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Take advantage

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Chris Wajciechowski, Alfa Laval, USA,
explains how the introduction of welded plate heat exchangers has optimised naphtha hydrotreater efficiency at a major refinery on the US Gulf Coast.

TAKE ADVANTAGE

The need for hydrotreating is increasing as refiners adapt to changing sulfur regulations in motor fuels. To help meet these regulations for gasoline, a naphtha hydrodesulfurisation unit is used; generically called a naphtha hydrotreater (NHT). NHTs are critical refinery process units that remove sulfur from gasoline components by reacting with hydrogen in the presence of specialised catalysts. The process is energy intensive and requires a high degree of heat integration to lower the energy operating expenditures. In the past, the energy was recovered with shell-and-tube heat exchangers; however, more recently, refineries have been boosting process efficiency by using welded plate heat exchangers in key heat recovery positions. This article will explore the benefits of using welded plate heat exchangers, realised in a grassroots NHT.

A Gulf Coast refiner sought to build a hydrotreater to comply with US Tier III sulfur regulations and retained a design firm to perform the necessary process designs and refinery modifications. A traditional design was drafted using conventional shell-and-tube heat exchangers to perform the heat transfer in the process. To improve energy recovery in the process, the combined feed/effluent and feed/bottoms heat exchangers were initially designed as multiple shell-and-tube units in series. Any additional heat not recovered by these heat exchangers would have to be supplied by energy purchased from the hot oil heater and the reboiler. The refinery wanted to lower capital and operating expenditures of the plant, so the company directed the design firm to evaluate welded plate technologies to optimise the process. Three services were selected to evaluate whether performance could be improved with welded plate technology: the combined feed/effluent exchanger; the stabiliser feed/bottoms exchanger; and the hot oil heater.

Naphtha combined feed/effluent exchanger (CFE)

In this heat exchanger, process feed is combined with hydrogen. It is heated and boiled to a superheated vapour in a series of heat exchangers. The heat source is reactor product vapours, which need to be cooled, condensed, and then separated into various components. Maximising this heat exchanger's performance by minimising the feed/effluent approach temperature is critical as it drives the energy efficiency of the entire process. Heat exchanger designers focused on the hot-end approach temperature (hot side outlet T – cold side outlet T = hot approach temperature or HAT) and the minimum internal delta temperature (ΔT_{min} or the 'pinch') as limitations to the thermal design. Pinch temperatures are a function of service and heat transfer technology. For a shell-and-tube unit in the hydrotreater CFE service, the pinch temperature is typically between 22 and 44˚C (40˚ and 80˚F). Enthalpy/temperature curves are provided to represent the HAT and pinch, aiding the heat exchanger design (Figure 1). In a typical design, heat recovery is limited to the performance of six to eight shell-and-tube heat exchangers in series as this has historically been determined to be the practical optimum between investment costs and heat recovery benefits. This Gulf Coast refiner's process was originally designed with seven shell-and-tube heat exchangers in the CFE.

Since the CFE design dictates several other design and operating parameters, its performance should be determined

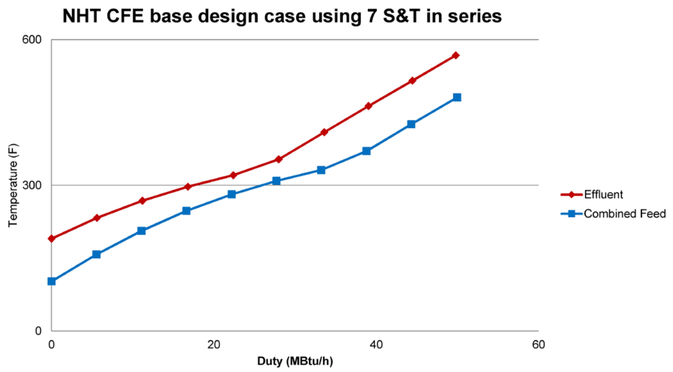

Figure 1. Curve depicting the performance of seven shell-and-tube units in series in a combined feed/effluent exchanger.

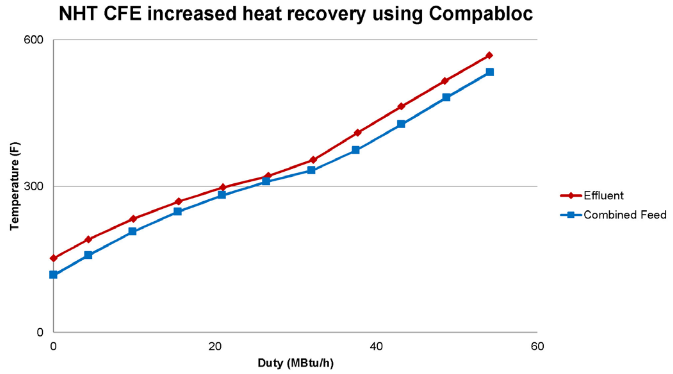

Figure 2. Improved performance and heat recovery.

Table 1. Temperature approach comparison

CFE heat exchanger	Hot approach temperature	Internal pinch temperature
Shell-and-tube	48.2˚C (86.8˚F)	22˚C (39.6˚F)
Compabloc	19.11˚C (34.4˚F)	6.7˚C (12.1˚F)

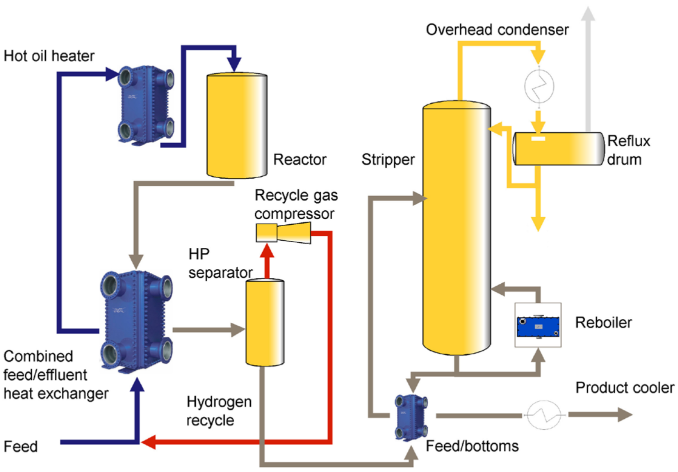

Figure 3. Optimised naphtha hydrotreater unit using Alfa Laval technology for a Gulf Coast refiner.

early in the process design phase. This is the proper time to evaluate alternative heat exchanger technologies such as the performance of welded plate heat exchangers. Welded plate heat exchangers 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 of traditional technologies while minimising the fouling rate. The flow geometry also achieves close to countercurrent flow, which is suitable for small temperature differences and high heat recovery. Finally, a single welded plate heat exchanger can replace several shell-and-tube heat exchangers, reducing the amount of space required for installation by 90%. Because there is a risk of salting or gumming in the CFE, the Compabloc is designed to be fully mechanically cleanable on both sides through hydroblasting on site.[1]

The project team evaluated an alternate heat integration for the CFE exchanger to capitalise on the advantages of the higher performance provided by the Compabloc (Figure 2).

The results of the comparison showed a more than 50% reduction in HAT and an internal pinch temperature that was less than one-third than that of the shell-and-tube design. Table 1 shows the temperature comparison between the shell-and-tube heat exchangers and the Compabloc unit.

It should be noted that the shell-and-tube technology can technically perform at the higher heat recovery levels; however, due to the low temperature difference, more than 12 shells in series and a substantial amount of surface area would be required to do so. The goal of the comparison was to understand the practical amount of heat recovered in the two technologies and its effect on the capital and operating expenditures, not the least of which was the hot oil heater duty. Because of the increased performance of the Compabloc CFE, the hot oil heater duty was reduced by 40%.

Stabiliser feed/bottoms exchanger

This position in the process recovers heat from the naphtha product and preheats the feed to the stripper tower. Heat recovery optimisation here will reduce the stripper reboiler load, thereby lowering operating costs for the column. The stabiliser feed/bottoms exchanger is also suitable for welded plate technology instead of shell-and-tube technology and this position was optimised around the performance of a single welded plate exchanger. If shell-and-tube technology were used to perform the same duty, four or more shells in series – at considerably higher cost – would be required.

Hot oil heater

For this refinery's process, hot oil – not a fired heater – supplies the heat to warm the reactor feed to the required reaction temperature. It is advantageous for the hot oil temperature and flow rate to be as low as possible to reduce operating costs; a hot oil temperature of approximately 16.6˚C (30˚F) above the reactor temperature was selected. Because of the small temperature difference between the fluids, several large shell-and-tube heat exchangers would be required to perform the heating duty; even after considering the 40% reduction in duty of the Compabloc CFE.

In addition to the above two services, a single heat exchanger was also selected to heat the reactor feed.

Case study conclusion

Substantial capital and operating cost benefits can be realised by replacing shell-and-tube heat exchangers with welded plate exchangers as a combined feed/effluent heat exchanger, hot oil heater, stabiliser feed/bottoms exchangers (Figure 3). The value of this performance improvement was calculated at the process design stage and, early in the project cycle, drove the decision to use welded plate technology. Throughout the project, the end user, contractor and supplier worked together to design, install, start-up and operate these heat exchangers. The exchangers were installed and successfully commissioned in 2016.

According to the refinery's process engineering manager, the units are performing well with no increase in pressure drop that would indicate fouling or salting. This Gulf Coast refinery is now operating one of the most energy-efficient hydrotreaters in the world, thanks to the use of welded plate heat exchangers.

Recommendations

- It is important to consider how welded plate heat exchangers may enhance heat exchanger performance during the initial phases of a NHT design or revamp project. Designs that rely on rules of thumb for the use of traditional equipment limit the potential for performance and cost optimisation.
- Improved heat exchanger performance often has profound effects on the cost and performance of upstream and downstream equipment. The process designer along with the heat exchanger supplier can recognise and monetise the potential value by simulating improved heat exchanger performance and its effect on the process.
- Engaging key suppliers in the process design stage will not only give the process designer the data to simulate performance, but also to leverage that supplier's experience in order to ensure a good design results in reliable operation in the field.
- A heat exchanger does not necessarily need to be used in a heat recovery service to benefit from the enhanced performance of welded plate technology. Using welded plate technology in certain positions, such as overhead condensers, product coolers, or product heaters (e.g. the hot oil heater), may also deliver measurable performance improvements to refiners. Therefore, replacing shell-and-tube technology with welded plate technology in these positions may also prove beneficial.

Conclusion

The performance of many refinery and petrochemical processes can be improved by welded plate heat exchangers. However, a paradigm shift is required to study their performance at the earliest stages of a project, where traditionally rules-of-thumb are used to determine heat exchanger performance. Collaboration with key suppliers is the key to unlock the value in increasing performance; as evidenced by this US refiner.

Reference

1. MARK, W. and GRAY, G. L., 'Proper Design and Operation of NHT CFE Equipment', Mucek, American Fuel & Petrochemical Manufacturers, (2011).