Increasing crude unit preheat

Cost-effective exchanger network solutions, designed to increase crude preheat temperature and reduce energy consumption, need to rely on more than just pinch technology if they are to be successful

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Fuel gas prices are increasing and supplies are tight, making energy-efficiency improvements a necessity when revamping crude units. The last time efficiency projects were of major interest was in the early 1980s. During the many low margin cycles since then most of those projects did not meet the corporate investment hurdles of one-to two-year simple payouts. Even so, capital was scarce. Consequently, few were implemented. Refiners are again looking to reduce energy consumption, and pinch technology is once more being touted as the answer. However, the real question remains: does pinch technology address all the considerations needed to reduce crude unit energy consumption, or is it just a mathematical model in the revamp engineer's toolkit?

Increasing the crude preheat temperature to reduce the fired heater duty and save energy depends on more than just exchanger network configuration. Distillation system design, crude hydraulics, exchanger fouling, fired heater operation and other factors all influence the crude preheat temperature. Exchanger network revamps that achieve a high preheat temperature at start-of-run (SOR) when the exchangers are clean but then limit the crude rate when the exchangers foul, or require specific crude blends to meet the targeted crude charge rate, are not the answer. Pinch technology is no different to any other process or equipment model, in that practical know-how must be used to temper one's answer.

Pinch technology

Linhoff and Vredeveld introduced the term pinch technology to represent a methodology that uses the first and second laws of thermodynamics to identify the minimum energy usage and exchanger network capital costs while recognising the pinch point concept. Pinch technology relies on the stream rates, stream temperatures and the available energy in each heat source stream to predict the minimum fired heater duty, minimum exchanger network area and minimum number of exchanger services.

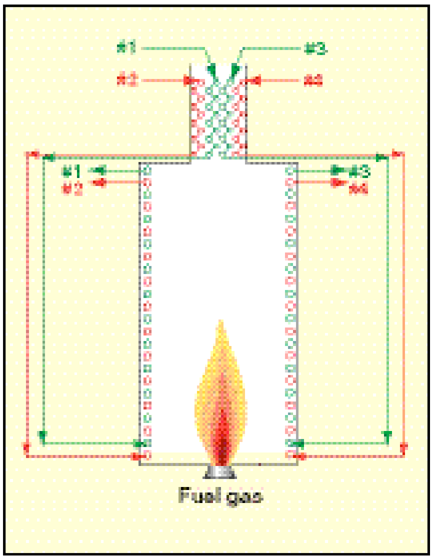

Figure 1 Original heater: serpentine pass layout

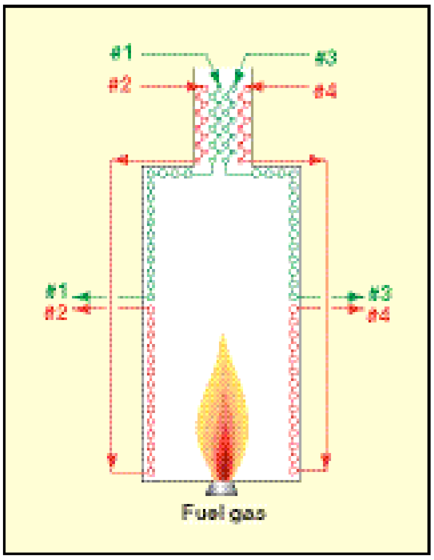

Figure 2 New heater: stacked pass layout

Pinch technology is good at identifying the minimum temperature approach, yet it ignores crude hydraulics, pumparound (PA) and product pump capacity, exchanger fouling, existing equipment mechanical limits and other peculiarities of an existing crude unit. This makes practical application when it comes to a revamp difficult at best. Non-optimum process flow schemes, poor distillation equipment performance, a high rate of exchanger fouling and unreliable fired heater performance all contribute to a low crude preheat temperature. Heater outlet temperature and pressure, plus the distillation equipment determine the available heat source duties and temperatures. Low oil velocity or poor exchanger design can lead to rapid fouling, causing the preheat temperature to drop following start-up. When the preheat temperature drops, the heater outlet temperature may also need to be reduced to avoid over-firing. This reduces the distillate yields, which decreases the amount of heat available for the crude preheat.

Pinch technology's weakness is that the stream flow rates and temperature used in the analysis are dependent on actual process and equipment performance. However, pinch technology specialists who are well versed in the model's mathematics rarely set foot in a refinery to observe what is really happening. Valid assumptions concerning stream flow rates and temperatures are essential when using pinch models. All critical factors influencing the preheat temperature need to be addressed, not simply the pinch point.

Engineering tools and know-how

Engineering tools speed calculations and allow many alternatives to be evaluated, but do they replace know-how? For example, one recent revamp objective was to increase the heavy vacuum gas oil (HVGO) product yield to unload the coker unit, allowing a higher crude rate. Increasing the HVGO yield requires a higher heater outlet temperature without causing rapid coke

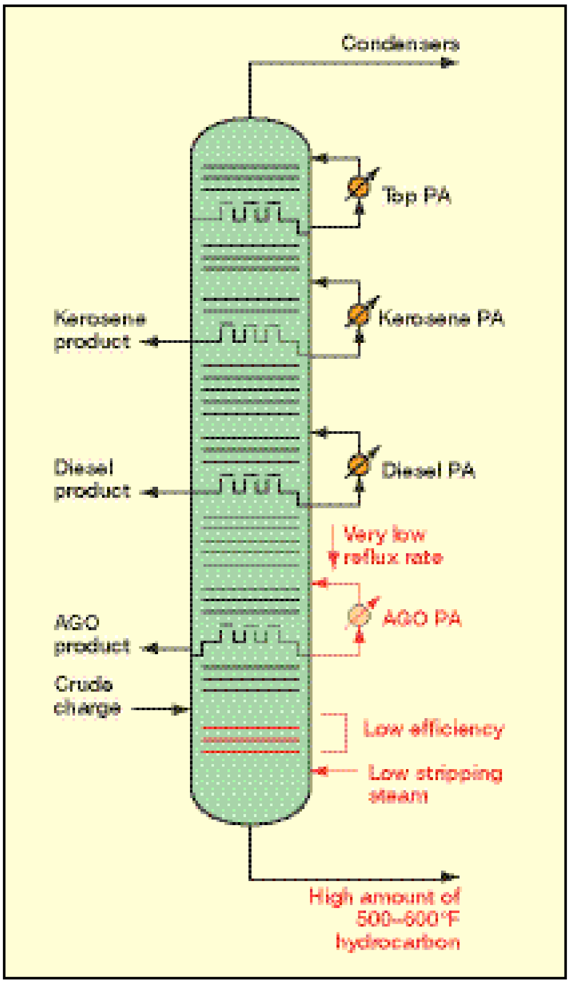

Figure 3 *Low diesel product yield*

formation. The vacuum unit had two fired heaters: the original heater (Figure 1) was started up in 1959 and the second (Figure 2) was added in 2000. Engineers using fundamental principles and slide rules designed the original, while the heater installed in 2000 was designed with the latest models including computational fluid dynamics (CFD) software. The heater built in 1959 operated for four years without requiring decoking at a radiant section average heat flux of 10 500btu/hr-ft^2-°F, but the new heater had coking problems at a 9000btu/hr-ft^2-°F.

Both heaters are four-pass single-cell box-type heaters operating without any coil steam. The 1959 heater was designed with two passes on each wall using serpentine tubes, with pass outlets exiting the top of the box. The new heater had the passes stacked on the walls — one pass on each wall was upflow and the other downflow — with the outlet tubes exiting the middle. Both heaters were operated with pass flow rate balancing to maintain the same outlet temperature from each pass. The original heater operated with nearly equal flow to each pass, while the new heater required a high flow rate in the two passes located in the lower section of the heater and a low flow rate in the upper two passes. The original heater had equal heat absorbed per pass (equal heat flux), whereas the new heater had a high heat flux in the bottom passes and a low heat flux in the passes in the top of the radiant section. Furthermore, the original heater operated at mass flux rates of 350lb/sec-ft^2 in each pass, while the new heater operated at 250lb/sec-ft^2 in the high flow rate passes in the lower part of the radiant section. The new heater has had two-year run lengths, while the original heater has operated for four years between decoking since 1959.

The first heater design is fundamentally sound and the second is not. The revamp engineer has the latest software (which was used to design the new heater) at his disposal, yet the original design using slide rule calculations and fundamental principles, such as balancing the "pass" heat flux, minimising the radiant section heat flux variability and optimising the oil mass flux (to reduce the rate of coke formation), was better. Fundamental principles and lessons learned from other operating heaters went into designing the original heater, but the new heater was designed by modelling specialists relying on complex computer models and failing to consider fundamental principles and lessons learned.

Crude unit heat exchanger network design is more complicated than heater design. As previously mentioned, it involves crude hydraulics, distillation, heat exchanger and heater system performance. Computer models are great tools, but there is no substitute for know-how. Successful application of pinch technology, like other models, depends on users' experience of the unit being revamped. Mathematical model results alone will not produce a reliable crude unit heat exchanger network.

Crude units

Every crude unit's process flow scheme and equipment design varies; many have already been revamped more than once. Some are well designed, efficient and reliable, while others are not. Whichever the case, the revamp engineer must deal with the steel on the ground, in spite of its idiosyncrasies. Some crude units lose 50°F (28°C) or more in the first six months of operation, because the crude precipitates asphaltenes, the exchanger tube- and shell-side velocities are low or the condensers foul, raising the column operating pressure and thereby reducing the distillate yield. Some crude oils have high fouling tendencies that force high crude-side oil velocities to mitigate fouling. However, a high velocity generates a high pressure drop, requiring a high pump head and high equipment design pressures. Process and equipment models must represent reality, and reliable revamp solutions need to fix existing problems.

Process design, equipment mechanical design and true equipment performance cannot be ignored. In a recent crude unit revamp, the engineer doing the simulations made assumptions concerning the process flow scheme and equipment performance. The designers' process models indicated the unit would produce 18 vol% of the product as diesel, yet when it started up the actual yield was 13 vol% because the distillation column equipment, PA system design and condenser performance prevented a higher distillate (diesel and AGO product) yield (Figure 3). A low distillate yield occurred because the unit's true performance did not meet the assumption used in the simulation.

In this case, model assumptions and reality were quite different. Since the atmospheric distillate yield was low, there was insufficient cold train preheat, resulting in:

— Low desalter temperature

— High brine content in the desalted crude

— Salt hydrolysis to HCl in the crude heater

— Amine in the slop reacting with the HCl, causing salt laydown in the top pumparound (TPA) exchangers

— Salt laydown inside the atmospheric column.

One consequence was a low crude heater inlet temperature. A low distillate yield will reduce the crude preheat temperature even if the exchanger network is designed properly. In this example, further unit changes were needed to improve the distillate yield, thereby raising the desalter temperature by 50°F with only minor exchanger network configuration changes. A higher preheat temperature was a consequence of several factors, and pinch analysis was not one of them.

The crude unit's distillate yield depends on the atmospheric column's operating pressure, the stripping section's efficiency, the stripping steam rate and the heater outlet temperature. The column's operating pressure is set by condensing load and condenser performance. When the raw crude is exchanged against the column overhead vapour, it is common to generate an increasing pressure drop as the run length progresses, because the condensing side fouls with the amine salts. Fouled condensers force the atmospheric reduced crude (AR) stripping steam rate to be reduced to a lower condensing load. A high column operating pressure and poor AR stripping reduces the distillate yield, thus decreasing the PA and product heat available for the crude preheat. As a consequence, the crude preheat temperature drops.

Determining the existing crude unit's limitations is essential when evaluating cost-effective exchanger network solutions to increase the crude preheat and reduce the fired heater duty. Once the limits are known, fundamental principles and know-how gleaned from other crude unit revamps can be applied. Designing a revamp that does not work following start-up is a major learning experience. It teaches what is important. Stream flow rates and the temperature used in the pinch analysis are the result of process flow scheme and equipment performance. If they are not correct, the network solution will not work.

Process models need to match reality, not the designers' wishful thinking. Since process flow sheet models have become so easy to use, they are being employed without considering whether the results of the model match the plant's performance. Revamps should begin with a thorough evaluation of the units' performance. Some units run well and others do not. One cannot wish away problems; they need to be fixed.

Crude type

Crude type affects the crude preheat temperature and the exchanger network solution. Heavy crudes have higher viscosity, some have a higher salt content and they are all more difficult to distill than lighter crude oil blends. In addition, some of the bitumen upgrader synthetic crudes have a lower thermal stability than conventional crudes, increasing their fouling tendencies. Processing difficulties can be attributed to flow schemes and equipment designs that are not compatible with the heavy crude oil's characteristics. Special care must be given to the process flow scheme and equipment design, because heavy crudes are less forgiving than lighter ones.

Revamp process flow schemes must solve the inherent crude hydraulic and preheat dilemma when processing heavy crude oils. Higher viscosity reduces the raw crude charge pump's developed head, and exchanger pressure drops are very high because the flow regime is laminar in many of the cold train exchangers. Circumventing hydraulic limits can be expensive; therefore, hydraulics must be evaluated in the early engineering stages. Crude charge, PA and product hydraulics are not part of the pinch analysis, yet hydraulics determine the amount of crude that can be processed through a given heat exchanger network configuration.

Cold train exchangers have very low heat-transfer coefficients due to their laminar flow. Furthermore, there is less atmospheric distillate product decreasing the heat available in the cold train. Since heavy crude requires a higher desalter inlet temperature for efficient operation, more cold train exchanger surface area and more services are generally needed when revamping. New exchangers are often added in parallel to reduce the pressure drop, but this approach also lowers the crude's velocity, increasing the rate of fouling. When the exchangers foul, the heat-transfer coefficient decreases and the pressure drop increases. It is not unusual when processing heavy crudes such as Christina Lake, Cold Lake, LLB

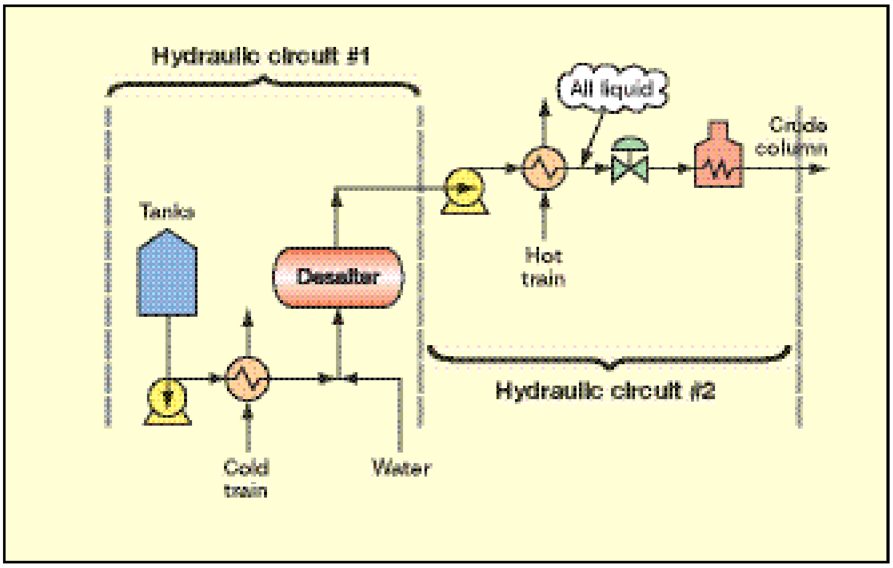

Figure 4 *Crude hydraulics: two circuits*

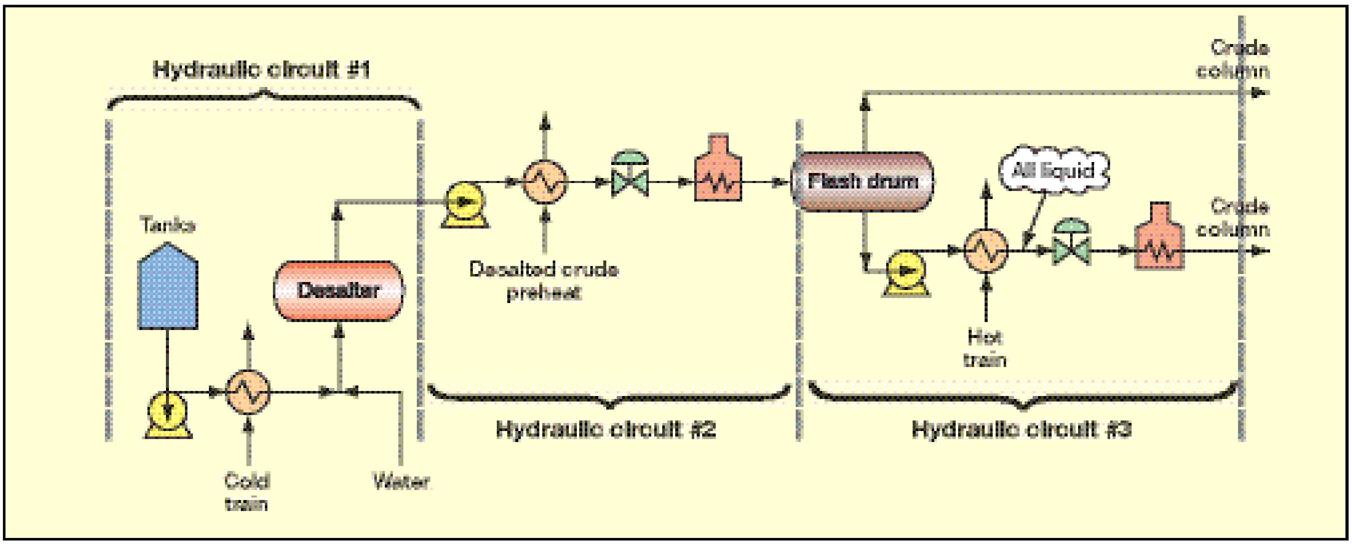

Figure 5 *Crude hydraulics: three circuits*

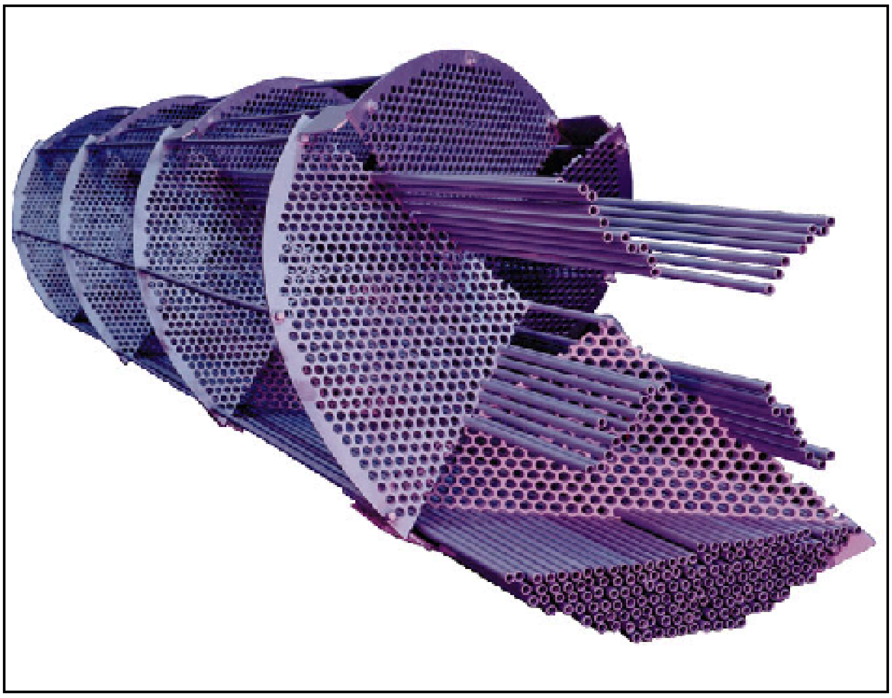

Figure 6 *Helical baffle exchanger (Photo courtesy of ABB Lummus Heat Transfer)*

or Merey to have service heat-transfer coefficients as low as 8–12btu/hr-ft^2-oF in the cold train.

Higher volumes of heavy Canadian crudes are being produced, and many US refiners are considering revamps to process them. Some are blends of bitumen and coker product or condensate that can have high sediment and clay contents, which cause rapid fouling in the cold train. Desalter operation is more difficult, because stable emulsions form a "rag layer" that must be intermittently drained. If desalter performance deteriorates, the crude preheat temperature usually drops. Crude type is a factor in the exchanger network solution.

Crude hydraulics

Crude hydraulics often dictate the exchanger network configuration. Crude must be pumped from storage through the exchangers, desalters and heater to the atmospheric column. Figure 4 shows a typical unit with two hydraulic circuits. Raw crude is pumped from storage to the desalters, and desalted crude is pumped from the desalter to the atmospheric column. Exchanger and desalter maximum allowable working pressure (MAWP) cannot be exceeded. The minimum desalter operating pressure must be high enough to prevent oil and water from vapourising. Furthermore, the operating pressure at the heater pass control valves must be high enough to suppress vapourisation of the desalted crude oil and water. Two-phase flow can cause heater pass imbalances, short run lengths due to rapid coke formation and, in the worst-case, a tube rupture. Some crude revamps need to install a preflash drum or column to break the hydraulics into three circuits (Figure 5). Desalted crude is pumped from the desalter to the preflash, and flashed crude is pumped from the preflash to the atmospheric column. Flashed crude contains less water and is heavier than desalted crude, so it can be heated to a higher temperature at a lower pressure without vapourising. There are also fewer exchanger services, allowing a higher oil velocity without exceeding existing exchanger MAWPs.

Existing crude unit equipment MAWP limits the pump discharge pressures needed to overcome the exchanger pressure drop. Booster pumps can sometimes be added to balance the pressure drop against equipment MAWP. Other times, new exchangers are needed to meet the higher operating pressures. Existing equipment MAWP and crude hydraulics constrain the exchanger network design and dictate practical exchanger solutions.

Exchanger fouling

Exchanger fouling affects the required surface area, the number of services and ultimately the pressure drop to meet a targeted heater inlet temperature. Much has been written about fouling, yet fouling is largely determined by the velocity on the tube- and shell-side plus the shell-side baffle designs. Exchanger design using proprietary Helical Baffles (Figure 6) will reduce fouling. Increasing the velocity minimises fouling, but also generates a higher pressure drop. In some cases, all that is needed is a higher head pump, but often the existing exchanger MAWP prevents the installation of a higher head pump.

The exchanger network design will determine the pressure drop when clean, but the system needs a sufficient control valve pressure drop at SOR to allow for an increased pressure drop caused by fouling. Maximising the crude oil velocity to minimise fouling without exceeding the exchanger MAWP is a challenge. Exchangers designed for low velocity have a low calculated pressure loss when clean but foul quickly, raising the pressure drop. High fouling rates require larger exchanger surface areas, but the effective area is low. Conversely, designing an exchanger for high velocity lowers the fouling and exchanger surface area, yet results in a higher calculated clean pressure drop. Since a high exchanger velocity reduces fouling, pressure drop increases are relatively small as the run length progresses. Determining how much pressure drop to allow for fouling and balancing this against existing equipment MAWP is often the single most important factor driving the exchanger network configuration.

When raw crude is exchanged against overhead vapour or there is a TPA, the desalter performance will influence the crude preheat temperature. As the desalter temperature drops, oil water separation becomes increasingly difficult and desalted crude water and salt content increases. Furthermore, some refiners processing extra-heavy crudes have had to switch from series to parallel desalter operation to reduce the frequency of desalter upsets. Single-stage desalting removes 90–95% of crude salt. Hence, desalted crude often contains 3lb/1000 barrels or more of salts, resulting in fouling and corrosion in the overhead condensers and TPA system. Exchanger network solutions must consider fouling.

Manipulating heat source rates and temperatures

Crude heat source temperatures and stream flow rates are not fixed. They are controlled by the heater outlet temperature, column operating pressure, distillation column product yields and PA locations. Manipulating these variables can minimise the exchanger surface area and decrease the number of exchangers, thus reducing the crude-side pressure drop. Raising stream flow rates or increasing the heat source temperature needs to be part of the heat exchanger network solution.

Determining whether process flow scheme changes can raise heat source rates or temperatures while meeting downstream unit feed quality is essential. For example, some crude units produce heavy naphtha as a side-draw product and combine it with the overhead product before fractionating it to LSR and naphtha in a downstream (Figure 7) splitter. Sometimes, these units also have a TPA. Since the TPA draw temperature is largely determined by overhead product distillation, eliminating the side-draw and producing full-range naphtha overhead will raise the TPA draw temperature by 30–50°F, depending on the amount of side-draw produced. Even though this increases the overhead condenser duty and may require condenser modifications, sometimes inexpensive bundle changes or the installation of cooling water booster pumps to raise the cooling water velocity is all that is needed to increase condensing capacity. Exchanger TPA-side temperature change is typically only 50–70°F, so raising the draw temperature by 30–50°F has a dramatic influence on the exchanger temperature difference (LMTD) and the amount of TPA heat that can be recovered in the preheat train. In one instance, five series TPA exchangers were reduced to three when the TPA draw temperature was increased by 50°F. This reduced the cold train pressure drop, allowing the crude rate to be increased.

Some units combine kerosene and diesel into a single draw from the column or at battery limits, because the refinery does not produce kerosene or jet fuel. Varying kerosene and diesel product yields or separating a single draw into two products from the column changes the heat source rates and their temperatures. Increasing the kerosene product yield at the expense of the diesel yield raises both draw temperatures. When the column has both kerosene and diesel Pas, it also raises both PA draw temperatures. In one case, diesel and kerosene were produced as a single stream from the column. Installing a new kerosene product and PA higher up in the column created a 440°F kerosene PA and raised the existing diesel draw temperature from 480–550°F. These changes increased the crude preheat without adding exchanger services or area.

Heavy crude is difficult to vapourise, resulting in a low atmospheric distillate yield. The same boiling-range material yielded in the atmospheric column has a much higher temperature than producing it as light vacuum gas oil (LVGO) in the vacuum column. The product draw temperature depends on column pressure. The atmospheric column's operating pressure is typically between 30–45psia, whereas the vacuum column operates at 1psia. As diesel and AGO material is shifted to the vacuum tower, the amount of high-temperature heat available for the crude preheat decreases. Diesel and AGO pumparound/product temperatures are approximately 550°F and 610–625°F respectively, but the same material yielded as LVGO is only 300–335°F, which is too low to recover against the crude oil. Following some heavy crude revamps, the atmospheric distillate yield is so low it reduces the vacuum column heavy vacuum gas oil (HVGO) product

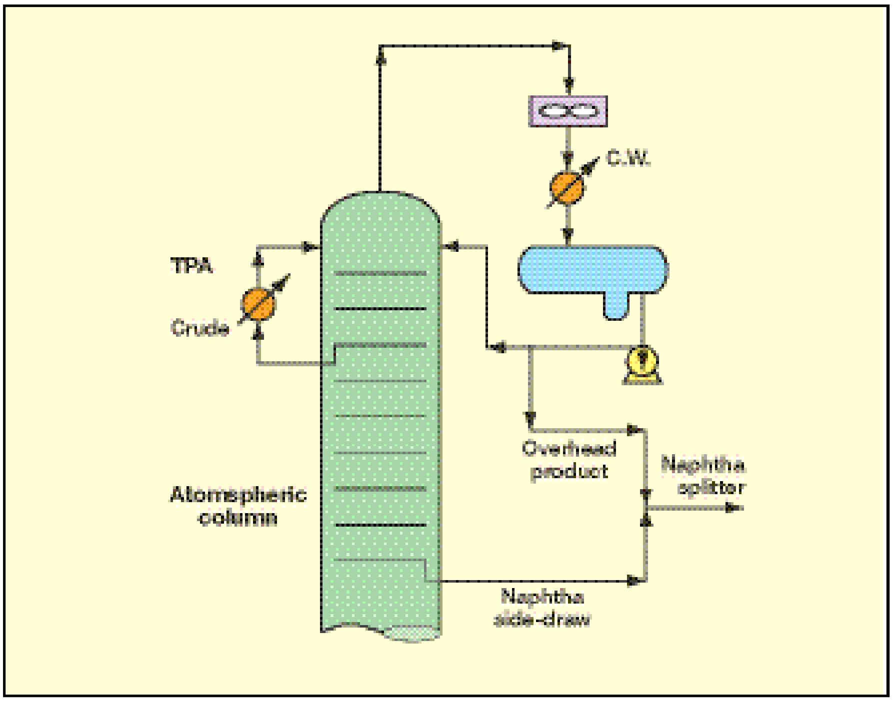

Figure 7 *Atmospheric column naphtha yield*

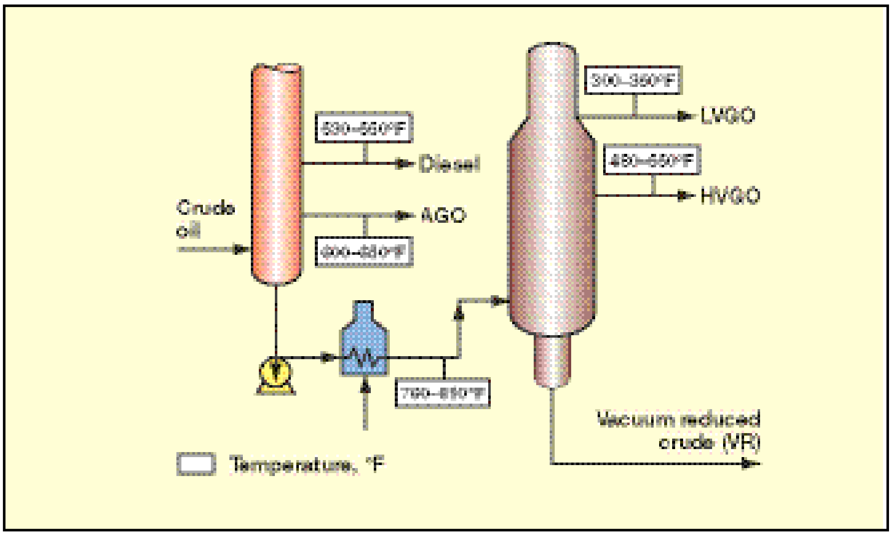

Figure 8 Low atmospheric distillate yield

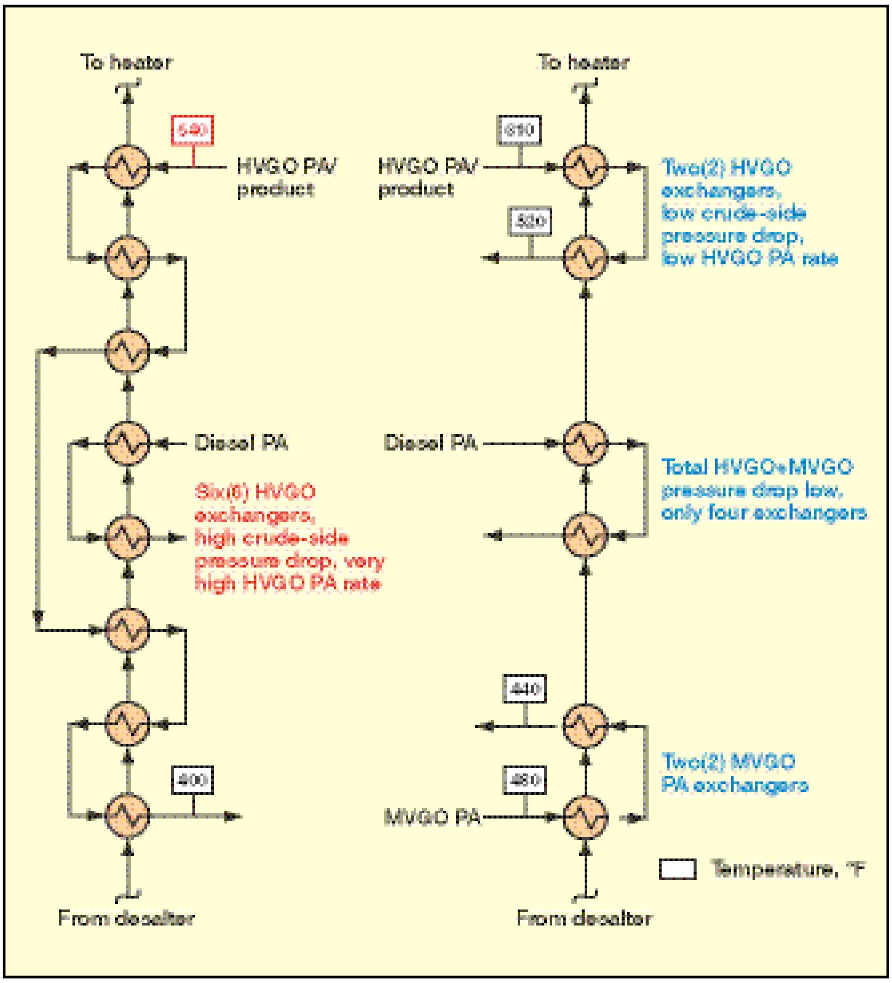

Figure 9 Reducing number of exchangers

draw temperature, further reducing the amount of heat available to the preheat crude (Figure 8).

A large portion of the crude preheat comes from the HVGO PA duty on most crude units. Vacuum columns designed with only two products have high HVGO PA duty and the draw temperature is only 480–540°F. Some of the HVGO PA heat must often be used to generate steam, because the draw temperature is too low to exchange all of the heat against crude. Moreover, heavy crudes have more VGO, thus increasing the total LVGO and HVGO PA heat that must be removed. Increasing HVGO product cut-point further raises the heat removal, exchanger surface area and HVGO PA rates. In one instance, six exchangers in series were used in the hot preheat train to recover HVGO PA heat. Increasing the number of exchangers increases the crude- and HVGO PA-side pressure drops.

Managing crude hydraulics is critical, and minimising the number of exchangers is essential. In the previous example, adding a third product and PA to the vacuum column reduced the number of exchangers and surface area, allowing more heat to be recovered to crude. A portion of the HVGO product and PA heat was shifted to the new MVGO system, thereby increasing the HVGO PA temperature to over 600°F. The number of hot train exchangers was reduced from six in series to four (Figure 9). It also reduced the HVGO PA circulation rate to stay within the existing pump and piping limits. Manipulating heat source rates and temperatures should be part of the exchanger network revamp.

Practical exchanger network revamps

Revamping crude unit heat exchanger networks to raise the crude preheat temperature reduces energy consumption, which is especially important when fuel gas prices are high. However, a reliable solution depends on many factors, including managing crude hydraulics, mitigating fouling, manipulating heat source rates and temperatures, and maximising heater performance. Balancing crude-side and shell-side velocity on exchangers and optimising baffle design without creating hydraulic limitations minimises fouling. This reduces the exchanger surface area, generating less pressure loss. Raising the crude preheat temperature allows for a higher heater outlet temperature at the same heater firing, thereby increasing the amount of high-temperature atmospheric column heat for recovery against crude oil. Pinch technology has a place in crude unit energy efficiency; nevertheless, its results should be tempered by all factors influencing exchanger network design.

The Helical Baffle Exchanger is a mark of ABB Lummus Heat Transfer.

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