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HEAT EXCHANGER PERFORMANCE ENHANCEMENT THROUGH THE USE OF TUBE INSERTS IN REFINERIES AND CHEMICAL PLANTS – SUCCESSFUL APPLICATIONS: SPIRELF®, TURBOTAL® AND FIXOTAL® SYSTEMS

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ABSTRACT

For many years, heat exchanger tube inserts have been used for fouling mitigation and heat transfer enhancement in refineries and chemical plants; the benefits are clearly established in numerous industrial installations and test applications.

The combination of increased turbulence and movements results in reduction of the tube side fouling layer (mechanical effect) and improvement of the inner heat transfer rate (turbulent effect).

Benefits of these systems include energy savings, extended run lengths of exchangers, reduction in maintenance costs, production enhancement and de-bottlenecking, with emission reductions as a side effect.

INTRODUCTION

Shell and tube heat exchangers are the work horses of thermal operations in the chemical or refining industry. Prevention of fouling in this type of equipment is of major concern.

Among solutions available to operators are anti-foulant additives, re-design of equipment and use of enhanced performance tubes, however current fouling tendencies often do not match the initial design specifications. Also, in the case of refining operations, blending of incompatible crude types may lead to asphaltene precipitation due to the modification of their solubility.

In many cases, the only way to deal with fouling is to clean heat exchangers at regular intervals, resulting in higher maintenance costs and operational consequences.

Petroval SA, based in France, can offer different types of tube inserts, based on the initial development in refining operations of two major European Oil Companies, Total and Elf. These devices are:

- SPIRELF® (developed by Elf)
- TURBOTAL® (developed by Total)
- FIXOTAL® (developed by Total)

This paper describes the principle of these three systems. Fig. 1,2,3 and 4 show the devices and their effects. Their specific functions and applications are highlighted, including pilot plant and industrial results in different applications.

Fig. 1: Rotating insert: TURBOTAL®

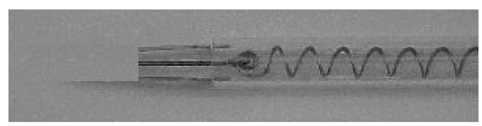
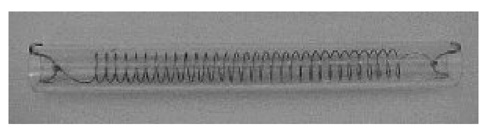


Fig. 2: Vibrating insert: SPIRELF®

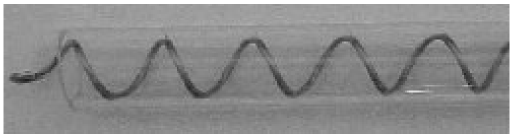


Both devices aim primarily at reducing of the tubeside fouling rate by mechanical effect (rotation for TURBOTAL®, vibration for SPIRELF®). They also enhance heat transfer as a favorable side effect.

- Typical applications are: Crude Preheat Trains, hydrotreaters, feed-effluent exchangers
- Typical debottlenecking installations in Crude Distillation Unit preheat trains :
    - Improved operating conditions for the 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)
- Better cooling of outgoing products to storage.

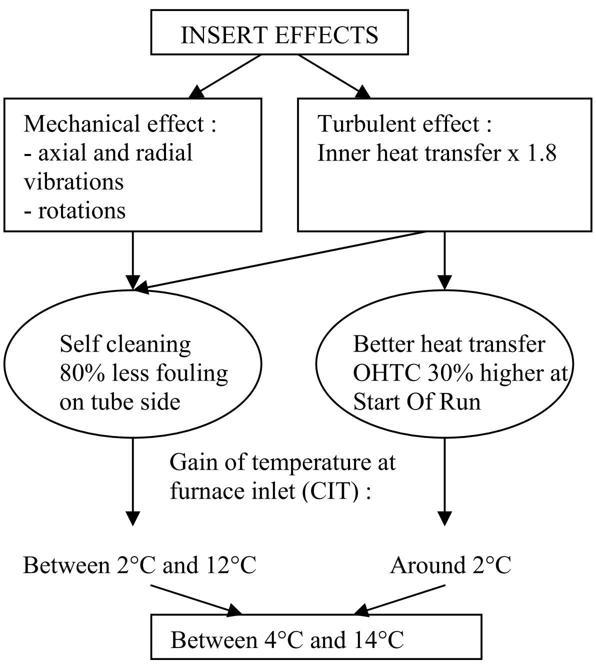
Fig. 3: Fixed insert for heat transfer enhancement: FIXOTAL®



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 dependent type of fouling (polymerisation, solidification of wax, water scaling)

- Typical applications : Air coolers, U tubes, mixed phase flow

Fig. 4: Insert actions



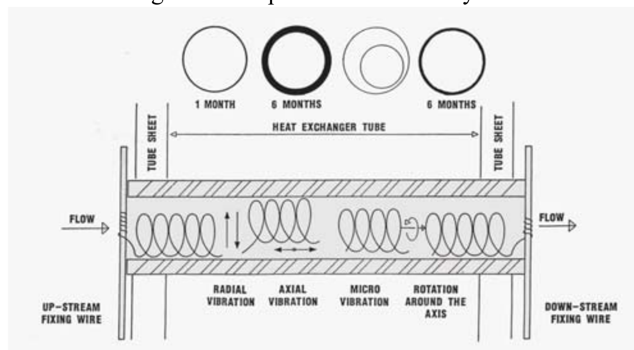
SPIRELF® SYSTEM

Description

The SPIRELF® system is a helicoidal flexible metal device that is inserted into heat exchanger tubes

The devices are are held in place by straight wires at each end (inlet and outlet) (see Fig. 5).

Fig. 5 : Principle of SPIRELF® System



Operating principle

After installation, the insert stays under tension, and under the effect of the circulating flow, enters into vibrations, radially and axially. The repeated contact between the turns and the inner wall has two effects :

- to prevent the formation of deposits,
- to renew continuously the tube-side boundary layer

.

As consequences, the mechanical effect of the SPIRELF® system reduces fouling build-up inside heat exchanger tubes, and the turbulent effect achieves an improvement of the heat transfer rate (the internal heat transfer coefficient is multiplied by a factor of 1.8).

Overall, the combination of these two effects results in a reduction of the apparent fouling factor by approximately 66% to 75% (see Fig. 4).

Applications of SPIRELF® System

The SPIRELF® system is used primarily in crude distillation units (CDU's), where the fluid is normally single phase, and the main fouling layer is composed by asphaltenes, and coke. In this application, the aim is primarily energy savings but also to improve maintenance management through extension of exchanger run times which at the same time can improve throughput capacity.

Main advantages of SPIRELF® system in crude preheat trains - Heat transfer enhancement.

* Through higher flow turbulence (inner heat transfer coefficient X 1.8),
* Reduction of fouling and coking in heat exchanger tubes :
- typical result: energy savings of up to USD 500,000 per year
- Installation example – Fuel savings of 23,800 barrels = 3,400 tons of oil equivalent (TOE) per year
- average cost/benefit ratio : 1 to 5.

Reduction of maintenance work/cost.

* Decrease of exchanger cleaning through reduction of tube side fouling,
* Extended run time through increase of cleaning intervals : the run time with SPIRELF® is typically two to three times the previous run time, with a maximum life time of 6 years (or more in specific applications).
* Extended tube life/reduced leakage due to reduction of under-layer corrosion,
* Designed to avoid mechanical tube erosion.

De-bottlenecking - improved throughput capacity. Detailed in the introduction.

Combination with antifoulant chemicals.

* Increased efficiency of additives through higher turbulence,
* Decrease of consumption/dosage of antifoulants by 50 % or more.

Pressure drop.

* The pressure drop caused by SPIRELF® devices is between 0.15 and 0.2 bar (2 and 3 psi) per pass (depending on tube dimensions, crude type, flow velocity),
* The pressure drop caused by fouling has to be considered for comparison (EOR conditions without SPIRELF®)
* The pressure drop resulting in increased flow turbulence (es proven in multiple cases, the inner heat transfer coefficient is multiplied by a factor of 1.8 or better).

Typical installations.

* Crude preheat train (with crude flow tube side) last exchangers before furnace, pumparound/reflux lines, product lines to storage,
* Retrofit installation,
* Newly built exchangers to be equipped to improve exchanger performance/extend anticipated run time.

Metallurgies available.

* Stainless steel (different grades for high/low temperature applications),
* Special alloy (Inconel, with high Ni and Cr content),
* Carbon Steel for specific applications (shorter lifetime),
* Tested lifetime of SPIRELF® devices 6 years and longer, depending on the application and choice of metallurgy.

Industrial results with SPIRELF®

Application 1. Crude unit preheat train : 5.6 MT/year – 120,000 bpd throughput
Previous cleaning frequency : 6 months
- Description: Exchanger 1047 AB has been equipped and compared to the identical but unequipped exchanger installed in parallel 1407 CD. Both exchangers have crude flowing on tube side and gasoil P/A on shell side.
- Results: New service time of this exchanger is 1.5 year

-Comments: Subsequently, the installation of SPIRELF® devices was extended to a total of 6 other exchangers of the preheat train (11 bundles).

The average Crude Inlet Temperature (CIT) at the furnace has been increased (see Fig.6) in average by 6.8°C (12°F), with peak values at 15°C (27°F).

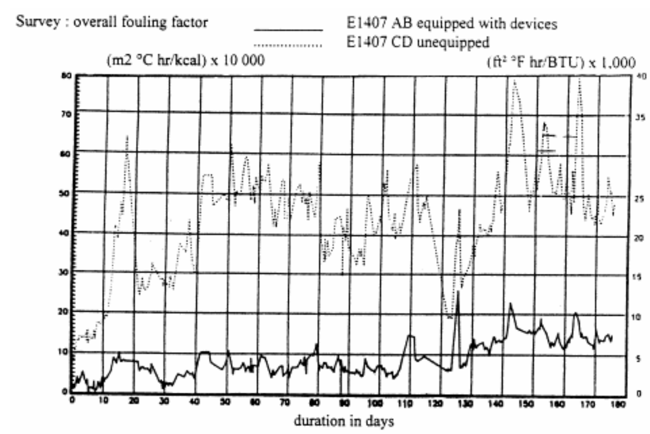
<u>- Economical Results :</u>

Savings per year:

2,700 tons (19,000 barrels) of fuel	USD 270,000
2 cleanings avoided	<u>USD 90,000</u>
Total savings :	USD 360,000

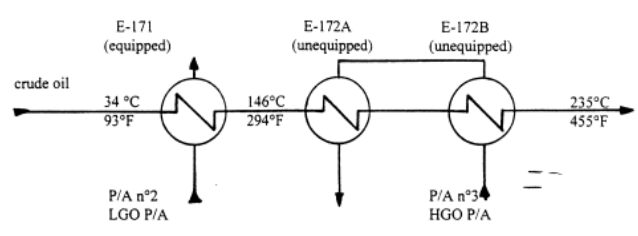
- investment on a yearly base: 9950 devices including installation USD 133,000
- net profit per year : USD 227,000
- pay back time : (133,000 / 360,000) less than 5 months

Fig. 6: Fouling factor survey



Application 2. Crude unit preheat train: 7.5 MT/year – 145,000 bpd throughput.

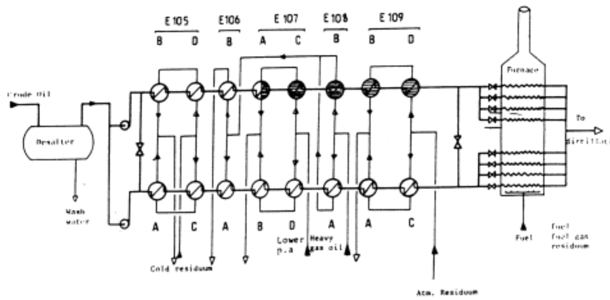
Fig. 7:Preheat train



Previous cleaning frequency : 4 months
- Description: The hottest part of the preheat train has two identical branches. The last three exchangers (5 bundles) of one branch have been equipped with SPIRELF® devices, and performance compared to the unequipped branch (see Fig. 7).

Branch A: devices installed in 5 bundles – (E107A being half equipped).

Fig. 8: Schematic of the crude preheat train



- Results: 12.5°C (22°F) gain of temperature at furnace inlet (CIT) due to the devices after 4 month service time.
- service time of the equipped exchangers more than two times longer : 1 year
<u>- Economical Results (calculated on the basis of an equipment of the two branches):</u>

- Average gain at CIT :6.7°C (12°F) increase of CIT

Savings per year:

3,400 tons (24,000 barrels) of fuel	USD 340,000
1 cleaning avoided (6 exchangers)	<u>USD 100,000</u>
Total savings :	USD 440,000
- investment : 10,266 devices including installation	USD 200,000
- net profit per year :	USD 240,000

- pay back time : (200,000 / 440,000)less than 6 months

Note: this comparative test has been carried out with the help and under the control of the European Economic Community (EEC).

Application 3. Crude unit preheat train.
Previous cleaning frequency : 4 months
- Description: Exchanger E-171 has been equipped with SPIRELF® and compared to the downstream exchangers. This exchanger belongs to a train composed by 3 exchangers in series. All of them have on shell side clean products : pump-around n°2 and 3 of the distillation tower, equivalent to LGO and HGO (see Fig.8).

After 6 months, for the exchanger equipped with SPIRELF®, the fouling factor is kept at its initial level, whereas the other unequipped exchangers E172 A and B see their respective fouling factor multiplied by a factor 4 and 1.5 (see Fig.9).

- Results: New cleaning frequency : more than 2 years
- Survey: Overall Fouling Factors (hr.ft2.°F/BTU unit) during the first six months (see Fig.9).

Fig. 9: Fouling factor survey

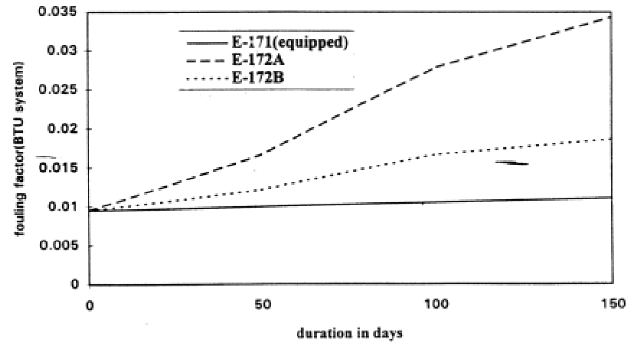
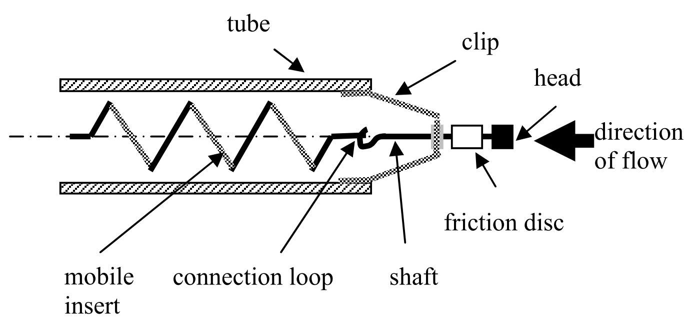


Fig. 10: Basic sketch of TURBOTAL® technology



TURBOTAL® SYSTEM

Description

TURBOTAL® device is a rigid helicoidal insert, held at the upstream end of the exchanger tubes by a system allowing rotation under the fluid drag (see Fig. 10). The downstream end of the insert is free, and remains unattached. The wire diameter and pitch will vary in accordance with flow conditions.

The basic idea was to develop a device set in motion by the fluid itself and which would be able to scrub continuously the inside surface of the tube, thus eliminating deposits at their early stage of formation.

Operating principle

While rotating, the mobile element scrubs most of the tube surface, thereby reducing the fouling rate. Furthermore, this rotation induces a high turbulence in the immediate vicinity of the tube wall and enhances heat transfer. The boundary layer is continuously renewed; the difference between bulk and wall temperature is reduced, which in turn limits fouling. The rotational design offers a large flexibility to the system. The rotation speed adjusts itself instantaneously to the hydrodynamic conditions such as :

- flow rate variations,
- variations in the physical properties of the fluid,

- possible vaporization (fluid hammer effect) due to water surges

Sizing of the TURBOTAL® devices

The insert diameter is a few millimetres smaller than that of the tube internal diameter. The other parameters – i.e. pitch, spiral diameter – are designed allowing for the hydrodynamic conditions to reach a trade off between the speed of rotation (to be kept at the most desirable RPM level), the mechanical resistance of the insert, the pressure drop and the resulting cleaning efficiency. The clip holding the insert at the upstream end of the tube is based on the trolling spoon principle.

The design and selection of the material for this essential piece of the equipment have been continuously improved through industrial experience, to account for friction, mechanical resistance to wear, and the manufacturing processes.

Applications of TURBOTAL®

Heat transfer enhancement, effect on pressure drop, effect on fouling rate, operational life were extensively studied initially on a pilot scale, either with a cold flow model or using a hot flow loop; and wide experience was gained in many industrial installations, which have also been used to improve the technology.

Main Advantages Of TURBOTAL® System - Heat transfer enhancement. As expected, the relative heat transfer enhancement is higher when the flow regime is less turbulent. Even in turbulent regimes, the internal heat transfer enhancement using TURBOTAL® is increased by 50 % to 80 %.

The internal heat transfer enhancement results in an increase of the overall heat transfer coefficient which depends on the resistance to heat transfer both inside and outside of the tube. In some cases (typically, CDU preheat train), the overall heat transfer coefficient can be improved by 30 %.

As an example, in a French refinery with two parallel branches, after a 5 month run, the fouling resistance on the exchangers train equipped with TURBOTAL® <u>was 5 times lower</u> than the one not equipped. TURBOTAL® was then installed in the whole heat exchanger arrangement. The corresponding energy savings were over 8,700 tons of Fuel Oil Equivalent per year (61,000 barrels), with <u>a pay-back time under 3 months</u>.

Reduction of maintenance work/cost.
* It reduces exchanger shutdowns for cleaning, and thereby saves maintenance costs,
* Extended run time through increase of cleaning intervals, thereby increases revenues: the run time with TURBOTAL® is typically two to three times the previous run time, with a maximum life time of 2.5 to 3 years,.
* Extended tube life/reduced leakage due to reduction of under-layer corrosion,
* Designed to avoid mechanical tube erosion.

De-bottlenecking - improved throughput capacity. This is detailed in the introduction.

Combination with antifoulant chemicals.
* Increased efficiency of additives through higher turbulence,
* Decrease of consumption/dosage of antifoulants by 50 % or more

The preheat train of a 220 000 BPD (11 MT/year) crude distillation unit was made up of two identical parallel trains A and B. Train A was partially equipped with TURBOTAL® while on train B anti fouling additive was continuously injected.

After one year of operation, with equivalent throughputs on each train, the temperature at the furnace inlet on train A was <u>20° C (68°F) higher</u> than on train B, showing a drastic efficiency of TURBOTAL® compared to antifoulants.

Pressure drop. The tube internal heat transfer coefficient increases at the expense of an increase in pressure drop which depends on fluid properties, velocity, tube size and roughness, and the geometric characteristics of the insert (spiral shape and dimensions).

The additional pressure drop remains low (typically less than 0.1 bar per pass – 1 psi) compared to the other types of inserts and the overall pressure drop of the exchanger, which not only depends on the friction in the tubes but also on head losses in inlet and outlet nozzles and in the distributor boxes at both ends.

Typical Installations. Detailed in the introduction.

Industrial experience of TURBOTAL®.
* Over fifteen years
* Over 80,000 TURBOTAL® devices currently in use
* Used by refineries world-wide

TURBOTAL® has been applied successfully in the following services: crude and atmospheric residue, gasolines, furfural, lubricants, hydroquinone, ethyl-benzene, various chemicals.

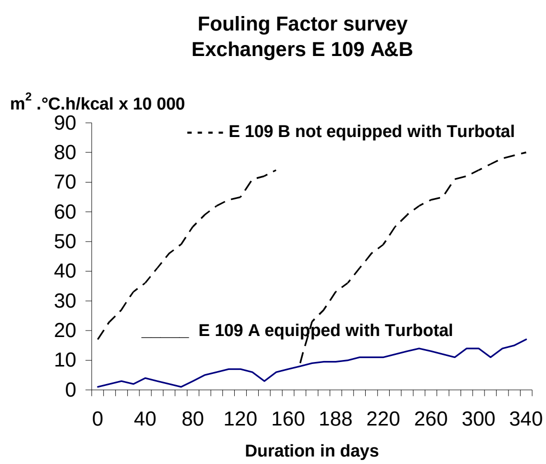
In general, this technology is potentially beneficial whenever fouling takes place inside the tubes. So far, more than 500,000 devices have been installed world-wide, and TURBOTAL® inserts are currently used in 20 process units.

Metallurgies Available.
* Carbon steel (standard application in crude service),
* Stainless steel (different grades for high/low temperature applications),
* Tested lifetime of TURBOTAL® devices 2.5 years and longer, depending on the application, choice of metallurgy and rotation speed of the mobile.

Industrial results with TURBOTAL®

Application 1. Crude unit preheat train: 7.5 MT/year – 145,000 bpd throughput.
Previous cleaning frequency : 5 months
- Description: The hottest part of the preheat train has two identical branches. The last exchangers (E109 - 2 bundles) of one branch have been equipped with TURBOTAL® devices, and performance compared to the unequipped branch. Crude is flowing on tube side and atmospheric residue on shell side.
TURBOTAL® devices, and performance compared to the unequipped branch. Crude is flowing on tube side and atmospheric residue on shell side.
- Results: New service time of this exchanger : 1.5 year
- Comments (see Fig. 11): After a 5 month run, the fouling resistance on the exchangers train equipped with TURBOTAL® was 6 times lower than the one not equipped. After a second run, TURBOTAL® was then installed in the whole heat exchanger arrangement.
As a result, the frequency of cleaning dropped from 5-6 months to 18 months. The corresponding energy saving was over 8500 tons (60,000 barrels) of Fuel Oil Equivalent per year, with a pay-back time under 3 months.

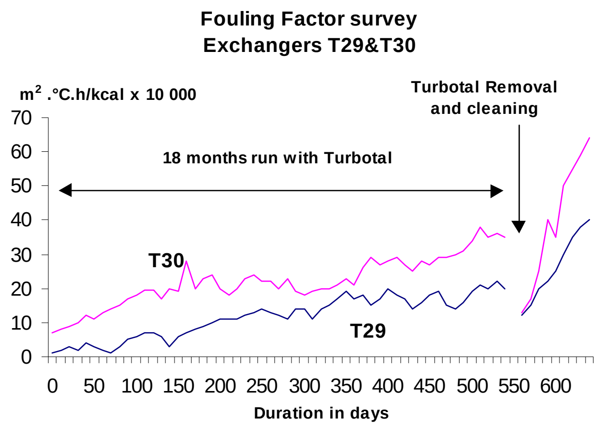
Fig. 11: Fouling factor



Application 2. Crude unit preheat train.
- Description: Exchangers T-29 and T-30 are the last exchangers of this crude preheat train. They have been equipped with TURBOTAL® and at the same time antifoulant chemical was injected. After 18 months, the TURBOTAL® were removed for a test the fouling factor with antifoulant chemical only was monitored (see Fig. 12).

- Results: After TURBOTAL® removal, with antifoulant being used only, the fouling factor after 3 months was 4 times more than with TURBOTAL® + anti-foulant. TURBOTAL® was put back in service.

Fig. 12: Fouling Factors



Application 3. Crude unit preheat train.
- Description: Exchangers E8A (2 bundles) and E8B (2 bundles) of this crude preheat train are located on two separate identical branches. E8A has been equipped with TURBOTAL®, E8B remaining unequipped. Performances have been compared. Crude is flowing on tube side, Gasoil P/A on shell side.

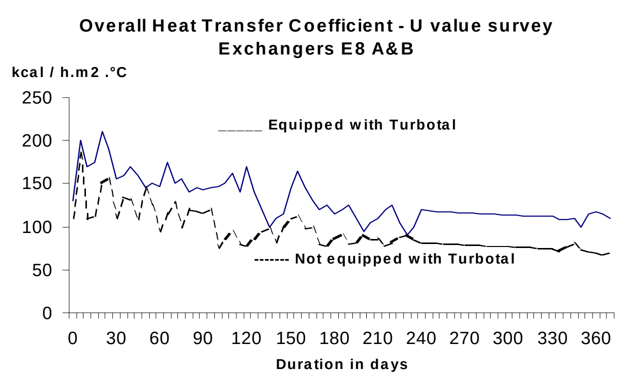


Fig. 13: Overall heat transfer coefficient

Comments on Fig. 13: For the branch equipped with TURBOTAL®, the overall heat transfer coefficient is approximately 40% higher than the unequipped branch.

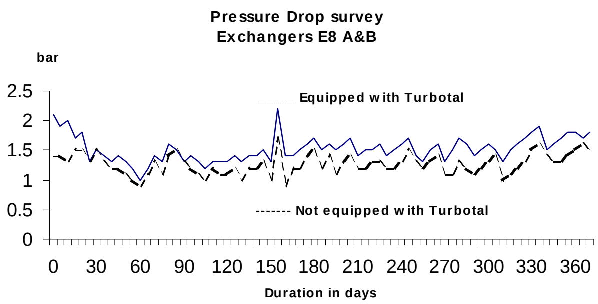


Fig. 14: Pressure drop of the exchanger group

Comments on Fig. 14: The survey shows an additional pressure drop of approximately 0.3 bar in average for a total of 4 passes is series equipped with TURBOTAL®, that is 0.075 bar per pass. Thus, the additional pressure drop created by TURBOTAL® remains very low.

The additional ΔP for the fixing clamp is minimal in comparison to the value of the insert inside the tube (average 0.2 bar per pass).

FIXOTAL® SYSTEM

Description

FIXOTAL® consists of a wire coil, which is inserted inside every tube, with the wire in firm contact with the inside tube wall. Once in place, the device has no possibility of displacement (no vibration, no rotation, and no shifting inside the tube).

Operating principle

The main effect of the wire is to induce a high turbulence in the immediate vicinity of the tube wall and to enhance heat transfer. The boundary layer is continuously renewed ; the difference between bulk and wall temperature is reduced, which in turn limits fouling.

The result is a significant increase of the tube side heat transfer coefficient. This has two major consequences :
*Increase of the thermal efficiency of the exchanger, due to an increase of the overall heat transfer coefficient.
The extent of the gain depends on the split of the overall heat transfer resistance between the inside and the outside tube surface.
*Decrease temperature gradient between tube wall and bulk. This leads to a decrease of the tube inside surface fouling rate, especially with foulants such as paraffinic material, scaling water, …and other "wall temperature dependant" types of fouling.

Sizing of the FIXOTAL® devices

Before stretching, the coil diameter is usually a few millimetres bigger than that of the tube. Then the coil is stretched (the diameter of the coil thus decreases), inserted inside the tube and released. FIXOTAL® insert is then blocked in the tube by self tightening.

FIXOTAL® inserts are designed allowing for the hydrodynamic conditions to reach a trade off between the pressure drop created and the resulting heat transfer enhancement.

Different materials and shapes may be used to manufacture the insert element. The material is chosen in order to avoid galvanic and piting corrosion and erosion.

Applications of FIXOTAL® system

As FIXOTAL® increases the tube inside heat transfer coefficient, the highest gain will be obtained when the resistance to heat transfer is mainly located inside the tubes (viscous or waxy liquids, condensers with cooling water inside the tubes and condensing vapours on the shell side). In this case, the overall increase of the duty can be as high as +50%.

Main advantages of FIXOTAL® system - heat transfer enhancement.
* Through higher flow turbulence (inner heat transfer coefficient X 1.5 or more), turbulence effect equivalent to double the fluid velocity
* Reduction of fouling in heat exchanger tubes as a favourable side effect

Reduction of maintenance work/cost.
* Decrease of exchanger cleaning through reduction of tube side fouling
* Extended run time through increase of cleaning intervals
* Designed to avoid tube corrosion.

De-bottlenecking - improved throughput capacity. Detailed in following industrial results.

Combination with antifoulant chemicals.
* Increased efficiency of additives through higher turbulence,
* Decrease of consumption/dosage of antifoulants by 50 % or more

Pressure drop.
* Delta-P caused by FIXOTAL® devices is between 0.15 and 0.2 bar (2 and 3 psi) per pass (depending on tube dimensions, fluid type, flow velocity,…),
* Delta-P caused by fouling to be considered for comparison (EOR conditions without inserts),
* Higher Delta-P resulting in increased flow turbulence (inner heat transfer coefficient X 1.5 at least).

Typical installations.
* Air coolers, water coolers, feed/effluent tubular exchangers, two phase flow, U tubes,
* Retrofit installation,

* New exchangers to be equipped to improve exchanger performance/extend anticipated run time.

Industrial experience of FIXOTAL®.
* Over six years
* Over 5 000 FIXOTAL® devices in use
* Used by refineries in Europe

Metallurgies available.
* Stainless steel (different grades for high/low temperature applications),
* Special alloy (Inconel, high Ni and Co content),
* Carbon Steel for specific applications,
* Tested lifetime of FIXOTAL® devices 5 years and longer, no specific limitation in life duration of the insert.

Industrial results with FIXOTAL® - air coolers

Application 1. Gas Oil Hydrotreating Unit – air cooler positioned upstream of the HP separator.
Description & position of the problem: The capacity of a Gas oil hydrotreating unit when treating VGO for the FCC unit was lowered from 5 000 t/day (35,000 bpd) to 3 000 t/day (21,000 bpd) because of the poor efficiency of the air cooler E403 on this kind of feedstock (E403 is the air cooler just upstream of the H.P. separator).
Results : After the partial equipment of E403 with FIXOTAL®, the full capacity of the unit was recovered : extra pressure drop was negligible. The potential benefit was roughly 9 000 USD/day.
Application 2. Furfural unit – air cooler upstream storage tank.
Description & position of the problem : E210 is an air finfan cooler, which cools the raffinate stream from a Furfural extraction unit before an intermediate storage tank. Because of its poor efficiency, the storage temperature was too high : 80°C (176 °F) instead of 60°C (140°F) expected.
The financial penalty was estimated at 400 000 USD/year, disregarding the safety problem associated with the high storage temperature (risk of boiling over in the tank).
Results: After equipment with FIXOTAL®, outlet temperature dropped from 80°C (176°F) to 50°C (122°F). The financial penalty was fully recovered.

Industrial results with FIXOTAL® - tubular heat exchanger

Application 1. Wax Hydrotreating Unit – Reactor feed / effluent heat exchanger.
Description & position of the problem: E501 is the feed / effluent heat exchanger of a wax hydrotreating unit.
Since the unit start up, the usual throughput of the unit has been increased from 240 t/day (1,700 bpd) to 300 t/day (2,100 bpd) on light grade, with the same heater and preheat train.
Because of this increased throughput, reactor temperature had become too low and the refined wax was sometimes not stable enough.
Results: The equipment of the feed / product heat exchanger with FIXOTAL® resulted in an increase of preheat temperature of 18°C (64°F), (the expectation was 14°C (57°F)), the full capacity of 280-300 t/day (2,100 bpd) on light grade has been recovered.

Application 2. CDU preheat train
The cycle duration achieved using FIXOTAL® was 2.5 times longer than previous.

Pilot results with FIXOTAL® - tubular heat exchanger – cooling water

In addition to the variety of industrial implementations, which are mainly aimed at heat transfer enhancement, it has been demonstrated through pilot plant work that FIXOTAL® is able to reduce dramatically the inside rate of scale deposit for exchangers with cooling water flowing inside the tube (fouling rate divided by at least two). Also, the thickness of the deposit layer ($CaCO_3$) was divided by 3. This should enable longer run lengths without shutdowns for maintenance cleaning.

CONCLUSIONS

Petroval can offer efficient fouling mitigation and heat transfer enhancement systems through application of the three complementary devices. The choice of insert and design of the insert is customized for each specific application, taking into account the fluid properties, the operating conditions of the heat exchanger, the fouling type and the expected service time.

A WORD OF THANKS:
We would like to thank the organizers of the conference for permitting us to present these heat exchanger enhancement systems

ABBREVIATIONS

BPD : Barrels Per Day
CDU : Crude Distillation Unit
CIT : Crude Inlet Temperature
Cr : Chrome
EOR : End Of Run
FCC : Fluid Catalytic Craking
HGO : Heavy Gas Oil
LGO : Light Gas Oil
MT : Metric Tons
Ni : Nickel
PSI : Pounds per Square Inch
RPM : Rotations Per Minute
SOR : Start Of Run
VGO : Vacuum Gas Oil