

Role of Some Organic Compounds as Corrosion Inhibitors for 316L Stainless Steel in 1 M HCl

A.S. Fouada^{1,*}, M. A. Diab², and S. Fathy¹

¹ Department of Chemistry, Faculty of Science, El-Mansoura University, El-Mansoura-35516, Egypt

² Chemistry Department, Faculty of Science, Damietta University, New Damietta, Egypt

E-mail: asfouda@mans.edu.eg*

Received: 9 October 2016 / *Accepted:* 23 November 2016 / *Published:* 12 December 2016

The corrosion inhibitors, namely, (E)-3-oxo-2-(m-toyldiazenyl) pentanenitrile compound (A), (E)-3-oxo-2-(phenyldiazenyl) pentanenitrile compound (B) and (E)-3-(phenyldiazenyl) pentane -2,4-dione compound (C) were influence on the corrosion of SS 316L in 1 Molar hydrochloric acid has been detected by utilized mas reduction, (EFM)electrical frequency modulation, tafel polarization, (EIS) method. Polarization value lead to this organic compound plays as mixed inhibitors kind. The temperature effect on corrosion protection had research on the adsorption parameters and activation thermodynamic measured. EIS was utilized to detect the technique of corrosion protection. EFM can be utilized a fast and non destructive test for record rate of corrosion. The adsorption follow Temkin's isotherm.

Keywords: SS 316L; HCl; organic derivatives, EFM; EIS

1. INTRODUCTION

SS utilized in many applications due to rise corrosion counteraction, for example in the pharmaceutical, petrochemical, generation power industries and water treatment plants. Pickling and cleaning eliminating foreign metal and stability promote, perform a arranged surface that is resistant to corrosion localized. SS was chosen as good passivation for corrosion resistance due to a film oxide protective [1].

The chosen of suitable inhibitors rely on the acid kind, its temperature and dose. The actual of liquefaction inorganic and/ or organic compound, kind of metallic metal which bare to acidic solution action [2-4]. Yet, availability, toxicity, and cost are significant factors in the utilization and chosen of these inhibitors. Many researches have recently found in the literature [5-16] in acidic medium for

corrosion protection of SS 316L by organic compounds. The selection of these compounds is based on: a) are highly soluble in the test medium, and b) contain polar functional groups (such as –CN, N=N and C=O) and multiple bonds (double bonds and triple bonds) and extensive conjugation in the form of aromatic structure of the ring which adsorb on surface of metal. Examples of heterocyclic compounds are N-heterocyclic compounds such as triazole, tetrazole, pyridine, pyrazole, pyrimidine, pyridazine, indole and quinolone used in investigating their inhibition efficiency in acidic media on steel species [17]. In neutral media, good corrosion inhibitors that are used include benzoate, nitrite, chromate and phosphate. The choice of a corrosion inhibitor depends on several factors including but not limited to cost and amount, availability and its effects on the environment [18].

The aim of the paper is to determine the inhibition effect of these organic compounds on the corrosion of austenitic stainless steel in acidic environment using different techniques.

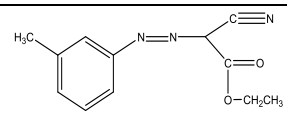
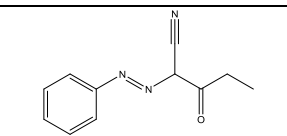
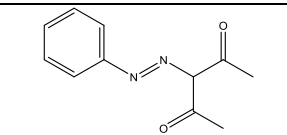
2. EXPERIMENTAL

The 316L SS utilized in this paper had the chemical structure C 0.02 %, Mn 1%, P 0.054%, S 0.02%, Si 1%, Cr 16%, Ni 11%, Mo 3% Cu 0.2% and Fe balance.

HCl 37 % Analar grade and bi-distilled water were utilized to readying all the solutions. All the experiments were done at 25 °C.

The synthesized inhibitors identical to a last described experimental method [19] characterized and cleaning by NMR, IR spectroscopy and elemental technique before utilized. The formula of structure of the examined organic assembled is obtain in Table (1).

Table 1. Chemical structures of the investigated compounds

Comp.	Structure	Name	Mol. Formula& 231.25
(A)		Ethyl 2-cyano-2-(m-tolyldiazenyl) acetate	$C_{12}H_{13}N_3O$ 231.25
(B)		(E)-3-oxo-2-(phenyldiazenyl) pentanenitrile	$C_{11}H_{11}N_3O_2$ 217.23
(C)		3-[(E)-Phenyldiazenyl]-2,4-pentandion	$C_{11}H_{12}N_2O_2$ 204.22

Mass reduction calculations were found on 316L SS coins with size 20 x 20 x 2 ml in 1 Molar hydrochloric acid with various doses of the organic inhibitors. The coupons were scratch with various sizes up to 1200 of emery papers, dried, weighted, and then suspended in 100 ml solution of acid attendance and lack of unlike doses of the organic assembled studied for exposure period of three hours at the temperature range from 30 to 45°C. The coins were washed with water distilled.

Electrochemical method utilized by SS 316L specimen of the similar structure was putted in glass rod with area 1cm^2 . The electrochemical tests were given in a conventional three-electrode with 316L SS act as working, sheet of platinum play as counter, and reference electrode (SCE). The potential of electrode changed from -600 to $+400$ mV versus (E_{OCP}) with a scan rate of 1 mVs^{-1} . For electrochemical impedance spectroscopy (EIS) tests experiments the amplitude was 5 mV . For (EFM) electrochemical frequency modulation tests experiments were done utilized two frequencies 2 and 5 Hz [20].

Electrochemical calculations were found with Gamry instruments and a personal computer. Echem Analyst software 5.1 was utilized for drawing curves. The measurements were carried out

3. RESULTS AND DISCUSSION

3.1. Mass reduction (WL)

To illustrate the technique of protection and to measure the thermodynamic corrosion parameters, WL record was obtain at 30 to $45\text{ }^\circ\text{C}$. WL of 316L SS was calculated, at different time attendance and lack of various dose of studied organic assembled derivatives (A-C). The data given from WL-time plots are shown in Figure (1) inhibitor (A) the best effective. Same plots were given for other organic assembled inhibitors (not shown).

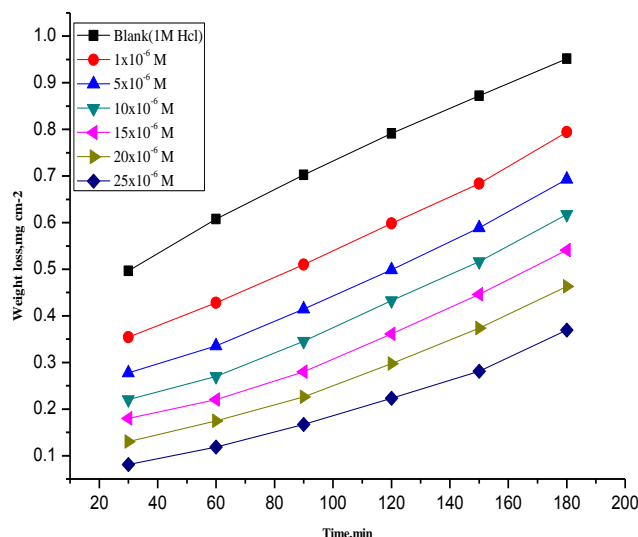


Figure 1. Time- WL plots for liquefaction of 316L SS in attendance and lack various doses of compound (A) in HCl at $30\text{ }^\circ\text{C}$

The plots obtain with inhibitors fall down noted that of blank (HCl). In all cases, the increases in the dose of inhibitor were associated by a lower in WL and improve in the $\% \eta$. These data obtain led to the resulted that, these organic assembled is good inhibitors for 316L SS liquefaction in HCl solution. (θ) and the protection efficiency ($\% \eta$) were measured by :

$$\% \eta = 100 \times \theta = [1 - (\Delta W_{inh} / \Delta W_{free})] \times 100 \tag{1}$$

ΔW_{inh} = Mass loss per unit area with organic assembled inhibitors and ΔW_{free} = Mass loss per unit area lack inhibitor.

The values % η obtained for studied derivatives at various dose and record in Table (2).

The order of η was as obtain: C < B < A

Table 2. % η of corrosion of 316L SS in 1 Molar hydrochloric with and without various doses of the different derivatives at 30 °C and at 120 min immersion

Conc., M	% η		
	A	B	C
1x10 ⁻⁶	27	21	18
5x10 ⁻⁶	49	43	38
10x10 ⁻⁶	51	45	40
15x10 ⁻⁶	60	53	48
20x10 ⁻⁶	67	59	53
25x10 ⁻⁶	76	69	61

3.1.1 Adsorption isotherm behavior

The characteristics of corrosion protection have been noted to determine the type of the inhibitors adsorbed. The surface coverage degree (θ) for various concentrations of the inhibitors has been record from WL measurements. The values were plots to fitting the best isotherm isotherms. The best fitting of data utilized by plotting (θ) against $\ln C$ suggesting adsorption of research organic inhibitors on SS surface followed Temkin isotherm model (Fig. 2). From Temkin isotherm calculated (θ) from equation:

$$KC = \exp (-2a\theta) \tag{2}$$

Where K = equilibrium constant of the adsorption technique and “a” = interaction molecular parameter.

The ΔG°_{ads} were measured from:

$$\Delta G^\circ_{ads} = - RT \ln (55.5 K) \tag{3}$$

R = constant universal gas, T = temperature absolute and 55.5 = water dose in solution in mol l⁻¹.

The standard free energy for adsorption was measured utilized Eq. (3) where one water molecule is change by one organic inhibitor molecule [21]. The data of ΔG°_{ads} and K are record in Table (3). The -ve of ΔG°_{ads} indicates that the adsorption of these inhibitors on the surface of SS is a spontaneous. Commonness, the important of ΔG°_{ads} average -20 kJ mol⁻¹ or lower -ve lead to electrostatic interaction among the charged surface of metal and inhibitor molecules (i.e. physisorption)[22-23]. In this paper, the measured data of free energy of these inhibitors Table (4) are -

20 kJ mol⁻¹ or less which lead to that adsorption of these organic assembled inhibitors on 316L SS surface takes place via physisorption. Lower data of K_{ads}, lead to the interactions among adsorbing inhibitor molecules and the surface of metal are weaker, i.e., organic inhibitor are facility removable [24].

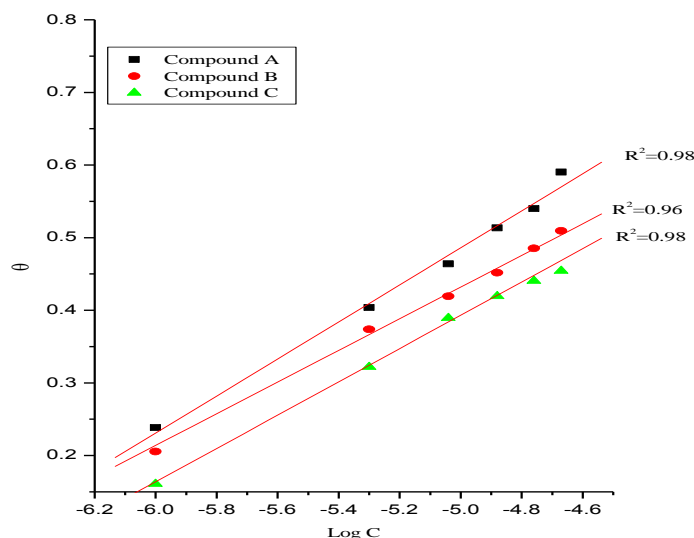


Figure 2. log C against θ of the organic inhibitor of 316L SS in one molar hydrochloric acid from WL test at 30°C

Table 3. K_{ads} and ΔG°_{ads} for the adsorption of inhibitors molecules on 316L SS one molar hydrochloric acid from WL method at 30°C

Inhibitor	Temkin adsorption isotherm	
	K _{ads} × 10 ⁻⁴ , M ⁻¹	-ΔG° _{ads} , kJ mol ⁻¹
A	875	24.7
B	188	21.8
C	153	20.5

3.1.2 Temperature effect

The temperature effect of %η of the utilized inhibitors was measured in the attendance and lack of various inhibitors at dose of 1 × 10⁻⁶ - 25 × 10⁻⁶ M at 30 – 45°C. In testing the influence of temperature on the corrosion of 3016L SS with studied organic inhibitors in one molar Hydrochloric acid solution, Arrhenius Eq. (4) was utilized [25]

Arrhenius – type plot:

$$k = A e^{(-E_a^*/RT)} \tag{4}$$

A = frequency factor and E_a^{*} = apparent activation energy.

Plots 1/ T vs. log k in Fig. (3) for 316L SS in one molar Hydrochloric acid, given slope = - E_a^{*}/2.303R and E_a^{*} calculation were record in Table (4).

Activation 316L SS were calculated from transition state- kind equation:

$$k = RT / Nh e^{(-\Delta H^* / RT)} e^{(\Delta S^* / R)} \tag{5}$$

The relation among $1 / T$ against $\log k / T$ led to lines straight Fig. (4), from their slopes and intercepts, ΔH^* and ΔS^* can be measured and their values are represented in Table (4).

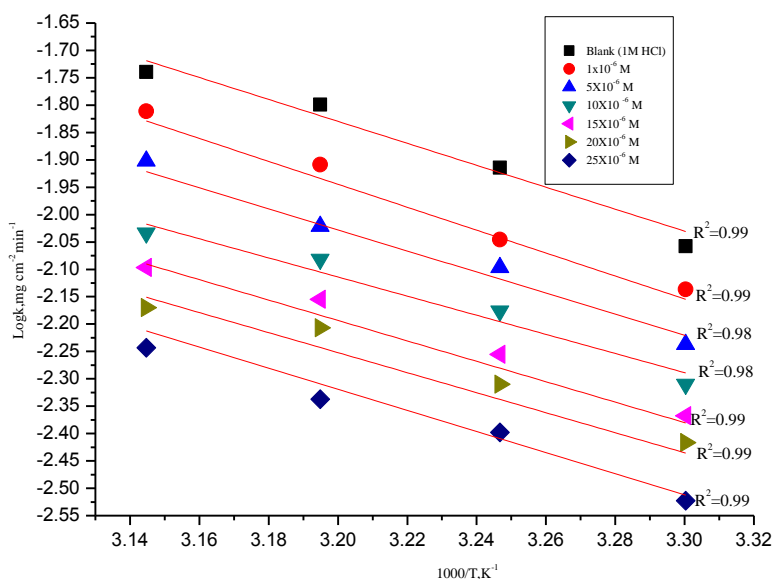


Figure 3. Arrhenius plots for the 316L SS in one molar hydrochloric acid corrosion without and with various doses of inhibitor (A).

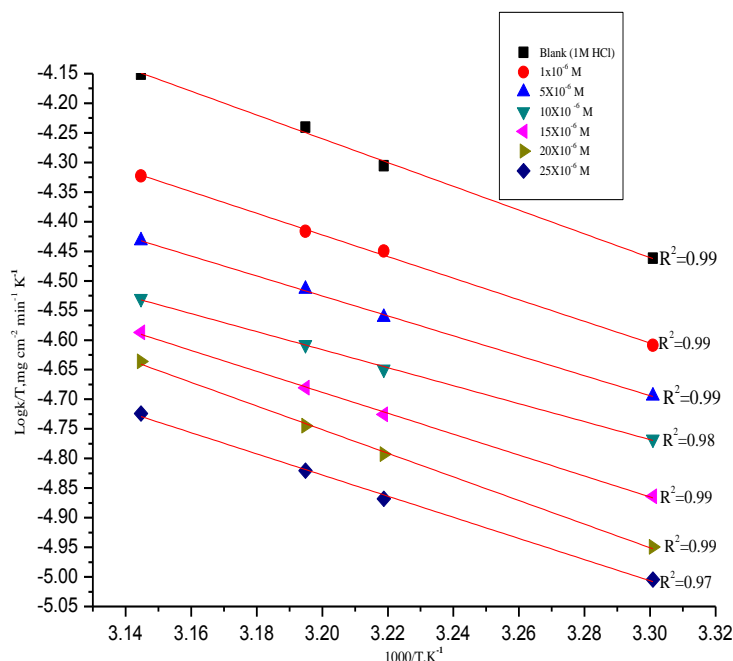


Figure 4. Transition plots for the 316L SS corrosion in one molar hydrochloric acid without and with various doses of inhibitor (A)

The values are represented from Table (4) revealed that, the attendance of inhibitors improvement the activation energies of 316L SS led to adsorption very hard of the inhibitor molecules on the 316L SS surface and the attendance of these organic assembled rise energy barrier with higher

inhibitor dose. The E_a^* rise with inhibitor dose is often illustrated by adsorption physical with the genesis film of an electrostatic character [26]. The +ve sign of ΔH^* given endothermic corrosion process. The large -ve ΔS^* this led to activated complex favorite association rather than dissociation step, led to lowering in disorder obtain [27].

Table 4. Thermodynamic for liquefaction of 316L SS corrosion in one molar hydrochloric acid without and with various dose of investigated derivatives

Inhibitor	Conc. x10 ⁶ M	E _a [*] kJ mol ⁻¹	ΔH [*] kJ mol ⁻¹	-ΔS [*] J mol ⁻¹ K ⁻¹
Blank	0.0	28.1	9.4	194.7
A	1	32.9	12.6	192.1
	5	35.7	14.4	179.3
	10	36.9	15.1	170.4
	15	53.7	16.8	156.1
	20	58.6	21.0	123.3
	25	64.0	25.9	88.5
B	1	29.2	12.4	192.7
	5	33.4	14.0	180.6
	10	36.9	14.8	172.1
	15	52.6	16.5	157.5
	20	58.4	17.9	148.2
	25	60.6	25.2	95.4
C	1	27.5	11.6	193.2
	5	32.9	12.6	181.0
	10	36.3	14.6	173.6
	15	45.0	15.2	166.3
	20	54.4	17.5	152.4
	25	39.4	22.8	114.4

3.2. Electrochemical measurement

3.2.1. Tafel polarization method

Polarization calculation were done to obtain Tafel plots in without and with of various dose of the inhibitors. Figure (5) were given the polarization plots in the attendance and absence of organic (A). The same diagrams were given for other organic inhibitors (not shown). It is noted that the density of current of the cathodic and anodic type is change to decrease data. This change is more evident with the rise in dose of the inhibitors when compared to the material blank. The electrochemical corrosion parameters such as E_{corr} , i_{corr} , C.R., (β_a , β_c) Tafel constants and inhibition efficiency η_{Tafel} (%) are given in Table (5). The (η_{Tafel} %) was measured from polarization curves as follows [28] :

$$\eta_{Tafel}\% = [1 - (i_{corr} / i_{corr}^0)] \times 100 \quad (6)$$

where i_{corr}^0 = current corrosion densities without inhibitor and i_{corr} = current corrosion densities with inhibitor.

The results obtain on the attendance of inhibitors affect both SS liquefaction and evolution of hydrogen; consequently these inhibitors can be act as mixed corrosion inhibitors [29].

According to the results in Table (5) the order of the η_{Tafel} (%) was as follows: C < B < A. It is significant to note that there exists various η_{Tafel} (%) determined by WL and polarization methods. This may be, due to the longer time taken in case of weight loss (3 h) than in case of polarization method (30 min after reaching OCP).

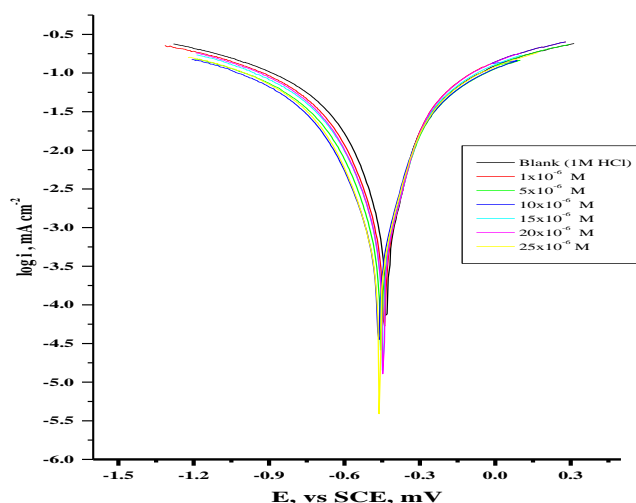


Figure 5. Tafel polarization plots for the liquefaction of 316L SS in one molar hydrochloric acid without and with various dose of inhibitor (A) at 30°C

Table 5. Parameters given from polarization tests for the of 316L SS in one molar hydrochloric acid corrosion without and with various dose of investigated inhibitors at 25 °C

Inh.	Conc. x10 ⁶ , M	-E _{corr} vs SCE, mV /SCE	i _{corr} mA cm ⁻²	β _c mV dec ⁻¹	β _a mV dec ⁻¹	R _p Ω cm ²	θ	% η	CR mm y ⁻¹
Blan	0	399	128.0	109	94	313	-----	-----	85.2
A	1	394	69.8	107	86	546	0.45	45.7	32.6
	5	393	48.9	110	79	1260	0.62	62.3	28.6
	10	397	30.6	108	76	1426	0.76	76.8	13.9
	15	400	15.6	86	62	2023	0.88	88.01	7.51
	20	389	11.8	93	57	4068	0.91	91.0	5.0
	25	390	9.8	92	61	4088	0.93	93.0	3.7
B	1	380	76.4	106	98	365	0.40	40.2	50.4
	5	380	50.7	110	77	511	0.60	60.8	45.5
	10	384	37.1	97	93	1271	0.71	71.5	15.6
	15	371	24.4	92	114	1735	0.81	81.4	11.1
	20	365	18.6	105	78	3908	0.85	85.5	9.1
	25	354	15.7	93	81	4013	0.87	87.8	7.7
C	1	380	85.5	108	93	351	0.33	33.7	70.1
	5	398	61.5	99	83	475	0.51	51.6	66.1

	10	376	44.8	110	71	958	0.65	65.8	38.8
	15	400	27.3	112	73	1255	0.78	78.7	18.0
	20	388	21.4	97	76	1521	0.83	83.1	13.6
	25	396	19.7	98	86	1669	0.84	84.6	11.8

3.2.2. EIS method

Figure (6) illustrated EIS a plot occurs in one molar hydrochloric acid attendance and lack inhibitors (A). The (R_{ct}) resistance charge transfer is record from the various under and larger frequencies. C_{dl} and the frequency are calculated from equation:

$$C_{dl} = (1/2\pi f.R_{ct}) \tag{7}$$

The equivalent circuit qualify the metal/electrolyte is shown in Fig. (7). % η and EIS parameters were measured and record in Table (6). Figure (6) the EIS curves contain of one higher capacitive loop. The rise in R_{ct} data, and consequently of % η , may be due to the gradual change molecules of water by the inhibitor molecules adsorption on the 316 L SS surface to form an a film adherent on SS surface and this led to the coverage of the SS by the film lower the thickness of double layer. Data of C_{dl} lower to the maximum extent with of inhibitors. This lowering in C_{dl} a solution / metal interface with improving inhibitor dose which can illustrate from a lower in local dielectric constant due to inhibitors adsorbed on the 3016 L SS surface at both cathodic and anodic region [30-32].

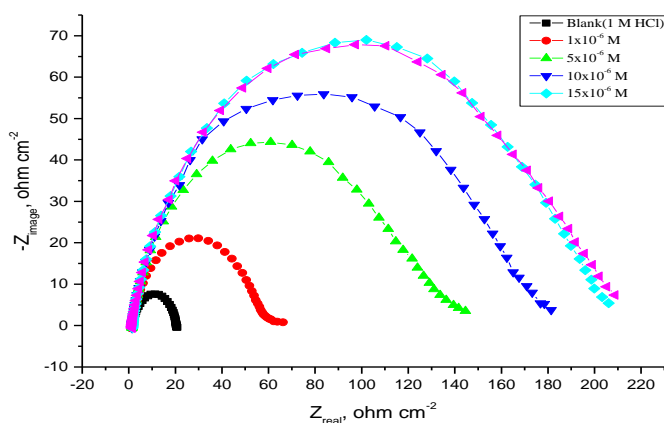


Figure 6. The Nyquist curves for 316L SS in one molar hydrochloric acid solution attendance and lack of various dose of inhibitor (A).

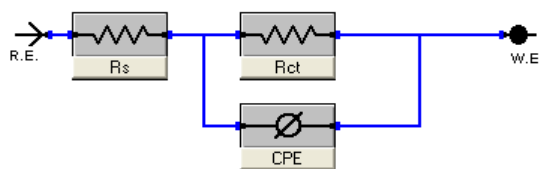


Figure 7. Circuit equivalent utilized to fitting the EIS dat for 316L SS 1 one molar hydrochloric acid.

Table 6. Parameters given from EIS tests for the corrosion of 316L 1 one molar hydrochloric acid solution attendance and lack of various dose of investigated inhibitors at 30°C

compounds	Conc.,x10 ⁶ M	C _{dl} , μF cm ⁻²	R _{ct} , Ω cm ²	θ	% η
blank	0.0	560	5.68	----	----
A	1	350	9.08	0.374	37.4
	5	240	13.75	0.586	58.8
	10	205	15.51	0.635	63.5
	15	160	19.31	0.710	71.0
B	1	430	7.40	0.233	23.3
	5	280	13.07	0.565	56.5
	10	210	14.80	0.616	61.6
	15	180	19.24	0.705	70.5
C	1	480	6.58	0.138	13.8
	5	340	12.74	0.554	55.4
	10	262	14.73	0.614	61.4
	15	220	17.67	0.678	67.8

From the value of Table (6), the lower data of i_{corr} noted in the attendance of these organic additives and the % η is higher. The lowering orders of i_{corr} are agreement with potentiostatic polarization test. The lower data of i_{corr} obeys the same order as that given for the C_{dl} data.

3.2.3. EFM method

Several authors proposed (EFM) as new tests for electrochemical corrosion online record [33-36]. In corrosion study, the nature of corrosion mechanism is non-linear. The data of EFM given that this non-linear carried out with enough data about the corroding system so that the current of corrosion measured directly. The causality factors is higher strength data of the EFM which act as an internal check on verified data and of the EFM test.

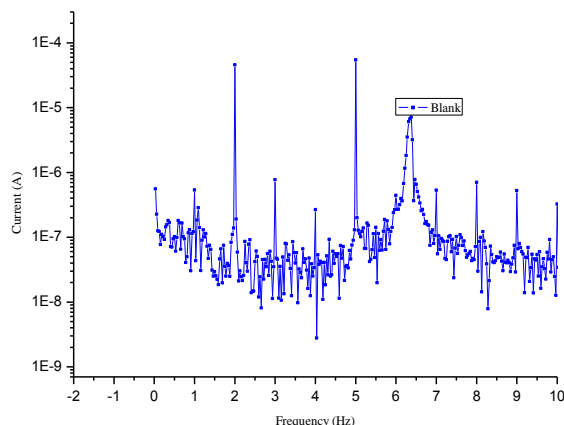


Figure 8. EFM spectra for 316L SS in acid (blank)

Figures (8, 9) show the larger peaks were utilized to measure CF-2 and CF-3, (i_{corr}) and (β_a and β_c) Tafel slopes. These parameters at various doses of inhibitors in 1 M HCl at 25 °C were same measured and record in Table (7). The % η measured from Eq. (6), rise by improving the dose of inhibitor studied.

The best data of CF-2 and CF-3 in Table (7) are alike to their theoretical data of 2.0 and 3.0, continually lead to the calculated value are quality good.

The % η obtain from mass reduction, tafel plots, EIS and EFM testes are in good agreement.

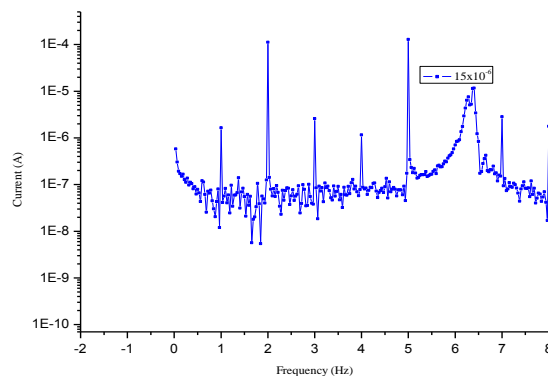


Figure 9. EFM for 316 L SS in one molar hydrochloric acid with of 15×10^{-6} M from inhibitor (A)

Table 7. Parameters given from EFM tests for 316L SS 1 one molar hydrochloric acid solution attendance and lack of various dose of investigated derivatives

Inh	Conc., $\times 10^6$, M	$j_{corr.}$, $\mu A\ cm^{-2}$	β_a , $mV\ dec^{-1}$	β_c , $mV\ dec^{-1}$	CF-2	CF-3	% η_{EFM}
blank	0.0	83.33	98	125	1.93	3.13	-----
A	1	15.53	99	136	2.10	2.85	82.0
	5	14.16	123	135	2.15	2.78	83.1
	10	6.37	103	114	2.04	2.93	92.4
	15	5.57	112	121	2.02	3.01	93.4
B	1	17.40	200	214	1.96	2.97	79.2
	5	14.45	144	154	1.98	2.95	82.7
	10	12.03	135	144	2.08	2.86	85.6
	15	6.64	124	135	1.92	2.91	92.1
C	1	18.38	140	151	1.89	2.81	78.0
	5	16.10	124	128	2.08	2.72	80.7
	10	13.59	125	131	2.04	2.70	83.7
	15	12.48	146	156	2.10	2.80	85.1

3.2.4 Theoretical study

Quantum-chemical measurements have been many utilized to research the reaction process and to illustrate the experimental value to solve the chemical haziness. They improved to be a very

significant for mechanism of corrosion protection [37- 38]. The DFT theory is a best good method to probe the interaction surface / inhibitor and calculated tested value.

The quantum chemical parameters related to the reaction metal-inhibitor. The energy of the HOMO is carried with the molecule capacity to electron donate which given a rise in the data of E_{HOMO} with easily the adsorption and therefore the protection efficiency, lead to the ability of the molecule to given electrons orbital to an suitable acceptor with empty orbital. Similar way decrease data of energy gap $\Delta E = E_{\text{LUMO}} - E_{\text{HOMO}}$ will give best protection efficiencies, due to the energy require to change an electron from last orbital occupied will be low [39-40]. Decrease data of (μ) will the same favor to the summation of molecules inhibitor on metallic 3016 L SS [41]. The optimized geometry of investigated compounds is given in Fig (13) from PM3, the Mulliken densities charge of organic compounds have been measured together with similar physical properties same as the E_{HOMO} , E_{LUMO} , $\Delta E = E_{\text{LUMO}} - E_{\text{HOMO}}$ and (μ) (Table 8). The results data indicate that both the data of (ΔE) , as well as the data given form the dipole moment (μ) , favor compound (a), lead to its effectiveness as a corrosion protection. The utilized of Mulliken calculation to give adsorption center have reported [42-43]. There is a general agreement by many authors that the more -ve heteroatom charged is the best adsorbed on the surface of metal through donor acceptor kind interaction [44-45]. It has also been noted that molecules have attack electrophiles at sites of -ve charge [46]. The data of Mulliken charge in Fig. (11), given notes that all the O and N atoms attendance a considerable improve of -ve charge.

3.2.5 AFM test

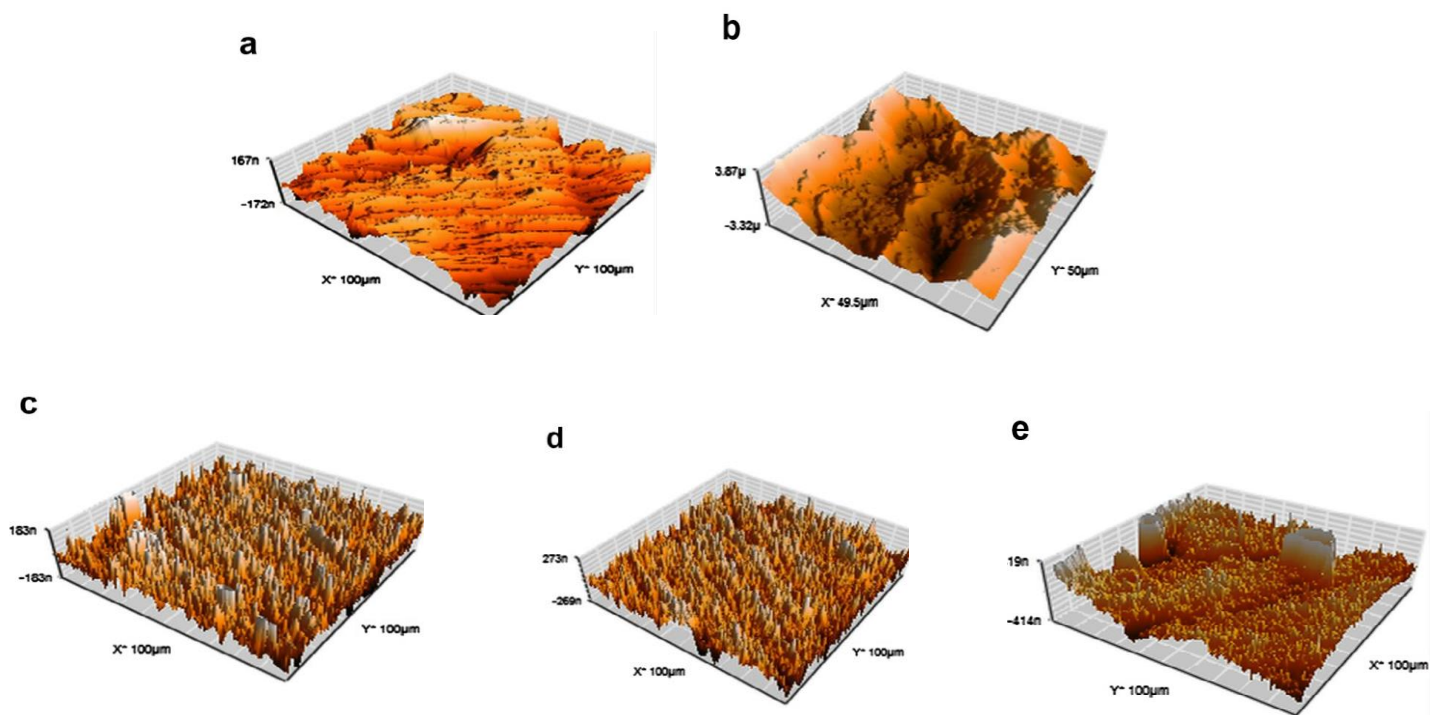


Figure 10. AFM of SS surface (a) polished SS, (b) SS in 1 M HCl solution, (c) in the presence of inhibitor (C) , (d) with inhibitor (B) and (e) in the presence of inhibitor (A) .

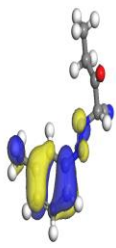
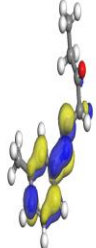
The three-dimensional AFM images of polished, with and without inhibition of 306 L SS coins are given in Fig. 10 (a-e). The mean of roughness data of polished 306 L SS sample (Fig. 10a) and 306 L SS sample in one molar hydrochloric acid solution lack of inhibitor (Fig. 10b) were obtain as 25 and 650 nm . It is given in Fig. 10(b) that 306 L SS is badly destroyed because the acid attacks on 306 L SS. The attendance of optimum dose (25×10^{-6} M) of compounds C, B and A as given in Fig .10(c-e), the mean roughness data were obtain as 77, 66 and 63 nm, respectively. The decrease data of roughness for compound (A) than (B) and (C) revealed that compound (A) protect SS surface more efficiently than (B) and (C) .

3.2.6 Prediction of theoretical parameters

The activity of the inhibitor is due to E_{HOMO} , E_{LUMO} [47]. Higher E_{HOMO} of the adsorbent had given rise ability electron donating [48]. Decrease E_{LUMO} lead to acceptor gains easily electrons. The measured quantum chemical lead to (E_{HOMO} , E_{LUMO} , μ) of organic assembled are list in Table (8). Various $\Delta E = E_{\text{LUMO}} - E_{\text{HOMO}}$ is the energy need to move an electron from HOMO to LUMO. Decrease (ΔE) easily adsorption of molecule and given increase protection efficiency. The gap energy (ΔE) rises from (A) to (C). This fact illustrated the lowering protection efficiency: $A > B > C$.

Table (8) and Fig (11) give the best structures of three organic compounds. It was noted from Table (8) the inhibitor (A) has the lowest ΔE comparatives with the other inhibitor. However, it could be given that inhibitor (A) has more readiness to adsorb on the 306 L SS surface than the other inhibitor. The measured given that the biggest data of μ is assigned for the compound (A) which has arisen protection efficiency, the attendance of an donating substituent electron such as $-\text{OCH}_3$, $-\text{OH}$ group is more suitable than $-\text{Cl}$ group to improve the protection efficiency.

The HOMO and LUMO density electronic distributions of these molecules were drawing in Fig (11). For the HOMO of the research organic compounds that the O-atom, N-atoms benzene ring, and have a higher electron density. The value listed in Table (9) show that the measured dipole moment decrease from $C < B < A$.

Inhibitor s	HOMO	LUMO
A		

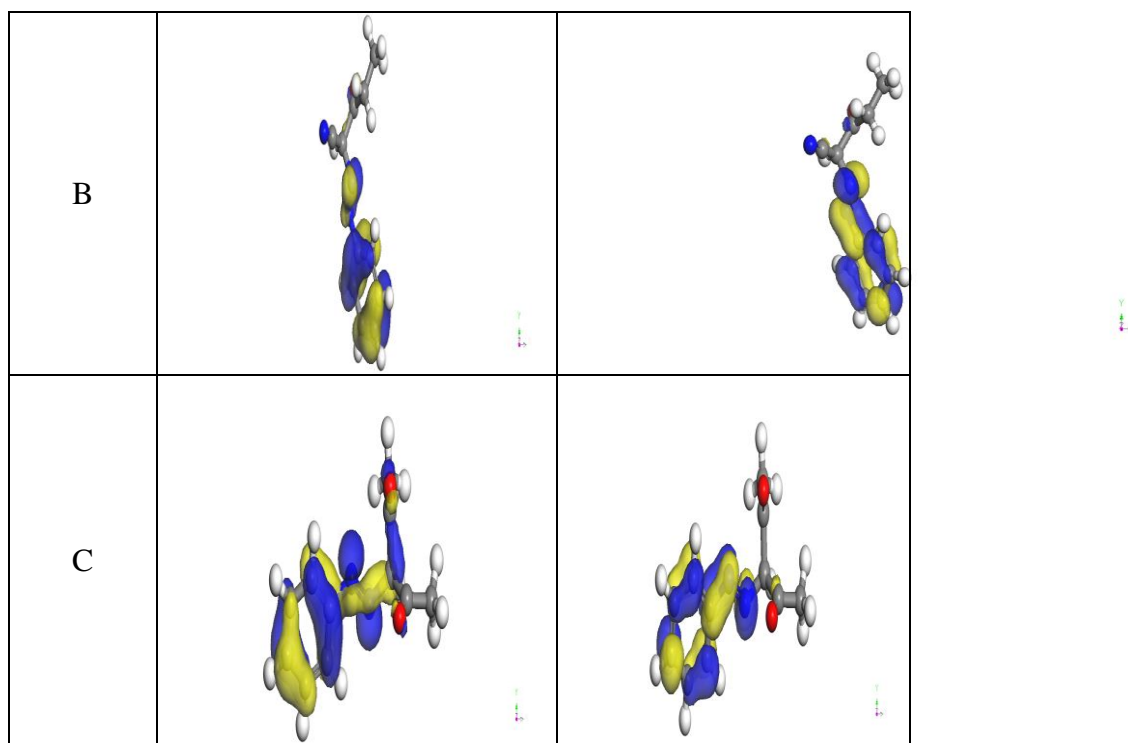


Figure 11. The molecular frontier orbital density distribution of the investigated inhibitors (LUMO and HOMO).

Table 8. Quantum chemical parameter for investigated derivatives

Inhibitor	E_{HOMO} (ev)	E_{LUMO} (ev)	ΔE , (ev) ($E_{\text{L}} - E_{\text{H}}$)	μ Debye)(
A	9.669	0.615	9.054	4.266
B	10.079	1.024	9.055	3.565
C	10.146	0.976	9.170	3.497

3.2.7 Chemical Structure and Corrosion Inhibition

In general, two methods of adsorption are given for the behavior of the metal surface in corrosive solution. In the first method, the unbiased particles might be adsorbed on the SS surface among the chemisorptions process, including the displacing of water particles from the SS surface and the electrons sharing among the iron and heterocyclic molecules. In the second method, the SS surface contains +ve charge in acidic medium [49-50]. Since chloride ions have a lower degree of hydration, the protonated organic compounds adsorb through electrostatic interactions among the charged positively and negatively of 3016 L SS surface. Thus there is a relation among adsorbed Cl^- ions and protonated studied heterocyclic compound. Thus we can conclude that inhibition of SS corrosion in corrosive medium due to electrostatic interaction.

4. CONCLUSIONS

The heterocyclic compounds give a good performance as corrosion protection in acid solution. The protection efficiency of research heterocyclic derivatives obeys the order: C < B < A. Polarization research given that these derivatives behave as mixed kind inhibitors for SS hydrochloric acid solution. EIS test lead to that R_{ct} data rise, while C_{dl} data lower with inhibitors. The adsorption of the investigated inhibitors was obeys adsorption Temkin isotherm. The % η given from WL, EFM, polarization plots and EIS are a good agreement.

References

1. C.D. Dillon, *Performance*, 33 (1994) 62.
2. W.P. Wang, D. Casta and P. Marcus, *J. Electrochem. Soc.*, 141 (1994) 2669.
3. P.Q. Zhang, J.X. Wu, W.Q. Zhang, X.Y. Lu and K. Wang, *Corros. Sci.*, 34 (1993) 1343.
4. A. Atrens, B. Baroux and M. Mantel, *J. Electrochem. Soc.*, 144 (1997)3697.
5. A.H. Fadda, A. Zaki, Kh. Samir and F.A. Amr, *J. Chem. Heterocycl. Comp.*, 9 (2003) 1413.
6. R.W. Bosch, J. Hubrecht, W. F. Bogaerts, B.C. Syrett, *Corrosion*, 57 (2001) 600.
7. M. Kendig, S. Jeanjaquet, *J. Electrochem. Soc.*, 149 (2002) B47.
8. F. Mansfeld, M.W. Kendig and S. Tsai, *Corrosion*, 38 (1982) 570.
9. F. Mansfeld, *Electrochim. Acta*, 35 (1990) 1533.
10. K. F. Khaled, *Electrochim. Acta*, 53 (2008) 3484.
11. W. Huilong, Z. Jiashen and L. Jing, *Anti-Corros. Meth. Mater.*, 9(2) (2002) 127.
12. M. T. Said, S. A. Ali and S. U. Rahman. *Anti-Corros. Meth. Mater.*, 50(3) (2003) 201.
13. A. Atia and M. M. Saleh. *J. Appl. Electrochem.*, 33(2) (2003) 171
14. S. Tamilselvi and S. Rajeswari., *Anti-Corrosi. Meth. Mater.*, 50(3) (2003) 223.
15. S. Deng, X. Li and X. Xie, *Corros. Sci.*, 80(2014)276
16. B.S. Devi, and S. Rajendran, *J. Chem. Sci. Technol.*, 1(1)(2010)79
17. M. Scendo and J. Trela, *Int. J. Electrochem. Sci.* 8(2013) 9201.
18. B.E. Rani and B.B. Basu , *Int. J. Corros.* 26 (2011) 2012
19. D.A. Jones, Principles and Prevention of Corrosion, second ed., Prentice Hall, Upper Saddle River, NJ, 1983.
20. Gamry Echem Analyst Manual, 2003.
21. N.O. eddy and E.E. Ebenso, *Int. J. Electrochem. Sci.*,5 (2010) 731-750.
22. F.M. Donahuce and K. Noor, *J. Electrochem. Soc.*, 112 (1965) 886.
23. E. Kamis, F. Bellucci, R.M. Latanision and E.S. El-Ashry, *Corrosion*, 47 (1991) 677.
24. M.A. Amin, S.S. Abd El-Rehim, M.M. El-Naggar and H.T. Abd El-Fattah, *J. Mater. Sci.*, 44 (2009) 6258.
25. E.E. Oguzie, *Mater. Chem. Phys.*, 99 (2006) 441.
26. A. Popova, E. Sokolova, S. Raicheva and M. Christov, *Corros. Sci.*, 45 (2003) 33-58.
27. A.S. Fouda, H.A. Mostafa, G.Y. Elewady, M.A. El-Hashemy, *Chmical engineering communications*, 195(8) (2008) 934.
28. M. Kendig and S. Jeanjaquet, *J. Electrochem. Soc.*, 149 (2002) B47.
29. M.E. Nicho, H. Hu, J.G. Gonzalez-Rodriguez, V.M. Salinas, *J. Appl. Electrochem.*,36(2) (2006) 153.
30. E. Mc Cafferty, N. Hackerman, *J. Electrochem. Soc.* 119 (1972) 146.
31. H. Shin, H. Mansfeld, *Corros. Sci.*, 29 (1989)1235.
32. S. Martinez M. Metikos-Hukovic, *J. Appl. Electrochem.*, 33 (2003)1137.
33. R. W. Bosch, J. Hubrecht, W. F. Bogaerts, B. C. Syrett, *Corrosion*, 57 (2001) 60.

34. K. F. Khaled, *Electrochim. Acta*, 53 (2008) 3484.
35. K. F. Khaled, *Int. J. Electrochem. Sci.*, 3 (2008) 462.
36. D. A. Jones, *Principles and Prevention of Corrosion*, second ed., Prentice Hall, Upper Saddle River, NJ, 1983.
37. J. Cruz, T. Pandiyan and E. Garcia-Ochoa, *J. Electroanal. Chem.*, 583 (2005) 8.
38. H. Ashassi-Sorkhabi, B. Shaabani and D. Seifzadeh, *Electrochim. Acta*, 50 (2005) 3446.
39. N. Khalil, *Electrochim. Acta*, 48 (2003) 2635.
40. J. Fang and J. Li, *J. Mol. Struct.*, 593 (2002) 179.
41. N. K. Allam, *Appl. Surf. Sci.*, 253 (2007) 4570.
42. F. Kandemirli and S. Sagdina, *Corros. Sci.*, 49 (2007) 2118.
43. G. Bereket, C. Ogretic and C. Ozsahim, *J. Mol. Struct.*, 663 (2003) 39.
44. D. Wang, S. Li, Y. Ying, M. Wang, H. Xiao and Z. Chem, *Corros. Sci.*, 41 (1999)1911.
45. M. Ozcan and I. Dehri, *Prog. Org. Coat.*, 51 (2004) 181.
46. J.M. Costa, J.M. Lluch, *J. Corros.Sci.*, 24 (1984) 929.
47. C. Lee, W. Yang and R. G. Parr, *Phys. Rev. B*, 37 (1988) 785.
48. R. M. Issa, M. K. Awad and F. M. Atlam, *Appl. Surf. Sci.*, 255 (2008) 2433.
49. G.N. Mu, T.P. Zhao, M. Liu and T. Gu, *Corrosion*, 52 (1996) 853.
50. A.K. Singh and M.A. Quraishi, *Corros. Sci.*, 52 (2010) 1529.

© 2017 The Authors. Published by ESG (www.electrochemsci.org). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/4.0/>).