E3S Web of Conferences **551**, 01012 (2024) https://doi.org/10.1051/e3sconf/202455101012
EEPES 2024

Preventing scale formation on heat transfer surfaces

Karlygash Idrissova[1], *Hristo* Beloev[2], *Aitbala* Tumanova[1], *Gulzira* Koldassova[1], and *Iliya* Iliev[3*]

[1]Almaty University of Power Engineering and Telecommunications Named after G. Daukeev, Department of Thermal Power Engineering, Almaty 050013, Kazakhstan
[2]University of Ruse “Angel Kanchev”, Department of Agricultural Machinery, 7017 Ruse, Bulgaria
[3]University of Ruse “Angel Kanchev”, Department of Heat, Hydraulics and Environmental Engineering, 7017 Ruse, Bulgaria

Abstract. The article considers the problem of scaling in power equipment on the example of Thermal Power Plants in the Republic of Kazakhstan. The most optimal solution is proposed – replacement of the traditional preparation of the feed water in the heat network by an ion exchange method for a more effective method using complex-forming reagents. The influence of inhibitor of mineral salts concentration (IMSC), trisodium phosphate, and Zinc Complex 1-hydroxyethylendiphosphonic acid (Zn-OEDF), as well as the heat carrier temperature on scaling intensity, has been studied to prevent the equipment from scale formation and corrosion. The technological parameters of feed water in the presence and absence of complex formers have been determined. The corrosion resistance of steel No. 3 samples in the presence of said reagents has been studied. The most optimal complexone has been chosen to prepare feed water for the TPP heating network.

1 Introduction

The control of scale formation is the main task that can be solved in the water treatment process at various power facilities, as the contamination of heat exchange equipment surfaces with deposits of mineral salts leads to reduced efficiency of equipment operation, and often the failure thereof [1].

A considerable number of experimental and theoretical studies are devoted to the problem of scaling [2]. However, there is still no unanimous opinion on the mechanism of scale formation and quantitative patterns of sediment growth, the uniform method of complexone selection and dosing. This is due to the complexity of scaling processes and the insufficient study of physical and chemical foundations of the scale formation on heat exchange surfaces, as well as the influence of various factors (temperature, speed, presence of impurities, quality composition of source water, etc.) on the growth of sediments.

The scale is formed by the interaction of water or reagents present in it with the heat-transmitting surface of the metal, as well as by the release of various soluble substances in

---

* Corresponding author: iiliev@enconservices.com

the water during boiling, heating and evaporation. The thermal conductivity of scale is tens, and often hundreds times less than the heat conductivity of the steel that the heat exchangers are made of. Therefore, even the thinnest layer of scale creates a large thermal resistance that leads to overheating and tearing of pipes.

At present, copper and iron oxides with more or less significant mixtures of silicic acid and zinc oxides are the main components of the sediment in the steam power plant. The appearance of iron and copper deposits in steam generators not only leads to the formation of bulges and fistulas, but also causes metal corrosion [3].

The influence of temperature on the scale formation varies in pure water and industrial solutions [4]. The increased water hardness contributes to the increased formation of scale, which significantly reduces the heat exchange rate, leads to high fuel consumption and overheating of metal surfaces [5]. The layer of scale comprises included metal corrosion products. The formation of the scale layer and corrosion products leads to a number of undesirable consequences:

- decreasing heat transfer coefficient and efficiency of heat power equipment;
- reducing working surface area and decreasing the efficiency of the vacuum deaerator;
- increasing energy cost of pumping water and difficulty in getting water to consumers;
- incomplete removal of old deposits;
- necessity of washing operations in the off-season with interruption of hot water supply;
- impossibility of cleaning outdoor and in-house heating and hot water networks [6].

Various control methods are available to prevent the scale formation: mechanical cleaning, chemical acid dissolution, ultrasonic cleaning, membrane filter application, magnetic water treatment, ion exchange methods. One of the modern and promising methods is the usage of complexone technologies. It is known that their application is advisable:

- when anti-scale measures are not very effective, for example, the used reagents are low effective, or the operation of existing water treatment plants is ineffective;
- when operating costs are very high or there is no water treatment plant;
- when there are restrictions on salt discharges in case of water softening by Na-cationization, H-cationization or liming methods.

2 Materials and methods

The Thermal Power Plant enters into the district heating supply zone of Almaty. It provides more than 30% of the total thermal load in the heating zone and provides electricity to the interconnected power system.

The projected capacity of the heat supply plant is 9200 m^3/h. The Plant of the heat supply system contains some units of "Asterisk" type. There are 14 units in total. The capacity of one unit is 720 m^3/h in sodium-cation mode and 1000 m^3/h in buffer mode. According to the tests, the minimum capacity of the unit in buffer mode is 900 m3/h. The hot water system is open.

The thermal recharge unit operates in the acidification and metering mode of the inhibitor of mineral salts concentration (IMSC), with subsequent decarbonization, and is intended to prepare water as an additive to be used in urban heat networks.

The source water, heated to a temperature of 35 – 40°C, is supplied from the turbine department to the unit of the heating network by one of the 1020 x 10 pipelines.

In order to prevent the scale formation on heating surfaces of heat exchangers, the source water is pre-treated, including acidification with technical sulphuric acid.

The purpose of the treatment of feeding water by acidification is to reduce the carbonate hardness (alkalinity) of the treated water by neutralizing the bicarbonate ions with hydrogen ions. Also in the treatment scheme of the feed water is provided by dosing IMSC to prevent the deposition of hardness salts on the surfaces of heating heat exchangers.

In accordance with articles [7, 8], the water-chemical regime shall ensure the operation of the equipment without damage of its components and economy reduction caused by corrosion of internal surfaces, and without scale and sludge formation.

The calculation of the consumption rate of complexones to treat the network water and to prepare the water for recharge of heat networks was carried out according to article [9].

Some laboratory tests of complexones, in particular the determination of corrosion rate and deposit formation in different waters at different temperatures were carried out in accordance with RD 153-34.1-17.465-00 “Guidelines to estimate the intensity of internal corrosion processes in thermal networks” [10].

The procedure described in article [11] was used to determine the rules for the use of complexones and corrosion inhibitors.

The laboratory studies of corrosion inhibitors determined the factors that characterize and influence the results of their use in different energy systems. Based on these data, instructions and flow charts for the management of the Water-Chemical Regime (WCR) and the operation of the Water Treatment Plants (WTP) according to [12] are drawn up.

The conditions for using complexones to prevent the formation of deposits and reducing the corrosion rate in the feed water preparation scheme for the thermal networks were determined.

Experimental procedure: To determine the possibility of using complexones for the preparation of the feed water for heating networks, as well as for the purpose of comparative analysis of the efficiency and technological feasibility of the treatment of feed water for the heating network reagents were investigated. They are IMSC, trisodium phosphate, and Zn-OEDF. They are permitted to be used in open water systems.

The experiments were performed in accordance with articles [10, 13, 14].

Water chemical analyses before and after laboratory experiments were carried out in accordance with articles [15-18].

According to the normative documents, the concentration of the inhibitors of salt deposits related to a specific object was selected based on the results of experiments taking into account the real composition of water, and the temperature of its heating.

In order to determine the optimum inhibitor concentration, parallel experiments were conducted at selected temperatures with different or identical concentrations of various complexones.

The essence of the technique for determining the optimal complexone concentration is that the initial water is treated with different doses of complexone and affects water with different temperatures. During the experiment, water samples are examined for water quality indicators, and the concentration and mode of complex treatment are selected, in which the scaling and corrosion processes are the least intense or not observed.

3 Results and discussion

Source water analysis was carried out and the status of water quality was estimated by hardness, calcium hardness, alkalinity and pH analysis.

Table 1. Source water quality indicators.

No	Indicators	Value
1	Total hardness, mg-Eq/dm^3	5.3
2	Calcium hardness, mg-Eq/dm^3	3.8
3	Alkalinity, mg-Eq/dm^3	4.2
4	pH	7.5

Water stability is a key indicator of water quality. Stable water is water, which in prolonged contact with metal and concrete surfaces does not change its composition, and does not emit or dissolve calcium carbonate.

To assess the impact of water stability on the corrosion processes in question, several calculation indices are now available. Most of these indices suggest estimating the behavior of carbon dioxide water compounds in specific thermodynamic conditions with the help of individual calculation formulas, for example, the Langelier index (in domestic practice known as «saturation index»). This index characterizes the properties of water qualitatively: water is either corrosive-active or has a propensity to scale.

The Riesner Stability Index (RSI) is an attempt to incorporate empirical data on the observed sediment thickness in urban water networks, or water supply systems. Like the Langelier index, the RSI is based on dissolved matter concentration. Risnar proposes to determine the relationship between calcium carbonate solubility and scale formation.

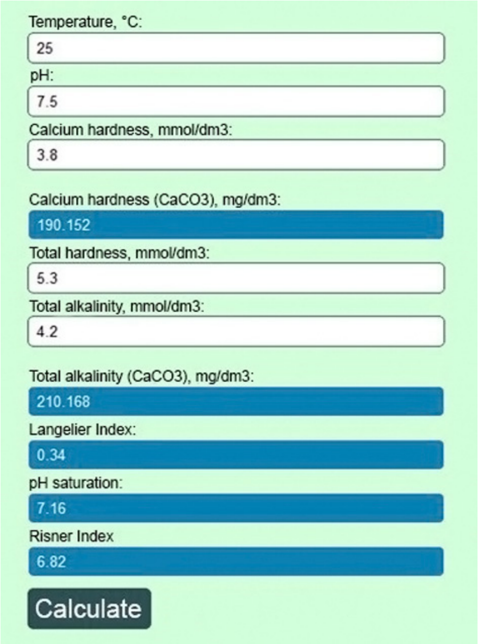
If the Langelier index is higher than the critical value, this indicates that the water is too much calcium carbonate; conversely, at lower critical values, the indices indicate that it is aggressive. The relationship of the Riesner index to the corresponding critical value is inverse.

The presence of several calculated indices of stability and their corresponding models of the composition of non-corrosive or non-corrosive carbonate-producing water shows, on the one hand, the complexity of the processes and, on the other hand, that each index is not universal.

In this regard, the monitoring of reagent doses and the parameters of water stabilization installations should be carried out by applying several stability indices and refined during technological research.

In this work, the control of the source water was carried out using the Langelier index and the Riesner index.

According to the estimation of calculated values of indices on the calculator "Water Stability" (see Figure 1), it was determined that the source water of the TPP has a tendency to scaling and corrosion.



Temperature, °C: 25
pH: 7.5
Calcium hardness, mmol/dm3: 3.8
Calcium hardness (CaCO3), mg/dm3: 190.152
Total hardness, mmol/dm3: 5.3
Total alkalinity, mmol/dm3: 4.2
Total alkalinity (CaCO3), mg/dm3: 210.168
Langelier Index: 0.34
pH saturation: 7.16
Risner Index 6.82

Fig. 1. "Water Stability" calculator.

The carbonate index of the source water at TPP *Ic* = 22.26 mg-eq/dm3, which exceeds the standard values. The excess of the carbonate index indicates a high scaling property of water. This can be caused by the presence of various salts in the water: mainly cations Ca2+ (calcium hard water) and Mg2+, organic substances (algae, colloids, humic substances from fertile soil - about 5 mg/l) which are dissolved by contact with natural water and soil.

Thus, the source water of the plant is unstable, that is, it has a propensity for scaling and corrosion, as well as having an above-normal carbonate water index. It follows that the use of source water is not possible without the preparation of a heating system as the feed water.

3.1 Analysis of IMSC efficiency according to the concentration at different temperatures

The IMSC laboratory tests were carried out at three temperatures: 60, 80, 100° C, with concentrations of 2mg/kg, 3mg/kg, and 4 mg/kg, not exceeding the maximum permissible concentration (MPC). The IMSC MPC in drinking water supply shall not exceed 4 mg/kg.

Some data on water quality indicators from laboratory experiments, which consisted of the experimental determination of the optimal concentration of complexone at different temperatures, are given in Table 2.

Based on laboratory data, it is possible to determine the efficiency of inhibitor anti-scale action and to select the optimal concentration of the complexone at different temperatures. The results of the laboratory experiments were processed in accordance with CO 34.37.536-2004 [14, 19].

The efficiency and optimum concentration of the complexone are determined by comparing the amount of variation of water hardness during the experience at different reagent concentrations. The efficiency of the complexone anti-scale action (*E*) is determined by the equation:

$$E = \left(\frac{Z_a}{Z_b}\right) \cdot 100\%, \tag{1}$$

where is Zb and Za – total water hardness before and after the experiment, respectively.

The phosphonate is considered quite effective when the E value is at least 95%.

As a result of the analysis of the obtained data, it should be noted that during the entire period of laboratory testing there is a small efficiency of IMSC. The maximum efficiency of the complexone anti-scaling action at 60°C is achieved at a dosage of 3 mg/kg

E=32.08%, at dosing IMSC with a concentration of 3 mg/kg and 4 mg/kg. The overall hardness of water does not change, it follows that at this temperature there is no need to dose IMSC with a concentration above 3 mg/kg.

The maximum reduction in total and calcium hardness at a temperature of 80°C occurs with a dosage of IMSC of 4 mg/kg. Thus, the maximum effectiveness of the anti-scale effect of IMSC at a temperature of 80°C is achieved at a dosage of 4 mg/kg E=50.94%. However, this efficiency of the complexon for a temperature of 80°C is a low indicator that will not be able to ensure scale-free and safe operation of thermal power equipment.

At a temperature of 100°C, maximum efficiency is achieved when dosing IMSC with a concentration of 4 mg/kg E=69.81%.

It is worth noting that at 100°C additional experiments were carried out with a higher concentration of IMSC to evaluate the scale-forming properties. As a result, it is observed that with a larger dosage of IMSC with a concentration of 4.5 mg/kg, the effectiveness of the inhibitor decreases, which indicates the inappropriateness of dosing the complexone above 4 mg/kg. Thus, the optimal dosing concentration of IMSC into the source water of the thermal power plant is 4 mg/kg.

Table 2. Results of experimental studies of complexons.

Reagent	**Temperature, °C**	**MPC of complexone, mg/kg**	**Concentration, mg/kg**	**Total hardness, mg-eq/dm^3**	**Calcium hardness, mg-eq/dm^3**	**Alkalinity, mg-eq/dm^3**	**Alkalinity for ph-ph, mg-eq/dm^3**	**Efficiency of anti-scale action complexone, E, %**
IMSC	60	4	2	3.8	2.4	4.6	0	28.30
			3	3.6	1.8	5.0	0	32.08
			4	3.6	1.4	5.6	0	32.08
	80	4	2	3.8	2.2	4.8	0	28.30
			3	3.6	1.8	5.0	0	32.08
			4	2.6	1.4	6.2	0	50.94
	100	4	2	2.8	2.0	4.0	0.6	47.17
			3	2.0	1.2	4.2	0.4	62.26
			4	1.6	1.0	4.8	0.2	69.81
			4.5	3.0	1.8	6.0	0.2	43.40
			5	2.6	1.6	6.2	0.2	50.94
Trisodium phosphate	60	3.5	2	5.4	2.8	3.6	0.4	-1.89
			3	4.4	2.6	3.4	0.4	16.98
			4	4.6	2.8	4.0	0.2	13.21
			8	3.8	1.4	4.8	0.2	28.30
			12	1.8	1.0	3.6	0.4	66.04
			16	1.6	0.4	3.6	0.4	69.81
	80	3.5	2	5.2	3.8	4.0	0.4	1.89
			3	4.6	2.8	3.8	0.4	13.21
			4	4.4	2.8	4.0	0.2	16.98
	100	3.5	2	4.4	3.4	4.0	0.4	16.98
			3	4.0	2.6	3.6	0.4	24.53
			4	3.8	2.8	4.0	0.4	28.30
			5	2.6	1.4	6.2	0.4	50.94
Zn-OEDF	60	5	2	2.5	1.6	3.4	0	52.83
			3	2.0	1.4	3.6	0	62.26
			4	1.8	1.2	3.8	0	66.04
	80	5	2	2.3	1.4	3.6	0	56.60
			3	1.6	1.3	3.8	0	69.81
			4	1.3	1.0	3.8	0	75.47
	100	5	2	2.1	1.2	3.8	0	60.38
			3	1.3	1.0	3.9	0	75.47
			4	0.8	0.6	3.9	0	84.91

As a result of the studies, the very low effectiveness of trisodium phosphate was noted.

The maximum effectiveness of the anti-scale effect of trisodium phosphate at a temperature of 60°C is 16.98%, which is achieved at a dosage of 3 mg/kg, and at a dosage of 4 mg/kg the effectiveness drops to 13.21%, which is associated with the instability of trisodium phosphate under conditions of high carbonate hardness.

Also, from the table data you can see the greatest reduction in total hardness when dosing trisodium phosphate 4 mg/kg, at which the maximum anti-scale efficiency of 16.98% is achieved.

At a temperature of 100°C, the maximum effectiveness of trisodium phosphate is 28.30%, which is achieved at a concentration of 4 mg/kg. At this temperature, an additional experiment was carried out with the addition of trisodium phosphate to the water at a concentration of 5 mg/kg, with which the efficiency increased to 50.94%.

During the laboratory experiment, additional experiments were carried out at a temperature of 600C with dosing trisodium phosphate into water with a concentration of C=8 mg/kg, at which the efficiency (E) was 28.30%, at C=12 mg/kg, E=66.04%, with C=16 mg/kg, E=69.81%. It follows that with an increase in the concentration of trisodium phosphate, an increase in the efficiency of inhibition is observed, however, these concentrations exceed the MPC standards in water for heat supply systems.

Based on the above, it follows that the use of trisodium phosphate for the preparation of make-up water for heating networks is inappropriate, due to its very low efficiency at temperatures up to 100°C.

However, this method of correcting impurities in boiler water is the main means of preventing the formation of calcium scale at thermal power plants, when introduced into boiler water containing hydrates, the following reaction occurs:

$$10Ca^{2+} + 6PO_4^{3-} + 2OH^- = 3Ca_3(PO_4)_2 + Ca(OH)_2 \, . \tag{2}$$

Unlike Ca^{2+} and Mg^{2+} phosphates, Ca^{2+} sulfate and silicate, which are deposited in the form of scales, hydroxyapatite is released into the solid phase in the form of dispersed sludge. With increasing temperature and pH of the solution, the solubility of hydroxyapatite decreases. The corrective phosphate regime is based on the constancy of the solubility product at a given temperature and depends on the processes of hydrolysis and complexation, which change with changes in the pH of the environment. With an increase in the concentration of trisodium phosphates, there is a danger of the formation of phosphate scales of magnesium and iron. In the presence of trisodium phosphates in boiler water, slight overheating of the wall of the steam-generating pipe causes sub-sludge corrosion.

It is known that inhibition of the scaling process with the help of phosphorus-containing complexons is based on the phenomenon of a threshold (or substoichiometric) effect, which is determined by the selective sorption of organic molecules on the active centers of the resulting crystals. These complexons increase the specific surface energy of the nucleus, its radius, and reduce the rate of nucleation. The unique ability of phosphonic compounds to inhibit the crystallization process of calcium carbonate is determined by the closeness of the crystal lattice parameters of $CaCO_3$ and the phosphonate ion, which has the shape of a distorted tetrahedron with a third-order symmetry axis.

The presence of phosphonate ion leads to an increase in the distance between cations and anions in the $CaCO_3$ molecule and, as a consequence, to a decrease in the energy of the crystal lattice of scale crystals, observed when treating water with phosphonic compounds in the form of an effect of reducing the strength of scale. In addition, in scale deposits, as a result of recrystallization of calcite into aragonite, needle-shaped crystals begin to grow, which, by the force of their growth, destroy the existing solid deposits, i.e. a self-cleaning process of the surface occurs - another phenomenon of the complexonic water-chemical regime, which is characteristic of Zn-OEDP.

In addition, zinc complexes of phosphonic acids, for example Zn-OEDP are also effective corrosion inhibitors.

From the results of laboratory studies it follows that the effectiveness of Zn-OEDP as a scale inhibitor increases with increasing concentration of the complexone in water and at a concentration of 4 mg/kg provides protection against scale deposits: at a temperature of 60°C - 66.04%, at a temperature of 80°C - 75.47%, at a temperature of 100°C - 84.91%. The increase in the effectiveness of the anti-scale effect of Zn-OEDP depending on the concentration at different temperatures can be seen from the data in Table 2. Thus, the optimal concentration of Zn-OEDP for the source water of the thermal power plant was 4 mg/kg.

When treating water with Zn-OEDP, a stable, constant decrease in total and calcium hardness can be noted. With a given chemical composition and water temperature in the range of 60-1000°C, the inhibitory effect of the reagent to prevent scale formation can be considered satisfactory. This can be explained by the fact that the complexon forms stable complexes with almost all cations, including alkali and alkaline earth metal cations, and has proven to be very effective in preventing the formation of deposits of such poorly soluble compounds as calcium carbonates, sulfates and phosphates.

In particular, the zinc complex of 1-hydroxyethylidene diphosphonic acid (Zn-OEDP) is effective for calcium carbonate, relatively ineffective for calcium sulfate, and is one of the most effective inhibitors of calcium phosphate precipitation.

Moreover, Zn-OEDP is used not only to correct the water chemical regime, but also to clean water heating equipment and pipelines from previously formed deposits.

In this work, an analysis was carried out of the influence of water temperature on the intensity of scale formation when dosing complexones: IOMS, trisodium phosphate, Zn-OEDP. With an increase in temperature from 60°C to 100°C, one can observe an increase in the efficiency of all complexons used in the experiment.

The increase in the effectiveness of inhibitors at the same concentration with increasing water temperature is explained by the fact that when boiling, bicarbonates turn into poorly soluble carbonates:

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O; \tag{3}$$

$$Mg(HCO_3)_2 \rightarrow MgCO_3 + CO_2 + H_2O. \tag{4}$$

And the more intense the heating occurs, the more intense these reactions occur. The content of $Ca(HCO_3)_2$ hydrocarbonates in the solution increases when the technological regime is violated, and depends on the pH of the solution. Calcium bicarbonate in solutions is in an unstable state, and any external influence can accelerate the crystallization of bicarbonates. The behavior of magnesium bicarbonates is similar to $Ca(HCO_3)_2$, but decomposition into carbon monoxide (II) and poorly soluble carbonates is one and a half times slower.

Carbonates $CaCO_3$ and $MgCO_3$ behave unstable. Thus, the solubility of carbonates decreases with increasing temperature and at constant pressure, and if the temperature and pressure are increased, the solubility increases, and $MgCO_3$ dissolves more intensively than $CaCO_3$, and at high solution temperatures, $MgCO_3$ hydrolyzes and, losing CO_2, transforms into $Mg(OH)_2$ [4].

Thus, temporary water hardness is eliminated, which explains the increase in the effectiveness of inhibitors with increasing temperature, but permanent water hardness cannot be removed by boiling. In these laboratory experiments, the constant hardness of water was eliminated by dosing IMSC, trisodium phosphate and Zn-OEDP into the water.

Based on the results of laboratory tests, the following conclusion can be drawn: for the considered reagents at a temperature of 100±5°C, the most effective inhibitor of deposits and corrosion for the preparation of source water from thermal power plants is Zn-OEDP. It is worth noting that Zn-OEDP is resistant to high temperatures (thermal decomposition is observed at temperatures above 210°C). Thus, laboratory studies made it possible to conduct a comparative analysis of inhibitors for corrective treatment of heating network make-up water and to determine the effect of temperature when dosing various complexes on the intensity of scale formation and corrosion occurring in the test water with the addition of inhibitors at different temperatures.

However, the conditions created in the laboratory cannot fully reflect the processes occurring in real conditions on real equipment. Therefore, when choosing a water treatment method, mandatory industrial tests using chemical and technological control methods are required.

To assess the intensity of corrosion processes, calculate the corrosion rate of an individual sample (*P*), mm/year, which is calculated using the formula:

$$P = \frac{47000\cdot(g_1 - g_2 - \Delta g)}{T\cdot S}, \tag{5}$$

where g_1 is the mass of the sample before testing, g; g_2 is the mass of the sample after testing and removal of corrosion products, g; Δg is the average for three samples that did not participate in the tests, the loss of mass of the base metal when removing corrosion products with acid, g; *T*-test time, days; *S* - surface area of the sample in contact with the coolant, mm^2.

The aggressiveness of supply water should be considered an indicator (criterion) of the danger of internal corrosion.

An indicator of the effectiveness of a complexone for protection against corrosion is the protective ability of the inhibitor (*Z*), which is calculated using the following formula:

$$Z = \frac{(\Delta P - \Delta P_1)}{\Delta P} \times 100, \%, \tag{6}$$

where ΔP - corrosion losses on a sample in a corrosive environment without the addition of an inhibitor, g; ΔP_1 - corrosion losses on a sample in a corrosive environment with the addition of an inhibitor, g.

Table 3. Results of experimental studies of complexons.

Experiment	**Weight of the sample before the experiment, m_1, g**	**Weight of the sample after the experiment**		**Weight loss of the sample after removal of corrosion products, %**	**Protective ability of the inhibitor (Z), %**	**Corrosion rate P, mm/year**	**Scale formation rate**
		Weight gain, m^2, g	**Weight loss (after removal of corrosion products), m^3, g**				
Single experience	105.3094	105.2695	105.2034	0.1007	-	0.0908	-2.5866
Experience with IMSC	105.6480	105.6558	105.6081	0.0378	62.36	0.0843	0.5057
Trisodium phosphate experience	104.0629	104.0417	103.9551	0.1036	-1.70	0.1037	-1.3743
Experience with	105.4148	105.4150	105.3986	0.0154	84.72	0.0454	0.0130

Analysis of steel samples showed that the use of IMSC in the source water of thermal power plants reduces the corrosion rate to 0.0843 mm/year compared to the values of a blank experiment, which is estimated by the permissible aggressiveness of network water. The reduction in corrosion rate when using IMSC can be seen in Figure 2.

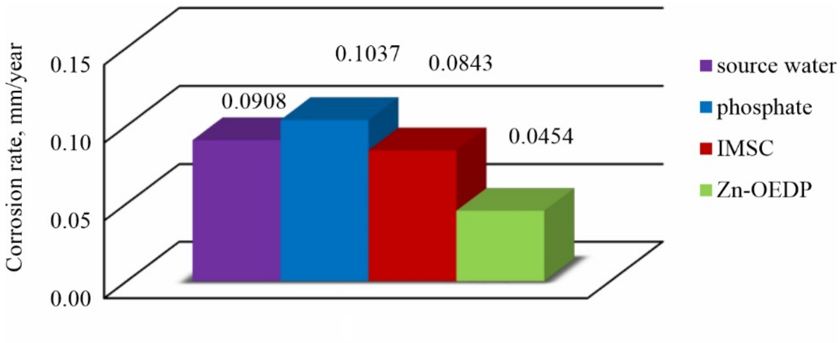


Fig. 2. The influence of inhibitors on the rate of metal corrosion

The protective ability of IMSC against corrosion is 62.36% (Figure 3).

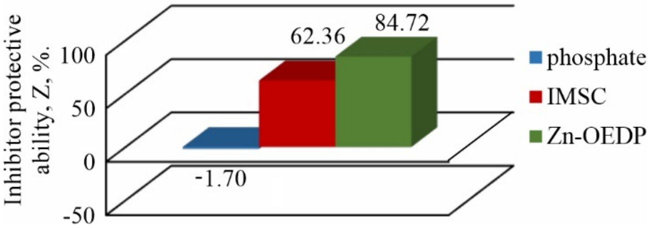


Fig. 3. The influence of inhibitors on the degree of metal protection against corrosion.

When the sample is kept in a solution with trisodium phosphate, the greatest weight loss of 0.1036% and the highest corrosion rate of 0.1037 mm/year are observed, characterized by high aggressiveness, which shows that trisodium phosphate is not only unable to protect against corrosion but also has the property of corroding metal, which is unfavorable and unacceptable for heat exchange equipment. However, when using trisodium phosphate, no increase in the rate of scale formation is observed.

Thus, in the current situation, there appear to be limitations to the use of trisodium phosphate given its unstable quality. The use of this reagent leads to negative consequences and a significant decrease in the effectiveness of the inhibitor. In Figure 3 you can see the negative corrosion protection value for trisodium phosphate.

Analysis of the corrosion rate results shows that the Zn-OEDP inhibitor exhibits satisfactory anti-corrosion properties. This is justified by the fact that when dosing Zn-OEDP, acceptable corrosion rates of indicator samples (see Figure 2) and scale formation rates were obtained, and Zn-OEDP has a high degree of inhibitor protection of 84.72%, Figure 3.

When analyzing the state of the surfaces of metal samples kept in a solution with complexones, signs of corrosion were observed when dosing IMSC and when dosing trisodium phosphate. The sample immersed in a solution with Zn-OEDP had the smoothest surface.

The high efficiency of Zn-OEDP as an inhibitor of scale formation and corrosion is explained by its belonging to zinc complexes of phosphonic acids, which are also effective corrosion inhibitors. Moreover, Zn-OEDP is able to wash away previously formed deposits, which are explained by the action of phosphonate ions to reduce the lattice energy of scale crystals, thereby reducing the strength of scale. As a result, recrystallization of calcite occurs, needle-shaped crystals begin to grow, which, by the force of their growth, destroy the existing solid deposits, i.e. the surface self-cleaning process occurs.

Thus, the results of experimental studies indicate the effectiveness of using Zn-OEDP.

4 Conclusion

Laboratory experiments to determine the Langelier index and the Riesner stability index of the source water at the station revealed that it is unstable, that is, it has a propensity for scaling and corrosion, and has an above-normal carbonate water index. It follows that the use of source water as feed water of the heating network is impossible without preparation.

In order to avoid the equipment from becoming covered with scale and corroded, we have selected the most optimal complexone for the feed water preparation scheme in the heating system, and laboratory tests of IMSC, trisodium phosphate and OEDF-Zn have been conducted.

The analysis of the data obtained shows that when dosing even the maximum concentration of IMSC and phosphonate allowed for an open heat supply system, the protective characteristics of corrosion inhibitors do not meet the requirements for safe operation and recharging of the heating network without scale and damage.

As a result, when dosing trisodium phosphate with a concentration of 4 mg/kg, the efficiency of complexone anti-scale action is 28.30%, the corrosion rate is 0.1037 mm/year; the degree of corrosion protection is 1.7%. At dosing IMSC with the most optimal concentration of 4 mg/kg, the efficiency of anti-scale action - 69.81%, the corrosion rate - 0.0843 mm/year, and the degree of protection against corrosion - 62.36%.

Based on the results of laboratory experiments and complexones comparative analysis, it is established that the water treatment method with the help of OEDF-Zn makes it possible to eliminate carbonate scale formation and to minimize corrosion at heating temperatures of up to 100°C and above. When OEDF-Zn is dosed with the most optimal concentration of 4 mg/kg, the efficiency of the anti-scale is 84.91%, the corrosion rate is 0.0454 mm/a, and the corrosion protection degree is 84.72%.

The results of the pilot studies thus indicate the effectiveness of OEDF-Zn.

The complexity of action mechanism and the variety of factors that affect the complexone effectiveness have not yet allowed the calculation methods to determine the possibility of their application. Therefore, experimental methods are commonly used to assess their effectiveness under different conditions, as we have done in the laboratory.

Laboratory conditions cannot fully reflect the processes taking place in the real world at production. Therefore, when choosing a method of water treatment, we recommend conducting mandatory industrial tests using chemical and technological control methods.

This study is financed by the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project BG-RRP-2.013-0001-C01.

References

1. Golovin V.A., Tyurina S.A., Shchelkov V.A., Russian Technological Journal, **10**, 3, 93-102 (2022)
2. K.I. Popov, M.S. Oshchepkov, N.A. Shabanova, Yu.M. Dikareva, V.E. Larchenko and E. Ya. Koltinova, International Journal of Corrosion and Scale Inhibition, **7**, 1, 9-24 (2018)

3. Karlygash Idrissova, Aitbala Tumanova, Gulzira Koldassova, International Journal of Engineering and Advanced Technology (IJEAT), **8**, 3S, 326-330 (2019)
4. Kekin P.A., Dissertation for the competition, Degree of candidate of technical sciences in specialty 05.17.01 – Inorganic technology substances, Moscow (2017)
5. Idrissova K.S., Tumanova A.A., Eurasian chemical-technological journal, **16**, 4, 329-332 (2014)
6. Chausov F.F., Kazantseva I.S., Heat supply News, **7**, 107, (2009)
7. Rules for the technical operation of electrical stations and networks of the Republic of Kazakhstan, SO 153-34.20.501-2003 (2003)
8. Rules for the design and safe operation of steam and hot water boilers, With changes No.1 and No.2, St. Petersburg: DEAN Publishing House, p.208 (2002)
9. List of regulatory documents on water treatment, treatment facilities, condensate purification, on the operation of energy oils and electrolysis plants, mandatory for execution by technological departments of energy enterprises, RD 34.01.203.
10. Guidelines for assessing the intensity of internal corrosion processes in heating networks, RD 153-34.1-17.465-00.
11. Maximum permissible concentration of chemicals in water of drinking and cultural water supply facilities, GN 2.1.5.1315-03.
12. Guidelines for the development of instructions and regime maps for the operation of pre-boiler water treatment plants and for maintaining the water-chemical regime of steam and hot water boilers, RD 10-179-98.
13. Guidelines for determining the brand and optimal concentration of anti-scale agents for treating make-up and network water of heating supply systems, approved by RAO UES of Russia, RD 153-34.0-37.533-2001, M.: JSC VTI, p.55 (2005)
14. Guidelines for the use of anti-scale agents and corrosion inhibitors OEDFC, AFON 200-60A, AFON 230-23A, PAF-13A, IOMS-1 and their analogues, SO 34.37.536-2004.
15. Production waters of thermal power plants. Methods for determining hardness, SO 153-34.37.523.8-88.
16. Production waters of thermal power plants. Method for determining alkalinity, SO 153-34.37.523.7-88.
17. Production waters of thermal power plants. Method for determining calcium hardness, SO 153-34. 70. 953-25 – 92.
18. N. Zlatov, I. Iliev , A. Terziev, V. Kamburova, *Influence of climatic data and degradation factor on the efficiency of the Photovoltaic modules*, in Proceedings of the 15th International Workshop on Research and Education in Mechatronics REM, (2014)
19. B. Ongar, I. K. Iliev, G. K. Smagulova, A.I. Nurova, Numerical simulation of the formation of nitrogen oxides in pulverized furnaces Journal of Engineering Science and Technology Review, **2**, 171-175, (2020)