ON-LINE FOULING MITIGATION FOR PREHEAT TRAINS USING ULTRASONIC SCALE PREVENTION

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ABSTRACT

Preheat exchanger trains used in oil, chemical and electrical power plants are designed to reduce energy consumption. However, due to the nature of their respective operating conditions, heat transfer can be severely diminished by scale formations. While the fouling characteristics and behaviours often differ from plant-to-plant, effective operation due to fouling in crude oil preheat trains is a multifaceted problem that affects refiners globally.

This paper examines the effects of an ultrasonic scale prevention technology that is applied directly onto preheat crude exchangers, to mitigate fouling while the heat exchanger remains in normal operation.

After one full year in service with the ultrasonic equipment applied, the performance data is measured against the baseline and historical process data points from the same PHT network. The key performance metrics measured and studied were: OHTC, fouling resistance and duty performance.

INTRODUCTION

The impact of crude oil fouling is increasing for all refining organizations. Crudes are generally becoming heavier and more complex, yet refineries were generally designed to process the lighter, more scarcer crudes then some we see today. The worldwide shortage of middle distillates is also a driver to the processing of heavier, dirtier crudes that have a higher yield of these valuable components. (S. Macchietto et al.,[1])

As refiners scramble to take advantage of emerging opportunity crudes to satisfy market demand in peak seasons, the consequences from fouling will ultimately become more severe.

This severity of fouling of heat exchangers in the refining industry results in significant economic penalties. Detailed studies performed by Van Nostrand et. al. [2]) for a hypothetical refinery, processing 100,000 barrels (15,900 cubic meters) of crude oil per day.

The estimated total cost of fouling was nearly $10 million US dollars. To bring this closer in financial perspective, (L. Jackowski et al., [3]), applied a cost escalation factor of 2.73 and extrapolated the crude oil refining capacity to 75 million barrels per day (corresponding to 2016 global refining throughput), the worldwide cost of fouling is about 20 billion US dollars per year (2016 prices).

While this is significant in itself this same author notes that this figure excludes the cost of fouling for miscellaneous operations such as power generation and cooling of process streams with water and air cooled heat exchangers.

Increasing energy costs posed by fouling intensifies the economic penalties. Approximately 6% of the energy content from each crude barrel processed in an oil refinery— is used in the refinery itself. With a global production of about 82-85 million barrels/day, this is roughly equivalent to the entire production of Exxon or Shell to operate the world's 720 refineries. [1a]

While there has been good progress made in experimental studies of crude oil fouling, it appears that an asymptotic state of knowledge has been reached. Data driven mitigation is an active area of study for many in this field, which offers a response, but not cure. [1b]

In further support of these statements, other works find that laboratory experiments cannot replicate actual field conditions just by maintaining the same fluid velocities and surface temperatures. The time scale, impurities, ever-changing crude slates, and once through operation is about impossible to accomplish using laboratory scale conditions. (H.M. Joshi et al.,[4], [3a])

For this reason, our work focused on the use of an in-field fouling mitigation technology as opposed to development of new and/or improved fouling model. Having said that, this author acknowledges that laboratory experiments produce valuable information pertaining to fundamental chemical and physical mechanisms.

This paper examines the use an ultrasonically based technology that attaches directly to heat exchangers, for disrupting the adhesion of fouling deposits from heat transfer surfaces.

The objectives of this paper however, are to explore the field data, historical backgrounds and

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changes in operational plans, from a one year case study concerning fouling resistance and heat transfer enhancement by ultrasonic vibrations. The study, follows two pre-heat, Kerosine reboilers, with specialized measuring equipment on both the inlet/outlet to allow for accurate data capture within the SMART Perform® software suite.

ULTRASOUND 101

The use of acoustic waves for commercially based cleaning applications can be accurately dated back to the 1950's. That being said, during the research phase of this paper, I came across a number of uncorroborated sources that would suggest applications of acoustic cleaning being employed much earlier.

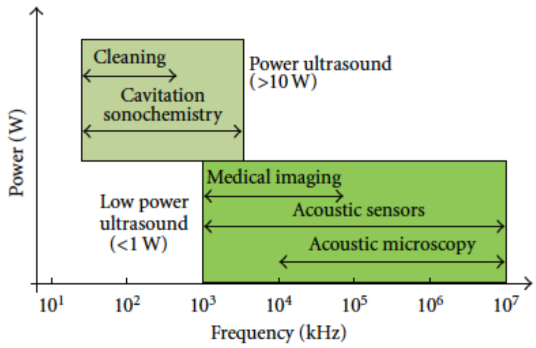

Fig. 1. Utilizations of ultrasound according to frequency and power. [5a]

Acoustic waves of which frequencies are higher than the upper limit of the human hearing range, usually around 16 or 20 kHz, are called ultrasound. These waves are often classified according to their frequency or power.

Between 20 and about 100 kHz, waves are defined as "low frequency ultrasound" or "power ultrasound". Indeed, it is usually transferred at a high power level (a few tens of Watts), and therefore, ultrasound is able to modify the medium where it propagates. Power ultrasound can disrupt a fluid to create cavitation or acoustic streaming, two phenomena with powerful macroscopic effects for heat transfer enhancement. Therefore, power ultrasound finds uses in various processes like cleaning, plastic welding, sonochemistry and so forth. (T. J. Mason et al.,[6]) It is also commonly used for heat and mass transfer processes intensification.

Further in the frequency spectrum, above 1 MHz, is found "low power ultrasound" (usually less than 10W), at a "very high frequency" which does not affect the medium of propagation. Consequently, it is especially used for medical diagnosis or nondestructive material control, and references
regarding heat transfer enhancement are very scarce in the literature. (M. Legay et al.,[5])

In the intermediate range 100 kHz–1MHz, "high frequency ultrasound" is found. It is less used than power ultrasound to promote heat transfer. Figure 1 shows some typical uses of ultrasound according to frequency and power.

THE INFLUENCE OF ULTRASOUND ON FOULING MITIGATION

For several industrial applications, the use of ultrasound is often a way to increase productivity in the process itself. It is being employed to improve system efficiencies, intensify chemical reactions and even produce more homogenous blending of chemicals, paints, even liquified metals. Other applications include: welding, drying, stress relief (in metal curing) and of course, cleaning.

With the above in mind, it's not a huge leap for one to consider the impact of ultrasound on heat transfer processes. This is globally present phenomena within industry, that includes: heat exchangers, chillers, evaporators, temperature control, and the like.

M. Legay et al.,[5b], tables this, in a thought provoking manner. 'It is somewhat logical and natural to wonder what could be the influence of ultrasound upon heat transfer systems. Strangely, it has not been a research topic deeply investigated until recently.'

While we are not going to take a deep dive into this research, I feel it important to acknowledge two examples from literature. One of the first studies was carried out by Kurbanov and Melkumov in 2003 [7]. They explained why ultrasonic vibrations are very well suited to increase performance of liquid-to-liquid heat exchangers. According to the authors, acoustic waves homogenize the velocity vectors of the sub-flows in pipes and decrease the surface tension of the fluid near the boundaries. The second, Benzinger et al. [8] have studied the effect of ultrasound on a micro-structured heat exchanger to avoid fouling. Their results are very promising because the convection heat transfer coefficient increases almost up to the initial value after an ultrasonic pulsation cycle.

The relevant examples brought forward here concerns heat exchangers, where it was found that ultrasound not only increases heat transfer rates, but might also be a solution to fouling reduction. [5b]

THE CLEAN-IN-PROCESS ULTRASONIC EQUIPMENT

The ultrasonic equipment applied in our case study includes custom fabricated magnetostrictive transducers and specialized, programmable ultrasonic generators.

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This equipment is referred to as USP, which is the acronym for Ultrasonic Scale Prevention. All equipment has been designed to work in harsh, ambient temperatures and is certified to operate safely, in all classifications of processing environments.

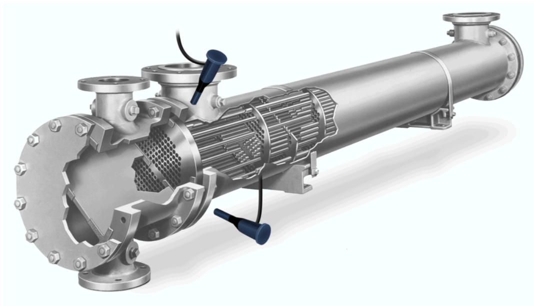

Fig. 2. Graphical representation of USP Transducers affixed to the tubesheet

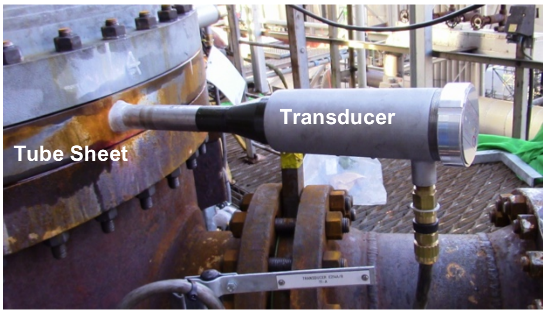

Fig. 3. One of the four, USP Ultrasonic transducers welded to the tube sheet of E-214A

The transducers are welded to the exposed tube sheet(s) of a shell and tube bundle as seen in Fig. 2 and Fig. 3. In this way, we leverage the tube sheet as the medium, for attenuating effective ultrasound down all of the tubes of the bundle. The premise is that the sonication of the tubes will disrupt fouling from staying on either the O.D. or I.D. of the tubes.

The micropulsed, ultrasonic generators drive the system. Figure 4. Micropulses from 30 to 100 mp/s and an ultrasonic frequency range, between 9.0 and 18.9 kHz provide the essential foundation for finding effective fouling mitigation.

Fig. 4. One of the four, USP Ultrasonic Generators required for E-214A/B

An important distinction at this stage of the explanation of USP, is that the system is really a fouling mitigation tool, not a heavy duty cleaning tool —like it's cousin, the ultrasonic bath. If the candidate bundle desiring USP, is completely fouled, the technology will not effectively remove the residual depositions already coating the tubes.

For this reason, installation of USP, often coincides with a T/A or an outage interval of the candidate exchanger. Proper cleaning and preparations are managed prior to the welding-on of the assigned number of transducers.

With the welding completed for all transducers, the generator cabinets installed and powered, the wiring between the transducers and the generators is completed.

Next, we commence the intentional search for the optimal fouling mitigation frequency that will help keep the process exchanger clean. We call this the calibration process, which when complete, allows us to bring the system online.

Calibration. Mounting electronic sensors to the exchanger bundle, we use feedback from the bundle itself, to cycle through a range of kHz frequencies, in search of an optimal frequency that sends the most effective soundwaves along the length of the tubes. An oscilloscope provides the visual interpretation of the amplitude and attenuation as we sweep frequencies. Once we have landed on the optimal frequency for this bundle, the setting is programmed into the CPU of the ultrasonic generator. This frequency is locked and can only be changed by reprogramming.

Micropulse timing, propagates the disruptive waves along the tubes. Determining the micropulse setting for an exchanger candidate (between 30 to 100 mp/s) is dependent on factors such as: the transfer mediums; flow rates; viscosities; age and condition of the asset along with historical fouling performance of the Hx.

BACKGROUND: KEROSINE REBOILERS

The Crude Distillation Unit 6 at our partner refinery has two kero reboilers E214 A/B. They were installed as new in 2006. These parallel reboilers are attached to the kero stripper column C-204. Both reboilers experienced fouling on the kero side (scaling) and on the intermediate hot residue side (sticky fluid). Mechanically cleaning these exchangers required a ten to fifteen day shutdown, which resulted in significant production loss. From 2011, a less effective online cleaning of these exchangers was conducted. This involves a combination of gasoil flushing and steam cleanout, performed every six to seven weeks to maintain minimum acceptable performance.

By 2013, it was estimated that the residual fouling in both exchangers was responsible for the short runs of acceptable performance, despite the frequent cleaning efforts.

Through support from key plant personnel and the offsite, global heat-transfer-team from the same refining org., a solution was sought out in order to address this frequent cleaning.

In May 2015, the refinery collective, installed the USP fouling mitigation technology on both E-214 A/B

Data from the SMART Perform® monitoring application was utilized to identify the initial USP results after one year of operation.

OVERALL FOULING FACTOR

The impact on overall fouling for both exchangers is illustrated in Fig. 5. The fouling factor for the year, with the USP technology applied, is denoted by the TA 2015 corresponding colored line. At day 55 and day 398 in Fig. 4, we notice a sharp resistance peaks. It was discovered through statistical analysis, that these were in fact, false fouling indications caused by upsets of equipment in the upstream residue circuit.

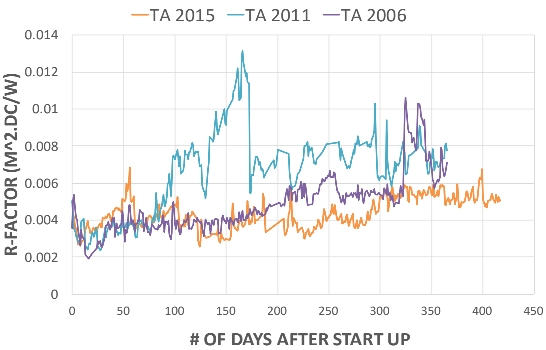

Fig. 5. CD6 E-214A/B : Overall fouling factor. (TA 2015 USP installed. April 27/15 = Day 0)

As the fouling gradient was performing better than anticipated, site process engineers decided to make a modification to the crude diet, to see if this would have an effect on fouling.

On day 234, a low sulfur crude run was started. As early as day 261, increases in the fouling rate was observed. As we were conducting monthly follow up calls with the refinery to review performance for each month, this increase in fouling was the key topic of discussion.

While we discussed the option of adjusting the power tap setting within the USP generators to reverse and correct this fouling trend, the refinery declined this intervention and reverted back to managing a high sulfur diet on day 322.

A notable observation, was that from May 2015 onwards, there was no online or mechanical cleaning performed on either of these exchangers, as it was not required.

OVERALL HEAT TRANSFER COEFFICIENT

With an expected behavior that would follow in line with the fouling factor, the OHTC observed in (Fig.6) was better than anticipated, even in light of the change in crude diet.

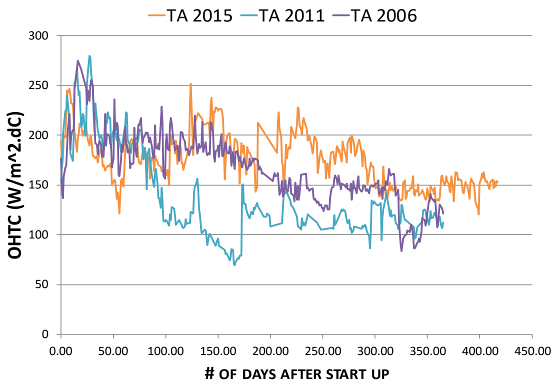

Fig. 6. CD6 E-214A/B : OHTC Performance. (TA 2015 USP installed. April 27/15 = Day 0)

DUTY

This was the key metric of interest and observation to the site engineering group. A minimum 6MW duty was required for this test run with USP to be considered a success. In 2011 and on to 2014, achieving 6MW duty consistently, was coming at a considerable economic trade off. Fig.7

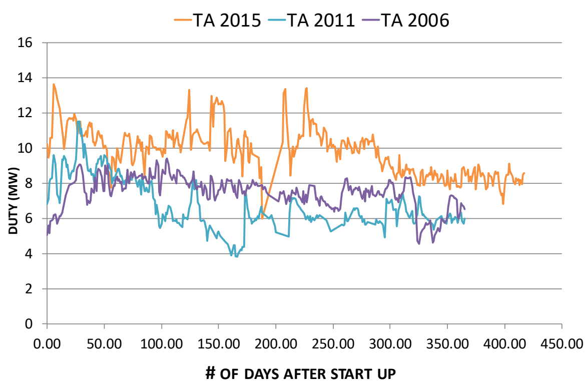

Fig. 7. CD6 E-214A/B : Performance DUTY (TA 2015 USP installed. April 27/15 = Day 0)

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RESULTS

The use of ultrasound has garnered considerable interest toward the possibility of it being a contributor to improving both heat transfer and fouling mitigation—in heat exchangers. For this particular refinery study, some notable results are worth mention:

1. When processing high sulfur crudes, the overall fouling coefficient increase was less steep than in any previous run.
2. From May 2015 through to May 2018, there was no online or mechanical cleaning of these exchangers required.
3. This refinery estimates the value delivered in energy recovery from using USP at $1.1 Million USD /yr.

At first glance, this recovery figure is a significant return when measured against the $275,000 USD budget for USP. However, under closer financial examination, the greater, more overarching benefit was derived from the additional run-time gained by not having to shut down for cleaning. The additional financial gain calculated from the increased run interval, was not shared with us.

CONCLUSION & DISCUSSION

While very promising results were observed in this study, there is obviously much left to explore and questions needing answers. In particular, why a reduction of sulfur in the crude diet caused fouling to increase. Some future activities have been slated to investigate this and other queries.

Since this study was conducted, we have had USP installations within Crude units having a lean sulfur diet.(2018) By providing an increased power output of our system, we were able to maintain optimal duty levels and offer reduced fouling. We cannot say for certain why this additional power setting was necessary, only that it seemed to correct the problem we encountered with the same type of kero-reboilers from our 2015 study.

In peer review of this paper it was noted that there are often differing fouling mechanisms observed in different parts of the crude preheat trains. This naturally leads to asking where this technology would be the most effective.

New installation opportunities will hopefully provide answers to the above and other queries we have posed since this paper was written, For example, we wish to study the correlation between the use of USP and improved asset life. Practical 3d modeling illustrates the reduction in residual fouling when using USP. Actual experiments would need to be conducted under the same condition, to observe the effect that USP might have on both the incidence and prevalence of under-deposit, tube wall corrosion.

Industry feedback and interest in USP has been quite favourable and has led to us exploring the use of this mitigation technology with other heat exchanger designs such as Compabloc and spiral types. This validation has spawned numerous conversations involving collaboration with industry on new heat exchanger designs and the potential for combining USP with other fouling mitigation technologies and/or improved operational best practices.

Subscript

USP	Ultrasonic Scale Prevention
OHTC	Overall Heat Transfer Coefficient
Compabloc	Brand of exchanger by Alfa-Laval
Hx	Heat Exchanger
ROI	Return On Investment

ACKNOWLEDGEMENT

This clean-in-process study arose from the installation of our ultrasonic technology, for a globally recognized, oil & gas producer and our partner in this study. We graciously thank this partner for sharing the performance data, so that we can continue to innovate both the technology and support programs behind the scenes.

By design, in depth costing or economics of the USP equipment used in this study was not discussed. Each Hx candidate and the process fouling in question, will have an impact on the number of ultrasonic transducers and generators required to provide adequate mitigation.

A brief Hx candidate questionnaire can provide those interested, with a budget figure for USP that can be measured against ROI and specific operational goals of the processing site.

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