Prevention of salt deposition in circulating water by the combined use of a salt deposition inhibitor and magnetohydrodynamic treatment

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Abstract. The article considers the possibility of using magnetohydrodynamic water treatment together with high-molecular polycarboxylates. The principle of calculating MHDT devices for increasing the efficiency of a polycarboxylate-based reagent is proposed. It is shown that the method of increasing the efficiency of a polycarboxylate-based salt deposition inhibitor in cooling water systems simultaneously with the use of magnetohydrodynamic treatment of circulating water allows reducing the reagent consumption, avoiding the use of nitrates and phosphates, and reducing technological costs. The effectiveness of the combined use of a polycarboxylate-based salt deposition inhibitor with the MHDT device has been confirmed by tests on the cooling water system equipment of an industrial enterprise. When testing the reduction of salt deposits with a polycarboxylate-based salt deposition inhibitor and MHDT, the inhibitor dosage was reduced from 5 to 1 ppm. Monitoring the efficiency of the heat exchanger (by temperature difference) showed that there were no deposits on the plates for three months. The number of heat exchanger repairs has been reduced by more than three times.

1. Introduction

The formation of deposits on the inner surface of the pipeline walls and equipment that contact with mineralized water occurs for several reasons:

- Presence of cations and anions that form insoluble or slightly soluble salts in water.
- Exceeding concentration of anions and cations (above the equilibrium concentration).
- Changes in the thermodynamic conditions of water transporting (increase in temperature, decrease in speed, increase in pressure in the presence of dissolved gases, etc.)

Until recently, organic and inorganic phosphates were widely used to prevent salt deposition. Phosphates form water-soluble complexes with divalent ions and minimize salt deposits. However, environmental standards for the phosphates quantity in wastewater are currently being reduced, which requires the search for alternative methods to prevent salt deposition.

Now researchers are testing polymer salt deposition inhibitors. For example, in [1-4], copolycarboxylates with acrylic and maleic acids were optimized to prevent deposits when using detergents with reduced content of phosphate or without them.
Limescale formation occurs due to the deposition and growth of crystals from such substances. Scaling of inorganic salts has been studied experimentally with an emphasis on time-resolved data to study this matter. It was found that in oversaturated with CaCO$_3$ water amorphous particles less than 100 nm in size are developing. These particles aggregate and / or dissolve before recrystallization. Conducting these experiments in the presence of polycarboxylates showed what techniques can be used to reduce / prevent scale formation. Polycarboxylate molecules effective stabilize CaCO$_3$ nanoparticles, forming a shell around them that prevents deposition on the surface and recrystallization [5, 6].

The processes of crystallization of supersaturated solutions were considered to increase the efficiency of using phosphorus-free compounds to prevent salt deposition. The principles of dilute solutions do not work on the heated surfaces of the equipment, but the concentration effects of the environment start to act [7, 8].

The main stage of the formation of salt deposits is crystal formation, i.e. a small number of clusters are completely transformed into crystals. As mentioned above, polycarboxylates interact well with clusters and individual ions, but they do not react and do not form complexes with crystals in general. It is necessary to create conditions for converting a significant proportion of calcium ions into clusters to form complexes and prevent the precipitation of hardness salts on the heating surface for 100% efficiency of polycarboxylates [9].

To increase the number of clusters of hardness salts obtained in the water flow, we proposed using the method of magnetic hydrodynamic treatment (MHDT) of water. The method was previously used to prevent salt deposition in oil fields [10, 11].

2. Results and discussion

The results of studies in [12-17] were obtained using the principles of magnetic treatment of water systems, without taking into account the flow rate and the directed movement of ions - electric current-induced in the water flow.

When the flow moves with a linear velocity $u>0$ of the magnetic field with an induction $B$ created by sources of a constant magnetic field, an electric current is induced in each cell unit of the water flow. Using formulas and dependencies from sources [16], distributions of flow vectors $U$, magnetic induction $B$, and induced current $i$ (figure 1). In [14], dependences of current $i$ calculation on the medium parameters, flow velocity, and magnetic induction value are developed.

![MHDT scheme](image)

**Figure 1.** MHDT scheme: j – direction of induced currents, $B=0$ - zones with zero induction value, $U$ - direction of the water flow vector, $B_{\text{max}}$ - maximum value of magnetic induction on the surface of the magnetic field source.

2.1. Calculation of the time until the formation of crystal nuclei and the beginning of crystal growth in the environment under with the MHDT influence

When a solution containing concentrations of calcium, magnesium, barium cations and carbonate and sulfate anions which are far from saturation, the relative displacement of ions of the opposite sign to the center between the two sources of the magnetic field occurs. The offset depends on the strength of the induced ion current. The movement of ions in this case occurs in a spiral with a radius $R_S$ and a linear velocity $V_S$. If we consider the volume of a solution located between magnetic field sources with
magnetic induction lines perpendicular to the sources, then cations and anions will simultaneously move towards each other at a speed of

\[ u'^+ U + u'^- U, \]

where \( u'^+ \) и \( u'^- \) are the mobility of calcium and carbonate ions, respectively

\[ U = j \cdot \varepsilon \cdot C_{Ca}, \] (1)

here \( \varepsilon \) is the molar electrical conductivity (\((\text{Ohms} \cdot \text{m}^2)/\text{mol})\), \( C_{Ca} \) is the concentration of calcium ions (mol/m³), since there are fewer calcium ions in the solution than carbonate ions, the concentration limits the process.

Given the speed of movement of each i-th ion and the time the solution is in the magnetic field, it can be assumed that a certain number of cations and anions will fall into the zone with zero magnetic induction equal to

\[ N_{Ca} = \sum_{i=0}^{n} V_S t_i, \] (2)

During \( t_i \), a certain amount of calcium ions will fall into the zone with zero magnetic induction and the concentration of ions in it will increase by \( k \) times. If we take a zone with zero magnetic induction with a thickness of \( \delta_0 \), to increase the concentration of calcium ions from the initial \( C_0 \) to the supersaturation concentration \( C_X \), the formation of crystal nuclei requires a time equal to

\[ t = \frac{\delta_0 \cdot C_X}{V_S \cdot C_0}, \] (3)

Thus, depending on the required speed of execution of the conversion process of soluble ions in the crystalline phase, the index \( X \) can be 2, 3, 6 and more.

The distance between the magnetic field source (if they are identical) to the zone with zero magnetic induction is equal to \( L \), to ensure the implementation of the clusterization in the gap must respect the condition:

\[ L = V \cdot t, \] (4)

where \( V \) – flow velocity, m/s.

In a real industrial flow of cooling water in pipelines, the diffusion component does not affect the rate of cluster formation. The formed clusters, when approaching the heated surface of the heat exchanger, are not being adsorbed on the surface, they begin to actively add calcium and carbonate ions and form a crystal in accordance with the saturation arising at the boundary of the heated body.

To determine the necessary and sufficient number of clusters formed. To completely form complexes of calcium ions with polycarboxylate molecules. To create conditions that prevent the formation of calcium carbonate deposits on the heating surface. It is necessary to reduce the amount of hydrated calcium ions to a concentration \( C_{Ca} = C_T \) less than the saturation concentration of \( C_T \) at the temperature \( T_T \) of the heating surface.

The water in the circulating water supply system makes several turns during an hour and is fed to replenish evaporation with fresh water saturated with calcium ions in the amount of 1-3% of the total water volume in the system. That is, in the system (excluding blowdown - water renewal), the concentration of calcium \( C_{Ca} \) increases by an average of 0,02 \( C_{Ca} \).

If a part of the pipeline flow with area \( S \) passes through the gap of the MHDT device with a cross-sectional area \( S_M \), then

\[ Y = \frac{S_M}{S}, \] (5)

The number of calcium ions in the system in one revolution will change by \( \Delta C_{Ca} \).

\[ C_{Ca} = Y \cdot C_X, \] (6)
At the same time, the stability of water and the absence of salt deposition on heated surfaces can be achieved under the condition $\Delta C_{Ca} > 0.02 C_{Ca}$, then the minimum and sufficient condition for the equipment to operate without scale will be to equip the circulating water supply pipeline with an MHDT device with a cross-sectional area

$$S_M = S \frac{0.02 C_{Ca}}{C_X},$$ (7)

In this case, $C_X$ is the concentration of supersaturation at the surface temperature of the most heated heat exchanger (pipeline section).

2.2. Coagulation and removal of microcrystals after the use of MHDT device with reagents

Depending on the degree of supersaturation of the solution with calcium, magnesium, carbonate ions, the amount of microcrystalline clusters formed in the gap of the MHDD device increases. Thus, the amount of fine-crystalline phase, which can be bound by polycarboxylate and removed from the stream by filtration or settling, increases significantly.

After laboratory experiments, it was decided to test the joint use of a scale inhibitor based on polycarboxylate (salt of the copolymer of acrylic and maleic acid esters, molecular weight (15-50)·10³) and MHDT.

The concentration of polycarboxylate (dry matter) in water was 1…4 ppm. The magnetic field strength at MHDT was 1.3 T.

In accordance with the data analyzes of circulating water (see table 1) and temperatures of the cycle of water circulation (+19 - +62 °C) the speed of the water flow through the MGDO device was 0.8-1.1 m/s. The parameters of the device were calculated in accordance with the quality indicators of the cooling water of the object being treated. The device was manufactured and installed on the line with the most problematic heat exchanger. This heat exchanger was cleaned every month and is covered with calcium sulfate and carbonate (figure 2). View of the plates after using the MGDO in figure 3.

| Overall stiffness | Calcium stiffness | Suspended solids | Chlorine | Orthophosphates (filter) | Mass concentration of total iron | Total alkalinity | Salt content | Hydrogen index | Electrical conductivity | Chemical oxygen consumption (COD) |
|------------------|------------------|------------------|----------|--------------------------|-------------------------------|----------------|-------------|----------------|------------------------|----------------------------------|
| mg·eq/dm³       | mg·eq/dm³        | mg/dm³          | mg/dm³   | mg/dm³                   | mg·eq/kg                      | mg/dm³         | pH          | mg·/dm³       | mkSm/sm                | mg O₂/dm³                         |
| 10.6             | 152.0            | 17.5            | 0.1      | 3.0                      | 0.3                           | 4.7            | 1179.6      | 8.5           | 1646.6                 | 73.3                              |

During the process of the joint use of a polycarboxylate-based salt deposition inhibitor with the MHDT device, the dosage of the inhibitor was reduced from 5 to 1 ppm.

Monitoring of the efficiency of the heat exchanger (by temperature differences) showed that there were no deposits on the plates for three months. After three months, the temperature drop decreased and the heat exchanger was opened to analyze the current situation. Figure 3 shows the appearance of the outer part of the heat exchanger plate. It can be seen that the change in the temperature regime was not due to the deposition of salts, but due to the ingress of petrochemical compounds – copolymers into the circulating water.
3. Conclusions
A method for increasing the efficiency of a polycarboxylate-based salt deposition inhibitor in cooling water systems has been developed. The reagent is proposed to be used simultaneously with magnetohydrodynamic treatment of circulating water.

The principle of calculating MHDT devices for increasing the efficiency of a polycarboxylate-based reagent was proposed.

The effectiveness of the joint use of a polycarboxylate-based salt deposition inhibitor with the MHDT device has been confirmed by tests on the equipment of the cooling water system of an industrial enterprise.

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