TUBE INSERTS FOR HEAT EXCHANGERS - FOR ENERGY CONSERVATION

N. Aubin

PETROVAL, Parc Eco-Normandie76430 ST ROMAIN DE COLBOSC, FRANCE (n.aubin@petroval.com)

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.

This study will only consider fouling in crude oil preheat trains which is caused by asphaltenes 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 0.1 bar per pass for a flow velocity of 1.0 m/s. The lifetime of the device is limited to three years because of mechanical erosion of the parts.

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.

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.

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

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.

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

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. 2 - Photo of the Spirelf® device in a cut tube](image1)

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.

![Fig. 3 - Photo of the Fixotal® device in a glass tube](image2)
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.

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

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

- 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 €.

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 1.4 Million € minimum.

\[
\text{Gain per } ^\circ \text{C} = \frac{M \times C_p \times 24 \times 365 \times \text{Yld} \times \text{LHV} \times 300}{1000 \times 1000} \\
\]

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

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).

- 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.

- 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.

- 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.

- 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 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.

- 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 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.

- The unit flow rate was debottlenecked up to +35% of design value with acceptable preheat of the feed.

- The unit flow rate was debottlenecked up to +35% of design value with acceptable preheat of the feed.

- 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 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

---

**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.

- The unit flow rate was debottlenecked up to +35% of design value with acceptable preheat of the feed.

- 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

---

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

**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 and looking for erosion.

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


