Polyoxyethylene stearate of molecular weight 6000 as corrosion inhibitor for mild steel in 2.0 M sulphuric acid

R.S. Abdel Hameed,^{1,2}* A. El-Zomrawy,¹ M. Abdallah,^{3,4} S.S. Abed El Rehim,⁵ H.I. AlShafey⁶ and Sh. Nour Edin⁷

 ¹Faculty of Science, Department of Chemistry, Al-Azhar University, 11884, Cairo, Egypt
²Chemistry Departments, Faculty of Science, Hail University, Hail 1560, Saudi Arabi
³Faculty of Applied Science, Umm Al-Qura University, 3712, Makkah Al Mukaramha, Saudi Arabi
⁴Chemistry Department, Faculty of Science, Benha University, 13518, Banha, Egypt

⁵Faculty of Science, Department of Chemistry, Ain Shams University, 11566, Cairo, Egypt ⁶Egyptian Petroleum Research Institute, Nasr City, 11727, Cairo, Egypt ⁷Environmental institute Ain Shams University, Abassya, 1156, Cairo, Egypt *E-mail: mredars2@yahoo.com

Abstract

Polyoxyethylene stearate of molecular weight 6000 (P6000) as nonionic polymeric surfactant was prepared by the esterification reaction between citric acid with polyethylene glycol (Mwt. 6000) in the presence of para toluene sulfuric acid, PTSA as a catalyst. The chemical structure of the prepared polymeric surfactant was recognized by FT-IR spectra. The inhibition of P6000 on mild steel surface in 2.0 M H_2SO_4 solution was investigated using different techniques such as open circuit potential, potentiodynamic polarization and weight loss. The inhibition efficiency of the used polymeric surfactant increases with increasing its concentration, but decreases with rising temperature. The potentiodynamic polarization proved that P6000 acted as a mixed inhibitor controlling both cathodic and anodic reactions. The inhibition process is the result of the adsorption of P6000 on the mild steel surface through the formation of P6000 on steel surface follows Langmuir's isotherm.

Keywords: corrosion inhibitors; steel; polarization; polymeric surfactants.

Received: March 26, 2017; revised: April 20, 2017. Published: May 15, 2017. doi: <u>10.17675/2305-6894-</u> <u>2017-6-2-8</u>

1. Introduction

The inhibition of steel corrosion is the subject of tremendous technological importance due to the increased industrial applications of this material. The use of inhibitors is one of the most practical methods to reduce the rate of dissolution of steel in acidic media. Several searchers used the organic compounds as an inhibitor for corrosion of steel in H_2SO_4 solution [1–10]. The protection efficiency of these compounds depends on the several

factors such as the chemical structure of the compounds, the molecular size, the presence of electro donating or electro repelling groups, the presence of hetro atoms in their chemical formula, the presence of some active centers to facilitate the adsorption process and its ability to form complexes. These compounds are given highly efficient inhibition but unfortunately it is toxic and harmful to health. Therefore, most of the recent studies tend to use surface active agents (surfactants) as corrosion inhibitors for steel in the acidic solutions [11–14]. These compounds have many advantages where they give high inhibition efficiency, low price, low toxicity and easy production. The adsorption of the surfactant on the metal surface can markedly change the corrosion-resisting property of the metal [15, 16]. Nonionic polymeric surfactants derived from plastic waste considered as green corrosion inhibitors. These compounds were tested as an inhibitor for dissolution of steel in nitric acid, acetic acid and sodium chloride corrosive medium [17-28]. In the present study the P6000 was prepared, characterized and tested as an inhibitor for the dissolution of mild steel in 2.0 M H₂SO₄ solution with open circuit potential, potentiodynamic polarization and weight loss methods and their results were compared. Also the adsorption properties of this surfactant on mild steel surface were investigated.

2. Experimental

2.1. Materials

P6000 compound, as a kind of nonionic polymeric surfactant, was prepared by the esterification reaction between stearic acid and polyethylene glycol (molar ratio 1:2). The esterification reaction was carried out in the presence of *o*-xylene as a solvent and *p*-toluene sulphonic acid 1.5% (weight present based on the total weight of the reactants), under nitrogen atmosphere at 170°C for 6 hours. Then the mixture was left to cool at room temperature and dried. The product of esterification P6000 and xylene, P6000 was washed by using methanol as non-solvent to remove the unreacted materials [29]. The chemical structure of the prepared surfactant was characterized by its infrared spectrum, using FT-IR Spectrometer Model Type Mattson Bench top 961. FT-IR (KBr, *v*, cm⁻¹), for the prepared compound P6000 shows the following characteristic absorption bands: 3404 cm⁻¹ (OH), 2950 cm⁻¹ (C–H), and 1730 cm⁻¹ (C=O) (ester group).



Polyoxyethylene mono stearate (P6000) (Where n = 136 and M.Wt = 6266)

2.2. Methods of investigation

The chemical composition of mild steel which was used in the present work is given in Table 1. The corrosion behavior of the mild steel was studied in 2 M H₂SO₄ solution devoid of (blank) and containing different concentrations of P6000 and at different temperatures (25–45°C) using an air thermostat. All solutions were freshly prepared using analytical grade without further purification and doubly distilled water. In the weight loss method, the mild steel specimens with dimensions $2 \times 2 \times 0.1$ cm were polished by 410 and 610 grade emery paper, degreased with acetone, then washed with distilled water and finally dried and weighed. Such treatment was carried out immediately before each experiment. The dried specimens were immersed in 100 ml of the test solution for a certain time until 10 hours, reweighed and the weight loss was reported. In the open circuit method, mild steel rod was tightly fitted into an Araldite holder exposing only 1 cm² surface area to contact the test solution. The potential of the cleaned electrode was measured relative to a saturated calomel electrode (SCE) in 2 M H₂SO₄ solution devoid of and containing different concentrations of P6000 and at different temperatures. In all cases the time recorded using Multi-tester until the steady-state potentials were reached. For potentiodynamic polarization measurement, platinum and saturated calomel electrode (SCE) was used as auxiliary and reference electrodes, respectively. The mild steel working electrode (1 cm²) was first immersed in the test solution for 30 minutes to establish a steady state open circuit potential. The effect of inhibitor on steel corrosion was determined by measuring the corrosion rate in different concentrations of P6000 for the evaluation of inhibitor concentration effects on the corrosion protection. The experiments were carried out in 2 M H₂SO₄ in the absence and in the presence of various concentrations of inhibitors. The effect of temperature on corrosion inhibition of P6000 was studied at different temperatures.

Element	С	Mn	Р	S	Cr	Mo	Si	Fe
Weight (%)	0.29	1.25	0.03	0.03	0.04	0.04	0.27	Rest

3. Results and Discussion

The prepared compound (P6000) was evaluated as corrosion inhibitor for steel in 2.0 M sulfuric acid using different techniques, namely: weight loss, open circuit potential, potentiodynamic polarization techniques.

3.1. Open circuit potential

Figure 1 shows the open circuit potential (OCP) for the mild steel electrode in 2.0 M H_2SO_4 solution in the absence and presence of different concentrations of P6000 at 25°C.

In blank solution, initially the OCP is shifted to more negative value. This behavior is due to an initial dissolution of pre-immersion oxide film present on the steel surface.



Figure 1. Potential-time curves of mild steel in 2.0 M H₂SO₄ in absence and presence of different concentrations of P6000 inhibitor at 25°C.

After a short time, the OCP slightly shifts to less negative potential and finally steady state potential is attained. Addition of P6000 surfactant to the acid solution shifts the steady state potential towards the less negative direction. The shift of the steady state potential (E_{steady}) increases with increasing the surfactant concentration, suggesting that the surfactant is adsorbed on the metal surface and consequently inhibits the corrosion of mild steel in 2.0 M H₂SO₄ solution. Figure 2 represents the influence of temperature on the OCP of the mild steel electrode in 2.0 M H₂SO₄ solution containing 1000 ppm of P6000. It is obvious that the rise of temperature shifts the E_{steady} to more negative values indicating that the amount of inhibitor adsorbed on the metal surface decreases with increasing temperature.



Figure 2. Potential–time curves of steel in 2.0 M H_2SO_4 in the presence of 1000 ppm of P6000 inhibitor at different temperatures.

3.2. Potentiodynamic polarization

Figure 3 displays the potentiodynamic polarization curves for the mild steel electrode in 2.0 M H₂SO₄ solution devoid of and containing different concentrations of P6000 at 25°C and scan rate 5 mV s⁻¹. It is apparent from this figure that, the polarization diagram exhibits Tafel type behavior. The presence of P6000 shifts both the cathodic and anodic curves towards lower current densities. The corrosion current density (I_{corr}) and the percentage inhibition efficiency P(%) were acquired from these curves and the values are listed in Table 2. The surface coverage (θ) and the inhibition efficiency P(%) of the inhibitor can be calculated from I_{corr} values according to the following equationы (Eq. 1 & 2), assuming that the inhibitor in question has a blocking mechanism of action [36–39].

$$P(\%) = \frac{I_{\rm corr}^0 - I_{\rm corr}}{I_{\rm corr}^0} \times 100$$
(1)

$$\theta = P(\%) / 100 \tag{2}$$

Where, I_{corr} and I_{corr}^0 are the corrosion current densities in the absence and presence of P6000 respectively, and θ is the degree of surface coverage.

Inspection of these data reveals that the presence of various concentrations of P6000 inhibits the cathodic hydrogen evolution reaction and anodic dissolution of the steel and no significant influence on the value of B_a and B_{C} . The results suggest that the additive has no influence on hydrogen evolution reaction or iron dissolution. This may lead to the conclu-



Figure 3. Potentiodynamic polarization curves of steel in 2.0 M H₂SO₄ in presence of different concentration of P6000.

		Weight l	OSS	Polarization				
Conc. (ppm)	W (mg/cm ²)	θ	P (%)	CR (mpy)	I _{corr} (mA/cm ²)	θ	P (%)	CR (mpy)
Blank	0.4112	_	_	180.24	0.3631	—	_	166.60
100	0.1765	0.5708	57.08	77.47	0.1122	0.6910	69.10	51.48
300	0.1471	0.6423	64.23	64.57	0.0933	0.7430	74.30	42.82
500	0.1335	0.6753	67.53	58.60	0.0692	0.8095	80.95	31.74
700	0.1099	0.7327	73.27	48.24	0.0513	0.8588	85.88	23.53
1000	0.0738	0.8205	82.05	32.39	0.0398	0.8904	89.04	18.27

Table 2. Effect of P6000 concentrations on the corrosion behavior of steel in 2.0 M H_2SO_4 solution at 25°C.

sion that the action of P6000 is the simple blocking of the steel surface by adsorption [30, 31]. This elucidate that the P6000 acts as a mixed type inhibitor. The values of $E_{\text{corr.}}$ is almost constant and the values of I_{corr} decrease with increasing of the P6000 concentration as a result of increasing the surface coverage. This finding interpreted on the fact that, as the inhibitor concentration increases led to the lowering the interfacial tension on the mild steel surface. This led to a decrease of the bulk concentration of the P6000 and increases the concentration of inhibitor at the mild steel surface. The inhibition effect of P6000 is due to its adsorption on the mild steel surface which tends to separate the metal from the

acidic corrosive medium. Similar potentiodynamic polarization curves were recorded for the mild steel electrode in 2.0 M H₂SO₄ containing 1000 ppm of P6000 at different temperatures, as shown in Figure 4. The kinetic corrosion parameters associated with these curves are given in Table 3. It is seen that the value of I_{corr} both in the absence and presence of the additive enhances with the increase in temperature indicating that the corrosion process is endothermic process. However, at any given temperature the value of $I_{\rm corr}$ in the absence of the inhibitor is higher than that in the presence of inhibitor confirming the inhibitory action of P6000. The computed values of θ and P(%) at different concentrations of P6000 and temperatures are given in Table 3, the data reveal that θ and P(%) increase with the increase in P6000 concentration but decreases with increasing temperature indicating the adsorption is physically. The corrosion inhibition is a result of adsorption and the formation of a barrier film which hinder an acid attack on the mild steel surface [30, 31]. The physical adsorption is arisen due to electrostatic interaction between the multi adsorption centers of the surfactant molecule and the metal surface. As the concentration of P6000 increases, higher values of θ and consequently P(%) was obtained and the amount of P6000 adsorbed at the mild steel surface is increased. On the other hand, the increase in temperature results in a decrease in the value of θ and hence the value of P(%). These results are related to desorption of some adsorbed P6000 molecules of the metal surface this result support the conclusion that adsorption of P6000 on the mild steel surface is physically.

	Weight loss					Polarization				
	Temp. (°C)	W (mg/cm ²)	θ	<i>P</i> (%)	CR (mpy)	I _{corr} (mA/cm ²)	θ	P(%)	CR (mpy)	
Blank	25	0.4112	_	_	180.24	0.3631	_	_	166.60	
	30	0.4182	_	_	183.30	0.4467	—	_	204.96	
	35	0.4470	_	_	195.93	0.5129	—	_	235.33	
	40	0.4734	_	_	207.50	0.5495	—	_	252.13	
	45	0.4884	_	_	214.07	0.6311	_	_	289.57	
P 600	25	0.0738	0.8205	82.05	32.39	0.0398	0.8904	89.04	18.27	
	30	0.1165	0.7214	72.14	51.11	0.0501	0.8878	88.78	23.00	
	35	0.1478	0.6694	66.94	64.84	0.0589	0.8852	88.52	27.02	
	40	0.1821	0.6153	61.53	79.88	0.0646	0.8825	88.25	29.63	
	45	0.2339	0.5211	52.11	102.61	0.0794	0.8741	87.41	36.45	

Table 3. Effect of temperature on steel corrosion in absence and presence of 1000 ppm of inhibitor compound P6000.



Figure 4. Polarization curves of mild steel in 2.0 M H₂SO₄ in presence of 1000 ppm of P6000 at different temperatures.

3.3. Weight loss measurements

The corrosion of mild steel specimens in 2.0 M H_2SO_4 solution in the absence and presence of different concentrations of P6000 and at different temperatures was investigated by weight loss measurements as shown in Figures 5 and 6, respectively. The inhibition efficiency P(%) of P6000 under different experimental conditions were calculated using the following equation:

$$P(\%) = (W^0 - W/W^0) \times 100 \tag{3}$$

Where, W^0 and W are the weight loss in the absence and presence of P6000. The calculated P(%) of P6000 is given in Table 2. The corrosion rate (CR) in mpy of mild steel in this medium was calculated using the following equation:

$$CR (mpy) = \frac{0.1288 \Delta W \times Eq.wt.}{d}$$
(4)

Where ΔW is the amount of weight loss in the absence and presence of the additive, *d* is the density (g/cm³), *Eq.wt*. is the equivalent weight of mild steel which is considered to be dimensionless in this calculation. The mild steel equivalent weight is estimated to be 28.25

[40]. The calculated CR values in mpy are listed in Table 2. It is clear that the corrosion rate of the mild steel decreases with increasing concentration of the inhibitor.



Figure 5. Weight loss–time curves of steel in $2.0 \text{ M H}_2\text{SO}_4$ in the absence and presence of different concentrations of P6000 inhibitor.



Figure 6. Weight loss-time curves of steel in $2.0 \text{ M H}_2\text{SO}_4$ containing 1000 ppm of 1000 ppm of P6000 inhibitor at different temperatures.

Inspection of these data reveals that the corrosion rate of the steel in the absence and presence of additive increases with increasing temperature. The addition of P6000 inhibits the corrosion rate of the mild steel specimens. The inhibition efficiency of P6000 increases with increasing its concentration but decreases with rising temperature. The obtained data from weight loss are in good agreement with the data obtained from potentiodynamic polarization measurements. This trend with inhibition properties of P6000 with the increase of temperature may be connected with decreasing the strength of adsorption and shifting the adsorption equilibrium towards desorption. The increase in surface coverage and the electrode surface becomes sufficiently separated from the aggressive acid medium.

3.4. Adsorption isotherm

Assuming that the inhibition of mild steel corrosion in 2.0 M H_2SO_4 solution is caused by the adsorption of P6000 molecules at the steel/solution interface [6], adsorption of P6000 molecules at the steel solution interface is regarded as a substitutional adsorption process between the P6000 molecules in the aqueous solution, P6000_(aq) and water molecule adsorption in the inner part of the Helmholtz double layer on the electrode surface, $H_2O_{(ads)}$

Inhibitor_(aq) +
$$xH_2O_{(ads)}$$
 = Inhibitor_(ads) + $xH_2O_{(aq)}$

Where, $P6000_{(aq)}$ and $P6000_{(ads)}$ are the P6000 molecules in the aqueous solution and adsorbed on the steel surface, respectively, $H_2O_{(ads)}$ is the adsorbed water molecules on the metallic surface and *x* the size ratio representing the number of water molecules replaced by one P6000 molecule.

Trials are made to find the appropriate adsorption isotherm. This can be obtained by using the calculated values of θ for various concentrations of P6000 in 2.0 M H₂SO₄ solution obtained from the potentiodynamic polarization and weight loss method to various isotherms, such as Langmuir, Frumkin, Freundlich and Florry–Huggins, were used to elucidate the inhibition property of P6000. It is found that the suitable isotherm obeys Langmuir isotherm, by plotting (C_{inh}/θ) vs. C of P6000 compound, in all cases gave a straight line with unit slope (Figure 7). This indicates that the adsorption at mild steel / 2.0 M H₂SO₄ solution interface following Langmuir isotherm model. The adsorption isotherm relationship of Langmuir is represented using the following equation:

$$C/\theta = 1/k_{\rm ads} + C_{\rm inh} \tag{5}$$

where k_{ads} is the equilibrium constant of the adsorption. Figure 8 shows fitting of potentiodynamic polarization and weight loss data obtained from the mild steel electrode in 2.0 M H₂SO₄ solution containing different concentrations of P6000 to Langmuir isotherm.



Figure 7. Langmuir isotherm for corrosion of mild steel in $2.0 \text{ M H}_2\text{SO}_4$ solution in the presence of different concentrations of P6000.

The free energies of the adsorption process ΔG_{ads}^0 was calculated from the equation:

$$K_{\rm ads} = \left(\frac{1}{55.5}\right) \exp\left(\frac{-\Delta G_{\rm ads}^0}{RT}\right) \tag{6}$$

Where 55.5 is the molar concentration of water. The calculated values of ΔG_{ads}^0 are -18.35 and -15.99 kJ mol⁻¹ for weight loss and potentiodynamic polarization measurements respectively. The negative value of ΔG_{ads}^0 implied that the adsorption of P6000 surfactant on the steel surface indicates that the inhibitor is strongly adsorbed on the metal surface [32]. Generally, a value of -40 kJ mol⁻¹ is usually adopted as a threshold value between chemi- and physisorption [33, 34]. The value found for P6000 on steel thus indicates that the adsorption is of a physical, probably electrostatic nature, and that no covalent bond between inhibitor molecule and metal surface is established.

4. Conclusions

From the results obtained in this study the following conclusions are derived:

- 1. P6000 acted as an inhibitor for the dissolution of mild steel in 2.0 M H₂SO₄ solution.
- 2. P6000 acted as a mixed type inhibitor controlling both cathodic and anodic reactions.
- 3. Inhibition efficiency increases with an increase in the concentration of P6000 inhibitor but decreases with a rise in temperature.
- 4. The adsorption of P6000 on the steel surface in H_2SO_4 solution obeys Langmuir isotherm.
- 5. The adsorption P6000 on the mild steel surface is physically and spontaneous process.
- 6. The data obtained from different techniques are in good agreement to each other.

References

- 1. S.S. Abdel-Rehim, K.F. Khaled and N.S. Abd-Elshafi, *Electrochim. Acta*, 2006, **51**, no. 16, 3269.
- 2. A.A. El Maghraby and T.Y. Soror, Adv. Appl. Sci. Res., 2010, 1, no. 2, 143.
- 3. A.A. El Maghraby and T.Y. Soror, Adv. Appl. Sci. Res., 2010, 1, no. 2, 156.
- 4. A.S. Algaber, E.M. El-Nemma and M.M. Saleh, Mater. Chem. Phys., 2004, 86, 26.
- 5. M. Abdallah, H.E. Megahed and M.S. Motae, Mater. Chem. Phys., 2009, 118, 111.
- 6. M. Abdallah, H.E. Megahed and M.S. Motae, Monatsh. Chem., 2010, 141, 1287.
- 7. A.S. Fouda, S.A. El-Sayyed and M. Abdallah, *Anti-Corros. Methods Mater.*, 2011, **58**, no. 2, 63.
- M. Abdallah, I. Zaafarany, K.S. Khairou and M. Sobhi, *Int. J. Electrochem Soc.*, 2012, 7, no. 2, 1564.
- 9. B.A. Al Jahdaly, I.I. Althagafi, M. Abdallah, K.S. Khairou and S.A. Ahmed, J. Mater. Environ. Sci., 2016, 7, no. 5, 1798.
- 10. M. Abdallah, H.M. Al-Tass, B.A. Al Jahdaly and A.S. Fouda, J. Mol. Liq., 2016, 216, 590.
- 11. M. Sobhi, R. El-Sayed and M. Abdallah, Chem. Eng. Comm., 2016, 203, 758.
- 12. M. Abdallah, Hatem M. Eltass, M.A. Hegazy and H. Ahmed, *Prot. Met. Phys. Chem. Surf.*, 2016, **52**, no. 4, 721.
- 13. M. Abdallah, B.A. Al Jahdaly and O.A. Al-Malyo, *Int. J. Electrochem Sci.*, 2015, **10**, 2740.
- 14. M. Abdallah, B.A. Al Jahdaly, M. Sobhi and A.I. Ali, *Int. J. Electrochem. Sci.*, 2015, 10, 4482.
- 15. F. Bentiss, M. Traisnel and M. Lagrene'e, Corros. Sci., 2000, 42, 127.
- 16. C.M.A. Brett, I.A.R. Gomes and J.P.S. Martins, Corros. Sci., 1994, 36, 915.
- 17. R.S. Abdel Hameed, H.I. Al-Shafey, S.A. Soliman and M.S. Metwally, *AlAzhar Bull. Sci.*, 2008, **19**, no. 1, 283.
- 18. R.S. Abdel Hameed, H.I. Alshafy and O. Farghaly, *Res. Rev. Electrochem.*, 2012, **3**, no. 2, 41.
- R.S. Abdel Hameed, H.I Al-Shafey and E.A. Ismail, *AlAzhar Bull. Sci.*, 2009, 20, no. 1, 185.
- 20. R.S. Abdel Hameed, H.A. Shehata, H.M. Abdelbary, S.A. Soliman, A.M. Salem and A.M. Atta, *Mater. Sci.*, 2012, **8**, no. 7, 289.
- 21. R.S. Abdel Hameed, Adv. Appl. Sci. Res., 2011, 2, no. 3, 483.
- R.S. Abd El-Hameed, H.I. Al-Shafey and O.A. Farghaly, *Res. Rev. Electrochem.*, 2012, 3, no. 2, 41.
- 23. M.M. Ibrahim, R.S. Abdel Hameed, Abd-Alhakeem H. Abu-Nawwas, *J. Org. Chem.* OCAIJ, 2013, **9**, no. 12, 493.
- 24. R.S. Abdel-Hameed, J. Phys. Chem., PCAIJ, 2013, 8, no. 4, 146.
- 25. R.S. Abdel Hameed, Abd-Alhakeem H. Abu-Nawwas and H.A. Shehata , *J. Adv. Appl. Sci. Res.*, 2013, **4**, no. 3, 126.

- 26. R.S. Abdel Hameed, Port. Electrochim Acta, 2011, 29, no. 4, 273.
- 27. R.S. Abdel Hameed, H.I. Al-Shafey, A.S. Abul Magd and H.A. Shehata, J. Mater. Environ. Sci., 2012, 3, no. 2, 294.
- 28. R.S. Abdel Hameed, H.I. Al-Shafey, E.A. Ismail, Abd-Alhakeem H. Abu-Nawwas and O.E. El Azabawy, *Int. J. Eng. Res. Appl.*, 2013, **3**, no. 6, 1094.
- 29. Y. Chen, Y. Wang and G. Zhang, Daily Chem. Ind., 1986, 2, 56.
- 30. O.A. Hazzazi, M. Abdallah and E.A.M.Gad, Int. J. Electrochem. Sci., 2014, 9, no. 5, 2237.
- 31. A.S. Fouda, M.M. Farahat and M. Abdallah, Res. Chem. Intermed., 2014, 40, 1249.
- 32. P.W. Atkins, *Physical Chemistry, Sixth ed.*, Oxford University Press, 1999, 857.
- 33. El Sherbini and E.E. Foad, Mater. Chem. Phys., 1999, 60, 286.
- 34. R.S. Abdel Hameed, Adv. Appl. Sci. Res., 2011, 2, no. 3, 483.
- 35. R.S. Abdel Hameed, Adv. Appl. Sci. Res., 2016, 7, no. 2, 29.
- 36. Ya.G. Avdeev, D.S. Kuznetsov, M.V. Tyurina, S.V. Oleynik and M.A. Chekulaev, *Int. J. Corros. Scale Inhib.*, 2017, **6**, no. 1, 47. doi: <u>10.17675/2305-6894-2017-6-1-4</u>
- 37. Ya.G. Avdeev and A.Yu. Luchkin, *Int. J. Corros. Scale Inhib.*, 2013, **2**, no. 1, 53. doi: <u>10.17675/2305-6894-2013-2-1-053-066</u>
- 38. Ya.G. Avdeev, D.S. Kuznetsov, M.V. Tyurina and M.A. Chekulaev, *Int. J. Corros. Scale Inhib.*, 2015, **4**, no. 2, 146. doi: <u>10.17675/2305-6894-2015-4-1-146-161</u>
- Ya.G. Avdeev, L.V. Frolova, D.S. Kuznetsov, M.V. Tyurina and M.A. Chekulaev, *Int. J. Corros. Scale Inhib.*, 2016, 5, no. 2, 147. doi: <u>10.17675/2305-6894-2016-5-2-4</u>
- 40. O.I. Sekunowo, S.O. Adeosun and G.I. Lawal, Potentiostatic polarisation responses of mild steel in seawater and acid environments, *Int. J. Sci. Technol. Res.*, 2013, **2**, no. 10, 139.

*** * ***