Journal of Materials and Environmental Sciences ISSN : 2028-2508 CODEN : JMESCN

Copyright © 2018, University of Mohammed Premier Oujda Morocco J. Mater. Environ. Sci., 2018, Volume 9, Issue 9, Page 2730-2740

http://www.jmaterenvironsci.com



# Anticorrosion properties of three quinoxaline derivatives on mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> solution

K. Benbouya<sup>1,2</sup>, A. Rochdi<sup>1</sup>, M. El Bakri<sup>1</sup>, H. Larhzil<sup>1,3</sup>, R. Touir<sup>1,4</sup>, M. Ebn Touhami<sup>1</sup>

<sup>1</sup>Laboratoire d'Ingénierie des Matériaux et d'Environnement: Modélisation et Application, Faculté des Sciences, Université IbnTofail, BP. 133, 14000 in Kénitra- Morocco

<sup>2</sup>Laboratoire Énergétique, Matériaux et Environnement, École Supérieure de Technologie, Université Mohammed V, Salé Medina, B.P. 227, 10000 in Salé- Morocco

<sup>3</sup>Centre Régional des Métiers de l'Education et de la Formation (CRMEF), Meknes- Morocco

<sup>4</sup> Centre Régional des Métiers de l'Education et de la Formation (CRMEF), Avenue Allal Al Fassi, Madinat Al Irfane, BP

6210, Rabat- Morocco

Received 17 Jan 2018, Revised 26 May 2018, Accepted 28 May 2018

#### Keywords

- ✓ Quinoxalinederivatives,
- ✓ Methyl number,
- ✓ Adsorption mechanism,
- ✓ Corrosion inhibition,

✓ Mild steel

<u>@yahoo.fr</u>; Phone: +212

#### Abstract

The effect of 3-methylquinoxalin-2(1H)-one (MQO), 3.7-dimethylquinoxalin-2(1H)one (DMQO) and 3,7-methylquinoxaline-2(1H)-thione (DMQS) on mild steel corrosion in 1.0 M  $H_3PO_4$  has been studied by electrochemical measurements. The results indicated that these compounds act as good inhibitors. The DMQO and DMQS act as a cahodic inhibitors while the MQO acts as a mixed type inhibitors. So, it is found that their inhibition depend on the methyl number in their structure. It is shown also that the DMQO is the best inhibitor where its inhibition efficiency increases with concentration to achieve 92 % at 10<sup>-4</sup> M. A pseudo plate was observed directly from the corrosion potential in the presence of DMQO and DMQS. In addition, the adsorption of DMQO molecules on mild steel surface was also studied and it was found that is adsorbed according to the Langmuir isotherm model. In addition, the temperature influence and immersion time on performance of the best inhibitor (DMQO) was studied. It is establish that its inhibition efficiency increases with immersion time and take its performance at hot temperature.

# 1. Introduction

Phosphoric acidic which a medium-strong acid, was used in many industries applications. It is produced in large quantities in Morocco. This acid is a strong corrosive effect on ferrous or its alloy [1]. The application of inhibitors is an extremely important area given that it presents some advantages of economical and environmental nature. These compounds can adsorb on metallic surface and block the active sites and thereby slow down the corrosion rate [2]. The mechanism action of inhibitors will be affected by their molecular structure, chemical composition of solution, surface metal charge and other factors [3]. So, the most efficient inhibitors for phosphoric acid are organic compounds containing O, S, and/or N atoms and multiple bonds in the molecule [4-9]. The use of synthesis quinoxalines derivatives has been studied using several methods [10-13]. The objective of this paper is to study the influence of MQO, DMQO and DMQS addition on mild steel corrosion in 1.0 M  $H_3PO_4$  using electrochemical measurements. The adsorption of the best inhibitor on the metallic surface was studied. The effect of temperature solution and immersion time was also studied and discussed.

# 2. Experimental details

# 2.1. Electrochemical cell and materials

The chemical structures of the investigated compounds are shown in Figure 1.

The aggressive solution of  $1.0 \text{ M H}_3\text{PO}_4$  was prepared from analytical grade chemicals and distillated water. The electrochemical study was carried out in a standard three-electrode electrolytic cell. So, the working

electrode is mild steel which presented in Table 1. This electrode was embedded in a polyester resin to expose an area of  $1.32 \text{ cm}^2$ . Before each immersion test, the tested electrode surface was polished with emery paper, cleaned with acetone, washed with distilled water, and finally dried at hot air. The reference electrode was a saturated calomel electrode (SCE), and the counter electrode was a platinum plate



3-methylquinoxalin-2(1H)-one (MQO) 3, 7-dimethylquinoxaline-2(1H)-thione (DMQS) 3, 7-dimethylquinoxalin-2(1H)one(DMQO)

Figure 1: Names and chemical structures of quinoxalines derivatives.

Table 1	: Chemical	composition	of the	used mild	steel
I ADIC I	• Chemical	composition	or the	useu mme	sicci

Elements	С	Si	Mn	Cr	Mo	Ni	Al	Cu	Со	V	W	Fe
wt. %	0.11	0.24	0.47	0.12	0.02	0.1	0.03	0.14	< 0.0012	< 0.003	0.06	Balance

#### 2.2. Polarization measurements

These measurements were carried out using Potentiostat/ Galvanostat/Voltalab PGZ 100 monitored by a personal computer and for each concentration three independent experiments were performed. The working electrode was immersed in test solution during 30 minutes until the steady state open circuit potential ( $E_{OCP}$ ) was obtained. The cathodic polarization curve was recorded by polarization from  $E_{OCP}$  toward more negative direction with a sweep rate of 1 mV/s. After this scan, the same electrode was remained in solution until the obtaining of the steady state  $E_{OCP}$  ( $E_{OCP} \pm 0.002$  V), and then the anodic polarization curve was recorded from  $E_{OCP}$  to positive direction with the same sweep rate.

To evaluate corrosion kinetic parameters, a fitting by Stern–Geary equation was used [14] such as indicated in the previous works [10, 11].

The inhibition efficiency ( $\eta_{PP}$ ) and the coverage value ( $\theta$ ) were calculated using the following equations:

$$\eta_{PP} \% = \frac{i_{corr}^{0} - i_{corr}}{i_{corr}^{0}} \times 100$$

$$\Theta = 1 \frac{i_{corr}^{0}}{i_{corr}^{0}} \frac{i_{corr}}{i_{corr}^{0}}$$

$$(1)$$

$$(2)$$

where  $i_{corr}^{0}$  and  $i_{corr}$  the corrosion current density values without and with the inhibitor, respectively.

#### 2.3. EIS measurements

The electrochemical impedance spectroscopy measurements were carried out using the same equipment (Voltalab PGZ100), over the frequency range from 100 kHz to 0.01 Hz with 10 points per decade. The applied amplitude of AC signal was 10 mV<sub>rms</sub>. All experiments were performed at the open circuit potential. The obtained impedance data were analyzed in term of equivalent electrical circuit using Bouckamp's program [15] and the inhibition efficiency was evaluated with the relationship:

$$\eta_{EIS}\% = \frac{R_{ct} - R_{ct}^0}{R_{ct}} \times 100$$
(3)

where  $R_{ct}^0$  and  $R_{ct}$  are the charge transfer resistance values in the absence and presence of inhibitor, respectively.

#### 3. Results and discussion

#### 3.1. Potentiodynamic polarization curves

Potentiodynamic polarization curves for mild steel in  $1.0 \text{ M H}_3\text{PO}_4$  in the absence and presence of different concentrations of quinoxaline derivatives are shown in Figure 2. Their corresponding parameters and inhibition efficiency are listed in Table 1. It is noted that all compounds decrease the cathodic branches and a slight decrease in the anodic branches.



**Figure 2**: Potentiodynamic polarization curves for mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> at various concentrations of (a): MQO, (b): DMQO and (c) DMQS.

It can be seen from Table 1 that  $E_{corr}$  values show significant shifts cathodically at various concentrations of DMQO and DMQS, suggesting that these two compounds were mainly a cathodic-type inhibitor. In contrast, the  $E_{corr}$  has fewer identical values in the case of MQO, and this result qualifies MQO as a mixed type inhibitor. It can also be seen that the inhibitors addition decreases the  $i_{corr}$  values of mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> and reaches a minimum at 10<sup>-4</sup> M of all tested inhibitors. This behavior can be attributed to the formation of barrier film on mild steel surface. On the other hand, it is noted that the inhibition efficiency largely depends on the presence free electron pairs in nitrogen atoms and  $\pi$ -electrons on the quinoxalines derivatives favors their adsorption on the mild steel surface [16], and more precisely on the methyl group number in their structure. Indeed, the inhibition efficiency of these compounds follows the sequence: DMQO  $\approx$  DMQS > DMO.

	C (M)	$E_{corr}$ (mV/SCE)	$i_{corr}$ (mA cm <sup>-2</sup> )	$\eta_{pp}$ (%)	θ
$H_3PO_4$	0	-492	0.536		
	10-6	-464	0.489	9	0.09
	10 <sup>-5</sup>	-515	0.479	10	0.10
MQO	5×10 <sup>-5</sup>	-509	0.455	15	0.15
	10-4	-509	0.36	33	0.33
	5×10 <sup>-4</sup>	-489	0.386	28	0.28
	10-3	-499	0.40	25	0.25
	10-6	-531	0.075	86	0.86
	10-5	-547	0.07	87	0.87
DMQO	5×10 <sup>-5</sup>	-563	0.05	90	0.90
	10-4	-569	0.043	91	0.92
	5×10 <sup>-4</sup>	-560	0.058	89	0.89
	10-3	-577	0.059	89	0.89
	10-6	-538	0.245	54	0.54
	10-5	-513	0.24	55	0.55
DMQS	5×10 <sup>-5</sup>	-566	0.0538	90	0.90
	10-4	-568	0.0465	91	0.91
	5×10 <sup>-4</sup>	-580	0.0451	91	0.91
	10-3	-604	0.0302	94	0.94

**Table 2**: Electrochemical parameters values for mild steel in  $1.0 \text{ M H}_3\text{PO}_4$  in the presence of different concentrations of quinoxaline derivatives.

#### 3.2. Electrochemical impedance spectroscopy (EIS) study

Figure 3 represents the impedance diagrams for mild steel in 1.0 M  $H_3PO_4$  after 30 min of immersion time at the open circuit potential at various concentrations of quinoxalines derivatives. It may be noted that all obtained diagrams were composed by one capacitive loop where its center lies under the abscissa. These phenomena were corresponding to the surface heterogeneity [17]. For this, the fittig using constant phase elements (CPE) rather than an ideal capacitor was recommended [18]. In order to fit and analyze the EIS data, the equivalent circuit shown in Figure 4 was used. This circuit is generally used to describe the iron/acid interface system [19]. The obtained parameters are summarized in Table 3. It may be remarked that  $R_{ct}$  value increases while  $C_{dl}$  decreases with inhibitor concentration.

However, if the planar condenser model is assumed, then one can relate the double-layer capacitance  $C_{dl}$  and the film thickness d by equation 6:

$$C_{dl} = \frac{\varepsilon \times \varepsilon_0 \times S}{d} \tag{6}$$

Where  $\varepsilon$  is the dielectric constant of the protective layer,  $\varepsilon_0$  is the free space permittivity (8.854×10<sup>-14</sup> F cm<sup>-1</sup>), and S is the effective surface area of the electrode.

On the other hand, the decrease in  $C_{dl}$  values with inhibitors addition can be interpreted either by a decrease in local dielectric constant  $\varepsilon$  [20] and/or an increase in the thickness of the protective layer at the electrode surface [21]. It is also remarked that the solution resistance increases with inhibitors addition, which could be attributed to the protonation of molecules inhibitor and the proton ions (H<sup>+</sup>) consumption. It is also noted a good agreement between the inhibition efficiencies obtained from electrochemical impedance measurements and these obtained from potentiodynamic polarization measurements.



**Figure 3:** Nyquist plots for mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> at various concentrations of (a): MQO, (b): DMQO and (c) DMQS.



Figure 4: Proposed equivalent circuit mild steel/1.0 M H<sub>3</sub>PO<sub>4</sub>/Inhibitors system.

In the contuation of this study, the performance of DMQO at heat temperature and immersion time was investigated.

**Table 3**: Electrochemical parameters data for mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> containing different concentrations of inhibitors.

	C (M)	$R_{ct}(\Omega cm^2)$	$C_{dl}(\mu F \text{ cm}^{-2})$	$\eta_{EIS}(\%)$	θ
Blank solution	0	15.14	132		
	10-6	18.54	85.80	18	0.18
-	10 <sup>-5</sup>	19.06	83.49	20	0.2
	5×10 <sup>-5</sup>	18.96	83.92	20	0.2
MQO	$10^{-4}$	24.35	103.2	38	0.38
-	5×10 <sup>-4</sup>	22.97	87.29	34	0.34
	10 <sup>-3</sup>	22.19	90.35	32	0.32
_	10-6	104.2	38.15	85	0.85
	10-5	126	39.67	87	0.87
DMQO	5×10 <sup>-5</sup>	154	16.26	90	0.90
_	$10^{-4}$	176.4	22.54	91	0.91
	5×10 <sup>-4</sup>	160	31.40	90	0.90
	10-3	150	32.59	89	0.89
_	10-6	68	58.16	52	0.52
_	10 <sup>-5</sup>	70	45.74	54	0.54
	5×10 <sup>-5</sup>	141	28.20	89	0.89
DMQS	$10^{-4}$	198	16.01	92	0.92
_	5×10 <sup>-4</sup>	199	20.29	92	0.92
_	10-3	253	25.15	94	0.94

3.3. Thermodynamic parameters of the adsorption process DMQO

The fractional coverage surface ( $\theta$ ) DMQO molecules was determined from impedance measurements by the ratio  $\eta$ %/100 (Table 4). The adsorption isotherms models considered were as described in reference [22]:

Temkin isotherm

$$\exp(f \times \theta) = K_{ads} \times C_{inh}$$
<sup>(7)</sup>

Langmuir isotherm

$$\frac{\theta}{1-\theta} = K_{ads} \times C_{inh}$$

$$\frac{\theta}{1-\theta} \exp(-2 \times f \times \theta) = K_{ads} \times C_{inh}$$
(8)

Frumkin isotherm

Freundluich isotherm

Where  $K_{ads}$  is the equilibrium constant of the adsorption process,  $C_{inh}$  is the inhibitor concentration and f is the energetic inhomogeneity factor.

 $\theta = K_{ads} \times C_{inh}$ 

Figure 5 shows the relationship between  $C_{inh}/\theta$  and  $\theta$  for DMQO where the linear coefficient regression, r, was used to choose the suitable isotherm. The equilibrium constant value of the adsorption process,  $K_{ads}$  can be determined using the the following equation [23]:

(10)

$$K_{ads} = \frac{1}{55.55} \exp(-\frac{\Delta G_{ads}^*}{RT})$$
(11)

55.55 represent the water concentration (mol  $L^{-1}$ ), R is the universal gas constant and T is the absolute temperature.



Figure 5: Langmuir adsorption isotherm plot for mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> at different concentrations of DMQO

However, the calculated free energy of adsorption  $\Delta G^*_{ads}$ , is about -46.62 kJ mol<sup>-1</sup> indicating that its adsorption mechanism was typical of chemisorptions [24]. Thus, the possible mechanisms for chemisorption can be attributed via donor-acceptor interactions between the  $\pi$ -electrons of the aromatic rings and the unshared electrons pairs of the heteroatom (-N, -O and/or -S) to form a bond with the vacant d-orbital of iron atom on metallic surface.

#### 3.4. Thermodynamic parameters of the activation corrosion process of DMQO

The potentiodynamic polarization measurements were carried out at different temperatures range from 298 K to 328 K for mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> without and with optimal concentrations of DMQO and the obtained results are presented in Figure 6a and 6b. Their electrochemical parameters and inhibition efficiencies are listed in Table 4. It is shown that  $i_{corr}$  values increase with temperature. This increase is much more pronounced in free solution than in inhibited media. Moreover, no clear trends are observed in  $E_{corr}$  values at higher temperatures in both cases reflecting the enhancement of both anodic and cathodic reactions with the rise of temperature. However, the  $\eta_{PP}$  values increase with temperatures which explained by specific interaction between iron surface and inhibitor molecules [25]. Ivanov [26] explained this increase with temperature by the change in the nature of the adsorption mode where the inhibitors act physical adsorption at lower temperatures and by chemisorption at heat temperature.

However, activation parameters like activation energy ( $E_a$ ), enthalpy ( $\Delta H_a^*$ ), and entropy ( $\Delta S_a^*$ ) for the dissolution of mild steel in 1.0 M H<sub>3</sub>PO<sub>4</sub> without and with 10<sup>-4</sup> M of DMQO was determined using the following equations [27]:

$$i_{corr} = A \exp(-\frac{E_a}{RT})$$
(12)

$$i_{corr} = \frac{RT}{Nh} \exp(\frac{\Delta S_a^*}{R}) \exp(-\frac{\Delta H_a^*}{RT})$$
(13)

where  $i_{corr}$  is the corrosion rate, A is the pre-exponential factor, h is Planck's constant, N is the Avogadro number, and R is the universal gas constant.



Figure 6: Potentidynamic polarization curves of mild steel / 1.0 M  $H_3PO_4$  interface in (a) free solution, (b) the presence of  $10^{-4}$  M of DMQO.

Table 5: Electrochemic	al parameters and	inhibition	efficiencies	of mild	steel in 1.	0 M H <sub>3</sub> PO <sub>4</sub>	4 without and	with	10-4	M of
DMQO at different temp	peratures values.									

	T (K)	$E_{corr}(mV/SCE)$	$i_{corr}(mA cm^{-2})$	$\eta_{PP}(\%)$	$E_a(kJ mol^{-1})$	$\Delta H_{a}^{*}(kJ mol^{-1})$	$\Delta S_{a}^{*}(kJ K^{-1} mol^{-1})$
	298	-492	0.536	-			
Blank	308	-472	0.820	-	27.86	26.37	-189.70
solution	318	-497	3.341	-			
	328	-484	4.397	-			
	298	-569	0.049	91			
10 <sup>-4</sup> M	308	-556	0.061	92	10.09	11.66	-196.68
of	318	-534	0.086	97			
DMQO	328	-530	0.111	97			

Figure 7 and 8 show the Arrhenius plot  $ln(i_{corr})$  versus 1/T and the transition plots  $ln(i_{corr}/T)$  versus 1/T, respectively. Their corresponding parameters are given in Table 5. It is noted that the  $E_a$  value decreases with DMQO addition indicating a change in the corrosion process with the inhibitor addition [27-30]. In addition, this decrease in  $E_a$  with the presence of DMQO can be explained by a strong chemisorption at the metal surface [31]. In addition, the positive sign of the enthalpies  $\Delta H_a^*$  reflects the endothermic nature of the mild steel dissolution process, whereas large negative value of entropies  $\Delta S_a^*$  for DMQO imply that the activated complex in the rate-determining step represents an association rather than a dissociation step, meaning that a decrease in disordering takes place on going from reactants to the activated complex [32-34].



Figure 7: Arrhenius plots of mild steel in  $1.0 \text{ M H}_3\text{PO}_4$  without and with  $10^{-4} \text{ M}$  of DMQO.



**Figure 8:** Transitions plots of mild steel in  $1.0 \text{ M H}_3\text{PO}_4$  without and with  $10^{-4} \text{ M of DMQO}$ .

#### 3.5. Effect of immersion time

Figure 8 shows the impedance diagrams at different immersion times in 1.0 M  $H_3PO_4$  containing  $10^{-4}$  M of DMQO at the open circuit potential. It is noted that the obtained diagrams were composed one capacitive loop where its diameter increases with immersion time until 10 hours of immersion and then was decreases while the  $\eta_{EIS}$  values remained constant at the same time. These results demonstrate the formation of protective film by DMQO adsorption at the electrode surface.



**Figure 8**: Impedances diagrams for mild steel/1.0 M H<sub>3</sub>PO<sub>4</sub> interface in the presence of 10<sup>-4</sup> M of DMQO at different immersion time.

immersion time.	Table 8:	Electrochemical	parameters	for mild	steel i	n 1.0	) M	$H_3PO_4$	in the	presence	of	$10^{-4}$	М	of DMC	)O a	it va	rious
	immersio	n t <u>ime</u> .															

Immersion time (h)	$C_{dl}$ (µF cm <sup>-2</sup> )	$R_{ct} (\Omega cm^2)$	$\eta_{EIS}$ (%)
0.5	22.54	176.4	91
1	28.79	174.6	94
2	54.76	183	94
4	68.24	185	95
6	76.53	207	96
8	64.45	246	97
10	25.15	253.1	96
12	616.4	40.79	79

# Conclusion

The main conclusions can be drawn:

- 1. A good agreement between potentiodynamic polarization and electrochemical impedance spectroscopy techniques.
- 2. Potentiodynamic polarization measurements showed that the DMQO and DMQS act as a cathodic inhibitors while the MQO acts as a mixed type inhibitors.
- 3. EIS measurements also indicate that the inhibitor addition increases the charge transfer resistance and show that the inhibitive performance depends on molecules adsorption on the metallic surface.
- 4. The adsorption model of DMQO obeys the Langmuir isotherm at 298 K.
- 5. DMQO takes its performance at higher temperature (97 % at 328 K).
- 6. The obtained values of the apparent activation energy indicated that the DMQO molecules act via chemisorptions.
- 7. The inhibition efficiency increases with immersion time until 10 hours to reach 96 %. These results confirm the chemisorption character for DMQO obtained by temperature study.

# References

- 1. Y. Jianguo, W. Lin, V. Otieno-Alego, D.P. Schweinsberg, Corros. Sci. 37 (1995) 975-985
- 2. O.K. Abiola, Corros. Sci. 48, (2006) 3078-3090
- 3. G. Trabanelli. in Corrosion Mechanism, ed. by F. Mansfeld (Marcel Dekker, New York, 1987)
- 4. M. Abouchane, M. El Bakri, R. Touir, A. Rochdi, O. Elkhattabi, M. EbnTouhami, I. Forssal, B. Mernari, *Res. Chem. Inter.*,

41 (2015) 1907–1923

- 5. A. Zarrouk, H. Zarrok, R. Salghi, B. Hammouti, F. Bentiss, R. Touir, M. Bouachrine, J. Mater. Environ. Sci. 4 (2013) 177-192
- 6. T. Laabaissi, H. Lgaz, H. Oudda, F. Benhiba, H. Zarrok, A. Zarrouk, A. El Midaoui, B. Lakhrissi, R. Touir, J. Mater. Environ. Sci., 8, (2017) 1054-1067
- 7. M. Benabdellah, R. Touzani, A. Dafali, B. Hammouti, S. El Kadiri, Mater. Letter. 61, (2007) 1197-120
- T. Laabaissi, M. Bouassiria, H. Oudda, H. Zarrok, A. Zarrouk, A. Elmidaoui, L. Lakhrissi, B. Lakhrissi, E.M. Essassi, R. Touir, J. Mater. Environ. Sci. 7 (5) (2016) 1538-1548.
- 9. G. Gunasekaran, L.R. Chauhan, Electrochim. Acta 49, (2004) 4387-4395
- K. Adardour, R. Touir, M. El Bakri, H. Larhzil, M. EbnTouhami, Y. Ramli, A. Zarrouk, H. El Kafsaoui, E. M. Essassi, *Res. Chem. Inter.* 39(2013) 1843–1855.
- 11. K. Adardour, R. Touir, M. El Bakri, Y. Ramli, M. EbnTouhami, H. El Kafsaoui, C. KalonjiMubengayi, E. M. Essassi, *Res. Chem. Inter.* 39(2013) 4175–4188.
- 12. X. Li, S. Deng, H. Fu, Corros. Sci. 52, (2010) 3413.
- 13. K. Benbouya, N. Dkhireche, A. Rochdi, A. Chebab, R. Touir, M. EbnTouhami, M. Sfaira, *Euro-Mediterr J Environ Integr (2018) 3:2: DOI 10.1007/s41207-017-0042-9*.
- 14 M. Stern, A.L. Geaby, J. Electrochem. Soc. 104(1) (1957) 56-63
- 15 A. Bouckamp. UsersManual Equivalent Circuit, Ver. 4.51, 1993.
- 16. W.R. Fawcett, Z. Kovacova, A. Motheo, C. Foss, J. Electroanal. Chem. 326, (1992) 91
- 17. M. Benabdellah, R. Touzani, A. Dafali, B. Hammouti, S. El Kadiri ; Mater. Letter. 61, (2007) 1197-1204
- 18. C.H. Hsu, F. Mansfeld, Corrosion 57, (2001) 747-748
- 19. J.R. Macdonald; J. Electroanal. Chem. 223, (1987) 25-50
- 20. E. McCafferty, N. Hackerman, J. Electrochem. Soc. 119, (1972) 146–154
- 21. J.M. Bastidas, J.L. Polo, E. Cano, J. Appl. Electrochem. 30, (2000) 1173-1177
- 22. J. Marsh; Advanced OrganicChemistry, 3rd edn. (Wiley Eastern, New Delhi, 1988)
- 23. E. Khamis, F. Bellucci, R.M. Latanision, E.S.H. El-Ashry, Corrosion 47, (1991) 677-686.
- 24. C. Kustu, K.C. Emregul, O. Atakol, Corros. Sci. 49, (2007) 2800–2814.
- 25. L.N. Putilova, S.A. Balesin, V.P. Barranik, Metallic Corrosion Inhibitors (Pergamon Press, New York, 1960)
- 26. E.S. Ivanov, Inhibitors for Metal Corrosion in Acid Media (Metallurgy, Moscow, 1986)
- 27. S.S. Abd El-Rehim, M.A.M. Ibrahim, K.F. Khaled, J. Appl. Electrochem. 29, 593 (1999) 28. A. Popova, E. Sokolova, S. Raicheva, M. Christov, Corros. Sci. 45, (2003) 33
- 29. R. Raicheff, K. Valcheva, E. Lazarova, Proceeding of the Seventh European Symposium on Corrosion Inhibitors (Ferrara, 1990), p. 48
- 30. K.F. Khaled, Electrochim. Acta 53 (2008) 3484
- 31. F. Bentiss, M. Traisnel, L. Genegembre, M. Lagrenée. Appl. Surf. Sci. 152, 237 (1999) 123
- 32. S. Martinez, I. Stern. Appl. Surf. Sci. 199 (2002) 83
- 33. M. Dahmani, A. Et-Touhami, S.S. Al-Deyab, B. Hammouti, A. Bouyanzer, Int. J. Electrochem. Sci. 5 (2010) 1060
- 34. S. Aloui, I. Forsal, M. Sfaira, M. EbnTouhami, M. Taleb, M. Filali Baba, M. Daoudi. Port. Electrochim. Acta. 27 (2009) 599.

# (2018); <u>http://www.jmaterenvironsci.com</u>