HEAT EXCHANGER MONITORING TO IMPROVE INTEGRITY, RELIABILITY, AND OPERATIONS IN THE OIL AND GAS INDUSTRY

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ABSTRACT

The impact of heat exchanger fouling has traditionally focused on the cost of energy and the increase in greenhouse gas emissions. Previous work identified that fouling can cause increase in damage mechanism susceptibility which could lead to higher safety risks. This paper describes how analytical tools can allow prediction of the future thermal performance of heat exchangers and possible temperature excursions that could induce damage mechanisms. We focus on monitoring single shell heat exchangers, monitoring multiple shell heat exchangers, and monitoring complex heat exchanger networks with incomplete instrumentation that requires data reconciliation. This paper presents four case studies from upstream and downstream facilities including: crude oil stabilizer reboilers, naphtha hydrotreater feed-effluent exchangers, coker preheat exchangers, and a crude unit preheat train. These examples illustrate a wide range of benefits from utilizing predictive analytical tools in the monitoring of heat exchangers such as planning the turnaround activities, evaluating antifouling additives, and multiple aspects of crude preheat train performance beyond just preheat improvement.

INTRODUCTION

Evaluation of fouling in heat exchangers operating in Oil and Gas Industry focus on two factors: economic penalties and environmental impact manifested through increase in CO_2 emissions. Jackowski et. al., (2017) introduced the third factor related to safety in operation. It was shown, that in certain heat exchanger services, fouling may induce damage mechanisms leading to catastrophic accidents.

Extensive research was conducted to explain fouling mechanisms and develop fouling models. Wilson et. al., (2015) summarized the fouling models into three categories: deterministic models, threshold models such as Ebert-Panchal, (1996), Bennett, (2012, 2016), Bennett et. al., 2009, and neural network.

The purpose of this paper is to show how monitoring of single heat exchangers and heat exchanger networks can be utilized to improve reliability, integrity, and operations. To illustrate potential benefits, the authors present two case studies on monitoring single heat exchangers such as steam heated reboilers and feed-effluent exchangers and two case studies for heat exchanger networks, one simple six shells operating as Coker feed preheater, and another one for a complex Crude Unit preheat train.

MONITORING OF SINGLE HEAT EXCHANGERS

Heat exchanger monitoring, trademarked “HexMon®” by Chevron, is an invaluable tool. Chevron uses HexMon for turnaround planning assurance and avoidance of corresponding lost profit opportunities (LPOs); determination of fouling thresholds, thereby allowing Chevron to avoid certain fouling mechanisms altogether; troubleshooting and debottlenecking; analyzing economics and energy efficiency; and evaluating operational parameters such as the efficacy of anti-foulant chemicals.

Historically, HexMon was accomplished by Chevron using Excel spreadsheets. Recently, however, Chevron developed a tool we have named HexMon PI because it uses rigorous HTRI ***Xchanger Suite*** simulations within the OSIsoft PI Asset Framework (PI AF) environment. HexMon PI is fully automated, pulling process data from the PI Historian, pushing those process data into HTRI, running the HTRI software, and then pushing the results back into the PI Historian where they can be visualized with commercially available tools such as PI Vision, Spotfire, Excel, etc.

Case Study 1: Stabilizer Column Reboiler

Figure 1 presents fouling resistance versus operating time for a steam heated Stabilizer Column Reboiler utilizing anti-foulant chemicals. Trend data reveal that fouling began after about 200 days of operation. After about 280 days of operation, the injection of anti-foulant chemical was reduced by 50%, and the HexMon PI results clearly demonstrate that the fouling rate was unaffected. Three months later, after about 380 days of operation, injection of the anti-foulant chemical was ceased altogether and, again, the fouling rate was unchanged. These HexMon PI results allowed eliminating the use of the anti-fouling chemical, thereby resulting in significant operating cost savings.

Figure 1 also demonstrates that the fouling rate of this Stabilizer Column Reboiler was linear, allowing simple extrapolation to predict future fouling resistance. At this facility, the turnaround was planned to start after 560 days of operation. Extrapolation of HexMon PI trends predicted a fouling resistance of 0.00064 m^2 K/W. Entering this fouling resistance value into the HTRI simulation, along with the process conditions and the maximum achievable steam pressure of 34 barg, we found that the expected reboiler heat duty was sufficient for Stabilizer Column full throughput. This information was critical in planning the turnaround activities and avoiding a LPO.

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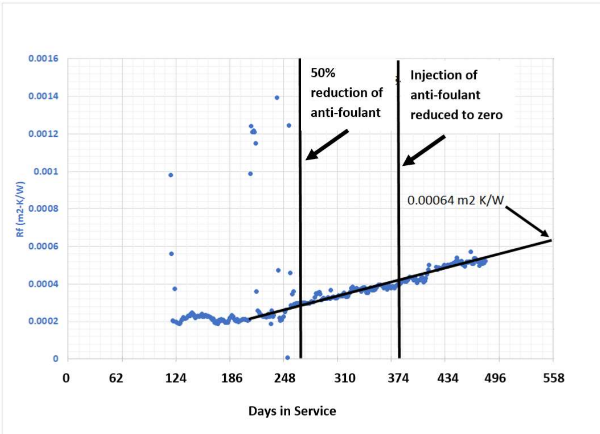

Figure 1. Fouling resistance versus days in service for a Stabilizer Column Reboiler. Fouling began after about 200 days in service. After 280 and 380 days in service, the dosage of an anti-foulant chemical was reduced by 50% and 100%, respectively. HexMon PI results clearly demonstrate that the fouling rate was unchanged.

Case Study 2: Naphtha Hydrotreater (NHT) exchangers

High temperature hydrogen attack (HTHA) is a serious safety concern that could lead to catastrophic incidents such as the one described in Chemical Safety Board (CSB) report, 2014. As shown by Jackowski et al., (2017), non-uniform fouling in feed effluent heat exchangers can result in operating temperatures within the region susceptible to the HTHA damage mechanism. HTHA is a material damage mechanism whereby hydrogen diffuses into carbon or low alloy steel at high pressure and temperature leading to decarburization, fissuring, cracking, and eventually, failure.

In the absence of thermocouples between F/E HEX shells, HexMon PI can be used to generate a worst case estimate of the temperature and proximity to the HTHA limit. With or without intermediate thermocouples, HexMon PI can be used to monitor the HTHA limit approach, and its alert feature can be used to notify interested parties if the HTHA limit is breached.

As an example of using HexMon PI for Integrity Operating Windows (IOWs), we considered Naphtha Hydrotreater (NHT) Feed/Effluent Heat Exchangers (NHT F/E HEXs) connected as 2 in parallel and 3 in series (Figure 2). The hot and warm shells (A/B/C/D) employ HTHA resistant materials such as stainless steel tubes and medium-chrome shells and channels whereas the metallurgy is changed to carbon steel in the cold shells (E/F) to permit water washing of the ammonium halide fouling deposits. Naturally, carbon steel is susceptible to HTHA, as described by API Standard 941. Figure 3 illustrates that as shell D fouled, the effluent temperature entering shell F got closer to the API 941 HTHA limit by about 35 °C, but it did not get close enough to the limit to trigger a HexMon PI alert

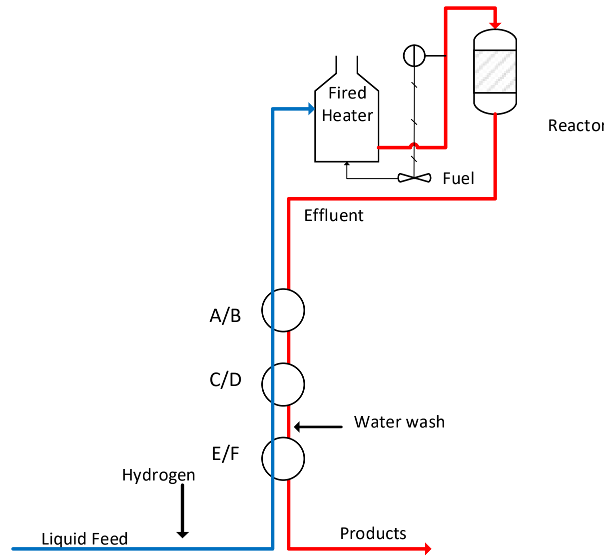

Figure 2. Schematic of a 2 in parallel x 3 in series Naphtha Hydrotreater (NHT) Feed/Effluent Heat Exchanger (F/E HEX) network

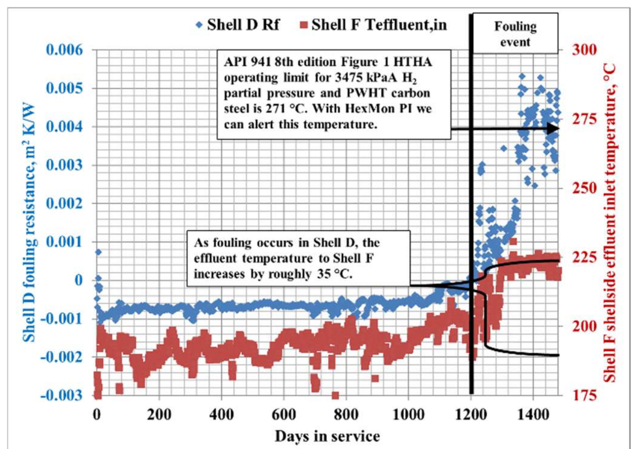

Figure 3. Shell D fouling resistance and Shell F shell side effluent inlet temperature versus days in service, demonstrating that as Shell D fouls, the effluent temperature to Shell F increases and approaches the HTHA limit, but not close enough to trigger a HexMon PI alert

MONITORING OF HEAT EXCHANGER NETWORKS

Most heat exchanger networks operating in the Oil and Gas Industry have insufficient instrumentation to calculate rigorous solutions for all exchangers. In some cases, when all temperatures and flow rates are known, faulty instruments may lead to incorrect heat and material balances and inaccurate results. In addition, some heat exchangers in the network may have installed unmonitored bypasses that lead to misleading heat exchanger network results. For these reasons, there is a strong need for simulation software with embedded data reconciliation features that will drive to a solution respecting heat and material balances with minimal errors. As an additional benefit of such an approach, instruments that are “bad actors” in the network can be identified and flagged for repairs.

Case Study 3: Vacuum Resid/HCGO pump around Network

Vacuum residuum (or vacuum resid) is a low-value heavy hydrocarbon and, as such, is often used as a feed stock in Coker Units. HCGO PA (Heavy Coker Gas Oil Pumparound)/vacuum resid exchangers (see Figure 4) are subject to intense fouling, especially coke build-up. As fouling increases, HCGO PA (red stream) outlet temperature from shells C and F increases and vacuum resid (blue stream) decreases. The unmonitored bypasses on the hot side of the exchangers are manually closed so that more heat can flow throught the exchanger. While it is typical to assume the vacuum resid temperatures limit operations, in the presented example, the reboiler utilizing HCGO PA as a heating medium has strict temperature limits, which may lead to shutdowns and/or feed rate cutbacks.

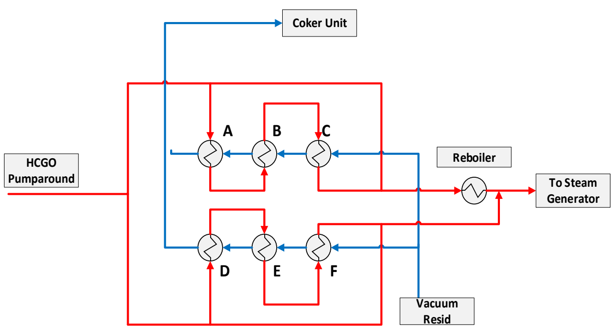

Figure 4. Simplified process flow diagram of Heavy Coker Gas Oil Pumparound (HCGO PA) and vacuum resid exchanger network. HCGO PA heats the vacuum resid before being utilized as a reboiler and steam generator heating media.

Network-based simulation tools such as HTRI’s SmartPM solution are beneficial when data reconciliation is required, Ishiyama et al., 2013. The unmonitored bypasses create heat imbalances that require data reconciliation to determine the unknown flow rates. Additionally, the HCGO PA feed does not split equally between the two branches, and it is common for the A/B/C exchanger branch (long loop) to see increased flows. Individually monitoring each exchanger is notpossible due to the lack of individual temperature sensors between the shells connected in series. In our analysis, plant data available for the last three turnaround cycles were used to perform heat and material balances. Assuming that the error in heat balance is due to the unmonitored bypasses, SmartPM reconciles the bypass flow rates to meet outlet temperatures. SmartPM uses the number of transfer units (NTU) method (also known as the effectiveness method) to calculate the estimated clean NTU of the branches A/B/C and D/E/F. Further, SmartPM estimates the clean NTU of each exchanger in series. This provides a ratio of fouling rates for all exchangers that is then used to distribute the overall fouling rate, Ishiyama et al (2011).

From reconciled data we were able to build a tracking model (Figure 5). A tracking model uses past data and the developed fouling model to estimated the past fouling based on the tag data. The closer a tracking model can replicate a reconciled model, the more confidence we have in the models ability to predict future prefromance. Based on fluid characteristics, the asphaltene precipitation fouling model developed by Polley (2010) was selected and, as a simplification, all fouling was assumed to be on the Vaccum resid (Ishiyama et al., 2013). The fouling thermal conductivity and fouling propensity factor – also known as the attachment probability factor are generated by the SmartPM tool after the representative fouling curve has been selected.

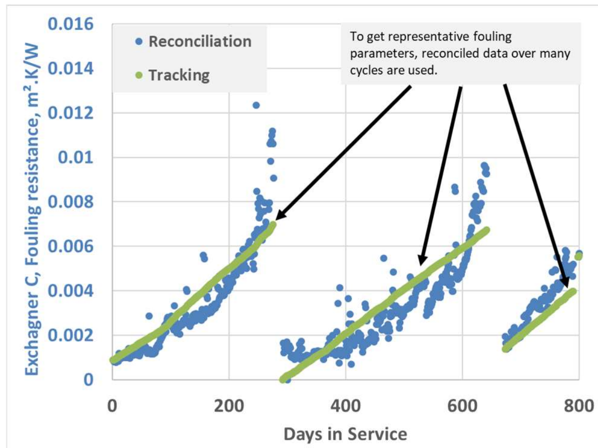

Figure 5. Fouling resistance trends over multiple cycles are used to develop a fouling model. The SmartPM software is currently limited to linear trending of data.

The SmartPM solution was also used to estimate flow rates in the bypass based on temperature reconciliation data; this was then validated with simple orifice calculations. As the exchanger network model moves through time the reconciled model outlet temperature from exchanger F surpassed the simulation estimates (Figure 6 bottom graph). However, the simulation estimate for the outlet from exchanger C is underpredicted and the reconciled model is less than the simulation (Figure 6 top graph). It is important to note that the reboiler downstream of exchanger C has the temperature limit of 280 ºC that is lower than that that for exchanger F (300 ºC). Therefore, the underpredicted performance for exchanger C is more consequential. Exceeding the reboiler inlet temperature above 280 ºC leads to the shutdowns of the unit due to excessive reboiler fouling. Ability to accurately predict when the temperature limit is reached allows for planing shutdowns or reduction in feed rates to continue production until the scheduled turnaround.

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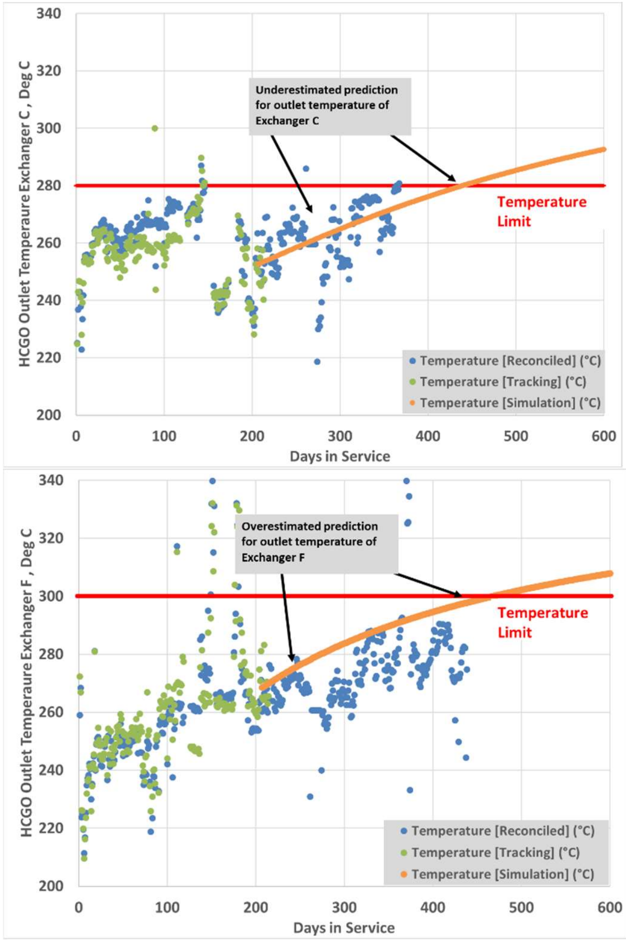

Figure 6. Fouling in the heat exchanger network results in increased outlet HCGO PA temperatures. The reconciled data are anchored to the monitored outlet temperature and further used to generate the tracking data based on the fouling model. The model allows predictions of future performance.

Case Study 4: Crude unit preheat train exchangers

Crude Unit preheat networks are some of the most complex exchanger networks in the refineries and, in most cases, are the largest energy user. For this reason, numerous studies have been dedicated to evaluate effectiveness of the preheat trains, A typical crude unit preheat train will consist of twenty or more exchangers and will heat the crude from ambient to temperatures of 250-290 ºC. Crude Unit preheat trains are often one of the largest drivers of energy cost within the refinery. Recovering the maximum amount of heat is often the main concern of plant operations. However, it is often overlooked that temperature drops in the desalter will lead to inadequate salt removal. Without adequate desalter temperature, deslater efficiency drop leads to increased corrosion and fouling throughout the refinery. By focusing only on the furnace inlet temperatures, we may be sacrificing overall refinery performance.

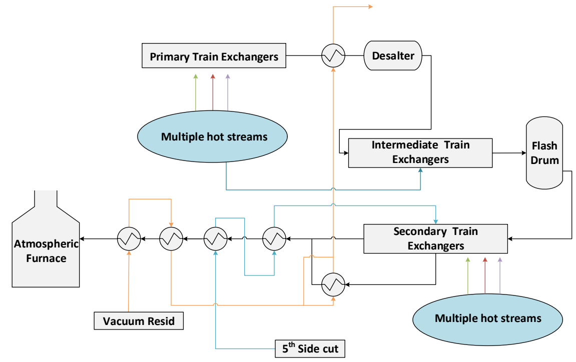

Figure 7. Simplified flow diagram of the Crude preheat exchanger shows the vacuum resid flow path. Vacuum resid is the final exchanger before crude enters the atmospheric furnace and is also the last exchanger upstream of the desalter. Adjusting bypasses will move heat from the secondary to primary train.

The level of heat integration in the Crude Unit preheat train leads to multiple exchangers using the same side cuts at different points in the train. To build a good network simulation, accurate exchanger and plant process data are required. There are also other factors to consider including poor or missing data (bad actors) and unmonitored bypasses that may significantly change the results. It is often the case that up to 100 data points per preheat train are used per simulation. It is also important to note that the active fouling mechanism(s) is(are) a function of location in the preheat train. Instead of simulationg each exchanger separately, as described by Jackowski at. al., (2017), we developed SmartPM simulations that provide the flexibility to use multiple fouling models within the same simulation. Creating a well-tuned model is a balance of reconciled data, bad actor identification, and extrapolation of fouling rates. The models can then be used to monitor key parameters such as furnace inlet temperature and desalter inlet temperature. This can be critical for identifying when when the plant will have to cut rates due to the duty limitation reached in the furnace.

In the example above, we can see that the plant data for the inlet temperature to the furnace and the inlet temperature to the desalter was used as the basis for the reconciled model. At the start of run there is a temperature offset at the desalter caused by a heat imbalance in reconciliation; this may be caused by an unmonitored bypass or by poor plant data and can be easily flagged for deeper analysis. However, in both plant data and the reconciled data, there is a decrease in desalter inlet temperature. Too low desalter inlet temperature may lead to high chloride content in the atmospheric column overhead and significant corrosion issues throughout the refinery. In the future, this type of data analysis will allow for predictions to estimate when the lower inlet temperature limit will be reached. The created SmartPM models like will be used to plan turnarounds or cut rates to prolong the need for a turnaround. Additionally, as we gain confidence in the model, it will be possible to evaluate the effects of different modes of operation by simulating opening bypasses to send more heat to the primary train to maintain desalter inlet temperature for the entire run.

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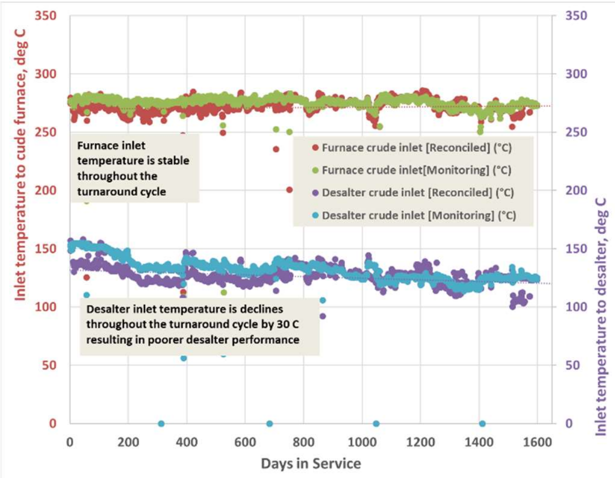

Figure 8. Furnace inlet temperature (red), is nearly steady for the entire 4+ years run. The desalter inlet temprature (purple) declines by about 30 ºC over the same time frame. Network simulations allow one to develop a strategy on how to maintain desalter inlet temperature.

These types of case studies will become invaluable as we estimate the effects of changes to operating conditions or exchanger geometries (Ishiyama et. al, (2009, 2011, 2012, and 2013) and Pugh et. al., 2015).

In our future work we will utilize the developed SmartPM model to evaluate:

- Impact of various options of heat exchanger retrofits on the preheat train network
- Changing operating modes to remove or add heat to different locations in the train
- Evaluate the bypass of an exchanger

CONCLUSIONS

Heat exchanger monitoring tools such as HexMon PI and SmartPM can be effectively used to predict future performance of single heat exchangers as well as heat exchanger networks. The results are critical to:

- plan future turnaround activities
- evaluate effectiveness of anti-fouling chemicals
- inform progress or onset of possible damage mechanisms
- evaluate the impact of possible changes in operation of the heat exchanger networks on critical parameters such as desalter and furnace inlet temperatures.

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