Compact Heat Exchangers: Improving Heat Recovery

Utilizing quench water energy at an European ethylene plant

Global warming is of major concern today. There is increasing pressure on industry to reduce both energy usage and the associated CO_2 emissions. An important and profitable action that industry can take is to recover more process energy and thus improve the efficient use of that energy. This not only reduces the cost of primary energy supply and lowers CO_2 emissions, but also provides benefits in terms of reductions in heat rejection and in the associated equipment and operating costs.

While making such investments, it is also important that financial returns are maximized and that further opportunities for saving energy and reducing emissions are not missed. This article considers the use of compact heat exchangers (CHEs) for improved heat recovery, as they often achieve higher levels of savings with a better payout rate than more conventional alternatives.

Compact heat exchangers

The dominant type of heat exchanger in process plants today is the shell and tube. In many cases, it is an appropriate selection for the service required. However, because engineers are familiar with shell-and-tube varieties, they tend to select them "by default," without considering alternatives. If engineers' minds were opened to alternative technologies, such as compact heat exchangers, many heat-exchanger specifications might look different.

There are many different kinds of compact heat exchangers. The most common is the gasketed plate-and frame heat exchanger. All CHEs These units offer distinct advantages over shell-and-tube heat exchangers, as quantified by the example presented here use corrugated plates between the heating and cooling media. The design provides the advantages of high turbulence, high heat-transfer coefficients and high fouling resistance. High heat-transfer coefficients allow smaller heat-transfer areas compared to traditional shell-and-tube heat exchangers used for the same duty. This ultimately results in significant size reductions and weight savings as less material is needed to construct the unit. This is especially important when working with expensive corrosion-resistant metals such as titanium and Hastelloys, for example.

The gasketed plate heat exchanger is often the most efficient solution. In petrochemical and petroleum-refinery applications, however, gaskets frequently cannot be used because aggressive media result in a short lifetime for the gaskets or because a potential risk of leakage is unacceptable. In these cases, all-welded compact heat exchangers without inter-plate gaskets should be considered. There are several different kinds available in the market today. In the case presented in this article, a unit with overall fully counter-current flow is used to enable the required heat recovery, while also allowing mechanical cleaning. In addition, all welds are accessible for repair purposes if this type of maintenance becomes necessary during the life of the exchanger.

Figure 1. **All-welded compact heat exchangers are very compact compared to shell-and-tube heat exchangers**

When to use CHEs

CHEs can be used in most industrial applications as long as design temperature and pressure are within the accepted range, which normally is up to 450°C and 40 barg. CHEs are often the best alternative when the application allows gasketed or fully welded plate heat exchangers, when a high-grade, expensive construction material is required for the heat exchanger, when plot space is a problem or when enhanced energy recovery is important.

When the application allows shell-and-tube heat exchangers to be manufactured completely of carbon steel, such design normally provides the most cost-efficient solution. However, even in those cases, CHEs can have advantages, such as space savings, superior heat recovery and a higher resistance to fouling, which make them well worth considering.

If you do not know if your application can be handled by compact heat exchangers, ask a vendor. Suppliers are normally willing to give you a quick budget quote when their equipment is appropriate for your application so that you can compare solutions and determine which would be best for you. As part of the vendor enquiry, design options for enhanced heat recovery can be quantified and additional energy saving benefits and capital cost changes can be defined. At this stage, in some circumstances, it may be favorable to respecify the heat-exchanger performance requirements to take advantage of the improved heat recovery that can be achieved with a CHE.

CHE versus shell-and-tube

All-welded CHEs consist of plates that are welded together (***Figure 3***). Among the many models available on the market today, all have one thing in common: they do not have inter-plate gaskets. This feature is what makes them suitable for processes involving aggressive media or high temperatures where gaskets cannot be used.

On the other hand, some of these all-welded heat exchangers are sealed and cannot be opened for inspection and mechanical cleaning. Others can be opened, allowing the entire heat-transfer area and all welds to be reached, cleaned and repaired if necessary.

Because all-welded heat-exchanger plates cannot be pressed in carbon steel, plate packs are available only in stainless steel or higher-grade metals. The cost of an all-welded compact heat exchanger is higher than that of a gasketed plate heat exchanger. Nevertheless, in cases where gaskets cannot be used, all-welded compact

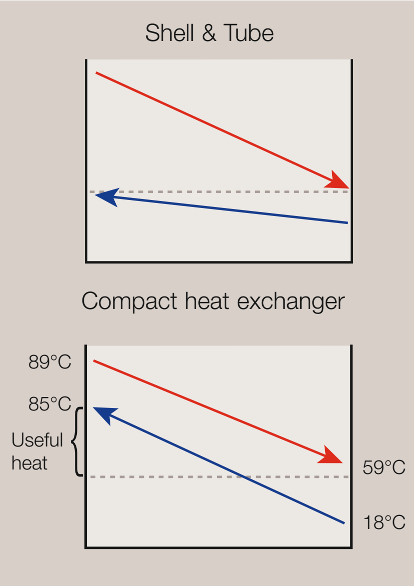


Figure 2. **For a compact heat exchanger with counter-current flow, as shown in Figure 3, it is normally possible to decrease the temperature approach to 3–5°C**

plate heat exchangers are still often a strong alternative to shell-and-tube heat exchangers.

The most-efficient, compact, plate heat exchanger designs have countercurrent flows or an "overall countercurrent flow" created by multi-pass arrangements on both the hot and cold sides. Such units can be designed to work with crossing temperatures and with temperature approaches (the difference between the outlet temperature of one stream and the inlet temperature of the other stream) as close as 3°C.

As mentioned before, all-welded CHEs are very compact in comparison to shell-and-tube heat exchangers. CHEs have this advantage due to their higher heat-transfer coefficient and the resulting much smaller heat-transfer area. The units typically occupy only a fraction of the space needed for a shell-and-tube exchanger. Space savings are accompanied by savings on foundations and constructional steel work, and so on. The space needed for maintenance is also much smaller as no tube-bundle access and withdrawal space is required.

Due to the short path through the heat exchanger, the pressure drop can be kept relatively low, although this depends on the number of passes and the phase of the fluid. For most liquid-to-liquid duties, a 70–100 kPa pressure drop is normal, while for a two-phase flow, the pressure drop can be as low as 2–5 kPa.

Regarding heat recovery, the main advantage of the CHE is that it operates efficiently with crossing temperatures and close temperature approaches. This makes it possible to transfer more heat from one stream to another or to use a heating medium that is just a few degrees warmer than the cold medium.

There are two main reasons why all-welded CHEs are more thermally efficient than shell-and-tube heat exchangers:

- All-welded CHEs have high heat-transfer coefficients. This is due to the high turbulence created in the corrugated plate channels. The high turbulence results in thin laminar films on the surface of the heat-transfer area. These have a much lower resistance to heat transfer compared to the thicker film found in a shell-and-tube heat exchanger
- Counter-current flows (or overall counter-current flows) can be achieved in all-welded compact heat exchangers. This means that a single heat exchanger, operating with crossing temperatures and a close temperature approach can replace several shell-and-tube heat exchangers placed in a serial one-pass arrangement, to emulate the counter-current flow of the compact heat exchanger design As a result, CHEs may be more cost-effective and may present a more practical alternative to shell-and-tube heat exchangers. In addition to the financial benefits, space savings can also be an important factor for upgrading existing plants as well as for new plant designs.

The advantages of CHEs over shell-and-tube heat exchangers will become clear with the following example taken from an actual application.

A real application example

In a recent feasibility study for improving the energy efficiency of a European ethylene plant, a number of opportunities to increase the export of high-pressure (HP) steam to the site's utility system were identified. The changes included unloading the refrigerant compressors and increasing heat recovery from the quench water loop.

One such opportunity was the replacement of an existing quench water/ polished water shell-and-tube heat exchanger that was limiting heat recovery. From an energy point of view, it was desirable to maximize heat trans-

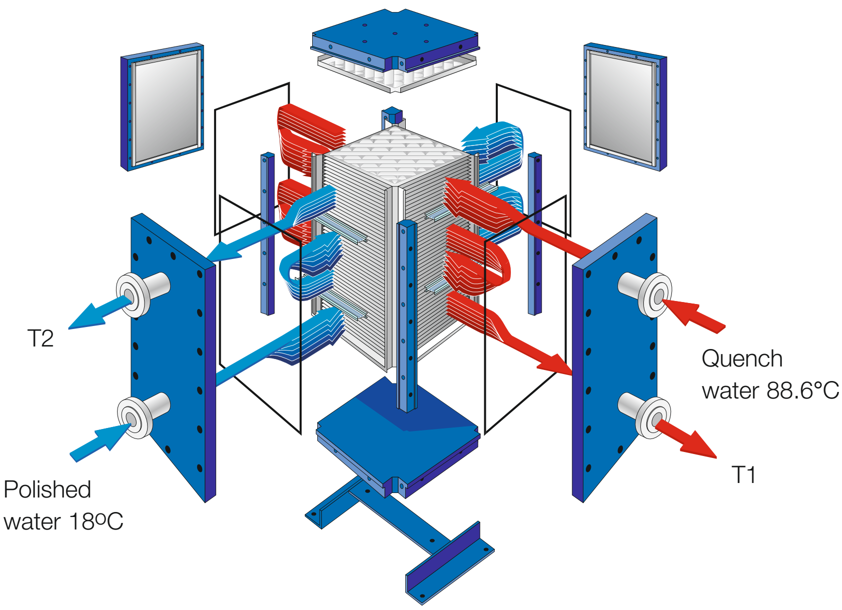


Figure 3. **Sectional view of Compabloc**

fer between these streams. This would reduce both the low-pressure (LP) steam required for boiler feed water (BFW) deaeration (due to an increase in de-aerator BFW feed temperature) and would also reduce the heat-duty load on the cooling water tower (a site bottleneck), due to a reduction in quench water cooling against cooling water.

The required minimum performance of the replacement heat exchanger is detailed in ***Table 1***.

Table 1. required minimum performance of replacement heat exchanger				
Process fluid		T in, °C	T out, °C	Duty, kW
Hot side	Quench water	88.6	58.9	10,000
Cold side	Polished water	18.0	77.0	

A preliminary assessment of the suitability of a shell-and-tube heat exchanger indicated that two shells in series (468 m^2) would be an economical compromise, achieving a heat recovery of 10 MW with an 11.6°C temperature approach at the hot end.

At this stage, a compact heat exchanger was compared with the shell-and-tube alternative. An all-welded rather than a gasketed plate heat exchanger was chosen because of limited gasket lifetime when there is contact with quench water. Additionally, because of potential quench-water side fouling, an all-welded heat exchanger that could be mechanically cleaned was preferred.

As mentioned previously, selecting an all-welded CHE instead of a shell-and-tube heat exchanger makes it possible to further increase energy savings, by reducing temperature approach. In this case, the hot-end temperature approach determines the duty and thus the size and design of the heat exchanger. For a compact heat exchanger with counter-current flows it is normally possible (and economical) to decrease the temperature approach to 3–5°C. To take advantage of this potential, various improved heat recovery designs were investigated.

A summary of alternative heat-exchanger designs is shown in ***Table 2***. There, it can be seen that the heat-transfer coefficient for the compact heat exchanger is much higher than for the shell-and-tube heat exchanger. This is due to the highly turbulent flow created by the corrugated plates in the CHE. As a result, a much smaller heat-transfer area is required. When comparing the cost of the all-welded CHE and the shell-and-tube heat exchanger, it should be remembered that the plate material in the CHE is stainless steel (ANSI 316L), while carbon steel is used in the shell-and-tube heat exchanger.

It should also be noted that the pressure drop is higher for the compact heat exchanger than for the shell-and-tube heat exchanger. This will, of course, increase the fluid-pumping cost. A true comparison must take these costs into account. However, since the pumping costs are usually small when compared to the overall energy savings achieved, the financial outcome for this example is unlikely to change.

The installation cost of shell-and-tube heat exchangers will be higher, especially for a multi-shell design. In this case, the total installed cost comparison would therefore be significantly more favorable for compact heat exchangers than the purchase cost comparison given above.

For the heat exchangers considered in this example, ***Table 3*** shows how energy and emissions reductions improve as the cold-side outlet temperature is increased to reduce the hot-end temperature approach from 11.6°C to 3.9°C. To achieve this, 50%

Table 2. A summary of alternative heat-exchanger designs										
Case	Type		# of units	Heat duty, kW	LMTD* corrected, °C	Overall heat-transfer coefficient, W/(m^{2}K)	DP hot side, kPa	DP cold side, kPa	Heat transfer area, m^2	Purchase cost, %
Base	Shell-and-tube	BEM	2	10,000	23.3	921	7	17	468	100
Case 1	Compact HE	CPK75-202	1	10,000	23.3	3,373	50	97	129	99.6
Case 2	Compact HE	CPK75-252	1	10,810	15.9	3,667	73	64	161	111.6
Case 3a	Compact HE	CPK75-302	1	11,310	14.8	3,993	53	104	193	125.5
Case 3b	Shell-and-tube	BEM	2	11,310	14.9	879	9	22	864	169.1
* Logarithmic mean temperature difference										

Table 3. Monetary saving comparison of compact heat exchangers versus shell-and-tube heat exchangers									
Case	Type		# of units	Heat duty, kW	LP steam saving		CO_2 credits		Total Million €/yr
					m.t./hr	Million €/yr	m.t./hr	Million €/yr	
Base	Shell-and-tube	BEM	2	10,000	11.7	1.38	3.0	0.50	1.88
Case 1	Compact HE	CPK75-202	1	10,000	11.7	1.38	3.0	0.50	1.88
Case 2	Compact HE	CPK75-252	1	10,810	13.0	1.53	3.2	0.54	2.08
Case 3a	Compact HE	CPK75-302	1	11,310	13.8	1.63	3.4	0.57	2.20
Case 3b	Shell-and-tube	BEM	2	11,310	13.8	1.63	3.4	0.57	2.20

more compact heat exchanger surface area is required. This increases the cost of the unit by only 26%; however, on the other hand, two shell-and-tube heat exchangers in series would be required to achieve the same performance, which would require 85% more heat-transfer area, at a 69% higher cost.

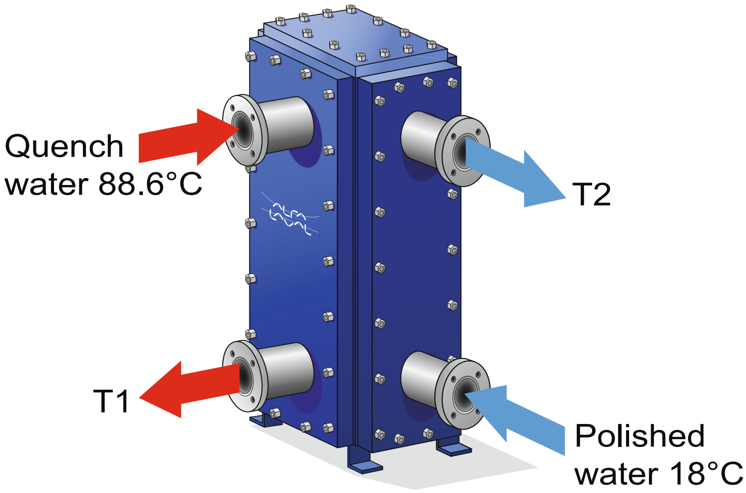
All design options offer reasonable monetary savings. Heat exchanger selection is therefore primarily driven by capital cost. A compact heat exchanger design allows improved heat recovery with only a marginally longer payback time, and therefore, is a strong candidate for selection.

The all-welded compact heat exchanger in Case 3a provides maximum energy savings and CO_2 credits at a lower size, cost and payback time than the corresponding shell-and-tube heat exchanger in Case 3b. With 17% additional monetary saving, the payback time for the compact heat exchanger is only 8% longer, whilst the payback time for the shell-and–tube heat exchanger design is 44% longer.

The following two points should also be noted:

- The installation cost of the all-welded CHE should be lower than for a shell-and-tube, especially when the shell-and-tube design is a multi-shell arrangement, as in this comparison
- All-welded CHEs often provide better lifecycle performance and lower maintenance costs than shell-and-tube designs, because there is less fouling. Less fouling means less-frequent cleaning, which in turn reduces downtime (or at least the maintenance work). Compact all-welded heat exchangers are also very easy to clean. Their panels can simply be removed to allow mechanical cleaning with high-pressure water. Shell-and-tube heat exchangers, on the other hand, take longer to clean.

Figure 4. **Counter-current flows can be achieved in all-welded compact heat exchangers. This means that a single heat exchanger, operating with crossing temperatures and close temperature approach, can replace several shell-and-tube heat exchangers placed in a serial, one-pass arrangement**



Final remarks

There is increasing pressure on industry today to reduce CO_2 emissions. Reducing energy use by improving process heat recovery, is an effective way for companies to respond to this pressure.

Reducing energy use lowers costs for primary energy supply and thus reduces operating costs. Also if primary energy supply is reduced, heat rejection must also reduce. Overall, the capital investment cost for all heat transfer equipment is often lower.

It is our experience that opportunities for improved heat recovery and reduced CO_2 emissions exist in most chemical process industries (CPI) plants, and that some of these opportunities can be realized with short payback times. This allows companies to contribute to CO_2 reduction initiatives and to reap financial benefits.

Effective feasibility studies for reducing energy use should follow a systematic approach and involve equipment vendors, to ensure that all potential opportunities are fully exploited.

Finally, all-welded compact heat exchangers can often improve heat recovery, while achieving greater savings with a better payback rate than more conventional alternatives such as shell-and-tube heat exchangers.

Figure 5. **The Compabloc is perfect for situations where minimal installation space is available and high heat recovery is desired.**

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