Improving Refinery RAM with Compact Plate Heat Exchangers

Despite the fact that highly efficient Compact Plate Heat Exchangers (CPHEs) can increase energy recovery in preheating duties, thereby minimizing both refinery energy costs and emissions from fired heaters, and being commonly used to reduce consumption of cooling water, by allowing higher cooling-water return temperatures, refiners have been hesitant to use plate technology in their main processes due to lack of operating experience. This paper will look at the conclusions to be drawn from more than 15 years of operating experience with CPHEs in main refinery processes. It will compare Reliability, Availability and Maintainability (RAM) for this technology versus traditional shell-and-tube heat exchangers, as well as outline the ease with which maintenance is carried out, should it be required. Considering the reductions in capital expenditure (CAPEX) and operational expenditure (OPEX) and improvements in RAM, there is today really no reason not to use CPHEs in main refinery processes.

It has long been acknowledged that plate-type heat exchangers with their thin, corrugated plates and counter-current flow provide more efficient heat transfer than traditional shell-and-tube heat exchangers. However their inter-plate rubber gaskets have a limited lifetime and create a risk of failure in some chemicals and in high temperatures and pressure duties. So these plate-type heat exchangers have mainly been used in low-temperature and low-pressure auxiliary refinery duties such as in secondary cooling water loops and in condensate systems.

But the development of the gasket-free, compact plate heat exchanger (CPHE) in the late 1980s put an end to these limitations and made it possible for refineries to benefit from the advantages of plate technology in the main refinery processes as well. As a matter of fact, the very stable, long-running and continuous refinery processes create optimal conditions for the CPHE concept. There is no reason why this technology should be less reliable than any other technology used in refineries today. On the contrary, the first CPHEs, installed more than 15 years ago, are still in operation. They provide solutions to problems such as corrosion, fouling, cooling-water limitations, space constraints, energy consumption, and bottlenecks for refineries around the world.

Today there are more than 180 different refineries where over 750 CPHEs operate – even in critical processes, such as crude distillation, catalytic reforming, isomerization catalytic cracking, hydrocracking, coking, and desulphurization.

Now, it is time to share the experience with Reliability, Availability and Maintainability (RAM) gathered from those installations.

Reliability & Availability

The high channel turbulence caused by the corrugated plates of the CPHE creates very high wall-shear stress. This wall-shear stress produces a cleaning effect, which reduces the rate of formation of chemical fouling on the heat-exchanger walls. Also, as there are no dead zones with low or stagnant flow rates where settling can occur, CPHEs have proven to provide much longer uptime in critical refinery processes than shell-and-tube heat exchangers.

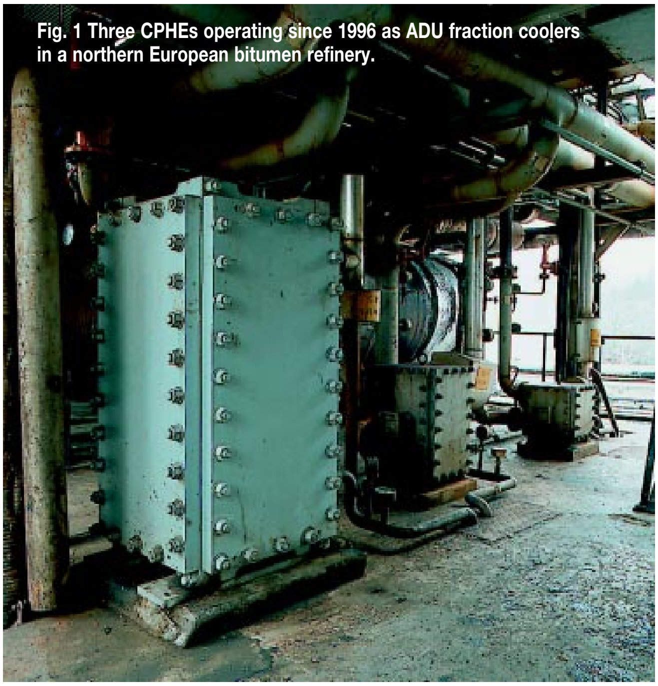

Fig. 1 Three CPHEs operating since 1996 as ADU fraction coolers in a northern European bitumen refinery.

One of the longest operating CPHE installations is in a bitumen refinery in northern Europe. Here, 14 CPHEs are in operation, the oldest since 1996. They have all replaced low-performing, high-fouling and corroding shell-and-tube heat exchangers. The CPHEs are used for various duties, such as ADU fraction cooling, VDU overhead vapour condensing and bitumen heating and cooling.

The old shell-and-tube heat exchangers required cleaning and inspection yearly, an operation that took one week. The CPHEs, on the other hand, require chemical cleaning only every third year, and it is easily carried out in a single day. In total, for these 14 units, the refinery has reduced maintenance costs by 96%!

Fig. 2 One CPHE preheating crude since 2002 in a Russian refinery.

The country that to-date has the highest level of acceptance for CPHE technology is Russia. Out of 28 refineries, 27 use the technology, both to replace old shell-and-tube heat exchangers and in new process units. One of the oldest CPHEs in Russia is installed in a crude preheat train. It preheats crude to over 200° C using atmospheric residue as the heating media. The 170 m^2 stainless steel CPHE replaced three corroding CS shell-and-tube heat exchangers with more than 1000 m^2 of heat transfer surface.

Since it was commissioned in February 2002, the CPHE has not required any maintenance whatsoever. Due to their positive experience with this heat exchanger, the refinery has since invested in three more CPHEs to improve heat recovery in their crude preheat train as well as one CPHE that operates as a gasoline cooler in their hydrotreatment plant. The latter uses seawater as cooling media.

North American refiners have also made the leap to more modern heat-transfer technologies. When one refinery wanted to expand its plant's capability to process price-advantaged crudes, new heat exchangers were needed in the crude preheat train. Due to space limitations in the plant, CPHE technology was chosen for the duty of preheating crude to up to 235° C using heavy vacuum gas oil (HVGO).

Fig. 3 Two CPHEs preheating crude since 2004 in a North American refinery.

As the technology was new to them, the refinery chose to install a 100% stand-by unit in parallel to the operating CPHE. However, one heat exchanger alone proved to be sufficient. It operated continuously for more than 18 months without any loss of performance. The stand-by unit is used only during periods when the HVGO duty needs to be maximized. It then operates in parallel with the other CPHE. The refinery says that the plate technology has paid for itself many times over, and they are now considering using plate technology in their next revamping project.

A final example proving that CPHEs provide both high availability and versatility, is a case from Australia. In this refinery, a CPHE has been operating since the beginning of 2006 as the thermosiphon reboiler in the naphtha splitter. The CPHE operates in parallel to and as a booster

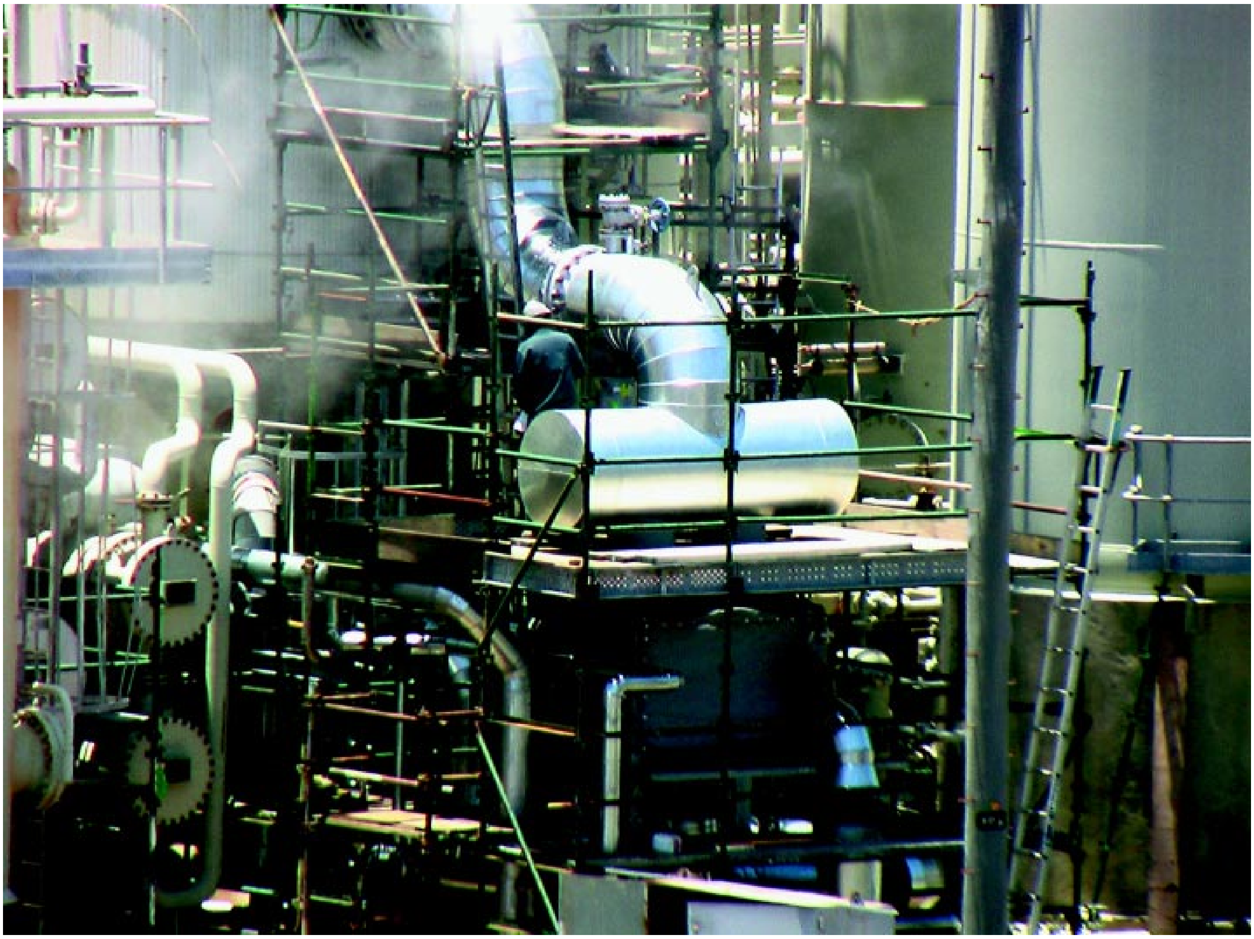

Fig. 4 One CPHE operating since 2006 as naphtha reboiler in an Australian refinery.

for an existing shell-and-tube reboiler. The shell-and-tube reboiler requires cleaning every six months, while the CPHE can operate for almost a year in-between maintenance.

Maintainability

Although uptime is longer and the need for maintenance less compared to traditional shell-and-tube heat exchangers, CPHEs do require regular maintenance. Cleaning and repair operations are both easily carried out on CPHEs installed in refinery processes.

Cleaning

For optimal CPHE performance, it is generally recommended that preventive maintenance is carried out every time there is a planned shutdown of the process. However, if the CPHE has shown no reduced heat-transfer performance or increased pres-

Fig. 5 Two out of four CPHEs operating since 1997as ADU overhead vapour condensers in a European refinery.

sure drop during the time it has been in operation, then it would be safe to let it run for another period without cleaning.

The two cleaning methods commonly used are chemical cleaning and mechanical cleaning.

Chemical Cleaning

Chemical cleaning is usually not effective for shell-and-tube heat exchangers operating in refinery processes. For CPHEs, however, chemical cleaning is very often more than sufficient to restore both thermal efficiency and hydraulic performance. CPHEs have much smaller hold-up volume, (as little as 10% of that of shell-and-tube heat exchangers) and no dead zones behind baffles or in turning chambers. Therefore cleaning chemicals can dissolve and transfer any soluble fouling material out of the heat exchanger channels. In addition, stronger, more efficient cleaning chemicals can be used in a CPHE because all the wetted parts are constructed of corrosion-resistant metals.

The advantage of chemical cleaning is of course that the panels of the CPHE do not have to be removed and therefore, no flange gaskets have to be replaced. In addition, if a mobile cleaning module is used (Cleaning-In-Place, CIP unit), the CPHE does not even have to be removed from the plant site or disconnected from the piping. As a result, maintenance time is reduced to a minimum.

One installation that provides proof of both long uptime and ease-of-maintenance is in a European refinery where four titanium CPHEs are used for maximum heat recovery from the ADU overhead vapours.

Both crude and boiler-feed-water is pre-heated by means of two CPHEs operating in series. The two parallel lines are installed high above ground, next to the distillation tower.

The first cleaning took place in 2002 after five years of operation. The cold circuits, crude and boiler-feed water, did not require any cleaning, while the vapour circuit was cleaned, mainly to remove salt crystals formed in the heat-transfer channels.

Chemical cleaning alone was used to restore the performance. First, hydrocarbon-related fouling was removed by circulating a heated caustic solution. Then, after rinsing, salts such as iron sulfide, were removed using a sulfamic acid cleaning agent. Finally, the CS piping was neutralized and passivated by circulating a sodium carbonate solution through the CPHE. Before the heat exchanger

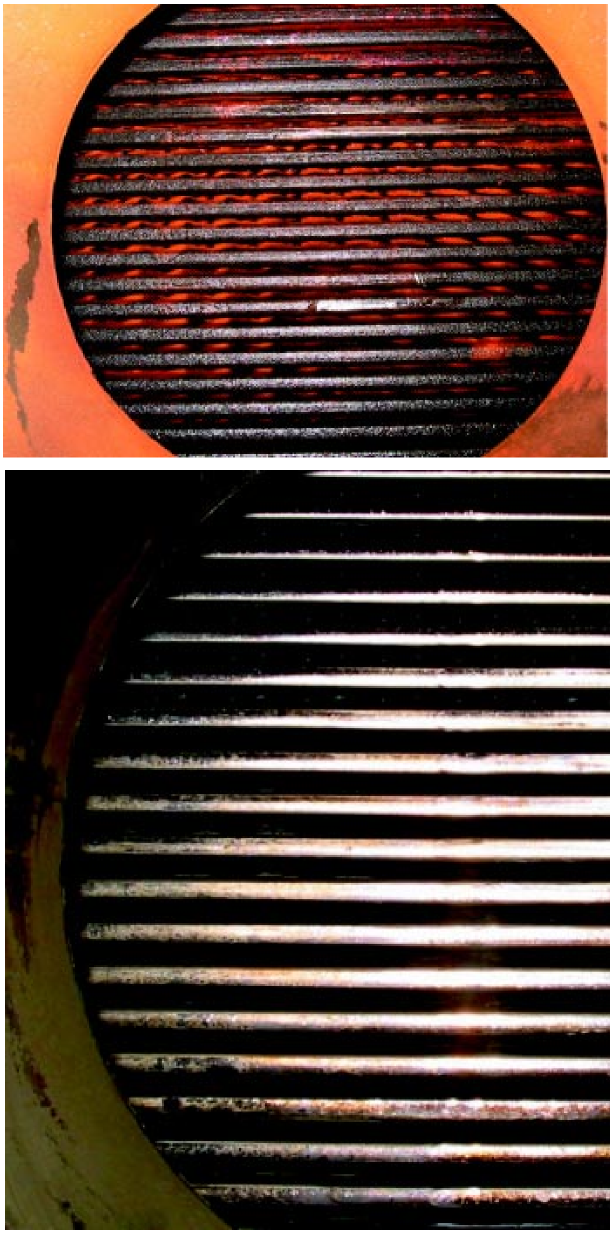

Fig. 6 Endoscopic photo of hot stripped water circuit taken from the inlet nozzle of a CPHE operating since 2003 as interchanger in a SWS unit in a South America refinery. Photo shows before and after chemical cleaning

was put back into operation, it was rinsed with demineralized water. The entire cleaning procedure took around three days.

Another example of successful chemical cleaning comes from a South American refinery. Here the CPHE operates as an interchanger between sour and stripped water in the SWS process. Due to the acidity of the sour water, the carbon-steel stripping tower suffers from corrosion problems, and iron oxides and sulfides enter the hot circuit of the CPHE with the stripped water. The heat exchanger must be chemically cleaned frequently to restore its performance.

First, the CPHE is flushed with hot water, and then a weak, heated caustic soda solution is circulated through its channels. After a second flushing with water, a weak, heated phosphoric acid solution is used. Finally, before the heat exchanger is put back into operation, it is flushed a third time with hot water.

The cleaning procedure takes around one shift, and the result is verified by means of endoscope photos of the heat-transfer channels taken from the connection nozzles.

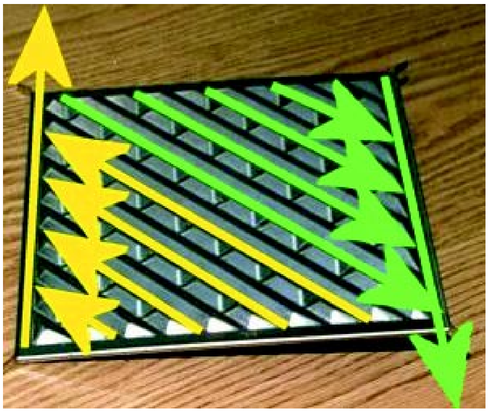

Fig. 7 Photo showing the un-restricted channels formed by the 45-degree angle plate pattern and the flat channels along the edges for draining. This means the hydro-jet passes through the heat-exchanger when the nozzle is tilted in 45 degree angle.

Mechanical Cleaning

If chemical cleaning is not sufficient to completely restore the CPHE performance, then mechanical cleaning with a high-pressure water-jet is a successful alternative. As the panels can be removed, giving access to the complete plate pack, there is no need to remove the plate bundle from the shell. Also, as the plate channels are much shorter than the shell-and-tube channels, high-pressure water-jet cleaning becomes very efficient. This is true even if the channel gap in the plate pack is very narrow.

Because the plate pattern is specifically made at a 45-degree angle, un-restricted channels are formed in this direction. Furthermore, the non-corrugated, flat channels at the edges of the plates efficiently drain the foulant out of the heat exchanger. By tilting the high-pressure water lance at a 45-degree angle, the entire plate area can be accessed if the plate pack is cleaned first from the front and then from the back.

Chemical cleaning of the heat exchanger prior to the high-pressure water cleaning will partially dissolve any chemical foulant and thus even better results can be obtained. Or, the high-pressure water cleaning can be made with heated water or using a weak chemical solution to further increase its efficiency.

In a European lube oil plant, a CPHE has been in operation since 2004 as a condenser in the solvent recovery part of the paraffin removal plant. It needs regular cleaning every 12-15 months due to calcium-carbonate scaling on the cooling-water side. It is cleaned with high-pressure water of 800 – 1000 bars, using heated water and either rotating nozzles or nozzles with narrow spraying angles. The cleaning procedure, which includes opening, cleaning, closing and tight-testing, takes eight hours and can be carried out during one shift.

The CPHE replaced three carbon-steel shell-and-tube heat exchangers that had problems with corrosion. The same cleaning procedure (including opening, cleaning, closing and tight-testing) for those heat exchangers took 2-3 days.

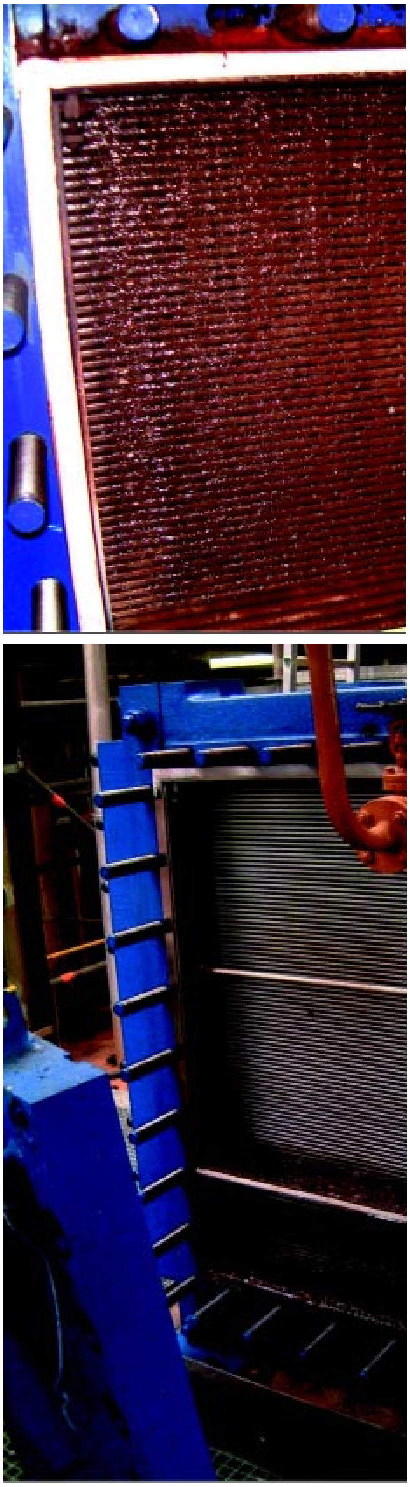

Fig. 8 Photo showing before and after high-pressure water-jet cleaning of the cooling water circuit of a CPHE operating as condenser in the solvent recovery part of a paraffin removal plant in Europe.

Repair

CPHEs operating in stable, continuous refinery processes are unlikely to fail. However, there are of course cases where a leak develops, and the heat exchanger must be repaired. Below, we will discuss three types of leaks and how to repair them: plate-weld leaks, corner/column-weld leaks and cross-leaks over the plate.

Repairing the CPHE is facilitated as all welds are external and accessible once the panels are removed.

Manual TIG welding is used to repair all types of leaks. To avoid oxidation, the welding must be done with argon gas shielding. All repair welds should be made by certified welders who are competent and experienced in weld repairing of thin metal plates. Preferably, the manufacturers' personnel should be involved, at least for supervising the operation in order to ensure that recommended procedures are followed.

After a weld has been repaired, its quality is tested using any or several of the following methods: air-bubble test, dye-penetrant test, hydrostatic-pressure test or helium-leak test.

However, before any repair work can begin, the leak has to be identified and localized.

Leakage localization

As the CPHEs are small and their frame panels can be removed, the easiest way to identify and localize a leak is to do an air-bubble test. The CPHE is placed horizontally on the floor, with the top panel removed and that circuit is filled with water. When air is blown through the other circuit, the resulting bubbles will quickly reveal the location of the leak.

Fig. 9 Photo showing a leaking corner weld of a CPHE being air-bubble tested

Fig. 10 Photo showing the result of the dye-penetrant test after a corner weld has been TIG repaired.

This area can now be dye-penetrant tested to further narrow the exact location of the leak

Corner/column weld repair

A corner or column weld leak is the most common type of failure because these welds are subject to the strongest mechanical forces. This is especially true for CPHEs operating in batch-processes with frequent shutdowns and start-ups or in unstable processes with high-amplitude pressure variations or high-frequency vibrations.

These leaks are uncommon in CPHEs installed in continuous and stable refinery processes and are known to have occurred in less than 2% of all installations.

Plate weld repair

Another type of failure is a leak in the plate weld that seals off one circuit from the other to form the heat-transfer channels. However, if the plate weld is a laser weld, this type of leak is uncommon because of the high quality of such a weld. The laser welding technique minimizes the heat affected zone, making the welds both mechanically and chemically strong.

Cross-leak repair

Another possible, yet rare type of leak can occur when a crack develops in the heat-transfer plate itself, causing cross-leakage between the two circuits. This type of leak is quite common in shell-and-tube heat exchangers where it is usually caused by mechanical fatigue of the long, vibrating tubes. It can also be generated by general corrosion of carbon-steel tubes or by galvanic corrosion around welds joining alloyed tubes to carbon-steel tube sheets.

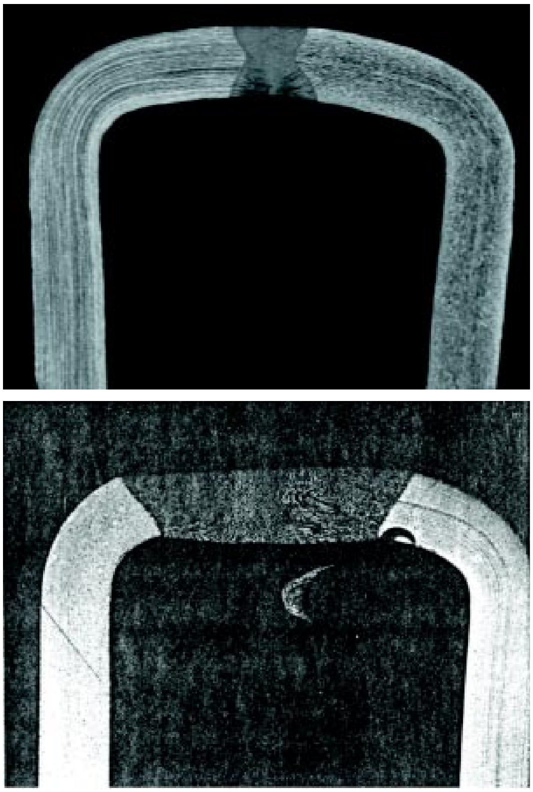

Fig. 11 X-ray photo showing the superior weld quality and minimized heat-affected zone of a laser plate weld as opposed to a TIG plate weld

In a CPHE, on the over hand, the short plates are welded together in a very stable construction and supported by the many contact points between the plates. This more or less eliminates any risk of fatigue cracks forming in the heat-transfer plates. Also, because all wetted parts are made of the same corrosion resistant material, there is no risk of chemical or galvanic corrosion.

However, in the rare instance that a hole does develop in a heat-transfer plate, the CPHE can be repaired in exactly the same way as a shell-and-tube heat exchanger with a cross-leakage: by sealing off the damaged channel.

In a shell-and-tube heat exchanger, it is easy to seal off such a channel by plugging the tube with a rubber plug. Sealing off a CPHE channel requires manual TIG welding of a metal strip to cover the entire plate channel.

A CPHE delivered for use in a refinery application is always designed with an extra surface margin of 15-20%. Hence, sealing off a few channels has little, if any, effect on the performance of the heat exchanger.

Conclusion

When summing up the experience from some of the 750 CPHEs operating in various refinery processes, it is clear that in cases where shell-and-tube heat exchangers are greatly affected by chemical fouling, CPHEs, with their higher turbulence and wall-shear stress, provide longer uptime and intact performance.

In addition, when maintenance is required, it is easily carried out either with chemical cleaning or a high-pressure water-jet. Due to their low hold-up volume, the limited length of the heat transfer channels and the complete accessibility of the plate pack, the thermal and hydraulic performance of CPHEs can readily be restored in less time than required for bulky shell-and-tube heat exchangers.

Finally, because refinery processes are stable and continuous, CPHEs are unlikely to develop mechanical failures. But if leaks do occur, they are easily

Fig. 12 Photo showing a cross-leaking CPHE channel sealed with a metal-strip

repaired because all welds are accessible from the outside once the panels have been removed.

In conclusion, CPHEs improve Reliability, Availability and Maintainability. They offer higher availability and require less maintenance. They are reliable and repairable. Therefore, there is no reason why refiners should not profit from the inherent advantages offered by the plate technology, even in their main refinery processes. More than 180 different refiners have already realized this and more CPHEs are being delivered every day – to already satisfied customers and to converted newcomers. **HA** *Enquiry Number* **01/03-05**

This publication thanks Eva Anderson for providing this paper for publication. She has been the Regional Refinery Manager (South East Asia) for Alfa Laval, Singapore, since 2008. Eva possesses a M.Sc. in Chemical Engineering from McGill University, Canada/ Lund University, Sweden and has 11 years working experience with Alfa Laval as a Heat Exchanger expert within various industries.