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Energy recovery with compact heat exchangers

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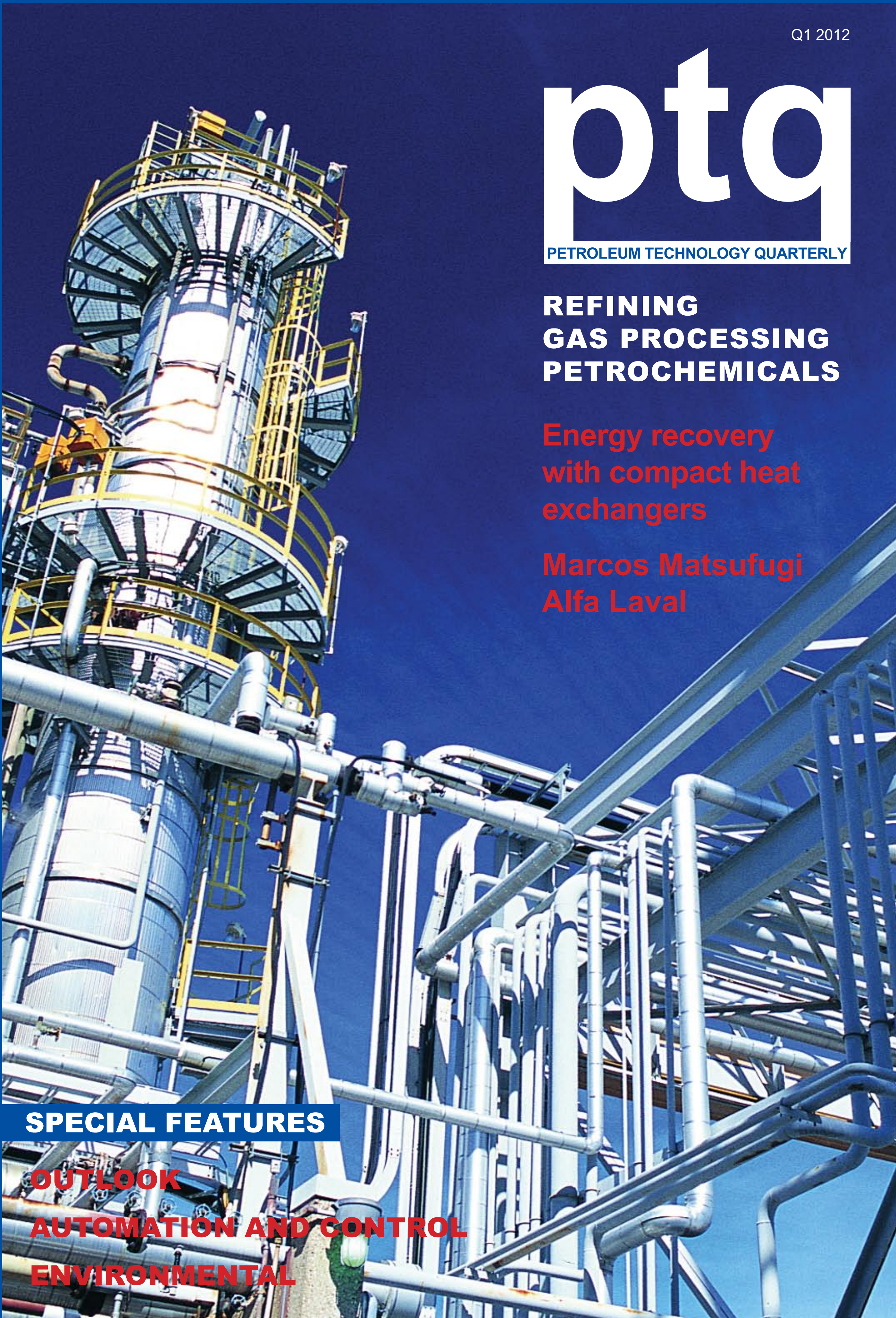

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Energy recovery with compact heat exchangers

Compact heat exchangers are used for heat recovery applications where high efficiency is vital, space or weight constraints apply, or exotic materials are required

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The refinery business is under constant pressure to increase efficiency. A highly competitive market combined with rising energy and feedstock costs require refineries to ramp up production while cutting operating costs.

Switching from shell-and-tube to welded plate heat exchangers (also known as compact heat exchangers) is a proven and straightforward way of solving the problem. The use of compact heat exchangers offers benefits in four areas:

- Energy savings
- Less maintenance
- Increased production
- Lower installation costs.

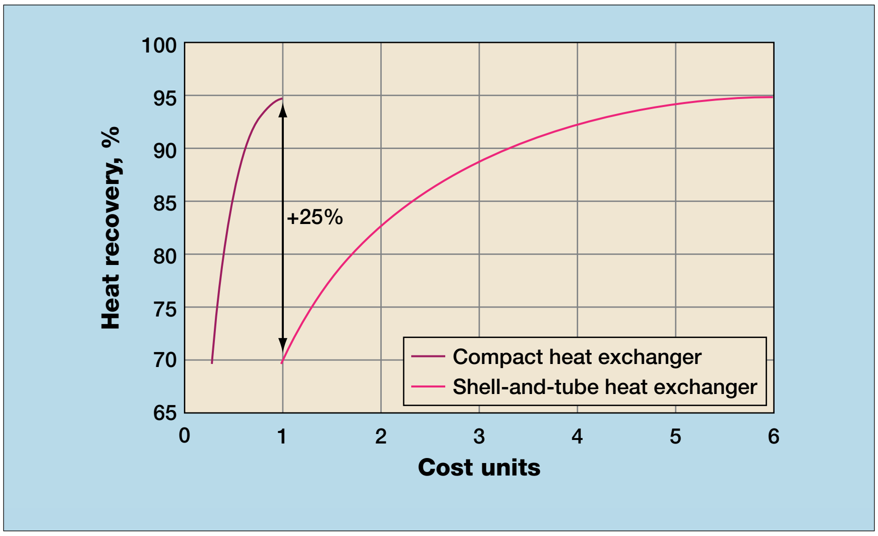

Figure 1 Comparison between a shell-and-tube system with stainless steel tubes and fusion-bonded compact heat exchangers

Energy savings

Up to 50% of a refinery's operating budget is tied up in energy costs, making energy efficiency a top priority. Energetics Incorporated estimates that the petroleum refining industry in the US could cut energy use by as much as 54% by incorporating best practices and new technology.[3]

Recovering and reusing energy is a profitable and easy way to cut energy costs. All refineries do this to some extent, but most still use outdated shell-and-tube heat exchangers with low thermal efficiency. Investing in more efficient heat exchangers is profitable for energy-intensive plants such as refineries. Payback periods are often less than six months.

Cut fuel costs

Heat recovery efficiency can be increased by up to 50% by simply switching from shell-and-tube to welded plate heat exchangers. More energy is then put back to use, energy that would otherwise have gone to waste. Atmospheric and vacuum distillation units are typical units with a high energy consumption and they represent an enormous potential for better heat integration.

Preheating of crude oil is the process that requires the largest amount of energy and where most gains can be made by using compact heat exchangers for heat recovery. There are plenty of other units in a refinery, such as hydrotreating, reforming and FCC, where switching to compact heat exchangers can be very profitable.

Reduced fuel consumption also leads to lower emissions of CO_2, NO_x and SO_x. If the plant operates under a cap-and-trade system this will cut operating costs even further.

Efficiency up to five times higher

The heat exchanger is a key component in heat recovery. The choice of heat exchanger is important and has a direct impact on a company's bottom line. Figure 1 shows the heat recovery level as a function of initial cost in a compact heat exchanger and a shell-and-tube. The yield from the compact heat exchanger is up to 25% higher than for the shell-and-tube at a comparable cost. Shell-and-tube solutions with the same level of heat recovery are often several times more expensive than a compact heat exchanger.

Turbulence and counter-current flow

The superior thermal efficiency of a compact heat exchanger is a result of its highly turbulent flow (see Figure 2). The corrugated heat exchanger plates cause much higher turbulence in the fluid than in a shell-and-tube at the same flow velocity.

The formula below describes the overall heat transfer coefficient.

High turbulence increases the film heat transfer coefficients (α_1 and α_2). Thin plates (small δ) also have a positive effect on heat transfer. The result is an overall heat transfer coefficient (k) that is three to five times higher than for a shell-and-tube heat exchanger:

$$\frac{1}{k} - \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \frac{\delta}{\lambda}$$

k = Overall heat transfer coefficient, $W/m^{2\circ}C$
α = Film heat transfer coefficient, $W/m^{2\circ}C$
δ = Wall thickness, m
λ = Wall conductivity, W/m°C

Another important feature of compact heat exchangers is the capability to operate with a counter-current flow; hot fluid enters the heat exchanger at the end where the cold fluid exits. This makes it possible to handle crossing-temperature programmes in a single heat exchanger (that is, to heat the cold fluid to a temperature that is higher than the outlet temperature of the hot fluid). This is especially important in heat recovery, since the maximum amount of energy is recovered when the cold fluid is heated to a temperature very close to that of the hot fluid.

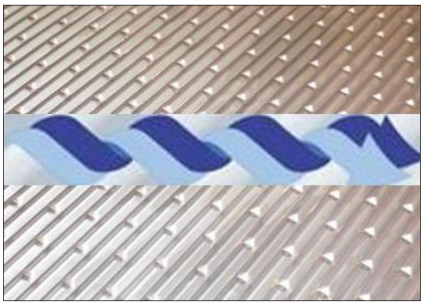

Figure 2 The highly turbulent flow in a plate heat exchanger results in superior heat transfer

The high efficiency means compact heat exchangers can exploit temperature differences as low as 3°C. This makes it possible to recover heat from sources that have previously been deemed worthless.

Feed/effluent exchanger performance

	Original design based on shell-and-tubes	Optimised design based on compact heat exchangers
Number of units	2	1
Heat load	5.8 MW (19.8 MMBtu/h)	8.3 MW (28.3 MMBtu/h)
Additional energy saved	0	2.5 MW (8.5 MMBtu/h)
Additional savings @ $24/MW and 85% heater efficiency	0	580 000 USD/year

Table 1

Overhead condenser exchanger performance

Additional heat recovery	11.5 MW (39.3 MMBtu/h)
Crude inlet temperature (CIT) increase	12°C (53.6°F)
CO_2 reductions	29 ktons/year
Savings on fuel consumption	2500 €/year

Table 2

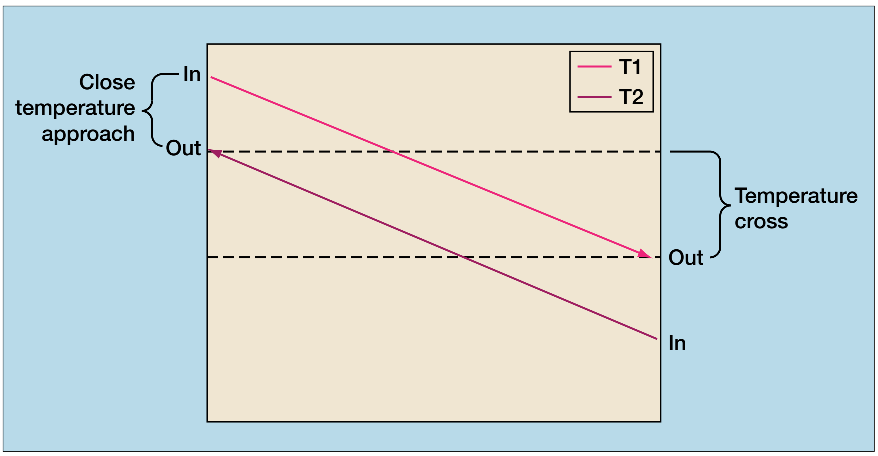

Figure 3 The capability to operate with a counter-current flow (hot fluid entering the heat exchanger at the end where the cold fluid exits) makes it possible to handle crossing-temperature programmes in a single heat exchanger

Case study: feed/effluent exchanger

A refinery in the US replaced two shell-and-tubes with a single compact heat exchanger as a feed/effluent exchanger in an isomerisation plant. The result was a 43% increase in heat recovery, from 5.8 MW to 8.3 MW. As an added bonus, the new solution also allowed the refinery to eliminate a downstream air cooler (see Table 1).

Case study: overhead condensers

A refinery in Italy replaced old air coolers on the atmospheric distillation column with two compact heat exchangers. The heat that was previously cooled off into the air is now recovered and used for preheating crude oil. The result is additional heat recovery of 11.5 MW (39.3 MMBtu/h) and an annual saving in fuel of €2.5 million (see Table 2).

Profitable energy recovery

Energy-saving investments often have short payback periods, even at much lower energy price levels than today's. In the future, energy efficiency will most likely be a prerequisite for staying in business.

In its *World Energy Outlook 2008* report, the International Energy Agency (IEA) predicts world energy demand to increase by 45% over the next 20 years.[2] It also predicts that the supply of fossil fuels will not be able to meet this demand, even when taking new, undiscovered fields into account.

More and more governments around the world will probably start charging industries for emitting CO_2, with emission credits becoming more and more expensive. The result of all this will undoubtedly be increasing energy prices; just how much is hard to predict. In 2007, the IEA predicted oil prices to stay at $50–55 per barrel until 2030. A year later, in June 2008, they peaked at $147 dollars.

There are many ways to fight the energy challenge. Consulting firm McKinsey made a thorough investigation of future energy needs and supply, comparing the benefits of different alternatives. It came to the following conclusion:

"McKinsey has looked long and hard to obtain an affordable, secure energy supply while controlling climate change. Energy efficiency stands out as the single most attractive and affordable component of the necessary shift in energy consumption."[1]

Obviously, the first step towards lower energy costs is to start using less energy. Increasing efficiency is the least costly and most easily implemented solution to the energy challenge for most refineries.

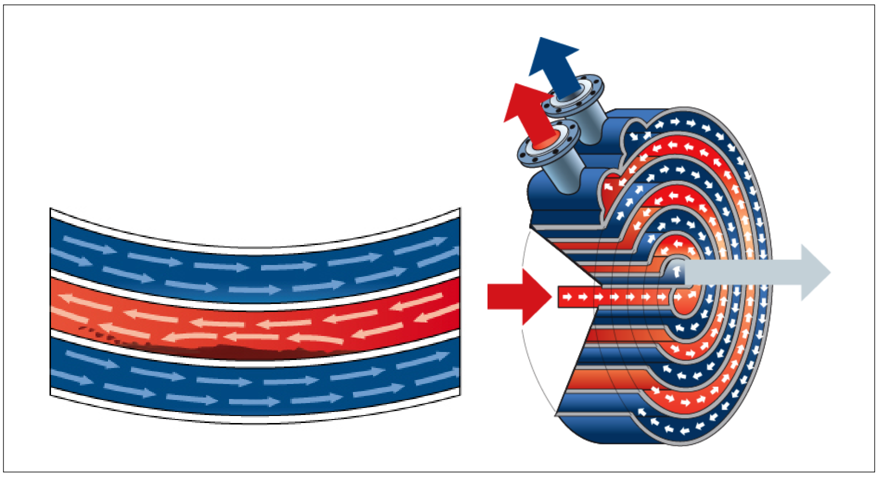

Figure 4 The self-cleaning design of spiral heat exchangers is appropriate for fouling duties

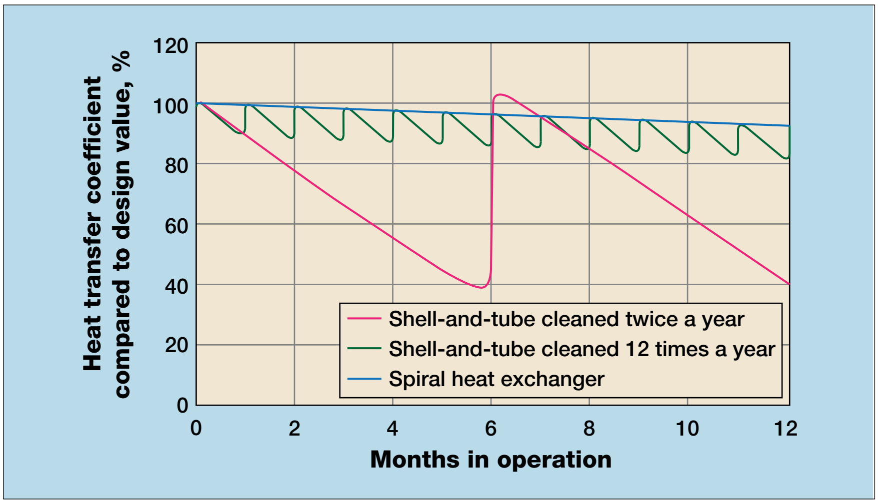

Figure 5 Comparison of heat transfer efficiency for a spiral heat exchanger (blue) and a shell-and-tube heat exchanger in an oil refinery visbreaker cooler

Less maintenance

One of the key features of a compact heat exchanger is the highly turbulent flow. Apart from improving heat transfer, it also makes heat exchangers less susceptible to fouling problems.

The high turbulence means fouling deposits are not deposited on the heat transfer areas. This results in longer service intervals, more operating time and more recovered heat than with a shell-and-tube design. Less fouling also leads to lower cleaning costs.

This self-cleaning effect is especially large in spiral heat exchangers (SHE). These are compact heat exchangers with a single channel design. This design causes fouling deposits to be flushed away wherever they start to build up. Spiral heat exchangers are the correct choice for heavy-fouling duties and can handle solids, slurries and fibres. Typical duties for spiral heat exchangers in refineries are cooling fluid catalytic cracking (FCC) bottom products or visbroken residues.

The smaller heat transfer area compared to a shell-and-tube heat exchanger means cleaning will be both quicker and require fewer cleaning chemicals. The small heat transfer area also leads to a smaller hold-up volume, which means compact heat exchangers respond faster to process changes. The equipment can therefore be shut down and restarted more quickly when serviced.

Energy savings

Fouling leads to higher energy consumption. Heat transfer efficiency drops as fouling builds up, meaning the boiler or burner has to provide more heat. Pumping the fluid through a fouled heat exchanger also requires more power to compensate for the increasing pressure drop. Reduced fouling will also have a positive effect on energy bills.

Case study: feed/effluent exchangers I

One of the largest refineries in the US had severe fouling problems in a desalter unit where two shell-and-tubes were used for cooling the desalter effluent. The problem was solved by substituting the two shell-and-tube exchangers for one spiral heat exchanger. The higher thermal efficiency meant a heat transfer area in the new heat exchanger could be half the size of the shell-and-tubes.

One of the main problems with shell-and-tube exchangers was the fast-increasing pressure drop caused by fouling. After the spiral heat exchanger was installed, the pressure drop was stable and thermal performance was much better over time.

The old shell-and-tubes had to be cleaned every month. The new spiral heat exchanger was cleaned

Feed/effluent exchanger performance			
Unit	Cleaning frequency (per year)	Cost per cleaning, USD	Total cleaning costs per year, USD
Shell-and-tubes (2)	12	6000	72 000
Spiral heat exchanger (1)	<1	3250	<3250

Table 3

for the first time after 14 months. No heavy fouling was observed, only a thin layer of grease on the effluent side and minor scaling on the feed-water side (see Table 3). The compact nature of the spiral heat exchanger means it is easier to perform maintenance.

Increased production

Many refineries have bottlenecks related to heating or cooling. It is often impossible or very costly to increase heating or cooling capacity, meaning they are left unresolved.

Investing in more efficient heat exchangers is often the best way to overcome these limitations. The higher the efficiency of the heat exchanger, the more heat can flow through it. This means the process fluid is heated or cooled with the extra degrees needed to resolve the bottleneck, simply by raising heat exchanger efficiency. The result is higher production capacity at a low investment cost.

Compact heat exchangers resolve bottlenecks without adding any additional investment or operating costs for more heating.

More performance per square metre

Thanks to the smaller heat transfer area required, compact heat exchangers offer significantly higher capacity per square metre of floor space than shell-and-tube exchangers offer. As restrictions in space and building structures often apply, switching to compact heat exchangers is a straightforward way to boost production without having to rebuild the plant. Using the same support structures, you get the required capacity boost simply by substituting the old equipment with new.

More uptime

Compact heat exchangers require less downtime for maintenance than do shell-and-tube exchangers, since service intervals are longer and the cleaning process is faster. Increased uptime also leads to higher production output over time. In the desalter example above, shell-and-tubes had to be cleaned 12 times per year and the compact heat exchanger less than once a year. The increase in uptime is substantial and leads to higher production output.

Case study: feed/effluent exchangers II

To improve overall performance in its semi-regenerative catalytic reforming process, a refinery in France replaced 12 shell-and-tube feed/effluent heat exchangers with a single, large-scale compact heat exchanger. This resulted in a 33% increase in capacity and reduced pressure drop from 4 to 1.5 bar. Improved heat recovery also led to lower energy consumption by 5.6 MW (19.1 MMBtu/h) and lower emissions for the fired heater. The payback time was 12 months.

Lower investment costs

Total investment costs are usually significantly lower for compact heat exchangers than for shell-and-tube exchangers. This is because the costs for the heat exchanger and installation are often lower, and because the utility systems can be used more efficiently.

Lower costs for the heat exchanger

Since the required heat transfer area is three-to-five times smaller for a compact heat exchanger than for a corresponding shell-and-tube design, much less material is needed to build the unit. This has a positive effect on price, especially when tough conditions call for exotic materials such as high-alloy steel or titanium.

Case study: atmospheric distillation unit I

Petrobras compared the costs for shell-and-tubes and compact heat exchangers. Heat exchangers were to be used in an atmospheric distillation unit, to preheat crude using heat recovered from kerosene and HVGO streams. The comparison showed that the costs for shell-and-tube exchangers were 3.8 and 5.6 times higher for the respective positions.

Lower installation costs

Installation costs can be cut considerably by using welded plate heat exchangers instead of shell-and-tube exchangers when expanding plant capacity. The foundations can be made smaller and the heat exchangers are easier to fit into existing structures thanks to their compact nature and lighter weight.

When estimating the total installed cost, a factor of 3.0–3.5 times the cost of the heat exchangers is often used for shell-and-tubes, compared to less than two for compact heat exchangers.

Case study: atmospheric distillation unit II

A refinery in Asia analysed different options for heat recovery on the atmospheric distillation column. Special alloys had to be used in the heat exchangers due to the aggressive media. Since the shell-and-tube solution would require a larger heat transfer area, the cost became 2.3 times higher than for a compact

ADU exchanger performance				
	Number of units	Heat transfer area, m_2	Material	Installed cost
Shell-and-tubes	8	5800	12 Cr/CS	2.3 X
Compact heat exchangers	2	1350	316 L	X

Table 4

heat exchanger setup (see Table 4).

A shell-and-tube installation (including space for extracting the tubes) would also occupy a 20 times larger volume on-site, 840 m^3 (12 x 14 x 5 m) compared to 37.8 m^3 (1.8 x 6 x 3.5 m).

Lower costs for utility systems

Before investing in new utility systems such as cooling towers and boilers, it is wise to see if the same result can be achieved by increasing heat recovery. Recovering more energy in the process often leads to reduced heating and cooling needs. Switching to compact heat exchangers often means production can be increased while still using the same utility systems.

Reliability

Compact heat exchangers offer the best of two worlds and combine the benefits of traditional plate heat exchangers with those of shell-and-tube exchangers. The all-welded design ensures trouble-free performance that does not change over time. Many of the compact heat exchangers that are in use in refineries have been operating for decades and are still delivering top results.

Apart from reliable sturdiness, compact heat exchangers bring you high efficiency, compact size, minimum maintenance, low pressure drop and the ability to operate at high pressures and temperatures.

Compact heat exchangers bring high efficiency and minimum maintenance

They can be used in many positions in a refinery. The installations are often for heat recovery applications, where high efficiency is essential (crude preheating, feed/effluent heat recovery and boiler feed water preheating). Compact heat exchangers are often being used where space or weight constraints apply (overhead condensers and reboilers) and where exotic materials are required due to corrosion (desalter water, naphtha toppings, sour water, amines and alkylation). The self-cleaning effect in spiral heat exchangers also makes them very suitable for heavy fouling applications (cooling FCC bottoms or visbroken residues).

References

1 Creyts J, *et al*, US energy savings: Opportunities and challenges, *McKinsey Quarterly*, Jan 2010.

2 International Energy Agency, *World Energy Outlook 2008*, www.worldenergyoutlook.org/2008.asp.

3 EDF Environmental Defense Fund, *Think US industries can't be more competitive? Think again*, 2010, http://apps.edf.org/documents/11209_LCMI-Refineries.pdf.

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