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FOULING: IMPLEMENTATION OF A CRUDE PREHEAT TRAIN PERFORMANCE MONITORING APPLICATION AT THE IRVING OIL REFINERY

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ABSTRACT

Use of KBC's proprietary fouling monitoring software at Canada’s largest Oil Refinery yielded early results when the tool highlighted a fouling event shortly after it occurred. Following a brief shut down, Crude Unit number 4 increased throughput and transfer temperatures back to normal conditions. During this time, significant fouling occurred in several exchangers. Using KBC’s tool to analyze the fouling event, it was possible to pin-point the exact time frame that the incident occurred; the exchangers that fouled; how much fouling had occurred and the value to the refinery of cleaning the fouled exchangers. This paper looks at the Fouling Monitoring software and the results from the case study as well as the consequent actions taken by the refinery.

BACKGROUND: IRVING

Irving Oil Refinery is the largest refinery in Canada. The refinery site in Saint John was officially opened in 1960 with one crude unit processing 38,500 BPD (New Brunswick Department of Environment, 2005). The refinery now processes 300,000 BPD (Irving Oil Refinery, 2008) of crude, which are shared between Crude Unit No 3 and Crude Unit No 4.

Irving is interested in energy efficiency and has had conducted a series of energy savings projects in the past six years preceding the study reported in this paper. Some involved moderate to major capital investment whilst others were operational projects focusing primarily on day-to-day optimization of steam and fuel.

The company recognised that for further improvement to be made, areas that have had not been looked at seriously before, like fouling, would have to be addressed. Although the refinery had not been experiencing significant fouling problems since a major revamp in 2003, the company’s technical manager was keen to install a fouling monitoring tool so that the cost of fouling could be monitored on a regular basis.

THE FOULING PROBLEM

Most fouling arises from asphaltene deposition from the crude oil onto the metal surfaces of the pre-heat train heat exchangers. This fouling leads to a decline in furnace inlet temperature; by perhaps as much as 30 °C (54 °F), and a subsequent need to burn extra fuel in the furnace to make up the temperature necessary for efficient distillation. Fouling also causes a significant decrease in the crude unit throughput, cutting production (IHS ESDU, 2007).

The costs associated with fouling in crude pre-heat exchangers are categorised as follows (IHS ESDU, 2007):

1. Energy costs and environmental impact. This corresponds to the additional fuel required for the furnace due to the reduced heat recovery in the pre-heat train as exchangers foul. Energy losses due to increased pressure drop (pumping power) may also be significant. The use of more fuel leads to additional production of CO2 with the associated environmental impact.
2. Production loss during shutdowns due to fouling. If the pre-heat train throughput is furnace-limited, a typical 10 per cent loss of production due to a drop in furnace inlet temperature in a 100 000 US barrel/day plant would cost $20 000 US per day (assuming $2 per US barrel of marginal lost production). This amounts to an annual loss in revenue of $7.3 million, if the fouling problem is not addressed.
3. Capital expenditure. This includes excess surface area, costs for stronger foundations, provisions for extra space, increased transport and installation costs, costs of anti-fouling equipment, costs of installation of on-line cleaning devices and treatment plants, increased cost of disposal of the (larger) replaced bundles and, finally, the (larger) heat exchangers.
4. Maintenance costs. This includes staff and other costs for removing fouling deposits and the cost of chemicals or other operating costs of anti-fouling

devices. There are also economic and environmental penalties associated with disposal of cleaning chemicals after cleaning.

FOULING MITIGATION AND MONITORING

For too many years, fouling has been considered as unavoidable and outside human responsibility. Owing to the enormous costs associated with fouling, a considerable number of fouling mitigation strategies has been developed. Fouling is a function of many variables. For example, fouling in crude oil exchangers is affected by the following variables: crude oil composition, inorganic contaminants, process conditions (temperature, pressure and flow rate), exchanger and piping configuration and surface temperature etc. Therefore effective control of the variables in certain conditions may minimize fouling. Generally, effective fouling control methods should involve:

- Preventing foulant forming: This can be done by filtering the crude oil from the well to remove sediments as well as by improving the crude desalting process.
- Preventing foulants from adhering to themselves and to heat transfer surfaces: This is mainly achieved by increasing the shear force on the heat exchange surface so as to prevent deposits from forming. If the wall shear stress is above the threshold value for the wall temperature, little or no fouling will register.
- Removal of deposits from the surfaces: This is basically heat exchanger cleaning. This can be achieved through mechanical, chemical or supersonic cleaning methods.

There are different forms of fouling in refinery exchangers (Bott, 2001). The amount of fouling experienced in any exchanger depends on the type of fouling, the service, the type of exchanger etc. Changes in refinery operation will have different effects on different exchangers. A number of different fouling patterns are known to be possible in exchangers, see Fig. 1 (SteinHagen, 1999). If a change in operation changes the fouling behaviour of an exchanger, or re-inforces the upward trend of the saw tooth type of fouling, it is important that this change be discovered and addressed.

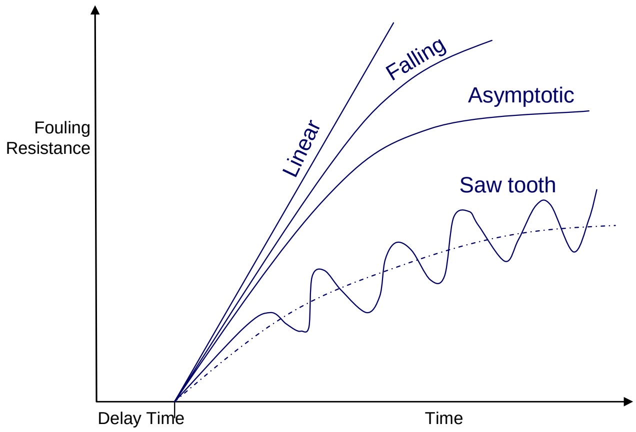

Fig. 1 Various fouling mechanisms observed in crude refining exchangers.

Considerable amount of material is available on the mitigation techniques discussed above (Master, et al, 2003; Pugh, 2008). It has even been reported that there is a fouling threshold velocity, whereby operating at velocities beyond the threshold value can virtually eliminate fouling in the exchanger (Ebert and Panchal, 1997). Whatever the mitigation technique, fouling monitoring is indispensable in ensuring that the cost of fouling is known so that a suitable mitigation technique can applied and on time.

FOULING MONITORING SOLUTION

Daily Plant Data

Fouling monitoring should start with an analysis of plant data, as obtained from the refinery's DCS. The data required are shown in Fig. 2. These include temperature and flow measurements, as well as product characterisation data such as API gravity and distillation assays. Measurements are picked up daily, where available, but less frequently for laboratory data.

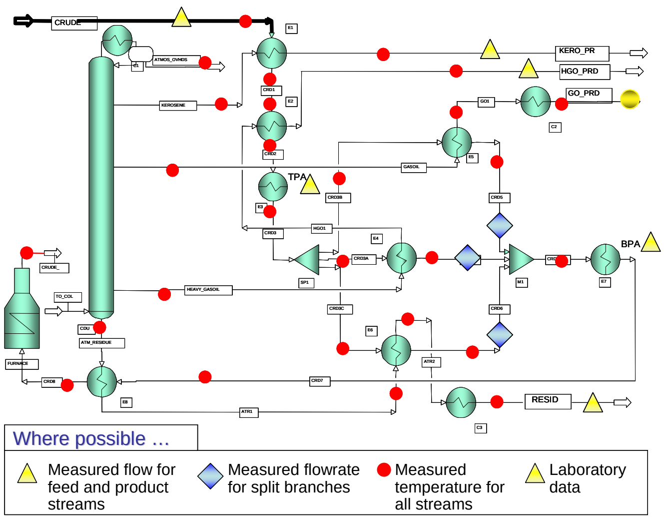

Fig. 2 Data Measurement required for fouling monitoring.

Data Reconciliation

The raw plant data should then be reconciled to ensure good enthalpy balance across the heat exchanger network, using an optimisation-based approach. The resulting reconciled data can be used for fouling calculations and other purposes such as Pinch Analysis.

The differences between measured data and reconciled data are reported to the user, since they may indicate problems with the measurements, particularly if the difference has suddenly increased. However, they can also indicate problems associated with physical properties or the model, in which case re-calibration may be needed.

Heat Exchanger Rating

The reconciled data establishes the actual heat transfer duty in the individual exchangers. The actual heat duty is generally lower than what the exchanger is able to do at the same process conditions, when there is no fouling in the exchanger. For fouling monitoring, it is necessary to perform rigorous exchanger rating for shell and tube exchangers, so that the fouling factors, responsible for the lower heat duty, are determined. Typically, this is calculated for all crude oil liquid-liquid exchangers in the preheat train.

Fouling Monitoring

The fouling factors for an exchanger can be examined over a range of days (preferably several years) to establish the fouling trend. A typical fouling trend chart for 6 years is shown in Fig. 3. This helps to understand the fouling pattern of each individual exchanger and is helpful in identifying any change in behaviour.

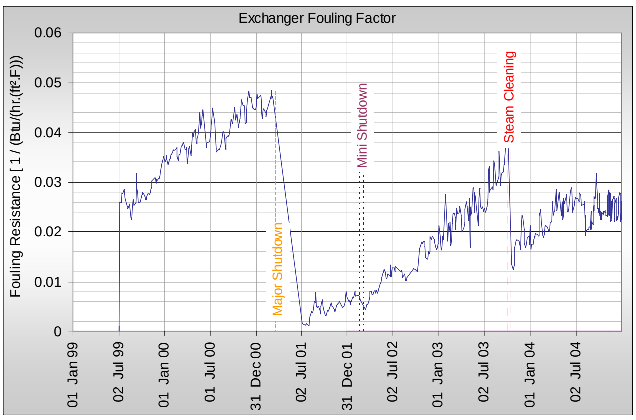

Fig. 3 Typical fouling trend chart for a refinery shell and tube exchanger.

Heat Exchanger Simulation

Fouling in an exchanger will reduce the heat transferred through that exchanger. However, the proportion of that heat loss that has to be made up by the furnace is much less than 100% for most exchangers on the train. Fig. 4 illustrates this principle for an imaginary crude preheat train. For instance, in Fig. 4, a 2 MMBtu/h reduction in the heat transferred in E12AB only led to a 0.5 MMBtu/h increase in furnace duty. However, a similar reduction in E14AB duty led to a full 2 MMBtu/h increase in furnace duty. Fouling in E14AB leads to a 1:1 loss in furnace duty because E14AB is the last exchanger on the preheat train and E14AB is the only exchanger on this HVGO service.

A further point that is often overlooked is the importance of exchanger size and driving force. A small amount of fouling in a large exchanger, in a crucial location, can have a much bigger effect than high fouling in a small, less significant exchanger. Also, cleaning a fouling exchanger may not lead to a significant improvement in its performance if the driving forces in adjacent exchangers are small.

The effect of fouling is therefore best understood through a full network simulation as it depends on the network arrangement and the driving forces in the exchangers.

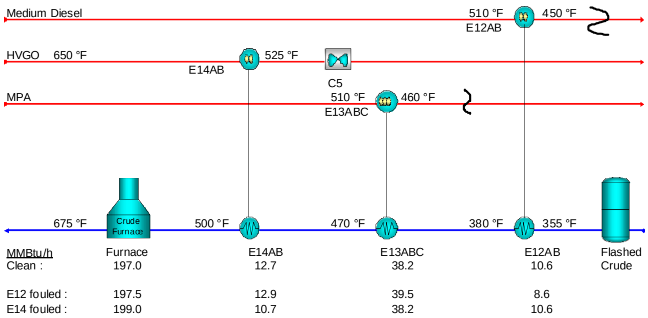

Fig. 4 The relationship between the loss in exchanger duty and increase in furnace duty depends on network arrangement and driving forces.

From simulation we can determine the downstream effect of the fouling in each individual exchanger, as the difference before and after fouling. This makes it possible to generate a chart representing the benefit that cleaning each exchanger will have on the furnace coil inlet temperature (CIT) and heat duty.

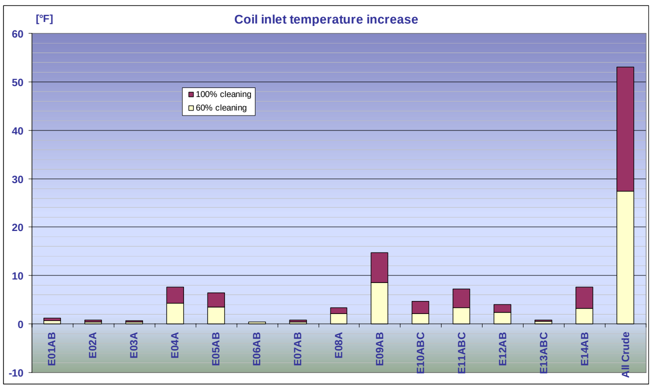

Fig. 5 Coil Inlet Temperature Increase from cleaning exchangers.

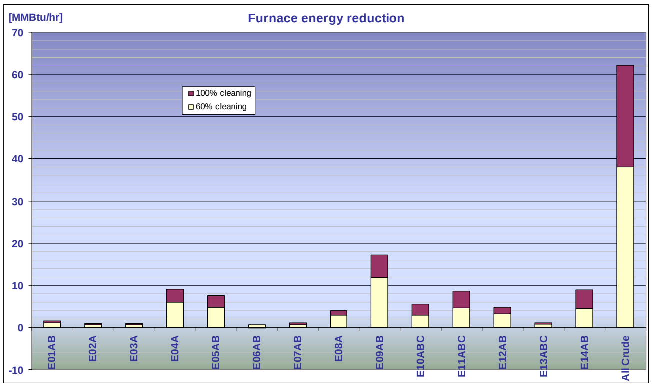

Fig. 6 Furnace Energy Reduction from cleaning exchangers.

In the charts above, the right-hand bar is the total for cleaning the whole network, while the other bars represent each individual exchanger. From this we can see that the fouling penalty is often concentrated in a few exchangers, although the fouling itself is more widespread.

Key Performance Indicators (KPI)

Fig. 7 shows a very effective graph for use in Fouling Monitoring. It simply shows the simulated benefit of cleaning the whole network at any point in time. This is typically expressed as the potential reduction in furnace duty or the potential increase in furnace inlet temperature.

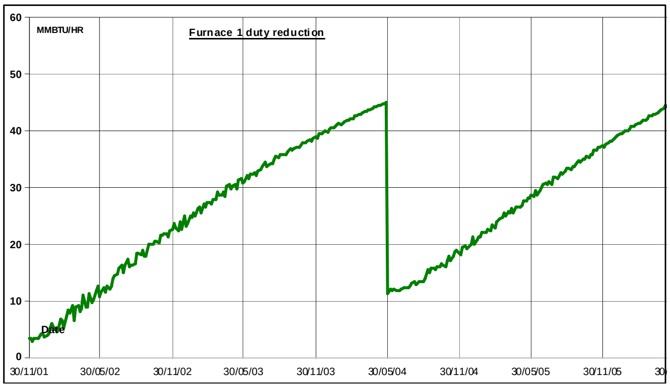

Fig. 7 Key Performance Indicator: Simulated benefit of cleaning whole network over several years

The graph in Fig. 7 is for a demonstration crude preheat train model, and shows a sharp decrease in May 2004. This corresponds to the cleaning of some exchangers, hence the reduction in potential afterwards. From this we can clearly see the benefit achieved by the cleaning, measured by the size of the drop, which can be difficult to determine otherwise.

Conversely, a sharp rise in the graph shows a significant increase in the impact of fouling. One can then look at the graph in Fig. 6 to see which exchangers are causing the problem, or “drill-down” into further details about exchanger performance.

Finally, because the graph is based on simulation, it factors out any complications due to different crude rates or process conditions.

EXPERIENCE AT IRVING

Irving commissioned KBC to perform a fouling monitoring study on its #4 CDU in 2006. The project started with a kick-off meeting during which KBC gathered over 6 years of plant data from the refinery’s data historian system.

DCS Data

The main data items obtained from the DCS were:

- Measured temperatures around the exchangers in the preheat train network, including coolers and the furnace.
- Measured flowrates of raw crude and desalted crude and associated branches.
- Measured flowrates of product and pumparound streams and associated branches.
- API gravity lab data for raw crude.
- API gravity and distillation assay lab data for product streams.

Daily data points, averaged over a critical 2 hour period, were used for the measured temperature and flowrates. As the lab data were only measured discretely, these were matched with the daily data as closely as possible.

The heat exchanger network with process instrumentation information was put together from the P&ID diagram. The data was then reconciled to achieve an energy balance across the heat exchanger network. The goal of the reconciliation optimisation is to calculate the temperatures in the network that will achieve energy balance, whilst minimising the difference between the calculated temperatures and measured temperatures. The differences between measured and calculated temperatures were within acceptable range for most measurements on the CDU4 preheat train.

The reconciliation was performed on daily data, averaged over a 2 hour time span.

Fouling Trends

The heat duties determined from the reconciled data were used to calculate the fouling factors for each day. The fouling factors determined for the range of days enabled the fouling trends to be derived. One of the fouling trends produced for the Irving exchangers is shown in Fig. 8.

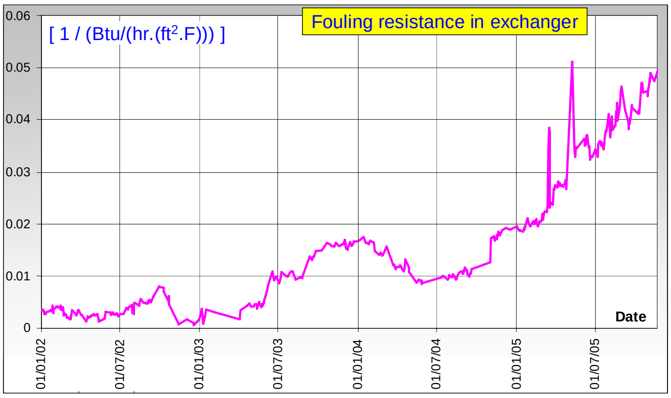

Fig. 8 Fouling Trend for an exchanger in the middle of CDU4 Preheat Train, over several years

Cleaning Benefit

To examine the potential benefit of cleaning on a particular day before the shutdown, simulation calculations were performed on the preheat train with the fouling factors calculated for that day. This showed that the CIT could be increased by 41 °F. More importantly, the analysis also pointed out that 66% of the potential CIT benefit could be achieved by cleaning just three out of the 25 exchangers on the preheat train. Thus, KBC's tool identified the exchangers that should be fitted with bypass isolation valves to enable cleaning in-between cycle.

The exchanger with the fouling trend shown in Fig. 8 (noted as exchanger A) is positioned somewhere in the middle of the preheat train. The crude stream leaving it runs through eight other exchangers before getting to the furnace. However, the network arrangement and driving forces are such that, the CIT impact of exchanger A is much more significant than that of the last exchanger on the train. Exchanger A, along with two other exchangers, B and C (also around the middle of the train), were responsible for about 66% of the lost performance in the network. Here we see that the last exchanger on the train is not necessarily the one whose fouling produces the greatest effect on the preheat train. Rigorous rating and simulation, such as is done in KBC's proprietary tool, is necessary to identify the most important exchangers.

Turnaround Planning

During shutdown, the cleaning of exchangers is often on the critical path of the turnaround process. As a result, being able to leave some exchangers without cleaning will reduce the duration of shutdown and enable refiners to commence operation and generate revenue. The cleaning benefit chart allows the exchangers to be ranked in order of cleaning importance. The least beneficial exchangers can then be considered for cleaning at a later stage, perhaps during a mini shutdown, to reduce the duration of the major shutdown.

Post Shutdown Experience

Since the study started a few months before the shutdown and was completed just before shutdown, Irving did not need an intermediate shutdown to clean exchangers A, B, C discussed above. Instead, they followed their normal shutdown pattern in cleaning all the exchangers. Following shutdown, CDU4 increased throughput and transfer temperatures returned to normal conditions.

Following start-up, an unscheduled shutdown took place and mysteriously, this led to an unusual fouling event (KBC, 2007). This was completely unexpected, and has still not been fully explained.

With regular monitoring of fouling and network performance using KBC's proprietary software application, Irving identified the fouling event soon after it happened.

The tool also identified when and where the fouling occurred, which enabled targeted cleaning and an investigation of the procedures at the time of the fouling. The refinery then planned for opportunity cleaning of the three identified exchangers (6 shells) during a refinery slow down 12 weeks after the event. The program also indicated that cleaning the exchangers recovered 20-25 °F of coil inlet, which equates to ~ 25 MMBtu/h of furnace firing (KBC, 2007).

At $10/MMBtu, this equates to ~$2 MM/y (KBC, 2007) of energy costs and an even greater value based on either reduced crude processing capability or reduced recovery on the atmospheric tower.

CONCLUSIONS

In this paper, we have shown that it is necessary to monitor crude preheat train fouling, so that changes in fouling behaviour, as a result of changes in crude type etc, can be identified on time. The ability to identify such changes in fouling will enable refiners to understand the potential fouling effect of changing to a particular type of crude or making other operational or design changes.

KBC have a fouling monitoring program, which calculates the fouling factors for each exchanger on a preheat train from daily plant data. The resulting fouling trend shows the fouling characteristic of individual exchangers, which enables any change in fouling behaviour to be identified within days of it occurring. Network simulation is then performed to determine which individual exchangers or selected groups of exchangers will offer the most significant benefit when cleaned.

The program has been used to model Irving Oil's CDU4 preheat train as part of a service provided by KBC. The model identified the exchangers that require bypasses to enable periodic cleaning. The model also identified an unusual fouling event, shortly after start-up, which could have cost Irving $2 MM/y (KBC, 2007) energy costs alone.

The fouling monitoring application has also been installed on Irving's #3 CDU unit to enable ongoing fouling monitoring. CDU3 exchangers had been revamped recently to minimise fouling propensity and therefore experienced less fouling than CDU4 exchangers. However, the fouling monitoring and cleaning study still identified opportunities to reduce the cost of fouling in the unit.

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