ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Moringa Oleifera Extract as Green Corrosion Inhibitor for Zinc in Polluted Sodium Chloride Solutions

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Manuscript Info

Manuscript History:

Received: 17 May 2014
Final Accepted: 11 June 2014
Published Online: July 2014

Key words:
Moringa; 3.5 % NaCl and 16 ppm Solution; Zinc Corrosion, Weight Loss; Potentiodynamic Polarization; EIS; EFM

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Abstract

In this work, moringa extract was examined as a green corrosion inhibitor for zinc in 3.5 % NaCl and 16 ppm solution by using weight loss, potentiodynamic polarization, electrochemical impedance spectroscopy (EIS) and electrochemical frequency modulation (EFM) techniques. Results obtained showed that this extract of moringa offered good protection against corrosion of zinc metal and exhibited high inhibition efficiencies. The inhibition efficiency was found to increase with increase in the extract concentration. The adsorption of the inhibitor molecules on the zinc metal surface follows Temkin adsorption isotherm and behaves as mixed type inhibitor.

Introduction

Corrosion is defined as the deterioration of a metal due to its interaction with the environment. Due to corrosion many useful properties of a metal such as malleability, ductility and electrical conductivity are lost. Synthetic organic compounds are widely used as corrosion inhibitors for the prevention of corrosion of many metals and alloys in various aggressive environments. Because of their hazardous nature, researchers focus their attention on developing cheap, non-toxic, biodegradable and environment friendly natural products of plant origin as corrosion inhibitors [1-10]. Extracts of plant materials containing nitrogen, oxygen and /or sulphur atoms have been used to control the corrosion of Zn and others metals in different corrosion medium such as NaCl , HCl ,.. [11-16].

The electrochemical properties of zinc metal were utilized to a large extent. Its utilization in alkaline batteries (primary alkaline zinc battery, secondary silver-zinc, and both primary and secondary zinc-air batteries) [17] Sacrificial protection of mild steel, especially in the building construction and automobile bodies [18] and in solar energy technology [19].

Moringa, commonly known as drumstick or horseradish, which is rich in vegetable oil and high in nutritional values, is used in Asia as a vegetable and medicinal plant. Moringa have a diverse range of medicinal uses as an antioxidant, anticarcinogenic, anti-inflammatory, antispasmodic, diuretic, antiulcer, antibacterial, antifungal and its antinociceptive properties, as well as its wound healing ability has been demonstrated. Additionally, the root bark has been used as an analgesic, alexeteric, antihelminthic, and treatment for heart complaints, as well as for eye diseases, inflammation and dyspepsia [20]. Structures of some of the previously isolated phytoconstituents from moringa are shown in scheme 1.

In the present work the extract of leaves and berries of moringa were used as green corrosion inhibitor for zinc metal in 3.5 % NaCl and 16 ppm solution using chemical and electrochemical techniques.

1. Experimental

1.1. Material Composition of the Sample

The zinc (BDH grade) used in this investigation has the following chemical composition:

Element	Pb	Fe	Cd	Cu	Zn
weight%	0.001	0.002	0.001	0.003	Rest

1.2. Solutions

The corrosion medium employed was 3.5 % NaCl and 16 ppm Na_2S prepared from analytical grade and bidistilled water was used for preparation of the solutions. A stock solution of sodium chloride (3 M) was prepared using distilled water. Dissolve 175.5 g of anhydrous sodium chloride in 500 ml freshly prepared distilled water then dilute to 1000 ml with the distilled water then withdrwal 20 ml from stok solution then dilute to 100 ml to prepare 3.5 % sodium chloride. A stock solution of sodium sulfide (1000 ppm) was prepared using bi-distilled water. Wash the sodium sulfide crystals with de-ionized water to remove the contaminants from oxidation products and blot dry the crystals with a tissue. Dissolve 1 g of anhydrous sodium sulfide in 250 ml freshly prepared distilled water then dilute to 1000 ml with the distilled water then withdrwal 1.6 ml from stok solution then dilute to 100 ml to prepare 16 ppm sodium sulfide.

1.3. Preparation of Plant Extract

The moringa plant was obtained from the local market. It is cleaned with tap water to remove mud particles. The leaves and berries of the plant were then dried in an oven for 2 hours at 40 °C and ground to get the powder form of the material. Then take 250 gm from Moringa powder then add 500 ml of 70% methyl alcohol then complet to 1000 ml with70% methyl alcohol and left standing for three days with occasional shaking. The solution was then filtered and the alcohol was evaporated to get a sticky mass. The sticky mass was left overnight in open air for complete dryness. A stock solution was prepared from the collected solid by weight and used to prepare the desired concentrations by dilution.

1.4. Measuring Methods

1.4.1. Weight-loss measurements: the test pieces were 20 x 20 x 2 mm. The pieces were first abraded with different grades of emery papers (up to 1200 grit size) in order to obtain a smooth surface, followed by ultra-sonically degreasing with ethanol, then rinsed with bidistilled water, dried between two filter papers and weighed.

In the weight loss experiments, the pre-weighed zinc metal specimens were suspended in a 100 ml beaker containing 50 ml of 3.5 % NaCl and 16 ppm Na_2S solutions for 180 minutes. Then the metal specimens are removed from the corrosive solution, washed with bidistilled water, cleaned, dried and reweighed. From this the metal weight loss was determined as the difference between the initial weight and weight after 180 minutes immersion in acid solutions. The experiments were repeated with both acids in the absence and in the presence inhibitors of different concentrations. Each experiment was repeated thrice and the average of the three values was taken as the final value.

The % inhibition efficiency (IE) and the degree of surface coverage (θ) were calculated using equation (1).

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

Where W_o and W_i are the weight losses per unit area in absence and presence of the extract.

2.4.2 Electrochemical measurements: Zinc electrodes were cut from zinc sheets, of thickness 0.088 mm. The electrodes were of dimensions 10 x 10 mm and were weld from one side to a copper wire used for electric connection and was mounted in epoxy resin, to expose geometrical surface areas of 1 cm^2. Prior to these measurements, the exposed surface was pretreated in the same manner as for weight loss experiments.

2.4.2.1 Potentiodynamic polarization measurement

The electrochemical experiments were carried out in a three electrode electrochemical cylindrical Pyrex glass cell with a platinum counter electrode and saturated calomel electrode (SCE) as reference. The working electrode had the form of a square cut from Zn sheet (1 cm^2). The exposed area was treated as before. A duration time 30 min was given for the system to attain a steady state and the open circuit potential (OCP) was noted. Both cathodic and anodic polarization curves were recorded potentiodynamically by changing the electrode potential between- 0.5 V and -2V, at the scan rate of 1 mVs^{-1}, the % inhibition efficiency (IE) and degree of surface coverage (θ) were calculated from the electrochemical measurements by equation (2):

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

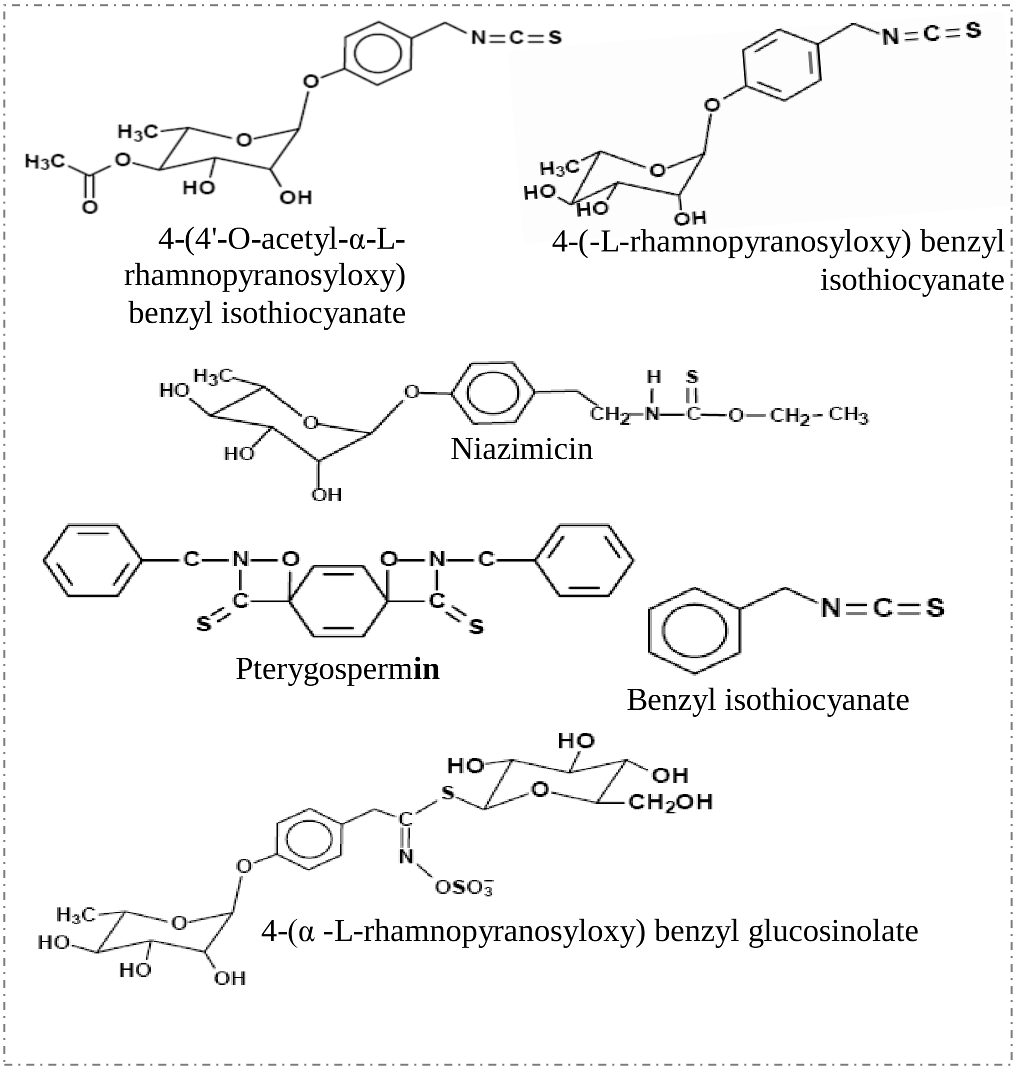
Where, $i_{inh.}$ = Corrosion current in presence of inhibitor and i_{free} Corrosion current in absence of inhibitor.

2.4.2.2 EIS and EFM measurement

Experiments for EIS measurements were conducted in the frequency range of 100 kHz to 10 mHz at open circuit potential (OCP). The amplitude was 5 mV. Experiments for EFM measurements were carried out using two frequencies 2 and 5 Hz. The base frequency was 1Hz with 32 cycles, so the waveform repeats after 1s. A perturbation signal with amplitude of 10 mV was used.

The electrochemical measurements were carried out using Potentiostat/Galvanostat/ Zera analyzer (Gamry PCI 300/4). This includes Gamry framework system based on the ESA400, and a personal computer with DC 105 software for potentiodynamic polarization, EIS 300 software for EIS, and EFM 140 software for EFM measurements. Echem Analyst 5.58 software was used for plotting, graphing, and fitting data.

2. Results and discussion



4-(4'-O-acetyl-α-L-rhamnopyranosyloxy) benzyl isothiocyanate

4-(-L-rhamnopyranosyloxy) benzyl isothiocyanate

Niazimicin

Pterygosperm**in**

Benzyl isothiocyanate

4-(α -L-rhamnopyranosyloxy) benzyl glucosinolate

2.1. Weight Loss Measurements

2.1.1. Effect of inhibitors concentrations

The weight losses of zinc in 3.5 % NaCl and 16 ppm Na_2S in absence and presence of different concentrations of moringa extract (50 - 500 ppm**)**, were determined at different times of immersion (30 to 180 min.) at 30°C. As shown in Figure (1) by increasing the concentration of moringa extract, the weight losses of zinc samples are decreased. This means that the presence of moringa extract retards the corrosion of zinc in 3.5 % NaCl and 16 ppm Na_2S solution or in other words, moringa extract act as inhibitor. Values of % IE are ranging from 50 for 50 ppm and 88.4 for 500 ppm. The values of the inhibition efficiency increased with increasing of extract concentration. This behavior could be attributed to the increase of the surface area covered by the adsorbed molecules of extract with the increase of its concentration. Moringa extract shows maximum inhibition efficiency of 88.4 % in 3.5 % NaCl and 16 ppm Na_2S at optimum concentration of 500 ppm at 30^{o}C

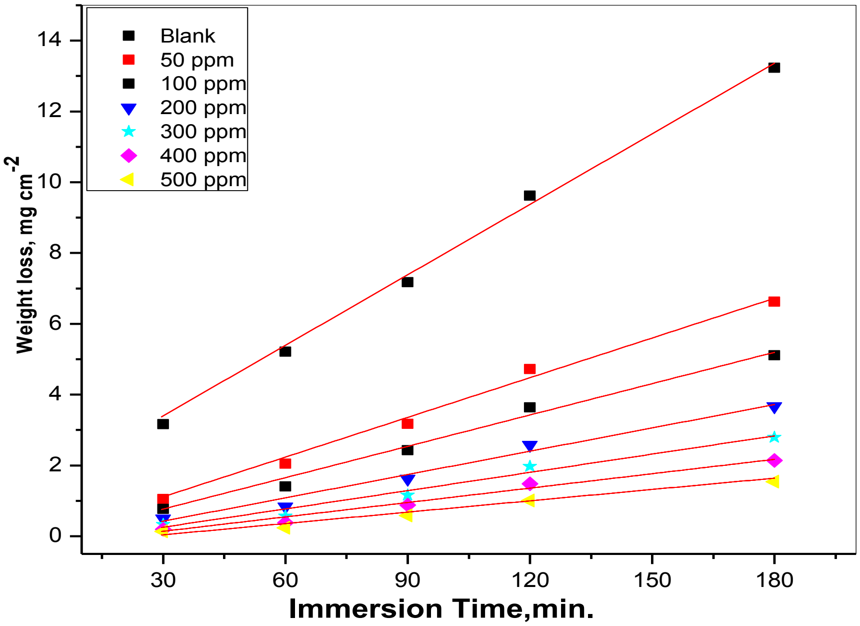


Figure (1): Weight-loss versus immersion time for Zn in 3.5% NaCl and 16 ppm Na_2S solution in the absence and presence different concentrations of moringa at 30^{o}C

2.1.2. Adsorption Isotherms

Moringa inhibitor reduce the corrosion of Zn by getting adsorbed on the metal surface forming a thin film which acts as a barrier between the metal and the aggressive media leading to corrosion inhibition. To study the mechanism of corrosion inhibition, attempts were made to fit the data available to the various adsorption isotherms such as Langmuir, Temkin and Elewady. The surface coverage (Θ) values for different concentrations of the moringa extract in 3.5 % NaCl and 16 ppm Na_2S at 30^{o}C have been evaluated from the weight loss data. The data were tested graphically to find a suitable adsorption isotherm and Temkin model is found to be the best fitted one, Figure 2, (R^2 is nearly to unity), hence the adsorption of the inhibitor molecules on the zinc metal surface obeyed Temkin adsorption isotherm (eq. 3).

$$\Theta = 2.303/a \log K_{ads} + 2.303/a \log C \quad (3)$$

K_{ads} is related to the standard free energy of the adsorption, ΔG^{o}_{ads} by:

$$(\Delta G^{o}_{ads} / RT) = \ln 55.5\, K_{ads} \quad (4)$$

Where C is the inhibitor concentration and K_{ads} the adsorption equilibrium constant, 'a' is a molecular interaction parameter depending upon molecular interactions in the adsorption layer and the degree of heterogeneity of the surface which can be evaluated from the intercepts of the plots. Also, at different temperatures it was found that Temkin adsorption isotherm is valid (Figure 3).

The values of K_{ads} and ΔG^o_{ads} are 41 x10^{-2} (mol^{-1}) and – 7.761 (kJ mol^{-1}) respectively, the negative sign of the free energy of adsorption indicates that the adsorption of the inhibitor at the zinc surface is a spontaneous process. The surface of the electrode in aqueous solutions is considered to be covered with water dipoles [21] Therefore, for inhibition to occur, these water dipole must be replaced by inhibitor molecules in a reaction of the type [22]

$$n\,H_2O_{ads} + Inh. \leftrightarrow Inh._{ads} + n\,H_2O \qquad (5)$$

The value ΔG^o_{ads} – 20 kJ mol^{-1} or lower indicate a physisorption i.e. electrostatic interaction between the double layer and the adsorbing molecules [23].

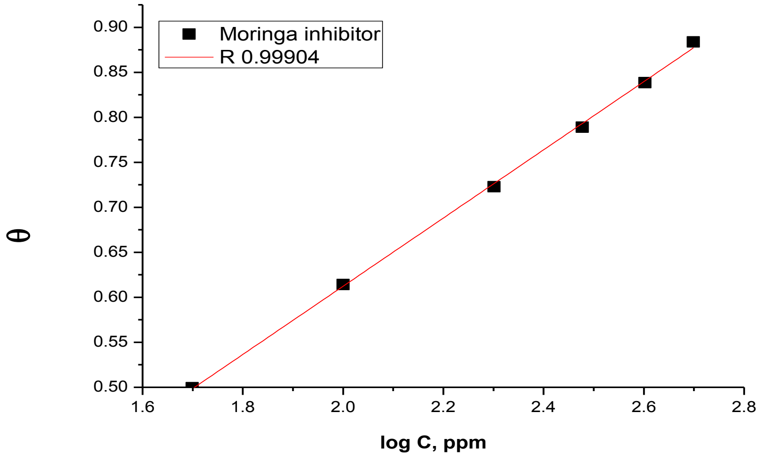


Figure (2): Temkin adsorption isotherm plotted as Θ vs log C of moringa extract for the corrosion of Zn in **3.5 % NaCl and 16 ppm Na_2S at 30°C**

2.1.3. Effect of Temperatures

The effect of temperature on the % IE of the moringa inhibitor was determined by weight loss method at different concentrations and at different temperatures (30-50°C) for a fixed immersion time of 180 min was shown in Table (1). The data in Table 1 revealed that the inhibition efficiency decreased by increasing the temperature, due to desorption of adsorbed inhibitor components on Zn surface. This indicates that the extract components are physically adsorbed on the metal surface.

It was found that moringa extract obyes Temkin adsorption isotherm at different temperatures (Fig. 3).

Table (1): The effect of temperature on the % IE of the moringa extract at different concentrations and at different temperatures (30-50°C) after 180 min.

Temp., °C	Moringa Conc, ppm					
	50	100	200	300	400	500
	% IE					
30	50.0	61.4	72.3	78.9	83.8	88.4
35	47.3	57.4	69.	75.6	79.8	84.0
40	45.1	55.5	66.7	72.8	77.7	81.0
45	40.8	51.7	62.2	68.3	73.2	77.2
50	38.8	49.5	59.9	66.1	71.3	75.0

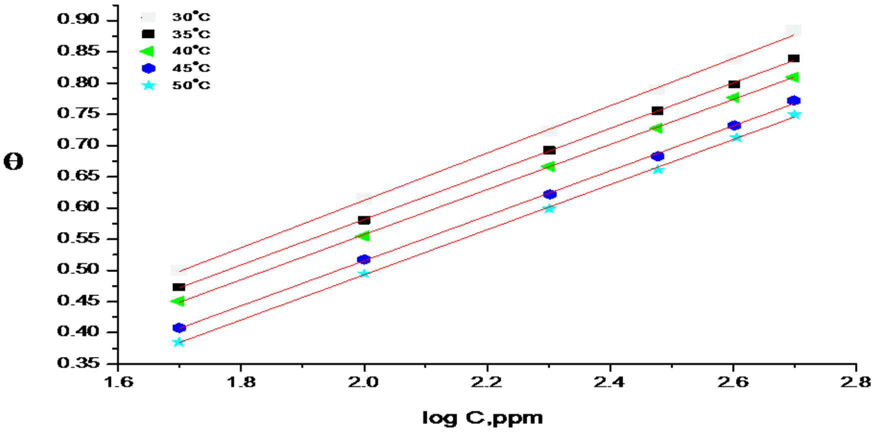


Figure (3): Temkin adsorption isotherm plotted as Θ vs. log C of moringa extract for the corrosion of Zn in 3.5 % NaCl and 16 ppm Na_2S at different temperatures

2.1.4. Thermodynamic Parameters

The apparent activation energy (E^*_a) of metal corrosion in acid media can be calculated from the Arrhenius equation [24].

$$\mathrm{Ln}k = (E^*_a)/RT + A \qquad (6)$$

Where k is the corrosion rate, (E^*_a) is the apparent activation energy for the corrosion of Zn, R is the universal gas constant, A is Arrhenius pre exponential factor and T is the absolute temperature. The values of the activation energies, $E_a{}^*$, were calculated from the slopes of the straight lines of Fig. 4. The values of the activation energies, E^*_a, for the dissolution of zinc in absence and presence of moringa extract in 3.5 % NaCl + 16 ppm Na_2S solution are given in Table (2).

An alternative formulation of Arrhenius equation is the transition state equation [24].

$$k = RT/ Nh \exp (\Delta S^*/R) \exp (-\Delta H^*/RT) \qquad (7)$$

where h is Planck's constant, N is Avogadro's number, $\Delta S^*$is the entropy of activation and ΔH^* is the enthalpy of activation. Figure (5) show a plot of log k/T against 1/T.A straight line is obtained with slopes of ($-\Delta H^*/2.303R$) and an intercept of ($\log R/Nh + \Delta S^*/2.303R$) [25], from which the values of ΔH^* and ΔS^* were calculated, respectively. The calculated values of the apparent activation energy, $E_a{}^*$, activation enthalpies, ΔH^* and activation entropies, ΔS^* are given in Table (2) which reported that these values indicate that the presence of moringa increases the activation energy, (E^*_a) and the activation enthalpy, ΔH^* and decreases the activation entropy, ΔS^* for the corrosion process. The increase in the activation energy indicating a strong adsorption of the extract molecules on Zn surface and indicates the energy barrier caused by the adsorption of the moringa molecules on Zn surface. The magnitude of activation energy gives an idea about the type of adsorption which is mainly physical or chemical. Low activation energies (5-40 kJ mol^{-1}) are characteristics for physisorption, while higher activation energies (40-800 kJ mol^{-1}) suggest chemisorption [26]. The results obtained was ranging from 28.5 to 34.9 kJ mol^{-1} indicating that the adsorption has a low potential barrier and corresponding to a physisorption. The increase in the activation enthalpy (ΔH^*) in presence of the inhibitors implies that the addition of the inhibitors to the 3.5 % NaCl + 16 ppm Na_2S solution increases the height of the energy barrier of the corrosion reaction to an extent depends on the type and concentration of the present inhibitor. The entropy of activation (ΔS^*) in the blank and inhibited solutions is large and negative indicating that the activated complex represents association rather than dissociation step [27].

Table (2): Activation parameters for dissolution of Zn in absence and presence of different concentrations of moringa extract in 3.5 % NaCl and 16 ppm Na_2S

Inhibitor	Conc., ppm	Activation parameters		
		E_a^*	ΔH^*	$-\Delta S^*$
Blank	3.5 % NaCl + 16 ppm Na_2S	19.1	8.3	165.4
Moringa extract	50	28.5	12.4	140.1
	100	29.0	12.6	139.8
	200	30.0	13.0	130.7
	300	30.7	13.3	125.8
	400	33.4	14.5	115.7
	500	34.9	15.1	104.9

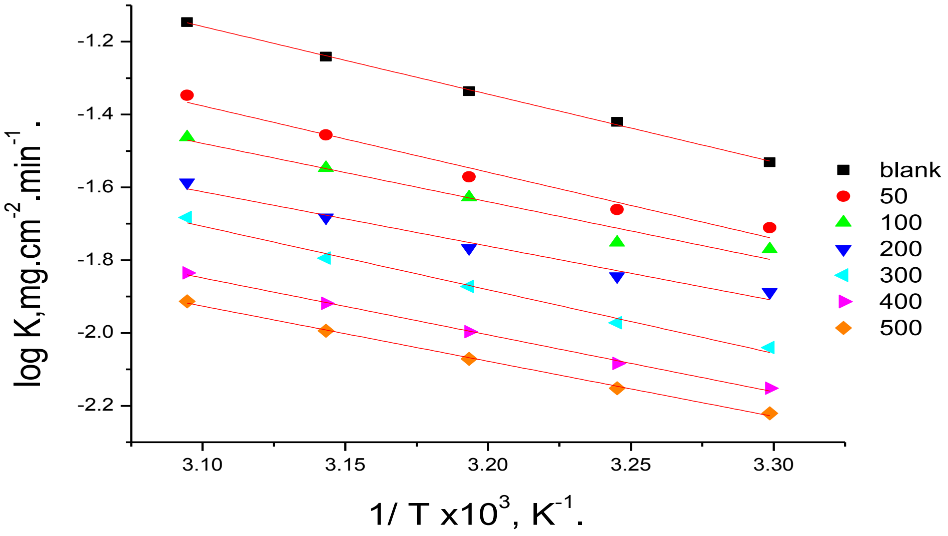


Figure (4) Arrhenius plots (log k vs.1/T) for Zn in 3.5 % NaCl and 16 ppm Na_2S in the absence and presence of different concentrations of moringa extract

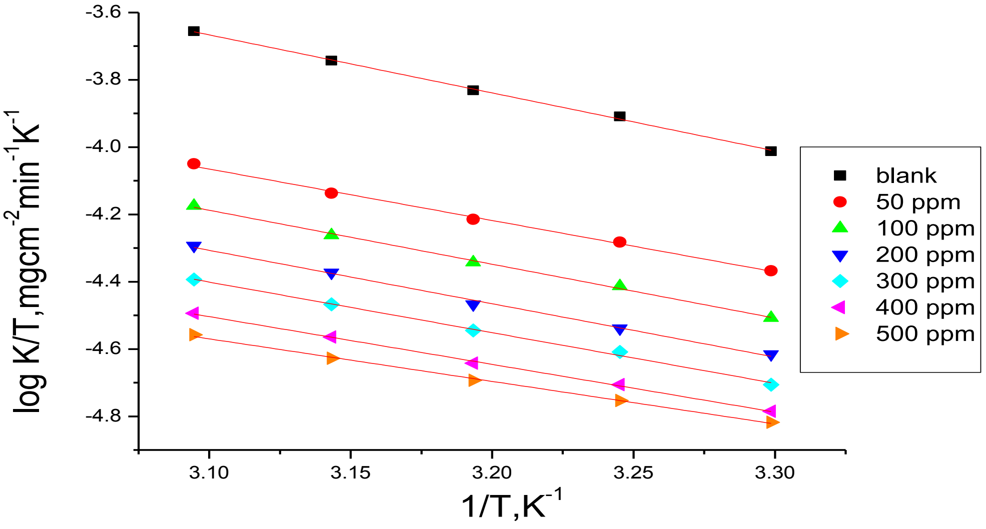


Figure (5): Arrhenius plots (log k/T vs.1/T) for Zn in 3.5% NaCl and 16 ppm Na_2S in the absence and presence of different concentrations of moringa extract

2.2. Electrochemical Measurements

3.2.1 Potentiodynamic polarization measurements

The cathodic and anodic polarization curves recorded for Zn in 3.5 % NaCl and 16 ppm Na_2S solution without and with various concentrations of moringa extract is illustrated in Fig. (6) Electrochemical corrosion kinetic parameters obtained by Tafel extrapolation method are given in Table (3). No definite shift in the corrosion potential (E_{corr}) is detected, although there was no specific relation between E_{corr} and inhibitor concentration. It can be seen from Fig. (6), that the cathodic and anodic reactions are affected by the presence of the extract indicating that moringa extract acts as mixed-type inhibitor. The addition of moringa extract to 3.5 % NaCl and 16 ppm Na_2S solution therefore reduces the anodic dissolution of Zn and also retards the cathodic hydrogen evolution reactions. It can be seen from the polarization results that the corrosion current density (i_{corr}) decreased with the increase in inhibitor concentration, due to the increase in the blocked fraction of the metal surface by adsorption. The polarization resistance (R_p) values were determined. It was found that R_p values increase with increase in moringa extract concentration. The inhibition efficiencies calculated from the corrosion current density and the polarization resistance increased with the inhibitor concentration reaching a maximum value at 500 ppm.

Table (3): Corrosion parameters of Zn electrode in 3.5 % NaCl and 16 ppm Na_2S solution in the absence and presence different concentrations of moringa extract at 30°C

Conc, ppm	$-E_{Corr,}$ mV vs SCE	i_{corr} mA cm^{-2}	Tafel slop		R_p Ω cm^2	θ	% IE
			$β_a$ $mVdec^{-1}$	$β_c$ $mVdec^{-1}$			
Blank	964	0.7319	173	35	29.12	--	--
50	964	0.3407	94	32	62.14	0.534	53.4
100	964	0.2633	84	29	85.68	0.64	64
200	964	0.1811	70	28	115.61	0.752	75.2
300	964	0.1423	61	26	171.92	0.805	80.5
400	964	0.1233	34	25	212.15	0.831	83.1
500	964	0.081	29	16	256.45	0.891	89.1

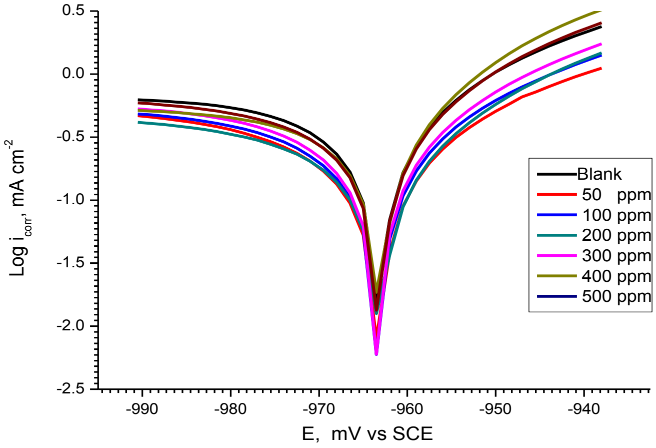


Figure (6): potentiodynamic polarization curve for zinc corrosion in 3.5% NaCl and 16 ppm Na_2S in the absence and presence of different concentrations of moringa extract at 30°C

3.2.2 Electrochemical impedance spectroscopy (EIS) measurements

Impedance diagram (Nyquist plot) obtained for Zn in absence and the presence of various concentrations of the moringa extract is depicted in Fig (7). It is apparent that the impedance response of Zn in uninhibited 3.5 % NaCl + 16 ppm Na_2S solution has significantly changed after addition of moringa in the corrosive solution. As a result, the semicircle in the presence of inhibitor is bigger than that in the absence of inhibitor (Blank) and increases as the inhibitor concentration increases. This confirms that the impedance of inhibited Zn substrate increases with the concentration of moringa extract in 3.5 % NaCl + 16 ppm Na_2S. The electrochemical impedance parameters (R_{ct} and C_{dl}) were calculated from the Nyquist plots and are given in Table (4). Values of charge transfer resistance (R_{ct}**)** increase with increasing extract concentration. This is attributed to high resistance shown by the adsorbed extract components at the metal – solution interface. Similarly, the decrease in double layer capacitance (C_{dl}**)** is attributed to increase in thickness of electrical double layer due to adsorption of extract components. The charge transfer resistance, R_{ct} and double layer capacitance (C_{dl}**)** is much higher than those in free acid. It is inferred that the extract molecules gradually replace the water molecules by adsorption at the metal/solution interface, which leads to the formation of a protective film on the Zn surface and thus decreases the extent of the dissolution reaction [28]. Moreover, the increase of extract concentration leads to the increase of R_{ct} and % IE values. The % IE obtained from EIS measurements are close to those deduced from polarization and weight loss methods. The equivalent circuit depicted in Fig (8) is employed to analyze the impedance spectra for moringa. Figure (9) shows the Bode plots obtained for zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence and in the presence of different concentrations of moringa at 30°C

Table (4). Impedance parameters and inhibition efficiency for zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence and presence of different concentrations of moringa at 30°C

Conce, ppm	R_{ct} ohm cm^2	$C_{dl\ x\ 10^5}$ $\mu F\ cm^{-2}$	Θ	% IE
Blank	82.37	1.8	----	----
50	178.50	0.74	0.539	53.9
100	225.50	0.66	0.635	63.5
200	329.20	0.59	0.750	75.0
300	426.6	0.45	0.807	80.7
400	524.00	0.34	0.843	84.3
500	723.60	0.21	0.886	88.6

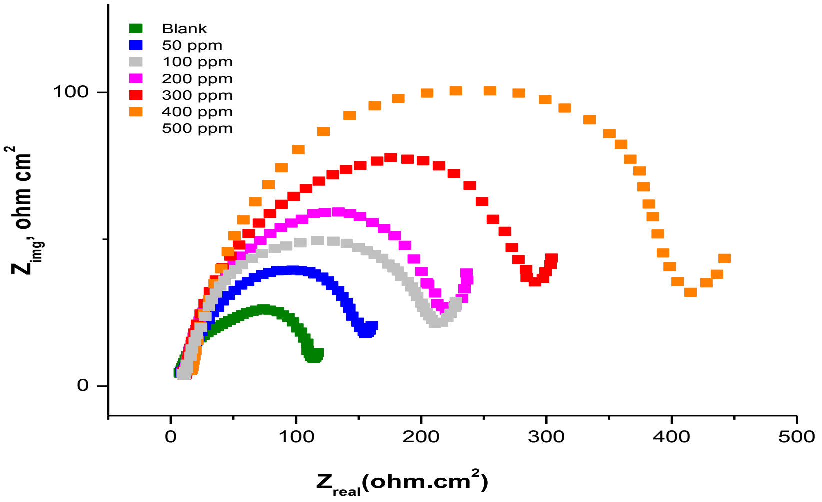


Figure (7): Nyquist plots for Zn corrosion in 3.5% and 16 ppm Na_2S solution in the absence and presence of different concentrations of moringa at 30°C

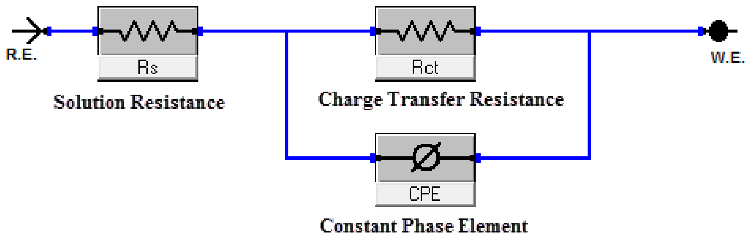


Figure (8): Equivalent circuit model used to fit experimental EIS data

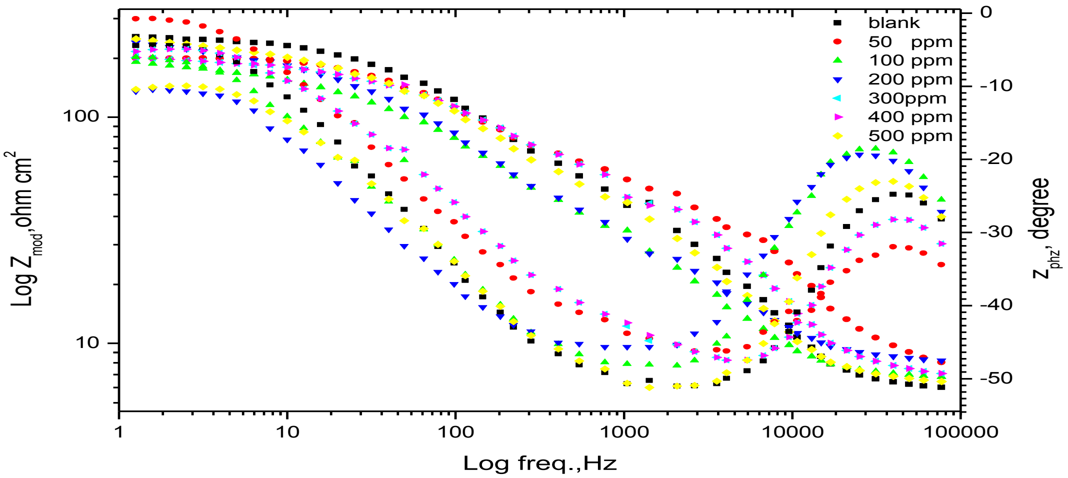


Figure (9). The bode plots obtained from zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence and in the presence of different concentrations of Moringa at 30̊C

3.2.3 Electrochemical frequency modulation (EFM) measurements

The EFM is a nondestructive corrosion measurement technique that can directly give values of the corrosion current without prior knowledge of Tafel constants. The theory of EFM technique is previously reported [29, 30]. Figure (10) shows the intermodulation spectra obtained from EFM measurements of zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence of the investigated moringa extract, and Figure (11) shows the intermodulation spectra obtained from EFM measurements of zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in presence of 500 ppm moringa extract. The calculated corrosion kinetic parameters at different concentrations of the moringa in 3.5 % NaCl and 16 ppm Na_2S at 30°C (i_{corr}, β_a, β_c, CF-2, CF-3 and % IE) is given in Table 5. From this Table, the corrosion current density decreases and the inhibition efficiency increases by increasing the concentration of investigated extract. The great strength of the EFM is the causality factor, which serves as an internal check on the validity of the EFM measurement [31]. Values of causality factors in Table 5 indicate that the measured data are of good quality. The standard values for CF-2 and CF-3 are 2.0 and 3.0, respectively. The deviation of causality factors from their ideal values might due to that the perturbation amplitude was too small or that the resolution of the frequency spectrum is not high enough. The results obtained from EFM showed good agreement with the obtained from weight loss, polarization and EIS methods.

Table (5). EFM spectra of zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence and presence of different concentrations of moringa at 30^oC

Conc., ppm	$i_{corr.}$ $\mu A\ cm^{-2}$	β_a $mV\ dec^{-1}$	β_c $mVdec^{-1}$	C R mpy	CF-2	CF-3	θ	% IE
Blank	331.5	71	203	305.5	2.249	2.161	------	------
50	159	31	113	90.6	2.082	5.921	0.520	52.0
100	122	32	127	86.21	2.054	2.412	0.632	63.2
200	84.5	37	142	53.44	2.074	2.385	0.745	74.5
300	65.1	44	150	44.04	2.098	5.916	0.804	80.4
400	52.3	49	200	37.42	2.052	4.621	0.842	84.2
500	40.6	51	82	29.78	2.033	6.420	0.878	87.8

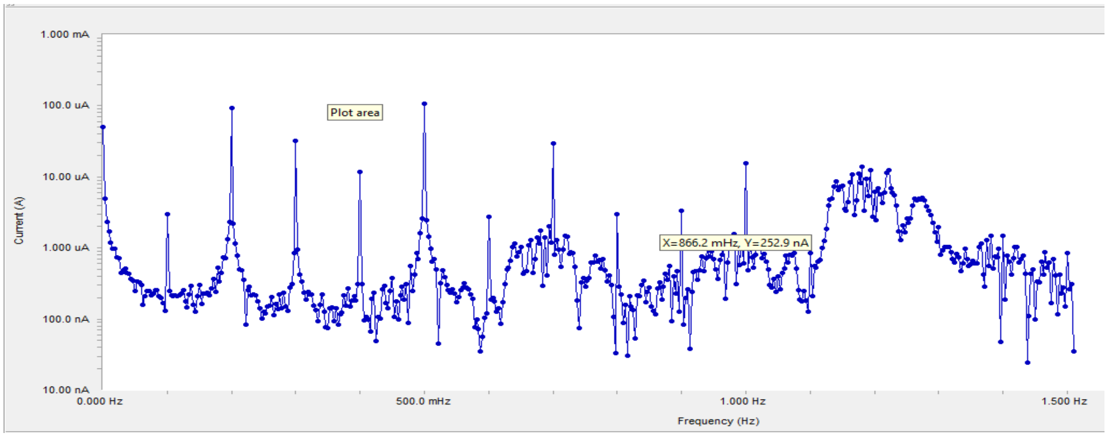


Figure (10): EFM spectra obtained for zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the absence of moringa at 30^oC

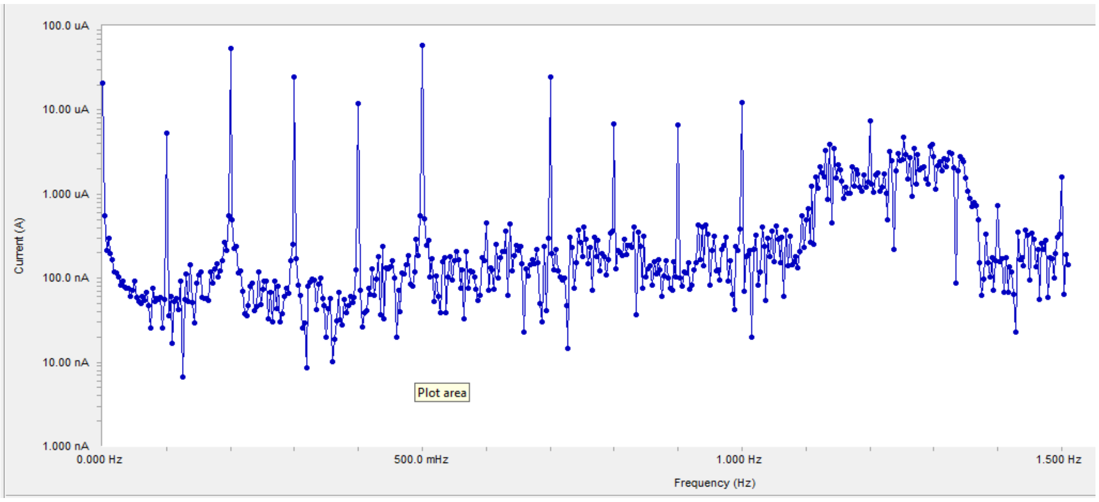


Figure (11): EFM spectra obtained for zinc corrosion in 3.5 % NaCl and 16 ppm Na_2S solution in the presence of 500 ppm of moringa at 30^oC

3.3 Mechanism of Corrosion Inhibition

The mechanism of corrosion inhibition is believed to be due to the formation and maintenance of a protective film on the metal surface, suggests that the inhibitor molecules cover both the anodic as well as cathodic regions through general adsorption following Temkin adsorption isotherm. The essential effect of moringa as corrosion inhibitor is due to the presence of free electron pairs in the N, O and S atoms, π-electrons on the aromatic rings, molecular size, heat of hydrogenation, mode of interaction with the metal surface, and formation of metallic complexes [32]. It is well known that Zn has co-ordination affinity toward N, O, and S bearing ligand. Hence, adsorption on Zn can be attributed to coordination through hetero-atoms and π-electrons of aromatic rings. In moringa, there are unshared electron pairs on N, O, and S, capable of forming σ-bond with Zn. Another striking feature for high inhibition performance of moringa presence of S-atom. The anodic inhibition may be due to the adsorption of principle phytochemical constituents present in the extract through nitrogen atom/or oxygen atoms/or ring oxygen atom in glucosinolate and /or oxygen atoms of –OH group in moringa phytochemical constituents and forms a protective coating on the metal surface, thus prevents the contact between the metal and corrosive media.

3.4 Conclusions

The moringa extract investigated in this paper acts as good corrosion inhibitor for zinc in 3.5% NaCl and 16 ppm Na_2S solution. The chemical and electrochemical measurements confirm the inhibitive nature of moringa extract. Inhibition efficiency increases with increasing the extract concentration and decreases with rise of the temperature. It exhibited a maximum inhibition efficiency of 88.4 % at 500 ppm concentration. The adsorption of the extract molecules on the metal surface obeyed Temkin adsorption isotherm. The extract behaves as mixed type inhibitor.

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