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Effect of various phosphate inhibitors on corrosion of low carbon steel in 3% sodium chloride solution

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Abstract. The inhibitory properties of various phosphate inhibitors were studied on low-carbon steel (St3) in 3% sodium chloride solution. Standard gravimetric method and electrochemical measurements were used. It has been shown that adding calcium manganese phosphate to a 3% NaCl solution in concentrations of 5-100 mg P₂O₅/l reduces the corrosion rate of St3. The inhibitor efficiency at 100 mg P₂O₅/l is 91.8%. Adding sodium polyphosphate at concentrations of 1-20 mg P₂O₅/L to the chloride solution increases the corrosion rate of St3. The inhibitor efficiency of NaPO₃ at 100 mg P₂O₅/l is 24.4%. The results of electrochemical tests obtained by taking and calculating polarization curves confirm the data of gravimetric measurements. Using electron microscopy, it has been shown that uneven loose deposits with low protective properties are formed on the steel surface in a 3% sodium chloride solution both without additives and with sodium polyphosphate additives. When sodium chloride (Ca, Mn)(PO₃)₂ is added to the solution, ordered fine-grained deposits with high protective properties are formed on the steel. IR spectroscopic analysis of deposits formed on the surface of St3 in 3% NaCl solution with addition of various phosphates was performed. It has been found that uniform coatings containing insoluble calcium hydrophosphates are formed in the presence of (Ca, Mn)(PO₃)₂.

Keywords: corrosion, corrosion rate, inhibitor, inhibitory properties, inhibitor efficiency.

1. Introduction

Low-carbon steel (St3) is the main structural material from which pipelines and systems of industrial and domestic and drinking water supply are made. Steel of this grade has low corrosion resistance in aqueous media [1, 2]. Therefore, the task of ensuring the reliable operation of these systems in a corrosive manner is urgent.

Violation of the established water supply mode due to corrosion damages of steel pipelines can lead to serious equipment accidents causing large material and environmental damage [1, 2].

Corrosion of metal in water is an electrochemical process. Products of cathode and anode reactions OH⁻ and Fe²⁺ formed near the metal surface can slow down the corrosion process [2-4]. The inhibitory effect of corrosion products is found in cases where they are deposited in a uniform, relatively dense and uniform layer in thickness. The possibility of formation of such a layer is determined by the operating mode of the water supply system and the chemical composition of the water. A continuous flow of water at a speed of about 0.5 m/s favors the formation of a protective layer of corrosion products [2].

Presence of increased concentrations of corrosion activating ions such as chlorides and sulphates in aqueous media prevents formation of protective rust layers. Chlorides and sulfates lead to the formation of loose, porous deposits of corrosion products that slightly inhibit the corrosion process and are easily washed away by water moving through the pipes. Chlorides and sulfates contribute to localized corrosive

lesions. Their concentration is always higher near the anode sites where the metal dissolution reaction takes place [2].

The most common method of corrosion protection of pipelines and water supply systems for various purposes is inhibitory protection [4]. The advantages of this method over others are [4]:

- possibility of timely response to changes in corrosion situation;
- possibility of use for protection of pipelines that have been in operation for a long time;
- there is no need to fundamentally change the existing process diagrams;
- relatively low capital expenditures.

The main advantage of inhibition is the ability to control the rate of corrosion. By changing the dosage of the inhibitor or using inhibitors with various anticorrosion properties, it is possible to reduce the corrosion rate to an acceptable level [4].

In world practice, organic compounds containing active basic functional groups are widely used.

The authors of a number of papers investigated the use of organic phosphonic acids to protect carbon steel from corrosion in neutral aqueous media and showed that they are quite effective inhibitors [5-7].

Organic phosphonic acids are widely used as water treatment agents due to their low toxicity, high stability and corrosion inhibition activity in neutral aqueous media [8-13].

The authors [12-15] studied the effectiveness of propylphosphonic acid (PPA) as a corrosion inhibitor in combination with the divalent cation Zn²⁺ by gravimetric and electrochemical methods. It has been proven that a synergistic

mixture of 75 ppm PPA and 100 ppm Zn²⁺ is an effective carbon steel corrosion inhibitor that not only slows down the anodic dissolution of carbon steel, but also reduces the oxygen content of cathodic regions during corrosion inhibition.

Despite the high anticorrosive properties, inhibitory compositions based on phosphonic acids and zinc salts are not widely used in Kazakhstan due to the lack of own production and the high cost of imported reagents.

Currently, there is also a tendency to use in the protection of water supply systems of the so-called "green" inhibitors, which are water extracts of products of natural origin, and in particular such as turmeric, saffron, oats, etc. According to the authors [16], these inhibitors are mixed-type inhibitors and their effectiveness increases with an increase in concentration from 0.04 g/L and higher. These studies are still at the stage of laboratory research.

Among inorganic substances, phosphate, silicate, chromate, nitrite, boron-containing compounds are used as inhibitors [2, 17-19]. However, despite the high efficiency, the use of chromates and nitrites does not find practical use due to their high toxicity [14]. The use of silicates is possible only for waters with low mineralization. In addition, their use can increase the pH of water [2, 18]. Highly soluble inorganic phosphates of alkali metals, including polymeric ones, have low efficiency at low concentrations, and at high concentrations they can increase the rate of metal corrosion due to the formation of soluble polyphosphate complexes [2, 19].

Kazakhstan has all the prerequisites for the production of domestic phosphate corrosion inhibitors. Their production is complicated by the fact that most of the natural waters of the Republic have increased concentrations of chloride and sulfate ions that promote corrosion of St3 steel.

Since the information on the inhibitory properties of inorganic phosphate inhibitors in waters with a high chloride content is extremely small in the scientific and technical literature, the purpose of this work was to study the corrosive behavior of low-carbon steel (St3) in sodium chloride solutions in the presence of various phosphate inhibitors.

The objects of research were the well-known sodium polyphosphate inhibitor NaPO₃ and the new calcium-manganese phosphate inhibitor (Ca, Mn)(PO₃)₂, developed earlier on the basis of manganese ore enrichment waste from some deposits in Kazakhstan [20, 21].

2. Materials and methods

2.1. Experimental

Studies of the inhibitory properties of the synthesized product were carried out by the gravimetric method at room temperature according to the standard procedure [22] on samples in the form of plates 20x50x1 mm in size. Samples were made from low-carbon steel grade St3 composition (according to State standard GOST380-2005): 0.12% C, 0.2% Cr, 0.17% Mn, 0.025% P, 0.17% Si, 0.018% S, 0.25% Ni, 0.25% Cu, the rest is iron.

Before testing, the surface of the samples was polished, washed with ethanol, distilled water [24], and dried in a desiccator with calcined calcium chloride to constant weight. For each sample, the initial mass was measured on high-precision scales (with an error of no more than ± 0.1 mg) and the surface area was measured. The tests were carried out on five parallel samples for each inhibitor and each concentration. Statistical

processing of the results was carried out using the Ordinary Least squares (OLS) method at a confidence level of 0.90 [24].

The corrosive medium was 3% sodium chloride solution in absence and in presence of phosphative inhibitors of various compositions and concentrations. The tests were carried out in glass chemical beakers, the volume of the tested solutions was 200 cm³. The well-known corrosion inhibitor sodium polyphosphate NaPO₃ served as the reference inhibitor. After the end of the tests, the samples were removed from the solutions, dried in air, and the surface was visually assessed. After visual evaluation, the corrosion products were removed with a plastic spatula, washed with ethanol, distilled water, dried in a desiccator with calcined calcium chloride, and weighed.

Potentiodynamic polarisation studies were carried out using Potentiostat/Galvanostat Model «Palmsens 4» at a scan rate of 1 mV s⁻¹ under static conditions. The studies were carried out in a classical three-electrode electrochemical cell at room temperature. A chlorine-silver electrode served as a reference electrode, and a graphite electrode 5 mm in diameter was used as an auxiliary electrode. Steel plates (St3) with dimensions of 10x10x1 mm served as working electrodes. The working surface area of the samples was 1 cm², the rest surface was isolated with epoxy resin. 3% sodium chloride solution in absence and in presence of inhibitors of different composition and concentrations was used as electrolyte. At the beginning of the test, the working electrode was immersed in a corrosive medium for 3 hours to obtain a stabilized open circuit potential.

The steel surface morphology after testing in a 3% NaCl solution supplemented with inhibitors was removed using a low-vacuum raster electron microscope JSM-6490LA.

The molecular composition of the deposits formed on the surface of steel samples during the tests was studied by IR spectroscopic method by pressing the test substance with a sample of potassium bromide. Infrared absorption spectra were recorded on the Fourier spectrometer «Nicolet 5700» in the 400-3600 cm⁻¹ region.

3. Results and discussion

The inhibitory properties of the calcium-manganese phosphate product were studied gravimetrically [22] under static conditions at room temperature. The corrosion rate of low-carbon steel grade St3 was determined by formula (1):

$$V_{corr} = \frac{(m_o - m_{sac})}{S \cdot T}, \frac{mg}{cm^2 \cdot day} \quad (1)$$

where m_o and m_{sac} are the mass of the sample before and after the testing and removal of corrosion products from the surface of the sample, g; S is the surface area, cm²; T is the time of testing, days.

Inhibitor efficiency, IE (%) was calculated by the formula (2):

$$IE = \frac{100(v_{corr}^o - v_{corr}^{inh})}{v_{corr}^o} \quad (2)$$

where V_{corr}^o and V_{corr}^{inh} are the corrosion rate in absence and in presence of inhibitor.

The protection coefficient γ was determined according to (3):

$$\gamma = \frac{(v_{corr}^o)}{v_{corr}^{inh}} \quad (3)$$

The rate of accumulation of corrosion-salt deposits on the surface of a steel sample was calculated by formula (4):

$$V_{dep} = \frac{(m_f - m_o)}{S \cdot T}, \text{mg} / \text{cm}^2 \text{day} \quad (4)$$

where m_o and m_f are the mass of the sample before and after the testing, g.

The results obtained are presented in Tables 1-2.

Table 1. Dependence of corrosion parameters on concentration of inhibitor NaPO₃ in 3% NaCl solution

Index	NaPO ₃ concentration, mgP ₂ O ₅ / l						
	0.0	1.0	5.0	10.0	20.0	50.0	100.0
Corrosion rate V_{corr} , mg/sm ² day	0.220	0.238	0.257	0.275	0.277	0.211	0.166
The protection coefficient γ	-	0	0	0	0	1.04	1.32
Inhibitor efficiency IE, %	-	0	0	0	0	3.91	24.4
The rate of accumulation of deposits on the surface of the metal, V_{dep} , mg/cm ² day	0.163	0.320	0.187	0.189	0.367	0.200	0.266

Table 2. Dependence of corrosion parameters on concentration of inhibitor (Ca,Mn)(PO₃)₂ in 3% NaCl solution

Index	(Ca,Mn)(PO ₃) ₂ concentration, mgP ₂ O ₅ / l						
	0.0	1.0	5.0	10.0	20.0	50.0	100.0
Corrosion rate V_{corr} , mg/sm ² day	0.220	0.226	0.219	0.213	0.198	0.168	0.018
The protection coefficient γ	-	0	1.004	1.030	1.11	1.31	12.22
Inhibitor efficiency IE, %	-	0	0.45	3.18	10.0	23.6	91.8
The rate of accumulation of deposits on the surface of the metal, V_{dep} , mg/cm ² day	0.163	0.150	0.194	0.188	0.188	0.272	0.087

It follows from the results that the known sodium polyphosphate inhibitor NaPO₃ in a 3% NaCl solution in the concentration range of 1-20 mgP₂O₅/l accelerates the corrosion process. At the same time, the corrosion rate of St3 increases from 0.220 mg/sm² day in a 3% solution of NaCl without additives to 0.277 mg/sm² day with the addition of 20 mgP₂O₅/L sodium polyphosphate (Table 1). Inhibitory properties for NaPO₃ begin to appear only at 50 mgP₂O₅/L (IE = 3.91%) and at 100 mgP₂O₅/L, the Inhibitor efficiency is 24.4% (Table 1).

Calcium-manganese phosphate inhibitor (Ca, Mn)(PO₃)₂ shows inhibitory effect already from 5 mg P₂O₅/l concentration. With an increase in its concentration, the corrosion rate decreases monotonously and at a concentration of 100 mgP₂O₅/l, the protection coefficient is 12.22 with the Inhibitor efficiency of 91.8%, which indicates high inhibitory properties of this phosphate (Table 2).

A histogram, shown in Figure 1, was constructed from gravimetric data to provide a clearer representation of the results of the effect of the test inhibitors on the corrosion resistance of steel samples.

The results of gravimetric tests are confirmed by electron microscopic images of the surface of steel samples (Figures 2-3). Deposits formed on the surface of a steel sample in a 3% NaCl solution without additives (Figure 2, A) are represented by dendrite-like grains of various shapes and sizes,

there are relatively large voids between the grains, which indicates the formation of uneven loose coatings with low protective properties.

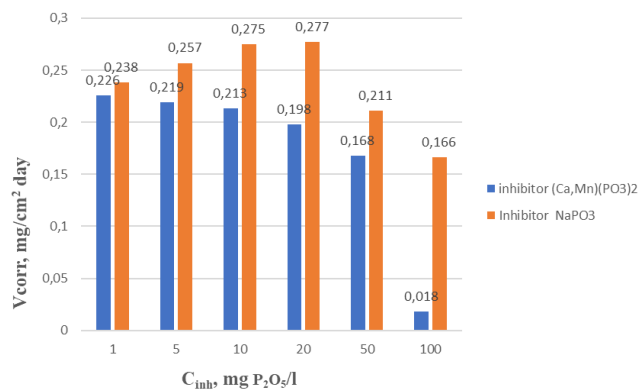


Figure 1. Histogram of the dependence of the corrosion rate of steel (Ct3) in 3% NaCl solution on the composition and concentration of phosphate inhibitors

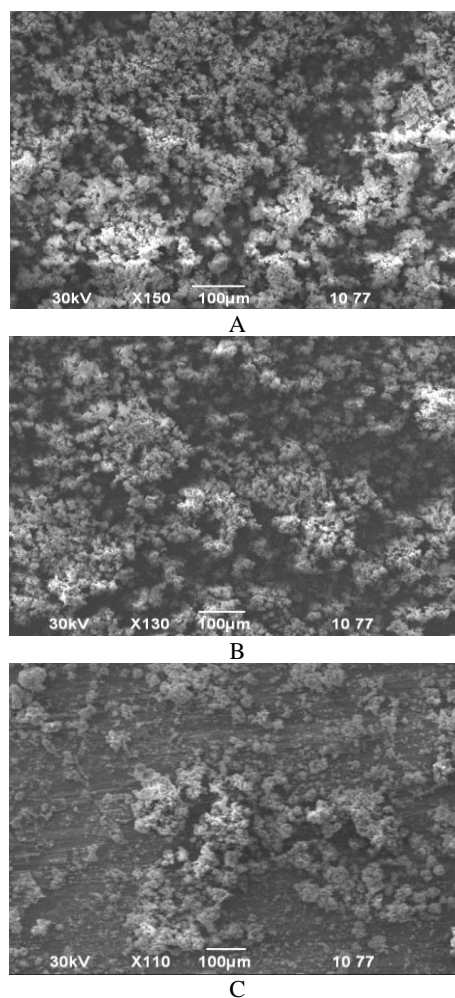


Figure 2. EM photographs of the surface of the steel sample after testing in 3% NaCl solution without inhibitors (A) and with NaPO₃ additives in concentrations (mgP₂O₅/L): B - 50; C - 100

The nature of the deposits on the steel surface in the sodium chloride solution with sodium polyphosphate additives (Figure 2, B-C) practically coincides with the nature of the deposits on the control sample without additives, which confirms the lack of protective properties of the NaPO₃ in the 3% NaCl solution.

Deposits formed on the steel surface in a 3% NaCl solution supplemented with calcium-manganese phosphate inhibitor (Ca, Mn) (PO₃)₂ at concentrations of 50-100 mg P₂O₅/L are more ordered and uniform and formed by fine grains of almost the same size and shape (Figure 3, A-B), which explains the high protective properties of this inhibitor.

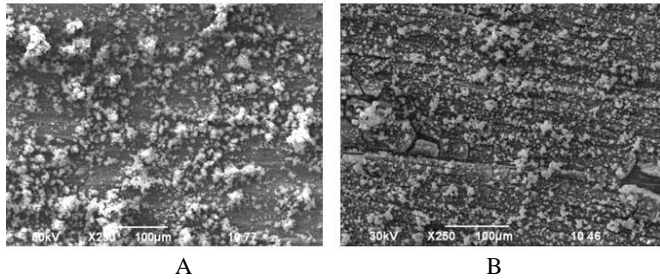


Figure 3. EM photographs of the surface of steel samples after testing in 3% NaCl solution supplemented with calcium-manganese phosphate inhibitor in concentrations (mgP₂O₅/L): A - 50; B - 100

The composition of deposits formed on the surface of steel samples was studied by IR spectroscopy. It follows from the results that deposits on the surface of a steel sample aged in a 3% NaCl solution without additives (Figure 4, A) consist mainly of hydrated iron oxide compounds, as evidenced by an absorption band in the region of 3200-3400 cm⁻¹, corresponding to valence fluctuations of OH groups of hydrated iron oxide compounds [25, 26].

The band in the region 1500-1600 cm⁻¹ corresponds to deformation oscillations of HOH molecules. The absorption band in the region 580-630 cm⁻¹ corresponds to valence oscillations of the Fe-O group (Figure 4, A) [22].

IR spectra of deposits formed on St3 in a 3% NaCl solution supplemented with calcium-manganese phosphate have characteristic absorption bands of 3400; 1605; 1150; 1100 and 613 cm⁻¹ (Figure 4, B-C).

It should be noted that the IR spectra of deposits formed in both 3% NaCl + 50 mg P₂O₅/l (Ca, Mn)(PO₃)₂ and 3% NaCl + 100 mg P₂O₅/l (Ca, Mn)(PO₃)₂ are absolutely identical (Figure 4, B-C) and indicate the presence of hydrophosphate ion HPO₄²⁻ in the deposits (bands 3400; 1150; 1100, 613 cm⁻¹), which confirms the high protective properties of calcium-manganese phosphate inhibitor (Table 2).

Electrochemical studies (Figures 5-6, Table 3) showed that additives NaPO₃ in a 3% NaCl solution at all concentrations shifted the corrosion potential towards negative values (Figure 5) compared to the control. At the same time, the corrosion current density is higher than in the sodium chloride solution without an inhibitor (Table 3), which indicates the absence of an inhibitory effect of NaPO₃ in waters with a high content of chloride ions and confirms the results of gravimetric tests.

The results also show that the addition of a calcium-manganese phosphate inhibitor to the sodium chloride solution provides a reduction in the rate of metal corrosion, that is, an inhibition effect is present (Table 3), although there is no clear correlation between inhibitor concentration and reduction in corrosion current density.

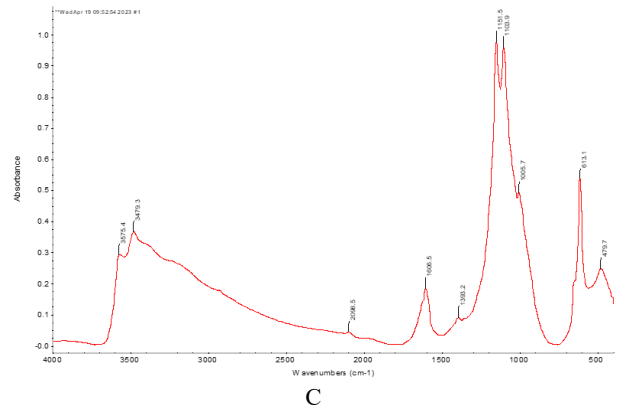
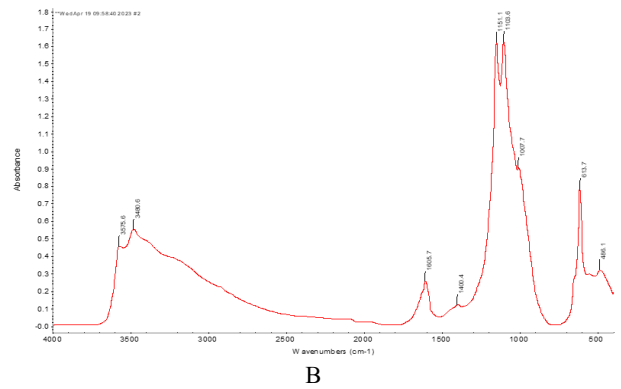
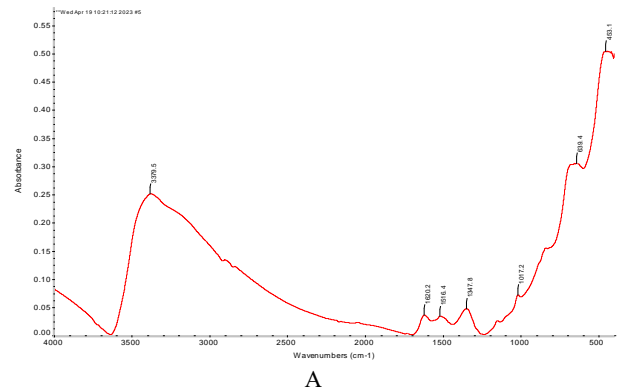


Figure 4. IR spectra of corrosion deposits formed on steel samples (St3) after testing in 3% NaCl solution without additives (A) and with calcium-manganese additives of phosphate inhibitor: B - 100 mg P₂O₅/l; C - 50 mg P₂O₅/l

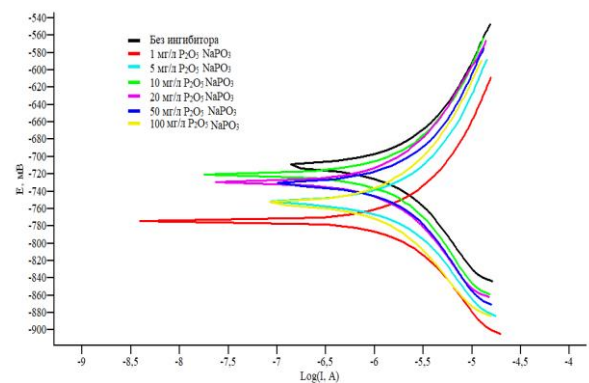


Figure 5. Potentiodynamic polarization curves taken for steel (St3) in 3% NaCl solution without and with inhibitor additives NaPO₃

Table 3. Corrosion parameters based on the results of electrochemical tests of St3 in 3% NaCl solution with additives of various phosphates

Corrosive medium	Inhibitor concentration, mg P ₂ O ₅ /l	Corrosion potential, V	Corrosion current density μA/sm ²	Corrosion rate, mm/year	Inhibitor efficiency, %
3% NaCl solution	0.0	-0.691	12.11	0.14	0
3% NaCl + (Mn,Ca)(PO ₃) ₂	1.0	-0.682	9.03	0.10	25.4
	5.0	-0.695	11.40	0.13	5.8
	10.0	-0.693	7.37	0.09	39.2
	20.0	-0.725	11.90	0.14	1.7
	50.0	-0.691	6.91	0.08	42.9
	100.0	-0.729	15.12	0.18	0
3% NaCl + NaPO ₃	1.0	-0.773	16.09	0.19	0
	5.0	-0.753	15.65	0.18	0
	10.0	-0.721	14.79	0.17	0
	20.0	-0.729	13.04	0.15	0
	50.0	-0.728	14.43	0.17	0
	100.0	-0.750	9.91	0.11	18.1

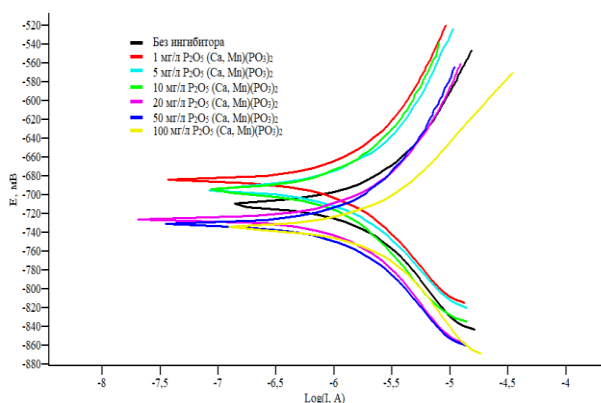


Figure 6. Potentiodynamic polarization curves taken for steel (St3) in 3% NaCl solution without and with inhibitor additives (Ca, Mn)(PO₃)₂

The dynamics of the working electrode corrosion potential in the 3% sodium chloride solution in the presence of various inhibitors was also studied (Figure 7).

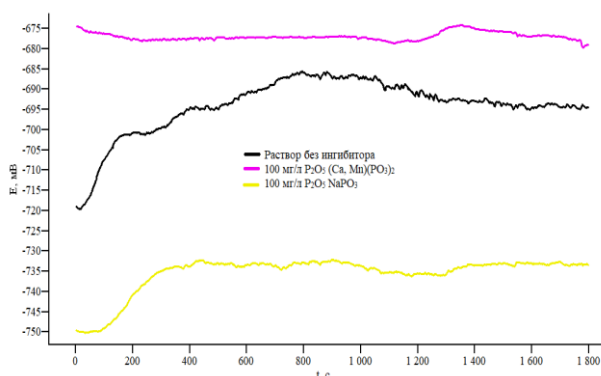


Figure 7. Changes in the corrosion potential of the working electrode in 3% sodium chloride solution in the presence of various inhibitors

It was found that the corrosion potential of the working electrode in the sodium chloride solution without the addition of inhibitors within 15 minutes shifts from -720mV to -685 mV, and then gradually stabilizes at -693 mV (Figure 7). The introduction of 100 mg P₂O₅/l NaPO₃ into the solution

shifts the corrosion potential towards negative values. After about 5 minutes, it stabilizes at -735 mV, confirming its low inhibitory properties (Figure 7).

Adding a calcium-manganese phosphate inhibitor to the NaCl solution shifts the electrode potential positively to -677 mV (Figure 7). This indicates the formation of a protective layer on the metal surface and, thus, confirms the effectiveness of the calcium-manganese phosphate product as an inhibitor of corrosion of low-carbon steel in waters with an increased content of chloride ions.

4. Conclusions

1. Anticorrosive properties of various phosphates for St3 in 3% sodium chloride solution were investigated.

2. It has been found that a known inhibitor NaPO₃ in a 3% NaCl solution at 1-20 mgP₂O₅/l accelerates the corrosion process. Inhibitory properties for NaPO₃ begin to appear only at 50 mgP₂O₅/l (IE = 3.91%). At 100 mgP₂O₅/l, the Inhibitor efficiency is 24.4%.

3. Calcium-manganese phosphate (Ca, Mn)(PO₃)₂ has been shown to have an inhibitory effect at a concentration of 5 mg P₂O₅/L. With an increase in its concentration, the corrosion rate decreases monotonously and at a concentration of 100 mgP₂O₅/l, the protection coefficient is 12.22 with the Inhibitor efficiency of 91.8%. This indicates high inhibitory properties of this phosphate.

4. Deposits formed on the surface of a steel sample in a 3% NaCl solution without additives are represented by dendrite-like grains of various shapes and sizes. There are relatively large voids between the grains, which indicates the formation of uneven loose coatings with low protective properties. The same pattern is observed for deposits on the surface of steel samples after testing in sodium chloride solutions with sodium polyphosphate additives. Deposits formed on the steel surface in a 3% NaCl solution with additives (Ca, Mn)(PO₃)₂ at concentrations of 50-100 mg P₂O₅/L are more ordered and uniform and formed by fine grains of almost the same size and shape, which explains the high protective properties of this inhibitor.

5. Electrochemical studies confirm the results of gravimetric tests. The introduction of NaPO₃ into the sodium chloride solution in concentrations of 1-50 mgP₂O₅/L shifts the corrosion potential towards negative values up to -728÷-773 mV, and its current density exceeds the current density in the test. This indicates an increase in the corrosion rate of St3 and the low efficiency of sodium polyphosphate as an inhibitor in chloride solutions.

6. When calcium-manganese phosphate is added to the NaCl solution, the corrosion potential is shifted to -682÷-691 mV, and the corrosion currents are reduced to 11.4÷6.91 μA/sm², which corresponds to Inhibitor efficiency of 5.8÷42.9%.

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Түрлі фосфатты ингибиторларының 3% натрий хлориді ерітісіндегі төмен көміртекті болаттың таттануына әсері

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Аңдатпа. 3% натрий хлориді ерітіндісіндегі төмен көміртекті болат (Ст3) үшін әртүрлі фосфат ингибиторларының тежеу қасиеттері зерттелді. Зерттеулер стандартты гравиметриялық және электрохимиялық әдістермен жүргізілді. 5-100 мг P_2O_5 /л концентрациясында 3% NaCl ерітіндісіне кальций марганец фосфатының қосылуы Ст3 коррозиясының жылдамдығын төмендететіні көрсетілген. Концентрациясы 100 мг P_2O_5 /л ингибитордың тиімділігі 91.8% құрайды. Хлорид ерітіндісіне 1-20 мг P_2O_5 /л концентрацияда натрий полифосфатының қосылуы Ст3 коррозиясының жылдамдығын арттырады. Концентрациясы 100 мг P_2O_5 /л кезінде $NaPO_3$ тиімділігі 24.4% құрайды. Поляризация қисықтарын алу және есептеу арқылы алынған электрохимиялық сынақтардың нәтижелері гравиметриялық өлшемдердің деректерін растайды. Электрондық микроскопияның көмегімен болат бетінде 3% натрий хлориді ерітіндісінде қоспасыз да, натрий полифосфат қоспаларымен де қорғаныш қасиеттері төмен біркелкі емес борпылдақ шөгінділер түзілетіні көрсетілді. Ерітіндіге натрий хлориді $(Ca,Mn)(PO_3)_2$ қосқанда болатта жоғары қорғаныс қасиеттері бар реттелген ұсақ түйіршікті шөгінділер түзіледі. Әртүрлі фосфаттар қосылған 3% NaCl ерітіндісіндегі

Ст3 бетінде түзілген шөгінділерді ИҚ-спектроскопиялық талдау, құрамында ерімейтін кальций сутегі фосфаттары бар біртекті жабындардың $(Ca, Mn)(PO_3)_2$ қатысында түзілетінін көрсетті.

Негізгі сөздер: коррозия, коррозия жылдамдығы, ингибитор, ингибиторлық қасиеттер, ингибитордың тиімділігі.

Влияние различных фосфатных ингибиторов на коррозию низкоуглеродистой стали в 3% растворе хлорида натрия

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Аннотация. Изучены ингибирующие свойства различных фосфатных ингибиторов для низкоуглеродистой стали (Ст3) в 3%-ном растворе хлорида натрия. Исследования проводили стандартным гравиметрическим и электрохимическим методами. Было показано, что добавление фосфата марганца-кальция к 3% раствору NaCl в концентрациях 5-100 мг P_2O_5 /л снижает скорость коррозии Ст3. Эффективность ингибитора при 100 мг P_2O_5 /л составляет 91.8%. Добавление полифосфата натрия в концентрациях 1-20 мг P_2O_5 /л к раствору хлорида увеличивает скорость коррозии Ст3. Эффективность $NaPO_3$ при 100 мг P_2O_5 /л составляет 24.4%. Результаты электрохимических испытаний, полученные путём снятия и расчёта кривых поляризации, подтверждают данные гравиметрических измерений. С помощью электронной микроскопии было показано, что на поверхности стали образуются неровные рыхлые отложения с низкими защитными свойствами в 3% растворе хлорида натрия как без добавок, так и с добавками полифосфата натрия. При добавлении в раствор хлорида натрия $(Ca, Mn)(PO_3)_2$ на стали образуются упорядоченные мелкозернистые отложения с высокими защитными свойствами. ИК-спектроскопический анализ отложений, образовавшихся на поверхности Ст3 в 3% растворе NaCl с добавлением различных фосфатов показал, что однородные покрытия, содержащие нерастворимые гидрофосфаты кальция, образуются в присутствии $(Ca, Mn)(PO_3)_2$.

Ключевые слова: коррозия, скорость коррозии, ингибитор, ингибирующие свойства, эффективность ингибитора.

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