May 2010 Postal Reg.No.MH/MR/N/31/2008-10 Price Rs 85/- ISSN-0971-5266

CHEMICAL INDUSTRY DIGEST

A BLOCKDALE PUBLICATION Refinery, Heat Exchangers, Plant Commissioning 23rd Year of Publication

Shift to Compact Heat Exchangers

For optimized heat recovery, efficient cooling and reduced chiller load

- **Henrik Andersson,** Alfa Laval, Sweden

Blockdale Publishing
15, Purshottam, 21 J P Road, Nr Navrang Cinema,
Andheri (W), Mumbai-400 058, INDIA
Tel: 022-26207402/32689321 **Fax:** 022-26254921
Email: bcid@vsnl.com **Website:** www.chemindigest.com

Shift to Compact Heat Exchangers

For optimized heat recovery, efficient cooling and reduced chiller load

Henrik Andersson

There is increasing pressure on industry to reduce both energy usage and the associated CO_2 emissions. Two important and profitable actions to take are to recover more process energy and optimize cooling efficiency. 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.

This article first considers the overall advantages of using compact heat exchangers over shell-and-tube heat exchangers through improving performance, savings and a faster payback rate. It then illustrates the advantages of compact heat exchangers with two examples from actual applications and a discussion of how cooling water can be used to reduce chiller load. The first example involves an interchanger in an ethylene cracking plant and the second a secondary condenser in a petrochemical plant.

AUTHOR

Henrik Andersson, marketing manager and application expert for the petrochemicals market unit, Alfa Laval, Sweden. He holds a Master of Science degree in chemical engineering and Bachelor of Science in Business and Economics from Lund University.

The dominant type of heat exchanger in process plants today is the shell-and-tube. There are many reasons why the shell-and-tube occupies this position of dominance, and in many cases shell-and-tube heat exchangers are the best or only option. On the other hand, too often shell-and-tubes are selected almost "by default" because they are a familiar technology. In other words, at times the decision to use a shell-and-tube rather than a compact alternative is made due to lack of knowledge about the performance and reliability of compact heat exchangers.

There are different kinds of compact heat exchangers available in the market today. The most common is the gasketed plate-and frame heat exchanger, which is often the most efficient solution. However, in petrochemical and petroleum-refinery applications, 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.

As quantified by the examples presented later in this article, compact heat exchangers offer distinct advantages over shell-and-tube heat exchangers. They use corrugated plates between the heating and cooling media and the plate 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

Compact heat exchangers offer distinct advantages over shell-and-tube heat exchangers. They use corrugated plates between the heating and cooling media and the plate 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.

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 or hastelloys.

In the two cases and the discussion presented here, the optimal solution is a fully welded heat exchanger that allows overall counter current flow in heat-recovery positions as well as condensation with a low pressure drop and optimal cooling-water utilization. The units are also accessible on both the hot and the cold side of the heat exchanger, which enables mechanical cleaning as well making all welds accessible for repair if needed.

When to use compact heat exchangers

Compact heat exchangers 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. When the application allows it, compact heat exchangers, either gasketed or fully welded, are often the best alternative in situations when a high-grade, costly material is required for the heat exchanger, when a small footprint is an advantage and when optimal energy recovery is important.

If you are not certain whether a compact heat exchanger is appropriate for your application ask a vendor. If the equipment is appropriate for your application, most suppliers are also willing to provide a quick quote so that you can compare solutions and determine which would be best for you.

Compact heat exchanger versus shell-and-tube

All-welded compact heat exchangers consist of plates that are welded together. Among the many models available in 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.

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 as close as 3°C (the temperature approach is the difference between the outlet temperature of one stream and the inlet temperature of the other stream).

Compact heat exchangers 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. When the application allows it, compact heat exchangers, either gasketed or fully welded, are often the best alternative in situations when a high-grade, costly material is required for the heat exchanger, when a small footprint is an advantage and when optimal energy recovery is important.

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, compact heat exchangers 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.

As mentioned earlier, all-welded compact heat exchangers are very compact in comparison to shell-and-tube heat exchangers. This advantage is a result of the higher heat-transfer coefficient and the resulting much smaller heat-transfer area of compact heat exchangers. The units typically occupy only a fraction of the space needed for a shell-and-tube heat exchanger. Small size also means lower weight, which can mean savings on foundation structures, steel work and equipment needed to service the unit. The space needed for maintenance is also much smaller as no tube-bundle access and withdrawal space is required.

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

- All-welded compact heat exchangers 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 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, compact heat exchangers 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.

Case Studies

The following examples taken from actual applications and the discussion further illustrate the advantage of compact heat exchangers over shell-and-tubes. The first example is an interchanger in an ethylene cracking plant and the second is a secondary condenser in a BTX plant.

Case Study 1:
Heat recovery in ethylene production

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. One position in which there was an opportunity to recover energy was in the quench water loop.

The existing quench water/polished water shell-and-tube heat exchanger was limiting heat recovery. From an energy point of view, it was desirable to maximize heat transfer between these streams. This would reduce the low-pressure (LP) steam required for boiler feed water (BFW) de-aeration (due to an increase in de-aerator BFW feed temperature). It 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 replace-

Table 1. Original and energy recovery programs					
	Quench water		Polished water		Heat load
	T,in °C	T,out °C	T,in °C	T,out °C	
Original temp. program	88,6	58,9	18	77	10 000
Energy recovery temp. program	88,6	55	18	85	11 300

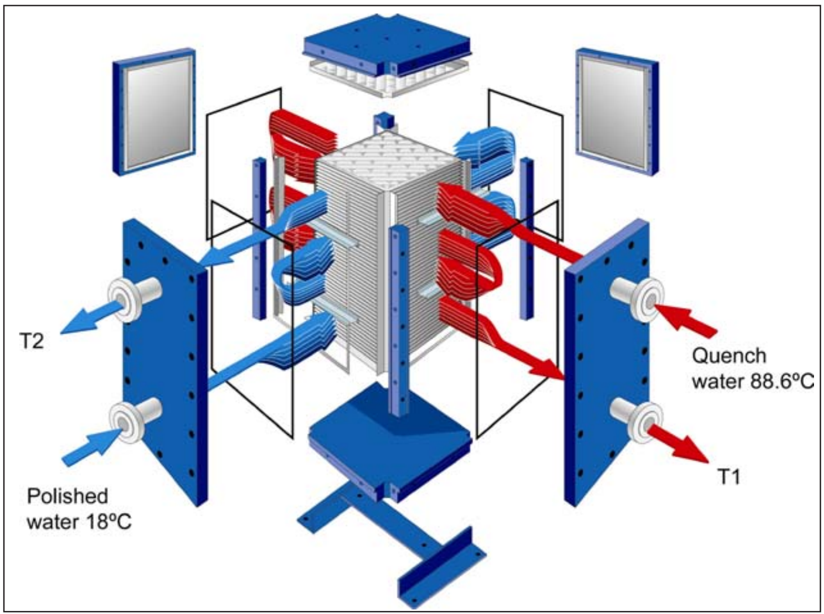


Figure 1. Sectional view of a Compabloc all-welded heat exchanger

ment heat exchanger and the alternative energy recovery temperature performance are detailed in Table 1.

A preliminary assessment of the suitability of a shell-and-tube heat exchanger indicated that two shell-and-tubes in series (468 m2) would be an economical compromise, achieving a heat recovery of 10 MW with an 11.6ºC 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 (Fig 1) that could be mechanically cleaned was preferred. As mentioned previously, selecting an all-welded compact heat exchanger 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 flow, it is possible (and economical) to decrease the temperature approach to 3–5ºC. To take advantage of this potential, various improved heat recovery designs were investigated.

Two alternative heat-exchanger designs are 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 compact heat exchanger. As a result, a much smaller heat-transfer area is required. When comparing the cost of the all-welded compact heat exchangers and the shell-and-tube heat exchanger, remember that the plate material in the compact heat exchanger is stainless steel (ANSI 316L), while carbon steel is used in the shell-and-tube heat exchanger.

With a compact heat exchanger it is possible to decrease the temperature approach to 3-5ºC. In this specific case, an extra 11.3% of useful heat could be recovered compared to the shell-and-tube (Figure 2).

The all-welded compact heat exchanger in the energy recovery case provides maximum energy savings at a lower size, cost and payback time than the corresponding shell-and-tube heat exchanger.

The all-welded compact heat exchanger in the original case provides maximum energy savings at a lower size, cost and payback time than the corre-

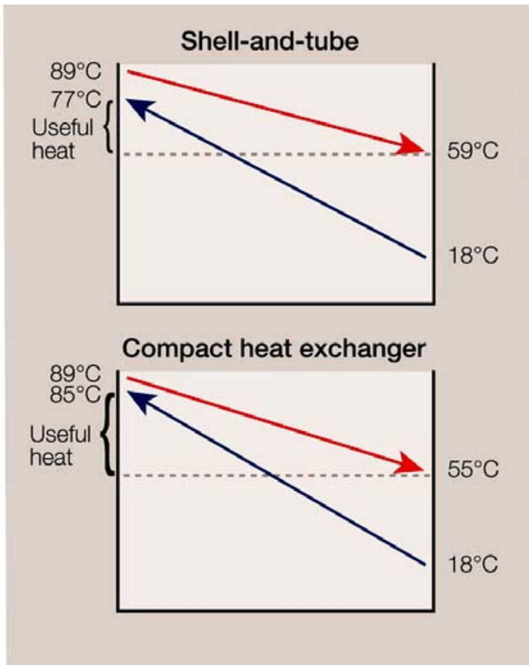


Figure 2. With a compact heat exchanger it is possible to decrease the temperature approach to 3-5°C.

Table 2. Comparison, CHE vs. S&T in quench water case.				
	Original case		Energy recovery	
Type	**S&T, BEM**	**CHE**	**S&T, BEM**	**CHE**
# of units	2	1	2	1
Heat load (kW)	10 000	10 000	11 300	11 300
Overall heat transfer coefficient (W/m^{2}K)	921	3 373	897	3 993
Heat transfer area (m^2)	468	129	864	193
LP steam savings (m.t./hr)				
Money savings (lakh INR)	780	780	920	920
Purchase cost (relative to base)	100%	99,60%	169%	125%

sponding shell-and-tube heat exchanger. In the energy recovery case, with 17% additional monetary saving, the payback time for the compact heat exchanger is only 8% longer, while the payback time for the shell-and–tube heat exchanger design is 44% longer.

Case Study 2:

Better cooling and higher production capacity in petrochemical plant

When a petrochemical producer in South Europe was experiencing product loss due to high summer temperatures, a compact heat exchanger turned out to be the best way to solve their problems.

The company was experiencing difficulties in their toluene column (UOP, Sulpholane process). High summer temperatures lowered the efficiency of the primary condenser (air-cooled condenser) and raised the temperature of the cooling water for the shell-and-tube trim condenser/subcooler. When new process specifications called for increased capacity, the shell-and-tube was unable to handle the increased heat load. The combination of a high cooling-water inlet temperature and cooling-water flow limited by the pressure drop caused excessive scaling: The cooling water rose to temperatures well above the 43°C design temperature. These factors combined led to a decrease in production capacity and loss of product.

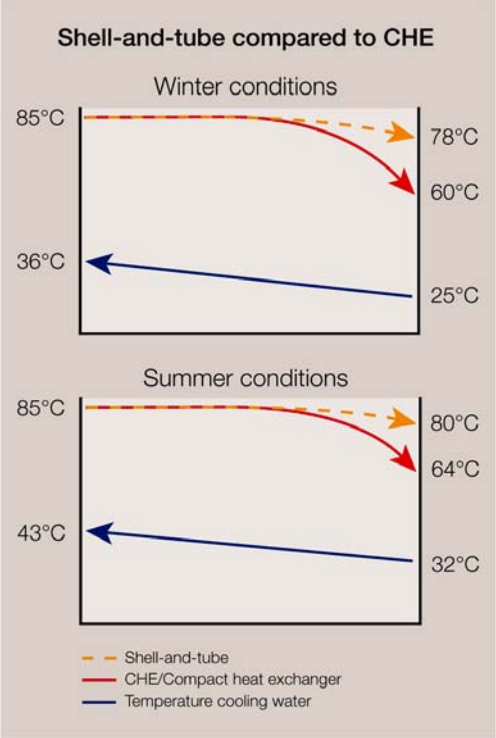
The company reviewed various alternatives and decided to replace the shell-and-tube trim condenser/subcooler with a fully welded compact heat exchanger (Fig 3). The compact heat exchanger is capable of handling the condensation at a very low pressure drop of only 2,1 kPa while reduce fouling by maintaining high turbulence on the cooling water side. The chosen solution also offers accessibility to both the process and the cooling water side for mechanical cleaning during routine maintenance shut downs.

During winter conditions the shell-and-tube just barely manages to achieve full condensation, which takes place at 78°C. With the higher temperatures in summer, full condensation could not be achieved with the shell-and-tube (Fig 4). However, in both cases the compact heat exchanger achieves full condensation including 14-18°C subcooling of the condensate.

The compact heat exchanger offered a number of advantages over a new shell-and-tube design. Three highly important factors made the decision an easy one:

Figure 3. The compact heat exchanger installed just below the primary condenser in the same space used for the old shell-and-tube.

Fig 4. Condenser and trim cooler



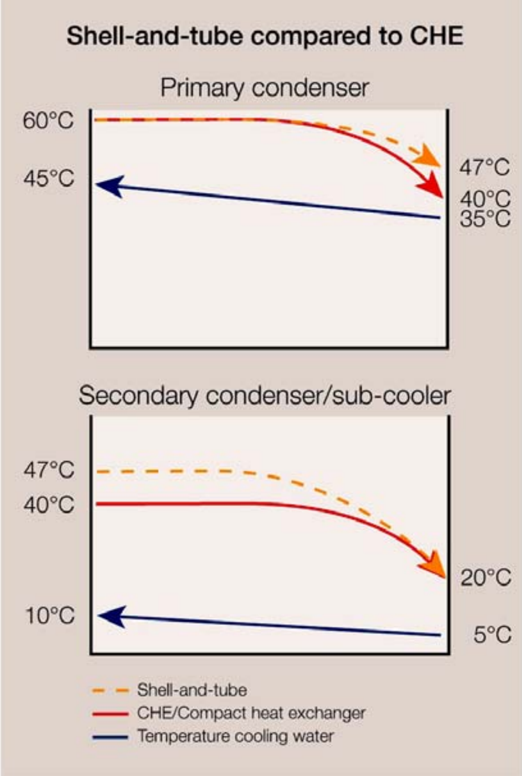
The continuous line shows the CHE thermal performance while the dotted line shows the shell and tube.
The temperature curve for the cooling water is more or less the same for both the shell-and-tube and the CHE.

- A multipass arrangement for the cooling water makes it possible to maintain a high flow velocity that generates sheer forces against the wall and keeps fouling/scaling caused by the cooling water at a minimum. This allows greater cooling efficiency as compared to the shell-and-tube design.
- A better cooling-water flow allows the outlet temperature of the cooling water to be kept at or below the 43ºC specified in the design. Therefore all products are fully condensed even at the highest cooling-water temperatures during summer.
- Because the original shell-and-tube was installed under the air-cooled primary condenser, the space for the new installation was limited. The shell-and-tube design that was proposed as an alternative to the compact heat exchanger solution was too large to fit in the original space allotted. This meant that a shell-and-tube installation not only required investment in the actual unit but also construction of a new foundation and support for the unit. The compact heat exchanger solution, on the other hand, fit perfectly in the original space allotted.

The compact solution offers enough space for both mechanical cleaning and visual inspection of the-heat transfer surface with no need to remove a tube bundle or move the heat exchanger (Fig 5).

Figure 5. The compact solution offers enough space for both mechanical cleaning and visual inspection of the-heat transfer surface.

Fig 6. Vacuum condensation



The continuous line shows the CHE thermal performance while the dotted line shows the shell and tube.
The temperature curve for the cooling water is more or less the same for both the shell-and-tube and the CHE.

Discussion: Reducing the use of chilled water by shifting condensation load to the primary condenser

In the last example above, a compact heat exchanger was used to de-bottleneck a critical position in the plant by switching to a more effective heat exchanger. The same principle of using a compact heat exchanger for de-bottlenecking makes it possible to reduce the use of expensive chilled water through better utilization of cheap cooling water in the primary condenser.

By shifting the cooling load from the secondary condenser to the primary condenser, a large reduction in the refrigerated cooling media can be made in the secondary condenser. Figure 6 shows a comparison between a shell-and-tube condenser system and a compact heat exchanger condenser system. The major difference is the possibility for crossing temperatures in the compact heat exchanger alternative.

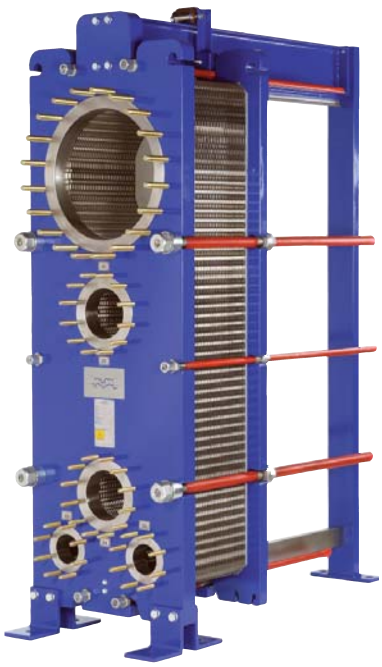
In a vacuum condensation system, the primary condenser is usually cooled with normal cooling water while the trim condenser/subcooler is cooled with a chilled cooling media. In a normal shell-and-tube installation, the outlet temperature of the condensate from the primary condenser is limited to the outlet temperature of the cooling water. Whereas with a compact heat exchanger, the outlet temperature of the condensate is dependant on the inlet temperature of the cooling water. This means that the inlet temperature to the secondary condenser will be considerably lower when a compact heat exchanger is used as a primary condenser. This will lower the cooling load on the refrigerated coolant in the secondary condenser. By replacing a shell-and-tube primary condenser with a compact heat exchanger solution, the load on the refrigerated coolant in the secondary condenser can be reduced by up to 55%.

Lower-pressure condensation can be carried out in highly effective specialized semi-welded compact heat exchangers capable of vacuum condensation with a very low pressure drops (Fig 7).

Myriad opportunities

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 en-

Figure 7. Semi-welded compact heat exchangers.



It is our experience that opportunities for improved heat recovery and reduced CO_2 emissions exist in most chemical process industry 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.

ergy use lowers costs for primary energy supply and thus reduces operating costs. Also, if the 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 industry 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.

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.

The examples described in this article represent but a few of the thousands of applications where compact heat exchangers can improve energy recovery or production capacity simply by optimizing performance. Experience shows that compact heat exchangers are suitable for almost all applications that fall into the range of temperature and pressure for which shell-and- tube heat exchangers are usually used today.

Reprinted from

CHEMICAL INDUSTRY DIGEST

Issue No: Vol.XXIII.5. May 2010

ISSN-0971-5266

PP100413EN 1006

Blockdale Publishing

15, Purshottam, 21 J P Road, Nr Navrang Cinema,
Andheri (W), Mumbai-400 058, INDIA
Tel: 022-26207402/32689321 **Fax:** 022-26254921
Email: bcid@vsnl.com **Website:** www.chemindigest.com