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Prevention of scaling and corrosion by reagent KISK-1

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ABSTRACT

The influence of the reagent KISK-1 (Russia) on the rate of corrosion of Steel 3 in mineralized (“hard”) waters of two industrial plants was studied. The water supply system of the two plants used in the study had sufficient difference in chemical composition. Thermostability of these waters was investigated in the presence of KISK-1 (the complex inhibitor of scaling and corrosion). It was shown that when used at correct dosage, KISK-1 is capable of significantly reducing the rate of corrosion of Steel 3 while also providing the water system’s thermostability in evaporation, i.e. preventing the formation of sediments and deposits of salts. It was shown that the optimum dosage of KISK-1 remains relatively stable, while the tested waters were evaporated by 1.7–2.5 times. At the same time, the existence of some threshold concentration, above which the increase in the concentration of KISK-1 does not produce a proportional decrease in the rate of corrosion of Steel 3 was established. The approach offered in this study provides a useful framework to conduct comparative analysis and choose suitable reagents for the prevention of scaling and corrosion in water supply systems in a variety of industrial plants.

Keywords: Thermostability; Inhibition of corrosion and scaling; Water supply system; Rate of corrosion; Hard waters

1. Introduction

Organophosphonates and various derived complex compounds and compositions have been broadly used in closed-circuit water systems of industrial and power-generating plants as a means to decrease the corrosion of metal and prevent scaling [1–6]. Estimated annual spend on water treatment reagents exceeds one billion US dollars equivalent with increases of approximately 10% annually [7]. The leading world suppliers of water treatment reagents are “Nalco” (USA), “BK Giulini Chemie” (Germany), “Tehnohimreagent” (Great Britain–Ukraine), “Himprom” (Russia), and “Niton” (Russia). However, most technical documentation for the reagents supplied by these producers provides no criterion allowing to estimate each reagent’s suitability and efficiency for use in specific conditions of particular water system or a plant. The properties of reagents are usually estimated by their respective under manufacturer “model” conditions that often significantly deviate from real-life industrial applications.

The purpose of the present work was to investigate the possibility to use KISK-1 (the complex inhibitor of

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scaling and corrosion) produced by chemical company "Niton" (Russia) to inhibit metal (Steel 3) corrosion and prevent scale formation in two closed-circuit industrial water systems in which feeding waters had different chemical compositions. The study also attempted to establish the relationship between the degree of evaporation of the waters and the effectiveness of KISK-1 in inhibiting scaling and corrosion.

In our opinion, the approach of this study can be applied to estimate efficiency and conduct comparative analysis and select a suitable reagent for concrete service conditions in a broad range of industrial enterprises and applications.

2. Experimental

Technical waters of "Chelyabinsk zinc factory" and production association "Balhashtsvetmet" (the water of Lake Balkhash) were used in this study. These waters feed closed-circuit water supply systems of the above two plants. Table 1 lists the chemical compositions of these waters on the basic components. It is seen that they have sufficient differences in salinity and concentrations of various components.

Investigations were carried out using the original waters (see Table 1) and waters after their evaporation by two, three, and four times, a proxy for possible service conditions in the circulating water supply systems of the plants. In order to prevent premature nucleation of scale crystals, evaporation of original waters to the required concentrations was done gradually, without boiling and under vacuum at temperature 40˚C, together with added KISK-1. Such mode of evaporation simulated operational condition of circulating water supply systems where slow evaporation of water takes place leading to a gradual increase in concentration. The concentration of KISK-1 in the original water before evaporation ranged from 2 to 40 mg/l.

The rate of corrosion of Steel 3 in evaporated and original waters was measured by electrochemical method using corrosion meter "*Expert 004*" (Russia) at natural aeration of water at 20˚C [8]. Measurements were carried out under vacuum in stationary cell (without water flow) using two-electrode test probes (samples made from Steel 3). The test probes were 6 mm in diameter and 50 mm in height. Before measurements, the surfaces of the test probes were polished mechanically and degreased according to GOST 9.502-82 (Russia) standard methology. Readouts of "*Expert 004*" were registered in 30-min intervals. The experiments were conducted until a constant rate of corrosion was achieved (4–6 h), while the solution was continuously stirred by a magnetic stirrer, resulting in the speed flow around the samples of about 1.2 m/s. The error of measuring the rate of corrosion with the help of "*Expert 004*" should not exceed 10%.

The thermostability of waters at evaporation was evaluated by measuring their alkalinity (the concentration of ions HCO_3^-) and Ca^{2+}. These parameters were determined by titration analysis [9,10].

3. Results and discussion

3.1. Rate of corrosion

At the first stage, the rate of corrosion of Steel 3 was measured in original waters, prior to their evaporation. The results are presented in Fig. 1.

As seen from Fig. 1, the rates of corrosion in the water of Lake Balkhash and technical water of "Chelyabinsk zinc factory" are different almost by two times. The higher salinity of Balkhash water corresponds to higher rate of corrosion of steel. However, from the comparison of salinity of the waters (1,792 and 220 mg/l, see Table 1), it is seen that this relation is not proportional, since the salinity of the tested waters differed by almost 10 times.

Table 1
The chemical compositions of tested waters

Components	Chelyabinsk zinc factory	Water of Lake Balkhash
pH	8.00	8.53
Ca^{2+} (mg/l)	52	48
HCO_3^- (mg/l)	220	287
Mg^{2+} (mg/l)	22.70	100.93
Fe_{total} (mg/l)	0.19	0.102
Cl^- (mg/l)	23.45	295.00
SO_4^{2-} (mg/l)	41.68	604.00
TDS (mg/l)	220	1,792

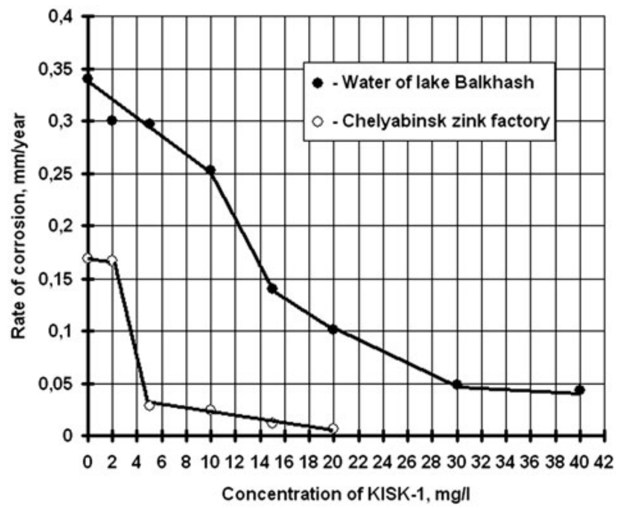

Fig. 1. Influence of KISK-1 on the rate of corrosion of Steel 3 in salt waters.

The introduction of KISK-1 allowed to decrease the rate of corrosion of Steel 3 in the tested waters. A threshold concentration of the reagent KISK-1, above which there was no sharp decrease in the rate of corrosion was observed in both waters. The salinity of the waters affects the value of this KISK-1 threshold. For technical water of "Chelyabinsk zinc factory," the threshold concentration of KISK-1 was about 5 mg/l, whereas for the water of Lake Balkhash, it was near 30 mg/l. Obviously, for efficient inhibition of corrosion in these waters, it is irrational to exceed the threshold concentration of KISK-1, since increasing the concentration of the inhibitor above that threshold does not result in the sharp decrease in the rate of corrosion. It should be also noted that in earlier studies of inhibition of scaling, similar threshold concentrations were found, above which no sharp decrease in the rate of scaling was observed [2].

The data from this study indicate a disproportionate increase in the rate of corrosion with an increase in the salinity of the water. Therefore, we supposed that a modest increase in the degree of concentration of the tested waters via evaporation in circulating water supply systems will not result in a sharp increase in the rate of corrosion. For examination of this supposition, experiments to measure the rate of corrosion of Steel 3 at different degrees of evaporation of solution were carried out. Results of these experiments are shown in Figs. 2 and 3.

As expected, Fig. 2 illustrates that the rate of corrosion of Steel 3 in technical water of "Chelyabinsk zinc factory" without introduction of KISK-1 slightly increases with the degree of evaporation (n) from 0.168 mm/year (the original water, $n = 1$) to

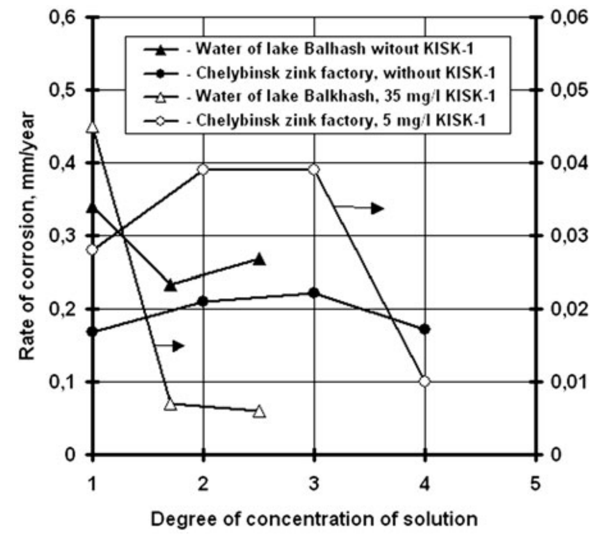

Fig. 2. Influence of KISK-1 on the rate of corrosion of Steel 3 in technical water of "Chelyabinsk zinc factory" and the water of Lake Balkhash at different degrees of evaporation of solution.

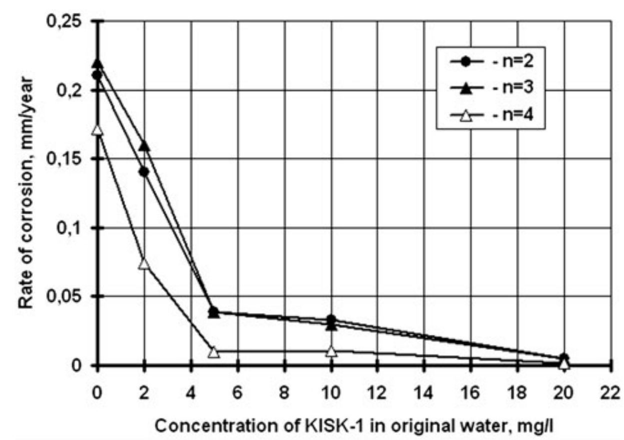

Fig. 3. Influence of KISK-1 on the rate of corrosion of Steel 3 in technical water of "Chelyabinsk zinc factory" at different degrees of its evaporation (n).

0.222 mm/year at $n = 3$. However, at $n = 4$, some reduction in the rate of corrosion to 0.172 mm/year is observed. A similar picture takes place after the introduction of KISK-1 into the solution. At concentration of KISK-1 in the original water before evaporation of 5 mg/l, the rate of corrosion at the beginning also increases with evaporation of the solution, but at $n = 4$, it sharply falls to 0.01 mm/year (Fig. 2). Overall, an increase in the concentration of KISK-1 in technical water of "Chelyabinsk zinc factory" produced significant reduction in the rate of corrosion. The value of the threshold concentration of KISK-1, however, does not change from 5 mg/l (Fig. 3).

At the evaporation of the water of Lake Balkhash, as opposed to technical water of "Chelyabinsk zinc factory," the decrease in the rate of corrosion of Steel 3 from 0.34 mm/year (the original water, $n = 1$) to 0.234 mm/year at $n = 1.7$ (Fig. 2) was observed immediately. This may be explained by the reduction in dissolved oxygen concentration in the solution (evaporation of the water was conducted under vacuum) or by sacrificial protection of steel as a result of accumulation of salts of alkali earth metals in the solution. Further evaporation of this water results in the increase in the rate of corrosion of Steel 3 (Fig. 2), which contradicts the sacrificial protection hypothesis. Introduction of KISK-1 into the solution before its evaporation, as in the case of "Chelyabinsk zinc factory" water, sharply decreases the rate of corrosion to a value 0.06 mm/year.

From Fig. 2, it is seen that there is a difference in the relationship of changing the rate of corrosion in tested waters without introduction of KISK-1. For example, with the evaporation of solution, the rate of corrosion in technical water of "Chelyabinsk zinc factory" immediately increases, but in the water of Lake Balkhash it falls (Fig. 2). These differences possibly result from various concentrations of dissolved oxygen in original and evaporated waters and may also be explained by the change in ionic strength of the solution. These factors have opposite effects on the rate of corrosion.

3.2. *Thermostability of waters*

The data on the influence of KISK-1 on thermostability of waters during evaporation are presented in Figs. 4–6. The dotted line in these figures shows an expected (theoretical) value of concentration of ions Ca^{2+} and HCO_3^- in the solution at different degrees of its evaporation and full thermostability, i.e. without formation of a deposit of hardness salts.

As can be seen from Fig. 4, increasing concentration of KISK-1 in technical water of "Chelyabinsk zinc factory" leads to an increase in the thermostability with deviations of experimental points from the theoretical line decreasing. The theoretical line coincides with experimental points at concentration of KISK-1 in the original water (before evaporation) equal or exceeding 5 mg/l. However, at evaporation of the solution above three, the thermostability of the water falls and significant deviations from the theoretical line are observed. This indicates the formation of hardness salts deposits. The rise in concentration of KISK-1 in the solution up to 10 and 20 mg/l does not result in stabilization of the water (Fig. 4). As expected, Fig. 5 reveals a similar relationship. This

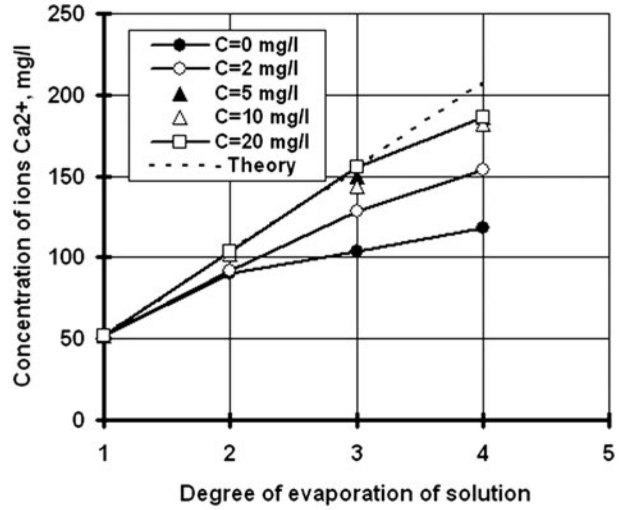

Fig. 4. Influence of concentration of KISK-1 (C) on the change of concentration of ions Ca^{2+} in technical water of "Chelyabinsk zinc factory" at different degrees of its evaporation.

illustrates that changes in concentrations of ions Ca^{2+} and HCO_3^- during evaporation of water indicate the beginning of formation of hardness salts deposits.

An investigation of thermostability of the water of Lake Balkhash found a similar relationship (Figs. 6 and 7). However, the study was done at concentration of KISK-1 in original water of 35 mg/l, which was optimal concentration for decreasing the rate of corrosion (please see Fig. 1). From Figs. 6 and 7, it can be

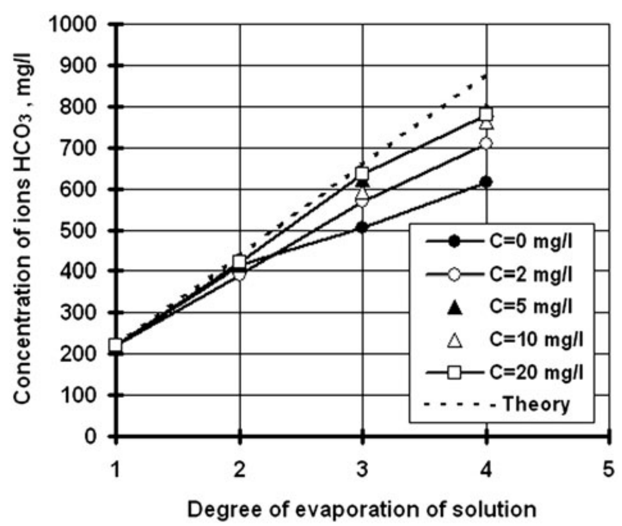

Fig. 5. Influence of concentration of KISK-1 on the change of concentration of ions HCO_3^- in technical water of "Chelyabinsk zinc factory" at different degrees of its evaporation.

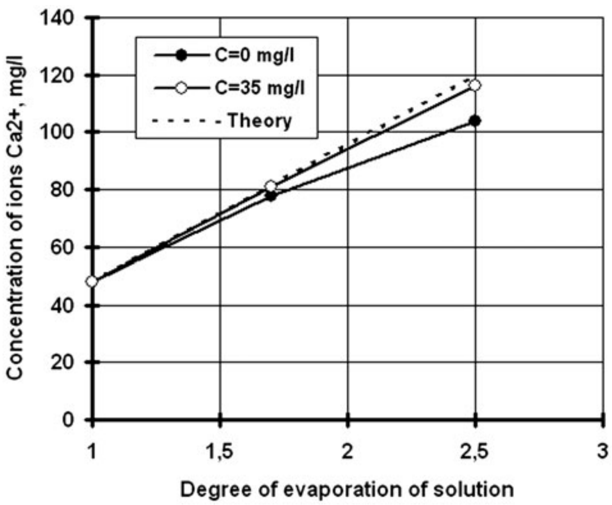

Fig. 6. Influence of concentration of KISK-1 on the change of concentration of ions Ca^{2+} in the water of Lake Balkhash at different degrees of its evaporation.

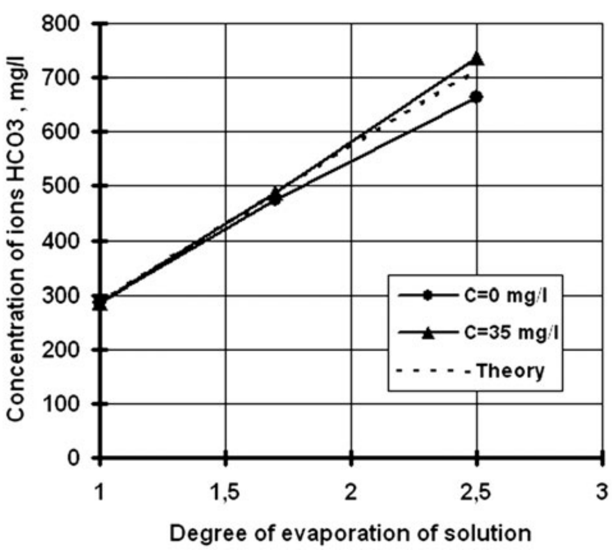

Fig. 7. Influence of concentration of KISK-1 on the change of concentration of ions HCO_3^- in the water of Lake Balkhash at different degrees of its evaporation.

seen that such concentration provides full thermostability of the water at its evaporation by 1–2.5 times in circulating water supply system of the plant. Comparison of these results with data for technical water of "Chelyabinsk zinc factory" revealed that concentrations of KISK-1 that simultaneously protect Steel 3 from corrosion and provide the thermostability of the water essentially coincides. This optimal concentration of KISK-1 in technical water of "Chelyabinsk zinc factory" is 5 mg/l (Figs. 1–5).

In summary, our investigations revealed that optimal dosage of KISK-1 allows to significantly decrease the rate of corrosion of steel and prevent precipitation of hardness salts in circulating water supply systems. In addition, the inhibiting effect of KISK-1 does not decrease at evaporation of circulating water by 1.7–2.5 times.

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