EXPERIMENTAL STUDY OF OIL DEPOSITION USING A DEPOSITION SIMULATOR (HLPS - HOT LIQUID PROCESS SIMULATOR)

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Abstract: 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 a varied composition. In the present study, analyzes were performed in the laboratory using a deposition simulator (HLPS - Hot Liquid Process Simulator), the test was carried out 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.

Resumo: Deposição em trocadores de calor é um problema recorrente e custoso para as refinarias de petróleo. Porém, o fenômeno é complexo e demanda avaliação experimental, pois os óleos tem composição variada. No presente estudo foram realizadas análises em laboratório utilizando um simulador de deposição (HLPS - *Hot Liquid Process Simulator)*, o teste foi feito com uma amostra de petróleo cru. Neste teste a deposição foi pequena, o que poderia ocorrer devido a característica do óleo.

Palavras-chave: petróleo; trocador de calor; deposição; HLPS.

1. 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.

Fouling is manifested by the deposition of solid material on the surface of equipment. 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), or by chemical reactions on surfaces (deposition by chemical reaction), or even the growth of organisms on the surface (bio deposition). It is an important phenomenon because the deposited solid material can restrict the cross-sectional area for fluid flow, causing an increase in pressure drop. 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.

Figure 1. HLPS equipment

With researched information, approaches were obtained for the construction of mathematical models 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.

2. METODOLOGY

Relating the properties of crude oil and diesel with the conditions provided by the HLPS apparatus, the experimental planning was based 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 certain parameters can satisfy two major objectives: the greatest possible statistical precision in the response and the lowest cost. Table 1 below shows the conditions used in the tests carried out with diesel and crude oil.

Table 1 - Crude oil deposition test conditions in HLPS

Test	T_{wall} (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

2.1 Experimental

The oil is contained in the supply and agitation reservoir which has the fluid pumped to the tube-in-shell heat exchanger which is heated by a single-pass, 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 respective inputs such as o-ring, washers, grease and their other connections. Leakage tests were conducted under conditions of atmospheric pressure of 10 bar with Nitrogen gas.

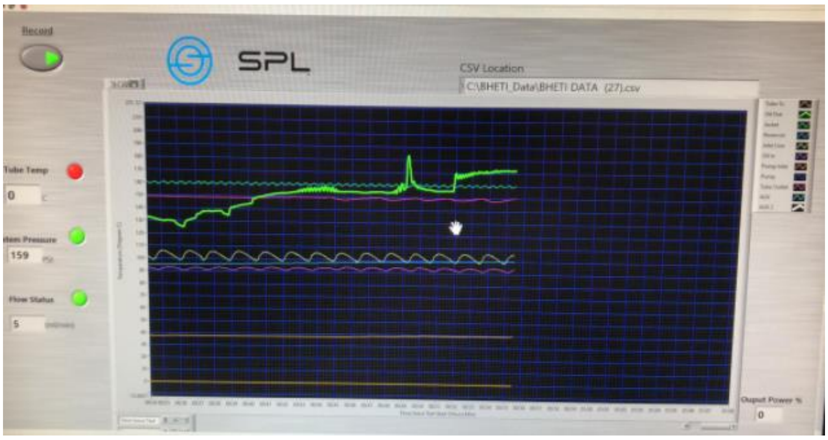
To start the experiment, the parameters are adjusted in the programmable logic controller (PLC) according to the experimental planning in table 1.

The performance of the experiment is monitored on the control panel screen for data collection and analysis for the mathematical modeling of deposition (Rf) which will be explained in the next topic.

Figure 2. Adding oil to the reservoir

Figure 3. Programmable Logic Controller (PLC)

Figure 4. Control panel



After the period under conditions determined in the planning, the “hot finger” is removed to investigate the oil deposit through the difference in weight (before and after the experiment). To occur the deposition phenomenon, the HLPS equipment uses an annular test section with a heated 60 mm length that has been calibrated at 38 mm. Figure 4 shows the deposition of heated oil in the annular section:

Figure 4. 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.

3. RESULTS AND DISCUSSIONS

The calculations performed were made considering the deposition in the hull and in the tube. The literature demonstrates several studies of predictive models, however, this work was based on some models. Considering the temperature of the tube in the condition calibrated for testing, its outlet temperature is higher than its inlet temperature. The experimental Rf calculations were based on the work of Trafczynsk et al. [3] and are performed according to equations 1 to 6.

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

Tempo (>0)

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

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

$$R_f = \frac{1}{U_f} - \frac{1}{U_c} \tag{4}$$

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

$$Re = \frac{Du\rho}{\mu} \tag{6}$$

Uf and other physical properties were calculated with flow and temperature values measured by the control panel every second.

The mathematical model adopted by Yeap et al. [4] the physical properties are determined by the proposed correlation shown in equations 7 to 12, where the bulk and wall temperatures are considered. Therefore, the Uf calculation used the average temperature and Q [4]:

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

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

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

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

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

$$b_{A7} = 0{,}28008b_{A6} + 1{,}6180 \tag{12}$$

The results of the thermal behavior of the input, output, wall and tube heating power obtained are shown in figure 5. The calculated Rf values are shown in figure 6.

Figure 5 – Thermal behavior of the HLPS simulation (crude oil, T wall = 292.74ºC and pressure = 11.93 bar).

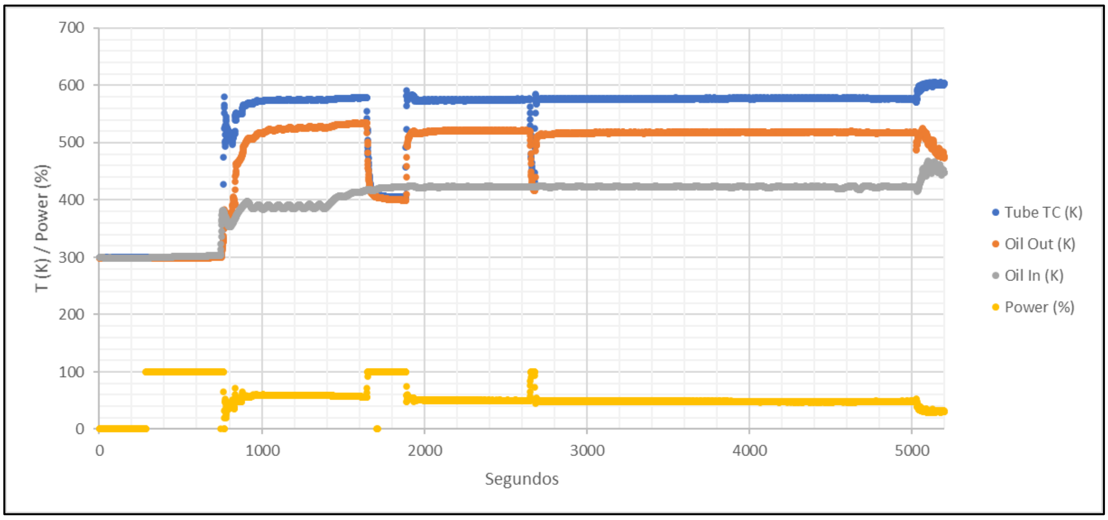
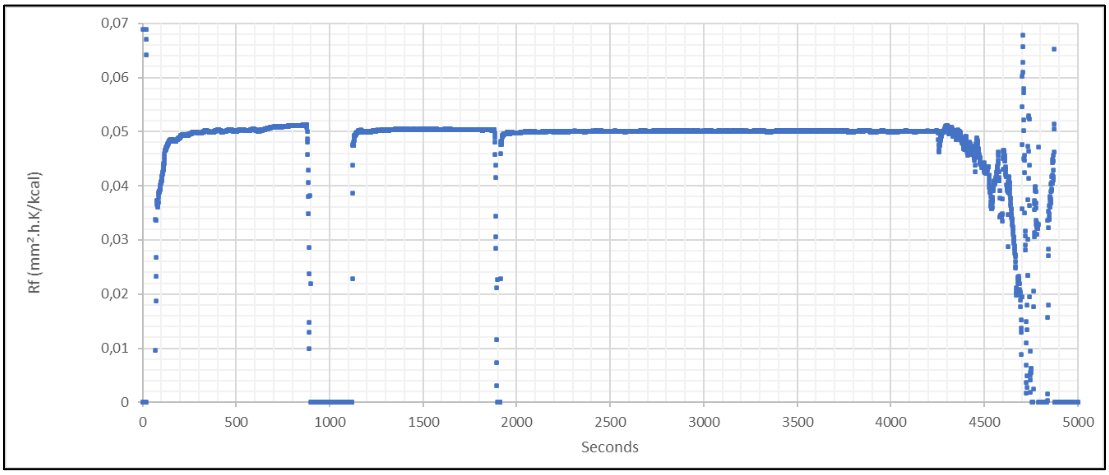


Figure 6 – Behavior of the Rf measured experimentally (crude oil, 292.74ºC Twall and 11.93 bar pressure).



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 1000 seconds and 2000 seconds represent a cooling of the equipment due to unforeseen programming of the controllers, but this has already been identified and corrected by the team. The important thing in this work is the development of the study, calculation of the Rf and evaluation of the deposition. As the equipment allows a fine and low flow control, it is possible to carry out tests in hours that represent months in the refinery. Thus, the next step is to carry out an exploratory study with the important parameters and obtain a better understanding of the phenomenon.

4. CONCLUSION

The study evaluated the methodology of the experiment in relation to threshold models in predicting deposition in heat exchangers. The data shows the need that the equipment is measuring successfully, however, to obtain deposition data, tests in other conditions or with denser samples are necessary. It is necessary to evaluate the influence of correlations, which take into account fluid conditions, such as temperature and density, on the accuracy of the data. Thus, it is clear the need for improvements and sequencing in the study, seeking a greater understanding of the deposition behavior of this oil.

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5. REFERENCES

[1] J. K. Pental, “Design and Commissioning of a Crude Oil Fouling Facility,” no. October, 2011.

[2] A. P. Watkinson, “Comparison of Crude Oil Fouling Using Two Different Probes,” *Heat Exch. Fouling Clean. Fundam. Appl.*, 2003.

[3] M. Trafczynski, M. Markowski, K. Urbaniec, P. Trzcinski, S. Alabrudzinski, and W. Suchecki, “Estimation of thermal effects of fouling growth for application in the scheduling of heat exchangers cleaning,” *Appl. Therm. Eng.*, vol. 182, Jan. 2021, doi: 10.1016/j.applthermaleng.2020.116103.

[4] B. L. Yeap, D. I. Wilson, G. T. Polley, and S. J. Pugh, “Mitigation of Crude Oil Refinery Heat Exchanger,” *Chem. Eng.*, vol. 82, no. January, pp. 53–71, 2004.

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