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Corrosion Inhibition Effect of some Pyridopyrimidine Derivatives for Carbon Steel in 0.5 M HCl Solution

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The impact of some Pyridopyrimidine derivatives on the corrosion of carbon steel (CS) in 0.5M HCl was examined utilizing mass loss (ML), potentiodynamic polarization (PP), AC impedance spectroscopy (EIS) and electrochemical frequency modulation (EFM) techniques. The inhibition efficiency (IE) increases with increasing concentration of inhibitor but decreases with rising the temperature. The inhibitors were adsorbed on the CS surface obey Temkin's isotherm. The electrochemical data indicated that all the investigated compounds act as mixed-type inhibitors. The mechanism of the inhibition process was discussed in the light with chemical construction and quantum-chemical calculations of the Pyridopyrimidine derivatives.

Keywords: corrosion protection; CS; EIS; EFM; HCl; Pyridopyrimidine derivatives

1. INTRODUCTION

Corrosion is an essential procedure playing a significant role in safety and economics, mainly for metals. The utilized of inhibitors are excellent techniques for inhibition versus corrosion, particularly in acidic solution [1]. The benefits of utilized organic inhibitors such as given higher protection efficiency, little price, toxicity low, and easy synthesis [2]**.** Many heterocyclic composites have been utilized for the corrosion hindrance of iron [3], copper [4], aluminum [5]**,** and other metals [6] in different corroding medium. The surfactant heterocyclic compounds adsorbed on the metal surface can distinctly change the property of corrosion- resisting for metal [7] and so the study of the relatives among the adsorption and corrosion protection is the great important. Heterocyclic compounds have displayed a high protection efficiency for iron in both HCl [8] and H_2SO_4 [9] solutions. It is well known, organic compounds containing O, S and N are utilized as corrosion inhibitors for metals in acidic solutions, such as: ethanolamine, diethanolamine and triethanolamine [10], docecyl benzene sulfonic acid sodium salt (SBDS) [11], 2-mercapto pyrimidine [12], some acridines [13], imines [14], dioxan-water mixtures [15],

quaternary ammonium , salts based on 2-acetylallylchloride [16], 2-mercapto benzimidazole [17], Ethoxylated fatty alcohols [18], Schiff base compounds [19], pyrrole and its derivatives [20], benzotriazole [21-29], Pyrazolocarbothioamide [30], 1,3-Thiazolidin-5-one[31], Pyrazolone [32], Distyryl [33]. These compounds can absorb onto metal surface and blocking the active sites and thus lowered the rate of corrosion.

As Pyridopyrimidine derivatives have rarely been studied as inhibitors for CS in HCl. For this reason, the objective of the current work is to examine the protecting action of Pyridopyrimidine compounds in 0.5M HCl at 25-55 ºC utilizing altered techniques.

2. EXPERIMENTAL METHODS

2.1. Materials

Techniques were achieved on CS coins of the following composition (weight %):0.350 Mn, 0.200 C, 0.024 P, 0.003 S, and the rest Fe.

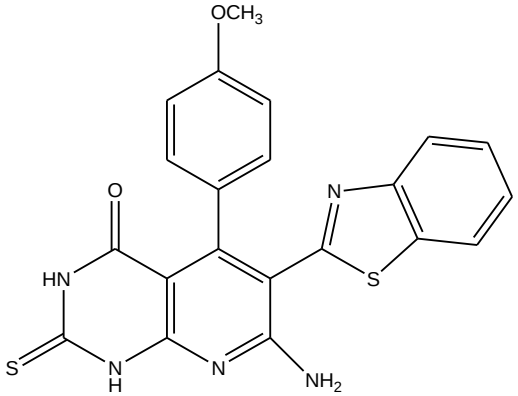
2.2. Solutions

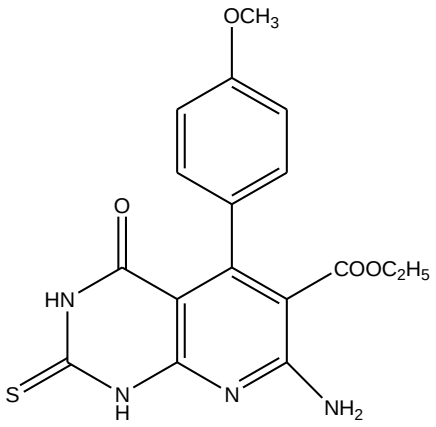
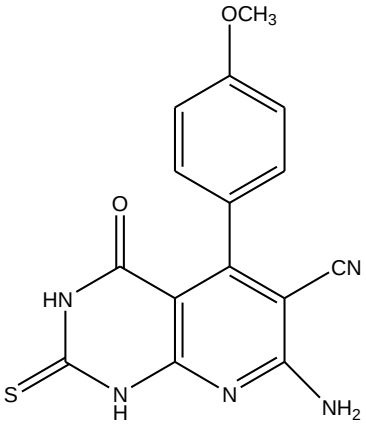
The aggressive solution, 0.5M HCl was ready by dilution of analytical grade (37 %) HCl with bi-distilled water. The range of the inhibitors concentration utilized was $1x10^{-6}$-$19x10^{-6}$ M.

2.3. Inhibitors

The investigated compounds were selected from Pyridopyrimidine derivatives and are shown in the Table (1).

Table 1. The molecular structure, names, molecular formulas, and molecular weights of Pyridopyrimidine derivatives

Inh.	Structure	IUPAC Name	Active center	Chemical formula, Mol. Wt.
(A)		7-amino-6-(benzo[d]thiazol-2-yl)-2,3-dihydro[2,3-d]pyrimidin-4(1H)-one	2O 5N 2S	$C_{21}H_{15}N_5O_2S_2$ 433.51

(B)		Ethyl7-amino-1,2,3,4-tetrahydro-5-(4-methoxy phenyl)-4-oxo-2-thioxopyrido[2,3-d]pyrimidine-6-carboxylate	4O 4N 1S	$C_{17}H_{16}N_4O_4S$ 372.4
(C)		7-amino-1,2,3,4-tetrahydro-5-(4-methoxy phenyl)-4-oxo-2-thioxopyrido[2,3-d]pyrimidine-6-carbonitrile	2O 5N 1S	$C_{15}H_{11}N_5O_2S$ 325.35

2.4. Mass Loss (ML) Tests

Seven parallel CS sheets of 25 × 20 × 0.6 mm were abraded with emery papers (grade 320–500–800) and then washed with bi-distilled water and acetone. After exact weight, the samples have pushed in 100 ml of 0.5M HCl acid existence and nonexistence of altered dose of inhibitors. After an altered rinsed time, the CS specimen were achieved, wash with water bi-distilled, and then mass. The (IE %) and θ, of Pyridopyrimidine derivatives for the CS were calculated as next [34],

$$IE\% = \theta \times 100 = [1 - (W/W^o)] \times 100 \quad (1)$$

Where W^o and W are the ML without and with of the Pyridopyrimidine inhibitor, correspondingly.

2.5. Electrochemical Measurements

PP method was taken in a typical three compartments glass cell [35]. The potential range was (-800 to +200 mV vs. SCE) at OCP with a scan rate 1 mVs^{-1}.

Then i_{corr} was calculated for the measurements and was used to calculate the %IE and the θ from Eq. (2) as below:

$$IE\% = \theta \times 100 = [1 - (i_{corr(inh)} / i_{corr(free)})] \times 100 \quad (2)$$

Where $i_{corr(free)}$ and $i_{corr(inh)}$ are the current in the absence and presence of Pyridoprymidine, correspondingly.

Impedance measurements were done by AC signs of 5 mV peak-to-peak amplitude and at a range of frequency of 10^7 Hz to 0.1Hz. The capacity of double layer C_{dl}, (% IE) and θ were founded from Eqs. (3) and (4) which are defined as:

$$C_{dl} = 1/ (2 \pi f_{max} R_{ct} \quad (3)$$

Where f_{max} is the maximum frequency

$$IE \% = \theta \times 100 = [1- (R°_{ct}/R_{ct})] \times 100 \quad (4)$$

Where R^o_{ct} and R_{ct} are the charge transfer resistances without and with Pyridoprymidine, respectively.

EFM technique used two frequencies of range 2 and 5 Hz depending on three conditions. The (i_{corr}), (β_c and β_a) and (CF-2, CF-3) (Causality factors) were measured by the greater two peaks

(EFM) and (EIS) technique was performed utilized the similar manner as earlier with a Gamry framework system rely on ESA400. Gamry apparatus includes software EFM140 for EFM tests and EIS300 for EIS method; the computer has used for summation value. Echem Analyst 5.5 Software was used for drawing and fitting data.

3. RESULTS AND DISCUSSION

3.1. Mass loss (ML) measurements

The mass loss of CS can be studied in presence of Pyridopyrimidine at 25°C. Figure 1 shows that Pyridopyrimidine derivatives decrease the ML and therefore the corrosion rate [36]. Similar curves were obtained in presence of the other inhibitors, but not shown. The (% IE) and then θ, of the CE for the CS were estimated from Eq. (1). The values of % IE are given in Table 2. The % IE of Pyridopyrimidine derivatives in the order: A > B > C.

Table 2. Values of % IE and C.R. after 120 min of CS in 0.5 M HCl without and with various concentrations of Pyridopyrimidine derivatives at 25ºC

Compound	Conc., x 10^6 M	ML, mg cm^{-2}	(C.R.) mg $cm^{-2}min^{-1}$	IE%
Blank	0.0	2.80	0.023	---
A	1	2.10	0.018	25.0
	5	1.70	0.014	39.3
	9	0. 90	0.008	67.9
	17	0. 50	0.004	82.1
	19	0. 30	0.001	89.3
B	1	4.80	0.040	20.8
	5	3.80	0.032	35.4

	9	2.40	0.020	50.0
	17	1.80	0.015	62.5
	19	0.07	0.001	85.4
C	1	4.40	0.037	15.9
	5	3.70	0.031	25.0
	9	3.30	0.028	38.6
	17	2.70	0.023	59.1
	19	1.10	0.009	75.0

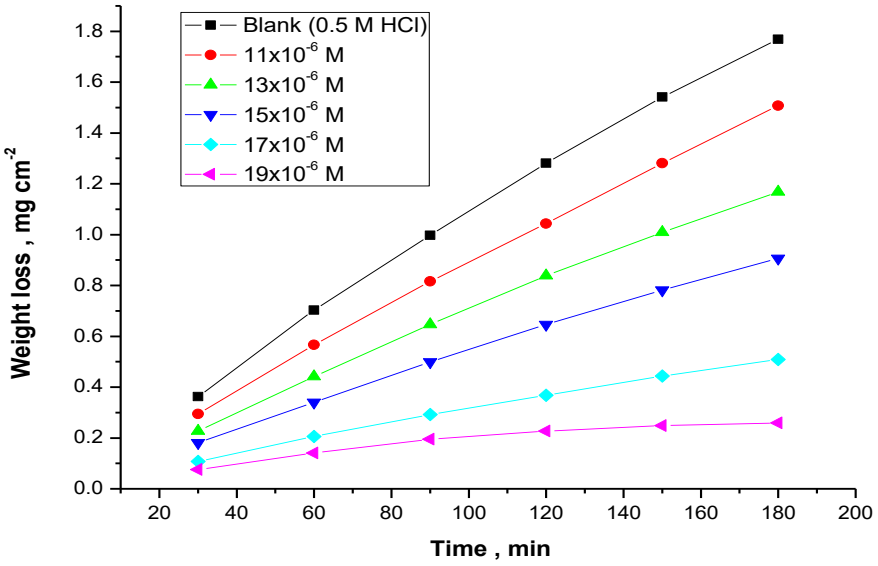


Figure 1. ML-time diagrams for the CS in 0.5 M HCl without and with various concentrations of compound (A) at 25 ºC

3.2 Potentiodynamic Polarization (PP) Measurements

PP has happened to obtain data linking to the kinetics of the cathodic and anodic reactions. Figure 2 illustrated the PP manner of CS in destructive solution existence and nonexistence of altered doses of Pyridopyrimidine derivatives (A). The % IE increases as the rise the concentration of inhibitor. The small change in the β_a and, β_c (Tafel slopes) and in E_{corr} with raising the derivative concentration indicate that these derivative behave as mixed type [37]. The results obtained from PP (Table 3) show reduction in i_{corr} with presence of inhibitors and increase % IE with improving the concentration. The parallel Tafel lines indicate that there is no change in the mechanism of CS corrosion [38]. The %IE of these Pyridopyrimidine derivatives follow the arrangement: (A) > (B) > (C).

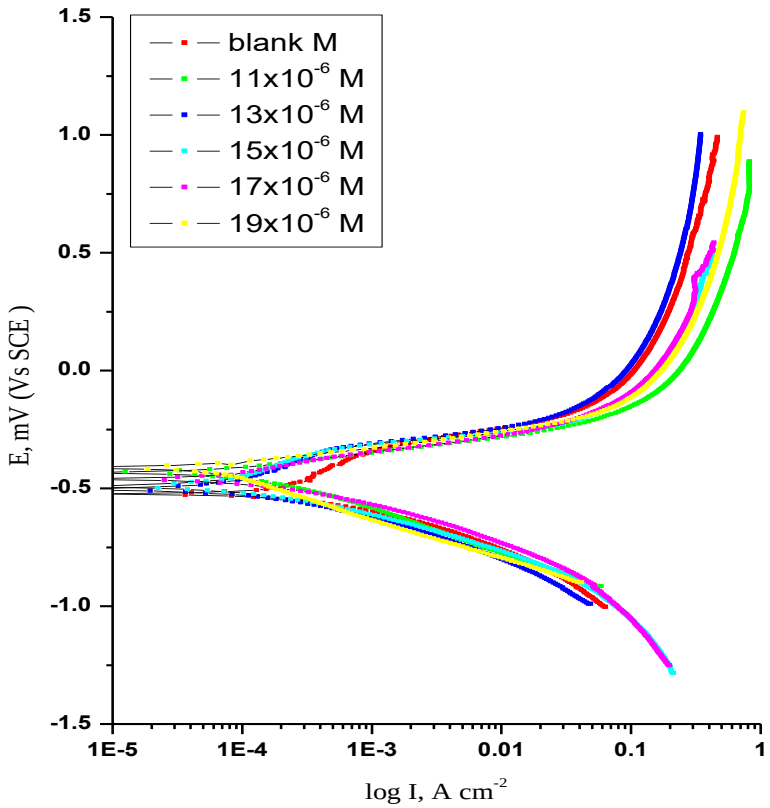


Figure 2. PP curves for corrosion of CS with and without various concentrations of inhibitor (A) at 25ºC

Table 3. PP parameters ($E_{corr.}$), ($i_{corr.}$), (β_a& β_c), (θ) and (% IE) for CS dissolution in HCl at 25ºC

Comp.	Conc., M.	- $E_{corr.}$, mV(vs SCE)	$i_{corr.}$ mA cm^{-2}	β_a mV dec^{-1}	β_c , mV dec^{-1}	θ	% IE
A	Blank	521	120	66	76		
	11×10^{-6}	433	63	83	38	0.475	47.5
	13×10^{-6}	503	56	29	96	0.533	53.3
	15×10^{-6}	491	46	58	80	0.617	61.7
	17×10^{-6}	460	36	97	71	0.700	70.0
	19×10^{-6}	411	31	47	73	0.742	74.2
B	11×10^{-6}	412	57	87	77	0.525	52.5
	13×10^{-6}	433	63	84	66	0.475	47.5
	15×10^{-6}	431	50	90	37	0.583	58.3
	17×10^{-6}	470	39	15	61	0.675	67.5
	19×10^{-6}	436	38	70	48	0.683	68.3
C	11×10^{-6}	503	81	39	107	0.325	32.5
	13×10^{-6}	479	70	37	99	0.417	41.7
	15×10^{-6}	540	62	28	122	0.483	48.3
	17×10^{-6}	503	50	22	85	0.583	58.3
	19×10^{-6}	521	45	26	84	0.625	62.5

3.3. Electrochemical Impedance Spectroscopy (EIS) Measurements

EIS tests were utilized to study the mechanism of corrosion. The results of Nyquist and Bode diagrams are demonstrated in Figure 3a, 3b, respectively.

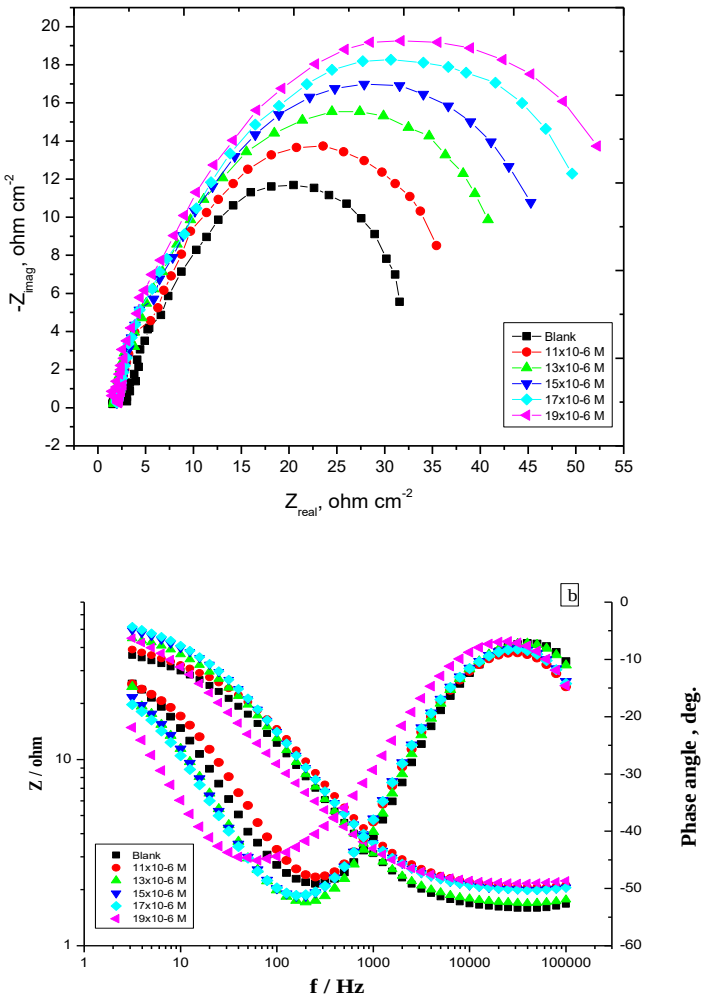


Figure 3. The Nyquist (a) and Bode (b) diagrams of CS in 0.5 M HCl in the absence and presence of various concentrations of compound (A) at 25°C

These figures indicate a gradual increase in the semicircle diameter of the Nyquist diagrams by raising the concentration of Pyridopyrimidine derivatives. So the Pyridopyrimidine derivatives retard the corrosion rate by adsorption [39]. From Figure 3a one noticed that the deviation from an ideal semicircle as a result of frequency dispersion because of the inhomogeneity of the surface. Table 4 gives different parameters of impedance as, (R_{ct}), (C_{dl}), (%IE) and electrolyte resistance (R_s). The data of Table 4 demonstrated that, the C_{dl} data lowered by raising the of Pyridoprymidine derivatives, this behavior as a result of molecules adsorbed on the surface of CS. Figure 4 shows the equivalent circuit which used in our study [40]. The %IE gotten from EIS tests is as follows: A > B > C

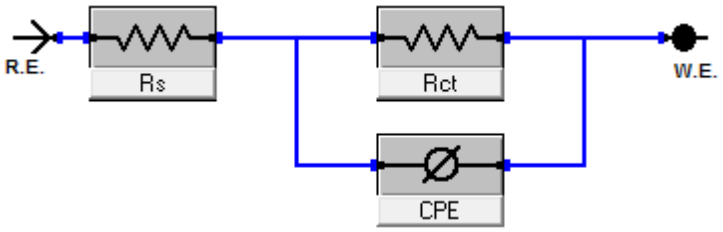


Figure 4. Circuit utilized for fitting the data of EIS in 0.5 M HCl

Table 4. EIS parameters for CS corrosion without and with various concentrations of pyridopyrimidine derivatives at 25ºC

Comp.	Conc., M	C_{dl},x10^{-3} µFcm^{-2}	R_{ct},x 10^{-4} Ω cm^2	θ	IE%
Blank	Blank	2.87	34.90	---	---
A	1x10^{-6}	2.12	49.86	0.301	30.1
	5x10^{-6}	1.83	68.43	0.490	49.0
	9x10^{-6}	1.51	96.94	0.636	63.6
	17x10^{-6}	1.36	166.19	0.791	79.1
	19x10^{-6}	1.11	317.27	0.897	89.7
B	1x10^{-6}	2.42	49.15	0.293	29.3
	5x10^{-6}	1.91	58.17	0.401	40.1
	9x10^{-6}	1.70	74.26	0.525	52.5
	17x10^{-6}	1.33	112.58	0.691	69.1
	19x10^{-6}	1.21	205.29	0.829	82.9
C	1x10^{-6}	2.33	39.21	0.112	11.2
	5x10^{-6}	2.06	46.53	0.249	24.9
	9x10^{-6}	1.31	54.53	0.365	36.5
	17x10^{-6}	0.98	81.16	0.571	57.1
	19x10^{-6}	0.88	129.26	0.732	73.2

3.4. Electrochemical Frequency Modulation (EFM) Measurements

EFM is characterized by speed and greatly accuracy in calculating the current data [41]. Figures 5 & 6 indicate the EFM of CS in 0.5 M HCl solution and at 19x10^{-6} M of pyridopyrimidine compound

(A). The EFM parameters such as (CF-2 and CF-3), (β_c and β_a) and (i_{corr}) can be measured from the higher current peaks. The CF is closer to the standard data proved the validity of the calculated data. The IE% increase with the raising of Pyridopyrimidine concentrations. The % IE_{EFM} rise by raising the Pyridopyrimidine concentrations and was measured as in Eq. (2):

Table 5. Parameters of EFM diagrams for CS corrosion without and with various concentrations of Pyridopyrimidine derivatives in 0.5 M HCl at 25°C

Comp	Conc., x 10^6 M	i_{corr} µA cm^{-2}	β_c $mVdec^{-1}$	β_a $mVdec^{-1}$	CF-2	CF-3	CR mpy	θ	IE%
Blank	0.0	1952.0	350	579	1.97	2.99	892.0	----	----
A	5	1061.9	239	318	2.04	6.69	485.3	0.386	38.6
	9	589.5	189	416	1.97	3.29	269.4	0.579	57.9
	17	294.8	252	329	2.07	6.65	134.7	0.779	77.9
	19	273.7	191	292	2.01	1.93	79.4	0.860	86.0
B	5	1169.3	243	326	2.04	6.09	534.3	0.204	20.4
	9	950.6	225	282	2.03	7.53	434.4	0.500	50.0
	17	694.9	228	302	2.04	10.18	317.6	0.720	72.0
	19	281.3	175	206	1.90	4.22	124.0	0.775	77.5
C	5	1368.4	291	401	2.02	6.37	625.3	0.119	11.9
	9	1180.9	111	136	1.53	1.05	539.7	0.361	36.1
	17	759.3	52	71	1.48	1.75	346.9	0.479	47.9
	19	443.1	47	59	1.12	1.53	202.5	0.715	71.5

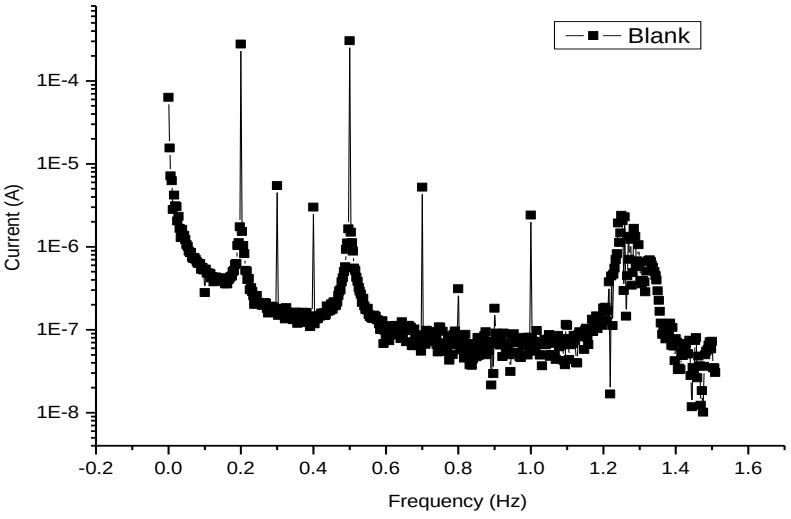


Figure 5. EFM spectra for CS in 0.5M HCl (blank)

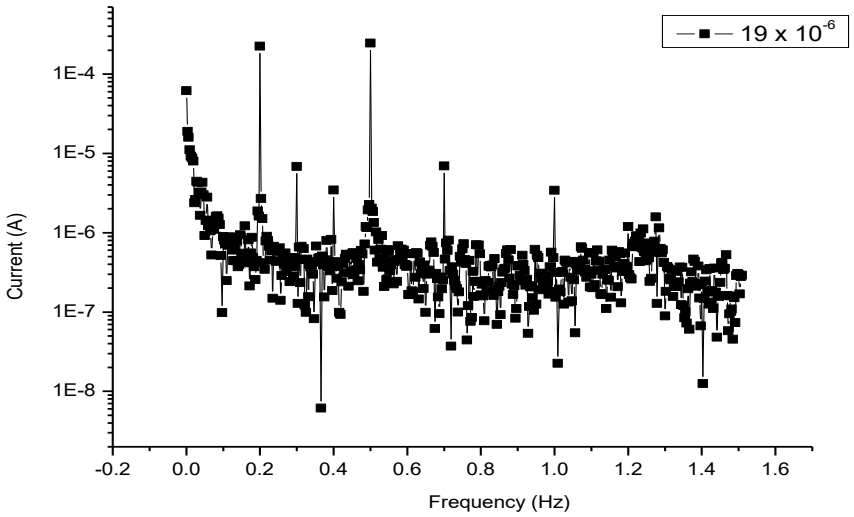


Figure 6. EFM spectra for CS in 0.5 M HCl with of $19x10^{-6}$M compound (A)

3.5 Adsorption isotherms

The behavior of adsorption can be demonstrated by the adsorption isotherms, it enables the elucidation of the investigated mechanism of the inhibition by understanding its behavior.

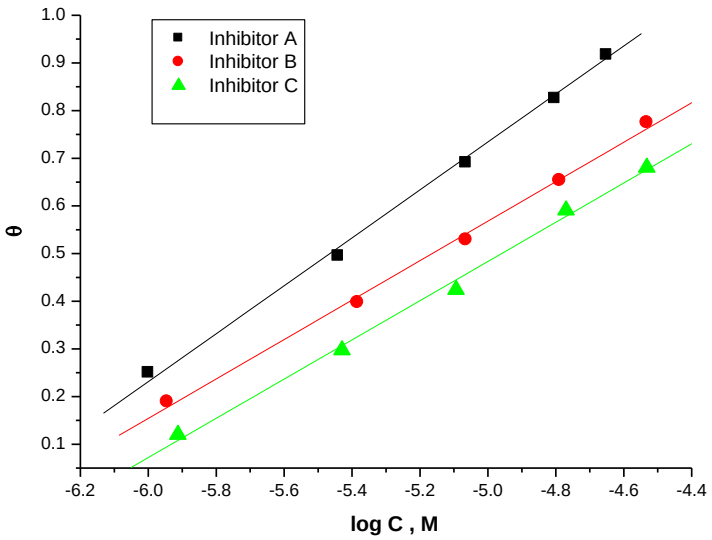


Figure 7. Temkin adsorption isotherm for Pyridopyrimidine derivatives at 25ºC

The common adsorption isotherms fitting were used to analyze the data are Langmuir, Freundlich, Temkin, Flory–Huggins and Frumkin [42]. In the present study, the data of our experiment, revealed that the best fit for Temkin isotherm. Figure 7 shows the plotting of θ against log C at 25ºC for

Pyridopyrimidine derivatives. This plot gave straight lines indicating that the adsorption of Pyridoprimidine derivatives on CS surface obeys Temkin isotherm:

$\theta = (1/f) \ln K_{ads}C$ (5)

C_{inh} is the inhibitor concentration, K_{ads} is the adsorption equilibrium constant, and "a" is a parameter of lateral interaction which describes the molecular interactions in the adsorbed layer and the degree of the surface.

$K_{ads} = 1/ 55.5 \exp (-\Delta G_{ads}/ RT)$ (6)

T is the Kelvin temperature and 55.5 is the concentration of water in solution (M).

The values of K_{ads} and ΔG^{o}_{ads} of the Pyridopyrimidine derivatives were measured and are listed in Table (6). The Pyridopyrimidine derivatives are adsorption on CS surface spontaneously and this is proved by the negative sign of ΔG°_{ads}. From the data of ΔG^{o}_{ads} (more than -20 and less than -40 kJ mol^{-1}), the Pyridopyrimidine derivatives are adsorbed by mixed one (physisorption and chemisorption) [43].

Vant't Hoff equation can be utilized to measure ΔH°_{ads} and ΔS°_{ads} Eq. (7):

$\Delta G^{o}_{ads} = \Delta H^{o}_{ads} - T \Delta S^{o}_{ads}$ (7)

A positive sign of ΔS^{o}_{ads} proved that the disorder of corrosion process is rise by utilizing Pyridopyrimidine derivatives (Table 6).

Table 6. Calculated results of the adsorption parameters of CS

Comp.	Temp., °C	$K_{ads}x10^{6}$ M^{-1}	$-\Delta G^{\circ}_{ads}$ kJ mol^{-1}	$-\Delta H^{\circ}_{ads}$ kJ mol^{-1}	$-\Delta S^{\circ}_{ads}$ J mol^{-1} K^{-1}
A	25	2.2	29.2	23.8	5.9
	35	2.3	29.1		
	45	2.5	28.6		
	55	2.5	28.7		
B	25	2.5	26.1	79.3	4.8
	35	2.9	23.7		
	45	3.0	23.8		
	55	3.2	22.8		
C	25	2.2	26.9	79.0	4.8
	35	3.3	20.0		
	45	3.6	18.6		
	55	4.2	15.2		

3.6 Influence of Temperature

The effect of temperature on the rate of corrosion of CS in 0.5 M HCl with and without various Pyridopyrimidine derivatives concentrations was examined in the range of temperature 25–55 ºC utilizing ML tests. The results indicate that the lower in % IE with the increase in the temperature proved the presence of physical adsorption of Pyridopyrimidine on CS surface. Arrhenius equation (3) can be utilized to measure the (E^{*}_{a}) of the activated energy according to Eq. (8):

$k_{corr} = A \exp (E^{*}_{a}/RT)$ (8)

Where E^*_a is activation energy and T is the absolute temperature. Using Figure 7, E^*_a can be measured (Table 7).

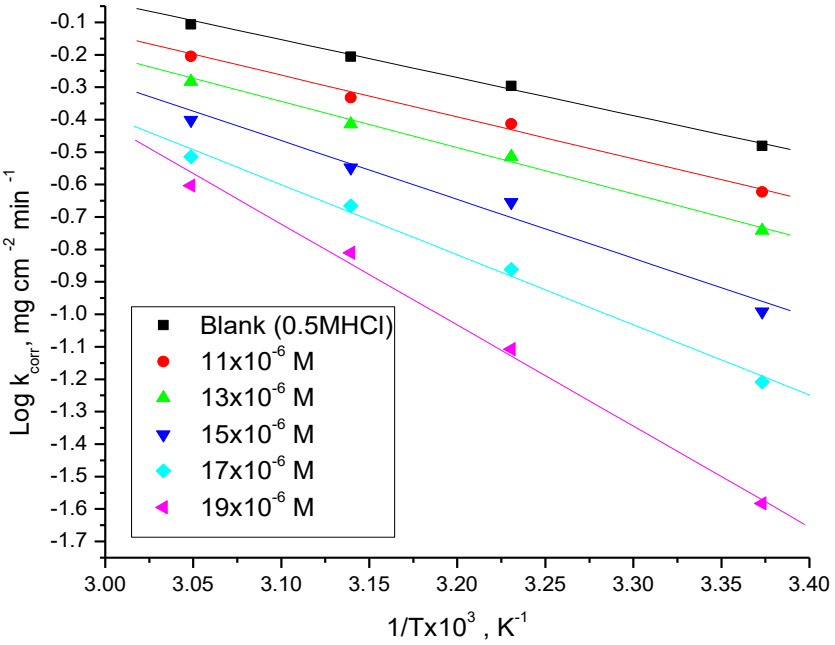


Figure 7. Log k_{corr} – 1/T curves for CS dissolution in 0.5 M HCl without and with various concentrations of compound (A)

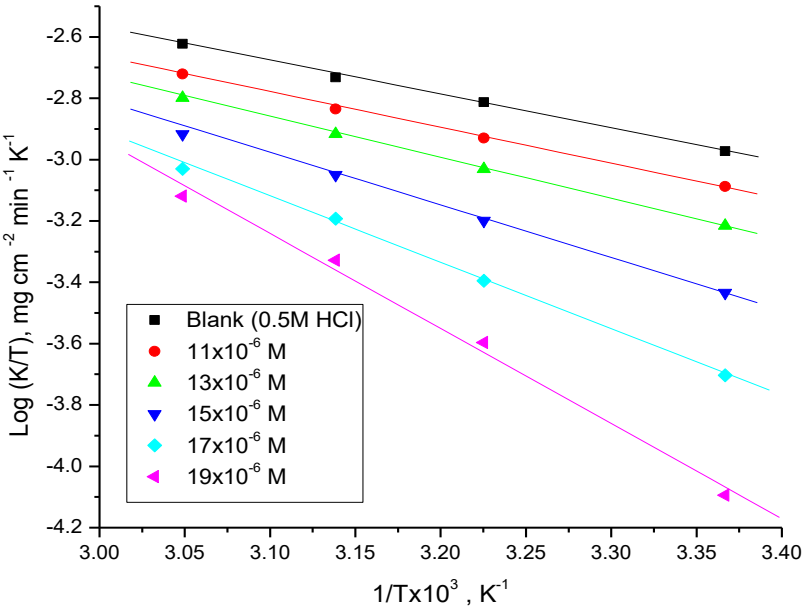


Figure 8. Plots log (k_{corr}/T) and 1/T diagrams for the CS without and with different concentrations of compound (A)

E^*_a values prove that the higher percentage of Pyridopyrimidine impede corrosion effectively by raising the energy barrier of the activated complex and improve that the process is controlled by diffusion [44]. The increase of E^*_a by rising the concentrations of Pyridopyrimidine, indicates that Pyridopyrimidine was adsorbed physically on CS surface (ΔH^*, ΔS^*) are measured by Eq. (9):

$$k_{corr.} = RT / Nh \exp(\Delta S^*/R) \exp(-\Delta H^*/RT) \quad (9)$$

Figure 8 shows the relation between log (k_{corr} /T) and (1/T) which used to measure the values of ΔH^* and ΔS^*(Table 7). The raising in E_a^* with rising CE dose Table 7 is typical of physical adsorption. The positive signs of ΔH^* reflect the endothermic nature of the CS dissolution process. The negative values of ΔS^* shows that during the rate-determining step, the formation of the activated complex is more ordered than that the reactants [45]

Table 7. Activation parameters for CS in 0.5 M HCl at $19X10^{-6}$ M for the investigated compounds

Inhibitor	E_a^*, kJ mol^{-1}	ΔH^*, kJ mol^{-1}	$-\Delta S^*$, J $mol^{-1}K^{-1}$
0.5 M HCl	22.4	20.5	185.3
A	63.6	59.6	73.9
B	37.5	35.0	149.0
C	32.9	30.8	158.0

The %IE of Pyridopyrimidine derivatives as E_a^* and ΔH^* and ΔS^* data are as follows: A > B > C

3.7 Simulation Analysis

The E_{HOMO} indicates the capacity of the molecule to donate electrons to an appropriated acceptor with empty molecular orbital but E_{LUMO} indicates its ability to take electrons. The lesser the data of E_{LUMO}, the more capability of the molecule is to gain electrons [46]. While the greater is the data of E_{HOMO} of the inhibitor, the easer is its donation electrons to the unoccupied d-orbital of CS surface and the larger is its IE. The obtained data record in Table 8 showed that the maximum energy E_{HOMO} is assigned for the Pyridopyrimidine A, which is estimated to have the maximum corrosion protection between the Pyridopyrimidine compounds. The HOMO–LUMO energy gap, ΔE approach, which is a significant constancy index, is practical to advance theoretical models for explaining the structure and conformation barriers in many molecular systems. The lesser is the data of ΔE, the more possible best IE [47]**.** There is a general consensus by numerous authors that the more negatively charged heteroatom is, the more is its capability to absorb on the CS surface among a donor-acceptor type reaction. Deviation in the protection efficiency of the Pyridopyrimidine derivatives is influenced by the existence of electro negative N- and O- atoms as a substituent in their molecular structure. The measured Mulliken charges of designated atoms are listed in Fig. (9).

Table 8. E_{HOMO}, E_{LUMO}, ΔE_{gap} and dipole moment (μ) for the various compounds obtained from B3LYP/6-31G(d) technique in a gas phase

Pyridoprimidine	$-E_{Homo}$	$-E_{Lumo}$	ΔE_{gap}	μ(Debye)	Area (Å^2)
A	8.99	1.52	7.47	8.46	400.29
B	9.24	1.62	7.52	4.1	352.09
C	9.29	1.72	7.57	3.75	306.19

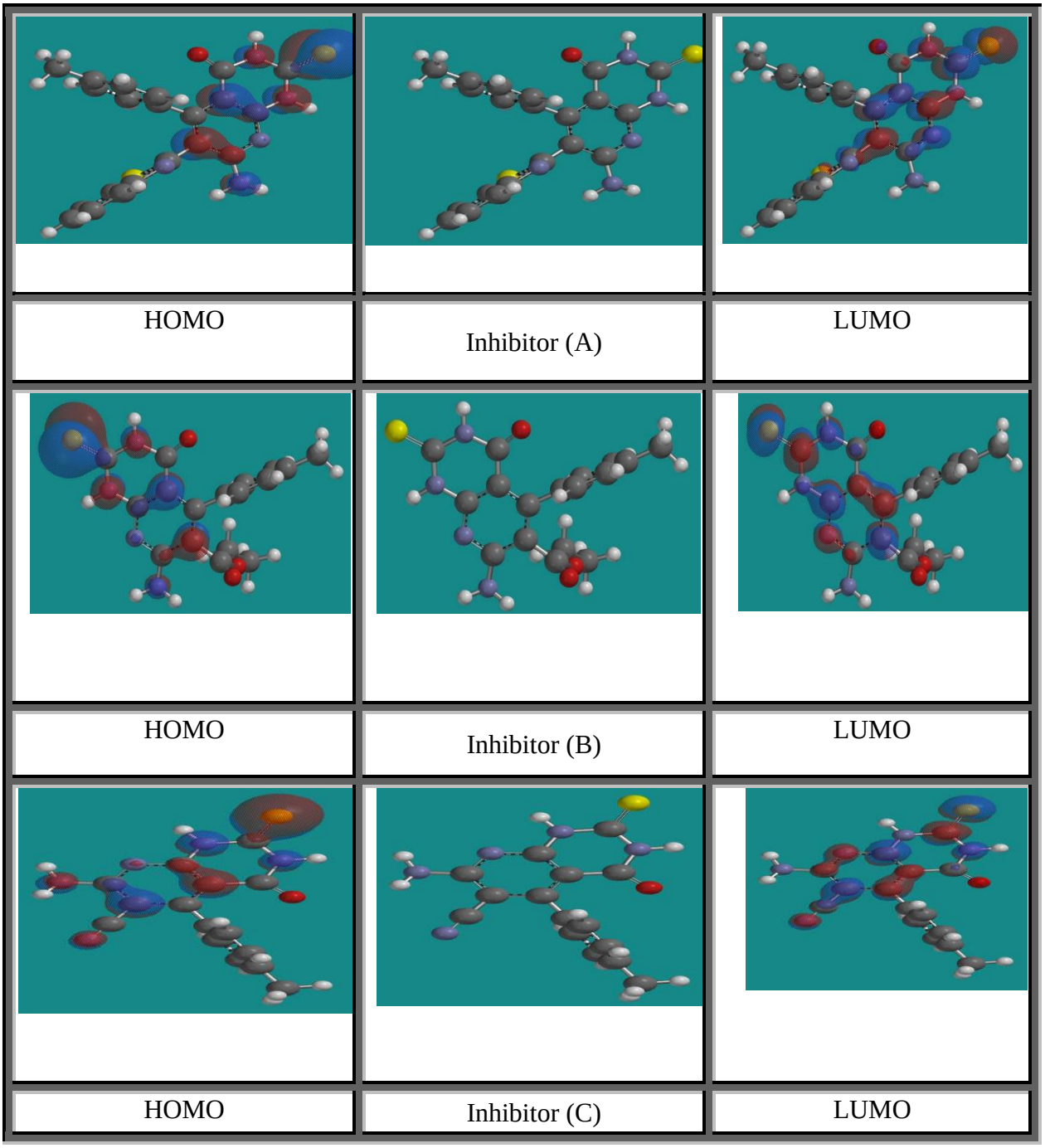


Figure 8. The optimized molecular structures, HOMO, LUMO for Pyridopyrimidine compound utilizing from B3LYP/6-31G (d) technique module

3.8 Mechanism of Inhibition

Corrosion protection of CS in HCl solution by the investigated Pyridopyrimidine derivatives chosen from ML, PP, EIS and EFM tests was found to depend on the concentration and the nature of the Pyridopyrimidine derivatives. The order of increased IE for Pyridopyrimidine derivatives is A > B > C. as indicated by the different tests. Compound (A) is the most efficient inhibitor due to: (i) the existence of two S-atoms, five N-atoms, two O-atoms, and 4 benzene rings which include π-electrons and (ii) it has a greater molecular size [48]. Compound (B) comes after inhibitor (A) in IE this is due to: (i) It has 4-O atoms, 4-N atoms, one-S atom and three benzene rings and (ii) it has lesser molecular size than (A). Compound (C) is the least effective one due to: (i) It has 2-O atoms, 5-N atoms, one-S atom and three benzene rings and (ii) it has lesser molecular size than compounds A & B. The following Table (9) gives a comparison of %IE with different investigated organic compounds. The present Pyridopyrimidine derivatives give considerably significant corrosion %IE compared to other organic derivatives. Thus, the present Pyridopyrimidine derivatives can be used as corrosion inhibitor with good results.

Table 9. Performance comparison of some organic compounds as corrosion inhibitors

Inhibitor	Medium	IE %	References
Pyridopyrimidine derivatives	1 M HCl	89.3-75	Our results
2-(3-Nitrophenyl) imidazo [1,2-a]pyridine	1 M HCl	80.0	[49]
3-Amino-2-phenylimidazo[1,2-a]pyridine	1 M HCl	86.1	[50]
2-Phenylimidazo[1,2-a]pyridine-3-carbaldehyde	1 M HCl	83,1	[51]
3-Bromo-2-phenylimidazol[1,2-α]pyridine	1 M HCl	86.8	[52]
2-Phenyl-3-nitroso-imidazo[1,2-a] pyridine	1 M HCl	73.0	[53]
2-Phenyl-3-nitroso-imidazo[1,2-a] pyridine	1 M HCl	88.8	[54]
2-Phenyl-3-nitroso-imidazo[1,2-a] pyridine	1 M HCl	87.1	[55]

4. CONCLUSIONS

Pyridopyrimidine derivatives are considered as good inhibitors for corrosion of CS in 0.5M HCl. From all experiments, the %IE increases with raising the concentration of the Pyridopyrimidine derivatives and lowered with raising the temperature. Adsorption of Pyridopyrimidine derivatives on CS surface obeys Temkin adsorption isotherm. From thermodynamic values addition of Pyridopyrimidine derivatives increases the activation energy. The negative sign of ΔG^{o}_{ads} and ΔH°_{ads} indicate that the adsorption was spontaneous and exothermic. PP technique suggests that Pyridopyrimidine derivatives can be utilized as mixed type inhibitors.

References

1. G. Trabanelli, Inhibitors - an old remedy for a new challenge, *Corrosion*, 47(1991) 410
2. I. A. Raspini, *Corrosion*, 49 (1993) 821

3. M.A. Migahed, E. M. S. Azzam, A.M. Al-Sabagh, *Mater.Chem.Phys.*, 85 (2004) 273
4. R.F.V. Villamil, P. Corio, J.C. Rubim, M.L. Siliva Agostinho, *J.Electroanal.Chem.,* 472 (1999) 112
5. S.S. Abd El Rehim, H. Hassan., M,AAmin, *Mater.Chem.Phys.,* 78 (2003)337
6. V. Branzoi, F. Golgovici, F. Branzoi, *Mater.Chem.Phys.,* 78 (2002) 122
7. F. Bentiss Traisnel, M. Lagrenee, *Corros.Sci.,* 42 (2002) 127
8. M. Elachouri, M.S. Hajji, M., Salem, S. Kertit, J. Aride, R. Coudert, E. Essassi, *Corrosion,* 52 (1996)103
9. A.S. Algaber, E.M. El-Nemma, M.M. Saleh, *Mater.Chem.Phys.*, 86 (2004) 26
10. H.M.Bhajiwala, and R.T. ().Vashi, *Bull. Electrochem*., 7(2001) 441.
11. 11 G. Mu. L.Tang and G.Liu, *Xitu-Chinese rare earths*, 22(2001)78.
12. L.Wang, D.S. Yunnan, and K. Ziran, *Protection of Metals,* 23(2001) 203.
13. V.V.Ekilik, A.G.Berezhnaya, and M.Svyataya, *Protection of Metals*, 37(2201)525.
14. S.K.Rajappa,and T.V.Venkatesha, , *J.Electrochem.Soc.Ind.,* 51(2002) 54.
15. M.T.Mohammed, J. *Electrochem. Soc. Ind.,* 551(2002)75.
16. D.A. Pisanenko, and I.S.Pogrebova, *Zh. Prikl. Khim. J.,* 75(2002) 1248.
17. L.Wang, X. Pu-Jian, and L. Hui-Chun, *Corros. Sci*., 45(2003) 677.
18. M. Abdallah, *Corros. Sci.,* 45(2003) 2705.
19. C. Emregul, Kaan and O. Atakol, *Mater. Chem. Phys*., 82(2003) 188.
20. S.I. N. Mani, Venkatakrishna and L. Bahadur Transactions *of the SAEST,* 38(2003) 67.
21. K. Wang, H.W. Pickering and K.G. Weil, *J. Electrochem. Soc.,* 150(2003) B176
22. N.Mani, S.I. Venkatakrishna and L. Bahadur, *Bull. Electrochem.,* 19(2003) 53.
23. M.N.Desai, J.D.Talati and K. Shah, Neesha,*Ind.J.Chem.Sec.A: Inorg. Bio-inorg. Phys. Theoret.Analyt. Chem.,* 42(2003) 3027.
24. N. Mani, S.I. Venkatakrishna and L. Bahadur, *J.Electrochem. Soc. Ind.* 52(2003) 23.
25. M.N.S. Desai, Y.K. Agrawal, J.D Talati, M.D. Shah, and N.K. Shah, *Corros.Sci.,* 46(2004) 633.
26. E.E.Foad, S.M.El-Sherbini, S.Abdel Wahab, and M. Deyab, *Mater. Chem.Phys.,* 89(2005) 183.
27. M.M.Mennucci, E.P.Banczek, P.R.P.Rodrigues, I Costa, *Cement & Concrete Composites* 31 (2009) 418
28. J.D. Talati, M.N. Desai, Shah and N.K. *Mater. Chem. Phys* . 93(2005) 54.
29. N.K. Shah, M.N. Desai, J.D. Talati, *Proceedings of 10th European Symposium on Corrosion and Scale Inhibitors,* Ferrara, Italy.(2005) 873
30. A.S. Fouda, F.M. El-Taweel, and M. Elgamil, Int. *J. Electrochem. Sci.,* 12(2017) 11397.
31. M. Abdallah, M.M. Salem, B.A. AL Jahdaly, M.I. Awad, E. Helal, and A.S. Fouda, *Int. J. Electrochem. Sci.,* 12(2017) 4543.
32. M.A. Deyab, A.S. Fouda, M.M. Osman, and S. Abdel-Fattah, *RSC Adv.,* 7(2017) 45232.
33. A.S. Fouda, T. Fayed, M.A. Elmorsi and M. Elsayed, *J. Bio. Tribo. Corros.,* 3(2017)1.
34. G.N. Mu, T.P. Zhao, M. Liu, T. Gu, *Corrosion*, 52 (1996) 853
35. R.G.Parr, D.A.Donnelly, M. Levy, M. Palke, *J. Chem. Phys.,* 68(1978) 3801
36. J. Aljourani, K. Raeissi, M.A. Golozar, *Corros. Sci.,* 51 (2009) 1836
37. H. Amar, A. Tounsi, A. Makayssi, A. Derja, J. Benzakour, A. Outzourhit, *Corros.Sci.*,49 (2007) 2936
38. M.A. Migahed, E.M.S. Azzam, S.M.I. Morsy, *Corros.Sci.,* 51 (2009) 1636
39. E.Bayol, K., Kayakirilmaz, M., Erbil, *Mater.Chem.Phys.,* 104 (2007) 74
40. J. C. Bessone Mayer, K. Kuttner, W. J. Lorenz, *Electrochim. Acta,* 28 (1983) 171
41. E.A.Noorand, A.H.Al-Moubaraki, *Mater.Chem.Phys.,* 110 (2008) 145
42. H. Ashassi-Sorkhabi, N., Ghalebsaz-Jeddi, *Mater.Chem.Phys.* 92(2005)480
43. A. A. El-Awady, B. Abd El-Nabey and S. G. Aziz, *Electrochem. Soc.,* 139 (1992) 2149.
44. S. L. F. A., Da Costa and S. M. L., Agostinho, *Corros. Sci.,* 45 (1989) 472
45. A.S. Fouda, A.A. Al-Sarawy, E.E. El-Katori, *Desalination,* 201 (2006) 1
46. G. Gao, C. Liang, *Electrochem. Acta,* 52 (2007) 4554.

47. S. Martınez, *Mater. Chem. Phys.*, 77 (2002) 97.
48. Ashish Kumar Singh and M.A. Quraishi*, Corros. Sci.,* 52 (2010) 1529
49. E. Ech-chihbi, R. Salim, H. Oudda, A. Elaatiaoui, Z.Rais, A. Oussaid, F.El Hajjaji, B.Hammouti, H. Elmsellem, M.Taleb, *Der Pharm. Chem.,* 8(13) (2016) 214
50. A.Ghazoui, R.Saddik, N.Benchat, B.Hammouti, M.Guenbour, A. Zarrouk, M.Ramdani. *Der Pharm. Chem.,* 4(1) (2012)352
51. A. Ghazoui , R.Saddik, B.Hammouti, A.Zarrouk, N.Benchat, M.Guenbour, S.S.Al-Deyab, I.Warad, *Res. Chem. Intermed.,* 39 (2013)2369
52. R.Salghi, A.Anejjar, O.Benali, S.S.Al-Deyab, A.Zarrouk, M.Errami, B.Hammouti, N.Benchat, *Int. J. Electrochem. Sci.,* 9 (2014)3087
53. K. Bouhrira, F.Ouahiba, D.Zerouali, B.Hammouti, M.Zertoubi, N.Benchat, *J. Chem.,* 7(S1) (2010) S35
54. A.Ghazoui, R.Saddik, N.Benchat, B.Hammouti, M.Guenbour, A.Zarrouk, M.Ramdani, *Der Pharm. Chem.,* 4(1) (2012)352
55. R.Salim, E.Ech-chihbi, H.Oudda, Y.ELAoufir, F.El-Hajjaji, A.Elaatiaoui, A.Oussaid, B.Hammouti, H.Elmsellem, M.Taleb, *Der Pharm. Chem.,* 8(13)(2016)200