International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4658-4661

Methods of Deposit Thicjness Control in Heat Exchangers

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Abstract

The article describes the study of kinetics and the solution of control and management methodological issues concerning the process of mineral deposit removal in heat exchangers. They performed the analysis of deposit removal process on technological equipment in the mode of its normal operation with the help of washing solutions. At the same time, scale deposits from the equipment of the water-steam heat supply system were considered. They offered the approach to the selection of detergent solution compositions, which makes it possible to accelerate the process significantly. The study of these deposits removal rate was carried out. They obtained the kinetic dependences of scale removal at different concentrations of complexonate. It has been established that at high rates of this process, the destruction of deposits occurs with the formation of a coarse suspension in the solution. The results of studying the kinetics of the process made it possible to establish the time of washing, the features of its course and the scope of this method. They developed the technique to control the thickness of deposits in heat exchangers during this process, which is based on the mathematical model of a heat exchanger and a recurrent least squares method. The sediment control technique can be used in the systems for monitoring and control the dosage of corrective reagents for the process of deposit removal in heat exchangers during their normal operation.

Key words: heat exchanger, deposits, removal kinetics, control technique.

1. INTRODUCTION

The negative impact on the process of deposits formed on the surface of heat exchangers in various industries is well known. For example, the accumulation of mineral and biological deposits on the inner surface of the condensers of thermal power plants leads to the decrease of the power unit generated power, the increase in hydraulic resistance and to the intensification of corrosion processes.

A large number of scientific papers have been devoted to the issues of accumulated deposit inhibition and removal in industrial devices. Particular attention should be paid to the work [1], devoted to the removal of mineral deposits from the water circulation system during the normal operation of the facility, called "washing on the fly." The peculiarity of this method lies in the fact that additives are introduced into the working environment of the apparatus, which are allowed by the technological regulations and ensure the washout and/or dissolution of deposits without stopping the process. Despite the attractiveness of this method, its use raises a number of technical and economic issues. When they implement this method, it is necessary to have a clear understanding of the process speed and controllability. Taking this into account, this work is devoted to the study of the kinetics and the solution of control and management methodological issues concerning the process of mineral deposit removal in heat exchangers during their normal operation.

2. METHODS

The method of “washing on the fly” is based on a physicochemical effect on sediments, which combines both the dissolution of a part of the substance and the physical separation of sediment particles due to the Rebinder effect [2]. Therefore, cleaning solutions should contain both solvents and surfactants, while it is obvious that the composition of the cleaning solution is selected for the specific composition of the deposits. This applies equally to deposits of different nature. In this regard, the first part of the research was devoted to the selection of the washing solution composition and the study of the deposit removal kinetics.

Scale on the equipment of a water-steam heat supply system was considered as an example of mineral deposits. A large number of scientific works have been devoted to the issues of water treatment stabilization and correction in thermal and circulating systems, but they almost lack information on the kinetics of sediment removal. For example, in [1], they considered a complexonate method of washing out the deposits of water circulation cooling systems. In this work, the recommended solutions were tested. Initially, the effect of some well-known film-forming amines and phosphonated complexonates was studied. However, the rate of sediment removal was very slow, and their noticeable removal occurred in 45 days. Then the solution of trisodium phosphate Na_3PO_4 was tested, which showed better results, and then a compositional composition of additives to an aqueous medium was selected, including complexonates/phosphates, surfactants and mineral or organic acids. Various substances were used as surfactants: sulfonol, tannins and various corrosion inhibitors. The purpose of the main components of the solution is well known: chelating agents and chelating agents for binding insoluble compounds into complexes that are readily soluble in water or acid; surfactants to reduce surface tension, loosen the top layer and penetrate the solution into the deposits; the acids to loosen the surface layer and dissolve hard compounds.

The experiment on washing the deposits was carried out in a thermostat vessel with the diameter of 80 mm, equipped with a stirrer with the diameter of 50 mm and filled with a washing solution. The experimental technique was as follows. A sample of the tube with the deposits on the inner surface was placed into the apparatus, and after turning on the stirrer and establishing the temperature regime, the washing process began, during which the thickness and weight of the remaining deposits were measured. The variable parameters of the washing process were the initial concentrations of the reagents, as well as the stirring rate and temperature of the medium. Figure 1 shows the examples of kinetic curves for washing off 34 mm thick deposits obtained under the same hydrodynamic conditions and temperature, but at different initial concentrations of reagents. According to the experiment results, it was possible to reduce the washing time to tens of hours, while varying the concentration of the complexonate, it is possible to increase the rate of washing off the deposits by 2 times. The studies of washing kinetics have shown one more feature of the process. During the process of washing, both the dissolution of a part of the substance and the detachment of solid particles from the surface occurred, after which the suspension accumulated in the solution. At the same time, the increase of complexone concentration leads to the increase of detached solid particle size, the amount of suspension and an uneven rate of washing. This phenomenon must be taken into account when organizing the cleaning process, since coarse dispersion can lead to the blockage of pipes and structural elements.

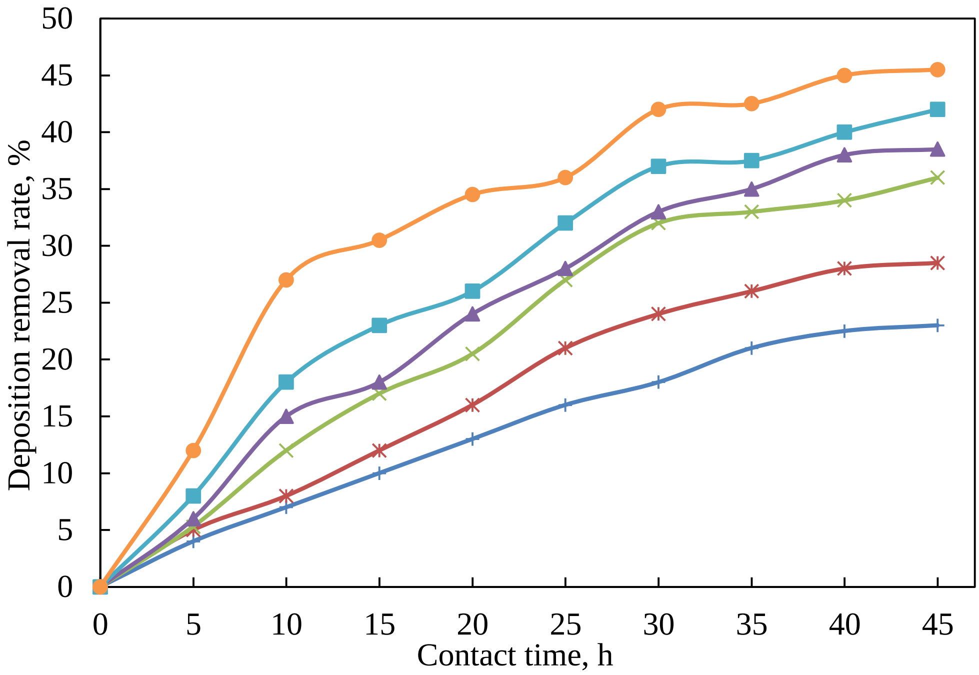

Figure 1. Kinetic curves of scale “washing off” at complexonate concentrations, where: —●— – 20 mg/kg; —■— – 15 mg/kg; —▲— – 12 mg/kg; —×— – 10 mg/kg; —*— – 8 mg/kg; —+— – 4 mg/kg.

Based on the results of the experiment removing mineral deposits by washing, the following conclusions can be drawn.

1. The mechanism of deposit removal with the help of detergent solutions containing surfactants can be represented in the form of four successive stages: 1) wetting the deposit surface with the solution of surfactants and reducing the interfacial (surface) tension; 2) the penetration of the solution into the sediments; 3) destruction and dispersion of sediment particles into the solution volume; 4) partial dissolution of sediment components.
2. The rate of deposit removal depends substantially on the composition and concentration of the washing solution components, the temperature of the process and the rate of the medium stirring. Washing time is up to 50 hours for mineral deposits.
3. The process of deposit washing away is accompanied by the accumulation of sludge, suspension or emulsion, and the higher the concentration of surfactants, the more coarsely dispersed the new phase is.
4. The considered method does not provide complete removal of deposits from the equipment surface, while the lower layer of deposits cannot be destroyed. Therefore, the method of "washing on the go" can only serve as a temporary measure to maintain the equipment until its

planned shutdown.

5. In order to save reagents, the washing process must be controlled by the deposit thickness, taking into account the speed of their removal. Concentrations of components can be used as the control parameters of the process.

Controlling the thickness of deposits during the cleaning process is not an easy task, since direct measurement of this parameter is not possible. For example, it is proposed in [1] to control the process of descaling by the concentration of hardness salt input. However, there is no direct relationship between the thickness of sediments and the concentration of hardness salts in water, and therefore, this parameter cannot serve as the main controllable and controlling parameter of the sediment washing process. Therefore, it is necessary to look for other ways to measure it indirectly.

This paper proposes the technique for real-time monitoring of deposits in heat exchangers. This technique is based on a heat transfer model and a recurrent least squares method.

For example, let's consider the process of heat transfer in the condenser of a steam turbine plant. The process of deposit removal in this apparatus is relatively slow, therefore it can be considered as a quasi-stationary process. The heat balance equation for the refrigerant with an ideal mixing of the flow in the stationary mode of the device operation is the following:

$$V_X C_X \rho_X (T_X - T_0) = K_T F (T_D - T_X), \qquad (1)$$

where V_X, C_X, ρ_X – the volumetric flow rate, heat capacity and cold flow density; T_D, T_0, T_X – the temperatures of steam and cold flow at the inlet and outlet of the heat exchanger; F - heat transfer surface; K_T - the heat transfer coefficient.

If the apparatus is equipped with flow rate control devices for the refrigerant to control its temperatures at the inlet and outlet of the apparatus, as well as the temperature of the steam in the apparatus, then the equation (2) can be used to calculate the current value of the heat transfer coefficient. For this purpose, we transform the equation (1) to the following form:

$$\begin{aligned} Y &= C_X; \\ Y &= V_X (T_X - T_0); \\ X &= T_D - T_X; \\ C &= \frac{K_T F}{C_X \rho_X}. \end{aligned} \qquad (2)$$

Tracking the temperatures and flow rates with a known heat transfer surface, it would be possible to calculate the heat transfer coefficients using these formulas. However, the presence of random disturbances, as well as the measurement errors and interference lead to the fact that the observed variables X and Y are changed randomly. Taking this into account, the use of the recurrent least squares method will be justified to solve the problem of parametric identification of the model (2) in real time. In accordance with this method, the proportionality coefficient Ck of the model (2) at each step of discrete measurements will be calculated according to the following recurrent formula:

$$\begin{aligned} C_{k+1} &= C_k + \frac{X_{k+1}}{S_k + X_{k+1}^2} \left(Y_{k+1} - C_k X_{k+1} \right); \\ S_k &= \sum_{j=0}^{k} x_j^2. \end{aligned} \qquad (3)$$

According to the value of the proportionality coefficient C_k of the formula (2), provided that the heat transfer surface remains at the design level, the heat transfer coefficient K_T is calculated. The heat transfer coefficient is related to the thickness of the deposits δ by the known relation:

$$\frac{1}{K_T} = \frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_2} + \frac{\delta_2}{\lambda_2}, \qquad (4)$$

where α_1, α_2 – heat transfer coefficients on both sides of the wall; λ_1, λ_2 – the coefficients of thermal conductivity of the wall and deposits.

If the heat transfer coefficients remain unchanged, then the formula (5) can be presented in a more convenient form:

$$\frac{1}{K_T} = \frac{1}{K_T^0} + \frac{\delta}{\lambda}, \qquad (5)$$

where K_T, K_T^0 – heat transfer coefficients at the initial and current moment; λ - the coefficient of deposit thermal conductivity.

3. RESULTS AND DISCUSSION

After these calculations, the deposit thickness will be diagnosed in the mode of receiving measurements concerning the heat exchanger technological parameters. Besides, the rate of deposit removal can be calculated.

4. CONCLUSIONS

The results of studying the kinetics of the process made it possible to establish the time of washing, the features of its course and the scope of this method.

5. SUMMARY

The developed method for deposit control can be used in the systems for monitoring and control the dosage of corrective reagents for the process of deposit removal in heat exchangers during their normal operation.

6. ACKNOWLEDGEMENTS

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4658-4661

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Biography:

Badriev Airat Irekovich works as a lecturer at Kazan Federal University. At the same time, Professor V.N. Sharifulin continues the scientific work as the head, the Doctor of Engineering. The range of interests covers the issues of heat exchanger efficiency increase on TPP devices. More than 20 scientific papers have been published.

Sharifullin Vilen Nasibovich worked at the Kazan State Power Engineering University. He is an expert in improvement the efficiency of equipment for the energy and oil industries. V.N. Sharifullin guided more than 10 applicants who defended their dissertations. More than 300 scientific papers have been published.