Determination of the Thermodynamic Parameters, Characterizing the Adsorption and Inhibitive Properties of some 3-phenyl-2-thioxo- 4-thiazolidinone Derivatives

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Abstract— The corrosion inhibition of C-steel in 1 M H_2SO_4 solution by five newly synthesized 3-phenyl-2-thioxo-4-thiazolidinone 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 Frumkin isotherm was found to provide an accurate description of adsorption behavior of the 3-phenyl-2-thioxo-4-thiazolidinone 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 OCH_3) better facilitates the adsorption of molecules on the surface than in the case with withdrawing groups (such as Cl and NO_2). The data obtained from the three different methods are in good agreement.

Keywords —Thermodynamic parameters, Corrosion inhibition, EIS, 4-thiazolidinone derivatives.

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1 INTRODUCTION

Carbon steel is the major structural material in industry, the protection of steel against corrosion has attracted. As most steels are generally stable in neutral and alkaline media, acidic environments are the major concern [1]. Acid solutions are generally used for the removal of undesirable scale and rust in several Petrolum 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 [2-5]. Although there are several studies on the corrosion inhibition effects of organic compounds in acidic solutions [6-15]. 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 [16]. 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 [17,18].

The aim of this work is to study the effect of some 3-phenyl-2-thioxo-4-thiazolidinone derivatives as inhibitors for the corrosion of C- steel in 1 M H_2SO_4 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.

2 EXPERIMENTAL

2.1. COMPOSITION OF MATERIAL SAMPLES

Table (1): Chemical composition (wt %) of the carbon steel.

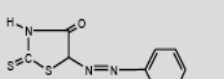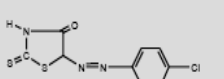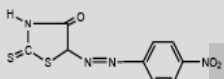| Element	C	Mn	P	Si	Fe
Weight (%)	0.200	0.350	0.024	0.003	Rest
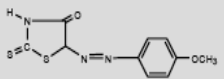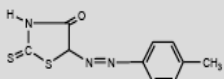
2.2. CHEMICALS

A- SULPHORIC ACID. (BDH GRADE)
B- ORGANIC ADDITIVES

3-phenyl-2-thioxo-4-thiazolidinone derivatives were prepared as reported [19]. Table (2) shows the name and the molecular structures of these compounds. The acid solutions were made from AR grade H_2SO_4. 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 (2): Molecular structures of 3-phenyl-2-thioxo-4-thiazolidinone derivatives.

Inhibitor	Structure	Name	Molecular weight
(I)		5-(4-methoxyphenylazo)-2-thioxothiazolidin-4-one	267.33
(II)		5-(4-methylphenylazo)-2-thioxothiazolidin-4-one	251.33
(III)		5-(4-phenylazo)-2-thioxothiazolidin-4-one	237.30
(IV)		5-(4-chlorophenylazo)-2-thioxothiazolidin-4-one	271.75
(V)		5-(4 -nitrophenylazo)-2-thioxothiazolidin-4-one	282.30

2.2. Methods used for corrosion measurements

2.2. Weight loss tests

C- steel sheets of 20 mm x 20 mm x 2 mm were

2.2. Weight loss tests

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 H_2SO_4 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 [20]:

$$\% \text{ IE} = [(W_o - W)/W_o] \times 100 \qquad (1)$$
$$\theta = [(W_o - W)/W_o] \qquad (2)$$

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

2.3. 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 (30 ±1 ºC) using a thermostat. %IE and the degree of surface coverage (θ) were defined as:

$$\% \text{ IE} = \left[\left(i_{corr} - i_{corr(inh)}\right)/i_{corr}\right] \times 100 \qquad (3)$$
$$\theta = \left[\left(i_{corr} - i_{corr(inh)}\right)/i_{corr}\right] \qquad (4)$$

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 Echem 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:

$$\% \text{ IE} = \left[1 - \frac{R_{ct}^o}{R_{ct}}\right] \times 100 \qquad (5)$$
$$\theta = \left[1 - \frac{R_{ct}^o}{R_{ct}}\right] \qquad (6)$$

where R_{oct} and R_{ct} are the charge transfer resistance in the absence and presence of inhibitor, respectively.

3. 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 (3) collects the values of surface coverage, inhibition efficiency and corrosion rate obtained from weight loss measurements in 1 M H_2SO_4 at 30 ± 0.1 °C. The results of this Table show that the presences of inhibitors reduce the corrosion rate of C- steel in H_2SO_4 and hence, increase the inhibition efficiency. The inhibition achieved by these compounds decreases in the following order:

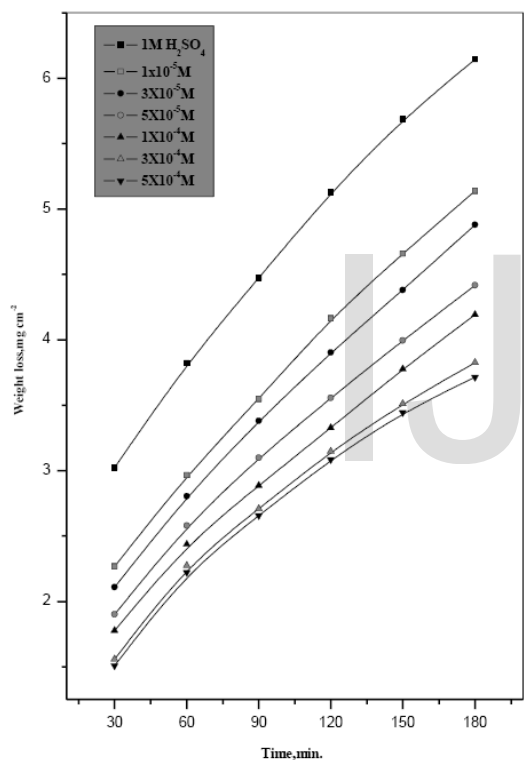Compound (I) > Compound (II) > Compound (III) > Compound (IV) > Compound (V).

Table **(3):** Inhibition efficiency of all inhibitors at different concentrations of inhibitors as determined from weight loss method for C-steel at 30 ºC.

Conc., M.	%IE				
	I	II	III	IV	V
1×10⁻⁵	51.50	48.70	47.68	39.19	37.05
3×10⁻⁵	55.48	52.28	51.27	41.15	39.03
5×10⁻⁵	59.20	54.70	52.65	47.70	43.97
1×10⁻⁴	63.47	60.74	59.83	55.40	49.20
3×10⁻⁴	66.35	64.99	63.95	59.30	54.00
5×10⁻⁴	70.24	67.72	66.90	61.82	56.04

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 [21]. 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 this inhibitor from 1 M H_2SO_4 solution on C-steel surface obeys Frumkin adsorption isotherm, where:

$$KC = \theta/1 - \theta \exp(-2\,a\,\theta) \tag{7}$$

Plotting of θ versus log C the data gives S-shape curve.

Fig. (1): Weigh loss-time curves for C-steel dissolution in 1 M H_2SO_4 in absence and presence of different concentrations of inhibitor (I) at 30 °C.
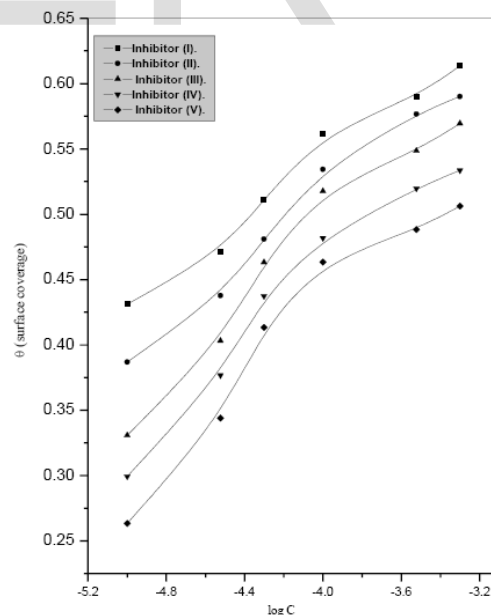

Fig. (2): θ- log c curves for C-steel dissolution in 1 M H_2SO_4 of different inhibitors from weigh loss measurement at 30 ºC.

3.1.2. Effect of tempertature

To investigate the mechanism of inhibition and to determine the activation energy of corrosion process, weight loss curves of C- steel in 1M H_2SO_4 were studied at various temperatures (30–60 oC) in the absence and presence of different concentrations of investigated compounds. These inhibitors retard the corrosion process at lower temperatures [22] whereas the inhibitions 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 1 M H_2SO_4 solution, in absent and presence of different concentration of inhibitor (I). The values of slopes of these straight lines permit the calculation of the activation energy, $E*a$, according to:

$$K = \exp(-E_a^*/RT) \qquad (8)$$

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 [23-25]. The higher values of E_a^* are good evidence for the strong adsorption of compound (I) on C-steel surface. Also, Free energy of activation (ΔG*) were calculated by applying the transition state equation [26]:

$$\Delta G^* = RT \left[\ln \frac{KT}{h} - \ln (corrosion\ rate) \right] \qquad (9)$$

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 [27]:

$$\Delta H^* = E_a^* - RT \qquad (10)$$

$$\Delta S^* = \frac{\Delta H^* - \Delta G^*}{T} \qquad (11)$$

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* 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 [28,29].
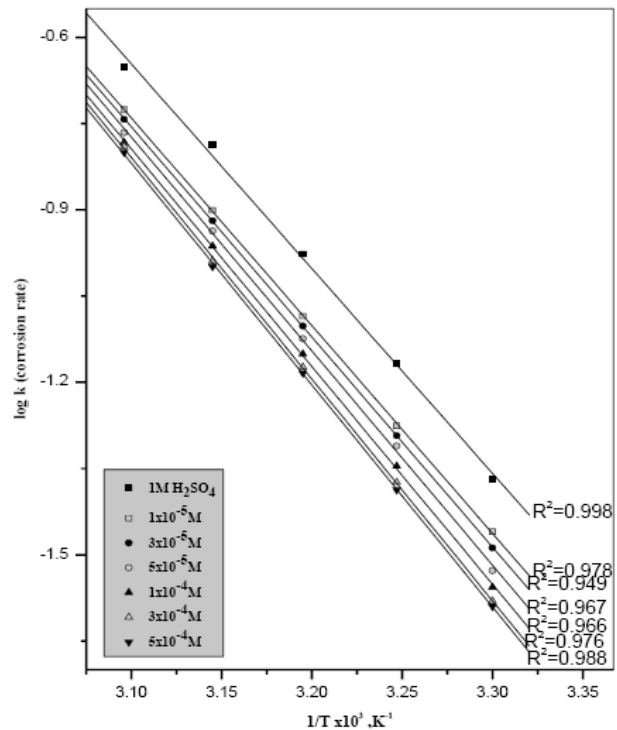

Fig. (3): log K (corrosion rate)-1/T curves for C-steel dissolution in 1M H_2SO_4 in absence and presence of different concentrations of inhibitor (I).
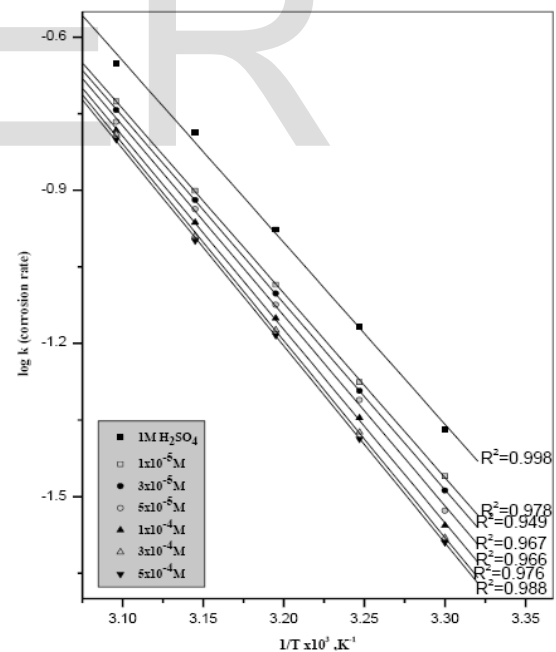

Fig. (4): log (corrosion rate /T)- (1/T) curves for C-steel dissolu tion in 1M H_2SO_4 in absence and presence of different concentration of inhibitor (I).

Table (4): Activation parameters for the dissolution of C-steel in presenc and absence of different concentration of inhibitors in 1 M H₂SO₄.

Inhibitor	Conc., M.	Activation parameters		
		E_a^* kJ mol⁻¹	ΔH^* kJ mol⁻¹	$-\Delta S^*$ J mol⁻¹ K⁻¹
Free Acid (1M H₂SO₄)	0	63.20	61.05	52.87
(I)	1 × 10⁻⁵	70.55	70.08	43.20
	3 × 10⁻⁵	72.33	72.44	37.00
	5 × 10⁻⁵	74.32	73.80	32.85
	1 × 10⁻⁴	77.16	76.65	24.72
	3 × 10⁻⁴	79.13	78.69	18.80
	5 × 10⁻⁴	81.04	79.67	17.00
(II)	1 × 10⁻⁵	69.05	69.00	46.33
	3 × 10⁻⁵	71.66	71.22	38.55
	5 × 10⁻⁵	73.66	73.89	33.06
	1 × 10⁻⁴	75.05	75.36	28.09
	3 × 10⁻⁴	77.63	77.33	22.76
	5 × 10⁻⁴	78.78	77.69	22.87
(III)	1 × 10⁻⁵	68.66	68.77	47.66
	3 × 10⁻⁵	71.00	71.14	40.22
	5 × 10⁻⁵	72.55	73.34	33.47
	1 × 10⁻⁴	74.66	74.77	29.00
	3 × 10⁻⁴	76.32	75.80	27.76
	5 × 10⁻⁴	77.09	76.13	26.44
(IV)	1 × 10⁻⁵	67.77	68.48	47.87
	3 × 10⁻⁵	70.76	70.39	42.36
	5 × 10⁻⁵	72.08	72.88	35.29
	1 × 10⁻⁴	73.34	74.09	31.88
	3 × 10⁻⁴	75.33	75.19	28.88
	5 × 10⁻⁴	74.22	75.66	29.17
(V)	1 × 10⁻⁵	66.70	68.10	48.09
	3 × 10⁻⁵	68.92	68.33	48.77
	5 × 10⁻⁵	71.66	70.64	41.44
	1 × 10⁻⁴	72.44	71.55	37.77
	3 × 10⁻⁴	73.09	72.63	36.26
	5 × 10⁻⁴	73.44	72.99	36.88

3.2. Potentiodynamic polarization

Fig. (5) shows the potentiodynamic polarization curves for C- steel without and with different concentrations of compound (I) at 30 ᵒC. Similar curves were obtained for other compounds. The obtained electrochemical parameters; cathodic (β_c) and anodic (β_a) Tafel slopes, corrosion potential (E_{corr}), corrosion current density (i_{corr}), and polarization resistance (R_P) were obtained and listed in Table. (5). Table (5) 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 [30,31]. The inhibition achieved by these compounds decreases in the following order:

Compound (I) > Compound (II) > Compound (III) > Compound (IV) > Compound (V).

The degree of surface coverage, θ at constant potential is given by the following relation from the polarization resistance

$$\theta = \left[(1 - R_{p(free)}) / R_{p(inh)} \right] \qquad (12)$$

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

$$\%IE = \left[(1 - R_{p(free)}) / R_{p(inh)} \right] \times 100 \qquad (13)$$

Also, the results of θ and %IE where 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 (I) > Compound (II) > Compound (III) > Compound (IV) > Compound (V).

The values of %IE determined from the two methods are very close to each other indicating the validity of the obtained results.
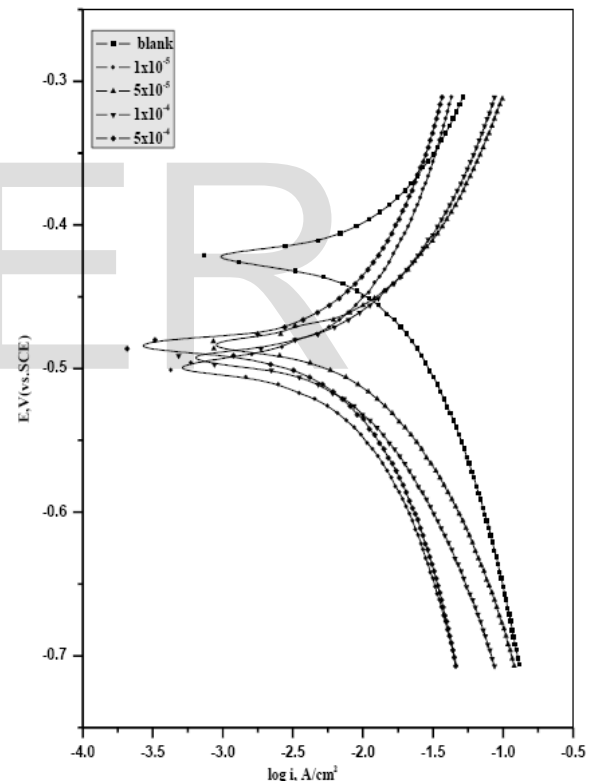

Fig. (5): Potentiodynamic polarization curves for C-steel dissolution in 1 M H₂SO₄ in absence and presence of different concentrations of compound (I) at 30 ᵒC.

Table (5): Electrochemical kinetic parameters obtained from potentiodynamic polarization technique for the corrosion of for C- steel in 1 M H₂SO₄ at different concentrations of investigated inhibitors at 30 °C.

	Conc., M	$-E_{corr}$ mV	$i_{corr} \times 10^{-4}$ μA cm^{-2}	β_C mV dec^{-1}	β_a mV dec^{-1}	R_P Ω cm^2	θ	% IE
Blank	1M H₂SO₄	501.3	3.470	266.9	230.7	4.670	-	–
I	1X10-5	494.2	1.763	258.2	225.1	2.963	0.4920	49.20
	5X10-5	498	1.143	243.1	187.9	4.028	0.6707	67.07
	1X10-4	497.3	1.131	195.3	155.9	3.328	0.6741	67.41
	5X10-4	500.2	1.074	200.2	158.6	3.624	0.6917	69.17
II	1X10-5	488.2	2.068	372.4	353.5	3.808	0.4065	40.65
	5X10-5	493.5	1.443	233.0	190.8	3.152	0.5851	58.51
	1X10-4	496.0	1.059	472.4	469.4	9.659	0.6949	69.49
	5X10-4	493.7	1.055	215.5	158.1	3.755	0.6960	69.60
III	1X10-5	498.6	2.259	531.2	498.7	4.944	0.349	34.9
	5X10-5	483.5	1.71	250.7	211.2	2.907	0.5064	50.64
	1X10-4	492.8	1.372	259.5	209.3	3.667	0.6047	60.47
	5X10-4	484.3	1.206	342.7	310.2	5.863	0.6525	65.25
IV	1X10-5	493.0	2.286	389.3	371.9	3.614	0.341	34.1
	5X10-5	500.6	2.197	296.6	263.7	2.756	0.367	36.7
	1X10-4	492.2	2.048	356.6	321.3	3.584	0.4099	40.99
	5X10-4	500.6	1.590	309.3	254	2.786	0.5419	54.19
V	1X10-5	494	2.522	26.41	225.7	2.096	0.2713	27.13
	5X10-5	488.4	2.419	2.9731	3.255	2.790	0.305	30.5
	1X10-4	493.9	2.265	387.1	348	3.514	0.348	34.8
	5X10-4	485	2.097	197.4	170.6	1.895	0.3978	39.78

3.3. Electrochemical Impedance Spectroscopy (EIS)

The corrosion of C- steel in 1 M H₂SO₄ in the presence of the investigated compounds was investigated by EIS method at 30 °C after 20 min immersion. Nyquist plots in the absence and presence of investigated compound (I) are presented in Fig. (6). 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 1 M H₂SO₄ are analyzed in terms of an equivalent circuit model Fig. (7) which includes the solution resistance R_s and the double layer capacitance Cdl which is placed in parallel to the charge transfer resistance Rct [32] 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:

$$C_{dl} = \frac{1}{2\pi f_{max} R_{ct}} \tag{14}$$

where f_{max} is maximum frequency. The parameters obtained from impedance measurements are given in Table (8). It can see from Table (6) that the values of charge transfer resistance Rct increase with inhibitor concentration [33]. 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 (I) > Compound (II) > Compound (III) > Compound (IV) > Compound (V).

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 molecules function by adsorption at the metal/solution interface [34]. 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
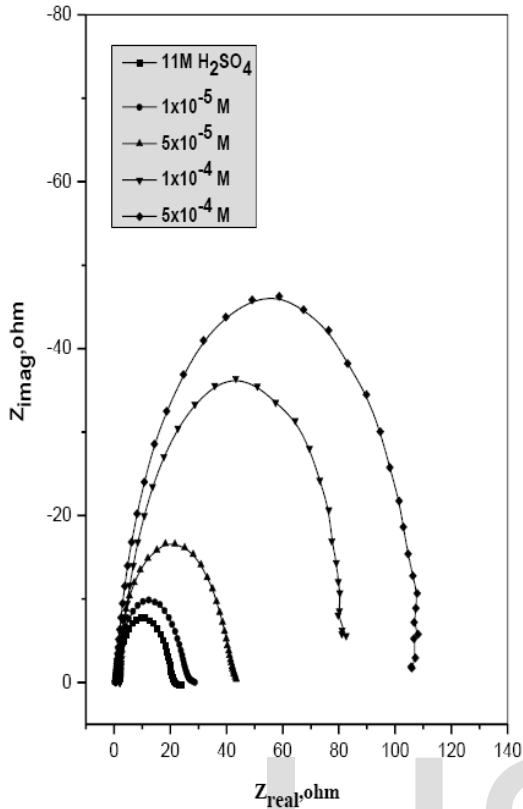
Fig. (6): The Nyquist plot for corrosion of C-steel in 1 M H₂SO₄ in absence and presence of different concentrations of compound (I) at 30 °C.
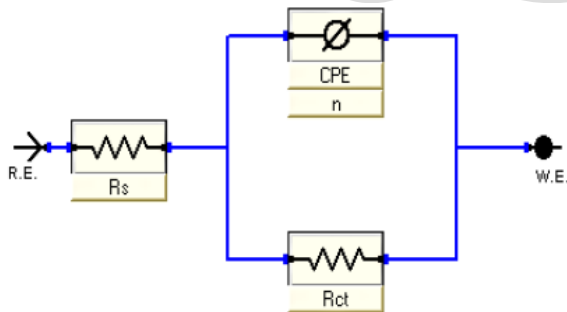

Fig. (7): Equivalent circuit model used to fit the impedance spectra.

Table (6): Electrochemical kinetic parameters obtained from EIS technique for the corrosion of C- steel in 1 M H₂SO₄ at different concentrations of investigated inhibitors at 30 °C.

compounds	Concentration, M	C_{dl}, $\mu F\,cm^{-2}$	R_{ct}, $ohm\,cm^2$	θ	%IE
Blank	1M H₂SO₄	132.1	2.96	-	-
I	1×10^{-5}	89.55	4.44	0.4970	49.70
	5×10^{-5}	70.77	9.16	0.6760	67.60
	1×10^{-4}	61.96	12.42	0.7611	76.11
	5×10^{-4}	42.50	30.28	0.9012	90.12
II	1×10^{-5}	91.30	4.24	0.3016	30.16
	5×10^{-5}	81.90	8.26	0.4610	46.10
	1×10^{-4}	64.52	11.53	0.7420	74.20
	5×10^{-4}	51.70	26.88	0.8896	88.96
III	1×10^{-5}	105.6	3.91	0.2431	24.31
	5×10^{-5}	87.60	6.24	0.5249	52.49
	1×10^{-4}	81.27	8.66	0.6770	67.70
	5×10^{-4}	65.29	21.16	0.8329	83.29
IV	1×10^{-5}	94.96	4.44	0.2310	23.30
	5×10^{-5}	78.70	8.20	0.5240	52.40
	1×10^{-4}	68.29	10.58	0.6577	65.77
	5×10^{-4}	76.19	17.76	0.8320	83.20
V	1×10^{-5}	117.3	3.71	0.200	20.00
	5×10^{-5}	91.5	5.51	0.4618	46.18
	1×10^{-4}	85.5	7.49	0.6042	60.42
	5×10^{-4}	83.4	14.52	0.7954	79.54

4- Chemical structure and corrosion inhibition

Inhibition efficiency of the carbon steel corrosion in 1 M H₂SO₄ solution by 3-phenyl-2-thioxo-4-thiazolidinone 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 [35].

The order of increased inhibition efficiency for 2-thioxothiazolidin-4-one derivatives is:

Compound (I) > Compound (II) > Compound (III) > Compound (IV) > Compound (V) as indicated from the different methods.

Compound (I) has the highest percentage inhibition efficiency. This due to the presence of *p*-OCH₃ group which is an electron repelling group with negative Hammett constants (σ = -0.27). This group will increase the electron charge density on the molecule. Compound (II) comes after compound (I), this is due to the presence of *p*-CH₃ group which is an electron donating group with negative Hammett constants (σ = -0.17), Also this group will increase the electron charge density on

the molecule but with lesser amount than *p*-OCH₃ group in compound (I). Compound (III) with Hammett constants (σ = 0.0) comes after compound (II) in percentage inhibition efficiency because H- atom in *p*-position has no effect on the charge density on the molecules. Compound (IV) and (V) come after compound (III) in percentage inhibition efficiencies. This is due to both *p*-Cl and *p*-NO₂ groups are electron withdrawing groups with positive Hammett constants (σ_{Cl} = +0.23, σ_{NO2} = + 0.78) and their order of inhibition depends on the magnitude of their withdrawing character [36].

Comparative analysis for potentiodynamic polarization measurements and electrochemical impedance spectroscopy (EIS) study of ligands (HL$_n$) is shown in Fig. (8) It is observed that the HL$_1$ is more potentiodynamic polarization measurements and electrochemical impedance spectroscopy (EIS) than the other ligands at concentration = 1×10^{-5} Molar.
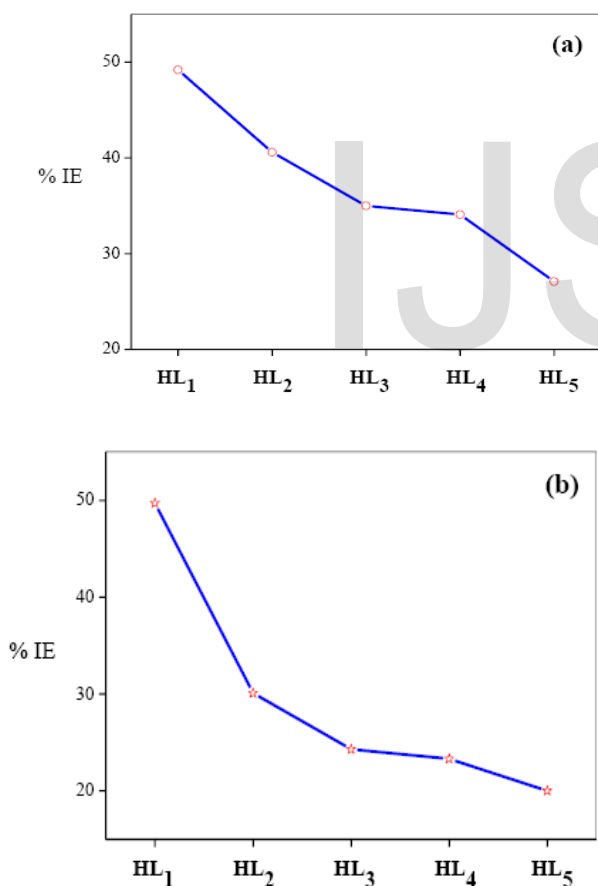

Fig. (8): Comparative analysis of ligands (HL$_n$) for (a) Potentiodynamic polarization measurements and (b) Electrochemical impedance spectroscopy (EIS) at concentration = 1×10^{-5} Molar.

5. Conclusions

3-phenyl-2-thioxo-4-thiazolidinone derivatives show good corrosion inhibition property against C-steel corrosion in 1M H₂SO₄ solution. Inhibition efficiencies are related to concentration, temperature and chemical structure of the investigated isoindoline derivatives. Generally, 3-phenyl-2-thioxo-4-thiazolidinone derivatives inhibition efficiencies increase when concentration increases and temperature decreases. Presence of aromatic ring and hetero atom such as nitrogen atom on the 3-phenyl-2-thioxo-4-thiazolidinone 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 Frumkin adsorption isotherm. EIS measurements clarified that the corrosion process was mainly charge transfer controlled and no charge in the corrosion mechanism occurred due to the inhibitor addition to acidic solutions**.**

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