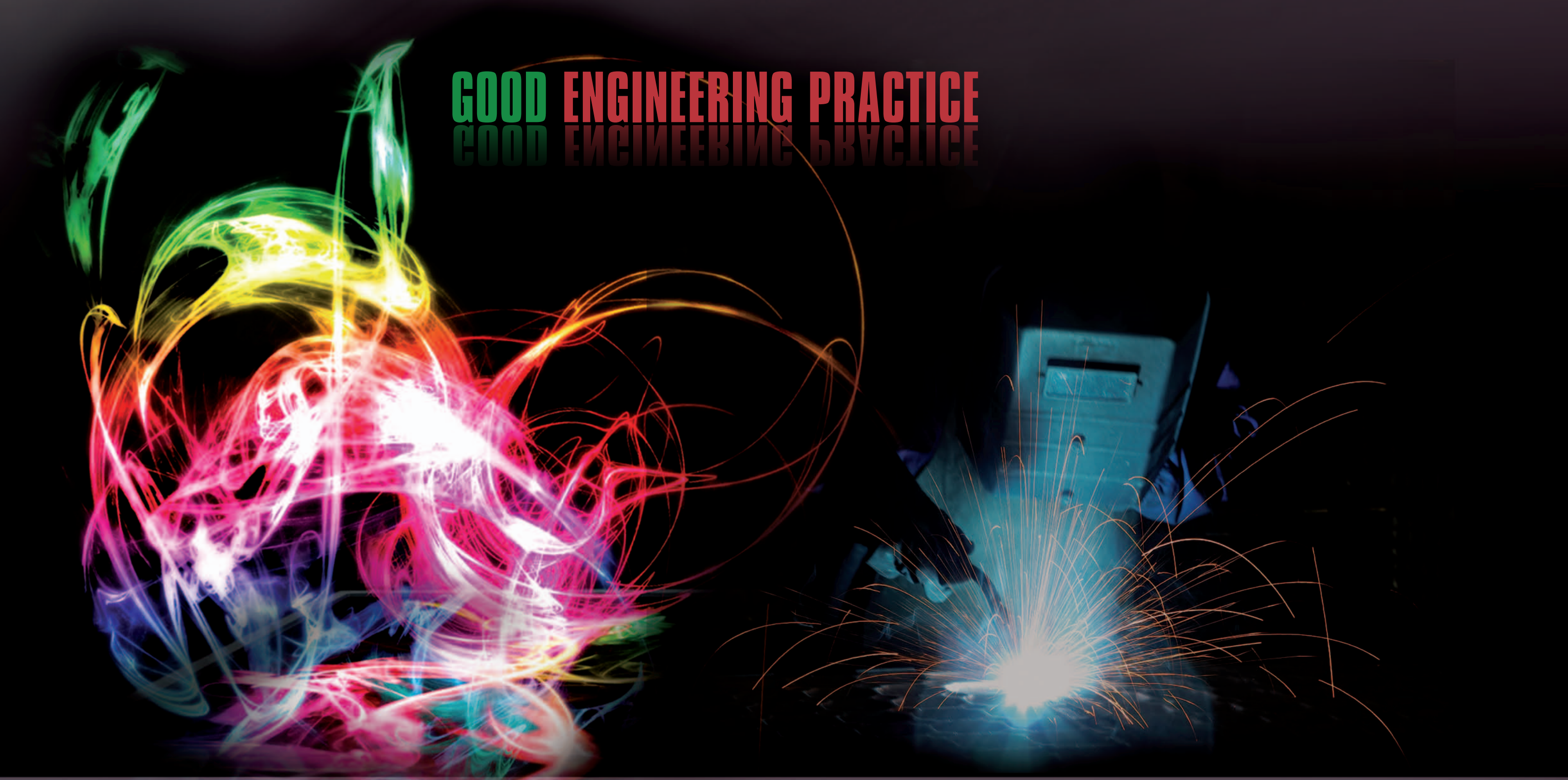
GOOD ENGINEERING PRACTICE



Stefan Gavelin, Tranter International AB, looks at engineering practices for all welded shell and plate heat exchangers.

All welded shell and plate heat exchanger technology is an emerging technology, which is rapidly becoming a promising choice for heat exchangers in the hydrocarbon industry, for both single phase flow and two phase multi component flow. The reason is the high heat transfer rates, small internal and external volume and small temperature differences (crossing temperatures) obtainable with this type of technology, factors which are very much in line with the industry's need to reduce energy consumption and greenhouse gas emissions. Plate technology is, however, not an emerging technology; it has been used for decades in the industry, but it is not until recently that the advantages of shell and plate technology over other plate technologies/shell and tube technology have become ever more apparent.

In comparison to shell and tube heat exchangers, the all welded shell and plate heat exchanger offers several benefits. As mentioned, the most important of these are the higher heat transfer coefficient (3 – 5 times higher) and the ability to work with crossing temperatures (hot fluid outlet temperature lower than cold fluid outlet temperature). However, in order to exploit these advantages to the maximum, it is necessary to consider the heat exchanger as part of a system and not as a single component. An efficient heat exchanger cannot be achieved if the design work has been carried out in isolation from the rest of the process. By considering the heat exchanger as part of a system, much can be done to reduce fouling and corrosion while improving the reliability, availability and maintainability (RAM) of the process.

This article attempts to explain these advantages in more detail by first exemplifying some common problems that may occur in the overhead condensers in a crude distillation unit (CDU) and then describing how the shell and plate heat exchanger can help solve these problems. The overhead condenser in a CDU is a perfect example of where good engineering practice regarding the design of the heat exchanger is required, and where the RAM is extremely important for the refinery's output. The

Figure 1. The plate patter exposes the vapour to the surface.

importance of a trouble free heat exchanger then becomes more apparent than ever. As will be described, much can be done to improve the design if the heat exchanger is considered as part of the system.

CDU

Excessive fouling and severe corrosion rates in overhead condensers are common problems in CDUs. The complex mixtures of crude oils make it a challenge to select proper equipment to minimise these problems. Some of the underlying problems are the varying quality of the incoming crude, inadequate desalting and the inappropriate use of process chemicals. The consequences of these problems are refinery downtime and increased energy consumption. It is therefore important for the heat exchanger designer to understand how different operating parameters affect the heat exchanger's performance, and what can be done to take these varying parameters into account in the design of the heat exchanger.

A typical problem

Consider a CDU with two overhead condensers connected in series. In such a case, condensation is achieved in two stages. The first stage operates at an inlet temperature of 150 ˚C and an outlet temperature of 120 ˚C. The second stage inlet temperature is 118 ˚C and the outlet temperature is 60 ˚C. The overhead stream is cooled by 40 ˚C crude oil that is preheated before entering the furnace. Corrosion inhibitors are injected ahead of the first condenser and wash water is injected prior to the second condenser. Furthermore, the current condensers are shell and tube heat exchangers in carbon steel with the crude oil on the tube side and the overhead stream on the shell side.

The CDU overhead condensers are causing significant problems in terms of the refineries' operability. Serious corrosion in the first stage condenser has been encountered and the pressure drop on the shell side of the shell and tube heat exchanger has significantly increased due to heavy fouling in the CDU overhead stream. The fouling has also resulted in an under surfaced heat exchanger, and thus the heat exchanger is not performing as required. The root of the problem may lie in the process operating parameters in conjunction with a wrong choice of condenser type. As will be shown, much can be done to improve the RAM of the process by studying the heat exchanger as part of a system and not as a single component.

A typical solution

Having 40 ˚C crude oil on the tube side of the heat exchanger generates local condensation points at the inlet of the first stage condenser, where hydrochloric acid vapour is absorbed almost instantaneously, creating low pH regions (first water droplet) and accelerated corrosion. The corrosion can be so severe that heat exchangers can completely fail in a matter of days. To avoid this, the continuous wash water injection point should be moved to the inlet of the first condenser, which, in combination with desalting, provides excellent protection against corrosion. The wash water helps maintain a sufficient amount of liquid water at the inlet of the overhead condenser, just enough to avoid the high acidity and low pH points.

The above change in the process will help mitigate the problem, but more can be done in relation to the problems with corrosion, fouling and under surface by studying the overhead condenser itself. The construction materials can obviously be changed to a more exotic material than carbon steel, such as HASTELLOY® or Inconel, in order to

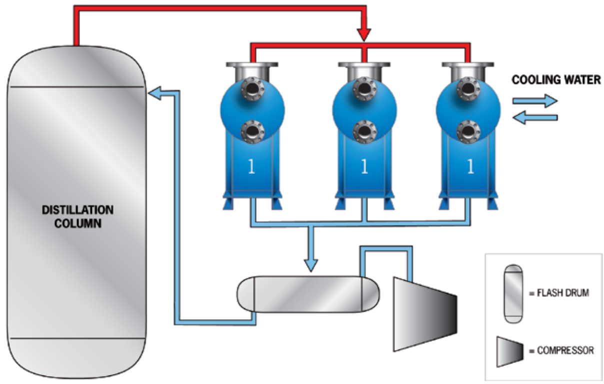


Figure 2. Shell and plate overhead condensers.

increase the corrosion resistance. Modifying the construction materials is a trade off between increased availability and cost of the heat exchanger. It then becomes apparent that the efficiency of the heat exchanger determines the return on investment, as the heat transfer area is inversely proportional to the efficiency. Since the shell and plate heat exchanger is more efficient than a shell and tube heat exchanger, it is not difficult to see that significant life cycle cost savings can be achieved by investing in this technology.

Regarding fouling on the shell side, it is obvious that the fluid shear stress on the tube wall is not sufficient to prevent fouling from occurring, thus it would be better to install a compact shell and plate heat exchanger that offers high shear rates due to the narrow channels that enhance turbulence. Furthermore, the wash water also reduces the condensing capacity of the overhead condensers (log mean temperature difference or LMTD decreases with water injection), and this has to be overcome by installing additional surface area. Again, it is clear that a highly efficient shell and plate heat exchanger is required to reduce the heat transfer area as much as possible. Fluctuating LMTDs also place special demands on the thermal design of the heat exchanger; these will be discussed further in the next section.

RAM considerations

- Reliability, thermal design of the heat exchanger.
- Availability, resistance against corrosion, fouling.
- Maintainability, ease of maintenance and overall maintenance cost.

Availability

Corrosion resistance is directly related to the construction material. As seen in the example with the CDU overhead condenser, the construction material for a shell and tube heat exchanger is often carbon steel, which is not very practical for preventing corrosion. A shell and plate heat exchanger is always designed with zero corrosion allowance and because of the highly efficient plate, less area is required in comparison to a similar shell and tube unit. It is therefore possible to upgrade the materials to reduce the risk of corrosion without necessarily increasing the cost. Plate materials such as 316L, 254SMO and C276 can be used, and in comparison to shell and tubes, the costs are lower.

The operability of shell and plate heat exchangers depends on the fluid fouling tendency. Normally, it is quite hard to model the heat exchanger's performance during extreme operating conditions, as the amount of fouling occurring on the plates varies from one process to another. An important design parameter to mitigate fouling is therefore the wall shear stress, which should aim to be at least 50 Pa in order to maximise the availability of the heat exchanger. The corrugated plate design enables turbulent flow at low velocities that not only results in high shear stress, but also high film coefficients. In comparison to shell and tube heat exchangers, the shear stress in a corrugated channel can

Figure 3. Shell and plate heat exchanger.

be approximately five times higher for the same duty, which will help minimise refinery downtime.

Many engineering firms, however, seem to think that being conservative is the best way to ensure that the heat exchanger will perform. It is therefore quite common that the heat exchanger is designed to handle flow rates that are significantly higher than the normal operating flow rates. What then happens is that the shear stress decreases due to the flow reduction in each channel, which not only reduces the shear stress but also results in an over surfaced heat exchanger that may be hard to control. Sizing a plate heat exchanger with high safety margins on the duty and flow rates is thus impractical, as in normal service the process does not have enough flow to maintain adequate velocity.

Maintainability

Maintainability is often associated with the exchanger's ease of mechanical cleaning. Efficient mechanical cleaning of the narrow channels in a welded plate exchanger is, however, almost impossible when the fouling is very severe (e.g. the type of fouling occurring in some amine heat exchangers). An openable exchanger makes mechanical cleaning/inspection of the plate pack easier, but it is nevertheless always recommended to invest in a proper chemical treatment programme, install upstream filters and prepare for cleaning-in-place (CIP) or back flushing. Because of the difficulties involved in mechanical cleaning of welded heat exchangers, maintainability here is assigned a somewhat different meaning, namely the preventive actions that should be taken to reduce the cost of maintenance.

To reduce this cost, it is important to understand the value of reliable and effective filtration upstream of the heat exchanger. If excessive fouling is expected, it may be beneficial to improve filtration to reduce fouling of the heat transfer surface. A plate heat exchanger is a good filter due to its narrow channels. It can be claimed that a plate heat exchanger is the most efficient filter available if the fluid has particles in it larger than the flow passages between plates. In such case, it is recommended to install a good self cleaning filter to protect the heat exchanger. The investment cost for such a filter varies with the efficiency, but the return on investment would be significant due to the difficulties associated with mechanical cleaning. Cleaning the welded heat exchanger repeatedly would also not eliminate the problem of a high maintenance cost.

Different chemical treatment programmes may also help in reducing the cost of maintenance. In some cases, a heat exchanger may need to be cleaned every 30 – 60 days, but with proper chemical treatments, the frequency could be reduced to every 8 – 10 months. The longer the run length of the heat exchangers, the higher the return on investment of the chemical treatment programme. The total maintenance cost of cleaning a heat exchanger needs to be calculated and plotted against the cost of the chemicals. Each cost is inversely proportional to the other, i.e. as chemical treatment increases, the maintenance cost decreases, but the cost of the chemicals increases. It is therefore important to perform a life cycle cost analysis when calculating the total maintenance cost. Apart from reduced maintenance cost, chemical programmes also offer other benefits, such as greater heat transfer capacity.

Reliability

As seen in the example with the CDU overhead condenser, the biggest reason for not installing the wash water system ahead of the condenser is the expected LMTD reduction that can significantly reduce heat exchanger performance. This must be compensated by additional heat transfer area. Selecting the correct heat transfer area can be somewhat difficult without knowledge of how exactly the wash water influences the LMTD. It is therefore important to understand the governing laws of condensation when designing a CDU overhead condenser to be able to make rough estimations of the additional area required and of how the LMTD reduction will affect the heat exchanger's performance.

The mechanisms of condensation in plate heat exchangers are basically those of gravity controlled film condensation and a shear controlled process in which convective mechanisms dominate. The corrugated plates have the advantage that the condensate drainage process is improved by surface tension drawing the liquid into the bottom of each corrugation, thus thinning the liquid layer on the active heat transfer surface. This action provides a liquid-free surface exposed to the hydrocarbon gas, which augments the heat transfer coefficient since no condensate film will form on the plate wall that would add resistance and restrict condensing. In comparison to a shell and tube heat exchanger, the shell and plate heat exchanger therefore has a greater percentage of surface area in direct contact with the gas, and this feature increases the efficiency, resulting in a more compact design. Figure 1 shows the corrugated plates that enhance heat transfer.

A heat exchanger duty specification usually specifies the required heat flux (q/A = h*deltaT), and then the classic Nusselt theory can be used for estimating the heat transfer coefficient in gravity controlled condensation:

$$\alpha = C \cdot \lambda \cdot \left(\frac{h_{fg} \cdot g \cdot \rho}{\nu \cdot L \cdot a / A} \right)^{1/3} \qquad (1)$$

The classic Nusselt theory is only valid for low Reynolds numbers (laminar flow) on a plain wall, which is a quite conservative approach for a plate heat exchanger. As plate heat exchangers have a rather different geometry, the heat transfer coefficient will be further improved by the shear controlled condensation where the liquid layer is assumed to be turbulent (high Reynolds numbers). In the shear controlled region, the velocity of the vapour will increase the heat transfer coefficient (provided that the vapour velocity increases the flow velocity of the liquid film on the condensing surface), thereby decreasing the film thickness. There are no general correlations available for this region, but one way to estimate the heat transfer coefficient is by using a multiplier of the liquid only coefficient. The following method was suggested by Thonon and Chopard (1995):

$$\alpha = \sqrt{\alpha_l^2 + \alpha_{Nu}^2} \qquad (2)$$

In this method, the liquid heat transfer coefficient is calculated using liquid properties and the entire mass flow as liquid. αNusselt is calculated using the theory by Nusselt (Equation 1). This approach predicts most data within ±25% and is an area averaged value if the local heat transfer coefficient, and hence the dependency of the vapour quality variations downstream of the plate, is not considered. Once the condensation film coefficient is known, the heat exchanger U value can be calculated using conventional theory for single phase heat transfer and pressure drop in corrugated channels. When the U value is known, the required area can be estimated from a simple heat balance across the heat exchanger. By calculating the required area for a range of LMTDs, it is relatively easy to understand how the fluctuating LMTD caused by the wash water in the CDU overhead condenser affects the performance of the heat exchanger.

Conclusion

Condensation of light hydrocarbons from the overhead of a CDU or any other low pressure or vacuum process is not only challenging from the point of view of corrosion and fouling but also from a thermal design point of view. Although the shell and plate heat exchanger provides the thermal efficiency required, it is still vital to consider the heat exchanger as a part of the system and not as a single component. This is to ensure that the RAM of the equipment is maximised. Proper filtration, cleaning methods, materials selection and process parameters are important for the overall RAM. If the information about the system is disclosed to the heat exchanger manufacturer it will be easier for them to optimise the design of the exchanger as more parameters that affect the performance can be taken into account. This provides a more system integrated design instead of an isolated single component design. An integrated design will in the long run contribute to higher RAM index for the process.

The shell and plate exchanger is a highly efficient, compact, all welded plate heat exchanger, ideal for many condensation applications. Constructed in stainless steel, HASTELLOY® or titanium, it offers the ability to upgrade construction materials at a lower cost compared to shell and tube units. The foundation layout and Mount of the shell and plate heat exchanger are almost identical to those of the shell and tube heat exchanger, allowing for easy retrofit applications. Generally, the shell and plate heat exchanger can also be designed to be more resistant to fouling due to the high shear stress on the plate wall. These features result in lower energy and maintenance costs for the plant. However, as mentioned, all heat exchangers are of little use if they have been designed in isolation. It is therefore essential that heat exchanger manufacturers and engineering companies cooperate to avoid costly surprises at a later date.