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Analysis of the influence of operating conditions on fouling rates in fired heaters

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HIGHLIGHTS

- Local fouling rates using thermo-hydraulic parameters are evaluated in a fired heater.
- The effect of throughput, excess air and inlet temperature upon fouling rate is analyzed along the crude path.
- Performance of the fired heater for specific conditions is presented showing overall operation data.
- Film temperature and wall shear stress plots as parameters dictating the deposition and removal rates are presented.
- Steam injection is an effective strategy to mitigate fouling especially at location prone to severe fouling.

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ABSTRACT

Fouling due to chemical reaction in preheat trains for the processing of crude oil plays a key role in the operation and maintenance costs and on greenhouse emissions to atmosphere in crude processing plants. A preheat train consists of a set of heat transfer units that provide the crude oil stream the required amount of thermal energy to reach its target temperature either by heat recovery or by direct firing. Fired heaters supply external high temperature heating through the burning of fuel which result in complex heat transfer processes due to the large temperature and pressure changes and vaporization that takes place inside the unit. In this work, a thermo-hydraulic analysis of the performance of fired heaters is carried out through the application of commercial software to solve the mathematical models using finite difference methods; the analysis is applied to the crude side of a vertical fired heater in order to evaluate the impact of process conditions such as throughput and crude inlet temperature (CIT) on the fouling that take place at the early stages of operation. Using a fouling rate model based on thermo-hydraulic parameters, fouling rates are predicted assuming steady state operation and clean conditions. Although variations in process conditions are known to influence fouling rates, little work has been done on the subject. In this work excess air and steam injection are studied as a means to mitigate fouling. Results show that throughput reduction brings about a marked increase in the fouling rates. A decrease in CIT affects only the convection zone and it is found that this effect is negligible. In terms of excess air, it is found that although it affects negatively the heater efficiency it can be used to balance heat transfer between the convection and radiation zone in a way that fouling rates are reduced; however this strategy should be considered right from the design stage. Finally it is observed that steam injection is an effective method to reduce fouling rates since it results in lower film temperatures and larger shear stress.

1. Introduction

Chemical reaction fouling [1] is likely to occur in heat exchangers located in the hottest section of a crude oil preheat train between the desalter and the distillation column. These heat exchangers are mainly of the shell and tube type, whereas the final piece of equipment responsible for providing the last amount of heat for the crude to reach its target temperature is a fired heater. It is well known that during operation fouling introduces additional thermal and hydraulic resistances which lead to additional fuel and pump power consumption, resulting in additional greenhouse emissions to atmosphere and reduced throughput [2] incurring in

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economic losses. Coletti and Macchietto [3] summarize economic penalties associated with fouling in a refinery processing 100,000 bbl day^{-1}.

Heat exchangers in general are designed using an empirical fouling resistance to account for fouling; typical values can be found in TEMA [4]. Unfortunately, those values do not reflect the real exchanger performance. Recent approaches propose the determination of fouling resistance from observed fouling rates to be used at the design stages [5,6]. Most fouling rate models for chemical reaction fouling [7–9], are a variation of the model introduced by Ebert and Panchal [10] where the phenomenon is described as a competing mechanism between a deposition and removal rate. The key process variables controlling the deposition and removal rate are: film temperature and fluid velocity. It is therefore expected that variations in process conditions will have a significant impact on fouling rates. The effect of variations in the operating conditions in a fired heater are more significant than in a heat exchanger located in the train due to the large change in bulk temperature and pressure. The liquid single phase at the entrance becomes a two-phase flow as it moves along the heater which brings about significant velocity and physical properties changes. Depending on the type of crude, its temperature is increased in a range from 250 °C to 350 °C in an atmospheric furnace and between 320 °C and 420 °C in a vacuum residue furnace.

A fired heater consists of a refractory lined chamber called the *radiant section* where combustion takes place with tubes conducting the crude oil adjacent to the walls. It is followed by a bank of tubes where the first and second rows exposed to the radiant section (shock tubes) are bare tubes. Located above the radiant section is the *convection section* where heat transfer in the tubes is maximized by the use of circular fins or studs. The final section is the stack which is equipped with a damper to regulate the flue gas flow rate. A large number of possible configurations in fired heaters exist as presented by Berman [11]. Fig. 1 shows a vertical fired heater consisting of a single cylindrical firebox with tubes in a vertical array followed by a convective section with horizontal tubes at the top.

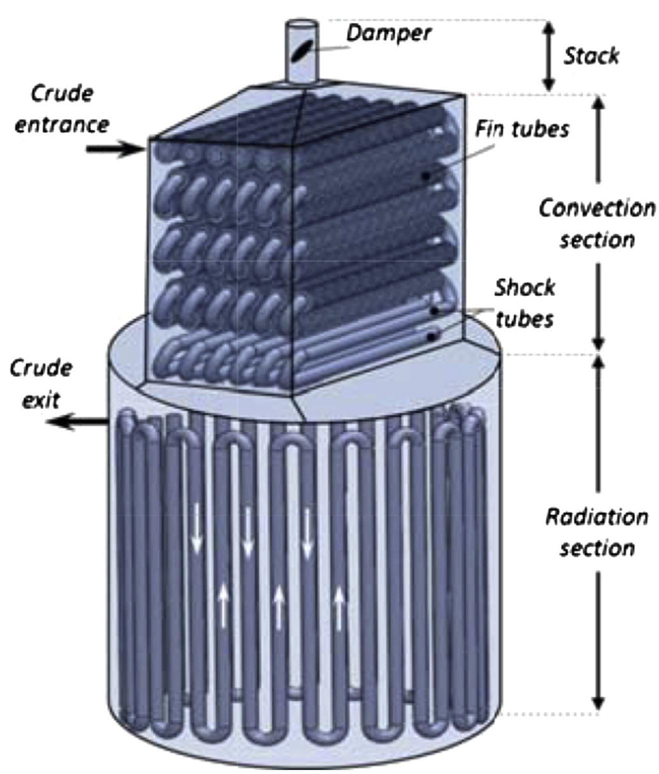

Fig. 1. Vertical fired heater with a cylindrical radiant chamber.

During operation throughput and crude inlet temperature (CIT) variations arise due to multiple circumstances, for instance due to degradation of the operating conditions and due to changing market demands. Low demand periods lead to low production while increased demand push the plant to top capacity. When throughput is increased additional fuel is burnt to compensate for the additional heat demand; the same applies in the case of reduced CIT. Both situations affect the local thermo-hydraulic conditions which has an influence upon the development of fouling.

The use of excess air and steam injection in fired heaters can be seen as a strategy to fouling mitigation. The percentage of excess air used in fired heaters depends on the type of fuel that is employed. It is a good operating practice to supply 10–15% excess air for gas fuels and 20–30% for liquid fuels. The value is adjusted in situ from measurements of oxygen at the flue gas exit. If a larger amount of excess air is used, the heater efficiency decreases and the flue gas temperature decreases leading to lower wall and film temperature, resulting in a reduction in fouling rates. The potential reduction on fouling rates using additional excess air might be worth analyzing.

Jegla et al. [12] summarize the main design and operating parameters that have an effect upon the heat flux absorbed by the tube coils in the radiant section which in turn have an impact on fouling. Among these design parameters are: tube size, furnace geometry and burner type. In terms of operating conditions the most important are: crude oil velocity, flow regime, crude type, combustion conditions and fluid temperature. In their study they also point out that heat flux imbalances originated from situations such as the location of the tubes and the number of passes in the radiant chamber leads to high tube metal temperatures and coke formation. Though those parameters are fully identified, the effect of fluctuating operating conditions such as throughput and bulk temperature on the local thermo-hydraulic conditions and its consequence on fouling rates has not been determined yet.

Steam injection is a common practice in systems processing heavier fractions of crude oil. In vacuum heaters steam is injected at the shock or radiant tubes where higher wall temperature occurs. Steam accelerates the crude stream reducing the residence time which results in less coke formation [13]. In thermal cracking processes steam is added to decrease the partial pressure of hydrocarbons and to minimize the formation of coke [14]. The steam used in atmospheric fired heaters is withdrawn in the overhead condenser of the distillation column; therefore lower amounts of steam are preferred to avoid additional cooling load in the condenser and the need for a further vacuum drying process. The use of steam brings about corrosion issues in the fired heater due to the presence of sulfides and chlorides in the crude; however, in practice they are neutralized with ammonia in the distillation column. Little information is available in the open literature related to steam injection in fired heaters.

The objective of this study is to evaluate the effect of fluctuating process conditions such as throughput and crude inlet temperature on fouling rates at an early stage of operation along the fired heater. An assessment of coke thickness and heater performance with time has been presented somewhere else [15]. Two strategies for fouling mitigation are studied: excess air and steam injection. Thermo-hydraulic simulation is carried out using commercial software [16]. A fouling rate model is then applied to determine the local fouling condition. It is observed that fouling rate under reduced throughput is considerably increased. A reduction in the crude inlet temperature increases fouling rates mainly in the convection section. Excess air increases film temperatures and fouling rate in the