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Crude Vacuum Tower Wash Bed Optimization

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The crude unit of today's modern refinery is where it all starts. Good, clean fractionation from the crude atmospheric and crude vacuum towers greatly impacts the operation of downstream units.
The wash bed in the Crude vacuum tower is one of those so-called evil necessities. When it operates well, it does not seem to garner much attention but, when things go wrong challenges can occur. The wash bed of the Crude vacuum tower is prone to coking/fouling due to the low liquid rates along with high vapor rates and high temperatures. Generally, the wetting rate at the top of the wash bed is minimized to prevent high-value product loss, but lower wetting rates lead directly to coke formation in the bed. The operating condition or the rate and severity of coking in the Crude vacuum tower wash bed is one of the key variables determining the cycle time or run length between turnarounds. So, the typical refiner works to balance the economics of product Heavy Vacuum Gas Oil (HVGO) recovery versus unscheduled or premature downtime to replace a coked bed. This case study shows the learning process over short operating cycles and an example of the operating stratagem to manage the operating life of the vacuum column wash bed over a multi-year operating cycle.

1. Introduction

Marathon Petroleum Company LP's (MPC) approach for operation of the vacuum tower wash bed is a novel approach. MPC regards the packing in the wash bed as a consumable item. The goal – fully consume the useful life of the packing by the end of the operating cycle to maximize operating profit by maximizing HVGO yield. MPC's objective is to manage the vacuum tower operating conditions to complete the required cycle run without completely coking the wash bed but maximize HVGO yield. In fact, the ideal would be that the wash bed packing would reach the end of its useful life right at the end of the cycle run. The objective is not to save the packing from coking at all but to tolerate coking of the packing at a "controlled" rate over time as long as desired operating rates and HVGO quality can be maintained until the end of the cycle run.
MPC uses Tracerco's ThruVision™ technology to routinely monitor the wash bed density to help manage the wash bed useful life during the operating cycle. The ThruVision™ technology provides a detailed density map at a specific vertical elevation that can pinpoint specific areas of liquid maldistribution or solids/liquid build-up.

2. Operation Challenge

The challenge was two-fold: first, what operating variables could be manipulated to control the coking rate and second what could be used to monitor the coking rate in the packing?
Figure 1 shows the general process schematic for one of MPC's Crude vacuum towers. The wash bed consists of two sections of packing – layers of grid packing on the bottom and layers of conventional structured packing on top of the grid packing. This arrangement was thought to better sustain a longer cycle run length than a bed of all structured packing. The grid portion would wash most of the solids out of the vapor stream and provide enough heat transfer (cooling of the vapor feed) to minimize fouling and coking in the structured packing. It has been MPC's observation that despite the best intentions the structured packing still is prone to coking.

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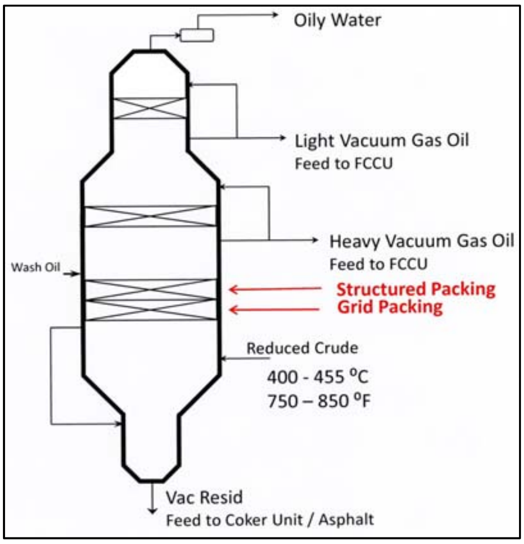

Figure 2 General Process Diagram of Crude Vacuum Tower

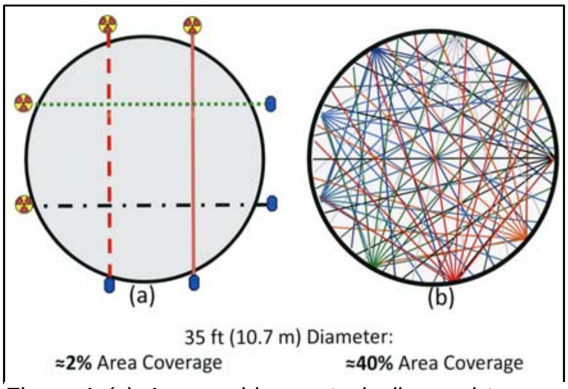

Figure 1 (a) 4-way grid scan typically used to scan entire height of tower for troubleshooting. (b) ThruVision™ tomography scan done at one elevation for detailed cross-sectional density profile.

In order to monitor the presence and rate of coking in the wash bed, gamma scanning was selected. Gamma scanning is a proven diagnostic technique used to troubleshoot the operation of separation towers.

The gamma scan process is all external and one key feature is that it is done with the tower in operation. Using a small radioactive source and a sensitive radiation detector on the outside of the tower, the scan data provides a density profile of the internal hydraulics at the current operating conditions.

To monitor the wash bed two scanning techniques are available. One method is the conventional vertical scan, typically called a grid scan as shown in Figure 2(a). The four scanlines measure the overall density through the packing through four quadrants. This method is best suited to look for internal damage, flooding, liquid maldistribution etc. but can be used to monitor the overall density of packed beds over time. A second method to use is a tomography (ThruVision™) scan, depicted in Figure 2(b). The advantage of the ThruVision™ scan is that it provides more thorough coverage of the column surface area but it is done at only one elevation while the grid scan covers the entire height of the tower. Both methods were used to monitor the vacuum tower wash bed but the ThruVision™ scan was best at monitoring the general increase in the wash bed density. MPC had experience where the bed started to coke so the elevation chosen for the ThruVision™ scans was near the bottom of the structured packing layer as shown in Figure 3.

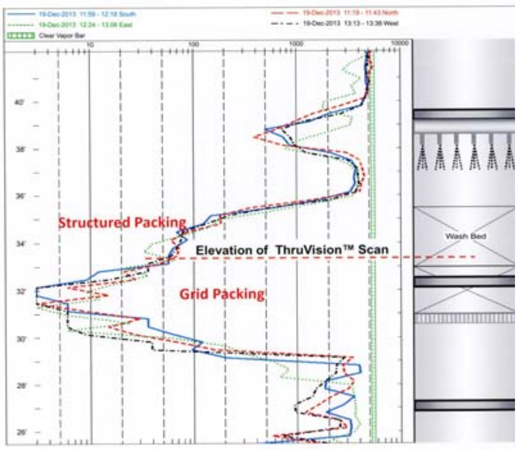

Figure 3 Baseline Tru-Grid™ scan results of Crude Vacuum tower. The four scan lines matched each other well indicating the same process density along each scan line suggesting good liquid distribution. One can see the shift in radiation counts, from right to left, due to the heavier bulk density of the grid packing.

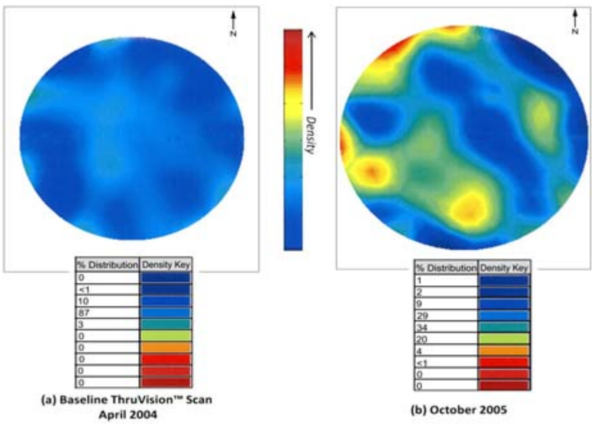

Figure 4 (a) Baseline ThruVision™ scan results of Crude vacuum tower Wash Bed. (b) ThruVision™ scan result at end of Cycle 1.

At the beginning of a cycle run a baseline grid scan and ThruVision™ scan were done. Figure 3 shows the results from the baseline grid scan and Figure 4a shows the initial ThruVision™ scan results. Thereafter the scans were repeated on a periodic basis, approximately every three months. The vacuum tower wash bed was operated very aggressively during the first cycle – minimum wash oil to maximize HVGO yield. This was purposely done to set parameters for aggressive operation. The first section of the graph in Figure 5 shows the average wash bed densities calculated from the ThruVision™ scan data for Cycle 1. Figure 4b shows the ThruVision™ scan from the end of this cycle run. Over the 2-year period there was a 40% increase in packing density due to coke buildup and/or excess liquid retention. After the two-year period there was an opportunity shutdown due to a problem unrelated to the coking. Subsequent shutdown and inspection showed the packing severely fouled with coke and the packing was replaced.
The next cycle run was purposely operated with less aggressive operation, higher wash oil rates to retard the rate of coking. This cycle run also lasted approximately two years due to a forced shutdown from a hurricane striking the area of the refinery. As seen from the second section of Figure 5, over the two-year cycle run the average packing density increased by a little more than 20%. The shutdown provided an opportunity to open the vacuum tower and inspect the packing; only surface deposits of coke were observed. The packing was again replaced to start the next cycle run with fresh, clean packing.

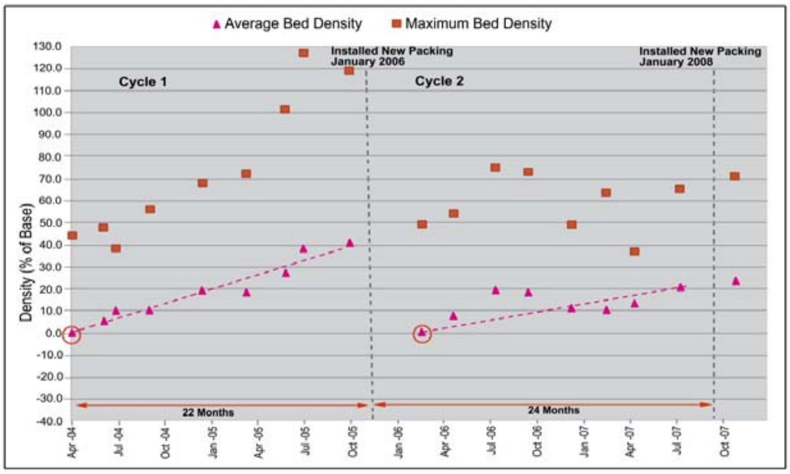

Figure 5 Cycle 1 wash bed densities when Vacuum column operated aggressively. Cycle 2 wash bed densities when Vacuum column operated more conservatively.

3. Data Analysis

Cycles 1 and 2 established boundaries for operating parameters between very aggressive operation and conservative operation. Several operating parameters were compared to the average packing density from the ThruVision™ scans to correlate the best operating parameter with the rate of coking. Figures 6 – 8 show this operating data versus the average bed density. There appeared to be no correlation between charge rate, flash zone temperature or flash zone pressure with the change in average bed density (reflecting the rate of coking). There appeared to be only a weak correlation between wash oil or slop wax rate with the change in average bed density. By far the best correlation came between the true over-flash rates versus the change in average bed density as shown in Figure 8. Therefore, for the next cycle run the true over-flash rate was going to be manipulated in order to try and regulate the coking rate.
The third cycle run lasted almost six years. This cycle run can be divided into three segments due to the operating demand placed on the refinery. The operating conditions for the first segment were based on the need for the Introduction vacuum tower wash bed to operate for five years without coking prematurely. Operations operated the wash bed with slightly less over-flash than during Cycle 2 in order to gain a higher HVGO yield yet still have some confidence that the wash bed would not coke prematurely.
In late 2010, management decided to lengthen the cycle time beyond the original five years. Therefore, the over-flash rate was dramatically increased in order to retard the coking rate at the expense of some HVGO yield. Then in mid-2012, management advanced the planned end of the cycle run. At that time, operations reduced the over-flash rate to increase HVGO yield. Knowing the wash bed packing was going to be replaced allowed Operations to tolerate an increased coking rate. However, to have a little cushion the decision was made to not be as aggressive as was done during Cycle 1.

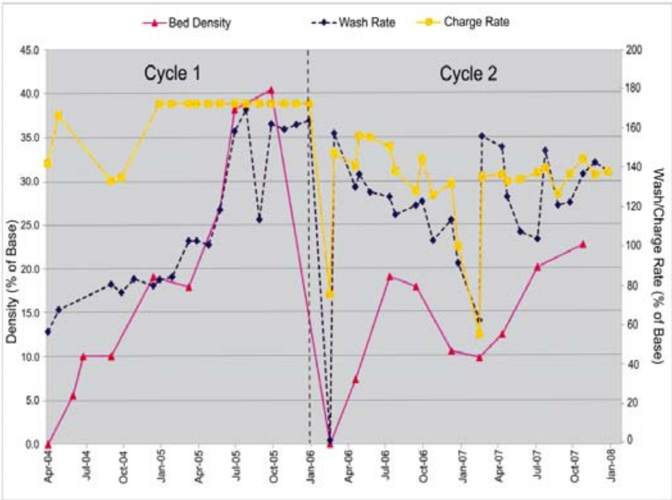

Figure 6 Trend of wash bed packing density versus wash rate and charge rate.

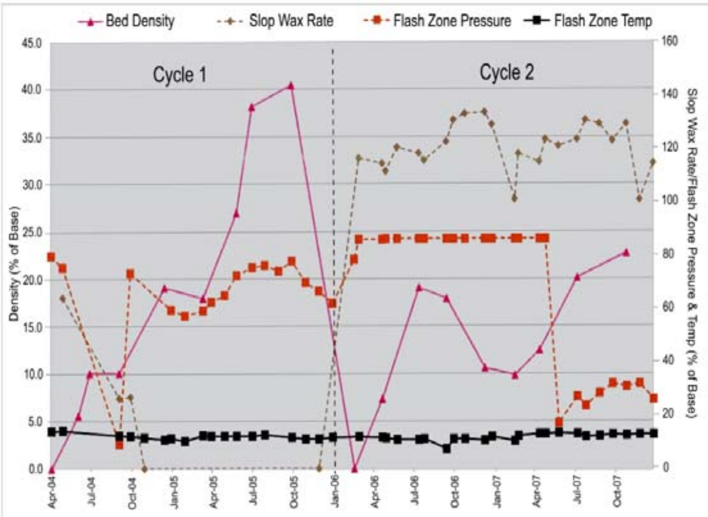

Figure 7 Trend of wash bed packing density versus slop wax rate, flash zone pressure and flash zone temperature

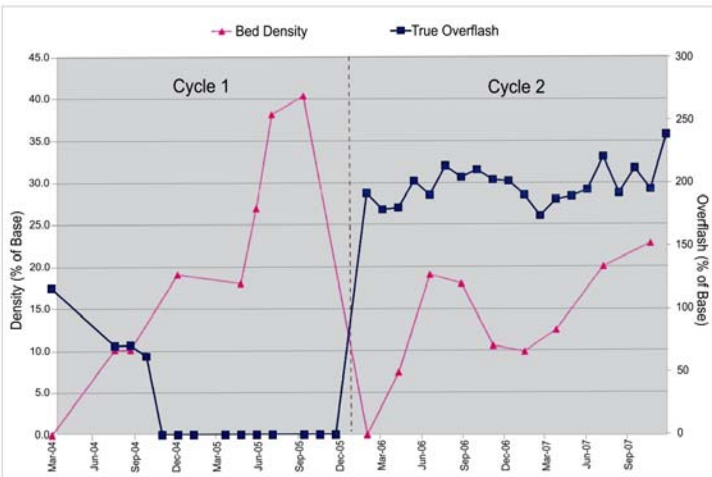

Figure 8 Trend of wash bed packing density versus true overflash

Figure 9 shows the over-flash rate versus the packing density during this entire 69-month cycle run. Also shown on Figure 9 is the slope of the overall increase in the average packing density over the time period for each operating stratagem. At the beginning of the cycle the rate of coke buildup was represented by a slope of 0.84, the most aggressive operating period. When the decision was made to lengthen the run time operation became more conservative with a higher over-flash rate and the slope reduced to 0.2. Later in the cycle when the cycle end date was advanced, operation became more aggressive, reducing the over-flash rate and getting a coke buildup rate of 0.54, in between the very aggressive and very conservative modes of operation. By the end of the cycle the average Wash Bed density was of the same order of magnitude as the very aggressive and short run of Cycle 1. Subsequent inspection of the wash bed packing during the turnaround showed the packing was not quite as severely fouled or coked showing a bit more runtime was left. But, operations were pleased that they had successfully managed the coking rate while maximizing HVGO yield through changing operating demands over the course of the cycle.

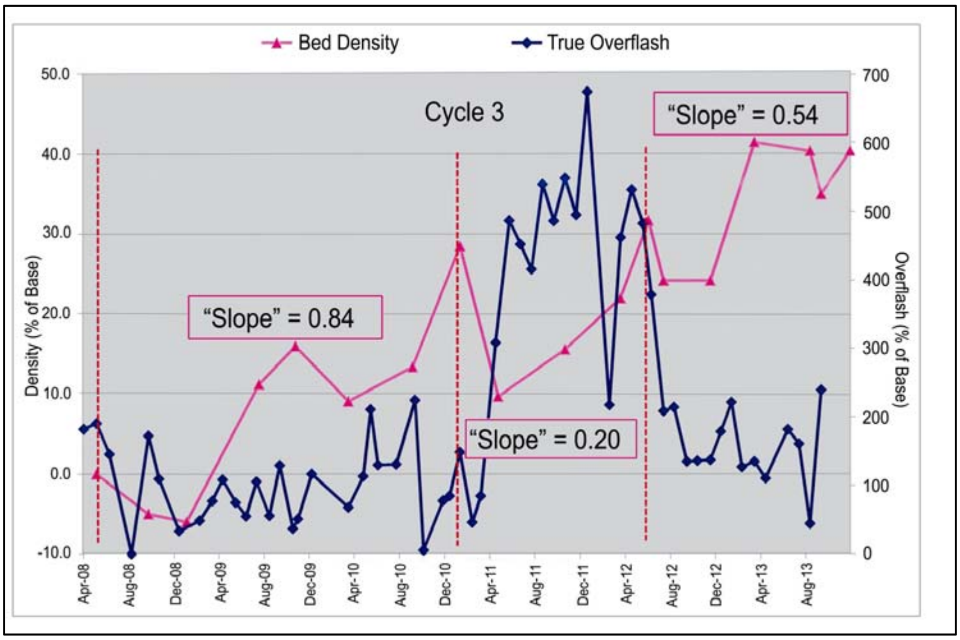

Figure 9 Trend of wash bed packing density versus true overflash over the 69 month run of Cycle 3

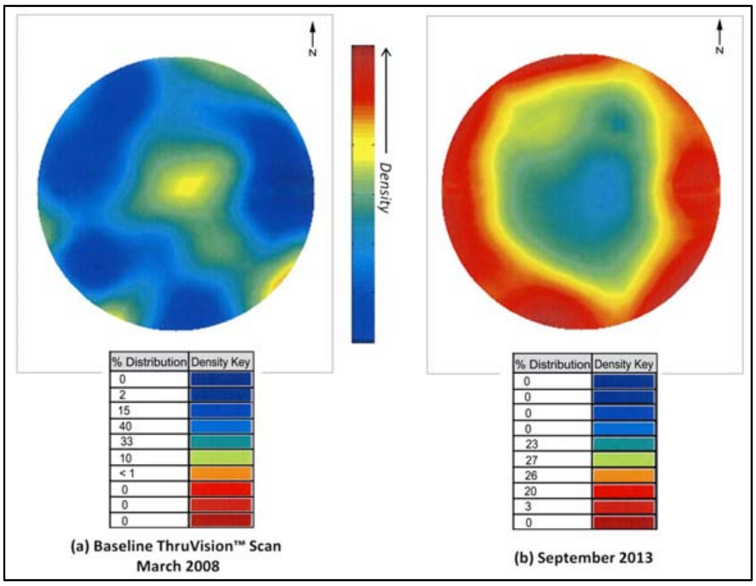

Figure 10 (a) Baseline ThruVision™ scan results of crude vacuum tower wash bed at beginning of Cycle 3. (b) ThruVision™ scan result at end of Cycle 3. Note increase in packing density both from change in color palette and from density range distribution.

ThruVision™ scans were used to monitor and determine the average wash bed packing density through the cycle run. While the primary purpose for doing a ThruVision™ scan is to study liquid distribution through a bed, the primary use for this application was to track the bed density to monitor the buildup of coke or the retention of liquid in the packing due to coke fouling. Figure 10 shows the baseline density profile and the cycle ending density profile. Note how the density range shifted over the cycle. We suspect that the bed densities through the core of the column were actually understated due to the high overall density not allowing the scan source to penetrate all the way through the middle of the bed.
Figure 11 is an alternative was to graphically present the density data from Figure 10 highlighting the overall increase in magnitude and span of density values in the wash bed over the operating cycle.

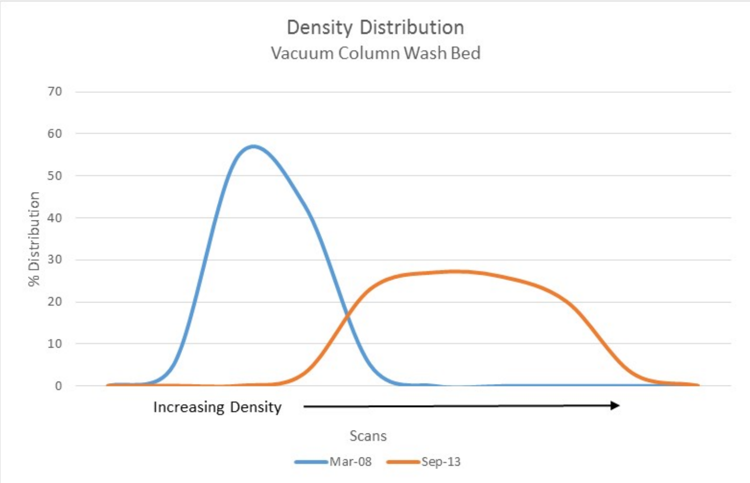

Figure 11 Density Distribution- highlighting the overall increase in magnitude and span of density values in the wash bed over the operating cycle.

4. Conclusions

Marathon Petroleum Company manages crude vacuum tower operating conditions to maximize HVGO yield through a complete cycle run. ThruVision™ technology provides a detailed density map yielding extensive cross-sectional coverage to monitor fouling/coking in packed beds. The operating stratagem of using Tracerco's ThruVision™ technology to routinely monitor the crude vacuum tower wash bed density for increases in density signifying coke buildup and adjusting the column operating true overflash rate is used to control the rate of coking, maximizing profit from HVGO yield and regarding the wash bed packing as a consumable expense.

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