# Improving Crude Oil Fouling Monitoring, Prediction and Mitigation Strategies in Refinery Preheat Trains

Emilio Diaz-Bejarano[1], Francesco Coletti[1,2*], and Sandro Macchietto[1,3]

[1]*Hexxcell Ltd., Innovation Hub, Imperial College - White City Campus, 80 Wood Lane, London W12 0BZ, UK.*

[2]*College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge, UB8 3PH, UK*

[3]*Department of Chemical Engineering, Imperial College London, London SW7 2AZ, UK*

* f.coletti@hexxcell.com

**Abstract**

Traditional heat exchanger monitoring methodologies rely on fouling resistance calculations that neglect the effects of fouling on pressure drops, and are not able to predict future performance as a function of process conditions, heat exchangers geometry and network configurations. In this paper, an improved approach to monitoring of fouling in refinery pre-heat trains that rely on rigorous predictive models is summarised and illustrated with an industrial case study.

## Introduction

Monitoring of crude oil pre-heat trains in atmospheric distillation units is key to ensure profitable and environmentally friendly refinery operations [1]. Traditional monitoring methodologies that rely on fouling resistance calculations neglect several key factors, including the effects of pressure drops, and are not able to predict future performance as a function of process conditions. As a result, maintenance and operating decisions are not data-driven and heavily relay on the operators' experience.

In this paper, an industrial case study is discussed that illustrate how advanced models implemented in Hexxcell Studio™, a comprehensive software framework integrates solutions for monitoring, design and retrofit analysis of heat exchangers and their networks, can be used to monitor operations, diagnose causes of fouling, and accurately predict future performance and lead to improved overall economics, environmental impact and safety.

## Method

Four analysis steps are applied in the case study:

1) *Dynamic Data Analysis™*: the evolution of the characteristics of the deposit is inferred directly from the plant data as a function of measured inlet conditions of temperature and flowrate, and heat duty calculated from primary measurements.
2) *Parameter estimation*: the fouling deposits grow over time as a function of local operating conditions according to deposition models. Unknown fouling parameters are estimated by fitting the models to and validating against extensive sets of plant data.
3) *Predictive cleaning scheduling and flow split control*: the predictive models in b) are used to produce improved cleaning schedules and flow split schemes by applying an algorithm with energy and economic based decision criteria.
4) *Dynamic Retrofit Test™*: an alternative retrofit design is proposed for one of the exchangers with the aim of reducing fouling and improving its performance. The retrofit is rated by "re-running history" with the new design and the fouling predictive models

obtained in b), which allows assessing the impact of the proposed geometry on fouling rates, the performance of the unit, and that of the network as a whole.

**Case Study**

The study focuses on the hot end of the preheat train of a refinery for which plant measurements (temperatures, flowrates) were available for ca. 1200 days of operation.

**1. Dynamic Data Analysis™**

The dynamic analysis is detailed analysis that uses historical plant data to provide deeper insight into the thermo-hydraulic and fouling behaviour of heat exchangers than previously possible. The analysis applied to the refinery considered allowed unveiling the time evolution of the fouling behaviour in each unit, the operating conditions inside the units in fouled conditions, the time evolution of their thermal and hydraulic performance and their relative contribution to the overall performance of the network. From the analysis, it was possible to obtain the following conclusions:

a) Mechanical and chemical cleanings were performed on recurrent basis at different frequency in different units. The efficiency of cleaning actions was estimated from the data and used later in the cleaning scheduling optimisation.
b) E01AB is the largest energy contributor to the network and was cleaned most often.
c) E04 showed a much larger fouling resistance despite having an almost identical design to other surrounding units. This was taken as indication of severe shell-side fouling.
d) Fouling severely impacts the performance of the units. The heat duty decreases down to 25% and the tube-side pressure drops increase up 250% due to the accumulation of deposits.
e) The two exchangers at the hottest end of the network, located in parallel branches, present significantly different fouling behaviour. The only difference is the higher shear in the unit with presenting lower fouling.

The reader is referred to another paper submitted to this conference for a more detailed discussion of the results [4].

**2. Parameter Estimation**

Once the fouling behaviour was analysed, the next step was the estimation and validation of fouling parameters to enable the prediction of tube and shell-side fouling. This step is essential to provide confidence in the accuracy of the predictions that will be used to optimise operations and test alternative designs.

The parameter estimation procedure used is detailed elsewhere [2], [3], [5]. Figure 1 shows an example of the fitting where data for a year of operations were used to fit the fouling model parameters. The remaining data, about 700 days, was predicted well within the measurement errors (±1.5% of the outlet temperature, as indicated by the green band in the figure).

**3. Predictive cleaning scheduling and flow split control**

The details of the simultaneous optimisation of cleaning scheduling and flow split control are provided in another paper submitted to this conference [6].

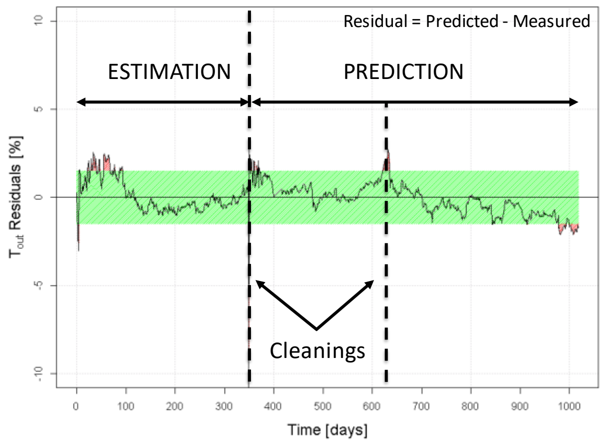



Figure 1. Model fitting and predictions for a exchangers in the network. The black line indicates the residual of the model simulation and green band indicates the uncertainty of the measurement.

The cleaning scheduling is performed by considering fixed and time-varying flow split control between the two parallel branches in the network. The results are compared to the actual cleaning schedule that was implemented in the refinery over the operating period considered. The results show that $2.7 MM savings could have been achieved compared to the cleaning schedule that was implemented in the refinery. Furthermore, the simultaneous consideration of cleaning scheduling and flow split control provides over 50% additional savings compared to the case where only the cleaning scheduling is optimised with a fixed flow split fraction.

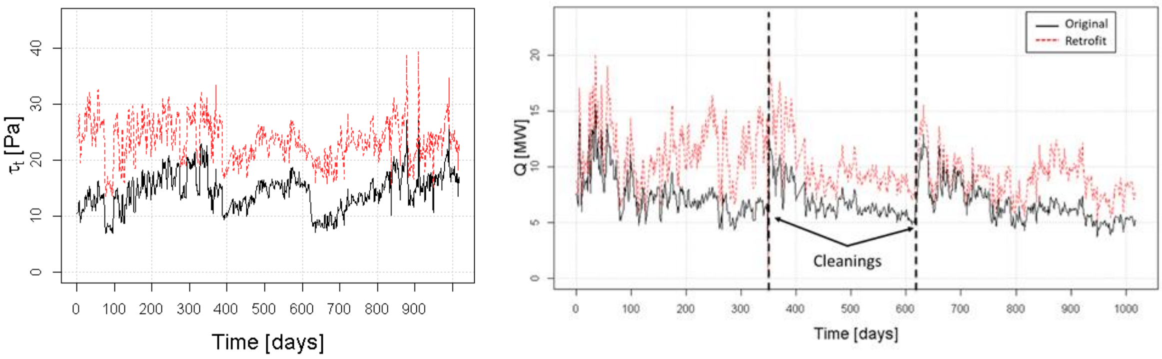
## 4. Dynamic Retrofit Test™

The steps above enabled deep understanding of the network behaviour and mitigating fouling from an operational point of view. However, it would also be desirable to assess he cost effectiveness of retrofitting selected units to mitigate fouling by design. The Dynamic Retrofit Test™ is a predictive approach to test performance of a proposed retrofit design using historical plant data. The method [9,10], allows assessing how a specific heat exchanger design would have performed if in operation over a given period. It allows identifying benefits in furnace savings as a result of reduced fouling in the retrofitted exchanger taking into account complex network interactions.using this method, a retrofit design was proposed for E05AB, located at the hottest extreme of one of the branches. This exchanger was chosen because: a) it was the second greatest contributor to heat recovery in clean or low-fouling conditions; b) it underwent severe fouling, which quickly decreased its heat duty and increased the tube-side pressure drop, heavily impacting the overall performance of the network; c) the equivalent exchanger in the other branch, designed for higher shear, was presenting significantly less fouling build-up (observed at Step 1), which indicated that a high shear design on E05AB could be indeed beneficial.

A re-design moving from 4 tube passes to 2 tube passes with smaller diameter was selected for testing with Dynamic Retrofit Test™. History was re-run with the new design for the same operating period in Figure 1. Figure 2a shows the comparison of the shear stress with the proposed design (red, dashed line) and the original design (black, continuous line). The new geometry significantly increases the shear stress under clean conditions, which decreases the rate of deposition. The consequence is greater heat recovery for most of the operation period, as shown in Figure 2b. The simulations are performed for the entire, interconnected network of exchangers, allowing the assessment of the impact of the retrofit on the inlet temperature to the furnace (CIT) and, consequently, of the fuel and energy savings achieved. On average, the proposed retrofit increases the heat recovery in the exchanger by 3 MW, leading to 1.6 MW increase in the overall heat recovery of the network which translate in a CIT increase of 3.5ºC. Economic savings are estimated in excess of $0.8 MM/yr.

## Conclusions

This paper has shown, through a comprehensive industrial case study, how advanced models implemented in Hexxcell Studio™ can be used to monitor fouling, performance an operating conditions in fouling, fit deposition models and accurately predict future performance, and lead to improved maintenance activities, operations and retrofits with substantial economic benefits and reduced environmental impact.




(a) (b)

Figure 2: Comparison of original design (continuous black line) and proposed retrofit design (dashed red line): a) tube-side shear stress in fouled conditions; b) heat duty.

## References


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

[2] 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.

[3] 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.

[4] F. Coletti, E. Diaz-Bejarano, and S. Macchietto, "137c: Dynamic Data Analysis of Large Scale Data to Monitor Fouling in Heat Exchanger Networks," in *2018 Spring Meeting and 14th Global Congress on Process Safety, Orlando, April 22-26, 2018*, p. Tuesday, April 24, 2018 043:30 PM-05:00 PM.

[5] 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.

[6] F. Coletti, F. Lozano, E. Diaz-Bejarano, and S. Macchietto, "148a: Optimization of Refinery Preheat Trains: Predictive Maintenance and Operations Improvement," in *2018 Spring Meeting and 14th Global Congress on Process Safety, Orlando, April 22-26, 2018*, p. 2018 Spring Meeting and 14th Global Congress on Pr.

[7] 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, no. 1, pp. 90–107, 2016.

[8] 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.

[9] F. Coletti. On the combined use of dynamic simulations and plant data to account for fouling in heat exchanger design. 2nd Thermal and Fluids Engineering Conference (TFEC), Las Vegas, NV, 2-5 April, 2017,.

[10] E. Diaz-Bejarano, M. Yugo Santos, Manolo García Dopico, L. Lanchas-Fuentes and F. Coletti. "The impact of fouling on the optimal design of a heat exchanger network: an industrial case study". Heat Exchanger Fouling and Cleaning, 11-16 June 2017, Madrid, Spain, 2017.