

ISOINDOLINE DERIVATIVES AS INHIBITORS FOR THE CORROSION OF C- STEEL IN HCL SOLUTION.

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ABSTRACT

The corrosion inhibition of C-steel in 2.0 M HCl solution by four newly synthesized isoindoline derivatives has been investigated using weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. Potentiodynamic polarization showed that these derivatives are mixed-type inhibitors. The percentage inhibition efficiency was found to increase with increasing the concentration of inhibitor and with decreasing temperature. The Temkin isotherm was found to provide an accurate description of adsorption behavior of the isoindoline derivatives. Some thermodynamic parameters were computed and discussed. The variation in inhibition efficiency depends on the type of functional group substituted in benzene ring. It was found that the presence of donating group (such as CH₃) better facilitates the adsorption of molecules on the surface than in the case with withdrawing groups (such as -H, -Br, and NO₂). The adsorption of these inhibitors is considerably enhanced by the addition of I⁻, SCN⁻ and Br⁻ due to synergistic effect. The data obtained from the three different methods are in good agreement.

Keywords: Isoindoline Derivatives- Corrosion Inhibitors – C- Steel

INTRODUCTION

Carbon steel is the major structural material in industry, the protection of steel against corrosion has attracted much attention. As most steels are generally stable in neutral and alkaline media, acidic environments are the major concern [Perry et al., (1997)]. Acid solutions are generally used for the removal of undesirable scale and rust in several industrial processes. Inhibitors are used in this process to control metal dissolution. Most of the well-known acid inhibitors are organic compounds containing O, S, and /or N atoms [Chetouani *et al.*, (2002); Bekkouch *et al.*, (1999) and Bouklah *et al.*, (2004)]. Although there are several studies on the corrosion inhibition effects of organic compounds in acidic solutions [Bentiss *et al.*, (2000); Popova *et al.*, (2003); Abdallah *et al.*, (2001); De Damborenea *et al.*, (1996); Mahmoud *et al.*, (2006); Ramesh *et al.*, (2004); Abdel Aal *et al.*, (2001); Mohamed *et al.*, (2000); Abd El-Rehim *et al.*, (1999) and Bentiss *et al.*, (2002)]. The inhibitive action is connected

with several factors including the structure and the charge distribution on the molecule, the number and the types of adsorption sites, and the nature of interaction between the molecule and the metal surface [Ebenso (2002)]. Corrosion inhibition occurs via adsorption of the organic molecule on the corroding metal surface following some known adsorption isotherms with the polar groups acting as active centers in the molecules. The resulting adsorption film acts as a barrier that isolates the metal from the corroding and efficiency of inhibition depends on the mechanical, structural and chemical characteristics of the adsorption layer formed under particular conditions [Fouda et al., (1986) and Abdallah et al., (2006)].

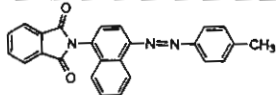
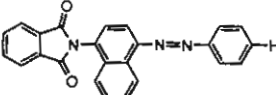
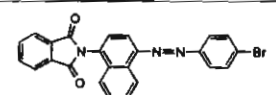
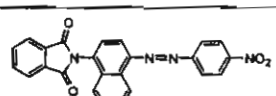
The aim of this work is to study the effect of some isoindoline derivatives as inhibitors for the corrosion of C- steel in 2M HCl solutions using weight loss, potentiodynamic polarization measurements and electrochemical impedance spectroscopy (EIS) techniques. These derivatives were selected because: availability, with large molecular size and containing three N and two O atoms.

EXPERIMENTAL METHODS

Materials and solutions:

Carbon steel used in this study has the following chemical composition by weight (wt%) V: 0.02%, Ti: 0.03%, P: 0.04%, S: 0.05%, Mn: 1.35%, C: 0.26%, Nb: 0.05% and the remainder is iron. Isoindoline derivatives were prepared as reported [Ameen (2005)]. Table (1) shows the name and the molecular structures of these compounds. The acid solutions were made from AR grade HCl (37 % Prolabo). An appropriate concentration of acid was prepared using bidistilled water. 10^{-3} M stock solutions from the investigated compounds were prepared by dissolving the appropriate weights of the used chemically pure solid compounds in absolute ethanol.

Table (1): Molecular structures of isoindoline derivatives.

Comp	Name	Structure	Molecular Weight
1	2(4(ptolyldiazeny)naphthalen-1-yl)isoindoline		363
2	2(4(phenyldiazenyl)naphthalen-1-yl)isoindoline		349
3	2-(4-((4-bromophenyl)diazenyl)naphthalen-1-yl)isoindoline		428
4	2-(4-((4-nitrophenyl)diazenyl)naphthalen-1-yl)isoindoline		394

Weight loss method:

Three parallel C- steel sheets of 20 mm x 20 mm x 2 mm were abraded with different grades of emery paper up to 1200 grit and then washed with bidistilled water and acetone. After weighing accurately, the specimens were immersed in 100 ml HCl solution with and without addition of different concentrations of inhibitors. After 3 hrs, the specimens were taken out, washed, dried, and weighed accurately. The average weight loss of the three parallel C- steel sheets could be obtained at required temperature. The inhibition efficiency (IE) and the degree of surface coverage (θ) of the investigated inhibitors on the corrosion of C-steel were calculated as follows [Oguzie (2005)]:

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

$$\theta = [(W_o - W) / W_o] \quad (2)$$

where W_o and W are the values of the average weight loss in the absence and presence of the inhibitor, respectively.

Electrochemical measurements:

The experiments were carried out potentiodynamically in a thermostated three electrode cell. Platinum foil was used as counter electrode and a saturated calomel electrode (SCE) coupled to a fine Luggin capillary as the reference electrode.

The working electrode was in the form of a square cut from C-steel under investigation and was embedded in a Teflon rod with an exposed area of 1 cm². This electrode was immersed in 100 ml of a test solution for 30 min until a steady state open-circuit potential (E_{ocp}) was attained. Potentiodynamic polarization was conducted in an electrochemical system (Gamry framework instruments version 3.20) which comprises a PCI/ 300 potentiostat, controlled by a computer recorded and stored the data. The potentiodynamic curves were recorded by changing the electrode potential from -1.0 to 0.0 V versus SCE with scan rate of 5 mV/s. All experiments were carried out in freshly prepared solution at constant temperature (25 ± 1 °C) using a thermostat. IE% and the degree of surface coverage (θ) were defined as:

$$IE \% = [(i_{corr} - i_{corr(inh)}) / i_{corr}] \times 100 \quad (3)$$

$$\theta = [(i_{corr} - i_{corr(inh)}) / i_{corr}] \quad (4)$$

where i_{corr} and $i_{corr(inh)}$ are the uninhibited and inhibited corrosion current density values, respectively, determined by extrapolation of Tafel lines.

The electrochemical impedance spectroscopy (EIS) spectra were recorded at open circuit potential (OCP) after immersion the electrode for 15 min in the test solution. The ac signal was 5 mV peak to peak and the frequency range studied was between 100 kHz and 0.2 Hz. All Electrochemical impedance experiments were carried out using Potentiostat/Galvanostat/ Zra analyzer (Gamry PCI 300/4). A personal computer with EIS300 software and E_{chem} Analyst 5.21 was used for data fitting and calculating.

The inhibition efficiency (IE %) and the surface coverage (θ) of the used inhibitors obtained from the impedance measurements were calculated by applying the following relations:

$$IE\% = \left(1 - \frac{R_{ct}^0}{R_{ct}}\right) \times 100 \quad (5)$$

$$\theta = \left(1 - \frac{R_{ct}^0}{R_{ct}}\right) \quad (6)$$

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

RESULTS AND DISCUSSION

3.1. Weight loss measurements:

Fig.(1) represents the weight loss-time curves in the absence and presence of different concentrations of compound (I). Similar curves were obtained for other inhibitors (not shown). Table (2) collects the values of surface coverage, inhibition efficiency and corrosion rate obtained from weight loss measurements in 2.0 M HCl at 30 ± 0.1 °C. The results of this Table show that the presence of inhibitors reduce the corrosion rate of C- steel in HCl and hence, increase the inhibition efficiency.

Table (2): Surface coverage (θ) inhibition efficiency (IE) and corrosion rate (C_R)(mg/cm²min) in the presence of isoindoline derivatives as determined from weight loss method at 30°C.

Conc.	Compound (1)			Compound (2)			Compound (3)			Compound (4)		
	θ	IE %	C.R.	θ	IE%	C.R.	θ	IE%	C.R.	θ	IE%	C.R.
1×10^{-4}	0.577	57.7	4.16	0.546	54.6	4.46	0.510	51.0	4.82	0.485	48.5	5.06
3×10^{-4}	0.625	62.5	3.69	0.594	59.4	3.99	0.563	56.3	4.29	0.523	52.3	4.68
5×10^{-4}	0.662	66.2	3.32	0.636	63.6	3.58	0.605	60.5	3.88	0.571	57.1	4.22
7×10^{-4}	0.700	70.0	2.95	0.679	67.9	3.15	0.653	65.3	3.40	0.624	62.4	3.70
9×10^{-4}	0.746	74.6	2.50	0.725	72.5	2.70	0.705	70.5	2.90	0.661	66.1	3.33
11×10^{-4}	0.815	81.5	1.82	0.784	78.4	2.12	0.748	74.8	2.48	0.703	70.3	2.91

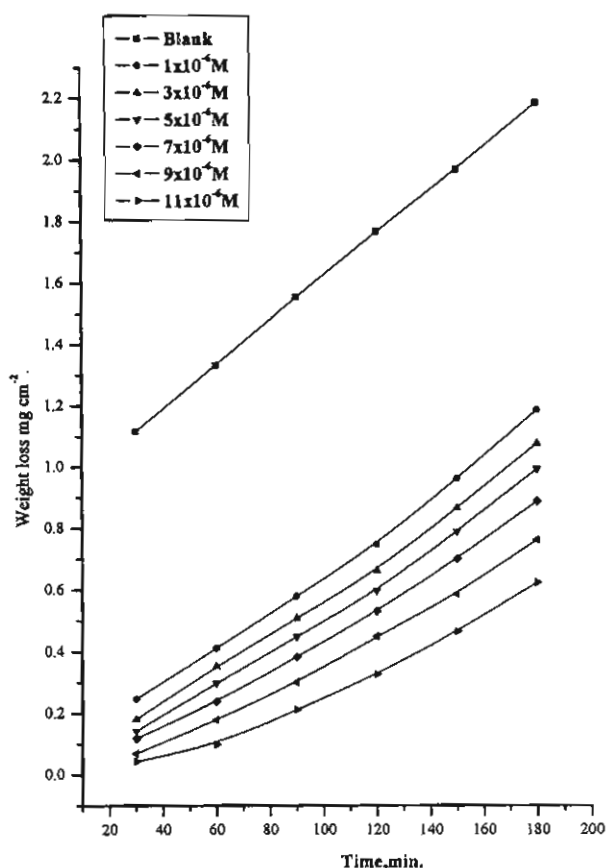


Fig.1. Weight loss time curves for the dissolution of C-steel in absence and presence of different concentrations of compound(1) at 30°C.

3.1.1. Adsorption isotherm

One of the most convenient ways of expressing adsorption quantitatively is by deriving the adsorption isotherm that characterizes the metal/inhibitor/ environment system [Szkłarska-Smiałowska (1991)]. The surface coverage (θ) values were tested graphically to allow fitting of a suitable adsorption isotherm. The plot of θ versus $\log C$ Fig. (2) yielded a straight line clearly proving that the adsorption of these inhibitor from 2.0 M HCl solution on C-steel surface obeys Temkin adsorption isotherm, where:

$$\ln KC = a \theta \tag{7}$$

where, a is the molecule interaction parameters, C is the inhibitor concentration in the bulk solution and K is the equilibrium constant of the adsorption process which related to the standard free energy (ΔG_{ads}°) of adsorption by the following equation [Khamis (1990)]:

$$= 1/55.5 \exp [-\Delta G_{ads}^\circ/RT] \tag{8}$$

Where, R is the universal gas constant and T is the absolute temperature.

From the results of Table (3), the strong correlation ($r = 0.99$) for the Temkin adsorption isotherm plot for all additives confirms the validity of this approach. The largest negative values of ΔG_{ads}° indicate that this investigated isoindoline derivatives are strongly adsorbed onto the C-steel surface, blocking the reaction sites and reduces the available area for further corrosion. We found that (a) is similar for all inhibitor and k decreases from inhibitor 1 to 4 [Talati *et al.*, (1983)].

Table (3): Inhibitor binding constant (K), free energy of binding (ΔG_{ads}°), number of active sites (1/y) and later interaction parameter (a) for the isoindoline derivatives for the corrosion of C- steel in 2 M HCl at 30 °C.

Inhibitors	Temkin		
	a	$K \times 10^{-8}$ mol L^{-1}	$-\Delta G_{ads}^{\circ}$ kJ mol^{-1}
Compound (1)	11.3	4.97	60.6
Compound (2)	11.3	3.49	59.7
Compound (3)	11.2	2.39	58.7
Compound (4)	11.2	1.79	58.0

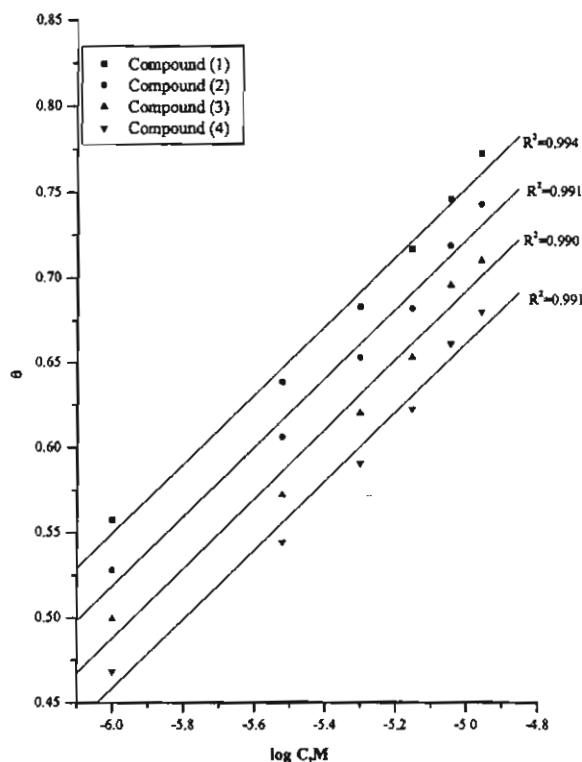


Fig. 2. Temkin adsorption isotherm plotted as (θ) vs $\log C$ of compounds 1, 2, 3 and 4 for corrosion of C-steel in 2M HCl solution at 30°C.

3.1.2. Effect of temperature:

To investigate the mechanism of inhibition and to determine the activation energy of corrosion process, weight loss curves of C- steel in 2.0 M HCl were studied at various temperatures (30–50°C) in the absence and presence of different concentrations of investigated compounds. These inhibitors retard the corrosion process at lower temperatures [Laque *et al.*, (1963)] whereas the inhibition are considerably decreased at elevated temperatures. The increasing of the corrosion rate with increasing the temperature is suggestive of physical adsorption of the investigated inhibitors on C-steel surface. Fig.(3) represents the Arrhenius plots of natural logarithm of corrosion rate versus $1/T$, for C-steel in 2.0 M HCl solution, in absent and presence of 7×10^{-6} M inhibitors. Straight lines with confidents of correlation higher to 0.99 are obtained. The values of slopes of these straight lines permit the calculation of the activation energy, E_a^* according to:

$$k = A \exp (-E_a^*/RT) \quad (9)$$

where k is the corrosion rate, A is the pre-exponential factor, E_a^* is the apparent activation energy, R is the universal gas constant and T is the absolute temperature.

The values of E_a^* are given in Table (4). The results of Table (4) revealed that, the values of E_a^* were increased by increasing the concentration of the investigated inhibitors indicating the dissolution of C-steel under these conditions is activation controlled and also, indicates the energy barrier of the corrosion reaction increases in the presence of these additives. Similar results were obtained by other authors [Fouda *et al.*, (2005); Fouda *et al.*, (2009) and Riggs *et al.*, (1967)]. The higher values of E_a^* are good evidence for the strong adsorption of compound (1) on C-steel surface. Also, Free energy of activation (ΔG^*) were calculated by applying the transition state equation [Banerjee (1985)]:

$$\Delta G^* = RT \left[\ln \frac{KT}{h} - \ln (\text{corrosion rate}) \right] \quad (10)$$

where, h is Planck's constant and K is Boltzmann's constant. The enthalpy of activation (ΔH^*) and the entropy of activation (ΔS^*) were calculated by applying the following equations [Zhao *et al.*, (1999)]:

$$\Delta H^* = E_a^* - RT \quad (11)$$

$$\Delta S^* = \frac{\Delta H^* - \Delta G^*}{T} \quad (12)$$

The values of (ΔH^*) are positive and higher in the presence of the inhibitors than in its absence. This implies that energy barrier of the corrosion reaction in the presence of the investigated compounds increases and indicates the endothermic

behavior of the corrosion process. On the other hand ΔS^\ddagger values are lower and have negative values in presence of the additives, this means that addition of these compounds cause a decrease in the disordering in going from reactants to the activated complexes [Gomma *et al.*, (1995) and Cahskan *et al.*, (2000)].

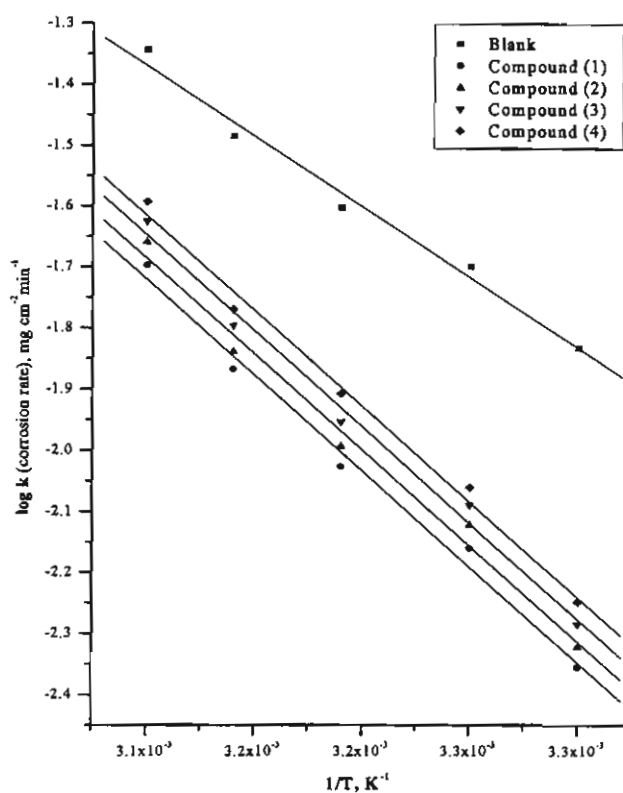


Fig. 3. Arrhenius plots ($\log K$ vs $1/T$) for C-steel in 2M HCl in absence and presence of 7×10^{-4} M of compounds 1, 2, 3 and 4.

Table (4): Activation parameters of the dissolution of C-steel in 2.0 M HCl in the absence and presence of 7×10^{-6} M different inhibitors.

Compound	Activation Parameters		
	E_a^\ddagger , kJ mol ⁻¹	ΔH^\ddagger , kJ mol ⁻¹	$-\Delta S^\ddagger$, J mol ⁻¹ K ⁻¹
Free acid	44.312	41.77	142.37
Compound (1)	60.01	59.24	101.23
Compound (2)	58.16	57.76	99.67
Compound (3)	56.43	56.26	97.67
Compound (4)	53.26	53.32	95.08

3.1.3. Synergistic effect:

The corrosion behavior of C-steel in 2M HCl solution in presence of 1×10^{-3} M KBr, KSCN and KI in presence of different concentrations of the investigated inhibitors was studied. The values obtained are summarized in Table 5. It can be seen from Table 5 that the addition of 1×10^{-3} M of these anions inhibits the corrosion of C-steel to a large extent and by increasing the concentration of additives, the percentage inhibition increases. This can be interpreted according to Schmitt and Bedbur [Schmitt *et al.*, (1985)] which proposed two types of joint adsorption namely competitive and cooperative. In competitive adsorption, anions and cations are adsorbed at different sites on the electrode surface, and in case of cooperative adsorption, the anions are chemisorbed on the electrode surface and cations are adsorbed on a layer of anions, apart from the adsorption on the surface directly.

From the data of Table 5 it is seen that KI would be considered as one of the effective anions for synergistic action with respect to the investigated salts. The net increment of inhibition efficiency shows a synergistic effect of these anions with investigated compounds. The inhibition efficiency in presence of these anions decreases the most concentration of the investigated is in the order: KI > KSCN > KBr [Khamis *et al.*, (2000) and El-Gaber *et al.*, (2008)]. The results suggested that the presence of these anions stabilizes the adsorption of the investigated compounds on C-steel surface and improved the inhibition efficiency of these derivatives.

Table (5): Inhibition efficiency of investigated derivatives for the corrosion of C-steel in 2.0 M HCl containing 1×10^{-6} M KI, KSCN and KBr from weight loss measurements.

Salt	Conc. M	Compound (1)			Compound (2)			Compound (3)			Compound (4)		
		θ	IE%	C.R.	θ	IE%	C.R.	θ	IE%	C.R.	θ	IE%	C.R.
KI	1×10^{-6}	0.676	67.60	2.61	0.643	64.29	2.88	0.625	62.49	3.02	0.581	58.10	3.38
	3×10^{-6}	0.705	70.47	2.38	0.672	67.18	2.64	0.644	64.44	2.86	0.622	62.24	3.04
	5×10^{-6}	0.734	73.39	2.14	0.701	70.09	2.41	0.673	67.35	2.63	0.652	65.15	2.81
	7×10^{-6}	0.772	77.21	1.84	0.738	73.77	2.11	0.710	71.02	2.33	0.688	68.83	2.51
	9×10^{-6}	0.807	80.70	1.55	0.773	77.25	1.83	0.744	74.38	2.06	0.715	71.50	2.30
	11×10^{-6}	0.829	82.87	1.38	0.806	80.57	1.57	0.783	78.26	1.75	0.754	75.40	1.98
KSCN	1×10^{-6}	0.640	63.95	2.76	0.622	62.22	2.89	0.593	59.32	3.11	0.553	55.28	3.42
	3×10^{-6}	0.677	67.74	2.47	0.666	66.58	2.56	0.643	64.27	2.73	0.596	59.64	3.09
	5×10^{-6}	0.720	72.03	2.14	0.702	70.23	2.28	0.685	68.49	2.41	0.639	63.87	2.76
	7×10^{-6}	0.761	76.13	1.83	0.749	74.92	1.92	0.725	72.49	2.10	0.683	68.25	2.43
	9×10^{-6}	0.803	80.28	1.51	0.785	78.46	1.65	0.760	76.03	1.83	0.718	71.79	2.16
	11×10^{-6}	0.853	85.33	1.12	0.834	83.43	1.27	0.809	80.90	1.46	0.765	76.47	1.80
KBr	1×10^{-6}	0.637	63.74	2.38	0.603	60.33	2.82	0.562	56.25	3.11	0.522	52.16	3.40
	3×10^{-6}	0.678	67.83	2.29	0.644	64.42	2.53	0.603	60.33	2.82	0.562	56.25	3.11
	5×10^{-6}	0.716	71.60	2.02	0.689	68.88	2.21	0.648	64.79	2.50	0.614	61.38	2.75
	7×10^{-6}	0.753	75.27	1.76	0.725	72.54	1.95	0.685	68.46	2.24	0.664	66.41	2.39
	9×10^{-6}	0.797	79.67	1.45	0.763	76.26	1.69	0.729	72.86	1.93	0.701	70.13	2.12
	11×10^{-6}	0.835	83.55	1.17	0.801	80.14	1.41	0.774	77.42	1.61	0.740	74.01	1.85

Isoindoline derivatives are organic compounds containing nitrogen and oxygen, which contain unshared electron pairs. In strong acidic solutions these derivatives may be protonated, leading to positive charge in molecule. It is also known that C-steel surface has positive charge in acid media [Popova *et al.*, (2007)], thus it is difficult for the positively charged isoindoline derivatives to approach the positively charged C-steel surface, due to the electrostatic repulsion, and this is why these derivatives can not act as excellent inhibitors for C-steel in 2 M HCl solution without anions. In presence of Γ^- , SCN^- and Br^- ions, these anions adsorbed on C-steel surface and makes the surface negatively charged by means of electrostatic attraction, after that protonated isoindoline derivatives are easily reached the surface of C-steel metal. This process is similar to the so-called phenomenon of anion-induced adsorption [Fishtik *et al.*, (1984)]. This ion-pair interaction consequently increases the surface coverage thereby reducing metal dissolution. The order of investigated compounds remains unchanged, as before.

3.2. Potentiodynamic polarization measurements:

Fig.(4) shows the potentiodynamic polarization curves for C- steel without and with different concentrations of compound (1) at 25 °C. Similar curves were obtained for other compounds. The obtained electrochemical parameters; cathodic (β_c) and anodic (β_a) Tafel slopes, open circuit potential (E_{OC}), corrosion potential (E_{corr}), corrosion current density (i_{corr}), corrosion rate (C_R) and polarization resistance (R_p) were obtained and listed in Table (6). Table (6) shows that i_{corr} decreases by adding the additives and by increasing their concentration. In addition, E_{corr} does not change obviously. Also β_a and β_c do not change markedly, which indicates that the mechanism of the corrosion reaction of C-steel does not change. Fig. 4 clearly shows that both anodic and cathodic reactions are inhibited, which indicates that investigated compounds act as mixed-type inhibitors [34]. The inhibition achieved by these compounds decreases in the following order: Compound (1) > Compound (2) > Compound (3) > Compound (4).

The degree of surface coverage, θ at constant potential is given by the following relation [Fisher (1960) and Mu *et al.*, (2006)] from the polarization resistance:

$$\theta = [1 - (R_{p(\text{free})} / R_{p(\text{inh})})] \quad (13)$$

where $R_{p(\text{free})}$ and $R_{p(\text{inh})}$ are the polarization resistance of uninhibited and inhibited solutions, respectively. The percentage of inhibition efficiency, IE%, at each concentration was calculated using the equation:

$$\text{IE \%} = [1 - (R_{p(\text{free})} / R_{p(\text{inh})})] \times 100 \quad (14)$$

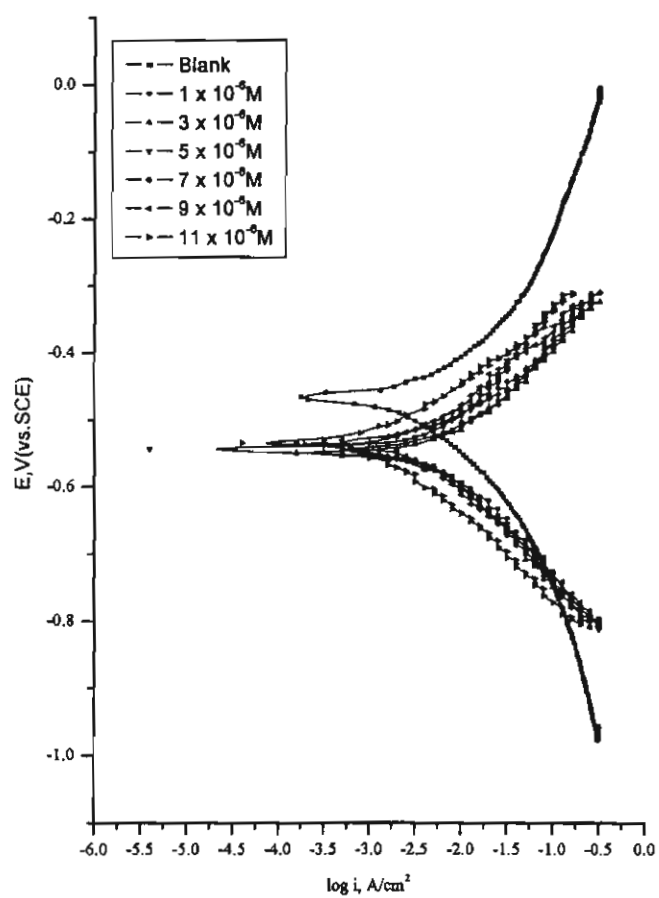


Fig. (4): Galvanostatic polarization curves of C-steel in 2M HCl in absence and presence of different concentrations of compound (1) at 30°C.

Table (6): Effect of concentration of compounds 1, 2, 3 and 4 on the electrochemical parameters of C- steel in 2.0 M HCl at 25 °C.

		$E_{cor}(mV)$	$i_{cor}(mA)$	% IE	$\beta_c, mV/dec$	$\beta_a, mV/dec$	$R_p, \Omega cm^2$	% IE
	Blank	-466.7	8.201	—	311.1	282.7	7.844	—
1	$1 \times 10^{-6}M$	-554.6	7.914	3.5	169.9	146.6	7.433	5.24
	$3 \times 10^{-6}M$	-548.6	6.891	15.97	168.6	143.8	6.523	16.84
	$5 \times 10^{-6}M$	-544.5	5.645	31.17	158.6	131.7	5.292	32.54
	$7 \times 10^{-6}M$	-543.9	4.728	42.35	153.5	132.4	4.490	42.76
	$9 \times 10^{-6}M$	-551.7	4.014	51.05	136.9	122.8	3.709	52.72
	$11 \times 10^{-6}M$	-535.4	3.587	56.27	146.0	110.1	3.284	58.13
2	$1 \times 10^{-6}M$	-551.3	7.673	6.44	164.9	146.2	7.275	7.25
	$3 \times 10^{-6}M$	-549.8	6.818	16.86	162.3	133.8	6.437	17.94
	$5 \times 10^{-6}M$	-549.9	5.469	33.31	167.1	128.7	5.082	35.21
	$7 \times 10^{-6}M$	-543.8	4.561	44.38	155.9	129.6	4.227	46.11
	$9 \times 10^{-6}M$	-549.9	3.938	51.98	134.4	118.5	3.651	53.46
	$11 \times 10^{-6}M$	-524.8	2.148	73.81	131.6	100.2	1.893	75.87
3	$1 \times 10^{-6}M$	-545.1	7.316	10.79	162.2	146.5	6.906	11.96
	$3 \times 10^{-6}M$	-549.6	6.282	23.39	161.0	134.6	5.843	25.51
	$5 \times 10^{-6}M$	-543.1	4.933	39.85	146.6	160.4	4.622	41.08
	$7 \times 10^{-6}M$	-536.5	4.390	46.46	152.0	118.4	4.298	45.21
	$9 \times 10^{-6}M$	-534.6	3.662	55.35	139.2	122.8	3.594	54.18
	$11 \times 10^{-6}M$	-533.7	1.426	82.61	126.1	107.5	1.206	84.62
4	$1 \times 10^{-6}M$	-541.9	8.078	1.5	156.2	161.8	7.557	3.66
	$3 \times 10^{-6}M$	-544.3	6.993	14.73	163.2	133.8	6.556	16.42
	$5 \times 10^{-6}M$	-553.9	5.639	31.24	144.9	135.0	5.212	33.56
	$7 \times 10^{-6}M$	-545.0	4.826	41.15	151.3	121.0	4.600	41.36
	$9 \times 10^{-6}M$	-549.8	4.104	49.96	137.2	121.5	4.019	48.76
	$11 \times 10^{-6}M$	-542.4	3.641	55.6	147.4	112.9	3.454	55.97

Also, the results of θ and IE% were calculated using i_{corr} values. The percentage inhibition efficiencies (IE %) calculated from i_{corr} and R_p of the investigated compounds are given in Table (7). An inspection of the results obtained from this Table reveals that, the presence of different concentrations of the additives reduces the anodic and cathodic current densities and the polarization resistance. This indicates that the inhibiting effects of the investigated compounds. The order of decreasing inhibition efficiency from i_{corr} and R_p is: Compound (1) > Compound (2) > Compound (3) > Compound (4). The values of IE% determined from the two methods (Table 7) are very close to each other indicating the validity of the obtained results.

Table (7): The inhibition efficiencies of different concentrations of compounds 1, 2, 3 and 4 for the corrosion of C-steel in 2.0 M HCl at 25 °C as obtained from potentiodynamic polarization measurements.

	Compound (1)		Compound (2)		Compound (3)		Compound(4)	
	IE%, i_{corr}	IE%, R_p	IE%, i_{corr}	IE%, R_p	IE%, i_{corr}	IE%, R_p	IE%, i_{corr}	IE%, R_p
1×10^{-6}	3.50	5.24	6.44	7.25	10.79	11.96	1.50	3.66
3×10^{-6}	15.97	16.84	16.86	17.94	23.39	25.51	14.73	16.42
5×10^{-6}	31.17	32.54	33.31	35.21	39.85	41.08	31.24	33.56
7×10^{-6}	42.35	42.76	44.38	46.11	46.46	45.21	41.15	41.36
9×10^{-6}	51.05	52.72	51.98	53.46	55.35	54.18	49.96	48.76
11×10^{-6}	56.27	58.13	73.81	75.87	82.61	84.62	55.6	55.97

3. Electrochemical Impedance Spectroscopy (EIS):

The corrosion of C- steel in 2.0 M HCl in the presence of the investigated compounds was investigated by EIS method at 25 °C after 20 min immersion. Nyquist plots in the absence and presence of investigated compound (1) are presented in Fig. 5. Similar curves were obtained for other inhibitors. It is apparent that all Nyquist plots show a single capacitive loop, both in uninhibited and inhibited solutions. The impedance data of C- steel in 2.0 M HCl are analyzed in terms of an equivalent circuit model (Fig. 6) which includes the solution resistance R_s and the double layer capacitance C_{dl} which is placed in parallel to the charge transfer resistance R_{ct} [Sekine *et al.*, (1992)] due to the charge transfer reaction. For the Nyquist plots it is obvious that

low frequency data are on the right side of the plot and higher frequency data are on the left. This is true for EIS data where impedance usually falls as frequency rises (this is not true for all circuits). The capacity of double layer (C_{dl}) can be calculated from the following equation:

$$C_{dl} = \frac{1}{2\pi f_{max} R_{ct}} \quad (15)$$

where f_{max} is maximum frequency. The parameters obtained from impedance measurements are given in Table (8). It can be seen from Table 8 that the values of charge transfer resistance R_{ct} increase with inhibitor concentration [Larabi *et al.*, (2006)]. In the case of impedance studies, IE% increases with inhibitor concentration in the presence of investigated inhibitors and the IE% of these investigated inhibitors is as follows: Compound (1) > compound (2) > compound (3) > compound (4).

The impedance study confirms the inhibiting characters of these compounds obtained from potentiodynamic polarization and weight loss methods. It is also noted that the (C_{dl}) values tend to decrease when the concentration of these compounds increases. This decrease in (C_{dl}), which can result from a decrease in local dielectric constant and/or an increase in the thickness of the electrical double layer, suggests that these compounds function by adsorption at the metal/solution interface [Lagrenée *et al.*, (2002)]. The inhibiting effect of these compounds can be attributed to their parallel adsorption at the metal solution interface. The parallel adsorption is owing to the presence of one or more active center for adsorption.

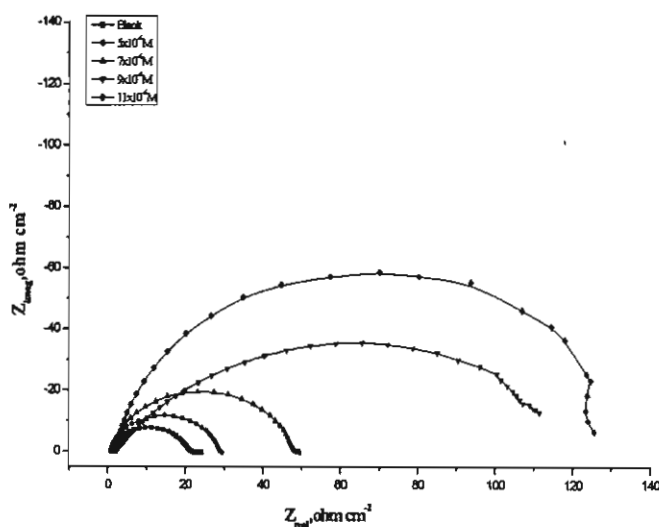


Fig (5): The Nyquist plots for corrosion of C-Steel in 2.0 M HCl in absence and presence of different concentrations of compound (1) at 25° C

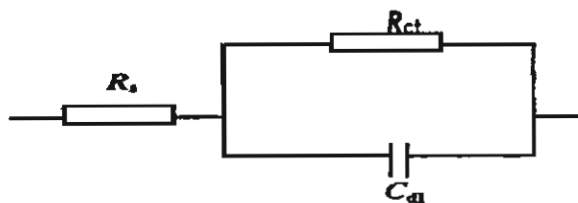


Fig. (6): The equivalent circuit model used to fit the experimental results.

Table (8): Electrochemical kinetic parameters obtained by EIS technique for the corrosion of C-steel in 2.0 M HCl at different concentrations of compounds 1, 2, 3 and 4 at 25 °C.

Compound	Conc., M	C_{dl} $\mu\text{F cm}^{-2}$	R_{ct} Ohm cm^2	θ	IE%
	Blank	97.46	18.82	---	---
1	5×10^{-6}	95.42	26.32	0.285	28.5
	7×10^{-6}	93.31	43.68	0.569	56.9
	9×10^{-6}	89.80	84.98	0.779	77.9
	11×10^{-6}	85.80	121.40	0.845	84.5
2	5×10^{-6}	94.67	24.05	0.217	21.7
	7×10^{-6}	92.51	39.21	0.507	50.7
	9×10^{-6}	88.70	79.07	0.762	76.2
	11×10^{-6}	84.94	109.50	0.828	82.8
3	5×10^{-6}	93.77	23.52	0.200	20.0
	7×10^{-6}	91.44	38.21	0.507	50.7
	9×10^{-6}	87.44	76.03	0.752	75.2
	11×10^{-6}	83.38	99.63	0.811	81.1
4	5×10^{-6}	93.00	22.75	0.173	17.3
	7×10^{-6}	90.10	33.80	0.443	44.3
	9×10^{-6}	86.63	61.15	0.692	69.2
	11×10^{-6}	82.07	92.44	0.796	79.6

4. Chemical structure and corrosion inhibition:

Inhibition efficiency of the carbon steel corrosion in 2.0 M HCl solution by isoindoline derivatives using the above techniques was found to depend on the number of adsorption active sites in the molecule and their charge density, molecular size and stability of these derivatives in acidic solutions [Khamis *et al.*, (1991)]. The inhibition effect of these compounds is attributed to the adsorption of the inhibitor molecules on the metal surface. The adsorption is assumed to take place mainly through the nitrogen atom in organic compounds (active centers).

Skeletal representation of the mode of adsorption of the isoindoline derivatives is shown in Fig. (7) and clearly indicates the adsorption centers. From the above sequence of IE %, it is clear that the compound 1 is more efficient inhibitor for corrosion of C-steel in 2.0 M HCl solution. This is most probably due to, the presence of CH₃ group which is an electron donating group with negative Hammett constant ($\sigma = -0.17$), Also this group will increase the electron charge density on the molecule. Compound (2) with Hammett constant ($\sigma = 0$) comes after compound (1) in IE %, because H-atom does not affect the electron charge density on the molecule. Compound (3) comes after compound (2) in IE %. This is due to p- Br atom is electron withdrawing group with positive Hammett constants ($\sigma_{Br} = +0.23$), this group will withdraw the electron charge density on the molecules and hence less inhibition efficiency. Compound (4) is the least efficient compound. This is due to p- NO₂ group is electron withdrawing group with positive Hammett constants ($\sigma_{NO_2} = + 0.78$) this group will decrease the electron charge density on the molecules and hence less inhibition efficiency was observed. The order of the inhibition efficiency of compounds 3 & 4 runs parallel to their σ values.

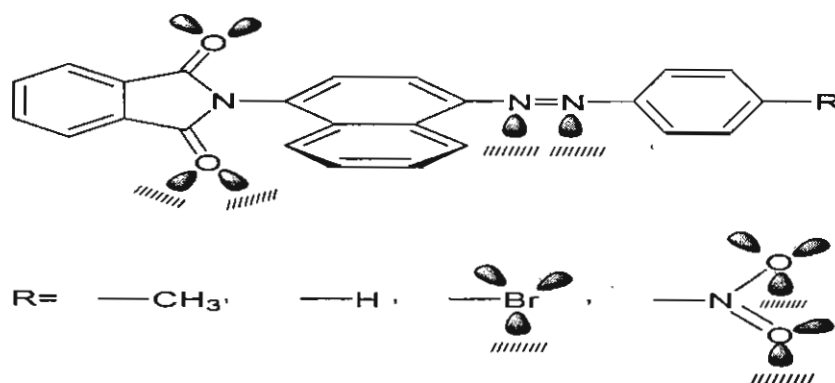


Fig. (7): Skeletal representations of the mode of adsorption of the investigated compounds.

CONCLUSIONS

Isoindoline derivatives show good corrosion inhibition property against C-steel corrosion in HCl solution. Inhibition efficiencies are related to concentration, temperature and chemical structure of the investigated isoindoline derivatives. Generally, isoindoline derivatives inhibition efficiencies increase when concentration increases and temperature decreases. Presence of aromatic ring and hetero atom such as nitrogen atom on the isoindoline structure causes a significant increase in inhibition efficiency. All investigated compounds affected both anodic and cathodic reactions, so they are classified as mixed type inhibitors. Adsorption of these derivatives on the C-steel surface obeys Temkin adsorption isotherm. EIS measurements clarified that the corrosion process was mainly charge transfer controlled and no change in the corrosion mechanism occurred due to the inhibitor addition to acidic solutions.

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مشتقات الازواندولين كمثبطات التآكل الصلب الكربوني في محلول حمض الهيدروكلوريك

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تم دراسه تثبيط تآكل الصلب الكربوني في ٢ مولر حمض الهيدروكلوريك باستخدام اربعة مشتقات من الازواندولين باستخدام طريقه فقد الوزن والاستقطاب البتتشيوديناميكي والمعاقه الكهربيه. وقد دلت نتائج الاستقطاب البتتشيوديناميكي ان هذه المركبات تعمل كمثبطات مختلطه وان نسبه الكفاءه التثبيطيه لهذه المركبات تزداد بزياده التركيز و تقل بارتفاع درجة الحراره وقد وجد ان هذه المشتقات تدمص على سطح الصلب الكربوني تابعه ايزوثرم تمكين وقد تم حساب بعض الدوال الترموديناميكيه لعملية التآكل وقد وجد ان كفاءه التثبيط تعتمد على المجموعات المستبدله في الجزيئات وقد تم دراسه تأثير بعض الايونات على عملية التآكل.