Revamping atmospheric crude heaters

The revamp of an atmospheric crude unit heater, which was suffering from coking caused by asphaltene precipitation and poor burner stability, resulted in a significantly increased heater run length

Michael Whatley *Navajo Refining Company*
Scott Golden and Jason Nigg *Process Consulting Services Inc*

Refinery atmospheric crude heaters can experience rapid increases in tube metal temperature (TMT), requiring unplanned shutdowns for decoking. In the case of the Navajo Refining Company facility in Artesia, New Mexico, USA, rapid increases in the atmospheric crude heater's TMT resulted in a shutdown every three to six months. In this case, as well as others observed in the industry, coke formation was initiated by asphaltene precipitation from unstable crudes.

Industry-wide, atmospheric crude heater coking is an unusual problem, with some heaters operating reliably at an average radiant section heat flux of 13–14 000 Btu/hr-ft^2 or higher. However, some crude oils, including those produced from North American fields in West Texas, New Mexico, Ohio/Pennsylvania and Alberta are known to be unstable when there is asphaltene precipitation in certain areas of the crude unit. The equipment in these areas includes preheat exchangers, fired heaters and atmospheric column flash zone and stripping section internals.

Atmospheric crude heater coking

The Artesia refinery was experiencing chronic coking in its atmospheric column heater, with periodic shutdowns to remove coke at intervals as short as 90 days. Figure 1 shows the process flow scheme with the heater located downstream from the prefractionator column. Flashed crude is charged to the atmospheric crude heater, which feeds the atmospheric crude column. The heater was a vertical-tube hexagonal-shaped four-pass design with 12 burners. Prior to the revamp, the radiant section's average heat flux rate was only 9400 Btu/hr-ft^2 with an oil outlet temperature of just 635°F. Furthermore, the heater had oil mass flux rates of 250 lb/sec-ft^2 and relatively poor flame stability. This, in combination with poor asphaltene stability, caused a very short heater run length even though the heater was operating at relatively mild conditions. Some atmospheric crude heaters operate at an average radiant section heat flux of 13–14 000 Btu/hr-ft^2 and oil outlet temperatures of 730°F or higher, while meeting four- to five-year run lengths.

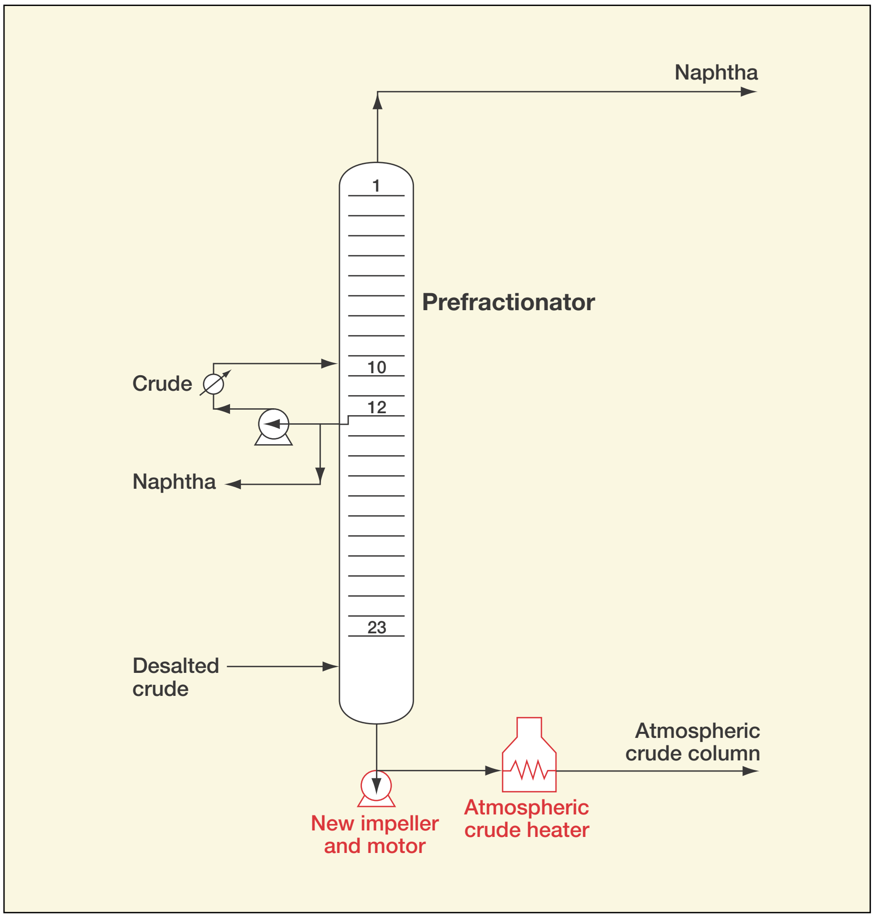

Figure 1 *Process flow diagram*

Heater coking

Coke forms because conditions in the shock or radiant tubes cause the oil to thermally decompose to coke and gas. The TMT increases as coke lays down on the inside of the tube. With rising TMTs, heater firing must decrease or the TMTs will progressively escalate until their limit is reached. The heater must then be shut down to remove the coke. Rapid coke formation is caused by a combination of high oil film temperature, long oil residence time and inherent oil stability. In the majority of cases where atmospheric heater coking occurs, the root cause is high average heat flux, high localised heat flux or flame impingement.

Oil stability

Oil thermal stability depends on crude type. For example, some Canadian and Venezuelan crude oils have poor thermal stability and begin to generate gas at heater outlet temperatures as low as 680°F. At outlet temperatures much above 700°F, these same crudes begin to

***Figure 2** Fouled exchanger tubes — asphaltene precipitation*

deposit sufficient amounts of coke to reduce heater runs to two years or less. Another form of oil instability is asphaltene precipitation. As the oil is heated, the asphaltenes become less soluble, depositing in low-velocity areas, fouling crude preheat exchangers, heater tubes or atmospheric column internals. In some cases, the asphaltenes do not drop out until they reach the bottom of the atmospheric column or inside the vacuum heater. With some Canadian crude oils, especially the bitumen-based oil sands crudes, asphaltene precipitation occurs inside the vacuum heater tubes rather than in the atmospheric heater. The same heater design parameters that improve atmospheric heater performance also increase vacuum heater run length.

When asphaltenes separate from the crude oil, the material deposits inside the tubes. This increases heat-transfer resistance, raising asphaltene temperature and TMTs. Furthermore, when asphaltene deposits are widespread in the convection or radiant sections, heater firing must increase to meet the targeted heater outlet temperature. This leads to a higher localised heat flux, further raising the temperature of the asphaltenes deposited on the inside of the tubes. The temperature of these asphaltenes eventually exceeds their thermal stability, resulting in coke formation and even higher TMTs, because the coke layer has lower thermal conductivity than asphaltenes. Heater TMTs eventually exceed metallurgical limits, requiring a heater shutdown to remove the coke. In this example, heater run lengths were as low as 90 days between piggings.

Asphaltene precipitation

Crude stability is a function of its source and highly variable. However, the designer can influence the process and equipment design to minimise the effect of poor asphaltene stability. In some cases, the material deposits inside the exchangers, piping, heater tubes or fractionation column. The lower the velocity, the more likely it is that asphaltenes will precipitate. In this example, the oil velocity inside the heater tubes was only 5.5–6 ft/s prior to the oil vapourising, which corresponds to a 250 lb/sec-ft^2 oil mass flux. At these velocities, whether in an exchanger or heater tube, asphaltenes will likely drop out. Heat exchanger data gathered from hundreds of operating exchangers shows the rate of fouling and the ultimate fouling factor are to a large extent determined by the velocity of the crude flowing through the tubes (assuming no shell-side design problems).

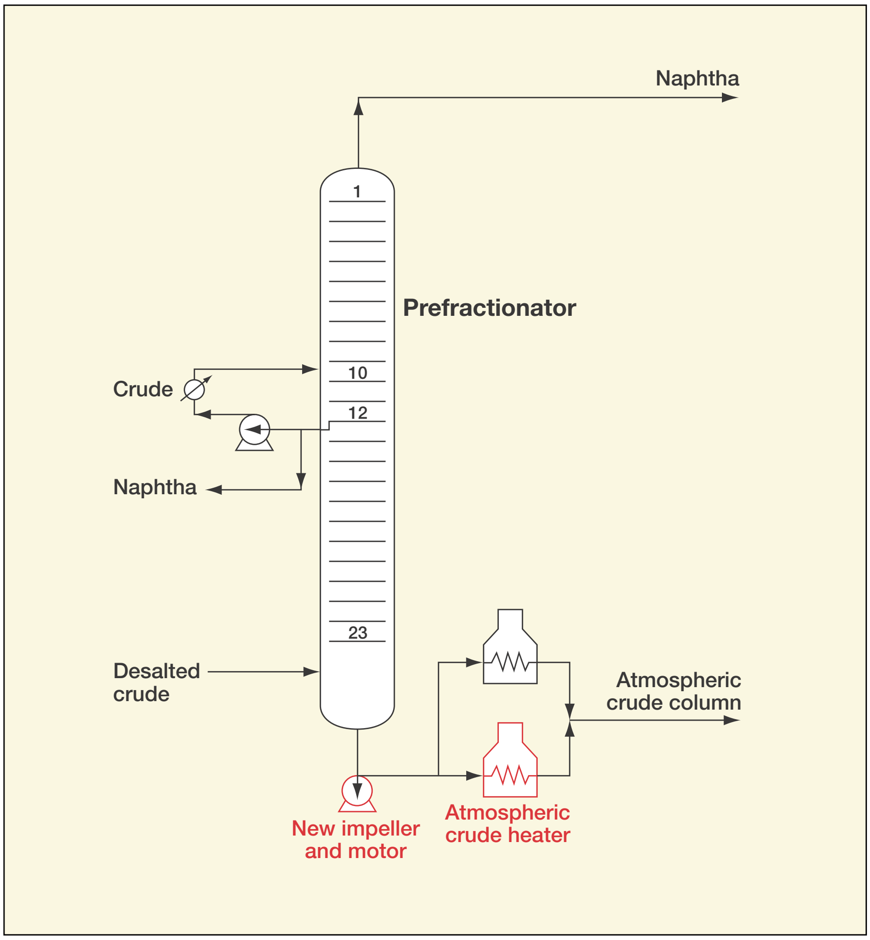

***Figure 3** Increased system pressure drop*

Asphaltene precipitation in crude preheat exchanger tubes is common. Figure 2 shows asphaltene precipitation inside the channel head and tubes in a unit processing West Texas crudes. In this case, the oil velocity inside the tubes was less than 5 ft/s and severe fouling occurred. Exchangers operating at higher velocities in the same unit had less fouling. Moreover, the atmospheric heater downstream of the fouled exchanger had short heater runs, with TMTs increasing at 1°F/day. This rate of TMT rise is similar to a delayed coker heater. Crudes with poor asphaltene stability are especially difficult to process and the equipment must be carefully designed.

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Maintaining a high velocity in the equipment minimises asphaltene precipitation. Crude preheat exchangers and heater tubes should be designed for oil velocities of 8–10 ft/s or higher. Experience shows significant improvements in crude preheat and heater reliability when velocities are high. Since many designers set the maximum allowable pressure drop through exchangers and the heater as design criteria, low velocities are often the result of meeting pressure drop specifications. Crude preheat exchangers and fired heater designs should be based on a higher velocity, with the pressure drop simply a result of the design.

Heater revamp

In late 2005, Navajo revamped its existing atmospheric heater and installed a new parallel "helper" heater. The helper heater was needed because the existing heater burner spacing was increased and the number of burners decreased for improved flame stability with Ultra-Low NO_X Burners (ULNB), resulting in lower design heater firing. Yet, installing the parallel heater without revamping the existing heater would have decreased oil velocity to less than 4 ft/s in the existing heater. Moreover, Navajo wanted to increase the atmospheric heater outlet temperature from 635–670°F to unload the downstream columns because they limited the crude charge rate. Since the root cause of heater coking was asphaltene precipitation inside the heater, reducing heater firing alone would not have improved the heater run length. Furthermore, designing the new parallel heater for similar tube velocities as the existing heater would have created a second reliability problem.

The revamped heater included a new convection section, completely retubed radiant section, new ULNB burners and floor. Prior to the revamp, heater performance showed the convection section was not performing well, radiant section tubes were fouled and the burners had poor flame stability. Poor convection performance was caused primarily by fin damage. Radiant section fouling was caused by asphaltene precipitation and poor burner stability resulting from the burners being too close together, causing adverse flame interaction.

Total fired heater "absorbed duty" is the sum of the convection and radiant section duties. Maximising the convection section duty minimises the radiant duty, which lowers the oil film temperature, reducing the rate of coking. In this example, the convection section was replaced with a similar design, except some of the tube fins were upgraded from carbon steel to 11–13 Cr to avoid damage from high temperature and to maintain performance throughout the run. The radiant section was completely retubed with smaller-diameter tubes. Bulk oil velocities were increased from 5.6–6 ft/s to almost 10 ft/s, which resulted in an oil mass velocity of 460 lb/sec-ft^2. The revamped heater mass velocity is over twice the rule-of-thumb (ROT) values of 150–200 lb/sec-ft^2 that have been used to design atmospheric crude heaters. The smaller tube diameter dramatically increased the pressure drop, requiring a larger pump impeller and motor in the flashed crude pumps (Figure 3). It is not uncommon for process design engineers to specify the pump design before the heater is designed because they assign a maximum allowable pressure drop to the heater. This approach expedites design but causes heater reliability problems once it is built.

Prior to the revamp, the burners had poor flame stability. The heater had 12 burners that were spaced too close together (Figure 4). A completely new floor was installed with six larger burners, which eliminated flame interaction, producing a stable flame (Figure 5). These burners were latest-generation ULNB burners.

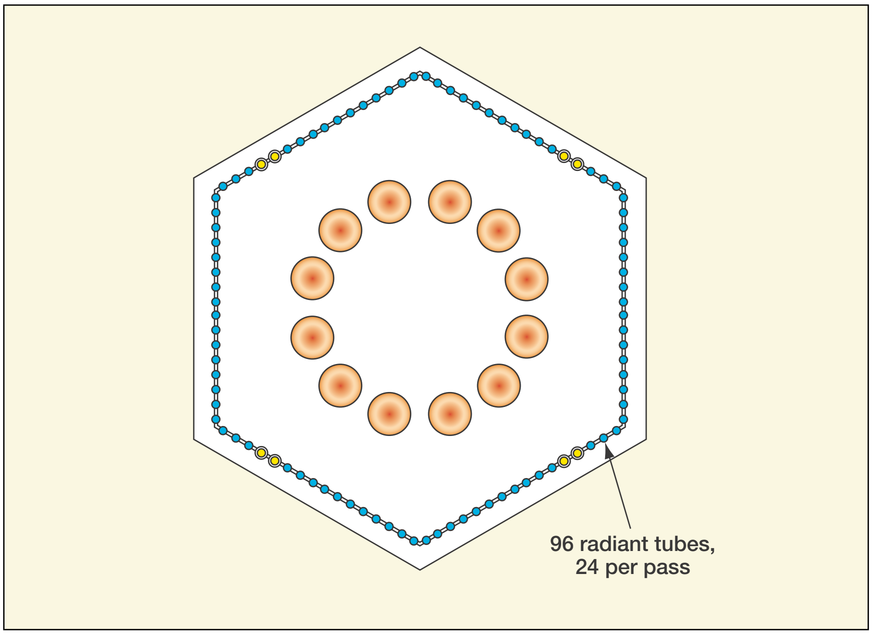

Figure 4 *Burner floor before revamp*

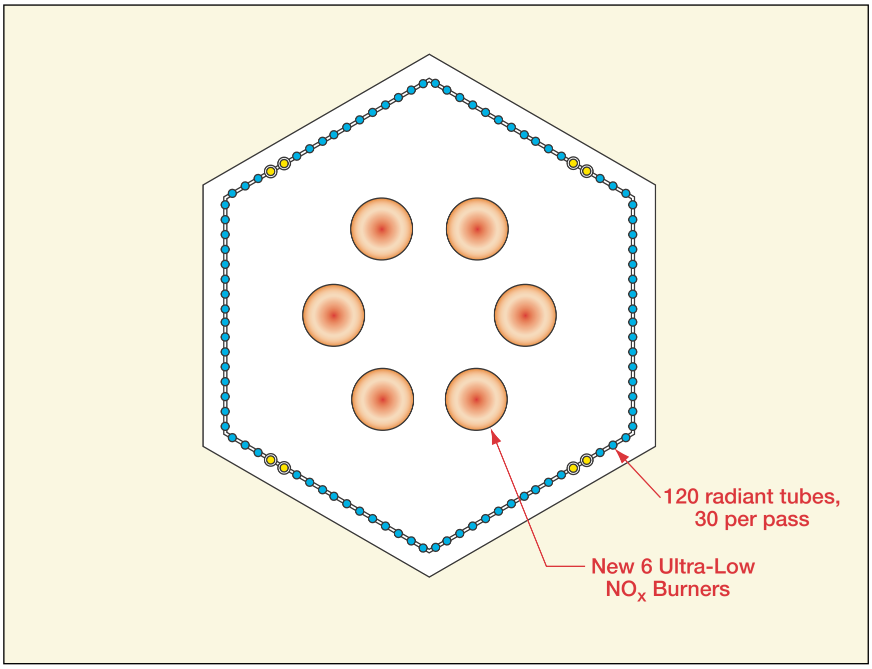

Figure 5 *Burner floor after revamp*

Revamp results

The revamped heater and new helper heater have been operating for 18 months without a shutdown. Crude charge has been increased by 14% and the heater outlet temperature has risen from 635–670°F, with the revamped heater operating at approximately 103% of the pre-revamp firing rate or 9700 btu/hr-ft^2 average radiant section heat flux. The heaters have not been pigged and the TMTs have shown very little rise since startup.

Michael Whatley *is engineering manager for the Navajo Refining Company refinery in Artesia, New Mexico, USA.*

Scott Golden *is a chemical engineer with Process Consulting Services Inc, Houston, Texas, USA. He earned a BS degree in chemical engineering from the University of Maine and is a registered professional engineer in the state of Texas.*
Email: sgolden@revamps.com

Jason Nigg *is a chemical engineer with Process Consulting Services Inc, Houston, Texas, USA. Nigg earned a BS degree in chemical engineering from Kansas State University. Email: jnigg@revamps.com*