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# The study of thiadiazole derivatives as potential corrosion inhibitors of low-carbon steel in hydrochloric acid

The inhibition effect of series of thiadiazole derivatives against the corrosion of mild steel in 15 % HCl was studied by weight-loss method and electrochemical measurements. The experiments were performed on steel St3 at 293 K, the exposure time of the samples in solution for weight-loss measurements was 24 h. Potentiodynamic polarization curves were obtained in a typical three electrode cell with the help of electrochemical measuring complex SOLARTRON 1280 C. A scan rate was 1 $mV\cdot s^{-1}$ and a measurement point was taken every 0.2 s. 2-aminothiazole, 5-amino-1,3,4-thiadiazole-2-thiol, 2-amino-1,3,4-thiadiazole, 2-amino-5-(furan-2-yl)-1,3,4-thiadiazole, 1,3,4-thiadiazole-2-ylamide of acetic acid were studied as potential inhibitors. The maximal inhibition efficiency was obtained at concentration 0.10-0.20 $g\cdot L^{-1}$. The best result was demonstrated by 5-amino-1,3,4-thiadiazole-2-thiol (inhibition effect was more than 90 %). The minimal inhibition effect had 1,3,4-thiadiazole-2-ylamide acetic acid. The corrosion inhibition effect calculated from data of the corrosion current density and from the weight-loss measurements were in sufficiently good agreement. The effective activation energy of the corrosion of St3 increased significantly due the presence of the inhibitors (from 3.3 to 94.8 $kJ\cdot mol^{-1}$). The results point to promising of investigating of series of thiadiazole derivatives and inhibitory compositions based on thiadiazole as potential acid corrosion inhibitors.

*Keywords*: low-carbon steel, corrosion, inhibitors, thiadiazole, thiazole, weight-loss method, impedance spectroscopy, adsorbtion.

## *Introduction*

Corrosion of metals and alloys is a big problem for the oil and gas industry. The use of acidic media leads to the failure of well equipment, oil collection and distillation units, and pipelines [1–3]. Inhibitors are specially selected compounds that are used to prevent the destruction of metals and alloys from corrosion [4, 5]. They are added into the corrosion system in a low concentration and reduce the rate of corrosion without significantly changing the composition of the system. At the present time, the development of new environmentally friendly corrosion inhibitors that do not contain toxic metals and inorganic phosphates is of great importance [6–9].

Many organic compounds containing heteroatoms are able to slow down metal corrosion in acidic media. The most widespread are inhibitors based on nitrogen-containing compounds [10]. However, compounds containing sulfur atom in the molecule are also of great interest today. Such compounds include thiols, thiosulfonic acids, thiophenes, and sulfur-containing triazoles [11, 12].

Thus, the purpose of this work was the research of some thiadiazole derivatives as corrosion inhibitors for mild steel in a 15 % solution of hydrochloric acid.

## *Experimental*

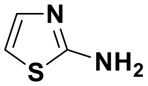
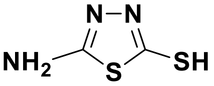
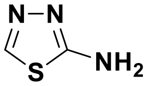
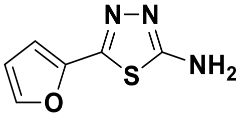
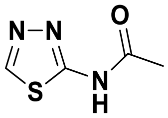
The material for the study were the samples made of low-carbon steel St3 of composition, wt%, Fe, 98.36; C, 0.2; Mn, 0.5; Si, 0.15; P, 0.04; S, 0.05; Cr, 0.3; Ni, 0.2; Cu, 0.2. All measurements were conducted in unstirred 15 % HCl solutions prepared on the basis of distilled water and HCl of the chemically pure grade. Products of organic synthesis, thiadiazole derivatives, were used as corrosion inhibitors (Table 1).

All the data presented in the work was obtained by averaging the results of three parallel measurements. MS Excel software was used to calculate the average results and standard deviations of direct and indirect measurements.

The main parameters of steel corrosion were estimated according to generally accepted methods [13]. Rectangular samples made of St3 steel with a size of 25×20×2 mm were used for weight-loss analysis. The working surface area was 1180 $mm^2$.

Table 1

**Chemical compounds studied in the work as corrosion inhibitors**

| Cipher | Formula | Name by nomenclature |
|---|---|---|
| АК-9 |  | 2-aminothiazole |
| АК-10 |  | 5-amino-1,3,4-thiadiazole-2-thiol |
| АК-23 |  | 2-amino-1,3,4-thiadiazole |
| АК-44 |  | 2-amino-5-(furan-2-yl)-1,3,4-thiadiazole |
| АК-69 |  | 1,3,4-thiadiazole-2-yl acetic acid amide |

The corrosion rates ($K$), the inhibition factor ($\gamma$) and the degree of protection ($Z_{gr}$) were calculated using equations:

$$K = \frac{m_0 - m}{S \cdot \tau};$$

$$\gamma = \frac{K_0}{K};$$

$$Z_{gr} = \frac{K_0 - K}{K_0} \cdot 100\ \%,$$

where $m_0$ is the mass of the initial sample, g; $m$ is the mass of the sample after corrosion testing and removal of corrosion products, g; $S$ is the surface area of the sample, m$^2$; $\tau$ is the immersion time, h; $K_0$ and $K$ are the corrosion rates of steel in pure solution and with the addition of an inhibitor, g·m$^{-2}$·hour$^{-1}$, respectively.

Electrochemical measurements were performed in a three-electrode cell with cathode and anode compartments separated by a porous glass diaphragm using a potentiostat-galvanostat with a built-in SOLARTRON 1280C frequency analyzer (Solartron Analytical). Polarization curves were obtained by potentiodynamic polarization from the cathode region to the anode region with scan rate of 1 mV·s$^{-1}$. All values of potential are presented in the standard hydrogen electrode scale.

Polarization measurements were carried out in the temperature range from 293 to 353 K. The cell was connected to an LT 100 thermostat with external circulation to set the required temperature.

Thanks to this method, it is also possible to determine the Tafel sections of the polarization curves and calculate the degree of protection from electrochemical data:

$$Z_{el/ch} = \frac{i_0 - i_{inh}}{i_0} \cdot 100\ \%,$$

where $i_0$ and $i_{inh}$ are the current densities of steel corrosion in pure solution and with the addition of an inhibitor, A·m$^{-2}$, respectively.

Based on the electrochemical results the activation energy of the corrosion process was calculated. The calculations were performed according to the temperature-kinetic method. The effect of temperature on the current density when concentration polarization or delayed discharge stage is described by an equation similar to the Arrhenius equation:

$$\ln i = -E_{ef} / RT,$$

where $i$ is the corrosion current density, A·m$^{-2}$; $E_{ef}$ is the effective activation energy of corrosion process, J·mol$^{-1}$; $T$ is the temperature, K.

A straight line in the coordinates $\lg(i) = f(1/T)$ allows to calculate $E_{ef}/R$ as the tangent of the angle of inclination.

Measurements of the impedance spectra were carried out at a temperature of ~293 K. The range of frequencies used in impedance measurements was $f$ from 20 kHz to 0.01 Hz, and the amplitude of the alternating signal was 5–10 mV. The electrodes were immersed into the solution for an hour to establish the corrosion potential.

Parameter $\chi^2$ (calculated in ZView2) was used as an evaluation criterion for equivalent electrical circuits for their suitability for simulation of experimental impedance spectra. The equivalent circuit was considered satisfactory at $\chi^2 < 10^{-3}$ (using weight coefficients calculated by the experimental values of the impedance module) [14].

The surface coverage (θ) of C1018-electrode by corrosion inhibitor was determined from equation:

$$\theta = \frac{C_o - C}{C_o - C_1},$$

where $C_o$, $C$ and $C_1$ are the capacity of the double electric layer in a pure acid solution, in a solution with a given concentration of the inhibitors and in a solution where $\theta = 1$, respectively.

The value of $C_1$ was determined by extrapolating the curve in coordinates

$$C = f\left(\frac{1}{C_{inh}}\right) \text{ to } \left(\frac{1}{inh}\right) = 0,$$

where $C_{inh}$ is the concentration of the inhibitor in solution, g·L$^{-1}$.

## *Results and Discussion*

At the first stage of the study, the corrosion rate of the St3 steel in 15 % HCl solution was studied by the weight-loss method. Then the corrosion rate of mild steel in the presence of some thiadiazole derivatives was measured. In the course of the work, it was found that some of the testing samples are not-well soluble in 15 % HCl solution. As the result the following concentrations were used: 0.05–0.2 g·L$^{-1}$.

The results are presented in Table 2.

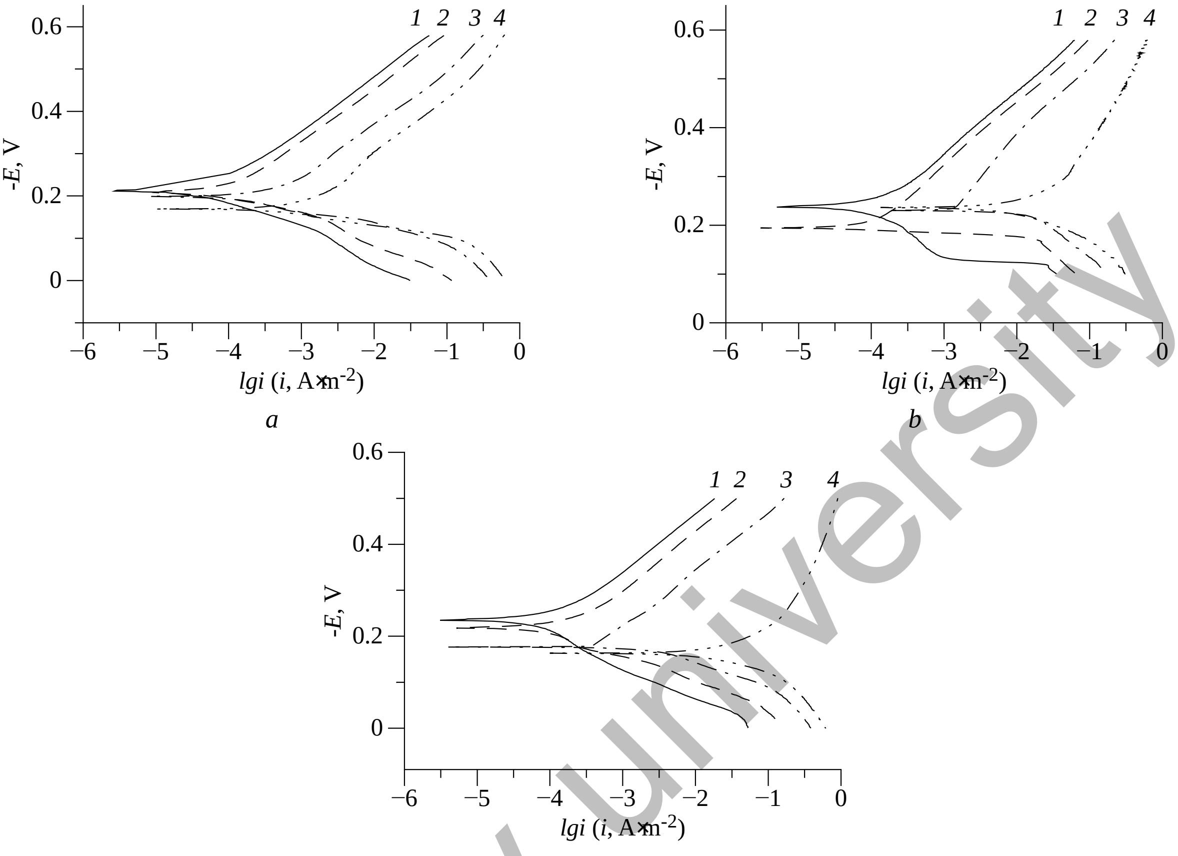
Table 2

**The main parameters of the St3 corrosion in 15 % HCl solution and in the presence of inhibitors**

| Cipher | $C_{inh}$, g·L$^{-1}$ | $K$, g·m$^{-2}$·hour$^{-1}$ | $Z_{gr}$, % | γ |
|---|---|---|---|---|
| – | – | 15.2±0.8 | – | – |
| AK-9 | 0.20 | 6.9±0.4 | 54±3 | 2.19±0.11 |
| | 0.10 | 8.0±0.4 | 48±2 | 1.91±0.04 |
| | 0.05 | 9.4±0.3 | 38±2 | 1.62±0.03 |
| AK-10 | 0.20 | 1.5±0.1 | 90±3 | 10.22±0.32 |
| | 0.10 | 2.6±0.1 | 83±3 | 5.91±0.13 |
| | 0.05 | 4.0±0.2 | 74±3 | 3.83±0.11 |
| AK-23 | 0.20 | 6.1±0.2 | 67±2 | 2.51±0.09 |
| | 0.10 | 10.0±0.5 | 46±2 | 1.53±0.04 |
| | 0.05 | 15.7±0.7 | 16±1 | 0.96±0.01 |
| AK-44 | 0.20 | 5.5±0.2 | 92±4 | 12.30±0.43 |
| | 0.10 | 1.2±0.1 | 64±3 | 2.77±0.04 |
| AK-69 | 0.20 | 11.6±0.6 | 40±2 | 1.67±0.03 |
| | 0.10 | 9.5±0.4 | 37±1 | 1.60±0.03 |
| | 0.05 | 9.1±0.4 | 24±1 | 1.32±0.02 |

According to the results of weight loss measurements presented in Table 2, the nature of the substituent in the thiadiazole molecule has a significant influence on the values of the inhibition effect. The corrosion rate of St3 increases in the presence of potential inhibitors with increasing in the acid concentration. From weight-loss measurements (Table 2) and the results of solubility of substances we can conclude that the optimal inhibition effect has been shown by AK-9, AK-10, AK-23. Then, a number of electrochemical studies for estimation of the mechanism of the action of inhibitors were made.

The polarization curves were obtained in 15 % HCl solution without and with addition of 0.1 $gL^{-1}$ of thiadiazoles. The temperature range varied from 293 to 353 K. The polarization curves are given in Figure 1, and the electrochemical parameters of the processes are presented in Table 3.



*a* *b* *c*

Figure 1. Polarization curves of St3 in solution of 15 % HCl in the presence of 0.10 $gL^{-1}$ inhibitor AK-9 (*a*), AK-10 (*b*), AK-23 (*c*) at temperatures of: *1* — 293 K; *2* — 313 K; *3* — 333 K; *4* — 353 K

In the solutions of 15 % HCl containing 0.10 $g \cdot L^{-1}$ of inhibitors, the corrosion potential of the St3 is shifted to the cathodic region.

The currents in the system are reduced in both the cathodic and anodic processes for each inhibitor. Therefore, testing substances can be classified as inhibitors possessing relatively mixed effect (anodic/cathodic inhibition) in acidic solutions. From the results of Table 3, it follows that the values of the Tafel coefficients $b_c$ decrease in comparison with the pure solution of 15 % HCl. This result indicates that hydrogen can be removed from the steel surface in two ways — by electrochemical desorption and recombination.

As can be seen from these polarization results, all inhibitors have significant effect on the $b_a$ values in the temperature range of 293–333 K. A sharp increase in $b_c$ is observed for AK-10 and AK-23 inhibitors at a temperature of 353 eK. The Tafel coefficients obtained in the presence of AK-9 are less affected by temperature.

This result indicates that the AK-9 protects St3 from corrosion effectively with increasing temperature, while in the case of the AK-10 and AK-23 protective effect significantly decreases with increasing temperature. It can be assumed that AK-10 and AK-23 slow down the corrosion process due to physical adsorption on the steel surface and they desorb from the electrode surface into the solution with temperature. In contrast, in the case of AK-9, a chemisorption process is likely.

The temperature dependence of the St3 steel dissolution in deaerated 15 % HCl and in the presence of thiadiazoles is ploted in Arrhenius coordinates ln $i - 1/T$ (where $i$ is the corrosion current density). The calculated values of the apparent activation corrosion energy in the absence and presence of AK-23, AK-10 and AK-9 are 23.3, 120.7, 60.8 and 35.3 $kJ \cdot mol^{-1}$, respectively.

The presence of the inhibitor increases the energy barrier for the dissolution process of St3 and this leads to a decreasing of the corrosion rate.

Table 3

**Polarization parameters and the corresponding inhibition efficiency for the corrosion of the St3 in solution of 15 % HCl containing 0.10 g·L$^{-1}$ of inhibitors in the temperature range 293–353 K**

| Cipher | *T*, K | $b_a$, mV | $b_c$, mV | $i_{corr}\cdot10^3$, A·m$^{-2}$ | $-E_{corr}$, V | $Z_{el/ch}$, % |
|---|---|---|---|---|---|---|
| – | 293 | 93±2 | 140±2 | 1.58±0.04 | 0.200±0.002 | - |
| AK-9 | | 47±1 | 133±2 | 0.06±0.01 | 0.192±0.001 | 96±2 |
| AK-10 | | 133±3 | 125±2 | 0.10±0.01 | 0.235±0.003 | 94±3 |
| AK-23 | | 65±1 | 154±3 | 0.06±0.01 | 0.208±0.001 | 96±2 |
| – | 303 | 74±2 | 148±2 | 2.01±0.03 | 0.197±0.001 | – |
| AK-9 | | 43±1 | 140±2 | 0.06±0.01 | 0.197±0.001 | 97±2 |
| AK-10 | | 138±3 | 123±2 | 0.45±0.01 | 0.250±0.003 | 78±2 |
| AK-23 | | 59±1 | 154±3 | 0.22±0.01 | 0.209±0.002 | 89±2 |
| – | 313 | 62±1 | 154±4 | 3.16±0.03 | 0.190±0.001 | – |
| AK-9 | | 40±1 | 143±3 | 0.08±0.01 | 0.201±0.002 | 97±2 |
| AK-10 | | 144±4 | 120±2 | 1.20±0.02 | 0.258±0.002 | 62±1 |
| AK-23 | | 54±1 | 154±5 | 0.40±0.01 | 0.208±0.001 | 87±3 |
| – | 333 | 55±1 | 167±5 | 5.01±0.02 | 0.180±0.001 | – |
| AK-9 | | 36±1 | 143±2 | 0.32±0.01 | 0.183±0.001 | 94±3 |
| AK-10 | | 160±3 | 167±4 | 2.0±0.02 | 0.191±0.001 | 60±2 |
| AK-23 | | 44±1 | 154±3 | 1.00±0.01 | 0.177±0.001 | 20±2 |
| – | 353 | 20±1 | 182±5 | 199.50±9.98 | 0.120±0.002 | – |
| AK-9 | | 31±2 | 151±2 | 0.71±0.01 | 0.167±0.001 | 99±1 |
| AK-10 | | 174±4 | 200±3 | 79.43±4.32 | 0.177±0.001 | 60±4 |
| AK-23 | | 28±1 | 250±4 | 158.50±6.98 | 0.168±0.002 | 20±3 |

In the case of AK-23 and AK-10 the corrosion process proceeds with kinetic control, but in the case of an uninhibited solution and AK-9 with a mixed one. One can notice definite contradiction between high inhibition effect and low values of activation energy of corrosion for AK-9 as compared to AK-23 and AK-10. This fact be explained possibly by the film formation in chemisorption process, which creates an additional diffusion barrier [15].

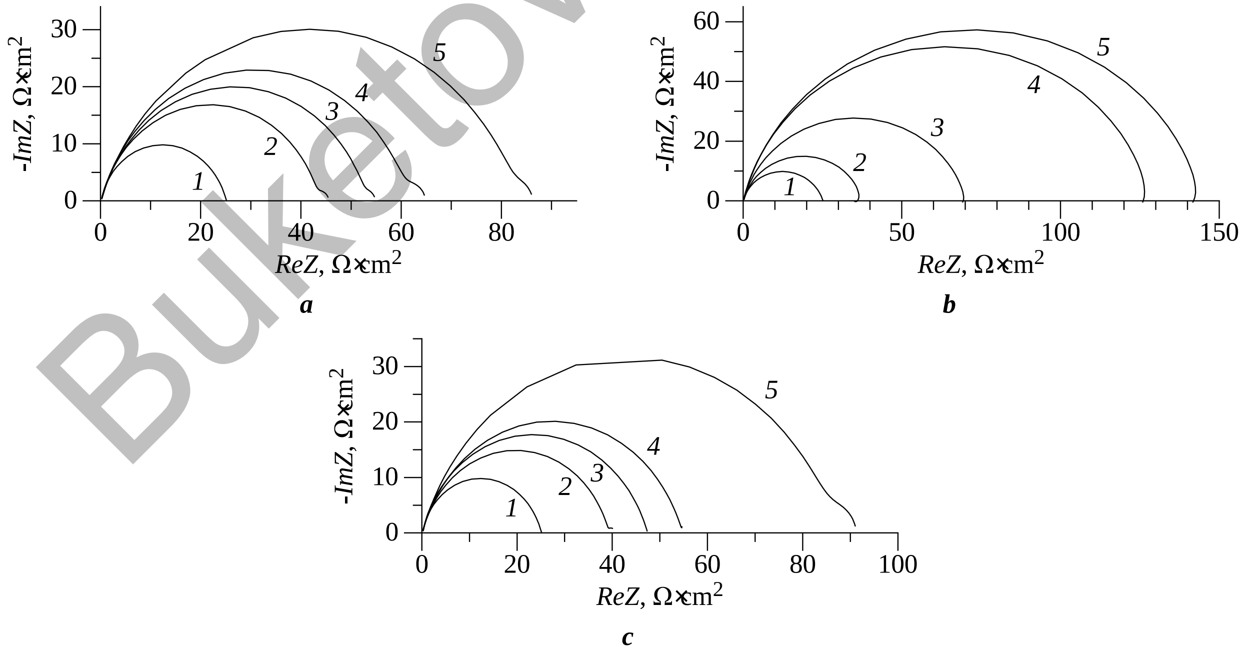


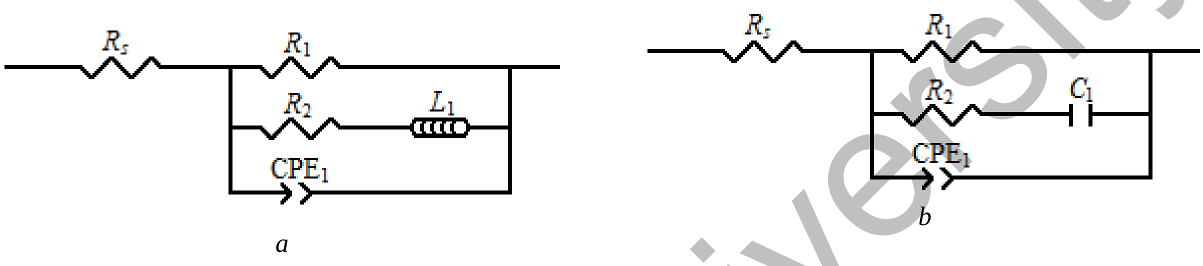
Figure 2. Nyquist diagrams of the St3 electrode in 15 % HCl solution at E$_{cor}$ (*1*) in presence of the compounds: (*a*) — AK-9, (*b*) — AK-10, (*c*) — AK-23 with concentration: *2* — 0.01 g·L$^{-1}$; *3* — 0.05 g·L$^{-1}$; *4* — 0.10 g·L$^{-1}$; *5* — 0.20 g·L$^{-1}$

The impedance spectra of St3 in 15 % HCl solution at corrosion potential $E_{corr}$ were in the form of combination of one semicircle in the high-frequency range and one inductive or capacity arc in the low-frequency range. In Figure 2 *ReZ* is the real component of impedance and *ImZ* is the imaginary e component of impedance.

The diameter of the capacitive semicircle increased the in the high frequency region in the solutions containing inhibitors. This growth is stronger at high concentrations of the inhibitor. This fact can be explained probably by the difficulties of realization of the electrode reactions.

To simulate the corrosion-electrochemical behavior of the St3 electrode in 15 % HCl solutions in the presence of AK-10 inhibitor the equivalent electrical circuit is proposed as shown in Figure 3*a*. In the presence of AK-9 and AK-23 inhibitors, the behavior of the St3 electrode in 15 % HCl solutions is acceptably described by the equivalent scheme in Figure 3*b*.

The values of the parameter $\chi^2$ for the schemes calculated in ZView2 were in the range of $(2–6)\cdot10^{-4}$, which indicates a good correlation with experimental data. The values of the parameters of the equivalent schemes are given in Table 4.



*a* *b*

Figure 3. Equivalent electrical circuits for the St3 electrode in 15 % HCl solutions at $E_{cor}$

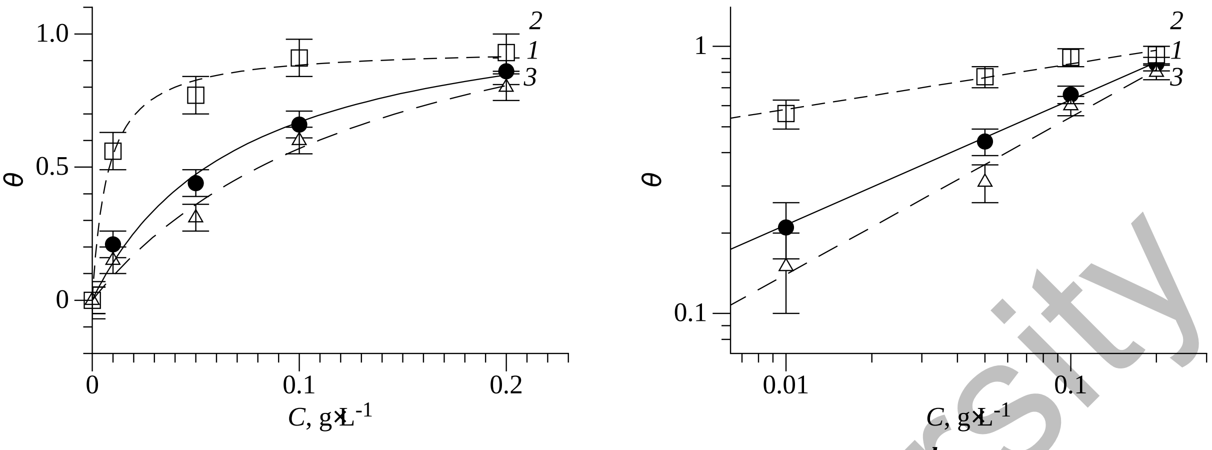
Table 4

**Numerical values of parameters of equivalent circuits**
**for St3 electrode in 15 % HCl solution without and in the presence of inhibitors**

| $C_{inh}$, g·L$^{-1}$ | $R_{ct}$, Ω·cm$^2$ | *R*, Ω·cm$^2$ | CPE$_{dl}$, μF·cm$^{-2}$·s$^{(p-1)}$ | | *C/L*, F·cm$^{-2}$/H·cm$^2$ | θ |
|---|---|---|---|---|---|---|
| | | | *Q* | *p* | | |
| Without inhibitor | | | | | | |
| - | 31.97±0.12 | 389.4±5.3 | 1.92±0.10 | 0.83±0.02 | 0.000195±0.000010 | – |
| AK-9 | | | | | | |
| 0.01 | 41.42±0.13 | 829.0±10.2 | 1.48±0.10 | 0.84±0.02 | 0.000225±0.000010 | 0.21±0.01 |
| 0.05 | 54.18±0.12 | 977.7±11.0 | 1.26±0.10 | 0.84±0.03 | 0.000378±0.000012 | 0.44±0.01 |
| 0.10 | 64.77±0.14 | 1156±15.4 | 1.22±0.10 | 0.82±0.02 | 0.000211±0.000010 | 0.66±0.01 |
| 0.20 | 77.56±0.16 | 2573±21.1 | 1.10±0.10 | 0.80±0.02 | 0.000070±0.000013 | 0.86±0.01 |
| AK-10 | | | | | | |
| 0.01 | 37.79±0.11 | 393.9±3.2 | 0.95±0.10 | 0.86±0.02 | 11.7±0.6 | 0.56±0.01 |
| 0.05 | 54.34±0.13 | 556.0±5.4 | 0.83±0.10 | 0.87±0.02 | 85.5±3.2 | 0.77±0.01 |
| 0.10 | 113.6±0.32 | 757.3±8.9 | 0.78±0.10 | 0.89±0.03 | 482.5±28.0 | 0.91±0.01 |
| 0.20 | 128.6±0.22 | 1263.0±9.3 | 0.82±0.10 | 0.86±0.02 | 786.5±35.1 | 0.93±0.01 |
| AK-23 | | | | | | |
| 0.01 | 29.46±0.11 | 711.0±11.2 | 1.38±0.10 | 0.86±0.02 | 0.000175±0.000019 | 0.15±0.01 |
| 0.05 | 33.28±0.12 | 1429.0±16.7 | 1.45±0.10 | 0.84±0.02 | 0.000140±0.000015 | 0.31±0.01 |
| 0.10 | 39.41±0.13 | 1508.0±12.9 | 1.31±0.10 | 0.84±0.01 | 0.000203±0.000010 | 0.64±0.01 |
| 0.20 | 91.38±0.15 | 1906.0±19.4 | 1.14±0.10 | 0.80±0.01 | 0.000125±0.000010 | 0.84±0.01 |

There is a regular increase in resistances $R_1$ and $R_2$ and a decrease in parameter $Q_1$ of constant phase element $CPE_1$ (with comparable $p_1$) with the increase of the concentration of AK compounds (it follows from Table 4). The latter increase indicates the inhibition of electrode processes (mainly the cathodic process) in the presence of the studied compounds and their adsorption on the electrode surface. The parameters $R_2$ and $C_1$ can also be associated with the kinetics of the adsorption of AK compounds on the electrode surface (the Frumkin–Melik-Gaikazyan impedance without diffusion impedance).

The capacity of the double-electric layer and the degree of the surface coverage by inhibitors were calculated (Table 4) from the obtained values of the parameters of the equivalent circuit (Fig. 5). These results were processed in the coordinates of the Langmuir and Freundlich equations (Fig. 4, Table 5).



***a*** ***b***

Figure 4. Langmuir (*a*) and Freundlich (*b*) isotherms of adsorption of AK-9 (curve *1*), AK-10 (curve *2*) and AK-23 (curve *3*) on the surface of St3 in 15 % HCl solutions

Table 5

**Parameters of Langmuir and Freundlich isotherms for the adsorption of AK-9, AK-10, and AK-23 on the surface of St3 in 15 % HCl solutions**

| Inhibitor | Langmuir | | | Freundlich | | |
|---|---|---|---|---|---|---|
| | $K$, dm$^3$·g$^{-1}$ | $Q$, μmol·m$^{-2}$ | R$^2$ | $K$ | $n$ | R$^2$ |
| AK-9 | 13.99 | 1.15 | 0.9870 | 1.85 | 0.47 | 0.9972 |
| AK-10 | 133.80 | 0.95 | 0.9927 | 1.27 | 0.17 | 0.9925 |
| AK-23 | 7.06 | 1.38 | 0.9838 | 2.11 | 0.59 | 0.9854 |

The calculated values of the correlation coefficients indicate that the process of the surface coverage by inhibitor molecules to a greater extent follows the Freundlich isotherm. It describes adsorption on an energetically inhomogeneous surface [16].

## *Conclusions*

Thiadiazole derivatives act as effective inhibitors of acid corrosion for the mild steel St3. They possess a mixed effect, reducing the rates of partial cathodic and anodic reactions. The mechanism of action of thiadiazoles changes with increasing temperature, that is expressed in a sharp increase in the coefficients $b_k$ of the Tafel equation. At the same time, the free corrosion potential shifts to the cathodic region. The analysis of the polarization curves correlates with the results that have been obtained by the impedance spectroscopy and they confirm mostly the cathodic mechanism of inhibitors action.

The degree of the surface coverage by inhibitor with growing of its concentration causes an increase in the protective effect. It was established from the analysis of the impedance spectra. The coverage of the St3 surface is described by the Freundlich isotherm for an energetically inhomogeneous surface. The activation energy values have been calculated and they indicate that the corrosion process is slowed down due to the physical adsorption on the surface of St3 in the case of AK-10 and AK-23. But the chemisorption process is more likely for AK-9. The values of the inhibiting effect calculated from the results of weight-loss and electrochemical measurements are qualitatively correlated. The differences in the results of the experimental methods used in this work are related to the peculiarities of the rate of the adsorption equilibrium establishing.

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# Тиадиазол туындыларын тұз қышқылындағы азкөміртекті болаттың коррозияға қарсы ингибиторлары ретінде зерттеу

Мақалада бірқатар тиадиазол туындыларын 15 % тұз қышқылы ерітінділеріндегі азкөміртекті болаттың коррозия ингибиторлары ретінде зерттеу нәтижелері келтірілген. Гравиметриялық сынақтар және электрохимиялық зерттеулер St3 аз көміртекті болатта 293 К температурада жүргізілді, сынамалардың әсер ету уақыты 24 сағ. Поляризация қисықтары катодты аймақтан үш электродты жасушада потенциодинамикалық режимде SOLARTRON 1280 C электрохимиялық өлшеу кешенін қолдана отырып тіркелді. 2-аминотиазол, 5-амино-1,3,4-тиадиазол-2-тиол, 2-амино-1,3,4-тиадиазол, 2-амино-5-(фуран-2-ил)-1,3,4-тиадиазол, сірке қышқылының 1,3,4-тиадиазол-2-иламидтері зерттелді. Зерттелген қосылыстар 0,10–0,20 $г \cdot л^{-1}$ концентрациясында барынша жақсы қорғаныс әсерін көрсететіні анықталды. 90 %-дан жоғары қорғаныш қасиетке ие болған қосылысқа 5-амин-1,3,4-тиадиазол-2-тиол жататыны анықталды. Ең аз қорғаныс қасиетке (60 %-дан аз) ие болған қосылысқа сірке қышқылының 1,3,4-тиадиазол-2-иламиді. Электрохимиялық зерттеулердің нәтижесі қарастырылған қосылыстардың аралас (катодты-анодтық) типті ингибиторлар болып келетінін көрсетті. Ингибиторлардың қорғау әсерін ток тығыздығының өзгерісі бойынша есептеу гравиметриялық сынақтардың нәтижелерімен сәйкес келетін нәтижелер береді. Ингибиторларды коррозиялық ортаға енгізу St3-тің еру процесінің тиімді активтендіру энергиясын 3,3-тен 94,8 кДж / мольға дейін едәуір арттырады. Жұмыстың нәтижелерін қышқылды коррозияның потенциалды тежегіштерін тиадиазол туындылары арасында іздеу және олардың негізінде ингибирлеуші композицияларды дамыту перспективалы екендігін көрсетеді.

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# Исследование производных тиадиазола в качестве потенциальных ингибиторов коррозии малоуглеродистой стали в соляной кислоте

В статье приведены результаты исследования ряда производных тиадиазола в качестве ингибиторов коррозии малоуглеродистой стали в 15-процентных растворах соляной кислоты. Гравиметрические испытания и электрохимические исследования выполнены на малоуглеродистой стали Ст3 при температуре 293 K, время экспозиции образцов составило 24 ч. Поляризационные кривые снимали в потенциодинамическом режиме в трехэлектродной ячейке из катодной области в анодную со скоростью развертки потенциала 1 мВ·с$^{-1}$, используя электрохимический измерительный комплекс SOLARTRON 1280 C. Исследованы 2-аминотиазол, 5-амино-1,3,4-тиадиазол-2-тиол, 2-амино-1,3,4-тиадиазол, 2-амино-5-(фуран-2-ил)-1,3,4-тиадиазол, 1,3,4-тиадиазол-2-иламид уксусной кислоты. Установлено, что исследованные соединения в концентрациях 0.10–0.20 г·л$^{-1}$ проявляют достаточно хорошее защитное действие. Наилучший результат дает 5-амино-1,3,4-тиадиазол-2-тиол с защитным действием более 90 %. Наименьшим защитным действием (менее 60 %) обладает 1,3,4-тиадиазол-2-иламид уксусной кислоты. Электрохимическими исследованиями установлено, что данные соединения являются ингибиторами смешанного (катодно-анодного) типа. Расчет защитного действия ингибиторов по изменению величин плотности тока коррозии показал результаты, качественно совпадающие с результатами гравиметрических испытаний. Введение ингибиторов в коррозионную среду значительно повышает эффективную энергию активации коррозионного процесса растворения Ст3 с 3,3 до 94,8 кДж·моль$^{-1}$. Результаты работы указывают на перспективность поиска потенциальных ингибиторов кислотной коррозии в ряду производных тиадиазола и разработки ингибирующих композиций на их основе.

*Ключевые слова*: малоуглеродистая сталь, кислотная коррозия, ингибиторы, тиадиазол, тиазол, гравиметрия, импеданс, адсорбция.

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