Dynamic Data Analysis™ of Large Scale Data to Monitor Fouling in Heat Exchanger Networks

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Abstract

Data collected from heat exchangers networks in the field are typically used to monitor the thermal performance of the individual units. However, the information extracted from the data is limited in quantity and quality by the simplified models typically used in practice. Key decisions such as cleaning of heat exchangers rely on the calculation of derived quantities such as the fouling resistance which lumps together a number of factors contributing to fouling. This approach has been severely criticised in the past by various authors but it is still widely used in the industrial practice [1]. In this paper it is shown that a significantly larger amount of information and insights can be extracted from the same measurements by using rigorous models and a flexible framework. It is shown how this approach leads to a much deeper analysis of the status of the network which, in turn, helps with diagnosis and troubleshooting. An industrial case study is presented to illustrate the benefits.

Introduction

With the reduction in cost of sensors technology and IT infrastructure, the process industry is experiencing an unprecedented explosion in the amount of information being collected from each piece of equipment in each unit operation on every site. However, these data are often not exploited, particularly in the analysis of fouling in heat exchanger networks.

This paper presents an in-depth methodology that exploits existing measurements and data to monitor fouling in heat exchanger networks. The methodology, powered by Hexxcell Studio™, consists of a detailed dynamic analysis that uses historical plant data in conjunction with advanced mathematical models [2–4] to provide deep insight into the thermo-hydraulic and fouling behaviour of heat exchangers. By using this systematic analysis, it is possible to assess the quality of the measurement used, the thermo-hydraulic performance of individual heat exchangers and the entire network, the economic impact of fouling and the efficiency of cleaning actions. The analysis also allows identifying opportunities for improvement in the network (e.g. different flow split operation, cleaning strategy etc), diagnose causes of fouling and detect changes in behaviour (e.g. inorganic breakthrough) and assess the effectiveness of mitigation strategies implemented such as antifoulants, revamps etc. Combined with blending information, it is also possible to unveil key correlations between operating parameters, crude slates and fouling behaviour. An industrial case study illustrating the above benefits is presented.

Method

The dynamic analysis of the data (Dynamic Data Analysis™) is performed by using an advanced heat exchanger model [2, 3] whereby the evolution of the characteristics of the deposit is calculated directly from the plant data as a function of measured inlet conditions of temperature and flowrate, heat duty calculated from primary measurements and (where available) pressure drop measurements (a full example of this is provided in [6]). In the absence of the pressure drop measurements (which is a very typical situation in oil refineries), the deposit thickness can be calculated by fixing the deposit thermal-conductivity, allowing the calculation of hydraulic variables under reduced flow area conditions due to the presence of the layer: fluid velocity, shear stress, pressure drops, etc.

Case Study

The case study focuses on the hot end of the preheat train of a mid-size oil refinery, comprising of a total of five heat exchangers. The data analysis was performed on a set of plant measurements (temperatures, flowrates) for an operating period of ca. 1200 days.

Results

The analysis provides a comprehensive insights into the evolution of fouling, the performance of the exchanger, operating conditions and dimensionless numbers of interest on both tube and shell sides. Here, we focus on some of the most relevant findings for this case study.

First, the evolution of the fouling behaviour was obtained for the entire period in a seamless simulation. For the sake of comparison, the overall heat transfer fouling resistance for three of the units is shown in Figure 1. The analysis helped quantify the efficiency of intermediate cleaning actions carried out at the refinery. Cleaning actions are indicated in Figure 1 with labels M for mechanical and C for chemical and are shown as sudden drops in the fouling resistance. In this case the analysis also helped identify differences in fouling behaviour between various units. The three units in Figure 1 share very similar tube-side design and operating conditions. However, the fouling resistance in E04 is approximately twice that in E02AB and E05AB indicating a possible shell-side fouling build-up in E04 which does not affect other units [7].

By considering tube-side fouling in all units, and a 50/50% distribution of fouling between tube and shell sides in E04, the analysis provided the thermo-hydraulic evolution of the performance of the various units shown in Figure 2a. The thermo-hydraulic plot (TH plot) displays the ratio of the fouled-to-clean heat duty against the ratio of the fouled-to-clean tube-side pressure drop.

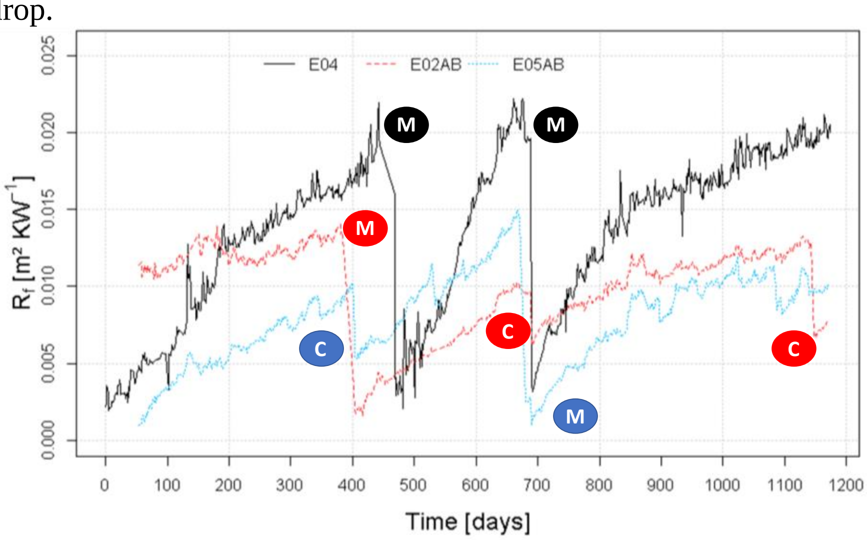
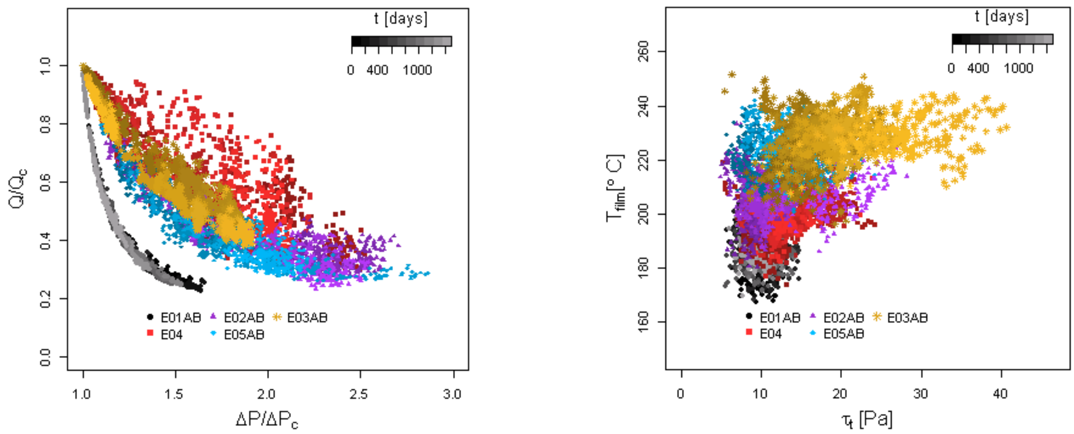


Figure 1. Total fouling resistance in E02AB, E04 and E05AB. M and C indicate mechanical and chemical cleaning, respectively (adapted from [7]).

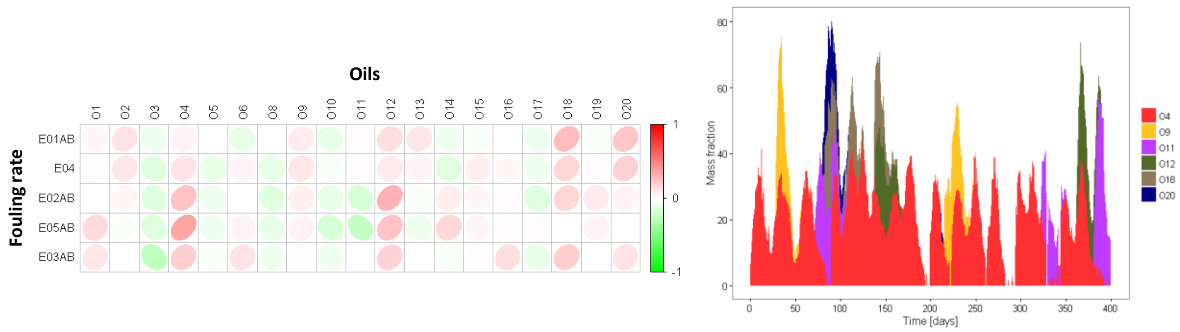


(a) (b)

Figure 2. Tube-side TH-plot (a) and tube-side film temperature against shear stress (b) under fouled conditions over a period of ca. 1200 days.

As fouling builds up, heat transfer gradually degrades and the cross-sectional flow area is restricted, which decreases the heat duty and increases the pressure drop. Simultaneously, the analysis provides the operating conditions at each point of the exchanger under fouled conditions. Figure 2b shows the tube-side film temperature against the tube-side shear stress. The figure shows that these conditions, which are typically used to characterize fouling behaviour, vary significantly during the operation. This variability is result of a combination of process variability and fouling build up. The latter can be visualized as the gradient from darker points (older in time) to paler points (latter in time). Figure 2 also shows that E04, with the fouling distribution selected, indeed operates under similar conditions and performance than E02AB and E05AB.

Finally, an extension of the method, the Fouling Propensity Analysis™, can be used to estimate fouling rates and find correlations between operating conditions and the concentration of the oils processed. This allows identifying oils that are particularly problematic with respect to fouling deposition or, conversely, oils that have a beneficial effect and help reducing the fouling resistance. Figure 3a shows the results of the correlation analysis between fouling rates and the mass fraction of the oils processed in the refinery. The information on oil composition has been modified to protect confidentiality without affecting the significance of the example presented.



(a) (b)

Figure 3. Result of correlation analysis between fouling rates and mass fraction of the oils processed (a) and processing history of oils identified as problematic (b). Information on oil composition has been modified to protect confidentiality without affecting the significance of the example presented.

Conclusions

An industrial case study has been presented in which Dynamic Data Analysis™ allowed studying the evolution of the fouling behaviour and its impact on the operating conditions inside the tubes (film temperature, shear stress) and the overall thermal and hydraulic performance of the exchangers. The analysis allowed identifying and quantifying the extent of cleaning actions and detecting the different fouling behaviour in one of the units, likely due to severe shell-side fouling. Finally, the fouling rates obtained were cross-correlated to information available on the crude oil slates processed. This permitted identifying oils particularly problematic towards fouling deposition.

References

[1] F. Coletti and G. F. Hewitt, Crude Oil Fouling: Deposit Characterization, Measurements, and Modeling. Boston: Gulf Professional Publishing, 2014.

[2] F. Coletti and S. Macchietto, "A Dynamic, Distributed Model of Shell-and-Tube Heat Exchangers Undergoing Crude Oil Fouling," *Ind. Eng. Chem. Res.*, vol. 50, no. 8, pp. 4515–4533, Apr. 2011.

[3] E. Diaz-Bejarano, F. Coletti, and S. Macchietto, "A new dynamic model of crude oil fouling deposits and its application to the simulation of fouling-cleaning cycles," *AIChE J.*, vol. 62, 1, pp. 90–107, 2016.

[4] E. Diaz-Bejarano, F. Coletti, and S. Macchietto, "Impact of Complex Layering Structures of Organic and Inorganic Foulants on the Thermohydraulic Performance of a Single Heat Exchanger Tube: A Simulation Study," *Ind. Eng. Chem. Res.*, vol. 55, no. 40, pp. 10718–10734, 2016.

[5] E. Diaz-Bejarano, F. Coletti, and S. Macchietto, "Thermo-Hydraulic Analysis of Refinery Heat Exchangers Undergoing Fouling," *AIChE J.*, vol. 63, no. 3, pp. 984–1001, 2017.

[6] E. Diaz-Bejarano, E. Behranvand, F. Coletti, M. R. Mozdianfard, and S. Macchietto, "Organic and Inorganic Fouling in Heat Exchangers – Industrial Case Study: Analysis of Fouling State," *Appl. Energy*, vol. 206, pp. 1250–1266, 2017.

[7] E. Diaz-bejarano, F. Coletti, and S. Macchietto, "Modeling and Prediction of Shell-Side Fouling in Shell-and-Tube Heat Exchangers," *Heat Transf. Eng.*, vol. Accepted f, no. https://doi.org/10.1080/01457632.2018.1446814, 2018.