Heavy crude upgrading: Up- and downstream options

By Dr Faisal S. Al-Humaidan,
Petroleum Research Centre, KISR/Kuwait

Heavy crude oils and extra heavy crude oils account for a major part of global oil reserves. They are expected to play a crucial role in boosting oil production in the near future, considering the limited discoveries of new conventional crude oil fields and the depletion of existing ones. Heavy and extra heavy crude oils, however, are less economically viable than conventional crude oils and can only with difficulty be processed by most existing refineries because they contain substantial amounts of asphaltenes and high levels of sulphur and metal impurities. The challenges associated with heavy oil processing result in limited market demand and commercial exploitation.

One viable option that can be used is the concept of upgrading, in which the heavy oil is partially upgraded by cracking only the heaviest fraction — the vacuum residue (VR). Thus, the objective behind the proposed heavy crude upgrader is not to produce a refined petroleum product, but a synthetic crude oil as an export commodity for countries producing heavy oil. Partial upgrading has been commercially employed to produce synthetic crude oils from Canada's oil sands and Venezuela's Orinoco tar sands. These commercial synthetic crude oils are unique as they do not contain vacuum residues (VR) and produce high yields of middle distillates and vacuum gas oils (VGO). Therefore, such synthetic crude oils are expected to find their way into the refineries as a substitute to the conventional low-sulphur crude oils.

Crude oil upgraders are distinct from refineries and normally have a smaller footprint and much simpler configuration, which result in a substantial reduction in the investment cost. The concept of the crude oil upgrader is schematically illustrated in Figure 1. The atmospheric distillation column in the crude upgrader has a much simpler configuration than the one installed in refineries because it does not require the separation of products into multiple streams; thus, only crude and vacuum flashers are needed. The distilled fractions from both flashers are hydro-treated to reduce the sulphur content in middle distillates and VGO. The VR from the vacuum flasher, on the other hand, is thermally treated to produce a cracked oil of various light distillates such as naphtha, kerosene, and gas oils. The cracked oil is then hydro-treated, before being mixed with the pre-separated fractions from the distillation units to make a low-sulphur synthetic crude oil. The unconverted residual carbon from the thermal cracking is recovered as a byproduct in the form of pitch or coke, depending on the type of the thermal

Figure 1. Concept of heavy crude oil upgrader

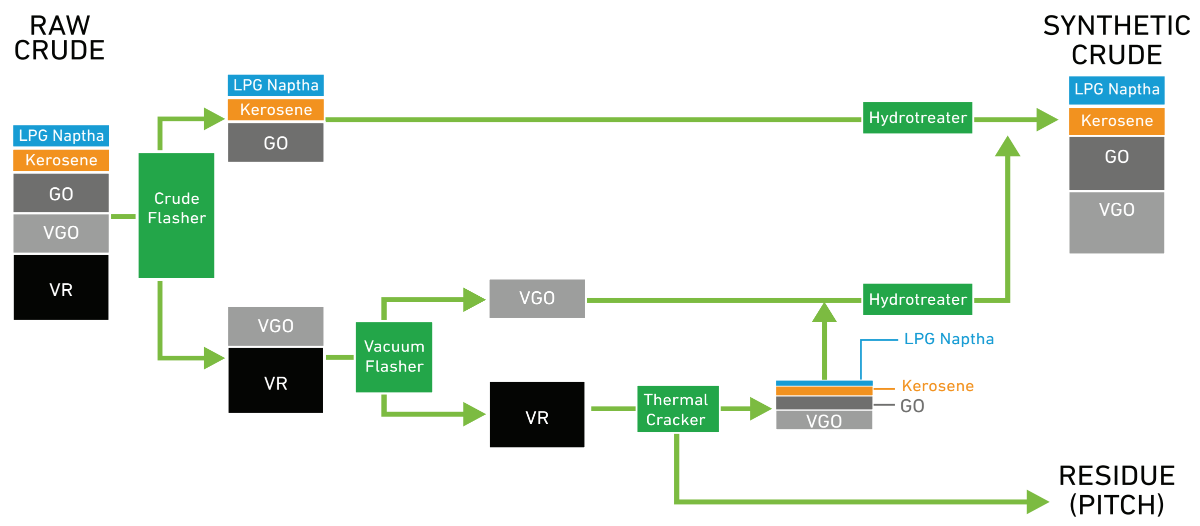
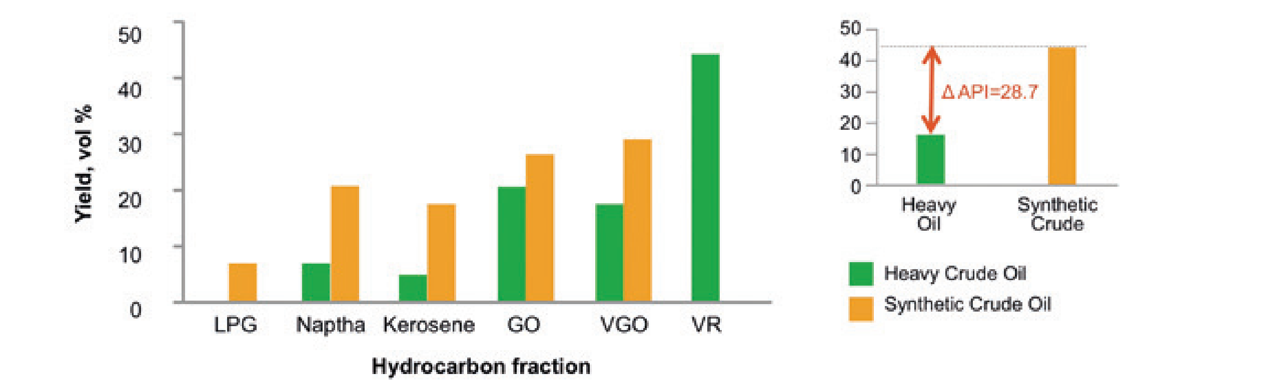


Figure 2. Comparison between hydrocarbon fractions in heavy crude oil and synthetic crude oil



cracking process. The yield of synthetic crude oil from such an upgrader is expected to be in the range of 85-95 per cent, with the rest as byproducts in the form of off-gas and residual pitch or coke. Synthetic crude oils from such upgraders are unique since they do not contain residues and have a low level of impurities. The post-distillation hydro-treatment also helps in stabilising the olefinic hydrocarbons that are expected to form by thermal cracking. Figure 2 illustrates how the partial upgrading of a heavy crude oil, with API gravity of 16°, can produce a low-sulphur synthetic crude oil with 45° API gravity. The VR fraction was totally eliminated from the synthetic crude oil and in turn the lighter fractions have increased. The material balance in Figure 2 clearly indicates that the synthetic crude quantity is less than that of the heavy crude oil, which is attributed to the formation of by-products like pitch and coke and of off-gas.

The concept of heavy crude oil upgraders can be used in both the upstream and downstream.. In the downstream, the upgrader should be integrated with an existing oil refinery to enable easy exchange of products or by-products, whereas the upstream upgrader should be set up near oil wells (field upgrader) to dilute the high viscosity heavy crude oil with synthetic crude oil. Different upgrading scenarios are proposed for the refinery-integrated and field upgraders by modifying the upgrader capacity and/or design configurations. The different configurations are achieved by selecting either a mild hydrocracker or a hydro-treater to treat the VGO from the vacuum flasher. Such selection depends on whether the upgrading or the sulphur reduction is prioritised. The changes in design configuration also involve the use of different reliable decarbonisation/thermal cracking processes to treat the VR. In the conceptual design of some refinery-integrated upgraders, the gasification option is utilised to improve the economic feasibility of the upgrader.

Synthetic crude oil can be marketed as a good substitute for the low-sulphur light crude oils. Alternatively, it can be blended with heavy crude oils to produce a medium-type synthetic crude. The market analysis indicates that the medium-type synthetic crude has higher demand because it is more compatible with the prevailing specification of existing conventional refineries. To illustrate the commercial prospect of the heavy crude oil upgraders, a price model was established for the heavy crude oils and the synthetic crude oils, where the price of heavy crude oil is estimated based on the average price of sour-type crude oils over 8 years while the price of synthetic crude is estimated from the average price of sweet-type crude oils. Based on this pricing model, the upgrade margin or the difference in price between heavy and synthetic crude oils is calculated for the different proposed upgrading scenarios.

The outcome of this study indicates that the technical viability and the economic feasibility of heavy crude oil upgrading depend on the upgrader capacity, its design configuration, and the upgrade margin. The upgrade margin, or the spread between synthetic crude price and feed crude price, proved to be the most influential factor for the feasibility of the upgrader. The study also indicates that the conceptual design of the upgrader can be further optimised, based on market demand, product price, and worldwide development plans for heavy crude oil.