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HEAT EXCHANGER TUBE INSERTS AN UPDATE IN NEW APPLICATIONS WITH TROUBLE SHOOTING ASPECTS IN CRUDE UNITS, RESIDUE SERVICE, REBOILERS, U-TUBES

"SPIRELF®, TURBOTAL®, AND FIXOTAL® SYSTEMS" APPLICATION EXAMPLES IN CHEMICAL PLANTS AND REFINERIES

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ABSTRACT

Heat exchanger tube inserts have been used for many years as reliable means for heat transfer enhancement and fouling mitigation in petroleum refineries and chemical plants.

In this paper, we will present several new application examples for optimization of heat exchangers and related equipment, resulting in enhancement of the function of such equipment and improvement of on-line availability of the plant.

Usual insert applications in refining pre-heat trains continue to give good performances for fouling mitigation and heat transfer conservation. For the refiner, this improvement brings interesting energy savings but also longer run times with better overall performance of the pre-heat train. Tube inserts are largely used in CDU and VDU applications.

In some new applications such as reboilers (liquid and mixed phase flows), air coolers, FCC units, and scaling water, the observed efficiency was valuable because the shorter initial service times have been expanded substantially (in some cases 4 to 6 times longer than the initial service time), and with higher efficiency levels achieved during this extended service time.

Some of these applications and results are described in this paper.

INTRODUCTION AND TUBE INSERT DESCRIPTIONS

Turbotal®

Spirelf®

Three inserts are available, the two first of which are aimed primarily at reducing fouling rate by mechanical effect (rotation for TURBOTAL®, vibration for SPIRELF®). They also enhance heat transfer as a favourable side effect.

Typical applications include Crude Preheat Train and hydrotreaters feed-effluent exchanger

Typical debottlenecking installations in Crude Distillation Unit preheat trains gets improved operating conditions at main distillation column through equipment of pump-around/reflux line exchangers. In case of limited furnace capacity, increase of crude temperature at furnace inlet is possible by equipping exchangers directly upstream of the furnace.

Improved throughput capacity due to reduced need for exchanger cleaning (runtimes at least doubled for equipped exchangers) is also observed because of tube inserts.

Better cooling of outgoing products to storage.

Fixotal®

FIXOTAL® is a turbulence promoter, with swirl effect. This fixed device is aimed primarily at increasing the inner heat transfer rate. Its effect is equivalent to double the fluid velocity. It also reduces fouling for « wall temperature dependant » type of fouling (polymerisation, solidification of wax, water scaling,…) Typical applications of Fixotal are in Air coolers, Cooling water, U tubes, mixed phase flow.

The "Spirelf System" is a flexible metal spring that is inserted into the exchanger tubes with a fixing wire at each end (see fig. 1)

SPIRELF SYSTEM FOULING MITIGATION AND HEAT TRANSFER IMPROVEMENT

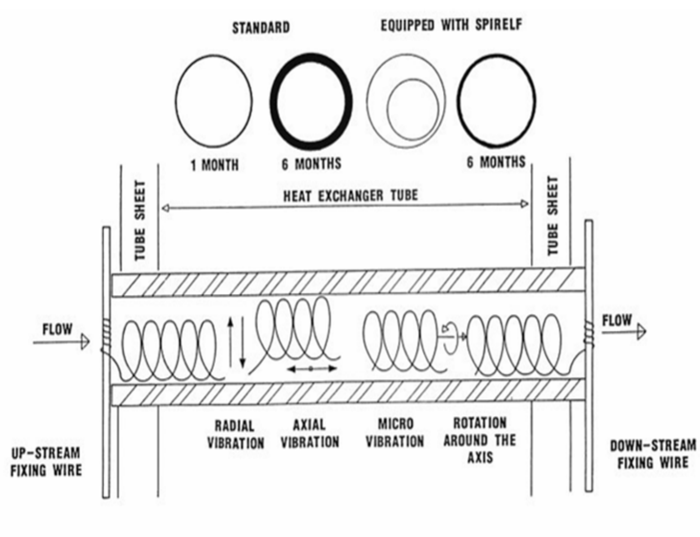

Fig. 1 : Fouling mitigation

1.3. Insert Effects:

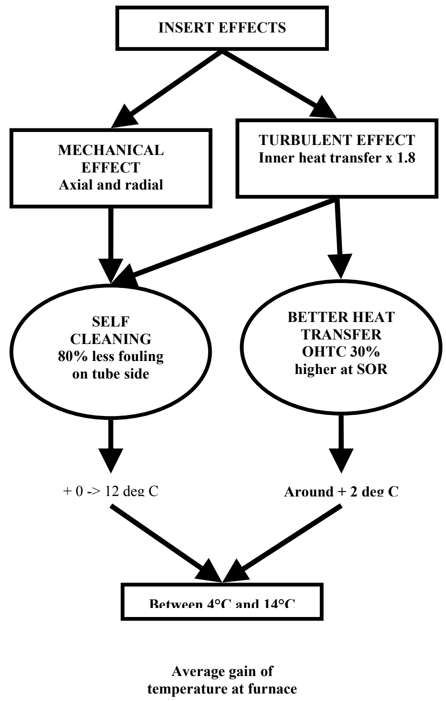

Fig. 2 : Tube insert effects

Table 1: POSSIBLE SAVINGS OF SPIRELF

Example: Refinery: 5.6MT/year – 120,000 b/d throughput
– Equipment: 6 exchangers before the furnace
– Previous cleaning frequency: 6 months
– Results: 1.5 year service time before cleaning
Average increase CIT at furnace: 6.8 °C

Energy saving
– 1°C increase at furnace = 1.2 ton of fuel saved per day
– Energy savings in 1.5 years: 4,450 Tons of fuel: Euro 445,000

Economic evaluation
– Total savings Euro 445,000
– Investment Euro 150,000
Material: 110,000 + Installation cost: 40,000 (Average estimation)
– Payback time Less than 5 months

Other savings:
– Maintenance savings
– Production loss savings

CDU APPLICATION: THE TURBOTAL SYSTEM - EFFICIENCY COMPARISON IN A CRUDE UNIT

Unit description

In November 2003, Turbotal has been replaced in CDU 1 heat exchangers 8ABEF. In order to evaluate the efficiency of the Turbotal in these heat exchangers, a comparison study has been performed between the 2 branches of the pre heat train (one equipped 8AB, one unequipped 8EF, see fig 3).

Details are provided in table 2

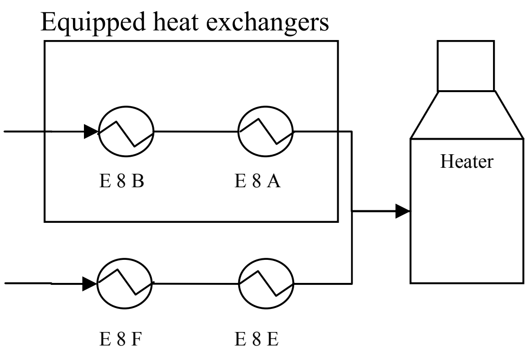

Fig. 3 : heat exchangers configuration

After 1 year operation, a new evaluation based on refinery results is prepared. No technical problem has been observed. Working performance of equipped heat exchangers is still around 40% higher than the unequipped one. The observed extra DP (average value around 0.6 bars) due to Turbotal is in line with the normal Extra DP evolution, especially in new tube configuration, with protective layer at tube wall built during the run.

Based on this experimental results, the energy savings generated by a better preheat train efficiency are already paid back.

Table 2: Heat exchanger characteristics (tube side) (Used for expected for study/real)

• Unit:	Crude Distillation Unit (Pre heat train)
• Heat exchanger number:	2 (2 branch of 2 heat exchangers in series)
• Position in the pre heat train:	Before the furnace
• Tube number / bundle:	1 424
• Tube length:	6,100 mm
• OD / BWG:	¾" / 14
• Product tube / shell side:	Crude / Atmospheric residue
• Flow rate (tube side):	400 t/h
• Flow velocity (tube side):	1.1 m/s
• Tube insert:	Turbotal
• Replacement frequency:	Every 2 years

The work working conditions since the last installation have been quite stabilized and generally match with the expected working conditions in tube side. One branch has been equipped in order to evaluate the efficiency of the Turbotal installed in the pre heat train.

Expected technical improvements

Based on Petroval technical evaluation following improvement had been estimated.

The Extra DP (at start of run) was predicted to be + 0.15 bar / bundle. As there is 2 bundles in series, the full extra DP would be + 0.3 bar.

Heat transfer improvements are with the inner heat transfer coefficient which would increase by a 1.8 coefficient.

The expected outlet temperature level conservation was estimated at about 4°C higher than without tube inserts.

Theoretical energy savings and pay back time for a full equipment of the 4 heat exchangers (Based on expected technical improvement and high price of 25 Euro) is for energy savings around 260 000 Euro with investment of 167 000 Euro

Expected payback time is around 8 months

Flow rate evolution

- Tube side situation

Between both heat exchanger branches, the flow is globally well balanced during the run with a partial flow in equipped branch 5% more than in unequipped one. This situation fluctuates during the run but since November 2003, fluctuation are very limited and should not affect the efficiency of the Turbotal.

- Shell side situation

Shell side flow rate is significatively different between both heat exchangers. Shell side flow rate is 50% more than in 8AB than in 8EF. Duty results have to be different as the working conditions are not similar in both heat exchangers. Globally, during the first year, the shell side flow is stabilized with 50% more in equipped heat exchangers compared with the flow in unequipped ones.

The two heat exchangers have different working conditions but both are stabilized and the duty variation evaluation shows the Turbotal efficiency, in the pre heat train. Except between March and April 2004 where both side flow rates had been changed. During this period, working conditions were to a lower level than the requested one for Turbotal use.

Heat transfer evolution and efficiency

During the 5 first month's operation, the improvement of heat transfer is between 50 and 30%. Due to flow reduction in March 2004 for 1 month in tube and shell side for both branches, the efficiency was a lot reduced but it kept anyway more than 10 % improvement. After this reduced production period, the improvement of heat transfer increased up to 20% and stabilized at the value since.

Between end of May and October 2004, the improvement was stabilized around 40 % and it increased up to 50% in November 2004.

After the initial part where tubes were new in equipped ones and just mechanically cleaned in unequipped, the difference in heat transfer efficiency was artificially better than usually at start of run (whereas it should normally be around 20% improvement). It is now back to normal comparison between equipped and unequipped ones. From August to November 2004, at stabilized working condition, whereas the duty in unequipped one decrease progressively, the duty in equipped one stay stabilized and even slightly increases a little bit in November 2004 (See comparison in Fig 4).

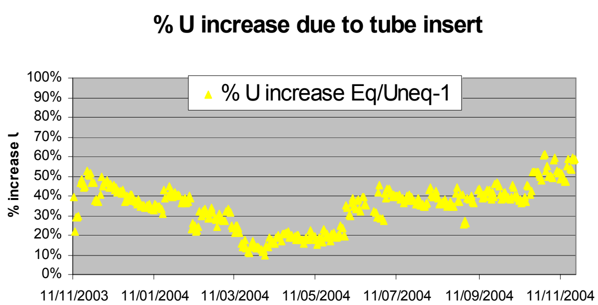

Fig. 4 : % U increase due to tube inserts

Explanation of the evolution:

Fouling is stabilized in equipped tubes and turbulent effect increased heat transfer compared with fouling accumulation situation in unequipped ones.

According to the flow sheet, shell side product is atmospheric residue which is usually a fouling product which strongly influence the global duty of the heat exchanger and against which the tube insert cannot work. The equipped heat exchangers are now running with 50% improvement for the duty compared than without. The fouling in tube side should be a very important limitation of the global heat transfer in these heat exchangers.

Table 3: The Delta T (Outlet – Inlet) evolution between both branches has been quite significativelly improved due to Turbotal:

Average value for the first year	Inlet °C	Outlet °C	Delta T	DT after 1 year
°C in 8AB (tube side)	203	242	39	37
°C in 8EF (tube side)	212	242	30	27

Tube inserts installation in heat exchanger 8AB increased the average DT during the first year by 9°C. A conservation of 9°C is possibly observed at the furnace inlet by using tube insert during this period. The final monitored Delta T is still +10°C

At stabilized working conditions (flow rates) between end of August and November 2004, the average of temperature difference between equipped and unequipped heat exchangers increased from 7 to 10 °C (See evolution in Fig 5).

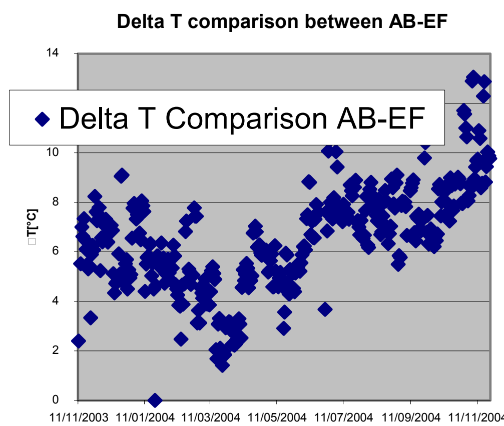

Fig. 5 : Delta T comparison

Energy savings evaluation

The interest of Turbotal installation is both cleaning effect and turbulent effect in tube side by mechanical action. As it has been observed in this heat exchanger, it brings some better heat transfer performance which help to keep higher outlet temperature of the heat exchanger and when it is installed into the most strategic heat exchanger, this thermal improvement can bring some money savings due to energy savings among others.

In this particular case, energy savings can be calculated as follow:

Table 4:Savings estimations

Investment for E8A/B/E/F:

Note: as the most efficient result would be to have both branches equipped, this estimation is done with a full equipment of E8.

Material: Euro 25 x (1424 x 4) = Euro 142 400

Installation: 8 shifts of 10 hours work at Euro 3 000 / shift = Euro 24 000

Total investment: Euro 166 400.

Energy saving calculation:

Data: normal crude flow-rate : 800 metric t/hr

- specific heat of crude : 0.65 kcal/kg.°C at 210°C
- furnace yield : 0.85
- heating power of fuel : 9,700 kcal/kg

1°C higher at the furnace inlet corresponds to a daily savings of:

$$\frac{800{,}000 \times 24 \times 0.65}{0.85 \times 9{,}700} = $$ 1,500 kg of fuel saved (9 bbl of fuel oil saved per day per °C)

Energy savings during one year of run :
3,285 bbl of fuel oil per year per °C
Based on 20 Euro / bbl for fuel oil:
Euro 65,700 savings per year per °C
With Turbotal, it has been calculated during the 6 first months of last run that an improvement of 9°C is a realistic improvement in these heat exchangers.
Euro 591,300 savings per year per 9°C

Global energy savings over 1 year :
Euro 591 300 during the first year

Pay Back Time :
4 months

This estimate is based on energy savings during one year. In this specific case, if all heat exchangers E8A/B/E/F had been fully equipped with Turbotal the payback based only on heat transfer improvement and energy savings, would have been already there. Then the 18 additional months would generate only purely energy savings.

Usually Turbotal installation generates also production loss savings and maintenance savings (if in between shutdown can be avoided).

Conclusion in this CDU

Results of efficiency improvement and technical characteristics of this evaluation are quite positive because it is in line with the expected results:

- The heat transfer improvement (“U” value) was at start of run around + 50% with an average value during the 6 first months around + 30 % and a final stabilization at + 20%. During the second semester, the duty increased from 20 % up to 50%. The increased was especially visible during a stabilized period between end of August and November 2004.
- This improvement results into higher outlet temperature of +10°C for equipped branch. And the average improvement is around +9°C.
- Energy savings are then better then initially expected
- Pay back time is shorter than the estimated one, less than 4 months instead of 8 months expected.

Vacuum Distillation Unit APPLICATION: RELIABILITY ENHANCEMENTS WITH THE “FIXOTAL SYSTEM”

Table 5: technical description

Heat exchanger characteristics	
• Unit:	Vacuum Distillation Unit (Pre heat train)
• Heat exchanger number:	3 (in series)
• Position in the pre heat train:	Before the furnace
• Tube number / bundle:	1200
• Tube length:	6,100 mm
• OD:	1”
• Replacement frequency:	Every 3 years (since 1998)
• Product tube / shell side:	Atmospheric residue / bottom reflux
• Flow rate (tube side):	400 t/h

Installation problematics

Before installation, the heat exchanger was 6 passes with a strong problem of efficiency due to too strong fouling whereas fluid velocity is quite high (around 2.2 m/s) and too short residence time (compared with the effective heat transfer coefficient with fouling).

Observed results and production constraints was poor heat transfer efficiency, high extra DP due to fouling, cleaning frequency of 6 months and furnace bottleneck because of lower inlet temperature

Decided modifications was pass configuration modification: from 6 to 2 passes (Flow velocity from 2.2 to 0.8 m/s) and Fixotal installation

Expected results was reduction of pass number: increase of residence time and global heat transfer. Strong increase of the fouling is foreseen (X3).

The Fixotal installation mitigate fouling and increase heat transfer by efficient turbulent effect at the tube wall.

Observed results are efficient heat transfer coefficient during the run, comparable service time and chemical cleaning every 6 months to recover periodically the initial performance.

(Results are shown in fig 6)

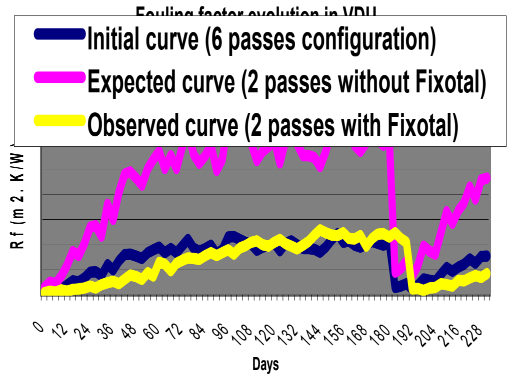

Fig. 6 : Fouling factor with Fixotal

Conclusion:

- Good thermal efficiency due to pass number reduction and Fixotal installation
- Good fouling mitigation due to Fixotal. Comparable fouling evolution whereas it should have been 3 times more severe and bring quite strong problem of the service time and production enhancement.
- Chemical cleaning every 6 months in order to recover the initial efficiency without removing Fixotal. A replacement is expected every 3 years.

REBOILER APPLICATIONS

Generally reboilers are heated on shell side by steam, and the organic product flows tube side.

In terms of heat transfer, there is a big difference between the outside and the inner heat transfer coefficients, and this latter one constitutes the main resistance for the heat transfer. This characteristic is even more pronounced in case of fouling coming from the organic product.

Consequently, any increase of the inner coefficient translates to about the same improvement on the global heat transfer coefficient.

Action of the Spirelf System on vertical reboilers' performance at start-up.

Spirelf devices have two actions, first a turbulent effect from the start-up of the reboiler, then a combinated effect, turbulent and mechanical, giving a reduction of the fouling layer during the service time of the reboiler.

From the start-up, through the increase of turbulence coming from the shape of the devices, there are different types of action on almost each region of the boiling tube.

Apart from the annular flow region where there is not enough liquid phase, Spirelf increases the performance of the convective boiling:

In the slug flow zone, due to its presence (as a packing), Spirelf reduces the formation of large size bubbles (reduction of the coalescence of small bubbles). It maintains a longer time the bubbly flow, more efficient than the slug (or plug) flow.

In the bubbly flow region, without change of the number of nucleation sites (mainly depending on the metal surface), the increase of turbulence associated to the motion of the spring going into contact with the wall, reduces the residence time of the bubbles on the metal surface, giving a better efficiency for each site of nucleation.

In the submerged area, at the lower part of the reboiler when this one is vertical, Spirelf reduces the "laminar layer" thickness on the surface of the tubes, increasing the convection coefficient (see description in fig. 7)

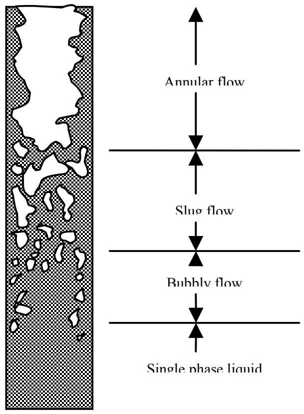

Fig. 7 :
flow distibution reboiler

Special case of thermosiphon reboilers.

In the case of thermosiphon reboilers, the increase of vaporization due to Spirelf leads normally to increase also the flow rate of product (when flowing in the tubes), but at the same time, the inherent extra pressure drop introduced by the springs has as effect to reduce it.

At the start-up, the global effect of Spirelf on a thermosiphon reboiler can be translated by:

Less liquid but more % vaporization = same duty

In fact, we have always noticed that at the start-up, the performance of a thermosiphon reboiler was not affected by Spirelf. This result has been observed every time when such type of reboiler has been equipped with Spirelf devices.

Spirelf effect in service

Generally fouling grows on the tube surface, and a source of fouling on the organic product side, comes from the high temperature of the wall, heated by medium pressure steam (around 200° C – 400° F). After forming of the first layer of deposit on the wall, the tube surface becomes rough what make easier formation of new deposits on it. As at the same time, the wall temperature becomes higher due to the resistance of the fouling layer, organic compounds are transformed into coke.

It is important, in order to prevent severe fouling, to reduce from the start-up the first fouling formation.

Without to take into account the mechanical effect of the Spirelf springs going into contact with the wall, the increase of turbulence itself reduces the "laminar layer" thickness, reducing the wall temperature and consequently fouling phenomena from the beginning.

This reduction of fouling is illustrated hereafter in one industrial case, where a direct comparison of performance has been made between two identical parallel reboilers.

Unit description N°1: Spirelf Effect during service time on a reboiler, thermosiphon type

This industrial test has been carried out during 5 months on two identical vertical reboilers, thermosiphon type, placed on the same distillation tower.

One exchanger was equipped (E-605). The other was unequipped (E-606)

Unit: Ethyl alcohol distillation

Problem to resolve: On average, the two bundles were cleaned tube side every 3 months through acid washing, meaning for the unit a total stop of production. The aim was to reduce fouling inside tubes in order to maintain the production a long time (Deposits are made of iron, carbon and silica).

Table 6 : efficiency results

Reboiler description: 926 tubes
¾" BWG 14 (inner diameter 15 mm)
4890 mm
16 feet long

Result: service duration three times longer than previously

Global heat transfer rate follow-up				
	Kcal/hr m² °C		BTU/hr ft² °F	
Reboilers	Equ'd	Unequ'd	Equ'd	Unequ'd
At SOR	1600	1700	330	350
After 5 months	1250	850	255	175
% of loss	22 %	50 %	22 %	50 %

Although the insert system is mostly used in crude unit applications, in liquid in horizontal exchangers, there are a number of applications also in vertical reboilers, with mixed phase flow. This is described briefly (see Fig. 8).

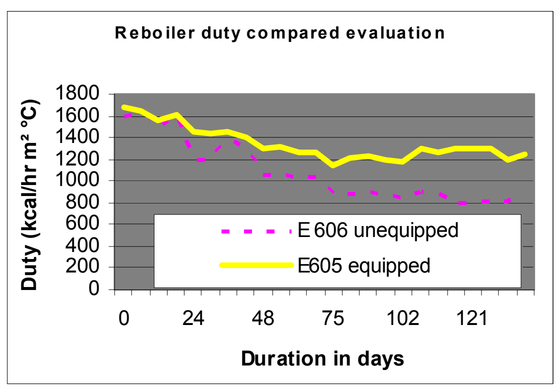

Fig. 8 : Reboiler result

Unit description N°2: Spirelf Effect for reboiler enhancement at a Caprolactam Plant in Thailand

This Caprolactam plant is located in Rayong Province, Thailand.

The distillation process at this plant consists of 8 (eight) columns, each of them having reboiler having attached. The function of these reboilers is impaired by the need for frequent cleaning, by water flushing, every 2 – 3 days, ut without the need for shut down. The problem encountered in this series (Col. C1, C2, C3, C4 and C5) is in the reboilers which usually need complete cleaning by water distillation, requiring a shut-down, usually twice per month.

Installation of tube inserts

The "Spirelf" System was installed in the reboiler 1140 E1 of Column C (1140 – C1), in March 2002. The reboiler has 1.001 tubes, 31-35 mm OD, 2-77 mm wall thickness, and 3.000 mm length. The material is C5, in a one – pass configuration. Each tube has been equipped with a tube insert. The installation has been performed by the plant's maintenance contractor, under the supervision of the plant Process Engineer, and a technical supervisor from Petroval. The installation was completed in two days, after previous cleaning of the tube (a requirement for installation of the inserts).

Reboiler Operational improvements

After installation of the inserts, the function of the reboiler has been improved as follows:

The reboiler has been operated continuously for 30 days, before water washing became necessary. This means an extension of the run time from 10 days (average) to 30 days, resulting in better reboiler performance, and the avoidance of 1-2 shutdowns during this cycle. The savings realised for the plant are:

- Avoidance of product loss (due to shutdown before installation of inserts)

- Avoidance of cleaning costs (through extension of the run cycle)

Unit description N°3: Spirelf Effect for increased efficiency in duty and service time for thermosiphon reboiler

This is an application of Spirelf in a vertical reboiler, where a strong fouling situation was a bottleneck issue for the chemical plant. This unit dealing with fluoric compound requested a monthly water injection in order to clean them and to come back to normal situation

The initial working conditions were:

- Natural thermosiphon
- 1 heat exchanger of 80 tubes and 1 pass on tube side,
- Flow rate: between 15 and 30 t/h,
- Boiling organic is flowing tube side,
- Straight tubes 1,500 mm / OD 27.45 mm / internal diameter 21.4 mm.

Due to the low velocity in single liquid phase, the implementation of Spirelf in this reboiler was proposed in order to generate a turbulent effect in this part of the tubes. This effect was expected to increase the convection coefficient of the liquid and accelerate the gas formation.

Due to higher turbulence and reduction of boundary layer thickness because of Spirelf, the fouling reduction was estimated around 50% reduction.

Service time with Spirelf is usually doubled (theoretical expectation). As normal Spirelf life time is about few years, if fouling mitigation is strongly effective it can last around 5 times or more the initial service time.

Observed results

Initial evaluation after first installation in February 2004 after 3 months installation the Spirelf was still in service and the 6 months service time without water cleaning was expected at the time of the evaluation. Observed results are a strong mitigation of the fouling deposition. Observed U value in equipped situation is now stabilised at higher U value than the expected stabilisation (expected around 200). In additional results, it is more than twice higher than the stabilisation without Spirelf. (Results presented in fig 9)

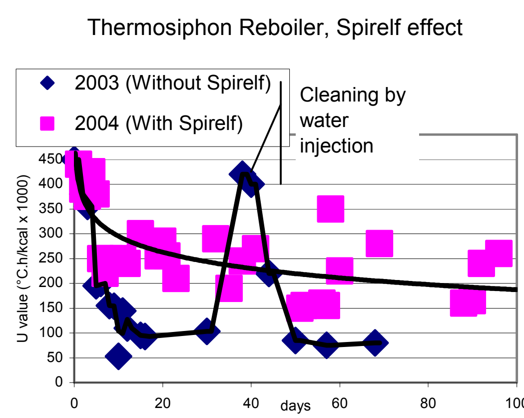

Fig. 9 : Thermosiphon reboiler results

There are 4 reboilers in the unit, and 2 of them were in bottleneck situation because of fouling. After this test, the chemical plant decided to equip both critical reboilers in order to be able to run 1 year with water injection every month.

U-TUBE APPLICATION

Table 7: technical description

<u>Heat exchanger characteristics</u>

• Unit:	Lube
• Heat exchanger number:	4
• Tube number / bundle:	48
• Tube length:	6,100 mm
• OD:	12 mm
• Replacement frequency:	Every 4 years

<u>Heat exchanger characteristics</u>

1. Box full of Fixotal
2. Final position at the tube sheet
3. Picture of an equipped heat exchanger with U-tube configuration

Fig 9: Fixotal installation

4. Sketch of equipped U-tube

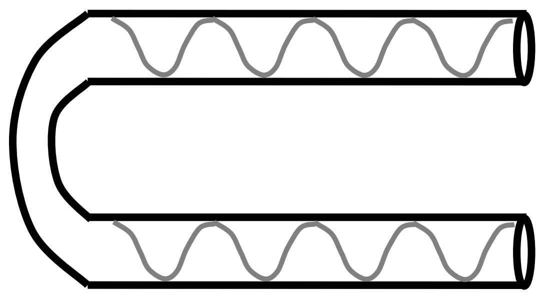

Fig. 10 : U tube configuration

Effects:

- In straight parts: turbulence and fouling reduction
- In U-section: additional turbulence (carry over from straight part)

SCALING WATER TEST APPLICATION WITH FIXOTAL

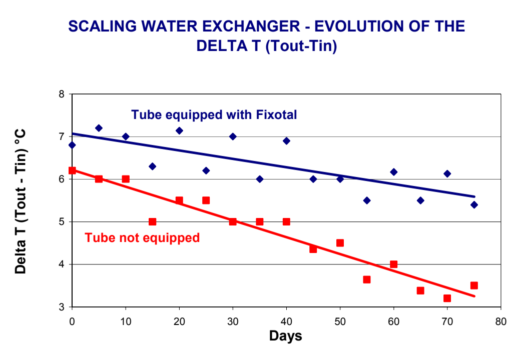

Fig. 11 : Scaling Water exchanger results

In this application, the difference of temperature between inlet and outlet of the heat exchanger was kept to higher value with Fixotal, compared with situation without Fixotal. Fig 11 shows in fact the fouling mitigation effect of Fixotal even if there is no direct mechanical effect. The turbulence at the tube wall and the heat transfer improvment increase both the efficiency of the heat exchanger.

Summary:

In all these recent case studies, the installation of tube inserts in these applications improved largely the efficiency of the heat transfer and the reliability of the unit. Turbotal, Spirelf and Fixotal had a very important impact in order to remove the bottleneck situation created by the fouling situation of these heat exchangers and reboilers.

The general impact on the performance of these units is maintenance reduction (fewer cleaninperiods), but also energy savings if well situated in the unit and production enhancement by increasing the service time at higher efficiency.

A word of thanks

The authors want to thank the management of the operators for the permission to publish this paper, and the organizers, ECI, for the acceptance of this presentation.

List of Publications

The Petroval Tube Inserts Systems: "SPIRELF®, TURBOTAL, and FIXOTAL
have been described in the following publications:

Petroles et Techniques n°295, Janvier fevrier 1983

Chem. Eng. Progress, September 1991,"Heat Transfer Heads into 21st Century"

ASME 1995, National Heat transfer Conference, 7 August 1995, "Field of application of double enhanced tubes in shell and tube and air cooled heat exchangers",

Hydrocarbon Processing, February 1998, "Revamping Crude Units"

AIChE, March 8-12, 1998, "New Heat Integration Techniques for Boosting Profitability",

AIChE, March 14-18, 1999, "A Practical Approach to Fouling Mitigation in Refineries: Spirelf System".

ESDU Doc. 000 16,2000, "Heat exchanger fouling in crude oil distillation units",

Proceedings, August 2000, 2nd Intl. Conference on Petroleum and Gas Phase/Fouling, Copenhagen,

UEF Heat Exchanger Fouling Conference, 2001, Davos (Switzerland)

Publico, 2001, Heat Exchanger Fouling Mitigation and Cleaning Technologies, Ed. H.Mueller-Steinh.

AIChE Spring Meeting, March 2002

ARTC 5th Annual Meeting, April 2002, Session on Refining and Petrochemical Technology, Bangkok

ARTC Reliability Conference, November 2002 Singapore (SK Corp. Korea)

HDT Haus der Technik Heat Exchanger and Cleaning Seminar, Sept. 2003 Bad Duerkheim (Germ.)

ARTC 7th Annual Meeting/Reliability Conference, April 2004 Singapore (Thai Caprolactam/Petroval)

AIChE National Meeting, April 2004, New Orleans (Shell/SGS, Argonne, Petroval)

HOD Intl. Conference on Heavy Organic Depositions, Nov. 2004, Los Cabos (Mexico)

NPRA National Petrochemical and Refiners Assoc. Technical Q&A sessions: 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004