Crude column revamp using radial temperature profiles

Designers need to be aware of all the factors influencing packed bed performance such as feed zone mixing problems. Accurate assessment of temperature variations above and below fractionation zones can pinpoint efficiency problems.

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Tools for troubleshooting distillation columns include sophisticated techniques such as computation fluid dynamics (CFD) and gamma scans, as well as the more fundamental measurements of temperature and pressure. The temperature variation around the circumference of a distillation column is a powerful diagnostic tool, able to infer composition gradient at a given elevation.

Variations in composition and temperature are consequences of problems with internal liquid or vapour stream distribution, poor mixing of external and internal streams at feed locations, or inadequate circulating reflux (pumparound) stream distribution causing uneven cross-sectional area condensation in heat-removal zones. While none of these can be directly measured, they can be inferred from radial temperature measurements at the same elevation in a packed column. This technique was used to facilitate the revamp scope definition of a large atmospheric crude tower at a Petrobras refinery.

Measuring fractionation performance

Packed column composition and temperature gradients at the same elevation degrade fractionation between products and reduce product yield. Since refiners typically use the gap or overlap between the 95% and 5% distillation temperatures on heavy oil columns as a measure of fractionating performance between adjacent streams, this value varies as fractionation performance changes.

In one case, a refiner changed from trays in their FCC main column to structured packing, with the expectation that the gap between gasoline and LCO products would improve from 24 to 33°C. However, it actually decreased to 0°C because of poor initial liquid distribution into the packed bed. So the apparent fractionation with over 6m of apparent fractionation with over 6m of structured packing was less than one theoretical stage. In another FCC example, half the spray nozzles above a packed LCO pumparound zone plugged, causing the temperature leaving the bed to vary by over 75°C. Even though the liquid distribution quality was very good into the gasoline/LCO fractionation bed, 5m of structured packing appeared to have only two theoretical stages. Vapour composition and temperature entering the bed were not uniform, so the fractionation suffered.

Packed column principles

Ideally, each cross-sectional area of a packed bed should have uniform liquid (L) and vapour (V) composition and rate entering it, otherwise parts of the bed will have different L/V ratios and compositions. L/V ratio, vapour composition entering the bed, and packed bed height drive fractionation. In one instance, poor distributor design caused parts of the bed to be nearly dry. Hence, the vapour composition entering the bottom of the bed and leaving was nearly identical in the cross-sections where the liquid rates were low. Poor fractionation, as measured by 95%/5% distillation temperature differences between adjacent products, resulted.

Packed columns use liquid distributors, collector trays and vapour horns for the initial distribution of liquid and vapour streams, respectively. In addition, collector trays mix the liquid leaving a packed bed prior to redistributing so that composition and temperature gradients are not propagated throughout the column. Packing’s inherent distribution quality will create some liquid maldistribution, even if the initial vapour and liquid distribution to the bed is perfect. So some radial temperature and composition gradient always exist above and below a packed bed. However, the designers need to be aware of all factors influencing packed bed performance and design the equipment to minimise the effects. Packing itself or typical collector trays will not correct poor initial liquid or vapour distribution, or composition gradient.

Temperature gradient - composition gradient

Figure 1 shows the measured temperatures in an atmospheric crude column after start-up. The revamp replaced standard trays with structured
Vapour was 357°C. The vapour was 374°C, and stripped hydrocarbon stream was 163°C, heater outlet stream two nozzles. Flashed crude overhead flash drum and hot heater outlet generated. In this case, two feeds, cold Otherwise, composition gradients are external and internal streams.

Meet the design basis expectations. Fractionation and product yields did not quality were very good, yet the apparent this case, vapour and liquid distribution essential to identify the root cause. In the design phase, the quenching effect of the cold flash drum stream on flash zone vapour rate was anticipated, although the magnitude was not. Flash drum vapour was routed to the flash zone because it occasionally was black prior to the revamp. Since the revamp increased the feed rate, the flash drum overhead vapour contained a significant amount of liquid carry-over due to foaming in the flash drum. Entrained liquid from the flash drum reduced AGO product yield by 2% on whole crude. When the cold flash drum overhead liquid and vapour entered the flash zone, a significant portion of the vapour from the heater was condensed to provide the heat needed to raise the flash drum vapour and liquid temperature.

Distillate product yield was low, because the flash drum foam layer was not contained inside the drum. Liquid and vapour from the flash drum and the charge heater outlet streams were not well mixed in the flash zone, therefore temperature and composition gradients were created across the cross-sectional area of the flash zone. These gradients were propagated through three packed beds. At each elevation, temperature indicators 180 degrees apart varied by approximately 28°C. Thus, the liquid and vapour compositions were not uniform. This example shows that packing and well-designed collector trays do not correct feed zone mixing problems. The designer needs to ensure that composition and temperature gradients are not created, because they are not easily corrected by packed column internals.

**Radial skin temperature profile**
Vessel skin temperatures, although slightly lower than column internal temperatures, can be used to infer temperatures in the column. The variations between temperatures inside the column and on the vessel shell are less than 10°C. Assuming ideal conditions, the temperature leaving a crude column’s packed kerosene/light diesel fractionation section would be the same around the circumference of the column. However, liquid and vapour distribution, and vapour composition entering the packed bed must be uniform across the column cross-sectional area for this to happen.

**Case study**
Petrobras operates a large crude unit at its Landulpho Alves refinery (RLAM) near Salvador in Bahia state, Brazil. The atmospheric crude column was designed in the late 1980s, with first-generation internals, including orifice pan distributors, pipe orifice headers and random packing. In 2001, Petrobras began a study to evaluate options to increase unit capacity, but it also needed to identify the underlying problems that reduced kerosene product yield. Figure 2 shows the crude column with six packed beds.

The kerosene/light diesel fractionation section is located just above the transition zone, where the column swedges from 7 to 6.1m. Liquid overflowing the kerosene product collector tray feeds an orifice pan distributor above a 3.8m-deep bed of 50mm-diameter random packing. Below the fractionation section is a pipe orifice header to distribute intermediate circulating reflux to a 4.8m-deep bed of random packing where approximately 16MKcal/hr of heat is removed. During the troubleshooting effort, this section of the column was studied in detail (Figure 3). A test run with complete heat and material balance data gathering, pressure survey and a radial temperature survey above and below the kerosene/light diesel fractionation bed were done to establish base line unit performance. Kerosene product distillation tail was 15°C and the overlap (5/95) between kerosene/light diesel was 30°C during the test run, both indicative of fractionation problems.

**Temperature survey**
Radial temperature surveys were done at an elevation just below the liquid distributor feeding the fractionation section and below the fractionating bed.
Radial temperature surveys to evaluate packing and generate internal liquid and vapour heat and material balance data was used to determine if other design issues would need to be addressed. In this case, the column’s fractionation beds distributors were all gravity-flow orifice pans with holes located on the bottom of the pan between the vapour risers. The intermediate circulating reflux (pumparound) was distributed with a pipe orifice header using a large main line and many smaller laterals with thousands of 13mm holes drilled in the bottom of the pipe. The orifice pan distributors were designed with holes distributed so that initial liquid distribution quality was reasonably uniform. The height of liquid on the distributors depends on the flow rate, total distributor hole area and vapour velocity through the risers. Since no liquid distributor can be installed perfectly level, good design practice maintains approximately 50mm liquid level on the pan at minimum flow to ensure reasonable distribution. Vapour risers need to have sufficient height to keep the liquid from overflowing. Riser height for the kerosene/light diesel liquid distributor was 370mm. Therefore, once the height of liquid reached this level, it would begin to overflow the risers. Furthermore, orifice pans filled with liquid deflect; hence, the riser with the lowest elevation will be the first to overflow. The overflow is not uniform down all risers.

Column heat and material balance modelling calculated 428m³/hr of liquid flowing from the collector tray to the orifice pan distributor above the kerosene/light diesel fractionation section. Yet, the design maximum flow was only 179m³/hr. Liquid height would need to be 1100mm based on the distributor holes area, yet the risers were only 370mm tall. Thus, one cause of the high temperature variation was poor initial liquid distribution. Due to the large temperature variation below the bed it was also likely the pipe distributor was not uniformly distributing liquid. A review of the distributor design showed the pipe total orifice area was approximately 50% of the mainline header pipe cross-sectional area. This design will not adequately distribute the liquid across a 7m column. In the heat transfer zone, if liquid distribution is not uniform, heat removal varies across the column cross-sectional area, resulting in temperature and composition variations.

Distributors above both the fractionation section and the intermediate circulating reflux section need to be replaced to improve fractionation. While the newer, more sophisticated techniques such as CFD and gamma scanning are becoming more popular, radial temperature profiles were able to identify the root cause of poor fractionation in this column.