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EXPERIENCE IN THE APPLICATION OF COMPABLOC^{TM} IN REFINERY PRE-HEAT TRAINS AND FIRST ANALYSIS OF DATA FROM AN OPERATIONAL UNIT

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ABSTRACT

Compabloc^{TM} heat exchangers have now been installed in numerous refineries around the world. The corrugated plates of the Compabloc exchanger induce turbulent flow in the channels, resulting in a high efficiency and low fouling design. Whilst many users report that the applications have been successful, most of those reports are verbal. (This is particularly the case respecting performance on fouling duties). Few users have published their experience.

In this paper the authors look at two reports that have been published. They then examine how well a fouling model (previously fitted to monitoring data obtained for a shell-and-tube heat exchanger) fits data obtained from the monitoring of a Compabloc ^{TM} unit. Finally, they outline the effort that is being made to obtain a better understanding of how these heat exchangers can best be used in pre-heat trains.

INTRODUCTION

Compabloc^{TM} is a plate type heat exchanger that, due to its gasket-free construction, can be used in high pressure and high temperature duties handling aggressive media.

To date, there are more than 750 Compabloc^{TM} exchangers installed in oil refineries around the world in various process units, with over 200 of them operating in the crude pre-heat train. However, there have been very few reports published on their behaviour.

The use of Compabloc^{TM} in optimising heat recovery has been reported by Andersson (2007). Among other advantages, Compabloc^{TM} are highly compact and can overcome many space restrictions. The amount of surface area per unit volume contained in these units is between 60 and 70. A shell-and-tube unit will contain between 7 and 9 sq.m. of surface per cubic metre.

The corrugated plate design leads to turbulent flow in the channels of both circuits. This results in high film coefficient and high wall shear stress, often at relatively low channel velocity. Wall shear stress is an important factor in fouling mitigation. The maximum value that can be obtained in a shell-and-tube heat exchanger is around 20 Pa, but most industrial units operate at much lower values (typically 10 – 15 Pa) because of pressure drop considerations. Compabloc units, which have much lower flow lengths, can operate at wall shear stresses in excess of 100 Pa whilst giving similar overall pressure drops.

Due to its corrugated plate design, the channel spacing varies between zero at the plate contact points to a maximum of 10 mm. Compabloc^{TM}, in this respect, is not recommended for fluids with high solids loading. If there is moderate amount of particulates or suspended solids in the streams during normal operation, duplex online filters /strainers of 2.5 mm mesh are recommended to be installed upstream of the exchanger to prevent clogging of the channels.

Thus far, fouling study on Compabloc^{TM} has not been subjected to detailed analysis. The current work takes the first steps towards such analysis.

Fouling in Exchangers at Hot End of Pre-Heat Train

Spangler et al (2006) report on a Compabloc^{TM} exchanger installed at the hot end of a pre-heat train. This unit extracted heat from an HVGO pump around stream. Following the installation, the pressure drop through the unit was observed to increase quite rapidly and the unit was shutdown for cleaning after five months of operation. It was found that prior to start-up of the new exchanger, existing piping had not been flushed. As a consequence the exchanger had become partially blocked with particulate material. Once the unit had been cleaned, satisfactory operation was obtained throughout the normal operating period of the plant. In fact even after eighteen months continued operation, the performance of the unit exceeded the original design objective.

The company had installed two units in parallel (one standby). At one stage, they needed to extract more heat from the pump around stream than was normally the case. As a consequence they operated the two units in parallel. Again the exchanger performance was according to expectation.

Fouling of Exchangers Positioned Prior to De-salter

De Castro et al (2008) report on tests conducted on a Compabloc unit positioned prior to the de-salter. The stream on the hot side of the exchanger was vacuum residue. With a shell-and-tube heat exchanger, fouling could be expected on both sides of the units. The tests were conducted for a range of throughputs over a period of 15 months and both thermal performance and fouling were investigated. No fouling was observed under any of these test conditions. It has to be noted that the maximum temperature of the heated crude was ~ 120-130 ^{o}C while the hot vacuum residue was ~ 200 ^{o}C.

From the test results, valuable design, operation and maintenance experience were gained. The user has decided to install more Compabloc™ in their pre-heat trains and they have expressed interest to carry out further performance and fouling tests at higher crude temperature and with partial crude vaporization.

No mention is made by DeCastro et al (2008) of the composition of the deposits formed in the shell-and-tube heat exchangers used in the pre-heat train. However, for the exchangers positioned prior to the de-salter, it is common to find that rather than being rich in organic material, the deposits have high concentrations of inorganic salts, iron and sulphur. This suggests that the fouling mechanism for exchangers in this part of the train could involve a combination of corrosion, sedimentation and crystallisation with corrosion acting as the trigger.

Mechanical Integrity

It is recommended that the tightening torque of the Compabloc™ panel bolts be checked (and re-tightened if necessary) on start-up.

The units can be designed to handle high piping and nozzle loads, equivalent to external loads imposed on shell and tube exchangers. It is therefore untrue that they are sensitive to such loads.

Material of Construction.

Fouling can sometimes result from the onset of corrosion in carbon steel shell and tubes heat exchangers. In Compabloc™ design, plate material selection is made with zero corrosion allowance. High content of chlorides can give rise to crevice corrosion at the contact points of corrugated plates and in some cases, an upgrade of material is necessary to completely eliminate corrosion. Compabloc™ exchangers can be fabricated in a range of corrosion resistant materials with 316L stainless steel plates as the lowest grade material.

Maintenance

Well-designed Compabloc™ exchangers generally prolong the operating periods between maintenance.

When maintenance and cleaning becomes necessary, one can use chemical cleaning-in-place (CIP) or mechanical cleaning. Chemical CIP is effective due to the small hold-up volume and turbulence induced by the corrugated channels.

If mechanical cleaning is required, the bolted frames allow access to both circuits for hydro-blasting of the channels up to 500 bar. It is worthy to note that the maximum plate length of the largest Compabloc™ model is less than 1.5 m (compared to over 6 metres for a conventional shell-and-tube unit). This means that the units do not require the use of special handling equipment in order to be extracted from the plant and can be extracted, cleaned and re-installed much quicker. In addition, the number of Compabloc™ exchangers is less than the number of shell and tube exchangers required for a specific thermal duty, particularly for heat recovery. Downtime for maintenance of Compabloc™ exchangers is thereby reduced compared to shell and tube exchangers.

Summary

The above comments are summarized in the Table presented at the end of this paper.

RESULTS AND DISCUSSION

Modelling of Chemical Reaction Fouling in Compabloc™ Exchangers

A number of users are now providing Alfa-Laval with data obtained from the monitoring of the performance of Compabloc™ units. The first data to be analysed comes from an exchanger positioned in the hottest section of a pre-heat train (the section following the pre-flash column). As in the test reported by De Castro et al (2008), the user looked at performance under turndown conditions as well as original design conditions.

Use of Ebert-Panchal Model

In this part of the train the fouling could be expected to follow a model developed for reaction fouling (see Polley et al, 2007). The Ebert-Panchal equation assumes that the overall fouling rate is made up of two terms: a deposition term and a suppression term. The deposition mechanism is viewed as a chemical reaction occurring in a “volume” associated with the thickness of the heat transfer boundary later and at a rate characterised by an Arrhenius Equation. The suppression term is simply considered to be a linear function of the shear stress. This model can be written as Eq. (1):

$$\frac{dR_d}{d\theta} = \frac{A}{\alpha}\exp\left(\frac{-E}{RT_f}\right) - \gamma\tau_w \qquad (1)$$

It is applied to the data obtained in tests below.

Unfortunately, information on the behaviour of neighbouring shell and tube exchangers was not provided. It was therefore not possible to determine the fouling parameters from historical monitoring data from the shell and tube exchangers. Consequently, a direct comparison between the two types of heat exchangers in the same plant could not be made.

Assumptions in Analysis

For the purposes of this study, typical parameters identified from analysis of a shell-and-tube exchanger on a similar duty (but on a different plant – and different feedstock) had to be used.

The behaviour of a single unit can be modelled exactly using a large combination of parameters. The values selected in Eq. 2 are based upon experience.

$$\frac{dR_d}{d\theta} = \frac{20}{\alpha}\exp\left(\frac{-42}{RT_f}\right) - (3e-09)\tau_w \qquad (2)$$

Comparison between measured and predicted fouling rates for the shell and tube is made in Fig. 1.

Compabloc™ data analysis

The values of the deposition constant, suppression constant and Activation Energy that are to be used in the fouling model are dependant upon the crude oil being processed and are generally obtained from analysis of monitoring data. As noted above, the data for the shell-and-tube exchangers used on this pre-heat train were not available. Consequently, the parameters could not be established. All we are able to do is compare the data obtained from monitoring the Complabloc™ exchanger with the predictions of equation 2.

We stress that the parameters that would have been obtained from analysis of the shell-and-tube exchangers could have been very different to the values used in equation 2. The benefit of the study is to demonstrate that the same “type” of model may apply. The predictions for the Compabloc™ are compared with plant measurements in Fig. 2.

The change in fouling behaviour after 12 000 hours arises from a deliberate step reduction in throughput. The data has to be interpreted as two separate sets rather than as a steady continuous development.

The time intervals between individual measurements are also large. So in applying the model it is assumed that the high flow conditions (termed period 1) were maintained throughout the first period of around eighteen months. After this time it is assumed that the flow through the unit was approximately halved and that this condition was maintained throughout the remaining period of monitoring.

A point model has been used in the comparisons. The reference condition has been assumed to be given by a wall condition computed from the mean hot and cold stream temperatures.

It has further been assumed that the temperature and flow conditions reported on a given date have applied up until the next report of performance.

The data for the “high flow” period are shown separately in Fig. 3. For the time period between 1660 hours and 2740 hours the flow conditions were such that the model predicts zero fouling. The plant data suggests that at the end of this period the fouling resistance had fallen.

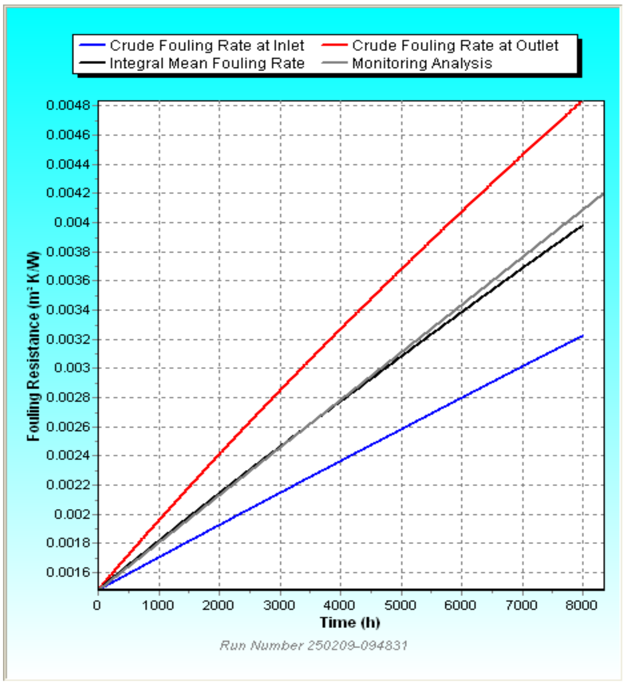

Fig. 1 Fouling in Shell-and-tube Unit

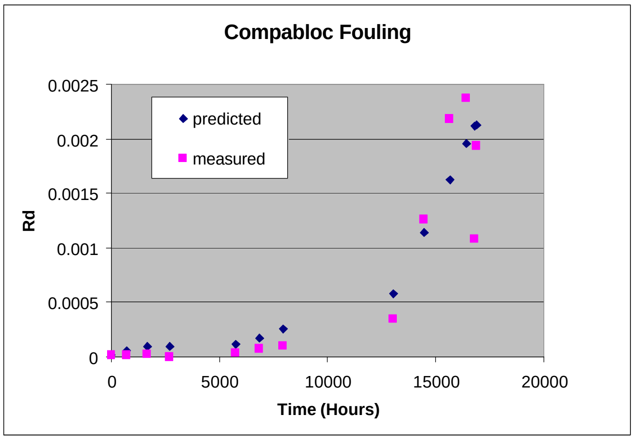

Fig. 2 Fouling in Compabloc Exchanger

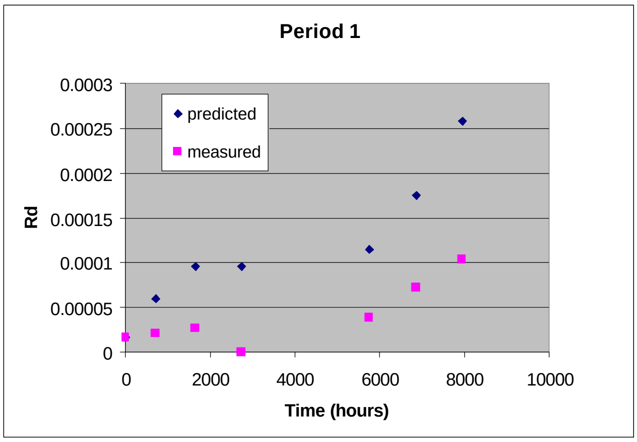

Fig. 3 Fouling in Period 1.

For the flow conditions present during the first operating period the clean overall heat transfer coefficient was around 2000 W/m^2 K. The fouling resistances were calculated using correlations for the clean film heat transfer coefficients with assumed properties for the crude oil and the hot process stream. In this situation an error in the calculation of the clean overall heat transfer coefficient can lead to significant error in the estimation of fouling resistance. A 10 % error in the estimation of the overall coefficient would result in an off-set of 0.00005 m^2 K/W in the fouling resistance.

The data for the period during which the flow was reduced are shown in Fig. 4. Here, given the approximate nature of the analysis the model appears to predict the fouling levels well.

The shell-and-tube heat exchanger operated at a velocity of 1.8 m/s (typical for such a unit). If we ignore roughness effects, the shear stress developed in the unit was around 6.5 Pa. The shear stresses reported for the Compabloc^{TM} units were around 90 Pa in the first period and around 20 Pa in the later experiments.

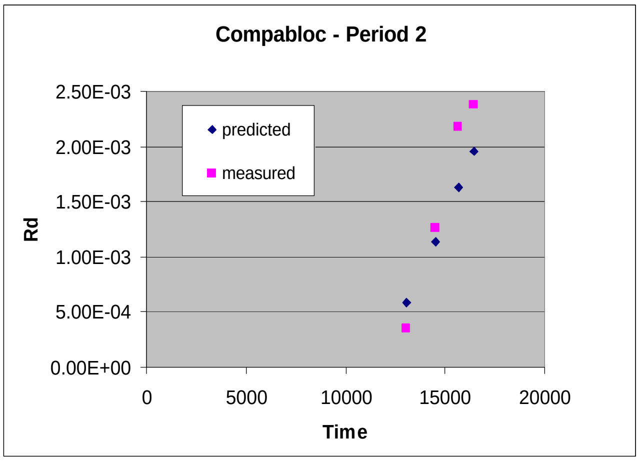

Fig. 4 Fouling during Period 2

These comparisons suggest that a model that applies to fouling inside tubes could be extended to fouling of an enhanced surface. If this proves to be the case, then it becomes possible to identify how a Compabloc^{TM} exchanger will foul using parameters derived from the monitoring of shell-and-tube exchangers. Analysis of data from other studies is currently underway.

CONCLUSION

1. Compabloc^{TM} exchangers have gained acceptance in the pre-heat train in many refineries worldwide, however, amount of performance data available for analysis is small in quantity. In no case is there data from shell-and-tube units and Compabloc^{TM} units operating on the same crude oil.

2. In this paper we have compared the performance of a Compabloc^{TM} exchanger with that of a shell-and-tube unit operating under similar temperature conditions. However, the units were at different refineries, operated by different companies and almost certainly processing different feed stocks. A fouling model was fitted to the data for the shell-and-tube unit. It was then applied to the Compabloc^{TM} unit. There was no iteration between the analysis of the two data sets.

3. The comparison between measurement and prediction was, given the quality of the data, reasonable. It gives rise to the possibility that fouling behaviour in Compabloc^{TM} exchangers follows the same pattern as fouling in shell-and-tube exchangers.

4. This hypothesis has to be verified by further data analysis of Compabloc^{TM} and shell and tube measurement operating on the same crude in the same refinery. We are in the process of obtaining these data.

5. If this proves to be the case it is a major step forward as it becomes possible to assess the likely behaviour of a Compabloc^{TM} exchanger from the analysis of fouling development in a shell-and-tube exchanger.

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NOMENCLATURE

A Deposition constant, 1/hr
E Activation energy, kJ / mol
R Gas Constant, 0.008314 kJ / mol K
R_d Fouling resistance, m^2 K / W
T_f Fluid Temperature, K
α Crude side film coefficient, W / m^2 K
γ Removal constant, m^2 K / W.hr. Pa
θ time, hr
τ_w Wall shear stress, Pa

Factor	Shell-and-tube	Compabloc
Area/Volume	7 - 9	60 - 70
Operational Shear Stress	Max. 20 Pa	> 100 Pa
Typical H.T.C. W/sq.m.K	Tubeside 2000 Shellside 800	Both sides 4000
Mechanical needs	none	Tightness of bolts to be checked on start-up.
Process Needs	none	In line filters during commissioning of new plant – cannot handle large solids
Maintenance	Large units require specialised handling equipment, relatively long extraction & restoration times, longer cleaning times	Low weight units having maximum length of 1.5 m. Quicker extraction & restoration. Faster cleaning.

Table 1. Comparison of Compabloc and Shell-and-Tube Units