Designing the CDU/VDU for opportunity crudes

New units for processing heavy crudes should not be designed using conventional practices or run length will be short, and product yields and quality poor

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Opportunity crudes cost less than other crudes because they are more difficult to refine into gasoline and middle distillate. Yet there is a perception that profitability will improve simply by substituting them for more expensive feedstocks. At times, certain crudes sell at huge discounts. This may be when production exceeds the industry's ability to process them, whether it is for short periods that are caused by unplanned shutdowns or longer periods when regional logistics arise such as distribution constraints for Canadian bitumen. Refiners tend to focus on conversion units such as the coker or hydrocracker, and the crude and vacuum unit (CDU/VDU) is often an afterthought. As more heavy and extra-heavy crudes enter the market, there will be more opportunity for refiners to run them. The question is whether it will be profitable or not. Will lessons learned be incorporated into unit designs or will refiners learn only through the school of hard knocks? CDU/VDUs must be designed or revamped for opportunity crudes or there will be unscheduled shutdowns, poor product yield and quality, and maintenance costs much higher than anticipated.

Processing opportunity crudes in high blend percentages reliably is different from running common heavy crudes such as Arab Heavy. Common problems encountered when processing extra-heavy opportunity crudes include poor desalting, which often results in severe atmospheric crude overhead system corrosion, including exchangers, piping and vessels. These crudes are viscous, contain solids, can have amines, can precipitate asphaltenes when blended with other crudes, and have a high fouling tendency in heat exchangers (see Figure 1), column internals and fired heaters. Some have a very high naphthenic acid content, causing desalter problems and corrosion requiring upgraded metallurgy. Other problems include heater coking and asphaltene precipitation inside heater tubes, which leads to short run lengths. When processing some Northern Alberta bitumens, the vacuum heater outlet temperature must be operated as low as 705°F (374°C) to avoid short run lengths even with well-designed double-fired tube designs. Asphaltene precipitation in the bottom of the atmospheric column can lead to stripping tray plugging, causing run lengths of less than a year. These are just a few of the obstacles experienced by upgraders and refiners processing heavy opportunity crude oils. These are the unfortunate realities, but it is better to design the unit for them than to suffer the consequences that many refiners continue to experience. As producers of opportunity crudes such as Canadian dilbit continue to ramp up production, refiners increasingly are suffering because they either ignored the realities of processing these crudes or were unfamiliar with them.

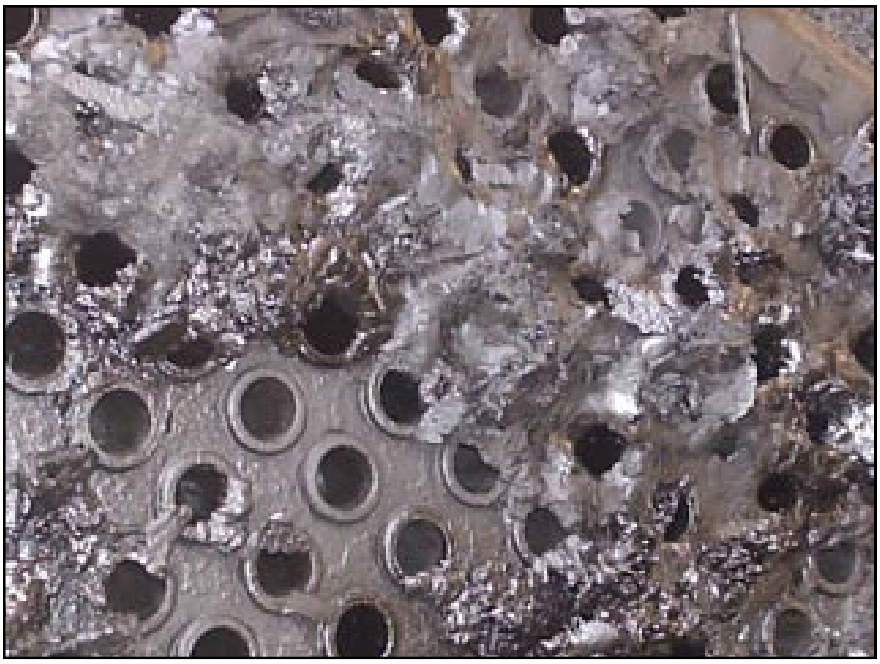

Figure 1 Fouled exchanger — asphaltene precipitation

Global opportunity crude supply

Historically, heavy and extra-heavy crude production has largely come from North and South America. Consequently, refining experience with these crudes is primarily in Canada, the US and South America, and only a few US refiners process high blend percentages. Some producing nations' crude units have very poor reliability and performance, but these realities are hidden from the global market. As the global distribution of opportunity crudes improves and more fields come on stream, the world's refining system will gain experience.

Today, most European refineries process light and medium crudes, while Middle East refiners run their own crudes. They process very little opportunity crudes. Refineries in China are primarily designed to process local and Middle East crudes and have little or no experience with opportunity crudes at high blend percentages. While China is planning to build refineries to process them, their approach is to rely on their own institutes or global engineering and construction companies that have little experience designing CDU/VDUs for opportunity crudes. The experiences they do have and have applied resulted in very poor reliability and a low refinery liquid volume yield. Opportunity crudes are different and the CDU/VDUs must be designed for them. One only needs to query refiners with long-term experience of processing opportunity crudes to get a true picture of the processing costs. Short run lengths, low middle and vacuum gas oil (VGO) product yields and poor product quality are common.

Refining and upgrader capacity has to match production. Currently, most Venezuelan crude is processed by US refineries, and most, if not all, Canadian crudes are upgraded or refined in Canada or the US. Far East refiners, primarily India, are processing some Venezuelan crudes, but the blend percentages are not high. Whether Canadian or Venezuelan, these crudes are a mixture of bitumen and lighter blend stocks. PetroZuata and Hamaca consist of coker products and bitumen, whereas Merey is a blend of Orinoco bitumen and lighter crudes, albeit there may be other names under which these 15 °API gravity Orinoco bitumen blends are marketed. Much of the Canadian crudes are a blend of bitumen and condensate (naphtha) or synthetic crude from the upgraders. Conventional Canadian heavy crude production, such as Bow River, is rapidly declining, with more crudes containing bitumen from Cold Lake, Athabasca or Peace River basins. Some of these bitumens are much more challenging than others and refiners should not assume they are all created equal. They are not!

Figure 2 Deep-cut VGO vacuum unit producing diesel from the top draw

In the mid to late 1980s, US Gulf Coast refiners began processing large volumes of 21-24° API gravity crudes from Mexico and Venezuela. In the mid to late 1990s, 15-18° API blends became more prevalent and this trend continues. At least two US refiners process these crudes neat through a CDU/VDU. In all cases, the designer touted a 1050°F (565°C) VGO product cutpoint, but not one actually achieved it in spite of the rhetoric. Today, few refiners process 100% heavy crudes, with most blending them with higher-gravity crudes. Some refiners claiming they process heavy crudes have blend gravities of only 27-30° API gravity. Processing heavy and extra-heavy crudes neat or in high blend percentages is another story completely. After more than 25 years of industry experience processing these crudes, the economic losses associated with poor CDU/VDU performance are still huge. Low VGO cutpoint is the norm whether refiners admit it or not. In spite of the claims, when one peels back the curtain, the picture is not so good. Short run lengths, low middle distillate and VGO yields, as well as poor product quality are the norm.

Refining and upgrading experience with extra-heavy crude

Canadian bitumen upgraders, Venezuelan refineries and upgraders, as well as a handful of US refiners, pioneered heavy and extra-heavy crude processing. Only these refiners or upgraders have long-term experience of processing them. Today, CDU/VDUs must operate for four to six years, while maximising middle distillate recovery and minimising vacuum residue (VR) yield. Poor product recovery and quality dramatically reduce the economic benefits of lower crude costs. Avoiding unscheduled outages has been a chronic problem, reducing profitability. A 10-day shutdown to replace failed exchangers or piping, or a longer-term outage to fix fire damage caused by loss of containment, dramatically reduces profitability.

There are only a handful of long-term producers in Canada with experience of processing 100% Canadian bitumen over more than a decade. Over the years, they have made many changes to the process and equipment designs to run reliably. Only recently have US refineries started to process these crudes in high blend percentages and they are experiencing problems similar to those encountered by the refiners processing Venezuelan crudes in the mid 1980s to early 1990s.

Refiners make money producing gasoline and middle distillates; coke is a by-product often having a negative value. A common CDU/VDU design basis is a 1050°F (565°C)

Problems associated with opportunity crudes

- Poor exchanger design — low exchanger heat transfer coefficients
- Poor desalting caused by low temperature, small desalters, poor water system design, high pH water, too small transformers, stable rad layer formation, periodic carry-over, etc
- Failure to design for high crude water content
- Crude hydraulic limits caused by poor exchanger design, resulting in rapid fouling, wrong viscosities used, low pump efficiencies and head, etc
- Preflash drum foaming and carryover
- Much lower crude preheat, causing high crude heater firing
- Crude column fouling and corrosion in top section plugging trays, resulting in shutdown
- Fouling in crude column top pumparound exchangers
- Severe crude column top section vessel corrosion
- Stripping section asphaltenes precipitation fouling trays and limiting stripping steam
- Low atmospheric crude diesel product yield caused by low vapourisation
- Crude heater asphaltenes precipitation and heater tube coking, requiring shutdown to pig tubes
- Vacuum heater coking requiring shutdown to pig tubes
- Crude and vacuum heater transfer line corrosion
- Vacuum column wash zone coking (see Figure 3)
- Vacuum ejector system fouling and corrosion, causing poor vacuum and high column pressure
- Fouling top pumparound section of vacuum column with amine chlorides
- Low HVGO product draw temperature caused by low crude column distillate yield, resulting in vacuum column heat removal limit
- Low VGO yield
- High metals VGO
- VGO pumparound and product system corrosion
- High chloride content light vacuum gas oil (LVGO)

Table 1

VGO product cutpoint; however, the reality is that most achieve only 950°F (510°C) or lower. This represents an almost 10 vol% higher VR yield on whole crude and means VGO is fed to the coker instead of the FCC unit or hydrocracker. Coking the heavy portion of the VGO converts 15-20% into coke, with the remainder downgraded to lower-value product than the virgin VGO. Even though VGO produced from extra-heavy crude has higher contaminants and consumes hydrogen to make ULSD and high-quality FCC feed, the quality of the coked VGO products is even lower. Heavy and extra-heavy crudes contain large amounts of VGO compared with other crudes, and the economics associated with incremental VGO recovery are huge. When crudes cost $100/bbl, the profit loss of turning 1000 b/d of VGO into coke is more than $35 million/y. Proper vacuum unit design is essential to maximise VGO and diesel product yield (see Figure 2).

Poor diesel recovery and high diesel boiling range material in the VGO are other consequences of poor CDU/VDU design. Maximum diesel recovery requires production from the vacuum unit, yet most US refiners have not designed their units for diesel production. Many large engineering and construction companies continue to design CDU/VDUs without it, hence the atmospheric gas oil (AGO) and VGO products contain large volumes of diesel. It is not uncommon for the FCC or hydrocracker feed to contain 25-30 vol% diesel boiling range material.

Heavy crude oil properties

Heavy crude oil's properties make it difficult to reliably process through a conventional CDU/VDU. Essential CDU/VDU design properties are TBP distillation and API gravity curves, contaminants distribution (MCR, asphaltenes and metals), viscosity, salt content, total acid number (TAN), solids content, and tramp amine and other trace components. These properties dictate the design, and if they are ignored the unit will not work as expected. For example, many of these crudes contain amines due to either production water treatment or an H_2S scavenger used. If the desalted crude has a high salt content and the amines are not removed they will cause severe plugging and corrosion in the top of the crude column, requiring replacement of the vessel's shell with exotic metallurgy. This has happened in several instances.

As crude blend distillations get heavier, the VR content increases and they become difficult to vapourise in the atmospheric and vacuum units. Units designed with a high crude column AGO cutpoint or a vacuum preflash column make the vacuum column feed very heavy. A high crude heater outlet temperature lifts more diesel and VGO range material out of the vacuum column feed, making it more difficult to vapourise in the vacuum column. A heavier vacuum unit feed lowers the VGO product yield for a given vacuum column flash zone pressure and vacuum heater outlet temperature.

CDU/VDU processing difficulties

Table 1 identifies some of the specific problems that refiners face when processing heavy crude oil blends.

These are only a few of the difficulties experienced by refiners processing high percentages of these opportunity crudes.

Future heavy crude sources

Up to about 10 years ago, Venezuelan and Mexico crudes were the major sources of heavy and extra-heavy crudes. The US was the predominant market for it. Very little Canadian bitumen was processed in the US and none outside. Today, the production of Canadian extra-heavy bitumen-based crude is around 2 million b/d from the Athabasca, Peace River and Cold Lake regions. Much of the Northern Alberta production is upgraded in the Fort McMurray region by the long-term operators Suncor and Syncrude, with newer upgraders operating for only the last five years. Northern Alberta crudes are the most difficult to processes and, in the near future, increasing volumes will reach the US market as diluted bitumen or synbit. Currently, Southern Athabasca, Cold Lake and Peace River blends are being processed, but only a very few refiners run high percentages in their blends. And none currently have long-term experience of processing 100%

Figure 3 Severe wash zone coking

Canadian bitumen blends in the 18-20 °API gravity range.

Heavy Venezuelan crudes have been processed since the mid 1980s in high blend percentages by only a few US refiners. In nearly all cases, the CDU/VDUs did not meet design capacity, product yields or reliability. In some instances, none of these goals were achieved, with the units requiring major revamps just to meet their original design basis. Today, Venezuelan crudes are increasingly going to India and the Far East because they are seen as low-cost alternatives to Middle East and West African crudes. In most instances, the lessons learned in the US have not been incorporated in the CDU/VDU designs. Few major engineering and construction companies have designed units for Orinoco bitumen blends, and the ones that have often repeat the same mistakes on future designs because they rarely perform rigorous post start-up audits and almost never look at unit performance one to four years after start-up when reliability problems show up.

Conclusions

Lessons learned by US refiners processing heavy Venezuelan crudes and Canadian upgraders processing bitumen should be applied to new projects that will process increasing amounts of opportunity crudes. These units should not be designed with conventional practices used for light and medium crudes; otherwise, run length will be short, product yields and quality poor, and maintenance costs high. Opportunity crude properties are very different and design requirements will raise initial costs. These higher initial costs will pay out over the life of the project through an increased VGO product yield, lower maintenance costs, fewer VGO contaminants and a longer run length between decokings.

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