EVALUATION OF ORIGINAL DEPOSITION MODELS (EBERT-PANCHAL AND POLLEY) AND MODIFIED FOR MODELING DATA OBTAINED IN REFINERY

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Abstract: The fouling phenomenon entails undesirable costs for the main industrial sectors. In the oil and gas industry oil preheat battery exchangers have serious problems with this. In the present work, predictive models based on the deposition threshold were evaluated. The methodology was based on the original proposals and on modifications using parameter estimation with the minimization of calculated and experimental data. The results point to the deficiency of the models in predicting the fouling behavior in exchangers, considering the deposition in the hull and in the tube, since they were validated with tube data and with fixed values of physical properties.

Keywords: fouling, heat exchanger, refinery, modelling, oil.

AVALIAÇÃO DE MODELOS DE DEPOSIÇÃO ORIGINAIS (EBERT-PANCHAL E POLLEY) E MODIFICADOS PARA MODELAGEM DE DADOS OBTIDOS EM REFINARIA

Resumo: O fenômeno da deposição acarreta custos indesejáveis para os principais setores industriais. No setor de petróleo e gás os trocadores da bateria de pré-aquecimento do óleo têm sérios problemas com isso. No presente trabalho, foram avaliados modelos de preditivos baseados no limiar da deposição. A metodologia baseou-se nas propostas originais e em modificações utilizando a estimação dos parâmetros com a minimização dos dados calculados e experimentais. Os resultados apontam a deficiência dos modelos em prever o comportamento da incrustação em trocadores, visto a deposição no casco e no tubo, já que os mesmos foram validados com dados de tubo e com valores fixos de propriedades físicas.

Palavras-chave: deposição, trocador de calor, refinaria, modelagem, petróleo.

1. INTRODUCTION

Deposition is a common phenomenon during the operation of heat exchangers,which consists in the formation of deposits on the surface of these equipment. Currently, in the literature, it is conceptualized that deposition can occur basically for three reasons, as a result of the phase change that arises from the temperature differences between the surface and the fluid (deposition by crystallization), by chemical reactions on the surfaces (deposition by chemical reaction) and by the growth of organisms on the surface (biodeposition). This phenomenon is of significant importance for study because, over time, incrustation decreases the fluid flow cross-sectional area, which results in the need for additional fuel to compensate for the decrease in the heat exchange area and greater pumping power due to the increase equipment load losses, leading to a considerable increase in energy costs.

Within the context of oil refining, deposition is such a common and recurrent phenomenon that there are periodic shutdowns for cleaning the heat exchangers, inside the pre-heating batteries, or BPAs, as they are known, it is common to use models of prediction of the deposition phenomenon to minimize the negative effects of this phenomenon. The phenomenon has effects that can be generalized, regardless of the type of fluid that passes through the equipment. However, the causes of deposition can vary greatly depending on process conditions and fluid types. There are reports of problems with equipment fouling in the petrochemical and crude oil refining industries. [1], [2]

Deposition mechanisms correspond to a classification to facilitate the study of this complex phenomenon. [3] Despite some classifications of deposition mechanisms in the literature, it is common to these classifications the existence of five types of mechanisms: biological, by crystallization, by particulate material, by corrosion and by chemical reaction. With the exception of the last one, all categories can be applied to deposition phenomena in heat exchange equipment, regardless of the type of fluid; deposition by chemical reaction has a much greater application to organic fluids, due to the complexity of reactions that can happen in this type of fluid with thermal variation. [4]

Table 1 shows the models studied and their characteristics. It was possible to notice that several factors influence the deposition such as: speed, temperature and pipe roughness.

Table 1 - Evaluated models

Model	Mean features
Ebert e Panchal [5]	First deposition threshold model. It uses film temperature in the Arrhenius term and shear stress in the removal term.

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Polley et al. [6]	It proposes modifications to the Ebert & Panchal model, changing the value fixed in the Reynolds exponent in the deposition term, using wall temperature in the Arrhenius equation and the Reynolds number in the removal term.

These models have high relative deviations (20-50%) to determine the deposition. Thus, in the present study, these models were used to model data from a real refinery. The original models and data were used, as well as correlations to calculate the physical properties and the re-estimation of the parameters, seeking the best adjustment to the experimental behavior.

2. METHODOLOGY

The semi-empirical deposition threshold model (threshold fouling) presented by Ebert and Panchal [5] is considered a landmark in the study of deposition in BPAs. It brings an innovation to the field of study, seeking to predict the linear rate of deposition for conditions in which deposition starts (deposition rate close to zero), given as a function of film temperature and fluid velocity, and from Furthermore, determine operating conditions of temperature and velocity at which deposition does not occur. The calculations were made considering the deposition in the hull and in the tube. The model is described in Equation (1).

$$\frac{dR_f}{dt} = \alpha \, \mathrm{Re}^{\beta} \exp\left(-\frac{E_a}{RT_f}\right) - \gamma \tau_w \tag{1}$$

where R is the universal gas constant, Tf is the film temperature, obtained by the arithmetic mean between the deposit-fluid interface temperature and the wall temperature, Re is the Reynolds number for the flow in contact with the deposit, é the shear stress on the surface of the deposit, and α and β are parameters of the deposition term of the model and is the parameter of the removal term. The parameters α, β and, in addition to Ea, are estimated for the experimental data.

The model by Polley et al. [6] better fits the data from Knudsen et al. [7] than that of Ebert and Panchal [5], both in relation to the initial conditions of deposition generation and the prediction of subsequent rates, after the beginning of the deposit generation. It also presented an average deviation of 6% in relation to industrial data from a Shell refinery used by Panchal et al. [8], equation (2) illustrates the equation proposed by Polley et al. [6].

$$\frac{dR_f}{dt} = \alpha Re^{-\beta} Pr^{-0,33} \exp\left(\frac{-E_a}{RT_w}\right) - \gamma Re^{0,8} \tag{2}$$

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The physical properties will be determined by the correlations proposed by Yeap et al., 2004. They take into account ºAPI, bulk and wall temperature, as shown in equations (3-7).

$$\rho = 1234{,}18 - 5{,}46API - 0{,}300T_b - 0{,}367T_w \quad (3)$$

$$\lambda = 0{,}1314 + 0{,}000727API - 0{,}0000321T_b - 0{,}0000392T_w \quad (4)$$

$$C_p = 342{,}57 + 11{,}273API + 1{,}82T_b + 2{,}227T_w \quad (5)$$

$$log_{10}^{\vartheta} = \frac{b_{A6}}{\left(1+\left((0{,}45T_w+0{,}55T_w)-310{,}93\right)/310{,}93\right)^{b_{A7}} - 0{,}8696} \quad (6)$$

$$b_{A6} = log_{10}\vartheta_{37{,}78ºC} + 0{,}8696 \quad (7)$$

$$b_{A7} = 0{,}28008b_{A6} + 1{,}6180 \quad (8)$$

In addition, a modification was made to the models, replacing the film temperature of the Ebert-Panchal model and the wall temperature of the Polley model by the logarithmic mean of the inlet and outlet temperatures of the hull and tube, as shown in Equation 9. It was considered that the tube passes the cold fluid (CT), which is being heated, and the hull passes the hot fluid (HT), which is being cooled.

$$\Delta T_{lm} = \frac{(HT_E - CT_S) - (HT_S - CT_E)}{ln\frac{(HT_E - CT_S)}{(HT_S - CT_E)}} \quad (9)$$

Thus, the evaluation methodology will be divided into 6 different analyses, considering the sum of the depositions in the hull and in the tube, as shown in Table 2.

Table 2 – Methodology developed for evaluation of models and modifications

Model	Properties	Temperature	Adjustable parameters	Set
Ebert-Panchal	Original data	Film	α, β, γ, E_a	1
	Yeap correlation	Film		2
	Yeap correlation	Log Media		3
Polley	Original data	Wall		4
	Yeap correlation	Wall		5
	Yeap correlation	Log Media		6

3. RESULTS AND DISCUSSION

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The parameters of the models were estimated using as objective function (OF) the difference of the sum of all experimental dRf/dt values by the calculated ones, as can be seen in Equation 10. The evaluated experimental data totaled 58. For the estimation of the parameters, it was A Quasi-Newton algorithm is used.

$$FO = Minimize \sum_{1}^{n} \frac{\left| \frac{dRf}{dt}_{exp,i} - \frac{dRf}{dt}_{calc,i} \right|}{\frac{dRf}{dt}_{exp,i}} \quad (10)$$

The FO values obtained, along with the mean deviations and parameter values are presented in Tables 3 and 4.

Table 3 - Objective function values and average deviation obtained in each scenario

Set	OF	Average deviation (%)
1	2837.80	48.93
2	1754.53	30.25
3	1708.15	29.65
4	1758.66	30.32
5	1755.12	30.26
6	1379.85	23.79

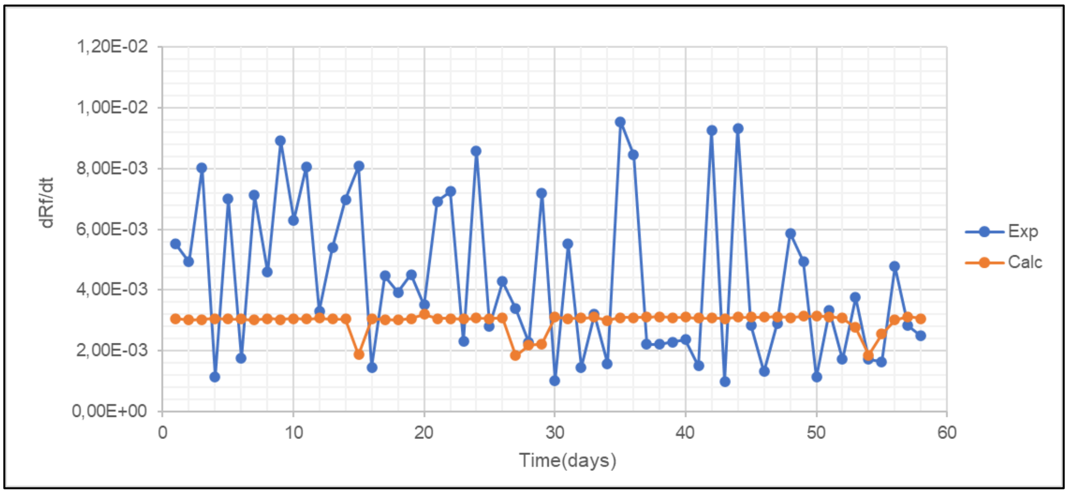
Table 4 - Values of the parameters obtained in each evaluated scenario

Result	Shell				Tube			
	α	β	γ	E_a	α	β	γ	E_a
1	88.00	-1.00	2.05E-05	346.27	78.86	-1.31	-1.05E-07	10.98
2	79.98	-0.89	2.20E-05	349.86	77.96	-1.52	-9.80E-06	14.32
3	77.23	-0.78	3.01E-05	306.63	75.54	-1.71	-1.12E-07	24.79
4	52.60	-0.76	-1.66E-09	987.24	51.09	-0.76	-1.42E-07	99.65
5	85.79	-0.90	9.43E-10	946.28	50.02	-0.79	-1.98E-07	100.83
6	117.16	-1.00	-1.35E-09	1024.36	46.66	-1.31	-4.12E-07	118.47

The estimation values obtained in scenario 6, with the lowest mean deviation, are shown in Figure 1.

The results show the difficulty of the models in predicting the behavior of the deposition phenomenon in exchangers and that the proposed adjustments improved the modeling. These values can be explained by the fact that the exchanger involves flow and deposition in the hull and in the tube, the models were designed for data with prediction only in the tube. Thus, it is possible to conclude that, for the studied data, the models based on the deposition threshold (Ebert-Pabchal and Polley) present difficulties to predict the deposition phenomenon.

Figure 1 – Experimental and calculated dRf/dt values using Polley's model with Yeap correlations and logarithmic mean



Set 6 showed the best results, with an average deviation between calculated and experimental of 23.79%, proving the difficulty of the models in predicting deposition.

4. CONCLUSION

The study evaluated the effectiveness of threshold models in predicting deposition in heat exchangers. The results show the difficulty in predicting the phenomenon, even with modifications and re-estimation of the parameters. The data show the need for their adjustments, with the inclusion of other important parameters for a satisfactory modeling, such as attention to the data used, since originally constant physical properties are used. Even using correlations, which take into account fluid conditions, such as temperature and density, the models did not achieve good accuracy. Thus, it is clear the need for improvements and sequence in the study, seeking models that achieve better results in modeling the phenomenon of deposition.

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