Experimental Study of Oil Deposition Using a Deposition Simulator (HLPS - Hot Liquid Process Simulator)

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Fouling in heat exchangers is a recurring and costly problem for oil refineries. However, the phenomenon is complex and requires experimental evaluation, as oils have varied compositions. In the present study, analyzes were performed in the laboratory using a deposition simulator (HLPS - Hot Liquid Process Simulator). We performed the test with a sample of crude oil. In this test, the deposition was small, which could occur due to the characteristic of the oil.
Keywords: Oil. Heat Exchanger. Fouling. HLPS.

Introduction

Fuels are still the main responsible for the world's energy Generation, and with the advancement and growth of industry and commerce, there is more and more demand for energy. This need for energy, and therefore derivatives, makes it necessary to increase their production. For this, it is necessary to refine more and more oil and, consequently, the unit operations involved, including the transfer of heat in exchangers. An important phenomenon in the operation of heat exchangers is fouling. The deposition of solid material on the surface of the equipment presented fouling. This deposition can occur as a result of the phase change that arises from temperature differences between the surface and the fluid (deposition by crystallization), by chemical reactions on surfaces (deposition by chemical reaction), or even the growth of organisms on the surface (biodeposition). It is an essential phenomenon because the deposited solid material can restrict the cross-sectional area for fluid flow, causing an increase in pressure drop. In addition, this material acts as a resistance to heat transfer, thus limiting heat recovery and increasing energy and cleaning costs [1]. Fouling rates are complex functions of oil composition, temperature, velocity, and particle content [2], simulation, and evaluate the deposition in heat exchangers.

We built mathematical models with researched information that associate the existing conditions and the deposit rate in oil streams. The performance of a comparative analysis of the prediction performance of models against deposition data sets, plus laboratory availability for experiments, was crucial for the selection of the concept for simulation in HLPS.

Materials and Methods

Relating the properties of crude oil and diesel with the conditions provided by the HLPS apparatus, we based the experimental planning

Figure 1. HLPS equipment.

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on variables: flow, time, and tube temperature; aiming to develop methods of indicating the period of maintenance of the process in function of the incrustation created by the deposit. The technique used to assess the influence of some conditions on a given event allows us to define which quantity and conditions of specific parameters can satisfy two significant objectives: the most significant possible statistical precision in the response and the lowest cost. Table 1 shows the conditions used in the tests carried out with diesel and crude oil.

Experimental

The oil is in the supply and agitation reservoir, with the fluid pumped to the tube-in-shell heat exchanger, a single-pass heated, annular section electric heating resistance system. The fluid is destined for a receiving reservoir similar to the inlet. The parts that make up the heat exchanger and the equipment supply lines must be sealed according to their inputs, such as o-ring, washers, grease, and other connections (Figures 2 and 3). Leakage tests were conducted under atmospheric pressure of 10 bar with Nitrogen gas.

To start the experiment, we adjusted the parameters in the programmable logic controller (PLC) according to the experimental planning (Table 1).

We monitored the experiment's performance on the control panel screen for data collection and analysis for the mathematical modeling of deposition (Rf) (Figure 4).

We removed the "hot finger" to investigate the oil deposit through the difference in weight before and after the experiment. The HLPS equipment uses an annular test section with a heated 60 mm length calibrated at 38 mm for the deposition

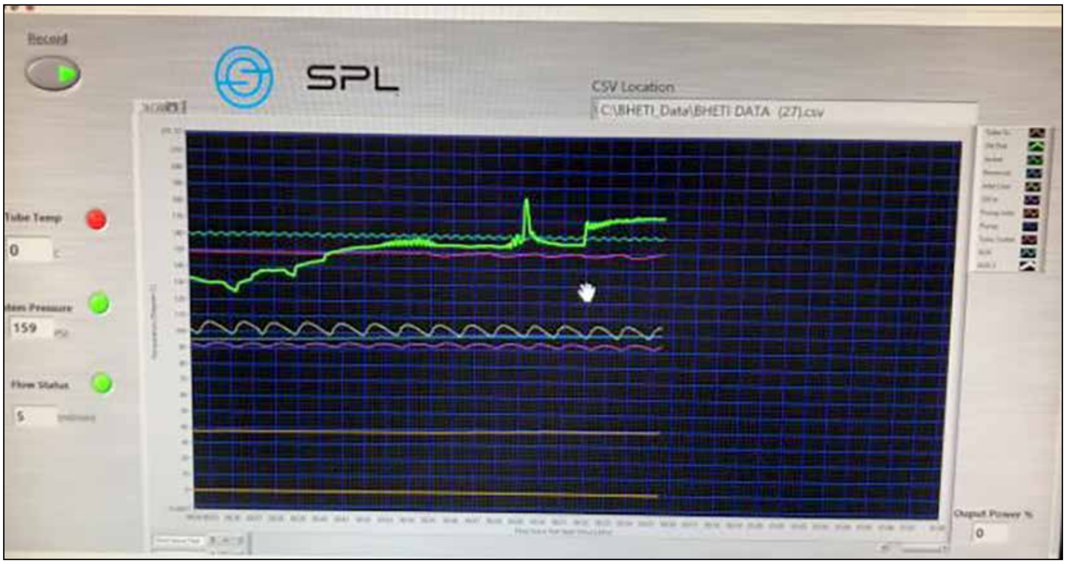
Figure 2. Adding oil to the reservoir.

Figure 3. Programmable Logic Controller (PLC).

Table 1. Crude oil deposition test conditions in HLPS.

Test	Twall (ºC)	Flow (mL/min)	Time (h)	T_{inlet} (ºC)	T_{bulk} (ºC)	T_{oulet} (ºC)	$P_{average}$ (bar)
PC	292.74	18	1.39	150.41	182.09	213.78	11.93

Figure 4. Control panel.



phenomenon. Figure 5 shows the deposition of heated oil in the annular section.

Figure 5. The hot fluid reservoir region.

For new tests, the equipment and lines are disconnected and washed with heptane, toluene, or hexane solvent in a hood with an exhaust.

Results and Discussion

We did the calculations considering the deposition in the hull and the tube. The literature demonstrates several studies of predictive models. Nevertheless, we based our study on some models. The outlet temperature is higher than the inlet temperature, considering the tube temperature in the condition calibrated for testing. We based the experimental Rf calculations on the work by Trafczynsk and colleagues [3] (Equations 1-6).

Uf and other physical properties were calculated with flow and temperature values measured by the control panel every second. In the mathematical model by Yeap and colleagues

Equations 1-6.

$$U_c = \frac{Q_t}{A\Delta T_{lm}} = \frac{mC_p\Delta T}{Af_t\Delta T_{lm}} \quad (1)$$

Tempo (>0)

$$U_f = \frac{Q_t}{A\Delta T_{lm}} = \frac{mC_p\Delta T}{Af_t\Delta T_{lm}} \quad (2)$$

$$\Delta T_{lm} = \frac{(TF_S - TF_E)}{ln(TF_S - TF_E)} \quad (3)$$

$$R_f = \frac{1}{U_f} - \frac{1}{U_c} \quad (4)$$

$$f_t = 0{,}014 + \frac{1{,}056}{Re_t^{0{,}42}} \quad (5)$$

$$Re = \frac{Du\rho}{\mu} \quad (6)$$

[4], the physical properties are determined by the proposed correlation (Equations 7-12), where the bulk and wall temperatures are considered. Therefore, the Uf calculation used the average temperature and Q [4].

Figure 6 presents the results of the thermal behavior of the input, output, wall, and tube heating power obtained.Figure 7 shows the calculated Rf values.

The results show the linear and continuous behavior of the exit and deposition temperatures, confirming the non-deposition in the tested conditions. Data close to 1,000 seconds and 2,000 seconds represent a cooling of the equipment, which means unforeseen programming of the controllers. However, this has already been identified and corrected by the team. The critical point in this work is calculating the Rf and evaluating the deposition. As the equipment allows fine and low flow control, it is possible to carry out tests in hours representing months in the refinery. Thus, the next step is to conduct an

Equations 7-12.

$$\rho = 1234{,}18 - 5{,}46API - 0{,}300T_b - 0{,}367T_p \quad (7)$$

$$\lambda = 0{,}1314 + 0{,}000727API - 0{,}0000321T_b - 0{,}0000392T_p \quad (8)$$

$$C_p = 342{,}57 + 11{,}273API + 1{,}82T_b + 2{,}227T_p \quad (9)$$

$$log_{10}^{\vartheta} = \frac{b_{A6}}{\left(1+\left(\left(0{,}45T_b+0{,}55T_p\right)-310{,}93\right)/310{,}93\right)^{b_{A7}}-0{,}8696} \quad (10)$$

$$b_{A6} = log_{10}\vartheta_{37{,}78ºC} + 0{,}8696 \quad (11)$$

$$b_{A7} = 0{,}28008b_{A6} + 1{,}6180 \quad (12)$$

Figure 6 . Thermal behavior of the HLPS simulation (crude oil, T wall = 292.74ºC and pressure = 11.93 bar).

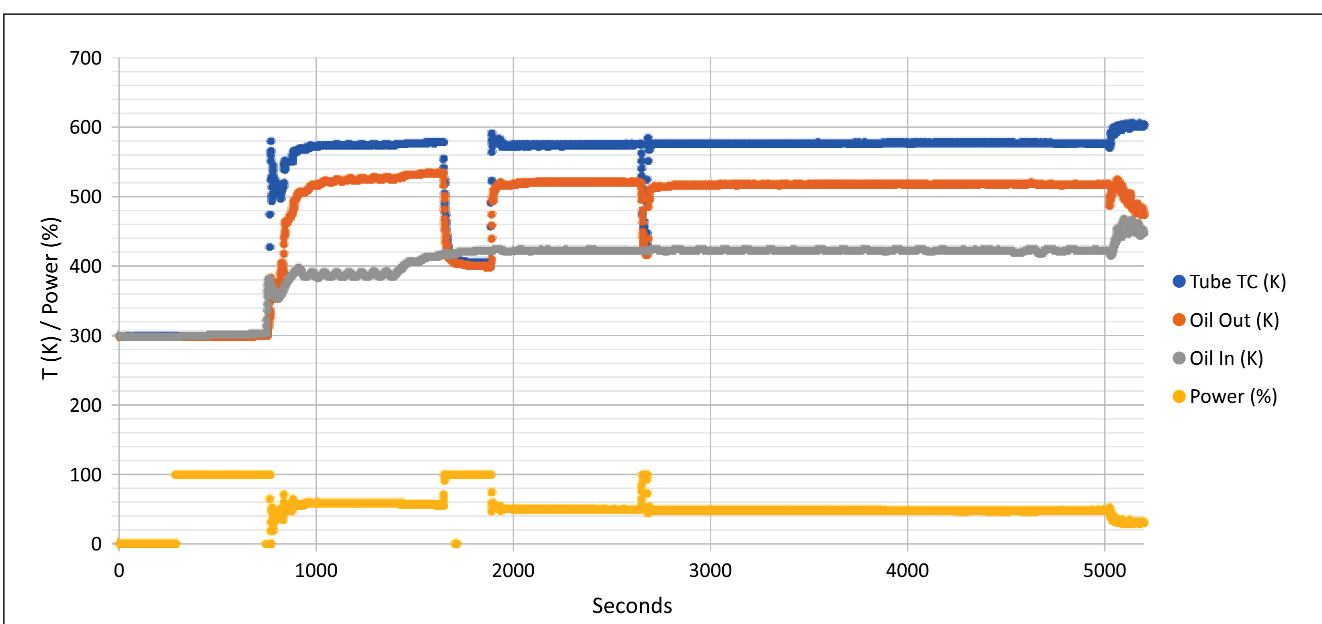
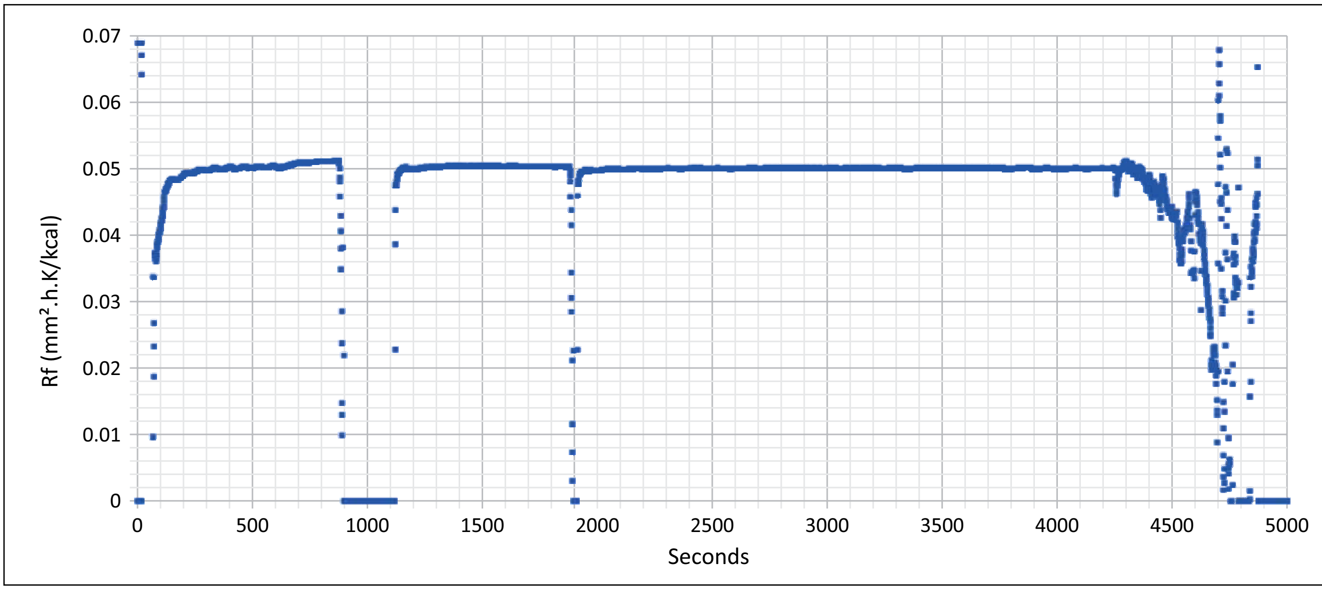


Figure 7. Behavior of the Rf measured experimentally (crude oil, 292.74ºC Twall, and 11.93 bar pressure).



exploratory study with the essential parameters and obtain a better understanding of the phenomenon.

Conclusion

The study evaluated the experiment's method concerning threshold models in predicting deposition in heat exchangers. The data shows that the need for the equipment is measured successfully. However, tests in other conditions or with denser samples are necessary to obtain deposition data. In addition, it is necessary to evaluate the influence of correlations, which consider fluid conditions, such as temperature and density, on the accuracy of the data. Thus, the need for improvements and sequencing in the study is clear, seeking a greater understanding of the deposition behavior of this oil.

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