Proceedings of the International Conference on Heat Exchanger Fouling and Cleaning - 2024 (Peer-reviewed)
April 21–26, 2024, Lisbon, Portugal; Editors: H.U. Zettler and E.M. Ishiyama

QUICK WIN ON CARBON FOOTPRINT BY IMPROVING EXISTING ASSETS VIA THE USE OF TUBE INSERTS IN SHELL AND TUBE EXCHANGERS.

N. Aubin,
Technical and R&D Manager
PETROVAL, Parc Eco-Normandie76430 ST ROMAIN-DE-COLBOSC, FRANCE (n.aubin@petroval.com)

ABSTRACT

The improvements that can be obtained from tube inserts in heat exchangers have been the subject of several studies published by TOTALENERGIES and PETROVAL.
These studies clearly demonstrated that both Turbotal® and Spirelf® improve heat transfer coefficients, mitigate fouling and reduce pressure drop at end-of-run within their application range.
Fixotal™ technology improves heat transfer coefficients over a wider range of applications than can be addressed by the other two technologies, but has only a limited effect on fouling as it will not provide a mechanical cleaning effect.
These tube inserts are customized for each exchanger and its operating conditions, to maximize the benefits achieved by our customers worldwide.
The benefits from using these technologies are manifested in extended run lengths between cleaning shutdowns, an increased heat transfer coefficient, a reduced fouling rate and stability of pressure drop. From an economic viewpoint, the payback is achieved within a few months from four sources of 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), the increased throughput and the positive environmental impact stemming from the reduction in CO_2 emissions (as a consequence of the better heat transfer performance). Indeed, a very substantial benefit can be obtained if a unit is bottlenecked by a heat transfer limitation or by the furnace.
This presentation and paper will show the improvements achieved on the preheat trains of crude distillation units. The comparison of the current runs with Turbotal®, Spirelf®, Fixotal are yielding substantial gains in heat transfer and fouling mitigation that will be highlighted throughout this presentation.

INTRODUCTION

Limiting the carbon footprint has become a objective that is not only trendy but also essential to achieve the net zero emission of the oil industry by 2050. This ambitious target will require large investments in new technologies for heat transfer efficiency and carbon capture. However, the technologies that will be required in the future are not yet available at an industrial scale; and time will be needed to mature the technologies, invest, and be operational on time.
The oil industry relies mainly on preheat shell and tube heat exchangers to reduce the amount of firing that must be done in fired furnaces, and these exchangers' performance is often limited by fouling and mechanical designs not upgraded for the required level of operation. Tube insert technologies are available on the market for a quick win in shell and tube exchangers performance, with immediate improvements in heat transfer right from start-of-run with no modification to the exchangers or the operating conditions.
The benefits from using tube insert technologies were previously demonstrated in terms of an increased heat transfer coefficient [1],[3], reduced fouling rate [2] and stability of pressure drop.
This current 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 Study C. Their performances were monitored over different periods between two and four years, depending on the circumstances, and compared to the durations of previous runs in similar process conditions. The improvements in heat transfer and the impact on CO_2 emissions will be highlighted.

DESCRIPTION OF TECHNOLOGIES AND STUDIES

Study A – TURBOTAL®

Turbotal® is a rotating device hooked onto a stationary head which is installed in the inlet end of the tube - see **Figure 1**. This system is a continuous online cleaning device whose purpose is to reduce the fouling layer at the tube walls by mean of a mechanical effect.
Turbotal® uses the energy of the flowing medium in the tubes to achieve rotation of the device at around 1000 rpm during the whole run duration. This rotation speed is determined at the design stage by the mechanical design of the Turbotal and issued from correlations determined on experimental skids.
The extra pressure drop generated by the device is typically in the range of 100 millibar per pass at a flow velocity of 1.0 m/s.

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

The lifetime of the device is limited to three years due to mechanical erosion of the parts.

The last two pairs of heat exchangers just before the furnace were suffering from severe fouling over a period of less than one year.

Figure 1 - Photo of the Turbotal® on a tube bundle

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 to 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
Number of bundles	2 branches of 2 bundles
No. of tubes per bundle:	626
Tube length:	6,100 mm
OD / BWG:	1” / 12
Product tube / shell side:	Crude / atmos residue
Flow rate (tube side):	260 / 330 / 430 t/h
Flow velocity (tube side):	1.0 to 1.70 m/s
Tube inserts:	Turbotal®
Replacement frequency:	Every 2 to 3 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 **Figure 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 flowing medium in the tubes to convert it into vibrations of the device, both radial and longitudinal.

The extra pressure drop generated by the device is typically in the range of 200 millibar per pass for a flow velocity of 1.0 m/s.

The lifetime of the device is limited to six years, since it must be removed and replaced at each turnaround for internal cleaning and inspection of the heat exchanger tubes.

Figure 2 - Photo of the Spirelf® on a tube bundle

The last pair of heat exchangers just before the furnace was suffering from 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 to the previous data. The comparative trends of the duty achieved, and the flowrates will be presented in the results section.

Position in the train	Just before the furnace
Number of bundles	2 bundles in parallel
No. of tubes per bundle:	600
Tube length:	6,100 mm
OD / BWG:	1” / 12
Product tube / shell side:	Crude / bottom P/A
Flow rate (tube side):	431 t/h design
Flow velocity (tube side):	1.87 m/s
Tube inserts:	Spirelf®
Replacement frequency:	Every 3 years

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

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

Study C – FIXOTAL

Fixotal acts as a promotor of turbulence at the inside surface of the tube. It significantly increases the shear stress at the wall, preventing stagnation of products in the boundary 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 appreciable 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 200 millibar per pass for a flow velocity of 1.0 m/s.
An example of Fixotal installed in a tube bundle is presented hereafter in **Figure 3,** to illustrate the device once installed.

Figure 3 - Photo of the Fixotal devices in the heat exchanger

The case study that was chosen will review the performance of a complete preheat train of twelve heat exchangers that are all operated with the same fluids. Crude is flowing on the shell side from the desalter to the furnace and atmospheric residue is flowing counter current on the tube side from the tower towards the beginning of the hot train.
Out of the twelve, only the last three exchangers were equipped with Fixotal technology. These last three heat exchanger were 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 OHTC and duty will be presented in the results section. Due to a lack of instrumentation, only three temperature measurements points were available on each flow pass: at the inlet, in the middle (after six bundles) and at the outlet. Consequently, the improvements achieved in the last three were mitigated with the normal performance of the other three that were not equipped between the two temperature indicators.

Position in the train	Just before the furnace
No. of tubes per bundle:	732
Tube length:	5,000 mm
OD / BWG:	1" / 12
Product on tube / shell side:	Reduced crude / crude
Flow rate (tube side):	134.2 t/h
Flow velocity (tube side):	0.80 m/s
Tube inserts:	Fixotal
Replacement frequency:	Every 4 years

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

RESULTS

Study A – TURBOTAL®

- The trend presented in **Figure 4** below shows the overall heat transfer coefficient of the four heat exchangers in operation on comparative runs. The reference run in blue lasted only 183 days, with a significant loss on performance as the OHTC dropped from 230 kcal/h.m².C at start-of- run to 87 kcal/h.m².C within this six-month period, after which a shutdown and mechanical cleaning was required to recover heat transfer on these exchangers.

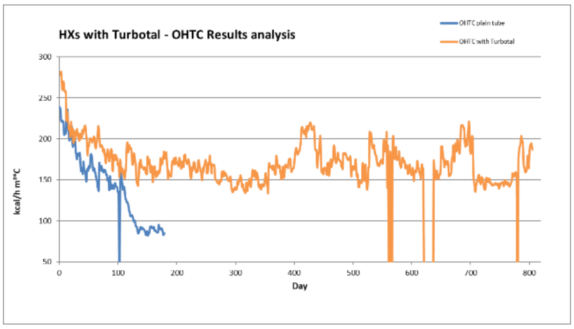

Figure 4 – Trend of OHTC for both cases with (orange) and without Turbotal(blue) in the same flow conditions.

The comparison of the first six months with Turbotal highlighted the direct benefits that are summarized in **Table 4** on heat recovery in the range of 1092 k€. There was also a significant reduction in the CO_2 emissions from the furnace, about 560 tons of CO_2. Depending on the location, these emissions can be subjected to taxes at different rates over the world

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

(CO_2 emissions are being taxed at 100€/ton in Western Europe.)

- In comparison, the run with Turbotal lasted 820 days of continuous operation. The start of the run was typically with an OHTC of 270kcal/h.m².C, which dropped slowly to 150 kcal/h.m².C within 300 days and remained in the range of 150 to 200kcal/h.m².C depending on the flow conditions.

This phenomenon is due to the fouling mitigation during the run. The Turbotal® significantly reduces the fouling rate but cannot avoid fouling deposition occurring. Some previous work identified that fouling resistance with Turbotal® ends up with an asymptotic profile corresponding to the distance between the tube wall and the Turbotal® device [4].

- The run length was multiplied by a factor of four, from 183 days for bare tubes to 820 days with Turbotal®. Again, the fouling mitigation allowed improved control of the fouling rate, and consequently control of the performance of the heat exchangers and the pressure drop related to the fouling layer even though no direct pressure drop measurement was available on these four.

	With TURBOTAL
Gain on Energy recovery (Gcal/year)	18200
Gain on Energy recovery (TOE/year)	1820
ENERGY SAVINGS	**1092 k€**
Gain on CO_2 emissions (Tons first year)	5460
REDUCTION IN CO2 EMISSIONS	**546 k€**

Table 4. – Impact on energy savings and CO_2 emissions on heat exchangers used in Study A (*)(**)

- A payback analysis was done on this application to evaluate the gains in energy (Table 4) compared to the cost of the Turbotal® and the installation (which was in the range of 130,000 €.)

The **payback calculated** by considering only the cost of energy and the gain on CO_2 emissions was about **1 month**. However, some other sources of savings should also be considered, such as the reduction of maintenance cost (avoidance of mechanical cleaning) and production losses (reduction of throughput during partial shutdown for cleaning).

Study B – SPIRELF®

The trend presented in **Figure 5** below shows successive runs during which the duty (blue trend) was plotted. The reference run, bare tubes, starting in Nov 2014. The average duty from 30/11 to 22/04 was roughly 36 GJ/h. The duty then decreased from roughly 36 GJ/h down to 22 GJ/h by 28 November 2015, for an average of 30 GJ/h over the entire reference run. The drop in duty was about 40% in one year, even though the flowrates on tube side and shell side remained very stable and close to the design case. The flow rate across the heat exchangers remained close to the design value, which resulted in a lower CIT at the furnace and extra consumption of fuel to compensate for this loss of preheat.

- Spirelf® devices were implemented during a cleaning shutdown and the performance of the exchangers were represented on the same trend. After the installation on 29/11/2015, the average duty was 37 GJ/h and perfectly maintained at this level until 19/04/2018, the date of the turnaround of the unit after 872 days in operation.

Over the entire run with Spirelf®, the crude flow rate was at design value and the performance of exchangers was limited by the regulation of the unit operating on the shell side flow (bottom pump around flowrate).

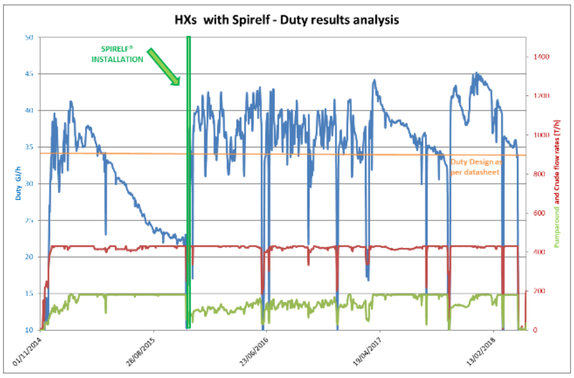

Fig. 5 – Trend of duty (blue) of the exchangers equipped with Spirelf® vs crude flowrate (red) and bottom pump around flowrate (green).

- A few unit upsets occurred but the exchangers were never opened, and performances benefited from occasional unit recirculation such as October 2017.

- The implementation of Spirelf® in these heat exchangers had considerably increased the run length from one year to two and a half years with a significant increase in duty, averaged at 25% and equivalent to the firing of more than 100 tons of fuel gas per month.

The savings on fuel consumption over the first year presented 872k€ and the benefit related to CO_2 emissions that were avoided was in the range of 436k€, as summarized in **Table 5** below.

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

	With SPIRELF
Gain on Energy recovery (Gcal/year)	14 500
Gain on Energy recovery (TOE/year)	1450
ENERGY SAVINGS	**872 k€**
Gain on CO_2 emissions (Tons first year)	4350
REDUCTION IN CO2 EMISSIONS	**436 k€**

Table 5. – Impact on energy savings and CO_2 emissions on heat exchangers used in Study B (*)(**)

Study C – FIXOTAL

- The trend presented in **Figure 6** below shows a reference run from November 2016 until October 2020. From November 2020, a new run started and the OHTC of the six exchangers including the three equipped with Fixotal (orange) were plotted. The trend in blue is the OHTC of the first six exchangers of the train and the green trend is the crude flow of the unit showing the sustainability of the operating conditions. The trend presented in **Figure 7** shows the duty comparison between the last six HXs (orange) and the first six HXs (blue) between the two consecutive runs.

- Start-of-run (SOR):

From the reference run, it was identified that within six months, the OHTC of the last six HXs (orange) dropped to the level or below the first six HXs (blue), showing the large impact of fouling on the performance of the exchangers.

The implementation of Fixotal in the last three exchangers was visible from the SOR with an OHTC 26% higher than the reference run over the first three months. This was the consequence of the higher turbulence generated on the tube side and visible in the duty exchanged in **Figure 7,** with +8.3% increase compared to reference run.

- Until chemical cleaning:

From the reference run, after six months, the performance of the last six HXs continued declining to an OHTC of 200kJ/h.m².K, until a chemical cleaning (red vertical dot line) was performed in late October 2018 (2 years of operation).

The comparison with the run with Fixotal showed the OHTC of the last six exchangers consistently remained above the OHTC of the first six HXs but declined significantly to an OHTC of 350 kJ/h.m².K late in September 2022 (period of chemical cleaning of the exchangers, red vertical dot line) after two years of operation. The last six HXs were then delivering +75% OHTC compared to the reference run at the same duration, even though only the half of the HXs were equipped with Fixotal.

The evaluation of the duty exchanged before the chemical cleaning revealed that 66% of the total duty of the train was achieved through the last six exchangers, compared to only 52% during the previous run. The gain in duty before the chemical cleaning was in the range of 14% of duty on the complete train, compared to the reference run for the same run duration.

Knowing that the Fixotal® will only have an influence on the tube side fouling rate and heat transfer coefficient, the performance of the last six HXs was impacted significantly by the fouling on tube side of the first three HXs and the fouling on crude oil shell side of the six HXs, which was the main contributor to the performance limitation.

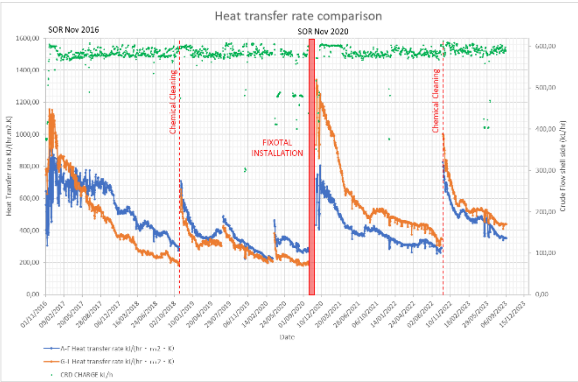

Figure 6 – Trend of OHTC with Fixotal equipment on half of the exchangers (Orange) study C.

- From chemical cleaning:

Chemical cleanings are typically performed after two years of operation, halfway through the turnaround cycle of four years. This cleaning consists of a recirculation of light aromatic gasoil on both tube and shell side, to soften fouling material, followed by steaming to flush and remove part of the fouling material. It is well known that such type of operation does not allow a full recovery on performance as the older deposits would harden and age so that only a mechanical cleaning would be efficient to fully recover the performance of the exchangers.

The evaluation of the OHTC after the chemical cleaning revealed a significant recovery for both runs. However, the reference run still indicated a lower OHTC for the last six HXs whereas for the run with Fixotal, the last six HXs were still producing a significantly higher OHTC (990KJ/h.m².K in comparison to the reference case at 660 KJ/h.m².K +50%). This was proof that fouling on the crude shell side was the limiting factor and that the chemical cleaning performed significantly improved the heat transfer performance of the preheat train. At this stage, the comparison of duty of the complete train, reveals a gain with the Fixotal of 9% of duty at 96.67 GJ/hr Vs 88.5 GJ/hr.

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

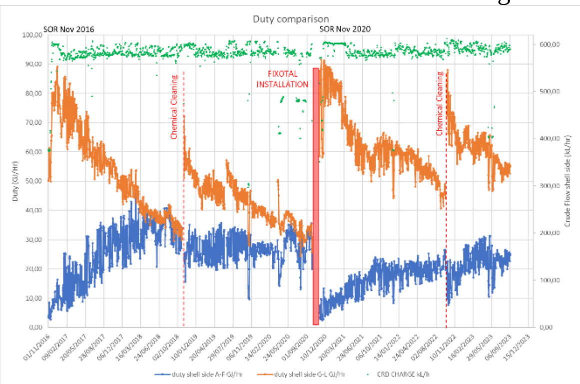

Figure 7 – Trend of duty with Fixotal equipment on half of the exchangers (Orange) study C.

- End-of-run (EOR):

The comparison of the two runs still shows a better heat transfer for the last six HXs when the last three are equipped with Fixotal (typically 50% higher than the reference run).

After 1035 days of operation, the last six HXs were achieving 69% of the total duty of the train, which was typically 10% higher than the previous run after the same duration.

- Average on the complete run:

By evaluating the complete run of 1035 days, the run with the Fixotal equipped in the last three exchangers of the preheat train was generating on average 34% higher OHTC on the last six bundles and a total average increase in duty of 20% on the last six exchangers. Overall, the preheat train with the Fixotal inserts was generating 3% more duty equivalent to 56,600 GJ over 1035days of operation. The energy savings from reducing the firing of the furnace, and consequently the reduction in CO_2 emissions of the plant, yielded economic benefits as summarized in **Table 6** hereafter, and is equivalent to 405k€ per year even though some heat transfer limitations were reached.

	With FIXOTAL
Gain on Energy recovery (Gcal/year)	4 500
Gain on Energy recovery (TOE/year)	450
ENERGY SAVINGS	**270 k€**
Gain on CO_2 emissions (Tons first year)	1350
REDUCTION IN CO2 EMISSIONS	**135k€**

Table 6. – Impact on energy savings and CO_2 emissions on heat exchangers used in Study C (*)(**)

As the residue on tube side was cooled down much faster than during the reference run, there was less potential for heat recovery through the first six HXs. In addition, the total crude flow was 8% lower during the run with Fixotal (due to some unit upsets), which reduced the heat transfer performance as a result of the lower Reynolds number. Nevertheless, the unit achieved better overall heat transfer performance.

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 applications A and B, the run lengths with the tube inserts were at minimum doubled compared to the same run with bare tubes, without any modifications of the heat exchanger tubes.

- In the case of Study C, the operator is constrained by regulation to shutdown and inspect the whole plant every four years. It is not possible to target extended run length, since a single chemical cleaning in the middle of the run is sufficient to recover enough heat transfer capacity. The implementation of Fixotal was therefore used to optimize heat recovery, even though the fouling on shell side was predominant.

- For each case the performances of the heat exchangers were increased in terms of heat transfer.

This improvement was translated in OHTC (Study A) with both an increased and a stabilized level of heat transfer over the run.

For Study B the benefit was directly expressed in duty, with an average increase of 25% during the run, which significantly reduced the firing of the downstream furnace by about 100 tons of gas per month.

For study C, the increase of OHTC with only three HXs equipped with Fixotal out of twelve unbalanced the preheat train performance and allowed an increase of duty and heat recovery even though the operating conditions were unfavorable compared to the reference run.

- The benefits achieved on the three applications demonstrate the potential improvements achievable with standard shell and tubes heat exchangers, when limitations come from either tube side or shell side film coefficient or from fouling deposition in either tube or shell side. It is then required to evaluate the complete range of operation to highlight the main contributors to the thermal resistances of the exchangers and assess if these limitations can be tackled with these inserts.

This must be done by comparing the effect of tube inserts with bare tubes at different levels of throughput, but also taking into account the level of fouling typically reached in these flow conditions at SOR and EOR.

Nowadays, many incentives are in place to encourage the reduction of CO_2 emissions at every level, and the

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

industry sector is one of the largest contributors [5]. Refineries and chemical plants are mainly operating with shell and tube heat exchangers for heat recovery. Reducing their CO_2 emissions can be done right now thanks to these technical solutions, even as longer-term projects are ongoing for large scale impacts. These technologies are available and can be retrofitted to any shell and tube exchanger within a few weeks.

- Comparing the three technologies would be a difficult exercise as they are not designed to operate on the same type of feed, the same level of flow conditions and do not have the same mechanical lifetime. However, whenever it is possible, and if fouling mitigation is the driving force to use inserts, priority should be given to selecting the inserts that provide a mechanical cleaning effect (Turbotal® and Spirelf®).

Even though there are already a wide range of potential applications, some benefits would also be very interesting on other ranges of flow conditions or other types of fluids or processes. The future developments in terms of technology could be on implementing new technologies on dual phase flows to benefit on heat transfer improvements at minimum cost on pressure drop.

NOMENCLATURE

HXs	Heat Exchangers
BWG	Tube wall thickness in Birmingham Wire Gage
OD	Outside Diameter of tube (mm)
CIT	Coil Inlet Temperature
OHTC	Overall Heat Transfer Coefficient kcal/h.m².C or kJ/h.m².K
SOR	Start Of Run
EOR	Enf Of Run
TOE	Ton Of Oil Equivalent = 10 Gcal
(*)	Cost of energy considered 600€ per TOE
(**)	Taxes on CO2 emissions = 100€ per ton

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. & 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.

5. Aubin N. & Joung J., 2023, Quick win on carbon footprint by improving existing assets, *AFPM 2023 Summit*, Dallas, Tx, USA.

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com