Assessment of scale formation in heat exchangers

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Abstract. The paper evaluates the influence of the scale formation on the inner surface of the heat exchanger on its technical characteristics. The subject of research is a heater 12 OST 34-588-68 Number 12 diameter of 219 of the second stage of hot water supply, intended for heating cold water into a hot water supply system. A survey of the Central heating point and connected heat and water supply systems located in the city of Moscow was conducted. For the study, an analysis of indicators of water quality at a heat point was carried out. In the course of the work, the following were calculated: the intensity of scale formation, their thickness, and also the deviation of the calculated value of the formed deposits from the actual one obtained by field measurements was found. As a result of the work, an increase in the hydraulic resistance inside the tubes of the heat exchanger was calculated in connection with the formation of deposits and an increase in the consumed electricity to ensure the required parameters of the hot water supply system.

1. Introduction
The most important operational characteristics of heat power equipment are reliability and energy efficiency, as well as environmental indicators. The main factor in the reliable and energy-efficient operation of the equipment is the organization of the optimal water-chemical regime. Violation of the water-chemical regime leads to a decrease in the inner diameter of the pipes due to the scale formation [1]. In this regard, the hydraulic resistance increases, which leads to an increase in the energy consumption for pumping water, and after a short time the heat-exchange equipment becomes unusable. In the most intense places of scale formation on the internal heat exchange surfaces overheating of the metal occurs, as a result, cracks and through damage caused by corrosion form on the surfaces. The scale formation can completely block the system, clogging it and accelerating the corrosion process [2]. The scale formation on the inside of the heating equipment is caused by the crystallization process: during heating, evaporation, or boiling, a solid phase is released from a supersaturated solution of salts in water, and the mechanism and rate of scale formation is due to their content in water [3]. The effectiveness of assessing the formation of deposits on the inner surface of heat engineering equipment can be achieved by selecting a methodology for predicting the intensity of scale formation for diagnosing the technical condition of equipment that ensures reliable operation based on determining the optimal operating mode [4].

2. Research formation of deposits in a hot water heat exchanger

2.1. Object of research description
A survey of the Central heating point and connected heat and water supply systems located in the city of Moscow was conducted. The central heating point has an independent heating load connection circuit and a closed hot water supply circuit. The temperature graph of the heating system is 95/70 °C. The hot water preparation system consists of two heaters. The first heater includes 4 sections with a diameter of 219 mm Number 12, grade 12 OST 34-588-68. The heating area is 516.67 ft². The second heater includes 4 sections with a diameter of 219 mm Number 12, grade 12 OST 34-588-68. The heating area is 516.67 ft².

The subject of research is a heater 12 OST 34-588-68 Number 12 diameter of 219 of the second stage of hot water supply, intended for heating cold water into a hot water supply system. Technical characteristics of the heat exchanger:

- inner diameter of the tubes is 14 mm;
- tube length 4 m;
- number of tubes in the section - 64;
- number of sections - 4.

2.2. Basic information
The selection of the solid phase from a supersaturated solution of a salt occurs [2]:

- with a decrease in the solubility of salt with increasing temperature;
- upon evaporation of water, accompanied by an increase in the concentration of salts for which the solution is closest to the state of saturation;
- when processes occurring in heated and evaporated water that cause the dissociation of some ions and the formation of others, giving sparingly soluble salts.

At first, primary germ crystals are deposited from a supersaturated salt solution on separate areas of the metal surface, because a surface metal possesses roughness. And then crystals expand and grow [5].

2.3. Analysis of scale formation
The analysis of the water-chemical regime of a heat point was performed in order to identify the main problems and the causes of their occurrence. The results of analyzes of samples of source tap water carried out during the heating period are presented in table 1.

| Indicators                      | 22.11 | 19.12 | 25.01 | 15.02 | 21.03 |
|--------------------------------|-------|-------|-------|-------|-------|
| pH                             | 7,40  | 7,70  | 7,50  | 7,80  | 7,60  |
| C-suspended solids, mg/l       | <5,00 | <5,00 | <5,00 | <5,00 | <5,00 |
| Total hardness, ppm            | 200,0 | 195,0 | 230,0 | 220,0 | 205,0 |
| Ca²⁺, ppm                      | 150,0 | 146,5 | 172,5 | 165,0 | 154,0 |
| Mg²⁺, ppm                      | 50,0  | 49,0  | 57,5  | 55,0  | 51,5  |
| Total alkalinity, ppm          | 167,0 | 153,5 | 154,5 | 162,0 | 153,0 |
| Cl⁻, mg/l                      | 20,54 | 22,14 | 21,39 | 21,18 | 20,15 |
| SO₄²⁻, mg/l                    | 32,46 | 33,18 | 33,03 | 32,78 | 33,05 |
| Fe, mg/l                       | 0,11  | 0,18  | 0,16  | 0,12  | 0,08  |

The following indicators are used as input data:

- heating temperature of the coolant supplied to the consumer is 60 °C;
- average speed water is 1,184 m/s;
- degree of recirculation is 0.3;
- hydrogen indicator (pH) is 7.6;
- value of carbonate index \((I_k)\) is 24 885 (ppm).

The calculation of the intensity of scale formation in the heating equipment is made according to the following formula [6]:

\[
m = 0.0142 \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot I_k
\]

where \(k_1\) is the heating temperature coefficient; \(k_2\) - the heated water flow rate coefficient; \(k_3\) - the heated water recirculation coefficient; \(k_4\) - coefficient taking into account the hydrogen indicator of the heated water; \(I_k\) - carbonate index, (ppm).

The intensity of the formation of deposits of hardness salts, calculated by the equation 1:

\[
m = 0.014 \cdot 0.59 \cdot 0.609 \cdot 0.931 \cdot 1.073 \cdot 24885 = 126.61 \frac{mg}{m^2 \cdot h}
\]

The thickness of the deposits on the inner surface of the equipment can be obtained using the following equation:

\[
\delta_w = \frac{m \cdot \tau}{\rho_w}
\]

where \(\tau\) is the operating time of the equipment, h; \(\rho_w\) - the density of carbonate scale, kg/m³.

The thickness of the deposits for two heating periods (17 040 hours), in accordance with equation 3, is equal to:

\[
\delta_w = \frac{126.61 \cdot 17040}{2.37 \cdot 10^6} = 0.91 mm
\]

The inner diameter in accordance with the calculation method is equal to:

\[
d_w = d - 2 \cdot \delta = 14 - 2 \cdot 0.91 = 12.2 mm
\]

The inner diameter of the tube at actual measurements was \(d_e = 12.4 mm\).

The deviation of the measured value from the calculated is:

\[
\delta_e = \frac{d_w - d_e}{d_e} \cdot 100\% = \frac{12.4 - 12.2}{12.4} \cdot 100\% = 1.61\%
\]

Inspection of the condition of the internal surfaces of the heat exchanger showed the presence of deposits shown in Figure 1.
Figure 1. Deposits of hardness salts in the heater of hot water supply.

To control the formation of deposits on the inner surface of heating equipment, it is advisable to continue systematic monitoring of water quality by analyzing the anionic composition (chlorides, sulfates), pH, and iron ions [7].

3. Conclusions

In this paper we consider an algorithm for calculating the thickness of deposits in heater using the example of a second-stage heater 12 OST 34-588-68 Number 12 diameter of 219 used as the second heating stage for the needs of hot water supply.

Based on the results of the work the following conclusions can be drawn:

- water quality indicators comply with the standards specified in [8];
- when water is heated, the ability to form deposits prevails;
- the rate of formation of deposits on heating surfaces of hot water heaters can reach 126,61mg/(m²·h);
- the average thickness of salt deposits in the heat exchanger is 0,91 mm;
- reduction of the inner diameter of the tubes of the heat exchanger from 14 mm to 12,4 mm;
- increase in hydraulic resistance in the heat exchanger is 1,2 kPa;
- increase in costs for pumping coolant 370,91 kW·h.

When comparing the actual measurement data with the calculated ones, the error was 1.61%. Thus, understanding and the ability to predict the characteristics of the formation of deposits will ensure the reliability and uninterrupted operation of heating equipment.

4. References

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