Identifying the Causes of Acute Fouling in Refinery Preheat Train

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Abstract

Crude oil fouling is typically treated in the literature as a phenomenon involving the deposition of organic material on the thermal surfaces of heat exchangers. Little attention is paid to the effects that inorganic species have on the thermal and hydraulic performance of the heat exchangers affected. When deposition of inorganic species occurs, it is often the cause of an upset in operations (e.g. issues with the desalter) that results in episodes of rapid (acute) fouling. In this paper, a method used to detect acute fouling episodes and identifying their causes is presented.

Introduction

Fouling deposition on heat transfer surfaces is a costly, long-standing problem particularly severe in pre-heat trains of crude distillation units [1]. Experimental analysis of fouling deposits collected upon dismantling such heat exchangers shows that both organic and inorganic species are typically present. These vary in proportion depending on the crude slates processed, refinery operating conditions, heat exchanger metallurgy and dominant fouling mechanisms. It has also been shown that the heat transfer given by fouling depends on the amount of the inorganic and organic phases, their structural arrangement and stratification or layering.

This paper presents a novel advanced mathematical model, implemented in Hexxcell Studio™, capable of describing the fouling deposit layer as a multi-component structure [2]–[4]. It is then shown how this approach is promising to detect acute fouling episodes and provide guidance on possible causes related to the composition of the deposit.

Method

Plant measurements are analysed using Dynamic Data Analysis™. This methodology uses an advanced solution mode of the shell-and-tube heat exchanger model implemented in Hexxcell Studio™ [5] to calculate the properties of the deposits over time as a function of inlet conditions of temperature and flowrate, heat duty and pressure drop. This allows estimating the tube-side deposit thickness and *apparent* thermal-conductivity over time (if shell-side fouling is negligible). The apparent thermal-conductivity is defined as the average value of the thermal conductivity of a homogeneous deposit that explains the overall thermal behaviour of the exchanger. The apparent thermal-conductivity is equal to the local conductivity of the deposit only if it remains constant over time, as this implies that the material that is depositing is of the same type and its properties do not change once it is settled. In reality, however, deposits are heterogeneous structures, with sub-layers that reflect variations in the deposition history (changes in type of foulant, temperature history, etc.). A heterogeneous deposit can be

detected if the apparent thermal-conductivity varies over time. The pattern observed in the time-varying signal can be used to establish the underlying causes.

Case Study

The case study focuses on a double-shell heat exchanger located downstream of the desalter in a pre-heat train of a middle-eastern refinery. The full details of the case study are provided in [6]. Temperatures, flowrates and tube pressure drop data were available for a period of over three years in-between shutdown. The compositional analysis of the deposits, collected at the end of the run, were also available.

Results

The plant data analysis allowed calculating the time-profiles of deposit thickness and apparent conductivity, shown in Figure 1 and Figure 2, respectively. The deposit thickness profile showed a falling rate shape, with an evident acute deposition episode at around 150 days. The thickness at the end of the period was of ca. 2.75 mm.

The apparent conductivity showed variations over time, indicating the presence of a heterogeneous deposit layer. The trend shows an increase during the initial 175 days, followed by a gradual, although non-monotonic, decrease until the end of the operation period. In order to explain such behaviour, the deposition processed was postulated to follow this sequence of events: i) deposition of fouling of deposits with intermediate conductivity until the acute episode; ii) fast deposition of high conductive material during the acute episode; iii) after then, slow deposition of material with low thermal conductivity, with some occasional deposition of high conductive material.

In this context, taking into account the location of the exchanger and operating conditions (just downstream of desalter, temperature < 180ºC), low and high conductive deposit can be associated to deposition dominated by organic and inorganic materials, respectively. An intermediate conductivity could be due to the two types of foulant depositing in similar proportions.
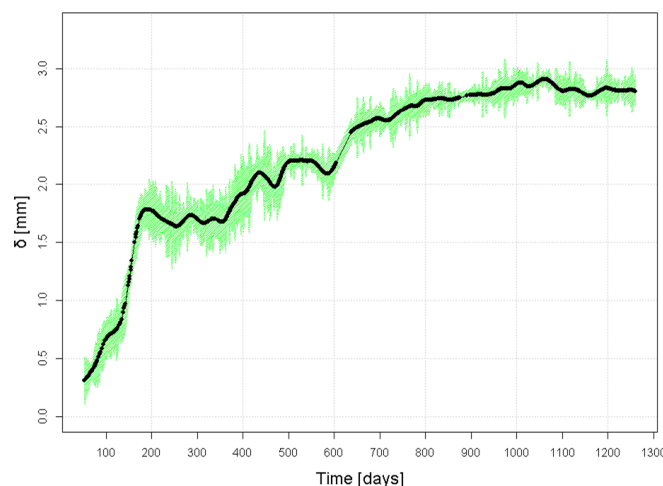

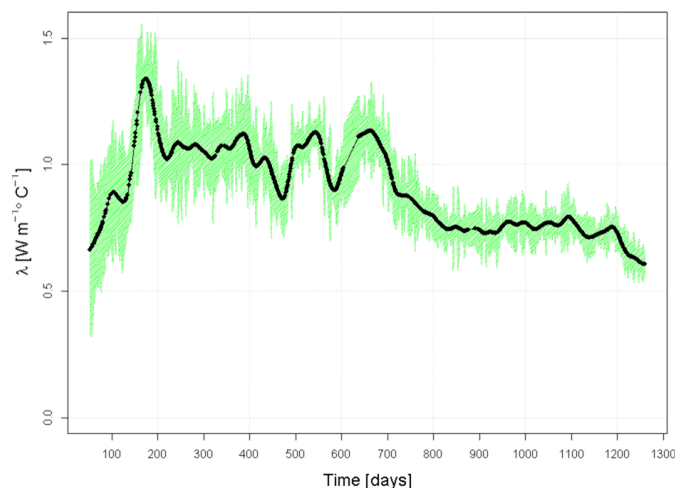Figure 1. Deposit thickness over time (adapted from [6])

Figure 2. Apparent thermal-conductivity over time (adapted from [6])

An initial verification of this theory was performed by comparing the data analysis results to the experimental analysis of the deposits collected in the refinery. First, the apparent conductivity and thickness were used to estimate the average composition of the deposit by applying the multi-component deposit model in [3] and assuming inorganic and organic to behave as two separate phases composing the deposit. By using a Co-continuous model to describe the deposit as a heterogeneous solid, an average inorganic content of $58_{wt}\%$ was estimated. This result was in excellent agreement with the inorganic content found in the deposits, $52_{wt}\%$.

Conclusions

The Dynamic Data Analysis™ of a refinery heat exchanger allowed calculating the time-evolution of the thermal-conductivity and thickness of the tube-side deposit. This was possible thanks to the availability of pressure drop measurements, in addition to the usual temperatures and flowrates. The analysis helped detect an acute deposition episode in the thickness time profile. The trends observed in the apparent thermal-conductivity indicated that such acute episode was likely due to the fast deposition of inorganic materials, which could be linked somehow to inefficiencies in the operation of the desalter. This interpretation of the results has been supported by comparison with experimental analysis of the deposits.

References
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