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TUBE INSERTS FOR HEAT EXCHANGERS - FOR ENERGY CONSERVATION

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ABSTRACT

Tube inserts in heat exchangers have been the subject of several studies performed by TOTAL.
These studies clearly demonstrated that both Turbotal® and Spirelf® improve heat transfer coefficients, mitigate fouling and reduce pressure drop at End Of Run (EOR) within their application range.
Fixotal® technology improves heat transfer coefficients over a wider range of applications than those addressed by the other two technologies, but has only a limited effect on fouling mitigation.
The paper hereafter will evaluate the level of performance achieved with the three here-above cited technologies applied in crude oil preheat trains.
These tube inserts are customized for each exchanger and its operating conditions to maximize the benefits achieved.
The benefits from using these technologies are evident in extending run duration between cleaning shutdowns, increasing heat transfer coefficient, reducing fouling factor and stability of pressure drop. From an economic viewpoint, the payback is generated by three improvements: the energy saved in the preheat train in service (by the increase in the heat transfer), the reduction in maintenance cost (reduced cleaning frequency) and the increased run throughput. Additionally, a very substantial benefit can be obtained when a unit is bottlenecked due to heat transfer limitation.

INTRODUCTION

The efficiency of (petro)chemical plants is strongly influenced by the efficiency of its heat exchangers. The level of heat recovery that can be reached represents significant margins that are estimated during the design phase of the plant itself. However, reality might be completely different once fouling occurs at any stage of the process. Fouling will lead to loss of heat recovery, increase in pressure drop and loss of throughput until a maintenance shutdown becomes mandatory.
The benefits from using tube insert technologies were already demonstrated in terms of an increased heat transfer coefficient [1],[3], a reduced fouling rate [2] and stability of pressure drop.
This study will only consider fouling in crude oil preheat trains which is caused by asphaltene deposition and/or coke formation on hot surface.
In these tests, heat exchangers forming part of preheat trains in three refineries were equipped with Turbotal® inserts for study A, Spirelf® inserts for Study B and Fixotal® for the third case named Study C. Their performances were monitored over different periods depending on the case between two and four years and compared to the previous run durations in similar process conditions.

DESCRIPTION OF TECHNOLOGIES AND STUDIES

Study A – TURBOTAL®

Turbotal® is a rotating device hooked on a fixed head and attached on the tube end on the inlet side see Fig. 1. This system is a continuous online cleaning device whose purpose is to reduce the fouling layer at the tube walls by mean of mechanical effect.
Turbotal® uses the energy of the flow running in the tubes to convert it in rotation of the device in the range of 1000 rpm during the whole run duration.
The extra pressure drop generated by the device is typically in the range of 0.1bar per pass for a flow velocity of 1.0m/s.
The lifetime of the device is limited to three years because of mechanical erosion of the parts.

Fig. 1 - Photo of the Turbotal® device in a glass tube

The last pairs of heat exchangers just before the furnace were suffering of severe fouling over a period of less than one year. The four heat exchangers were equipped with Turbotal® and operated in the same range of process conditions than previously see Table 1. The monitoring of the performance was then compared with the previous data; the comparative trend of the outlet temperature will be presented in the results section.

Position in the train	Just before the furnace
Bundle number	2 branches of 2 bundles
Tube number / bundle:	1 164
Tube length:	6,100 mm
OD / BWG:	1" / 12
Product tube / shell side:	Crude / Atmospheric residue
Flow rate (tube side):	580 / 830 / 920 t/h
Flow velocity (tube side):	1.2 to 2.2 m/s
Tube insert:	Turbotal®
Replacement frequency:	Every 2 years

Table 1. - Heat exchangers used in Study A - design and operating conditions.

Study B – SPIRELF®

Spirelf® is a vibrating device fixed on both tube ends by a fixing wire see Fig. 2. This system is also a continuous online cleaning device whose purpose is to reduce the fouling layer on the tube walls by mean of mechanical effect.
Spirelf® uses the energy of the flow running in the tubes to convert it in vibrations of the device both radial and longitudinal.
The extra pressure drop generated by the device is typically in the range of 0.2bar per pass for a flow velocity of 1.0m/s.
The lifetime of the device is limited to five years as it must be replaced at each turnaround for cleaning and inspection of the heat exchanger tubes.

Fig. 2 - Photo of the Spirelf® device in a cut tube

The last pair of heat exchangers just before the furnace was suffering of severe fouling over a period of less than one year. The two heat exchangers were equipped with Spirelf® and operated in the same range of process conditions than previously see Table 2. The monitoring of the performance was then compared with the previous data, the comparative trends of the heat transfer coefficients of each tube bundle and the crude flowrate will be presented in the results section.

Position in the train	Just before the furnace
Bundle number	1 branch of 2 bundles
Tube number / bundle:	710
Tube length:	9,144 mm
OD / BWG:	3/4" / 14
Product tube / shell side:	Crude / Atmospheric residue
Flow rate (tube side):	309 t/h
Flow velocity (tube side):	1.7 m/s
Tube insert:	Spirelf®
Replacement frequency:	Every 3 years

Table 2. - Heat exchangers used in Study B - design and operating conditions.

Study C – FIXOTAL®

Fixotal® acts as a source of turbulence in contact with the internal walls of the tube, preventing the stagnation of products in the layer adjacent to the tube.
The purpose of this fixed device is mainly to increase the rate of heat transfer by virtue of renewing the boundary layer at tube wall with an appreciated side effect on fouling mitigation including on certain types of fouling linked to wall temperature (polymerization, solidification of paraffin, scaling, crystallization, etc.).
The extra pressure drop generated by the device is typically in the range of 0.2bar per pass for a flow velocity of 1.0m/s. pressure drop may highly be increased in case of dual phase flow.
An example of Fixotal® in a glass tube is presented hereafter in Fig. 3 to visualize the device once installed.

Fig. 3 - Photo of the Fixotal® device in a glass tube

One heat exchanger just before the furnace was only possible to operate for periods of three to four months maximum due to the severe fouling that was building up in the tubes. This heat exchanger was equipped with Fixotal® and operated in the same range of process conditions than previously see Table 3. The monitoring of the performance was then compared with the previous data; the comparative trends of the fouling factor will be presented in the results section.

Position in the train	Just before the furnace
Tube number / bundle:	1114
Tube length:	6,100 mm
OD / BWG:	1" / 12
Product tube / shell side:	Crude / Atmospheric residue
Flow rate (tube side):	286 t/h
Flow velocity (tube side):	1.8 m/s
Tube insert:	Fixotal®
Replacement frequency:	Every 5 years

Table 3. - Heat exchanger used in Study C - design and operating conditions.

RESULTS

Study A – TURBOTAL®

- The trend presented in Fig. 4 below shows an increased outlet temperature at SOR in clean condition of 3°C. This gain is related to the extra turbulence generated by the rotation of the Turbotal® leading to an increased heat transfer coefficient on the tube side, typical increase in IHTC of 80% compared to bare tube.

- The second fact revealed by this trend is the slope of the decrease of the preheat that was almost three times slower with Turbotal® compared to bare tubes. This phenomenon is due to the fouling mitigation during the run and clearly identified with the linear correlations on both trends. The Turbotal® significantly reduces the fouling rate but can't avoid the fouling deposition to occur. Some previous work identified that fouling resistance with Turbotal® ends up with asymptotic profile corresponding to the distance between the tube wall and the Turbotal® device [4].

- The run duration is almost doubled, going from 320 days for bare tubes to 580 days with Turbotal®. Again, the fouling mitigation allows an improved control of the fouling rate and consequently a control on the performance of the heat exchangers and the pressure drop related to the fouling layer.

- A payback analysis was done on this application to evaluate the gains on energy compared to the cost of the Turbotal® and the installation that were in the range of 100,000 €.

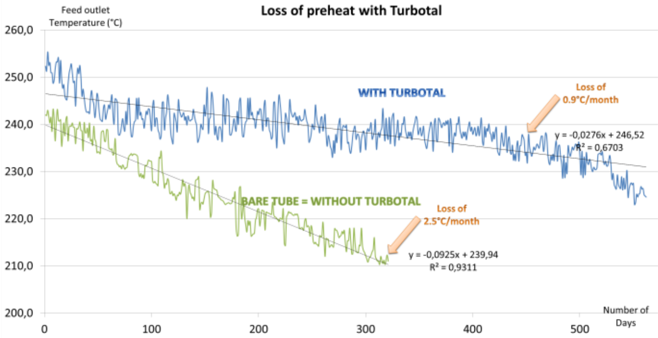

Fig. 4 – Trend of feed outlet temperatures with Turbotal® (Blue) compared to previous run with bare tubes (Green)

The energy saved for a gain of 1°C in one year represents 460 tons of gas saved following the equation (1) hereafter meaning an average gain of 140,000 € per °C.
An average gain of more than 10°C was achieved during the first year leading to a gain on energy of 1.4Million € minimum.

(1)

$$Gain\ per\ °C = \frac{M.Cp.24.365}{Yld.LHV} \times 300$$

M = 800 t/hr
Cp =0.65 kcal/kg.°C specific heat of crude at 250°C
Yld = 0.85 furnace yield
LHV = 11,630 kcal/kg of Fuel Gas
Cost of Natural Gas as alternative fuel 300 €/ton

The payback calculated by considering only the cost of energy is in the range of 1 month. However, some other sources of expenses would have to be considered such as the reduction of maintenance cost (mechanical cleaning avoided) and production losses (reduction of throughput during partial shutdown for cleaning).

Study B – SPIRELF®

The trend presented in Fig. 5 below shows a first run period lasting for one year, for which the OHTC (blue and red trends) decrease sharply from clean design level to only 70% within a year. The flow rate across the heat exchangers remains close to the design value which results in a lower CIT at the furnace and an extra consumption of combustible to compensate this loss of preheat.

- Spirelf® devices were implemented during the turnaround and the performance of each tube bundle is represented on the same trend. The OHTC with Spirelf® is then at the level of design value or up to 22% above for about 500 days.
Over this period, the crude flow rate was pushed above the design value, gradually increasing from +10% to +25% at

900 days. As the performance of some other exchangers was declining, the feed rate was slightly reduced during the cleaning period of other tube bundles without stopping the bundles equipped.

- Once the all train was back in service at 940 days, the feed rate was pushed back to +25% of design for 400 days with OHTC of both heat exchangers still above or at the level of design. A second maintenance period was carried out on some heat exchangers without stopping the heat exchangers equipped with Spirelf® as the duty was still acceptable.

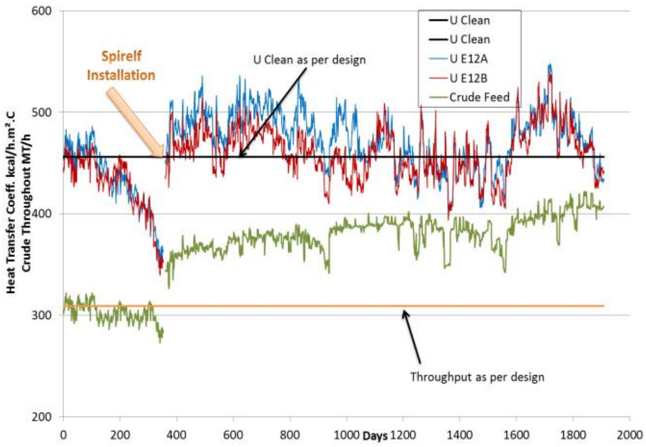

Fig. 5 – Trend of crude feed and OHTC for both tube bundles compared to previous run with bare tubes.

- After restarting at full capacity at 1400 days, the performances of the heat exchangers equipped were starting declining and the crude flow rate was slightly reduced.
The exchangers equipped with Spirelf® were by-passed at 1600 days for a recirculation of hot gasoil for a short period of time. This operation was carried out without opening the heat exchangers and the objective was to soften and remove some of the deposits that have built up over the years.

- Instantly after this flushing operation, the heat exchangers were reintroduced in the process and the throughput was pushed back gradually up to +35% of the design value with OHTC for each heat exchanger above the design up to +22%. The heat exchangers were still in service at the time this paper was produced.

- The implementation of Spirelf® in these heat exchangers has considerably increased the run duration from one year to more than four years. This allowed avoiding three maintenance periods on these heat exchangers.
- The performance of the heat exchangers were considerably improved in stabilized conditions compared to before the installation of Spirelf® allowing significant energy savings.
- The unit flow rate was debottlenecked up to +35% of design value with acceptable preheat of the feed.

Study C – FIXOTAL®

- The trend presented in Fig. 6 below shows the overall fouling resistance calculated from the operating conditions. The overall fouling resistance is a combination of both tube side fouling and shell side fouling. Knowing that the Fixotal® will only have an influence on the tube side fouling rate, the improvement on the overall fouling resistance will be diluted due to the fouling on the shell side that is very likely to happen as the shell side fluid was atmospheric residue. However, in this particular case, the performance is not in absolute value but in terms of duration..

- The first two periods (each lasting about 110 days) were run periods without inserts in the tubes. The fouling resistance increase sharply over this period from 0 at start up in clean conditions to 0.025 ft².hr.F/BTU when the heat exchanger gets fouled. At this stage, it is economically viable to by-pass the heat exchanger for mechanical cleaning of the tube bundle.

- The first period after the implementation of the Fixotal® devices presents a reduced slope of the fouling resistance compared to the previous runs with bare tubes. The run duration was 231 days (doubled) and the fouling resistance reaches 0.022 ft².hr.F/BTU. This extension of the run duration is directly related to the renewal of the boundary layer at tube wall and the fouling mitigation to some extent.

- At the end of the run, the tube bundle was removed for hydro-blasting both shell and tube side. As per design, the Fixotal® is a fixed device in tension at the tube wall and consequently the center of the tube is completely free of any obstruction parts.

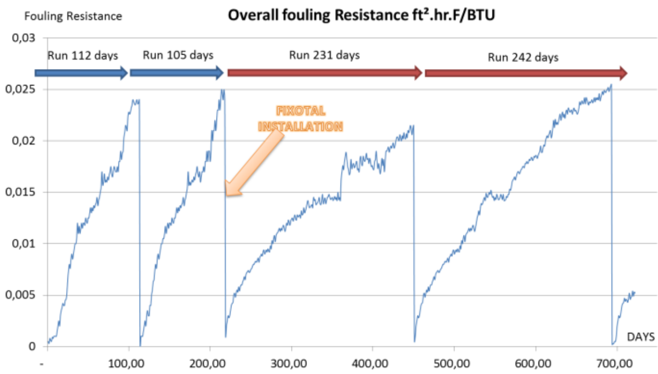

Fig. 6 – Trend of Overall fouling resistance over four periods of run.

As it was tested in advance during a field trial, the tubes equipped with Fixotal® could be hydro-blasted without removing the Fixotal® from the tube.
The multi-lancing equipment used could pass in the tubes without touching or damaging the Fixotal® in place.
The pressure applied was up to 3,000 bars without dislodging the Fixotal® from its position. This way, the

tubes were cleaned using this technic and the set of Fixotal® was reused for the next run period.

- The second cycle with Fixotal® in this heat exchanger shows similar performance with a run duration doubled compared to the first runs without inserts before reaching the same level of fouling resistance at 0.025 ft².hr.F/BTU.

The trend in Fig. 6 shows only two cycles after the implementation of the Fixotal®. However, this heat exchanger, by the time of this paper, is still operated with the same set of Fixotal® since the beginning and was cleaned already four times.
The fifth run is now ongoing with the same repeatability on the performances showing the reliability of the equipment.
Technically, this installation divided by a factor of two the maintenance frequency inducing significant reduction of the maintenance cost for the same set of Fixotal® bought initially.
The potential lifetime of the Fixotal® will have to be assessed over the years potentially by video inspection in the tubes, radiography or by inspection consisting in removing a few Fixotal® at random and checking the remaining thickness of the wire compared to the design.

CONCLUSIONS

Significant improvements related to the use of tube inserts were highlighted by the three studies presented and some concluding remarks can be drawn from these field data analyses;

- For the three applications, the run duration with the tube inserts was at minimum doubled compared to the same run with bare tubes without any operation on the heat exchanger tubes. Spirelf® in study B was even able to multiply by four the run duration.

- For each case the performances of the heat exchangers were increased in terms of heat transfer.
This improvement was translated in outlet temperature (Study A) where the gain on clean condition was 3°C and on average over the whole run duration more than 10°C.
For Study B the gain on OHTC was followed and reached +22% compared with -30% with bare tubes in less than a year.
The Overall fouling resistance was monitored for Study C revealing a fouling rate two times slower with Fixotal® compared to bare tubes.

- Tube inserts can be used to debottleneck to a certain extend an existing and limited preheat train (Study B). The capability of the train to preheat more can be used to increase the throughput of the unit. As identified in Study B, the capability to debottleneck is also function of the cleanliness and the availability of the whole train and not only the exchangers equipped.

- The equipment with Fixotal® on fouling services even if the technology doesn't provide a mechanical cleaning effect allows some improvements. These improvements could be even more significant as the set of Fixotal® is reused for several run periods. The potential lifetime of the Fixotal® will have to be assessed over the years potentially by video inspection in the tubes, radiography or by inspection consisting in removing a few Fixotal® at random and checking the remaining thickness of the wire compared to the design and looking for erosion.

- Comparing the three technologies would be a difficult exercise as they are not designed to operate on the same type of feed and don't have the same expected lifetime. However, whenever it is possible, the inserts providing a mechanical cleaning effect (Turbotal® and Spirelf®) would be chosen in priority if fouling mitigation is the driving force to use inserts.

NOMENCLATURE

BWG	Tube wall thickness in Birmingham Wire Gage
OD	Outside Diameter of tube (mm)
IHTC	Inner Heat Transfer Coefficient kcal/h.m².C
OHTC	Overall Heat Transfer Coefficient kcal/h.m².C
SOR	Start Of Run
LHV	Lower Heat Value kcal/kg
CIT	Coil Inlet Temperature °C

REFERENCES

1. Petitjean E., Aquino B. & Polley G.T., 2007, Observations on the Use of Tube Inserts to Suppress Fouling in Heat Exchangers, *Hydrocarbon World2007*, Ed. Touch Briefings, pp 47-51

2. Bories M. And Patureaux T., 2003, Preheat train crude distillation fouling propensity evaluation by Ebert and Panchal model, *Proc. Heat Exchanger Fouling & Cleaning: Fundamentals & Applications*, Santa Fe, July 2003.

3. Pouponnot F. & Krueger A. W., 2004, Heat Transfer Enhancement and fouling mitigation by heat exchanger tube inserts, *Int Conf. On Heavy Organic Depositions*, Los Cabos, Mexico.

4. Aquino B., Derouin C. & Polley G.T., 2007, Towards an understanding of how tube inserts mitigate fouling in heat exchangers, *Int Conf on Heat Exchanger fouling and Cleaning*, Tomar, Portugal.