve a difficult problem, but also charted a mode of maldistribution that, to the best of our knowledge, had not been previously reported: boiling inside a distributor.

In the case history described here, there were several factors conducive to boiling in the reflux distributor: a reflux consisting mixture of two major components, with boiling points 90 °C apart, a single feed point into the reflux distributor, and a large surface area for heat transfer in the distributor. One lesson learnt is that when the distributor liquid contains highly volatile components together with higher boilers it is important to avoid excessive heat transfer areas (as are provided with many commercial distributors).

A possibly related experience was reported by Bravo et al. (2). Small quantities of free water in the reflux went through the distributor and descended right down the packing, causing violent instability when reaching the hot bottom of a heavy naphtha vacuum fractionator. This experience never happened when the tower had trays. In the Bravo et al case, the feed was highly subcooled and their distributor was an orifice-trough without flow tubes, so it did not have excessive heat transfer area. It appeared that the boiling of the volatile component (water) took place in the packing, not in the distributor. Maldistribution could have played a role. Bravo et al used pilot tests (again, with an orifice pan distributor without flow tubes) to verify that violent boiling took place in the packing when free water was refluxed into a hot hydrocarbon tower.

Figure 1 shows the light-ends vacuum tower which was at the center of our study. The tower separated an overhead product consisting mostly of highly-volatile component A (about 25% molar) and 75% other components (B's) from a heavy C bottoms. The overhead product consisted about 10% of the total feed by weight. The reflux flow rate was more than half the feed flow rate. The tower was 1.5 meters in diameter and contained two packed beds, each 4.8 meters tall, with the feed entering between. The upper bed contained 0.7 inch random packing, whereas the bottom bed contained structured packing with around 220 m^2/m^3 surface area. The column was controlled to a fixed reflux to feed ratio. A reset from the lower TI in the upper bed (T3) manipulated reboiler heat under normal conditions. The reboiler heat input was set as a constant as the reset did not keep the lights out of the bottoms when the column went into upset.

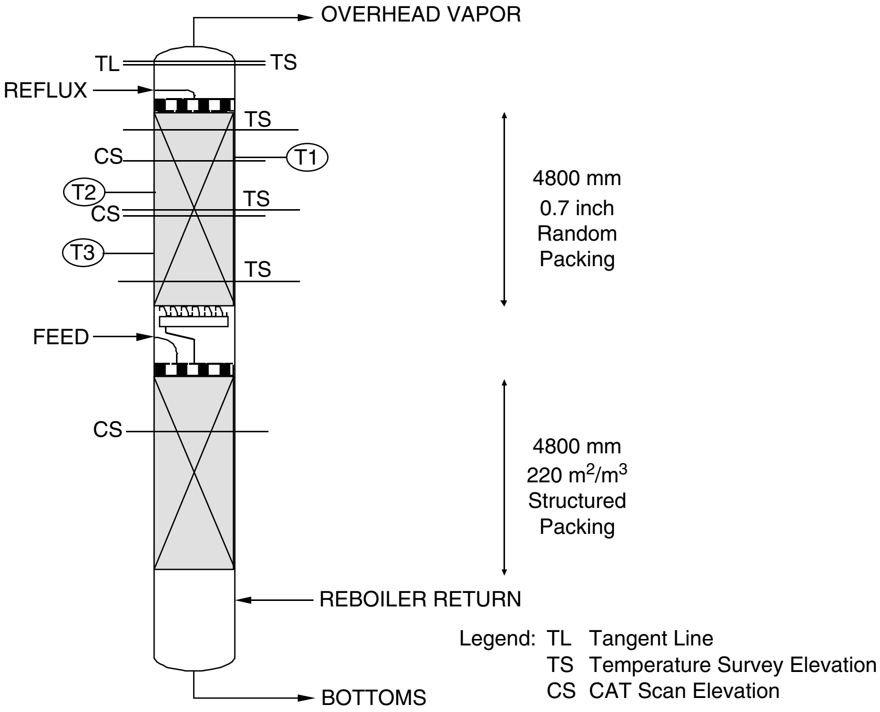

Figure 1. Tower schematic, showing locations of key measurements (roughly to scale)

PROBLEM DEFINITION

The tower experienced two operation modes: "normal" and "upset". In the upset mode the measured temperature near the top of the upper bed (T1) became 40 °C higher than normal, and a "reversal" occurred: this temperature became hotter than temperatures further down the bed. The heating up of T1 was accompanied by a large rise in heavies in the overhead product. At the same time, the lights impurity in the tower bottoms diminished. A shift to the "upset" mode was triggered mostly by raising the set point on the tower temperature controller, but also by excessively raising feed rates.

Our troubleshooting included surface temperature surveys, gamma scans, simulation, and hydraulic analysis. The temperature survey identified hot and cold spots, maldistribution and abnormalities. The gamma scans mapped maldistribution patterns and measured liquid levels in the distributors. The simulation determined packing efficiency, provided insight into the normal and upset operation modes, and supplied the basis for the hydraulic analysis. The hydraulic analysis checked operation of packing and distributors, identified bottlenecks, and formed a basis for formulating and testing theories.

TEMPERATURE SURVEY

For the temperature survey of the upper bed, holes were cut in the tower insulation 500 mm below the top of the bed, 2450 mm above the packing support, and 650 mm above the top of the packing support, respectively (referred to as the top, middle, and bottom rings). Each elevation had 6 holes around the circumference (at 60 degree angles). Similarly, holes were cut at different elevations in the lower bed, but due to the smaller temperature differences in the lower bed, the lower bed temperature survey gave less conclusive information and is not discussed in detail here.

An additional temperature survey ring was added later at 100 mm below the top tangent line, above the reflux entry nozzle. This level turned extremely informative. The full temperature survey was performed with the tower in the upset mode, giving what we consider good and reliable data. We intended to repeat the full survey with the tower in the normal mode following the gamma scans, but in the meantime over-zealous safety people removed the scaffolding, so only the top ring and the ring above the reflux inlet could be surveyed in the normal mode. This lost us some valuable data points.

Figures 2 and 3 show the results. Both normal and upset mode temperature surveys showed severe maldistribution in the upper bed. Here are some specific observations:

1. There was a cold spot on the north-west that persisted throughout the upper bed. That cold spot even extended to near the tangent line above the bed (above the elevation of the reflux inlet). Temperatures at the north-west near the top of the bed and above it were much closer to the reflux temperature of 87 °C than to the tower overhead temperature of 195 °C.
2. At the upset condition, the temperature of the vapor in the overhead was 195 °C. The wall temperatures above the distributor and the reflux inlet, just below the tangent line, were much lower than the overhead vapor temperature.

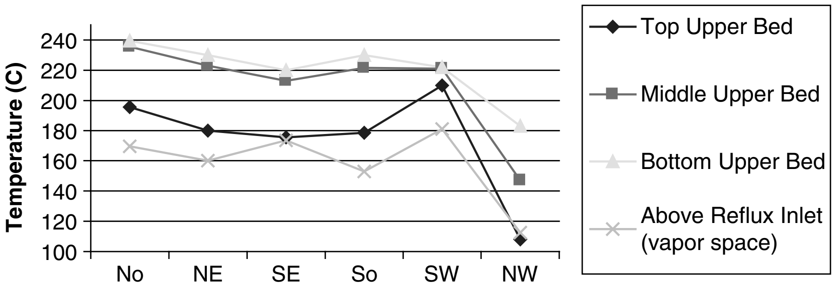

Figure 2. Surface temperatures upper bed-upset condition

3. At the upset condition, the temperature measured 300 mm inside the upper bed, about 700 mm below the top ring of the temperature survey, was 221 °C (T1). Except for the cold spot on the north–west (108 °C), wall temperatures along the top ring ranged from 176 °C to 210 °C, all colder than the inside temperature. In contrast, at the normal condition, T1 was 177 °C, much the same as the wall temperatures measured at the upper ring (168–184 °C) (except for the cold spot on the north-west that measured 108 °C). This suggests that the upset was a breakthrough of hot vapor in a specific bed location (compare to item 5 below).
4. At the upset conditions, the temperatures T2 and T3, measured 300 mm inside the upper bed, were colder than most of the wall temperatures measured at the corresponding elevation (except for wall temperatures in the cold spot on the north–west). T2 and T3 were located close to the north–west, right within the cold spot, which accounts for their relatively low temperatures.
5. Comparing the top ring and that above the reflux distributor shows that the upset caused heating up by as much as 35 °C in one or two locations, but little change (average of less than 2–4 °C warming) in other locations. This suggests that the upset condition caused a breakthrough of hot vapor in specific bed locations.

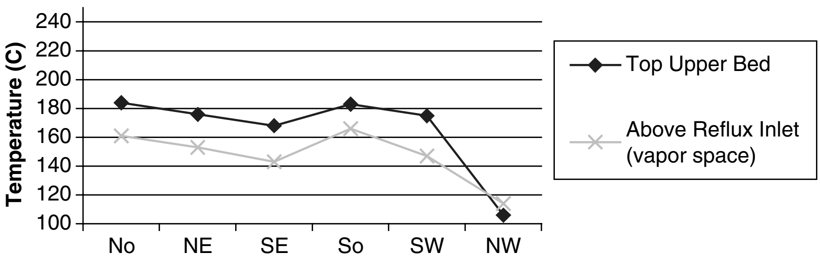

Figure 3. Surface temperatures upper bed-normal condition

INTERPRETATION OF THE TEMPERATURE SURVEY

We are usually concerned about maldistribution when we see differences exceeding 10 °C at the same radial elevation (differences not exceeding 5 °C are good). In the upper bed, the differences exceeded 100 °C at the same elevation.

At the upset mode, wall temperatures near the top of the upper bed were much lower than the center temperatures (as measured by T1). This suggests preferential liquid flow at the wall, and vapor in the center. There was a cold spot along the north–west, along the entire upper bed. At the normal condition, the north–west cold spot persisted, but otherwise the center temperature T1 was much more in line with the wall temperatures, suggesting that the above channeling pattern was alleviated. It appears like the upset was breakthrough of hot vapor in specific bed locations.

Above the top bed the wall temperatures were typically 15–35 °C below, but as much as 80 °C below, the overhead vapor temperature. This is very unusual, and suggests that reflux was being sprayed upwards from the distributor onto the walls

The lower bed temperature survey (not shown) suggested some irregularities, but is far less informative than the upper bed temperature survey due to the smaller temperature difference across this bed. There was evidence to suggest that the cold spot on the north-west persisted along the entire bottom bed. There was also an indication of colder zones close to the feed inlet and of preferential vapor flow right across from the reboiler return nozzle.

GAMMA SCANS

Grid gamma scans, special reflux and feed distributor scans, and top and bottom bed CAT scans were shot both at the upset and the normal conditions. The CAT scan of the upper bed was shot 1.15 m below the top of the packing, almost at the same elevation of T1. A second CAT scan was shot in the middle of the bed, 2.6 meters below the top of the bed. Both these scans were shot both at the normal and upset conditions. A CAT scan 1.5 meters below the top of the bottom bed was shot only in the normal condition. The grid scans are not included in this paper because of space limitations. The CAT scans at 1.15 meters below the top bed at the upset and normal conditions are shown in Figure 4.

REFLUX DISTRIBUTOR & ABOVE

The gamma scans indicated a liquid level of about 7 cm in the reflux distributor under both normal and upset conditions. No clear vapor space was visible between the distributor and the tangent line for any of the grid scans at either normal or upset condition. This indicates entrainment rising from the distributor along all scanned chords at both normal and upset conditions.

UPPER BED

Key observations were:

1. The upper bed CAT scans, both for the normal and upset conditions, clearly show a liquid-deficient central region with liquid-rich peripheral regions (Figure 4).

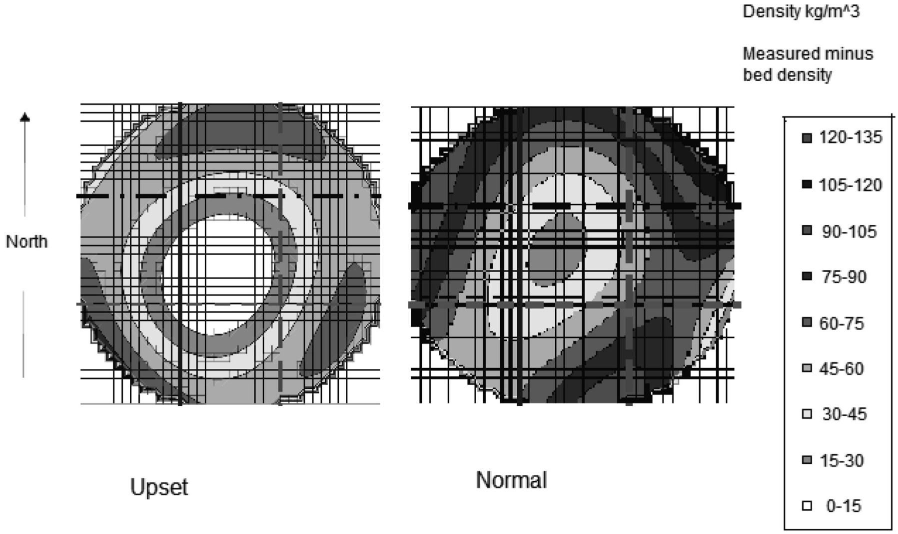

Figure 4. CAT scans of upper bed

The liquid content steeply increases as one moves radially from the tower center towards the tower wall.

2. At the upset condition, top CAT scan, there is a circle right in the center of the bed that approaches total dryness. This circle occupies about 15% of the tower cross section area. No other CAT scan shows any region approaching total dryness.
3. For the top CAT scan, at upset conditions, the median density was 43 kg/m^3. The equivalent density for the normal condition scan was much higher, 65 kg/m^3. That difference persisted in the lower CAT scan. Here the corresponding median densities were 65 kg/m^3 and 81 kg/m^3 for the upset and normal conditions.

   The lower densities throughout the bed in the upset condition would normally mean less liquid flow down the bed. However, since the reflux flow rate was the same in the normal and upset conditions, the liquid flow rate did not change, as verified by the grid scans. This suggests another explanation: a greater concentration of liquid near the wall in the upset condition. The CAT scans have difficulty measuring liquid near the wall, and the integration of densities was performed roughly over 80% of the tower cross section area. A large increase in liquid flow near the wall would elude the integration.
4. The grid scan of the upset condition showed no chordal maldistribution in the upper two meters of this bed. Below this, the east and west chords show a liquid bias. The liquid bias gradually intensifies over the next 0.8 meters, remaining steady to the bottom of the bed. The grid scan of the normal condition showed less maldistribution.

In summary, the pattern on the CAT scans was well in line with the results from the temperature survey. The scans indicated very severe maldistribution, with liquid around the periphery and vapor in the center. This pattern appears to propagate right through the bed. In the upset condition, this pattern appeared to intensify, with the center approaching dryness and the liquid building in the wall region. In addition, there is evidence for liquid entrainment from the reflux distributor above the bed.

FEED DISTRIBUTOR

Key observations were:

- The gamma scans indicate a liquid level of about 7 and 9 cm in the main channel of the feed distributor under normal and upset conditions, respectively. At the normal condition, liquid in the main channel was significantly less aerated than in the upset condition.
- At the normal condition, there appeared to be another 10 cm of froth or aerated liquid above the liquid level in the main channel. At the upset condition, this fluid became far less dense or more aerated, and its height grew, extending 10–15 cm above the top of the distributor.
- No clear vapor space was visible between the top of the distributor and the collector (about 0.8 meters with very little mechanical obstruction other than the feed pipe) in any of the grid scans at either normal or upset condition. The west and east chords in the upset condition get closer to clear vapor than others, but still do not reach it. The lack of clear vapor indicates entrainment rising from the feed distributor along all chords at both normal and upset conditions. Note the similarity of this observation to the one for the region above the reflux distributor.

LOWER BED

Key observations were:

- The grid scans for both the normal and upset conditions show a liquid bias along the east chord. In the normal condition, the bottom meter of packing showed good distribution, with the maldistribution becoming more significant above. The converse was observed in the upset condition, with the top 1.5 meters of the bed showing good distribution, with maldistribution below.
- The CAT scan showed higher liquid flow around the periphery than at the center of the bed. The central low-liquid zone was more or less circular, about half the tower diameter, and was centered due west of the tower center. The density of the low liquid zone was less than half the average density.
- The CAT scan showed high liquid flow rates on the east side, which is in excellent agreement with the grid scan. Also, it showed extremely high liquid flow rates near the wall in a narrow band along the north to north-west of the tower.
- The liquid level in the bottom was about 1.4 meters below the centerline of the reboiler return nozzle.

In summary, it appears that the feed distributor generated gross maldistribution in the bottom bed. There was a preferential flow of liquid along the periphery and on the east, and a preferential flow of vapor in a circular zone about half the tower diameter centered west of the tower centerline. There was no issue with the tower base liquid level.

OVERALL

The gamma scans showed no flooding, mechanical damage, fouling, corrosion, or other mechanical gross abnormalities anywhere in the tower. Liquid levels measured in distributors and at the tower base were not high. The gamma scans showed severe maldistribution in both beds, with peripheral liquid-rich zones and central liquid-deficient zones. The upset scan showed drying up of the central region near the top of the upper bed. In the lower bed, chordal maldistribution was also observed. Liquid entrainment was seen above both the reflux and feed distributors.

CONCLUSION

The temperature surveys and gamma scans revealed severe maldistribution in the top bed with vapor flowing in the central regions and liquid in the peripheral regions. Both also showed severe spraying of liquid from the reflux distributor all the way to near the tower tangent line. There were no indications of flooding nor of damage. The investigation identified the maldistribution of feed and reflux as the major root causes for the poor performance. Part 2 of this paper describes the use of simulation and hydraulic analysis to define the root cause of the maldistribution and upset condition and the solution to this problem.

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