# Influence of the acidity of the medium and the activity of chloride ions on kinetics of partial electrode reactions on steel with a superhydrophobic surface in chloride media

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#### Abstract

The electrochemical behavior of carbon steel with a superhydrophobic surface in weakly acid solutions with a constant ionic strength equal to 1 and a complex composition of the electrolyte x M HCl + (1-x) M NaCl with x = 0.0005-0.01 mol/L has been studied. The effect of the concentration (activity) of Cl<sup>-</sup> anions was evaluated in NaCl solutions with variable concentrations in the range 0.0005-0.01 mol/L of the salt. To obtain a superhydrophobic coating, the metal surface was textured by IR laser radiation of nanosecond duration followed MAF by chemisorption of (methoxy-{3-[2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl)oxy]propyl}silane from a solution of *n*decane. The thickness of the superhydrophobic coating, including the textured metal layer and the adsorbed nanosize layer of the superhydrophobization agent (2-3 nm), was of the order of 100  $\mu$ m. The wetting angle is 168.8 $\pm$ 1.5°.

The kinetic parameters of the hydrogen evolution reaction, accompanied by cathodic reduction of dissolved oxygen, and anodic ionization of the metal as a function of the acidity of the medium were obtained. With increasing duration of exposure, corrosion potential ( $E_{cor}$ ) shifts to the region of more negative potentials and the most negative  $E_{cor}$  is observed at minimal HCl concentration. The steady state is achieved only after 120 hours and the corrosion potentials of the steel that corrodes in the active state assumes very negative values (-0.550 to -0.580 V) due to inhibition of the cathodic reaction.

In media containing 0.0005–0.01 mol/L sodium chloride, the relationship between the kinetic parameters of the same electrode reactions and the activity of chloride ions  $(a_{Cl})$ 

has been studied. The anodic reaction is accelerated and the corrosion rate of the steel increases with an increase in the activity of chloride ions  $(1.0 \le d \lg i_a / d \lg a_{Cl^-} \le 2, 1.0 \le d \lg i_{cor} / d \lg a_{Cl^-} \le 1.3)$ . This may be a consequence of the participation of halogen anions in the anodic process.

*Key words:* superhydrophobic coating, carbon steel, kinetic parameters, hydrogen evolution, anodic ionization, corrosion rate, ionic strength, activity.

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## Introduction

The last 15–20 years in our country and abroad there is an increased interest in studying the possibilities of the method of corrosion protection of metals and alloys by applying to the corrosive surface of films of a hydrophobizer of nanoscale thickness. This causes an increase in the contact angle of wetting  $\Theta$  to 115–120° using a hydrophobic agent or up to 150–170° in the presence of a superhydrophobizer [1–18]. Superhydrophobization of the metal surface allows to achieve a reduction in the corrosion rate in neutral chloride media from 8 [19] to 10<sup>4</sup> [3] times. The protective effect is due to the resulting lack of water as a participant in electrode processes [20].

At the same time, similar studies were usually carried out in 3.0-3.5% sodium chloride solutions [8, 13, 16, 19], which makes it possible to evaluate the protective efficacy of super-hydrophobic coatings of nanoscale thickness, but does not contribute to the study of the kinetic characteristics of the partial electrode reactions that occur.

The purpose of this work is to study separately the effect of the concentration of hydrogen and chlorine ions on the kinetics of the hydrogen evolution reaction accompanied by parallel cathodic reduction of dissolved oxygen and the anodic ionization of carbon steel with a superhydrophobized surface. Simultaneously, the influence of the duration of the experiment (in situ) on the kinetic parameters of electrode reactions and the corrosion rate of steel was estimated from the data of polarization measurements.

## **Experimental**

The investigations were carried out on electrodes made of carbon steel St3 with a chemical composition (here and below, in mass %): C - 0.20; Mn - 0.50; Si - 0.15; P - 0.04; S - 0.05; Cr - 0.30; Ni - 0.20; Cu - 0.20, Fe - 98.36. Kinetic parameters were evaluated for samples with two types of preparation, reinforced in a mandrel made of cured epoxy resin ED-5 (types I and II).

The kinetics of the hydrogen evolution reaction (HER) was studied in solutions with a complex electrolyte composition x M HCl + (1-x) M NaCl and x = 0.0005-0.01 mol/L. In them, the ionic strength and activity of chloride ions remained practically constant. The effect of the concentration (activity) of Cl<sup>-</sup> anions was evaluated in NaCl solutions with

variable concentrations in the range 0.0005-0.01 mol/L of salt of "pure for analysis" grade. In this case, the change in the activity coefficient of chloride ions in media with different salt concentrations ( $C_{\text{NaCl}}$ ) was taken into account, which determined the lack of proportionality between  $C_{\text{NaCl}}$  and anion activity ( $a_{\text{Cl}^-}$ ). To estimate the  $a_{\text{Cl}^-}$  value for a known analytical concentration of chloride anions, the activity coefficients of individual ions were used, according to [21].

To obtain a Type I coating, the metal surface was textured by IR laser radiation of by nanosecond duration followed chemisorption of MAF (methoxy-{3-[2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl)oxy]propyl}silane) from a solution in *n*decane. The thickness of the superhydrophobic coating, including the textured metal layer and the adsorbed nanosize layer of the superhydrophobization agent (2-3 nm), was of the order of 100 µm. To obtain the second type of coatings, a nanoscale composite layer consisting of aggregates of aerosil nanoparticles was applied to the first variant. After chemisorption of the superhydrophobizer, the samples were held for at least 336 hours at room temperature for cross-linking in the protective agent layer. The wetting angle on samples of both types of preparation is  $168.8 \pm 1.5^{\circ}$ .

An IPC-Pro MF potentiostat (manufactured by the Frumkin Institute of Physical Chemistry and Electrochemistry of RAS) was used to carry out polarization potentiodynamic measurements (potential sweep rate -0.66 mV/s). The potentials were measured with respect to the saturated silver/silver chloride electrode and were recalculated to the standard hydrogen scale. The counter electrode is a smooth platinum, the area of the end working surface is  $0.8 \text{ cm}^2$ .

The working surface was rinsed with distilled water with a conductivity of no more than  $2 \cdot 10^{-6} \ \Omega^{-1} \cdot \text{cm}^{-1}$  and a negative reaction to metal cations (complexometric titration with Trilon B solution with Eryochrom black T or murexide indicator) before conducting the polarization measurements.

Electrochemical measurements in working solutions of all concentrations are given at room temperature in aerated media after 0.25 h exposure in the corrosive medium and then *in situ* in 24, 48, 72, 120, 144 h after that exposure.

Initially, the measurements were carried out in the solution with the lowest concentration. Then, the electrode was removed, rinsed with distilled water, dried with filter paper, washed in solution with the next higher concentration, and introduced into an electrochemical cell to perform measurements in this medium.

After this, the operation was carried out again, but already with solutions of the following concentrations. The measurements were terminated in the solution with the highest concentration, after which the electrode stayed in it for a day (18–20 hours). The next day it was removed from the working solution, rinsed again with distilled water, dried as before, and rinsed with the solution with the lowest concentration (0.0005 mol/L NaCl), was placed in an electrolytic cell and all procedures were repeated with measurements.

Thus, measurements were made in each new series of experiments that differed in time (immediately after immersion in the working solution, after 24, 48, 72 hours, *etc.*).

## **Results and discussion**

#### Effect of the concentration of hydrogen ions

When using a complex electrolyte, the effect of  $a_{Cl^-}$  should not be manifested at all. At the initial stage of the corrosive action of the medium (immediately after immersing the electrodes in the solution),  $E_{cor}$  of steel with a superhydrophobized surface is much more positive than the open-circuit potential of the unprotected metal, equal to -0.420 V (Figure 1). A qualitatively similar picture was earlier observed in a 0.5 M NaCl solution [20]. The kinetic parameters of electrode reactions (type I electrodes) are given in Table 1.



**Figure 1.** Polarization curves of hydrophobized steel (a – type I, b – type II) in a medium with an electrolyte *x* M HCl + 1.0 M NaCl, obtained after 0.25 h after immersion in solution. *x*, mol/L: 1 - 0.0005, 2 - 0.001, 3 - 0.005, 4 - 0.01.

On the cathodic polarization curves, there are no pronounced regions of the limiting current at  $C_{\text{HCl}} = 0.0001-0.001 \text{ mol/L}$ , but with a higher acidity of the medium, it is well pronounced. At potentials of points A (section AB, Figure 1a) and smaller, a parallel cathodic process of discharge of water molecules proceeds. With increasing duration of exposure ( $\tau_{\text{exp}}$ ) in a chloride medium up to 24 h,  $E_{\text{cor}}$  shifts to the region of more negative potentials (Figure 2a), and the most negative  $E_{\text{cor}}$  is observed in the maximally dilute solution.

A similar picture is also observed with a subsequent increase in  $\tau_{exp}$  in a corrosive medium twofold (48 h) (Figure 3a). Corresponding  $E_{cor}$  and other kinetic parameters are

given in Table 1. Thus,  $E_{\rm cor}$  in 0.0005 M HCl solution is -0.56 V (there is no limit cathodic current part),  $d \lg i_{\rm a} / d \lg a_{\rm H^+} \approx 1.3$ .

**Table 1.** Influence of the duration of action of weakly acid chloride solutions on the kinetic parameters of partial electrode reactions on steel with a superhydrophobized surface of type I.

Parameter		The time from the beginning of immersion of steel into the solution, h:					
		0.25	24	48	120	144	
$dE_{\rm c}/d\lg i_{\rm c}$ , V		0.130	_	_	_	_	
$dE_{\rm a}/d\lg i_{\rm a}$ , V		0.080	0.100	0.065	0.070	>0	
$d \lg i_{\rm c} / d \lg a_{\rm H^+}$		0	>0	>0	>0	-	
$d \lg i_{a} / d \lg a_{H^+}$		~2.0	~0.5	1.0	1.0	>0	
$d \lg i_{\rm cor} / d \lg a_{\rm H^+}$		0.8	>0	1.3	1.2	_	
$d \lg i_{\rm c,limit} / d \lg a_{\rm H^+}$		_	_	0.85	0.90	_	
	0.0005	0.160	0.580	0.560	0.560	0.540	
$-E_{\rm cor}$ , V at $C_{\rm H}^+$ , mol/L	0.001	0.290	0.460	0.460	0.560	0.510	
	0.005	0.420	0.450	0.440	0.460	0.430	
	0.01	0.450	0.450	0.440	0.440	0.430	



**Figure 2.** Polarization curves of hydrophobized steel (a – type I, b – type II) in solutions x M HCl + 1.0 M NaCl, obtained after 24 hours exposure. x, mol/L: 1 – 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.



**Figure 3.** Polarization curves of hydrophobized steel (a – type I, b – type II) in solutions x M HCl + 1.0 M NaCl, obtained after 48 hours exposure. x, mol/L: 1 – 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.

Quantitatively, at a  $\tau_{exp}$  equal to 120 h (type I of superhydrophobization of the surface), the kinetic parameters remain close to those observed at  $\tau_{exp}$ , corresponding to 48 h. Again, the corrosion potentials in media with the lowest activity of  $a_{H^+}$  are the most negative (Table 1).

The pattern observed on steel with a superhydrophobized surface with a  $\tau_{exp}$  of 144 h is shown in Figure 4.



**Figure 4.** Polarization curves of hydrophobized steel (type I) in solutions x M HCl + 1.0 M NaCl, obtained after 144 hours exposure. x, mol/L: 1 - 0.0005, 2 - 0.001, 3 - 0.005, 4 - 0.01.

Qualitatively, the situation is similar to the previous one. The smallest  $E_{cor}$  is again observed in the most dilute chloride solutions (Table 1).

Let us consider the effect of  $a_{H^+}$  and  $\tau_{exp}$  on the kinetic parameters of partial electrode reactions on steel with a superhydrophobic type II surface (Figure 1b).

As in the case of a Type I coating (Figure 1a), in the medium with the lowest activity of hydroxonium ions, the largest  $E_{cor}$  is realized at the initial stage of corrosion. When passing to a medium with  $a_{H^+}$  equal to 0.00095 mol/L, it decreases by 0.220 V and then decreases with increasing activity of hydrogen ions (from -0.390 to -0.450 V) (Figure 1b). The order of the anodic reaction for cations  $H_3O^+$  ( $d \lg i_a / d \lg a_H^+$ ) is again close to 2 (~1.7), which correlates qualitatively with a similar situation for type I superhydrophobization (Table 1), and  $d \lg i_c / d \lg a_H^+$  is again close to 0 (Figure 1a,b). The Tafel slope coefficient of the anodic section of the polarization curve is 0.070 V. Determination of  $dE/d \lg i_c$  is difficult due to the small length of the cathodic Tafel region. In general, the correlation in the behavior of steel with the I and II types of the superhydrophobic coating is quite satisfactory (Figures 1a, b).

With an increase in the exposure time up to 24 h, the picture remains also satisfactorily correlated with the influence of a coating of the I type (Figure 2a,b). Only with a minimum value of  $a_{H^+}$ ,  $E_{cor}$  is more positive by 0.060 V on electrodes with a coating of type II. Therefore, a region of the limiting cathodic current appears in curve 1 (Figure 2b), corresponding to the reaction of the hydrogen ion discharge, which transforms into the region of cathodic reduction potentials of water molecules.

In full measure, all that has been said is repeated also with 48-hour exposure (Figure 3a,b) of electrodes in a weakly acid chloride medium, with the same features as in Figure 2a,b. The same applies to longer times (up to 144 hours) of aging steel with a superhydrophobized surface in slightly acidic chloride media.

The data obtained in media *x* M HCl + 1.0 M NaCl in the range of x = 0.0005-0.01 mol/L, in general, confirmed a satisfactory correlation of the kinetic parameters of the partial electrode reactions on both types of superhydrophobized electrodes. Simultaneously, they showed the presence of peculiarities when cathodic processes and anodic ionization proceeded on them, related to the character of the effect of the activity of  $a_{H^+}$  (in comparison with unprotected steel).

# Effect of the concentration of chloride ions

Measurements in solutions of sodium chloride have made it possible to unambiguously estimate the effect of the concentration of chloride anions, or rather their activity, on the kinetics of partial electrode reactions on steels with a hydrophobized surface.

At the same time, we note the following. The value of the hydrogen index of the medium with a change in the NaCl content remained constant and close to 5.8.

Acidification is due to the presence of carbon dioxide in solutions. The cations of Na<sup>+</sup> are surface-inactive in the investigated conditions and their possible adsorption on the metallic surface can be neglected. In such media, the pH of the formation of  $Fe(OH)_2$  is not achieved during the experiment. Consequently, the hydrated cations  $Fe^{2+} nH_2O$  or  $FeOH^+ mH_2O$  pass into the solution.

The greatest error in the discussion of the results can be caused by the use of chloride solutions with significantly different ionic strength, thereby the activity of the chloride anion is changing, which with growth of  $C_{\text{NaCl}}$  may differ significantly from the analytical concentration. To level this effect, all data were obtained taking into account the actual activity coefficients of individual chloride ions,  $f_{\text{Cl}^-}$ , in accordance with [21]. The absolute values of  $f_{\text{Cl}^-}$  as a function of the concentration are shown in Figure 5. The real activity of chloride ions is shown in Table 2.



**Figure 5.** Dependence of real (1) and averaged (2) activity coefficients  $f_i$  of individual sodium chloride ions in solution, according to [21].

**Table 2.** Relationship between the analytical concentration and ion activity in solutions of sodium chloride, obtained with allowance for the activity coefficients of individual ions.

Substance	Ion concentration, mol/kg	$a_{\rm Cl}$ , mol/kg	a <sub>cation</sub> , mol/kg
	0.001	0.00096	0.00098
NaCl	0.005	0.00442	0.00490
NaCI	0.01	0.00840	0.00973
	0.05	0.0387	0.0438

We note that the effect of the concentration (activity) of chloride ions on the kinetics of anodic dissolution of steel can be ambiguous. If the anions take a direct part in the ionization of the metal, then the quantity  $d \lg i_a / d \lg a_{Cl^-}$  should be greater than zero. However, a value  $d \lg i_a / d \lg a_{Cl^-} < 0$  is also possible, which is caused by the displacement of OH<sup>-</sup> ions by chloride anions on the steel surface. Obviously, adsorbing in the active centers in this case, the Cl<sup>-</sup> anions block them and inhibit the oxidation of the surface iron atoms, proceeding with the participation of OH<sup>-</sup> [22]. In general, the dependence  $i_a = f(a_{Cl^-})$  can pass through an extremum.

Further, in connection with the limited volume of the publication, experimental results are given (Figure 6 – Figure 8) for electrodes with a superhydrophobized surface of both types. But the data are interpreted for electrodes with preparation of type 1, since in both cases they are more often qualitatively similar. The presence of significant discrepancies is considered at the end of the publication.

At the initial stage of the corrosive action of the medium, a significant correlation of the corrosion potential is observed (Figure 6a) with  $a_{Cl^-}$ . Thus, the transition from 0.0005 M to 0.01 M NaCl solutions lowers the  $E_{cor}$  of steel by ~ 0.150 V with simultaneous acceleration of the anodic reaction in the  $C_{Cl^-}$  range from 0.0005 to 0.005 mol/L. Further, the concentration effect of chloride anions is practically absent.



**Figure 6.** Polarization curves of hydrophobized steel (a – type I, b – type II) in solutions of NaCl, obtained after 0.25 hours exposure.  $C_{Cl}$ , mol/L: 1 – 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.

The value of  $d \lg i_a / d \lg a_{Cl^-}$  is close to 2. The Tafel slope coefficient of the anodic branch of the polarization curve  $dE/d \lg i_a$  approaches 0.080 V, which correlates well with the literature data over a wide range of concentrations of Cl<sup>-</sup> (0.0005–1.0 M Cl<sup>-</sup>) [23]. The rate of the cathodic reaction, which in this case is the reduction of dissolved oxygen, is

ambiguously associated with  $a_{\text{Cl}^-}$ . In the range of the studied activities (Table 2), the rate of reduction of the dissolved oxygen with  $d \lg i_c / d \lg a_{\text{Cl}^-} \approx -0.6$  is observed, in addition there is a sharp minimum in 0.005 M solutions of NaCl.

According to Figure 6a, the rate of corrosion of steel increases with an acceleration of the anodic process. Moreover, the quantity  $d \lg i_{cor} / d \lg a_{Cl^-}$  is close to 1.3. A characteristic feature of hydrophobized steel at the initial stage of corrosion in neutral chloride media is the high values of  $E_{cor}$ , which was observed earlier in 0.5 M NaCl [20]. However, this occurs only in the region of small concentrations of chloride anions (0.0005–0.001 mol/L). The transition to more mineralized media (0.01 mol/L NaCl) leads to a significant decrease in  $E_{cor}$  already at the initial stage of corrosion (Figure 6a), with practically unchanged values of  $b_a$  (0.090 V) and  $b_c$  (~ 0.110 V).

After a 24-hour exposure of the electrodes in a corrosive environment, the picture changes markedly. Potential corrosion of steel in media with  $0.001-0.01 \text{ mol/L } \text{Cl}^-$  is levelled, approaching the values characteristic for non-hydrophobized steel (Figure 7a).

However, in 0.0005 M NaCl solution, the value of  $E_{cor}$  is significantly shifted to the negative side due to the inhibition of the cathodic reaction, and there is no cathodic current limit region on the cathodic polarization curve (Figure 7a). In more concentrated media, these areas are clearly expressed, and the  $d \lg i_{limit} / d \lg C_{Cl}$  value close to 1 (1.05).



**Figure 7.** Polarization curves of hydrophobized steel (a – type I, b – type II) in solutions of NaCl, obtained after 24 hours exposure.  $C_{Cl}$ , mol/L: 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.

For the anodic process in the range of 0.001-0.01 mol/L NaCl, the value of  $d \lg i_a / d \lg C_{Cl^-}$  is close to 1.2, which suggests direct participation of chloride anions in the anodic ionization of steel, and  $b_a = 0.070 \text{ V}$ . It is of fundamental importance that at cathode potentials of the order of -0.6 V the discharge of water (section AB) begins.

After 48 hours of the steel stay with a superhydrophobized surface (samples of type I) in the corrosive medium, the picture practically does not change (Figure 8a). Again,

 $d \lg i_a / d \lg a_{Cl^-} \approx 1.2$ ,  $d E_a / d \lg i_a \approx 0.060 \text{ V}$ ,  $d \lg i_{cor} / d \lg a_{Cl^-} \approx 1.3$ ,  $d \lg i_{c,\text{limit}} / d \lg a_{Cl^-} \approx 0.90 \pm 0.05$ . In practice,  $E_{cor}$  remains unchanged (Figures 7a and 8a). In principle, it could be considered that a steady state has been reached.



**Figure 8.** Polarization curves of hydrophobized steel (a – type I, b – type II) in solutions of NaCl, obtained after 48 hours exposure.  $C_{Cl}$ , mol/L: 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.

However, after 120 hours of corrosive action, the behavior of the samples of hydrophobized steel of the first series changed again (Figure 9). Now  $E_{cor}$  moved to the negative side not only in 0.0005 M, but also in 0.001 M NaCl solution. Moreover, two regions of  $C_{NaCl}$ , *viz.*, 0.0005–0.001 and 0.005–0.01 M, became apparent in anodic behavior, within each of which the behavior of the metal is identical.



**Figure 9.** Polarization curves of hydrophobized steel (type I) in solutions of NaCl, obtained after 120 hours exposure.  $C_{Cl}$ , mol/L: 0.0005, 2 – 0.001, 3 – 0.005, 4 – 0.01.

But in the region of low concentrations, the rate of the anodic process (at  $E_a = \text{const}$ ) is much higher than in media with greater mineralization. In another day the picture remained qualitatively with certain quantitative changes, on the whole, not of a fundamental nature (therefore, these data are not given).

We also note some discrepancies in the kinetic parameters characteristic of type I and type II electrodes. Thus, in the second case, after 0.25 h after immersion in the solution, the following pattern is observed:  $dE_c/d\lg i_c = 0.100 - 0.110 \text{ V}$ ,  $dE_a/d\lg i_a = 0.030 - 0.065 \text{ V}$  (depending on the value of  $a_{Cl^-}$ ) (Figure 3b).  $d\lg i_c/d\lg a_{Cl^-} = 0$ ;  $d\lg i_a/d\lg a_{Cl^-} \approx 0$  (in the range of the same anion concentrations 0.005–0.05 mol/L. Only with the smallest content of sodium chloride, the rate of anodic ionization is significantly slowed down (Figure 6b).

After 24 hours of electrode stay in the corrosive medium, the differences remain (Figure 7a, b). They are particularly characteristic of the anodic process. The value of  $dE_c/d\lg i_c$  decreases to 0.090 V, although  $dE_a/d\lg i_a$  remains at the same level (0.060 V). The quantity  $d\lg i_c/d\lg a_{Cl^-} < 0$ ,  $d\lg i_a/d\lg a_{Cl^-} = 1.5$ , while it assumes a zero value for electrodes of the type I.

It is important that after a 48-hour exposure in a neutral chloride medium, the situation for the hydrophobized electrodes of both series approaches (Figure 8a, b). Finally, after 144 hours of residence in a sodium chloride solution, the picture is as follows:

Electrodes (type I)	Electrodes (type II)
$dE_{\rm c} / d\lg i_{\rm c} = 0.070  {\rm V}$	$dE_{\rm c} / d\lg i_{\rm c} = 0.080  {\rm V}$
$dE_{\rm a} / d\lg i_{\rm a} = 0.135  {\rm V}$	$dE_{\rm a} / d\lg i_{\rm a} = 0.105  {\rm V}$
$d \lg i_{\rm c} / d \lg a_{\rm Cl^{-}} = 1.1$	$d \lg i_c / d \lg a_{Cl^-}$ changes considerably with $a_{Cl^-}$ (quantitative estimation is difficult)
$d \lg i_{\rm a} / d \lg a_{\rm Cl} \approx 1.2$	$d \lg i_{\rm a} / d \lg a_{\rm Cl^-} \approx 2.0$

Consequently, the qualitative picture for electrodes of both types is particularly similar for long times of exposure to corrosive media.

### Conclusion

Superhydrophobization of the steel surface causes a significant change in the time of the kinetic parameters of the partial electrode reactions in dilute chloride solutions. The steady state is achieved only after 120 hours, regardless of the method of superhydrophobizer application.

When the stationary state is reached, the corrosion potentials of the steel that corrodes in the active state assumes very negative values (-0.550 to -0.580 V) due to inhibition of the cathodic reaction.

The anodic reaction is accelerated and the corrosion rate of the steel at current times and, when the stationary state is reached, increases with an increase in the concentration of chloride ions  $(1.0 \le d \lg i_a / d \lg a_{Cl^-} \le 2, 1.0 \le d \lg i_{cor} / d \lg a_{Cl^-} \le 1.3)$ , which may be a consequence of the participation of halogen anions in the anodic process.

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