PHYSICAL CHEMISTRY OF SURFACE PHENOMENA

Inhibitor Properties of Carboxylates and Their Adsorption on Copper from Aqueous Solutions

M. O. Agafonkina, Yu. I. Kuznetzov, and N. P. Andreeva

Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, Moscow, 119991 Russia e-mail: kuznetsov@ipc.rssi.ru

Received July 29, 2014

Abstract—Adsorption, protective and passivating properties of several sodium higher carboxylates on a copper surface was studied in a borate buffer solution at pH 7.4. Sodium oleyl sarcosinate is shown to possess the best protective and adsorptive properties. It is established that at E = 0.0 V, the adsorption of oleyl sarcosinate is poly-layered, giving the best protection of copper upon its anodic dissolution. In a moist atmosphere with periodic condensation of moisture on the samples, it exceeded that of 1,2,3-benzotriazole.

Keywords: adsorption, copper, ellipsometry, sodium oleyl sarcosinate, sodium oleate, carboxylates, benzotriazole.

DOI: 10.1134/S0036024415060023

INTRODUCTION

Heterocyclic compounds such as 1,2,3-benzotriazole (BTA), benzimidazole, benzotiazole and their derivatives are known as effective inhibitors of corrosion of copper and copper alloys [1–7] in solutions over a wide range of pH. Use of the most studied inhibitor BTA for the protection of copper and its alloys in water-supply facilities suffers from interactions with the chlorine used as a bactericide agent for water. Researchers therefore seek new inhibitors for copper that have low toxicity, easy biodegradation, economic accessibility, and are environmentally friendly.

Mono- and dinitrobenzoates [8, 9] were recently used as inhibitors of copper corrosion. They belong to a group of universal volatile corrosion inhibitors that have high oxidizing ability and involve organic cations adsorbed on surfaces of different metals (copper, zinc, aluminum and their alloys). These usually increase the efficiency of cathode processes, shifting the metal corrosion potential toward values that allow the formation of a passivating layer [8]. However, the high oxidizing ability of these compounds when used for copper protection leads to the formation of soluble copper chloride, which cannot protect metal from chloride ions [9].

The inhibiting properties of carboxylates of nonoxidizing type have been long recognized. These include, e.g., salts of aromatic, fatty, hydroxycarboxylic, and unsaturated carboxylic acids, which are able to protect ferrous and nonferrous metals from atmospheric corrosion [9–11]. These effectively protect copper in water and aqueous solutions of salts [12, 13]. The high degree of protection for copper in sulfate solutions by potassium sorbate was demonstrated in [14, 15].

The aim of this work was to compare the adsorption properties of nonoxidizing carboxylates on copper and estimate their effectiveness in inhibiting the anodic dissolution of copper in a neutral aqueous solution and protecting it from corrosion in a moist atmosphere.

EXPERIMENTAL

Electrochemical and adsorption investigations were conducted using a borate buffer solution with pH 7.40 and prepared on distilled water [16]. salts 11-phenylundecanoic Sodium of (PHUD), flufenamic $C_6H_5(CH_2)_{10}COONa$ $[3-(CF_3)C_6H_4NH]C_6H_4COONa$ (FFN), and mefenamic [(CH₃)₂C₆H₃NH]C₆H₄COONa (MEFN) acids, and sodium oleate CH₃(CH₂)₇CH=CH(CH₂)₇COONa (SOL), and sodium oleyl sarcosinate CH₃(CH₂)₇CH=CH(CH₂)₇CON(CH₃)CH₂COONa (SOS) were studied. The first three salts were prepared via direct neutralization of the corresponding acids with NaOH solution in an equimolar ratio. SOL (in a powdered form) and SOS (60% solution) were purchased from **BIOKHIM**.

The abilities of carboxylates to reduce active dissolution currents and promote the spontaneous passivation of copper were studied by means of potentiometry while recording the anodic polarization curves. These investigations were conducted using an IPC-PRO

 Table 1. Dependence of the pitting potential of copper (B)

 on the concentration of inhibitor in neutral borate-chloride

 solution.

c _{in} , mmol/L	FFN	MEFN	PHUD	SOL	SOS
0.0	0.60	0.60	0.60	0.60	0.60
0.25				0.76	0.67
0.50				0.79	0.75
0.80	0.55		0.56	0.84	0.82
1.60	0.79	0.67	0.60	0.87	1.04
3.10	0.96	0.71	0.69	0.95	1.20
5.80	1.08		1.32	1.14	1.40
8.00		0.76			
10.00		0.94			
20.00		1.18			

computer-controlled potentiostat on an M1 copper electrode with a surface area of 0.75 cm^2 in an electrochemical cell with widely spaced electrodes. The working electrode was preliminarily polished and degreased with acetone. Electrode potentials (*E*) were measured with respect to a silver chloride electrode and recalculated to the normal hydrogen scale. Platinum foil served as a counter electrode.

After reducing the oxide film by the cathodic polarization at E = -0.60 V for 15 min, the potentiostat was switched off to establish the free corrosion potential (E_{corr}). A solution of sodium chloride (10 mmol/L) and inhibitor was then added. After establishing the new value of E_{corr} , the anodic polarization curves were recorded with a potential scanning rate of 0.2 mV/s.

i, μ A/cm² 60 40 -20 -2 3 4 1 5 0 0 0.1 0.3 0.5 0.7 *E*, V

Fig. 1. Anodic polarization curves of copper in borate buffer at pH 7.4 containing (1) 10 mmol/L NaCl and PHUD (mmol/L): (2) 0.4, (3) 0.8, (4) 1.6, (5) 3.1, (6) 4.5.

RUSSIAN JOURNAL OF PHYSICAL CHEMISTRY A Vol. 89 No. 6 2015

Pitting potential $(E_{\rm pt})$ was determined from the sharp increase in current on the polarization curves with subsequent visual identification of pitting on the electrode's surface. The error in measuring $E_{\rm pt}$ was ± 0.02 V.

Isotherms of inhibitor adsorption on passive copper were obtained after reduction of the copper surface at E = -0.60 V with subsequent oxidizing of the surface for 30–40 min in a borate buffer at E = 0.0 V. The measurements were performed using an ellipsometer in a cell designed for simultaneous electrochemical and ellipsometric studies. A helium-neon laser with $\lambda = 640$ nm served as the light source; the angle of light incidence was 68.5°. The consistency of ellipsometric parameters after oxidation of the electrode allowed adsorption measurements on the stable oxidized surface of electrode. A concentrated solution of inhibitor was introduced into the solution and the time variations of the ellipsometric angle were recorded. Steadystate values of Δ and ψ were used to construct the dependence of the ellipsometric parameters on the concentration of adsorbed reagent.

The ellipsometric technique of measuring adsorption is based on the Drude equation. According to the Drude equation, variation in the angle of the ellipsometric phase shift (Δ) in the range of thinness (up to 10 nm) is proportional to the film thickness:

$$d = -\alpha \delta \Delta = -\alpha (\Delta - \Delta_0), \tag{1}$$

where α is the coefficient of proportionality, Δ_0 is the initial angle characterizing a so-called "pure" surface, and Δ is the current value of the angle. If angle Δ narrows during the experiment (i.e., $\delta\Delta < 0$), the film thickness increases; when $\delta\Delta > 0$, the film becomes thinner. In the first case, such variations in angle Δ indicate an increase in film thickness or the adsorption of inhibitor; in the second, a reduction of film thickness or the desorption of adsorbate.

The adsorption isotherm was plotted using the dependence of angle Δ on the concentration of inhibitor by assuming that the plateau of the plot corresponded to surface filling $\theta = 1.0$.

The corrosion experiments were conducted using plates of M1 copper polished and degreased with acetone. The protective inhibitor film was prepared via exposure for 5 or 60 min at room or elevated temperatures (60°C) in a borate buffer solution containing carboxylates or BTA with inhibitor concentration $c_{in} = 2 \text{ mmol/L}$.

After treatment, the samples were dried and placed in a sealed vessel in which hot water (50°C) was poured over the bottom. The vessel was then closed. Upon cooling, abundant water condensed on the vessel walls and samples. Water was replenished and the samples examined visually every day.

Inhibitor	SOS*	SOL*	PHUD	FFN	MEFN	BTA*
$-\Delta G_{ m a}^{\circ}$	62 ± 3	57 ± 3	30 ± 2	48 ± 2	43 ± 2	51 ± 3
$\log P$	7.00	7.70	5.89	2.47	2.18	1.34
$\log D$	5.65	5.10	3.68	2.57	2.29	1.32
pK _a	3.77	4.80	4.78	4.25	3.73	8.38
<i>d</i> , nm	0.31 ± 0.04	0.31 ± 0.04	0.96 ± 0.14	0.5 ± 0.13	0.7 ± 0.1	0.31 ± 0.04
<i>l</i> , nm	2.9	2.4	1.7-1.8	1.6	1.4	0.6

Table 2. Dependence of $(-\Delta G_a^\circ, kJ/mol)$ for oxidized copper in borate buffer at pH 7.40 and the logarithm of distribution coefficient log *D* on the nature of the inhibitor.

* Value $(-\Delta G_a^\circ)$ was estimated for the first monolayer of the inhibitor.

RESULTS AND DISCUSSION

The anodic polarization curves of copper with the added carboxylates were similar to one another. An area of active dissolution was observed at low values of $c_{\rm in}$; at higher contents of inhibitor, it was followed by a state of passivity that was disturbed by the chloride ions in the solution upon a subsequent potential sweep. Figures 1 and 2 show the typical anodic polarization curves for copper in a borate buffer with pH 7.4 and containing such additives as 10 mmol/L NaCl, FFN, or SOS. Table 1 gives the values of $c_{\rm in}$ and $E_{\rm pt}$ that were determined from an analysis of the curves recorded for all inhibitors. All anodic polarization curves of copper start from $E_{\rm corr} = 0.17 \pm 0.03$ V.

The anode polarization curves for copper in solutions that contained PHUD (Fig. 1) showed that there was spontaneous passivation of the electrode at $c_{\text{PHUD}} \ge 0.8 \text{ mmol/L}$ with positive variation of E_{pt} (Fig. 1). At

i, $\mu A/cm^2$ 70 35 -0 0 0 0 0.2 0.4 0.6 0.8 1.0 E, V

Fig. 2. Anodic polarization curves of copper in a borate buffer at pH 7.4 and containing (1) 10 mmol/L NaCl and SOS (mmol/L): (2) 0.08, (3) 0.17, (4) 0.4, (5) 0.8, (6) 1.6.

 $c_{\rm PHUD} < 0.8 \text{ mmol/L}$, the active dissolution current density of copper was reduced; e.g., adding 0.4 mmol/L PHUD suppressed it fourfold compared to the background curve, but $E_{\rm pt}$ was unaffected. The growth of $E_{\rm pt}$ was observed only when $c_{\rm PHUD} \ge$ 1.6 mmol/L, while at 5.8 mmol/L the value $E_{\rm pt}$ exceeded the potential of oxygen evolution. Table 1 shows that adding 1.6 mmol/L FFN (another carboxylate) shifted $E_{\rm pt}$ to 0.79 V, and at $c_{\rm FFN} = 5.8 \text{ mmol/L}$, $E_{\rm pt} = 1.08 \text{ V}$. Adding 1.6 mmol/L MEFN was less effective than FFN: $E_{\rm pt}$ increased only by 0.07 V and, even at 10 mmol/L MEFN, by 0.34 V.

Among the investigated sodium salts, SOS (Fig. 2) and SOL (Table 1) demonstrated the best protective properties. At $c_{SOS} = 0.08 \text{ mmol/L}$, the density of the passivation current was reduced by a factor of 15 compared to the background curve, and $E_{pt} = 0.67 \text{ V}$.

When $c_{SOS} = 0.17 \text{ mmol/L}$, SOS was able to passivate copper even without an increase in E_{pt} . At $c_{SOS} =$ 1.6 mmol/L, E_{pt} rose to 1.04 V; i.e., SOS was considerably more effective than the other carboxylates. At low concentrations ($c_{SOL} < 1.0 \text{ mmol/L}$), SOL turned out to be only slightly better than SOS in preventing the local depassivation of copper, but it became more effective as its concentration c_{in} grew. Logically, the great protective properties of SOS and SOL with respect to copper are associated with their high adsorption capabilities.

Ellipsometric measurements in fact revealed that the adsorption of SOS anions on the oxidized copper surface started in the area of low concentrations ($c_{in} \ge$ 0.02 nmol/L), while a poly-layered film started to form after the formation of a monolayer (shown by the dashed line in Fig. 3). This is not surprising, since SOS is known as a colloid surfactant used in a wide range of industrial applications because of its low toxicity [17].



Fig. 3. Change of the ellipsometric angle Δ with concentration of (1) SOS, (2) SOL, (3) MEFN, (4) FFN, and (5) PHUD on a copper surface at E = 0.0 V. The dashed line on isotherm (1) shows an arbitrary monolayer.

The first layer of such isotherm in the medium coverage range can be described with an accuracy of 95% by the Frumkin equation:

$$Bc = [\theta/(1-\theta)]\exp(-2a\theta), \qquad (2)$$

where *a* is a constant of attraction and *B* is a constant of adsorption, associated with the free energy of adsorption $(-\Delta G_a^\circ)$ by the relation $B = [\exp(-\Delta G_a^\circ/RT)]/55.5$. To

estimate ln*B*, the resulting isotherm was reconstructed in the coordinates $X = \theta$, $Y = \ln[\theta/(1 - \theta)c]$. The point where the tangent intersects with the *Y* axis in the medium range of coverage determined ln*B*. The resulting ln*B* was used to calculate $(-\Delta G_a^\circ) = 62$ kJ/mol; as it turned out, this exceeded the value for BTA, one of the best known inhibitors of corrosion for copper, by 11 kJ/mol (Table 2).

The adsorption of SOL on the oxidized copper started at $\log c = -9.00$, 1.5 orders of magnitude greater than the value for SOS. Two SOL layers formed in the range of $\log c = -(6.77-5.52)$ (Fig. 3). The formation of multilayers is possible in the range of high concentrations c_{SOL} similar to what was observed for iron in [18, 19]. This is clear from the kinetic of variation of angle Δ for $c_{SOL} = 0.1$ mmol/L (see Fig. 4).

A slowdown in the growth of $(-\delta\Delta)$ is observed on its time dependence (the insert in Fig. 4); this can be attributed to the formation of first monolayer. The SOL multilayers grow with the time of exposure.

PHUD turned out to be the least effective of the investigated inhibitors. This is consistent with the weak adsorption of PHUD on oxidized copper (Fig. 3). PHUD anions began to be adsorbed at $c_{\text{PHUD}} = 20 \ \mu\text{mol/L}$, three orders of magnitude higher than c_{FFN} . Calculations of the adsorption characteristics using Eq. (2) confirmed the lower energy of PHUD adsorption $(-\Delta G_a^\circ) = 30 \ \text{kJ/mol}$



Fig. 4. Kinetics of ellipsometric angle variations Δ on an oxidized copper surface (E = 0.0 V) upon the addition of SOL (logc = -4.00). The dashed line in the insert arbitrarily shows the first monolayer.

RUSSIAN JOURNAL OF PHYSICAL CHEMISTRY A Vol. 89 No. 6 2015

Table 3. Time before the occurrence of the first spot of corrosion (in days) on the M1 plates with and without passivation in the solution of inhibitor ($c_{in} = 2.0 \text{ mmol/L}$) at different temperatures in cells with 100% moisture and daily condensation of moisture on the samples.

Inhibitor	Ι	II	III			
Without inhibitor	1.2 ± 0.3					
SOS	10 ± 0.5	21 ± 0.5	23 ± 0.5			
SOL	7 ± 0.5	17 ± 0.5	18 ± 0.5			
PHUD	_	6 ± 0.5	22 ± 0.5			
FFN	_	7 ± 0.5	13 ± 0.5			
BTA	12 ± 0.5	15 ± 0.5	18 ± 0.5			

Symbols: I and II, exposed at room temperature for 5 and 60 min, respectively; III, exposed at 60°C for 5 min.

relative to those of FFN $(-\Delta G_a^\circ) = 48$ kJ/mol and MEFN $(-\Delta G_a^\circ) = 43$ kJ/mol (Table 2).

The variations in angle Δ during adsorption were used to determine the thicknesses of the inhibitor monolayers. At E = 0.0 V, an oxide film with refraction index $\approx 2.2 \pm 0.2$ [20] and proportionality coefficient from the Drude equation $\alpha = 0.8 \pm 0.1$ nm/deg formed on the copper surface. Comparing the thicknesses of conventional monolayers d and corresponding molecular sizes *l* calculated on the basis of bond lengths presented in Table 2, we may assume that the adsorbed SOS and SOL molecules were arranged horizontally (flat) on the copper surface. It should be noted that both inhibitors were adsorbed on iron surface [19] in the same range of concentrations and in a vertical orientation. Interactions between the inhibitors and iron surface occurred via the carboxyl groups of the inhibitor molecules, while the hydrocarbon radicals were oriented toward the solution. SOL and SOS molecules contain alkyl, giving them hydrophobic features and surface activity in water. However, SOS molecules include not only carboxyl groups but nitrogen that can form coordination bonds with copper and are probably responsible for the better surface adsorbability of SOS molecules.

Analysis of the results from adsorption and polarization measurements demonstrates the important role of anion hydrophobicity in the ability to inhibit copper dissolution. Hydrophobicity is estimated using the logarithm of the distribution coefficient derived from the data on the distribution of chemical compounds in the octanol—water system [21, 22]. Hydrophobic properties can be estimated using logarithm logP of the distribution coefficient of the investigated compound in the octanol—water system of two immiscible liquids [21], helping us calculate the characteristic magnitude of anion hydrophobicity corrected for acid dissociation [22]:

$$\log D = \log P - \log[1 + 10^{\text{pH} - \text{pKa}}].$$
 (3)

Our calculations yielded the highest values $\log D = 5.65$ and 5.10 (our results are given in Table 2) for SOL and SOS salts, respectively. They therefore had the highest surface activity and were able to reduce the currents of the active dissolution of copper even at low values of c_{in} and stabilize the state of passivation.

The least hydrophobic compound, MEFN, is capable of inhibiting copper in a borate-chloride solution and preventing local depassivation at rather high values of c_{MEFN} : 10.0–20.0 mmol/L, which exceed by 12 and 4 times those of hydrophobic SOL and SOS compounds, respectively. However, PHUD anions are highly hydrophobic and are adsorbed to a lesser degree than the other carboxylate-type inhibitors that were studied. Interactions with the copper surface are apparently due not only to the hydrophobic properties of a molecule but also to the presence of heteroatoms (particularly nitrogen) in its composition or multiple bonds that can form both additional intermolecular bonds between particles of an adsorbate such as SOS and other bonds with the protected metal surface.

Results obtained by other investigators [23–26] favor this version. These investigations demonstrated the impact of the tail groups of SOS molecules on interactions with metal surfaces. For example, the role of amide bonds in the self-organization of surfactants on a gold surface was revealed in [23]. Microbalancing was used to show that the ability to form hydrogen bonds resulted in more closely-packed arrangements on hydrophobic surfaces. Sarcosine derivatives form chelate compounds with a metal surface that can induce the polymolecular adsorption of SOS molecules.

Microbalancing and surface plasmon resonance were used in [24] to continue investigations of the adsorption of surfactants—SOS and sodium salts of other amino acids (*N*-lauryl sarcosinate, *N*-lauryl aminomalonic, *N*-lauryl aspartate)—from an aqueous solution on gold and quartz surfaces. All of these compounds contain polar tail groups with carboxyls that cling to gold surfaces and form monolayers.

Fourier spectroscopy, ellipsometry, and XPS were used to show that such inhibitors as SOS act as complexing reagents on steel surface [25]. Long hydrophobic fragments of molecules are oriented vertically to the surface and keep the corrosive components of the medium away from the metal. This was confirmed by the experimental data in [26]. The adsorption of SOS on steel proceeds via the formation of a complex of the molecule's amino acid fragments and the surface of the metal. When this happens, the hydrocarbon fragments of SOS molecules are oriented almost vertically.

Molecules of SOL and SOS inhibitors thus generate poly-layered films on copper that are bound firmly to the surface and can resist the effects of aggressive agents. It is important that SOS molecules are

1075

adsorbed on copper to a much greater extent than those of BTA, the well-known inhibitor of corrosion for this metal and its alloys that was investigated in [20]. The data from Table 2 show that the values $(-\Delta G_{2}^{\circ})$ for BTA are much less than those for SOS and SOL, but they are considerably higher than those for MEFN and especially FFN. At the same time, BTA is less hydrophobic than all of the other investigated higher carboxylates. This confirms our belief that while hydrophobic properties are important, they are not the only features responsible for the stability of adsorption bonds between an inhibitor and a copper surface, or its protective properties. Since BTA can generate poly-layered films on copper due to the polymerization of its complex with copper cations [3, 20], the formation of poly-layered coatings can be considered as a general and valuable feature of such different (in terms of chemical structure) inhibitors as SOS and BTA.

CONCLUSIONS

Corrosion testing of copper plates treated with diluted solutions of the investigated carboxylates at room temperature revealed that SOS exceeded other studied inhibitors in protecting copper from corrosion in a moist atmosphere (Table 3). From the time to the occurrence of the first corrosion spot in a moist atmosphere, we may conclude that the efficiency of SOS was 3–3.5 times higher than those of FFN or PHUD. The protection of copper by SOS and SOL was likely accompanied by self-organization in adsorption layers, since effectiveness grew substantially along with the duration of the passivating treatment of copper. It should be noted that the effectiveness of treating copper with SOS and SOL exceeded that of BTA [20].

The first corrosion spots on a copper surface formed much earlier in subsequent experiments on shortening the length of passivation to 5 min. This effect was attributed to there not being enough time to form an inhibitor film. When the temperature was raised to 60° C and the passivating treatment lasted for 5 min, the first corrosion spots appeared after 23 h for SOL (instead of 10 h at room temperature), 22 h for PHUD (instead of 6 h), and 13 h for FFN (instead of 7 h).

The investigated high carboxylates thus suppressed the anode dissolution of copper in neutral aqueous solutions, preventing local depassivation by chlorides. Sodium oleyl sarcosinate turned out to be the most effective of the other inhibitors. The adsorption of sodium oleyl sarcosinate on copper at E = 0.0 V was polymolecular in nature. The formation of the first monolayer of inhibitor started at an extremely low concentration (0.05 nmol/L), and adsorption was described by the Frumkin equation with the relatively high value of the free energy of adsorption $(-\Delta G_a^\circ) = 62$ kJ/mol, indicating that the chemisorption of oleyl sarcosinate is possible.

While important, the hydrophobic properties of carboxylates are not the only features responsible for the stable adsorption bonds between an inhibitor and a copper surface and their protection properties. The composition and structure of the functional ("head") group in an inhibitor molecule are important for generating possible bonds with the protected surface. The generation of a polymolecular inhibitor film and a complex compound of inhibitor with metal cations enhances the protection of copper. Corrosion testing of copper passivated in an aqueous solution of carboxvlates at room temperature and 60°C demonstrated the high efficiency of SOS inhibitor for protecting copper in a moist atmosphere, compared to the other investigated compounds. A rise in temperature lengthens the time before the occurrence of first corrosion spots even at relatively short times of passivation.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 13-03-00188.

REFERENCES

- 1. D. Zhang, L. Gao, and G. Zhou, Corros. Sci. **46**, 3031 (2004).
- 2. L. P. Kazansky and I. A. Selyaninov, Korroz.: Mater., Zashch., No. 5, 21 (2009).
- 3. Yu. I. Kuznetsov and L. P. Kazansky, Russ. Chem. Rev. 77, 219 (2008).
- M. M. Antonijević, S. M. Milić, and M. B. Petrović, Corros. Sci. 51, 1228 (2009).
- 5. W. Qafsaoui, Ch. Blanc, J. Roques, et al., J. Appl. Electrochem. **31**, 223 (2001).
- Yu. I. Kuznetsov, M. O. Agafonkina, and N. P. Andreeva, Russ. J. Phys. Chem. A 88, 702 (2014).
- F. Zucchi, G. Trabanelli, and M. Fonsati, Corros. Sci. 38, 2019 (1996).
- 8. I. L. Rosenfeld, *Corrosion Inhibitors* (Khimiya, Moscow, 1977) [in Russian].
- 9. Yu. I. Kuznetsov, Itogi Nauki 7, 159 (1978).
- 10. I. L. Rosenfeld and V. P. Persiantseva, *Inhibitors of Atmospheric Corrosion* (Nauka, Moscow, 1985) [in Russian].
- 11. I. L. Rozenfeld, V. P. Persiantseva, and Yu. I. Kuznetsov, Tsvetn. Metall., No. 13, 48 (1977).
- 12. N. G. Chen, Izv. Vyssh. Uchebn. Zaved., Khim. Khim. Tekhnol. 7, 221 (1964).
- 13. A. Altsybeeva and S. Levin, *Inhibitors of Metal Corrosion* (Khimiya, Leningrad, 1968) [in Russian].
- 14. Y. Ein-Eli, E. Abelev, and D. Starosvetsky, Electrochem. Solid State Lett. 9, 5 (2006).
- 15. E. Abelev, D. Starosvetsky, and Y. Ein-Eli, Electrochim. Acta 52, 1975 (2007).

- Yu. V. Karyakin and I. I. Angelov, *Pure Chemical Reagents* (Gos. Nauch.-Tekhn. Izd. Khim. Liter., Moscow, 1955), pp. 242, 365 [in Russian].
- 17. Chemical Encyclopedy (Bol'sh. Ross. Entsiklopediya, Moscow, 1995), Vol. 4, p. 580 [in Russian].
- 18. Yu. I. Kuznetsov, N. P. Andreeva, N. P. Sokolova, and R. A. Bulgakova, Zashch. Met. **39** (5), 1 (2003).
- 19. N. P. Andreeva, Ya. G. Bober, and Yu. I. Kuznetsov, Korroz.: Mater., Zashch., No. 9, 29 (2009).
- 20. N. P. Andreeva, M. O. Agafonkina, and Yu. I. Kuznetsov, Korroz.: Mater., Zashch., No. 9, 7 (2010).
- 21. C. Hanch and A. Leo, *Substituent Constants for Correlation Analysis in Chemistry and Biology* (Wiley-Interscience, New York, 1979).

- 22. R. A. Scherrer and S. M. Howard, J. Med. Chem. 20, 53 (1977).
- 23. R. Bordes, J. Tropsch, and K. Holmberg, Langmuir **26**, 3077 (2010).
- 24. R. Bordes, J. Tropsch, and K. Holmberg, Langmuir **26**, 10935 (2010).
- 25. G. A. Salensky, M. G. Cobb, and D. S. Everhart, Ind. Eng. Chem. Prod. Res. Dev. **25**, 133 (1986).
- 26. Hampshire Chemical Corp. 45, Form No. 472-0003-500 AMS (Hayden Avenus, Hampshire, USA, 2000).

Translated by E. Khozina