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IMPROVING HYDROTREATER PERFORMANCE WITH WELDED PLATE HEAT EXCHANGERS

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Improving hydrotreater performance with welded plate heat exchangers

Pressure has never been higher on refiners to improve the efficiency of their energy-intensive processes

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Recent volatile crude oil prices have led to the growth of several alternative methods for crude oil extraction around the globe. These extraction methods can often produce sour crude oil with a high sulphur content. At the same time, the demand for high sulphur products is decreasing as the understanding of the environmental effects of burning high sulphur fuels grows. This necessitates that refiners are now required to reduce the sulphur content of their products before they can be sold. This is most commonly done by hydroprocessing, such as hydrotreating and hydrocracking.

Focusing on hydrotreating as a process for removing unwanted impurities such as sulphur, nitrogen, and metals, there are several alternative configurations. However, at the heart of hydrotreating there is always the reactor section, featuring a high pressure reaction vessel as well as reactor internal technology and catalyst, enabling the feed to react with hydrogen. This unit operation is common for hydrodesulphurisation, but also in other fuel upgrading technologies such as isomerisation and catalytic saturation. These processes are energy intensive and as such require a high degree of heat integration to lower the energy operating expenditures (opex). Earlier, this heat integration was performed with shell-and-tube (S&T) heat exchangers. However, more recently refineries have been maximising energy efficiency by using welded plate heat exchangers by Alfa Laval in the main heat recovery positions. This article explains the advantages of using welded plate heat exchangers in key heat integration positions in hydrotreaters among several refiners around the world.

Process layout

Figure 1 shows a general process layout of a hydrotreater. Hydrogen is

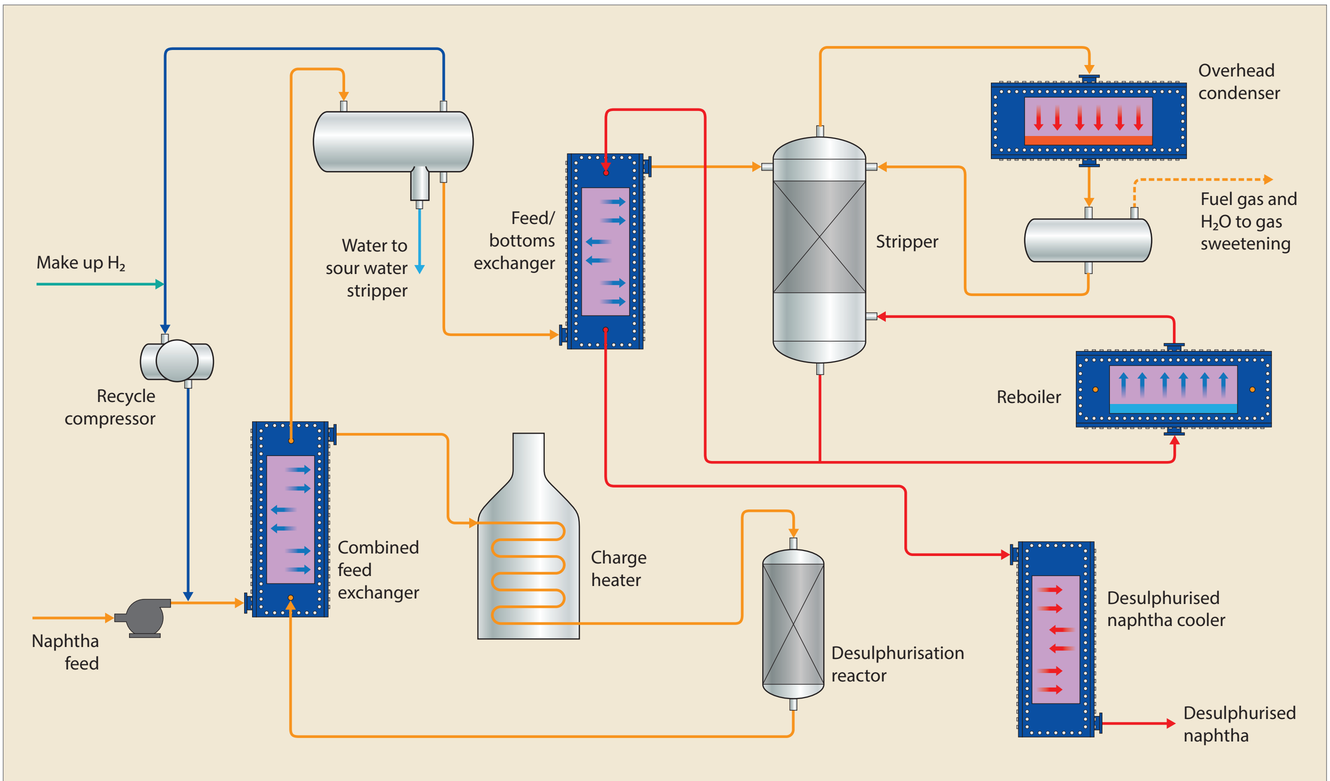

Figure 1 General process layout of a hydrotreater using welded plate heat exchangers in several positions: CFE, stripper feed/bottoms, product cooler, stripper reboiler, and stripper overhead condenser

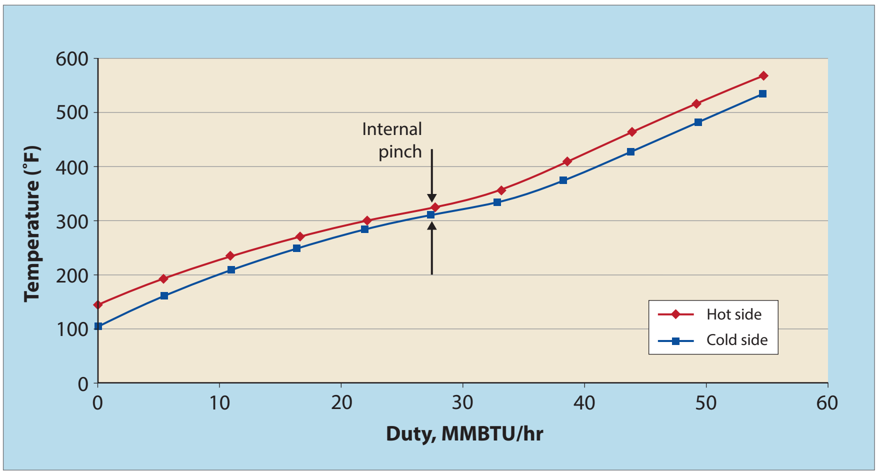

Figure 2 Generic enthalpy curves for a feed/effluent heat exchanger, welded PHE

added to the feed stream which is then vaporised and superheated in a heat exchanger. The reactor effluent is used as a heating medium; this in turn needs to be cooled and condensed before being separated into various products. The more you heat up the feed, the less energy has to be used in the furnace. And the more you cool down the effluent, the less energy has to be used in the subsequent (air) cooler. Therefore process designers usually focus on minimising the hot end approach temperature (HAT) and internal pinch (minimum delta T) of the combined feed/effluent (CFE) exchanger. Typical internal pinch temperature for this position when S&T is used is between 20°C and 40°C (36-72°F). However, with plate technology the temperature difference can easily be reduced to less than 6-10°C (11-18°F, see **Figure 2**). This means that by using a traditional technology, the number of S&T in series and the heat transfer area needed to do the same duty will be significantly higher, as will the cost of the heat exchangers.

Traditionally, a maximum of eight S&Ts in series have been used in such a service, as an optimum with respect to investment cost versus achieving more heat recovery. As the efficiency of these heat exchangers affects the surrounding process equipment, their performance should preferably be fixed at an early stage.

Benefits of Compabloc/Compabloc+

Welded plate heat exchangers, such as the Compabloc, extend the practical performance limits of heat recovery by using engineered corrugated heat transfer surfaces to generate three to five times the heat transfer coefficient compared to traditional technologies. At the same time, fouling rate is minimised. The flow geometry also achieves very close to counter-current flow, perfect for small temperature differences and high heat recovery. Further on, as already explained, a single Compabloc can replace several S&T heat exchangers, significantly reducing the amount of space required for installation by up to 90% compared to traditional S&T heat exchangers.

The heat recovery capability of Compabloc means that less fossil fuel is consumed, and that emissions and carbon footprint are reduced. A compact design makes installation easier and more cost effective. By freeing up space, Compabloc resolves bottleneck issues, enabling new ways to increase production and heat recovery.

Compabloc operates with superior shear stress, minimises fouling, and allows operation with cleaning intervals substantially longer than traditional S&T heat exchangers. It is equipped with four removable panels to allow full access to the heat transfer area for cleaning or inspection. The fully cleanable design with cleaning lanes at each side of the plates means that the exchanger can be returned to 100% performance when cleaning the plate pack by hydrojetting, ensuring a long and highly efficient operational life cycle. This is especially important in duties like naphtha hydrotreater CFE where gumming and salting can occur.

The classic range of Compabloc can go up to 38 or 42 bar depending on the model. The Compabloc+ range however allows operation up to 60 bar because of new features, and brings the benefits of Compabloc technology to a wider range of positions.

Compabloc+ is equipped with +Seal, a sealing concept that allows the panels to be reliably sealed at high pressure. In Compabloc+ design, the graphite gasket is fully contained in a groove and the compression is controlled with a metal-to-metal contact which prevents overtightening and related damage.

Several cases where Compabloc welded plate heat exchangers have been successfully utilised in hydrotreater systems will be presented in this article.

Case 1

A major refinery in Europe sought to debottleneck an existing naphtha hydrotreater and identified the CFE heat exchanger heat recovery as a limiting factor to its project goals. Additional S&Ts in series with the existing S&T CFE train were evaluated, but the performance of the additional shells fell short of its goals and the new train consumed too much pressure drop. Finally, as is often the case, not enough space was available to install the additional S&T exchangers so the project was not feasible with this technology.

Concurrently, the refinery evaluated Compabloc heat exchangers to be placed on the hot end of the feed side, vaporising and superheating the feed with hot reactor effluent while still using the S&T exchangers on the cold end. The operating parameters were optimised by a team consisting of Alfa Laval specialists and the customer's process specialists who iterated the Compabloc and S&T performances at different temperature approaches. The optimum point in this case was to design the Compablocs for a 12°C (21°F) pinch temperature and a 22°C (39°F) hot end approach temperature, limited by the performance of the existing S&T equipment on the cold end. This performance met the

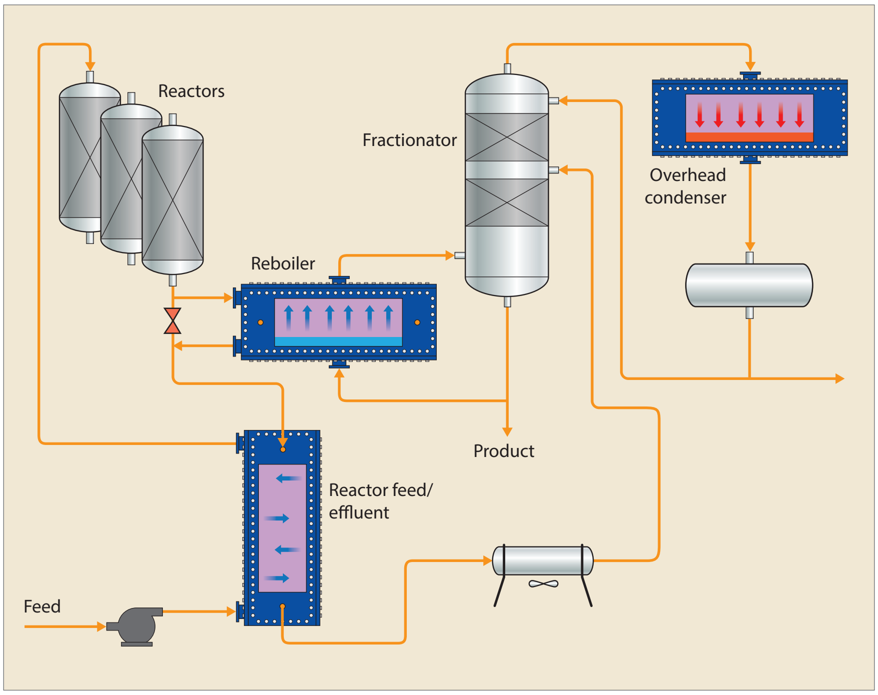

Figure 3 Isomerisation process employing Compabloc as CFE and process reboiler

project's goals and the solution was implemented in 2016.

The refinery started up the Compablocs in early 2017; initially, the thermal and hydraulic performance was exactly as expected. However, after several months of operation, increases in pressure drop were detected on the hot end of the feed side in the Compabloc, located at the dry point of the exchanger. The root cause of fouling was determined to be an excess of corrosion inhibitor being dosed in the naphtha upstream, causing the filming agent to be deposited at the dry point of the feed. The Compabloc was cleaned of the fouling material and a process adjustment was made, after which performance returned to typical unit cycle length. For more information, see page 12 in this issue's Q&A section where this case is discussed in more detail.

Case 2

In 2014, a prominent US refinery was developing a project to build a grassroots naphtha hydrotreater as part of its Tier III gasoline sulphur reduction initiative. The refiner had the ambition to design the process as efficiently as possible, but also needed to be held to strict limits on total installed costs. For both of these reasons the refinery identified Alfa Laval as a viable solution, and our specialists began working with the customer's process specialists to optimise a solution within cost constraints.

Similar to the European case, the first place to start was the CFE, and several iterations with different amounts of heat recovery were done to balance exchanger cost with the whole project cost. One counter-intuitive learning from the process was that increasing the Compabloc exchanger size actually lowered both the operating cost (better heat recovery) and the total capital cost (capex) by being able to downsize other equipment. The optimum design basis for this Compabloc CFE was to use a 7°C (12°F) internal pinch temperature and a 20°C (35°F) hot end approach (HAT) temperature. The economics also favoured employing Compabloc exchangers as the final reactor heater and as the stabiliser feed/bottoms heat recovery exchanger. All were optimised for efficiency and cost reduction and the three services were put into operation in 2016.

Since start-up, the performance of all exchangers has met expectations and no performance reduction has been detected. At this pace, the Compablocs will easily provide the required performance until the next scheduled turnaround. In fact, because of the success of this installation, the same refining company is installing Compabloc as CFE exchangers in another naphtha hydrotreater unit (NHT) in 2020. This NHT is being debottlenecked to a greater degree by employing Compabloc with similar tight temperature approaches.

Case 3

In this case, Compabloc was evaluated for debottlenecking an existing cracked naphtha hydrotreater (Axens Prime G+) in Canada as part of the refiner's Tier III sulphur reduction initiative. Seeking more heat recovery was interesting since the fired heater downstream of the CFE was limited both by size but also by environmental emissions limits. If this refinery wanted to expand, it needed to do so below the environmental limits. Recovering energy and saving emissions are ideal reasons to evaluate Compabloc, so a team of Alfa Laval and refinery process specialists optimised the heat recovery of the system and selected a Compabloc to be installed on the hot end of the gasoline desulphurisation (GDS) reactor in series with existing S&Ts. The HAT of this installation was optimised at 41°C (75°F), again limited by the S&T exchangers upstream on the cold end of the CFE.

In addition to the work at the process stage to optimise the process design, equally important is the installation and operation of Compabloc as CFE heat exchangers. Alfa Laval specialists worked with the refinery on developing the start-up and shutdown procedures, as well as design features such as water wash, sulphiding, and emergency shutdown procedures. This process unit was successfully started up in 2019 and is running smoothly.

Case 4

Similar to hydrotreating processes, other refinery and petrochemical processes employ a reaction section with feed/effluent heat exchangers that could benefit from plate technology. In this example, Compabloc was evaluated by an independent US refiner to debottleneck a gasoline isomerisation process licensed

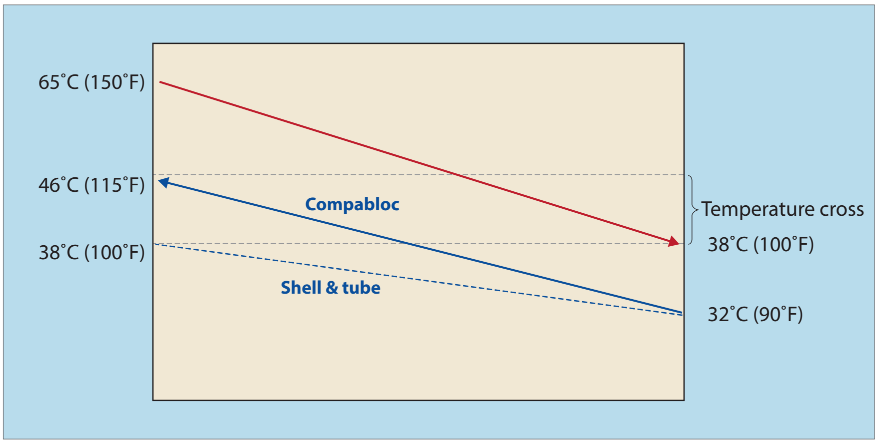

Figure 4 Typical product cooler temperature program

by UOP. The project was a revamp to increase throughput but also to replace a fired stabiliser reboiler with a heat exchanger using reactor effluent heat. The bottlenecks could be alleviated by recovering more heat in the CFE heat exchanger, so a Compabloc was a natural choice.

An evaluation was done by a team of Alfa Laval specialists and refinery site specialists to optimise the performance of the project. Quickly, it was discovered that if Compabloc was used both as the CFE heat exchanger and as the process reboiler, less reactor effluent needed to be diverted to the reboiler which reduced the overall project cost (see **Figure 3**). The refinery took full advantage of the performance benefits of Compabloc and the project moved forward. Both the CFE Compabloc and the reboiler Compabloc were installed and started up in 2017. Analysis of the operating data showed a 19°C (35°F) HAT on the CFE, exceeding design performance with no fouling detected in the first year of analysed data. The reboiler is performing with an average 3.3°C (6°F) temperature difference between the boiling fluid and the reactor effluent outlet temperature, which is world class performance for a reboiler. Both heat exchangers are expected to perform at this level well into the next turnaround schedule.

Case 5

Another process that employs reactor feed/effluent heat exchangers is the benzene saturation process. In this case study, a benzene saturation unit at a US refinery was revamped for additional capacity in response to the MSAT II gasoline benzene reduction initiative of 2011. Alfa Laval specialists worked with the refiner's corporate engineering to develop the scope that produced the best possible project outcome by using Compabloc heat exchangers.

In this process the bottlenecks were identified as the CFE pressure drop and the stabiliser overheads and bottoms coolers. In the CFE, the additional capacity was thermally and hydraulically limiting the existing S&T preheat train, so a Compabloc was placed on the hot end of the CFE, thereby replacing some of the S&Ts. The Compabloc was able to make up the additional heat needed by the process, while staying within the allowable pressure drop. This heat exchanger was started up in 2009 and was recently inspected for the first time during a 2018 turnaround.

Recovering energy and saving emissions are ideal reasons to evaluate Compabloc

Of similar importance to this project was the cooling capacity of the overheads and bottoms products from the product stabiliser. S&T heat exchangers existed in this system and were designed as: (hot outlet temperature) – (cold outlet temperature) = 0. For example, if the products needed to be cooled to 38°C (100°F), the maximum cooling water outlet temperature would be 38°C (100°F) as well (see **Figure 4**). This is typically done for S&T heat exchangers to avoid a temperature cross which forces shells-in-series, with the main disadvantages being that cooling water flow can be excessive or process outlet temperature is not as cold as desired. In this unit revamp, additional cooling capacity was needed but additional cooling water flow was not available. Either another S&T would need to be added in series, or a Compabloc could be installed in place of the S&T since this technology can easily perform temperature cross duties in a single heat exchanger. Compablocs were selected for both product coolers for their overall lower pressure drop, high thermal performance in a single shell, and dramatic space savings. These heat exchangers also started up in 2009 and have performed well throughout the turnaround cycle.

Conclusion

With increased focus on process sustainbility and social responsibility, the pressure on refiners is high to improve energy efficiency. Energy-intensive processes such as hydrotreating are frequent targets for improvement; as evidenced by the cases in this article, many refiners are choosing to improve efficiency with Compabloc technology. This is because it is not enough any more to settle for the efficiency limitations of S&T technology to accomplish goals. Refiners must improve efficiency to stay in business, but to thrive in today's market they need to innovate in the area of energy efficiency. An increasing number of refiners are turning to Compabloc technology to improve in this area, even for their most critical and demanding processes such as hydrotreating.

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Q Fouling in the feed/effluent exchangers to our naphtha hydrotreater is at unacceptable levels. The feed is straight run naphtha. Solutions please.

A Chris Wajciechowski, Business Development Manager, Alfa Laval Energy Division, chris.wajciechowski@alfalaval.com

Fouling on the feed or effluent side of a naphtha hydrotreater combined feed/effluent (CFE) heat exchanger can occur for a multitude of reasons. It is most important to first understand the root cause of fouling and then select the proper mitigating measure. Most root causes are well documented and remedies are readily available. For example, oxygen or olefins in feed can cause gums to form as the feed is heated; and the remedy is to avoid oxygen ingress or install an oxygen stripper to remove the contaminants. Other contaminants like chlorides can create effluent salts or corrosion products that foul or plug heat exchanger surfaces. Water washing to remove effluent salts or upgrading metallurgy to stainless steel to avoid high corrosion rates are acceptable ways to mitigate the effects of chloride contaminants.

Alfa Laval has installed a number of Compabloc welded plate heat exchangers in naphtha CFE service and the performance has been impressive. In one particular straight run NHT unit, unusual feed fouling was detected which increased the pressure drop and gradually reduced thermal performance over time. Analysis of the fouling confirmed it was present only on the feed side and at the point where 100% vaporisation occurred. A high-boiling component was being left behind when the naphtha flashed, and this component deposited on the plates. Gums were ruled out since the refinery was processing a low percentage of cracked feed, and feed composition or contaminant issues were ruled out as well. The root cause was an uncommon corrosion inhibitor additive that was being overdosed in the overhead system in the crude unit. This additive became the high boiling component of the NHT feed and coated the heat exchanger surface area at the dry point. Optimisation of the dosing rate reduced the fouling to an acceptable level to reach the typical unit cycle length.

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