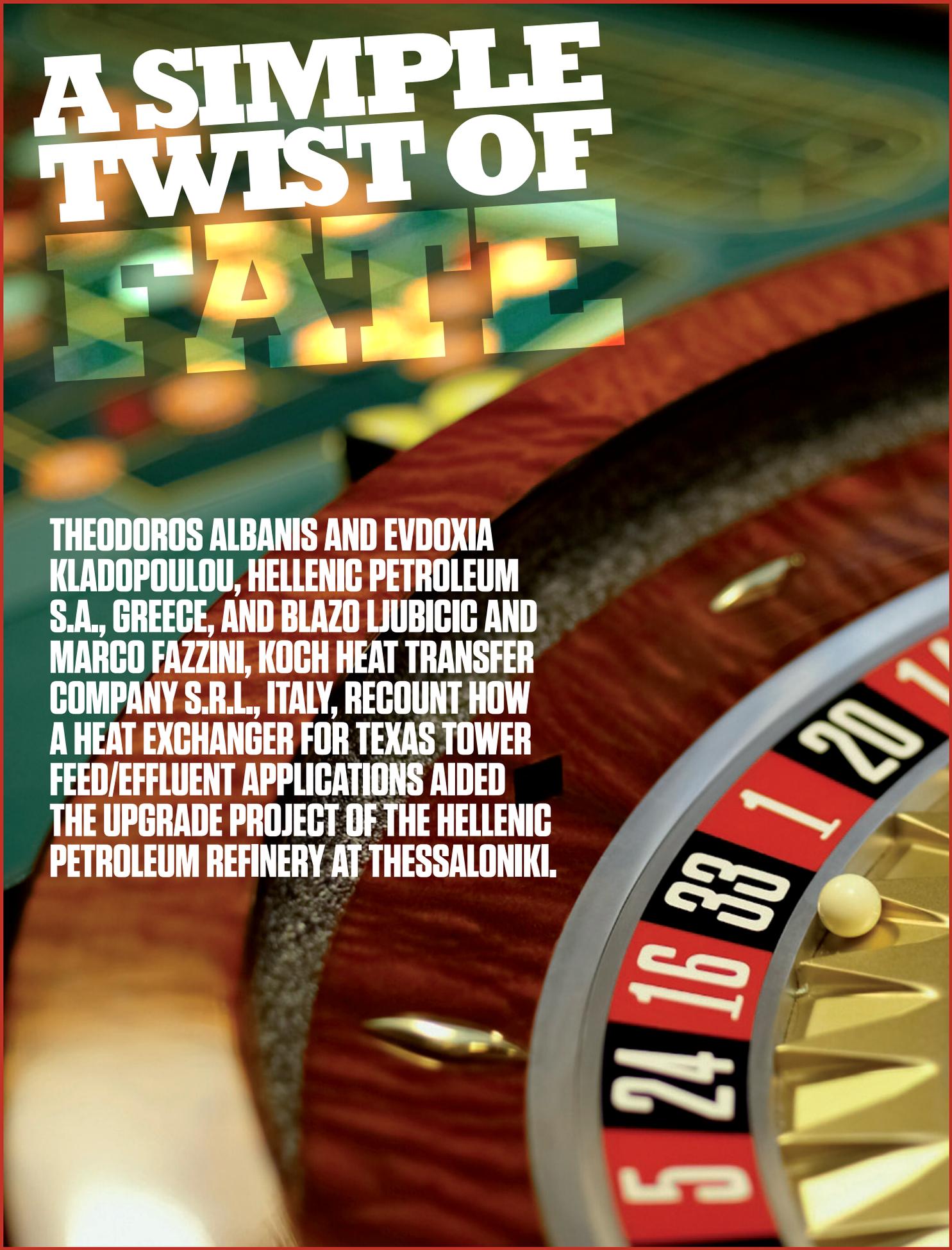


A SIMPLE TWIST OF FAVOR

THEODOROS ALBANIS AND EVDOKIA KLADOPOULOU, HELLENIC PETROLEUM S.A., GREECE, AND BLAZO LJUBICIC AND MARCO FAZZINI, KOCH HEAT TRANSFER COMPANY S.R.L., ITALY, RECOUNT HOW A HEAT EXCHANGER FOR TEXAS TOWER FEED/EFFLUENT APPLICATIONS AIDED THE UPGRADE PROJECT OF THE HELLENIC PETROLEUM REFINERY AT THESSALONIKI.



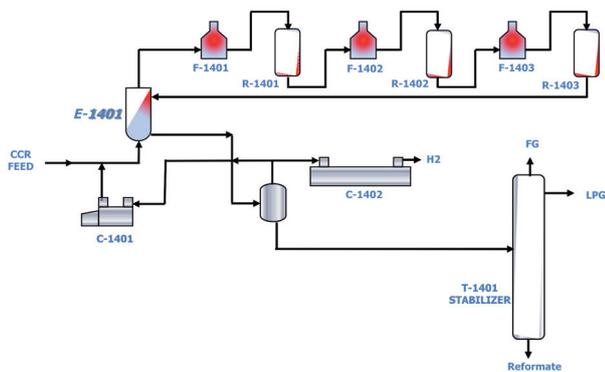


Figure 1. Simplified process flow diagram of the naphtha reforming plant of Hellenic Petroleum S.A.

In 2006, the Hellenic Petroleum (HELPE) Thessaloniki refinery made the decision to proceed with an upgrade project that would allow processing of low sulfur crude oils for the production of low sulfur diesel oil (<10 ppmw sulfur) and low sulfur fuel oil (<1 wt% sulfur) by expanding the diesel oil desulfurisation facilities and hydrogen availability. The project included:

- ↔ Four new crude oil tanks.
- ↔ A new outboard flash tower with an associated new furnace, desalter and crude preheat train.
- ↔ Modifications to existing units (atmospheric pipestill, hydrotreaters, crude light ends and heat integration facilities).
- ↔ Replacement of the existing 10 kB/SD semi regeneration reformer with a new 15 kB/SD continuous catalyst regeneration (CCR) naphtha reformer.

Table 1. A typical set of CCR unit operating data

Feed to CCR unit	CCR feed temperature - heat exchanger E-1401 inlet	65 °C
	Feed to CCR unit	100 m ³ /hr
	Average reactor pressure	3.9 kg/cm ²
Product rate	Average inlet reactor temperature	543 °C
	Reformate flow	80 m ³ /hr
	Hydrogen rich gas flow	35 000 Sm ³ /hr
	FG flow	820 Sm ³ /hr
Recycle gas	LPG flow	3.5 m ³ /hr
	Recycle gas flow	46 000 Sm ³ /hr
	Separator drum pressure	2.9 kg/cm ²
Heat exchanger E-1401	Temperature inlet (tube side)	65 °C
	Temperature outlet (tube side)	457 °C
	Temperature inlet (shell side)	492 °C
	Temperature outlet (shell side)	90 °C
	Hot end temperature approach test run	35 °C
Unit performance	Total pressure drop test run	0.4 bar
	RON clear	100
	Hydrogen yield	3.5 wt%
	Reformate yield	89 wt%

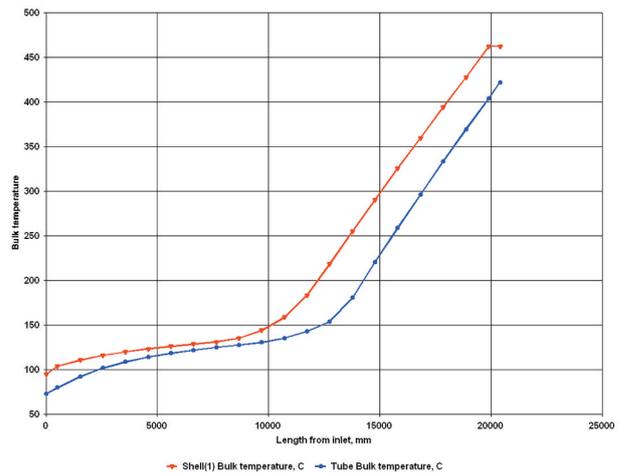


Figure 2. Stream temperature profile of the E-1401 reactor F/E TWISTED TUBE heat exchanger (reprinted with permission from HTRI software).

The project was successfully completed in April 2011 with a total investment cost of € 244 million.

Process description

The CCR unit applies Octanizing® technology, the Axens reforming process, in continuous catalyst regeneration. The purpose of the continuous catalytic reformer unit is to produce a high octane number reformate, which is the main component of the gasoline pool and a hydrogen rich gas that can be used in other refinery units. The unit is conceptually divided into two sections:

- ↔ The 'Octanizing section', including: three naphtha catalytic reforming reactors, three related heaters, an effluent heat recovery system and the stabilisation system of the final products.
- ↔ The 'Catalyst circulation and continuous regeneration section', which involves solids handling and moving bed technology. The purpose of the Octanizing section is to produce:
 - ↔ Reformate to be sent to a reformate splitter.
 - ↔ Hydrogen rich gas used in catalyst regeneration, the circulation process and, mainly, sent to the refinery hydrogen network for other hydrogen uses.
 - ↔ LPG sent to the LPG unit.

The Octanizing section includes the subsections of 'reaction' and 'absorption and stabilisation'. The reforming reactions take place in three moving bed catalytic reactors from which the flowing catalyst is withdrawn, regenerated and recycled. The catalyst circulation and regeneration is performed on a continuous basis with full automatic control of all operations. A high temperature (above 500 °C) is required to promote the chemical reactions which improve the octane number. On the other hand, the high performance of the Octanizing process is performed at low operating pressure.

The overall economics of the unit critically depend on the performance of the E-1401 feed/effluent heat exchanger, which preheats the combined feed/hydrogen against the third reactor effluent before it enters the first heater F-1401. E-1401 is specified as a heat exchanger with strict requirements for a minimum pressure drop and a maximum heat recovery.

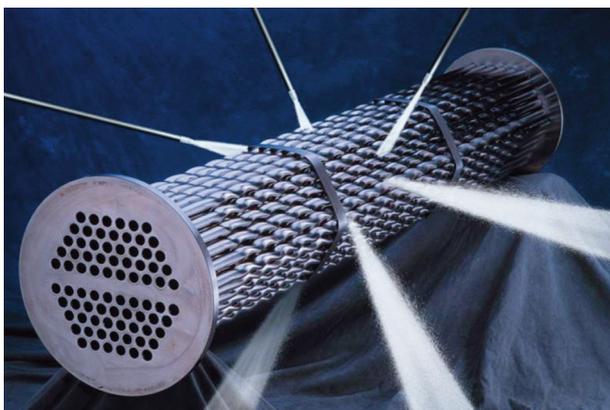


Figure 3. TWISTED TUBE bundles shell side hydroblast cleaning.

A typical set of CCR unit operating data is given in Table 1 and a simplified flow diagram of a section of the naphtha reforming plant is displayed in Figure 1.

Feed/effluent heat exchangers

Feed/effluent (F/E) heat exchangers are used to recover process heat from reactor (hydrotreater and reformer) products and preheat the feed stream: a mixture of petroleum feed and recycled hydrogen. In practice, the following types of F/E exchangers are used:

- ↔ Horizontal shell and tube with U tube bundles.
- ↔ Vertical combined feed exchanger (VCFE), also known as vertical Texas Tower F/E.
- ↔ Vertical welded plate exchangers.

The two phase flow feed is usually connected to tube side, with the product stream to the shell side. Non-uniform distribution of the petroleum feed and recycled hydrogen among tubes of horizontal as well as vertical F/E heat exchangers can induce high localised wall temperatures. If these localised wall temperatures are above threshold fouling conditions at the prevailing liquid phase wall shear stress, then formation of precursors (e.g. decomposition of organometallic complexes) could occur. Tubes with high vapour flows could produce undesired flow regimes (such as mist flows) with intermittent dryout or thin film, resulting in underperformance and in some cases high fouling/coking. Similarly, tubes with low

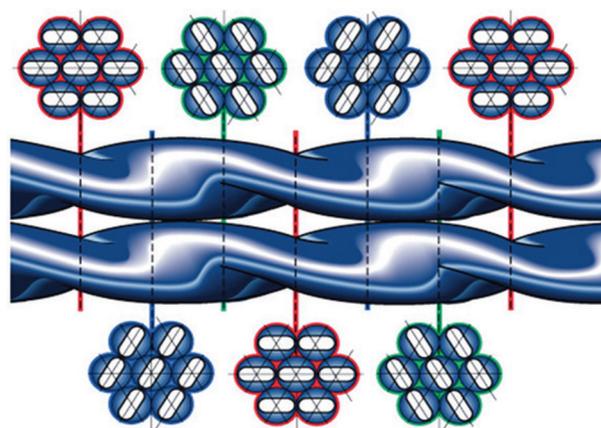


Figure 4. Bundle construction.

vapour flows produce slug or separated flow regimes with high residence time and low wall shear stress, which adversely affect the formation of fouling precursor in the liquid phase.

Selection

Selecting the E-1401 heat exchanger required consideration of the two key requirements:

- ↔ Low total pressure drop, which allows for a lower operating pressure and consequently maximises the reformate yield.
- ↔ Low hot temperature approach, which maximises the heat recovery of the unit.

For this service, a number of different designs, including all types of shell and tube and welded plate type heat exchangers, are used. HELPE refinery decided to consider shell and tube designs, including 'non-segmental baffle' technologies. After thorough consideration, a decision was made to use a Koch Heat Transfer TWISTED TUBE® heat exchanger. Compared to plate type heat exchangers, the selected design, although bigger in size, offered the same hot temperature approach and pressure drop, and allowed the refinery to use familiar, robust and low maintenance cost technology.

Design considerations

A number of complex two phase phenomena on both the shell side and the tube side must be considered during the thermal and hydraulic design of Texas Tower, shell and tube F/E units.

Table 2. Thermal and hydraulic design data of the reactor F/E TWISTED TUBE heat exchanger (design duty: 110% of operating duty)

Item	Shell side stream	Tube side stream	Design flow rate	Design duty	Shell side allowable pressure	Tube side allowable pressure
E-1401	Reactor effluent (hot)	HC feed + H ₂ recycle (cold)	91 773 kg/hr	27.1 Gcal/hr	0.5 kgf/cm ²	0.5 kgf/cm ²

Table 3. Characteristics of the E-1401 reactor F/E TWISTED TUBE heat exchanger

Item	TEMA size	Tube O.D	Tube thickness	Effective heat transfer surface area	Total weight (dry)	Bundle weight (dry)
E-1401	1700 x 21 000	19.05 mm	2.108 mm	5142 m ²	152.3 t	99.9 t

Table 4. Materials and design conditions of the reactor F/E TWISTED TUBE heat exchanger in the naphtha reforming plant of Hellenic Petroleum S.A.

Item	TEMA type	Shell side material	Tube side material	Tube material	Shell side design pressure/temperature	Tube side design pressure/temperature
E-1401	CES	1.25Cr-0.5Mo	1.25Cr-0.5Mo	1.25Cr-0.5Mo	5.9 kgf/cm ² / 565 °C	8.6 kgf/cm ² / 493 °C



Figure 5. Reactor F/E TWISTED TUBE heat exchanger, Texas tower type, ready for shipment.



Figure 6. Insertion of the bundle in the Texas Tower heat exchanger at the production site.

Table 5. Summary of data from the performance test executed on unit E-1401 at the Thessaloniki refinery

Case	Shell side in/out temperature (°C)	Tube side in/out temperature (°C)	Flow rate (kg/hr)	Duty (Gcal/hr)	Total pressure drop (kgf/cm ²)
Guaranteed for reference case	462/95	73/422	91 773	27.1	0.54
Guaranteed for actual test case	481/87	61/444	84 810	27.3	0.48
Measured for actual test case	481/86	61/446	84 810	27.4	0.40

At the shell side entrance, a large volumetric flow has to be managed carefully. To prevent the inlet pressure drop and to avoid flow induced vibration (FIV), conventional, segmental baffle designs often require no tube in window (NTIW) bundles. ‘Deresonating baffles’ may also be required to avoid acoustic vibrations. Finally, to limit the inlet pressure drop and minimise possible erosion, a vapour belt is often used under the shell side inlet nozzle.

On the tube side, challenges are by no means less complex. First, the liquid/vapour mixture has to be uniformly distributed across all tubes, and that in itself is far from a simple task. To make the distribution even more complicated, liquid feed and recycle gas are commonly brought to the exchanger in two separate lines and mixed just before they enter the inlet cone. In addition, formation of liquid droplets in the upward flow of recycle gas is difficult to model, and to mitigate possible misdistribution a distribution plate is usually placed in front of the floating tubesheet. However, design methods used for this are either non-existent or rather rudimentary.

Secondly, a tube side complete vaporisation in conventional rounded tube bundles is always challenging. Besides the need to stay away from ‘film boiling regimes’, once the flow enters the ‘mist flow regime’ and liquid droplets are no longer in contact with the wall, the vaporisation process becomes very inefficient. Swirl flow in TWISTED TUBE bundles effectively resolves these issues.

Moreover, the shape of the heat release curves of the two streams common in this service (Figure 2) usually exhibits the presence of a temperature pinch. Practically, this means that a heat transfer in the portion of the exchanger could be driven by a very small temperature difference. The magnitude of such a ‘pinch’ can actually be much smaller than other parameters, like the commonly used ‘hot temperature approach’.

The TWISTED TUBE heat exchanger technology is able to provide effective solutions to all of the aforementioned issues. The longitudinal uniform swirl flow on both sides of the exchanger and

increased heat transfer rates combined with practically vibration free construction allows the technology to be designed with reduced dimensions, weight and high thermal/hydraulic performance.

The technology

The TWISTED TUBE heat exchanger has a design that combines the robust and easily maintainable attributes of conventional shell and tube exchangers with the thermal and hydraulic efficiency of plate heat exchangers, resulting in a cost effective heat recovery and low pressure drop. These units consist of helically twisted, double radius elliptical tubes, welded by their rounded end to the tubesheet (Figure 3). The tubes are always arranged on triangular pitch and can be cleaned by hydroblasting (both tube side and shell side). They contact each other at their wider sides six times over the length of one 360° twist pitch, which makes them practically vibration free (Figure 4).

A bundle of these heat exchangers can enhance heat transfer on both shell side and tube side. Depending on the flow and heat transfer regime, heat transfer coefficients are doubled, with little or no increase in the resulting pressure drop.

The E-1401 TWISTED TUBE heat exchanger is a single pass (both shell side and tube side), pure countercurrent flow unit, installed in the vertical position. It preheats a mix of hydrocarbon fresh feed and recycled hydrogen gas by cooling the reactor effluent. The reactor effluent enters the unit on the top as a vapour and partially condenses downward, while the reactor feed enters the unit at the bottom and vaporises upward. The design data for the unit specified by the licensor’s process datasheet is summarised in Table 2 for the thermally controlling start of life case.

The unit is a TEMA type 'CES' with floating tubesheet at the bottom (Figure 5). The differential thermal expansion between shell and tube bundle is taken by the expansion bellow placed between the tube side inlet nozzle and the floating tubesheet.

The design pressures/temperatures and construction material are given in Table 4. Tubes are welded to both the upper (fixed) tubesheet, and to the lower (floating) tubesheet. The bundle is shrouded, and if required can be removed from the top. The bundle is built and shroud installed in a horizontal position (Figure 6).

Operating results

In September 2012, a performance test of the E-1401 TWISTED TUBE heat exchanger was performed at the Hellenic Petroleum S.A. refinery. As usual, the performance test was conducted at different process conditions to those defined as the nominal design case specifications. Table 5 summarises the performances test results, both based on the design conditions and on the actual test conditions.

The performance test proved the ability of the technology to not only meet the specified design conditions, but also to exceed them. The hot approach was in fact improved by approximately

2 °C, while the total pressure drop was decreased by approximately 17%.

Conclusion

A circumspect view is required to provide an in depth analysis and proper selection of the best heat exchanger configuration for a given service and particular process conditions. Considering the robustness and flexibility of shell and tube heat exchangers, extensive experimental testing, and positive field feedback, it is safe to conclude that TWISTED TUBE heat exchanger technology is able to successfully overcome most shortcomings of conventional segmental baffle and plate heat exchanger designs. As such, it has proven to be an attractive and economical alternative to those technologies.

The thermal/hydraulic effectiveness of the technology has been proven in most petrochemical services, while the installation at the naphtha reforming unit at the Hellenic Petroleum Thessaloniki Refinery, S.A. confirmed that the technology has passed the point of industry acceptance. These heat exchangers are emerging as a cost effective option in a wide range of applications, and even outside of the niches associated with retrofit projects. 