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Research Article

A Study of Salvia hispanica as Green Corrosion Inhibitor for Carbon Steel in Sulfuric Acid

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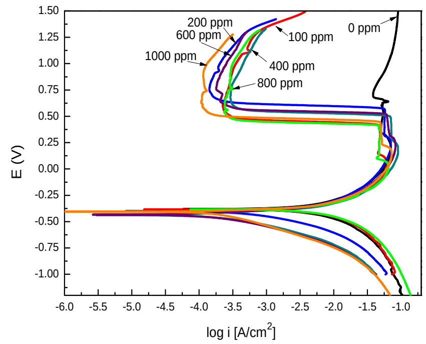
Abstract

A study on the use of Salvia hispanica as green corrosion inhibitor for 1018 carbon steel in 0.5 M H2SO4 has been carried by using gravimetric and electrochemical techniques. Techniques include weight loss, potentiodynamic polarization curves, electro-chemical impedance and noise measurements. All different techniques showed that Salvia hispanica acts as good inhibitor, with its efficiency increasing with the concentration. This is due to the physical adsorption of Salvia hispanica following a Langmuir type of adsorption forming a passive film. Additionally, electrochemical noise results indicated a reduction in the pitting corrosion susceptibility when Salvia hispanica was added to the solution.

Keywords: *Salvia hispanica*, carbon steel, acid corrosion, electrochemical noise



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Introduction

Acid pickling, industrial cleaning, acid decaling, oil well acid in oil recovery and the petrochemical processes are examples of industrial processes where acids are used and make important the study of steel corrosion phenomena for industrial and academic topic in recent years [1,2] . The main acids abundantly used in industries are HCl and H_2SO_4. One of the severe problems in using these acids is corrosion of metallic substrates. To overcome this problem, synthetic inhibitors have been used. These materials are substances which, when added in small concentrations to corrosive media, cause decrease or prevent the reaction of metal with media [3-7]. Among the used inhibitors, organic compounds act as good inhibitors due to their heteroatom structures such as sulfur, nitrogen and oxygen [8-11]. The results of all these studies suggest that the inhibitory behavior of the organic compounds subsists in some chemical species or molecules in the inhibiting substances forming a protective layer between the metal surface and the corrodent. The adsorbate layer formed isolates the metal surface from the corrodent thereby reducing the corrosion rate of the metal surface. The toxic nature of these organic inhibitors has required research activities in recent times toward finding alternative environmentally friendly acid corrosion inhibitors [12-18].

Natural products were previously used as corrosion inhibitors for different metals in various environments and their optimum concentrations were reported. Recently, natural products, for example, *Artemisia pallens* [19], *Laurus nobilis* t [20], *Punica granatum* [21], *Oxandra asbeckii* [22], and *Ruta chalepensis* extracts [23], all have been reported to be effective in reducing the corrosion rate of metals in acidic media. The inhibiting action of such extracts is often attributed to some organic constituents of the extracts (phyto-chemicals), whose electronic structures resemble those of conventional organic corrosion inhibitors.

Salvia hispanica L. (Chia) has a long history of plant-human interaction. In pre-Columbian Mesoamerica, the species known commonly as *"Chia"* was a major commodity and its seeds were valued for food, medicine, and oil [24]. It is native to southern Mexico and northern Guatemala and is interesting because it can be cultivated to produce oil for both food and industry. Chia seed has about 250–390 g oil/kg fresh matter [25]. The fatty acids (FA) of chia oil are highly unsaturated, with their main components being linoleic and α-linolenic acid, two polyunsaturated fatty acids (PUFAs), which cannot be produced in the human body. Moreover, chia seed contains some compounds such as myricetin, quercetin, kaemperol, and caffeic acid with potent antioxidant activity [26] but it does not contain toxic factors [27]. Linoleic and α-linolenic acid, **Figure 1**, are also known as essential fatty acids and within the body, they can be converted to other PUFAs, such as arachidonic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The ALA, EPA and DHA, known as omega-3 essential fatty acids [28] are found in fish and in some plants oils. Their beneficial effects include lowering cholesterol and triglyceride levels and blood pressure and reducing the risk of heart disease. The omega-3 fatty acids also act as anti-inflammatory agents, which make them beneficial for patients with rheumatoid arthritis and lupus [29].

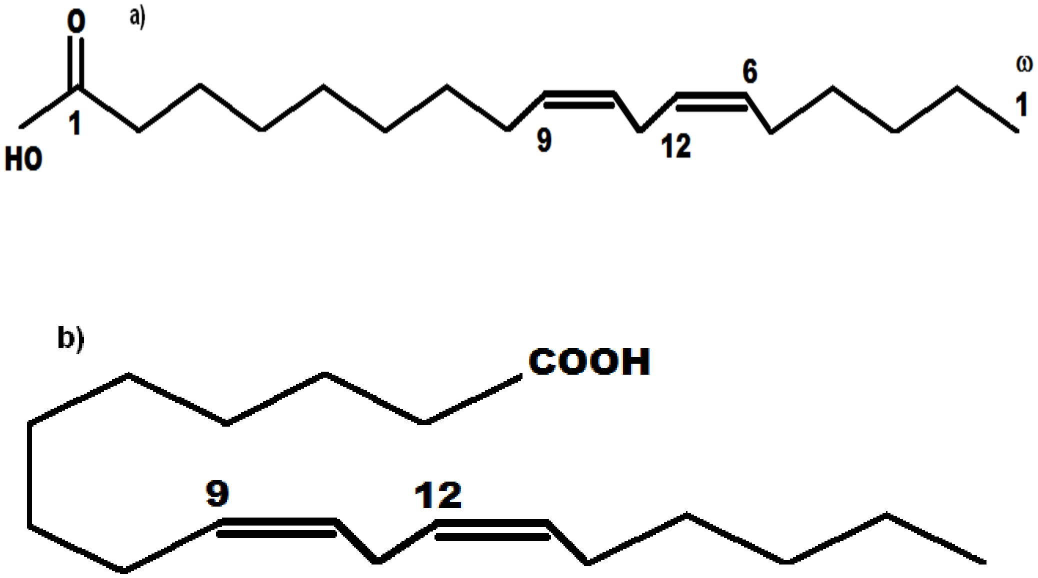

Figure 1 Chemical structure for a) Linoleic andb) α-linolenic acids.

Thus, the goal of the present manuscript is to evaluate the possibility of using *Salvia hispanica* L. (Chia) as a green inhibitor for the corrosion of carbon steel in 0.5 M sulfuric acid by using electrochemical techniques.

Experimental procedure

Material used in this work includes 1018 carbon steel rods containg 0.14%C, 0.90% Mn, 0.30%S, 0.030% P and as balance Fe, encapsulated in commercial epoxic resin with an exposed area of 1.0 cm^2. The aggressive solution, 0.5 M H_2SO_4 was prepared by dilution of analytical grade H_2SO_4 with double distilled water. Chia, *Salvia hispanica*, seeds were obtained from a local market, soaked in methanol (approximately 250 ml of methanol per 100 g of chia) during 30 days until all methanol was evaporated obtaining a solid, wich was weighted and dissolved in methanol and used as a stock solution and used then for preparation of the desired concentrations by dilution. Weight loss experiments were carried out with steel rods 2.5 cm length and 0.6 cm diameter abraded with fine emery paper until 1200 grade, rinsed with acetone, and exposed to the aggressive solution during 72 h. After a total time of exposition of 72 hours, specimens were taken out, washed with distilled water, degreased with acetone, dried and weighed accurately. Tests were performed by triplicate at room temperature (25 °C). Corrosion rates, in terms of weight loss measurements, ΔW, were calculated as follows:

$$\Delta W = (m_1 - m_2) / A \qquad [1]$$

were m_1 is the mass of the specimen before corrosion, m_2 the mass of the specimen after corrosion, and A the exposed area of the specimen. For the weight loss tests, inhibitor efficiency, IE, was calculated as follows:

$$IE\ (\%) = 100\ (\Delta W_1 - \Delta W_2)/\ \Delta W_1 \qquad [2]$$

were ΔW_1 is the weight loss without inhibitor, and ΔW_2 the weight loss with inhibitor. The degree of surface coverage (Θ) was calculated from the following equation:

$$\Theta = (\Delta W_1 - \Delta W_2)/\ \Delta W_1 \qquad [3]$$

Electrochemical techniques employed included potentiodynamic polarization curves, electrochemical impedance spectroscopy (EIS) and electrochemical noise (EN) measurements. In all experiments, the carbon steel electrode was allowed to reach a stable open circuit potential value, E_{corr}. Polarization curves were recorded at a constant sweep rate of 1 mV/s at the interval from -1000 to +1500 mV respect to the E_{corr} value. Measurements were obtained by using a conventional three electrodes glass cell with two graphite electrodes symmetrically distributed and a saturated calomel electrode (SCE) as reference with a Lugging capillary bridge. Corrosion current density values, I_{corr}, were obtained by using Tafel extrapolation. Inhibitor efficiency (values were calculated by using the equation:

$$IE\ (\%) = 100\ (I_{corr1} - I_{corr2})/\ I_{corr1} \qquad [4]$$

Where, I_{corr} is the corrosion current density without inhibitor, and I_{corr} the corrosion current density with inhibitor Electrochemical impedance spectroscopy tests were carried out at E_{corr} by using a signal with amplitude of 10 mV in a frequency interval of 100 mHz-100 KHz. An ACM potentiostat controlled by a desk top computer was used for the polarization curves, whereas for the EIS measurements, a model PC4 300 Gamry potentiostat was used. Finally, EN measurements for both current and potential were recorded using two identical working electrodes and a saturated calomel reference electrode (SCE). Electrochemical noise measurements were carried out by simultaneously recording potential and current fluctuations at a sampling rate of 1 point per second for a period of 1024 seconds. A fully automated zero resistance ammeter (ZRA) from ACM instruments was used in this case. Removal of the DC trend from the raw noise data was the first step in the noise analysis. To accomplish this, a least square fitting method was used. Finally, noise resistance, $R_{n,}$ was then calculated as the ratio of potential noise standard deviation, σ_v, over current noise standard deviation, σ_i.

Results

Parameters obtained from the weight loss results are shown in **Table 1**, where it can be seen that the weight loss decreases with increasing the inhibitor concentration, indicating that that the extent of inhibition depends upon the ammount of *Salvia hispanica* present, reaching a lowest weight loss value with the addition of 1000 ppm of *Salvia hispanica*.

The inhibition of corrosion occurs due to the larger coverage of metal surface by inhibitor molecules as shown in **Table 2**, where the Θ value increases with increasing the inhibitor concentration. Similarly, the inhibitor efficiency increases with the inhibitor concentration, reaching a value of 91 % when 100 ppm of inhibitor is added.

Table 1 Weight loss results

C_{inh} (ppm)	ΔW (mg/cm^2)	I.E. (%)	Θ
0	25.9	--	
100	24.5	5.052	0.05052
200	7.5	70.94	0.7094
400	4.1	84.22	0.8422
600	3.3	87.08	0.8708
800	2.4	90.55	0.9055
1000	2.2	91.17	0.9117

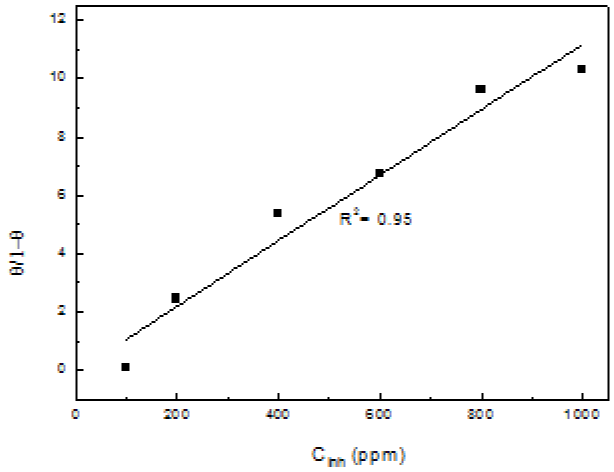

Figure 2 Langmuir isotherm for the adsorption of *Salvia hispanica* compounds on the surface of carbon steel obtained by the weight loss

The values of surface coverage (Θ) and inhibitor concentration (C_{inh}) were used to obtain the isotherms [30]. Various isotherms (Temkin, Frumkin and Langmuir isotherm) have been tested but the best fit was obtained for Langmuir isotherm as shown in **Figure 2.** Langmuir isotherm considers uniform activity over the surface for adsorption to take place and no interaction among adsorbed molecules. The Langmuir isotherm is given by:

$$K_{ads}C_{inh} = \Theta/1\text{-}\Theta \qquad [5]$$

Where, K_{ads} is the equilibrium constant of adsorption process. The equilibrium constant (K_{ads}) for the adsorption–desorption process is related to the standard free energy of adsorption ($\Delta G^0{}_{ads}$). The correlation between K_{ads} and $\Delta G^0{}_{ads}$ is shown in following equation :

$$\Delta G^0{}_{ads} = RT \ln K_{ads} \qquad [6]$$

Where, R and T are the universal gas constant and the absolute temperature, respectively. It has been well understood that the standard free energy of adsorption values of -20 kJ M^{-1} or less negative values are attributed to an electrostatic interaction between the charged molecules and the charged metal surface (physical adsorption) [31]. However, the standard free energy of adsorption values of -40 kJ M^{-1} or more negative values show charge sharing or transfer from the inhibitor molecules to the metal surface to form a coordinate covalent bond [31]. The calculated values of equilibrium constant (K_{ads}) and standard free energy of adsorption of *Salvia hispanica* extract on carbon steel are 2.99 M-1 and -1,17 kJ M-1, respectively. This means that the adsorption of *Salvia hispanica on carbon steel* is spontaneous and the adsorption type is physical.

Table 2 Electrochemical parameters obtained from the polarization curves for carbon steel in 0.5 M H_2SO_4 with different *Salvia hispanica* concentrations

C_{inh} (ppm)	E_{corr} (mV)	i_{corr} (mA/cm^2)	βa (mV/dec)	βc (mV/dec)	R_p (Ω cm^2)	i_{pas} (mA cm^{-2})	E_{pit} (mV)	I.E. (%)
0	-385	14	371	387	59	40	725	
100	-380	7.5	365	346	98	0.3	1100	46
200	-405	4	364	356	178	0.2	1150	71
400	-435	0.6	371	380	183	0.3	1130	95
600	-435	0.22	369	320	247	0.3	1145	98
800	-385	9	364	396	74	0.2	1180	35
1000	-405	0.17	354	380	263	0.1	1150	99

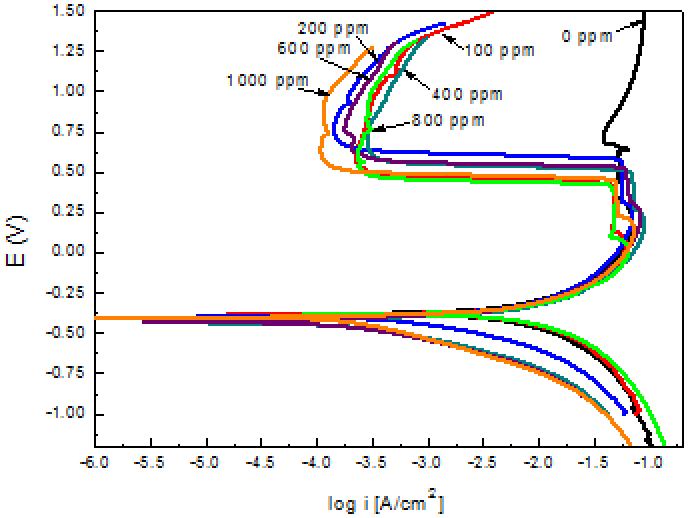

Figure 3 Effect of *Salvia hispanica* in the polarization curves for carbon steel in 0.5 M H_2SO_4

The effect of *Salvia hispanica* concentration in the polarization curves for 1018 carbon steel in 0.5 M H_2SO_4 is shown in **Figure 3**. It can be seen that in all cases, regardless of the inhibitor concentration, the steel shows an active-passive behavior. For the blank, uninhibited solution, the steel has an E_{corr} value of -385 mV and a corrosion current density value, I_{corr} very close to 14 mA/cm^2. As the applied potential is made more anodic, the anodic current density starts to in crease, with its surface covering with corrosion products which form a protective, passive layer around 680 mV, although this passive region is very narrow, since at a potential close to 725 mV the passive film is broken and a pitting, E_{pit}, or breakdown potential is achieved. The passive current density in this case was close to 40 mA/cm^2. As soon as 100 ppm of *Salvia hispanica* were added to the solution, the E_{corr} value remains the same but the I_{corr} decreases almost 50%, and the passivation current density decreases two orders of magnitude. The E_{pit} value also increases with the addition of the inhibitor, showing the beneficial effect of *Salvia hispanica*. Anodic current density values were unaffected by the presence of the inhibitor dislike the cathodic current density values, which indicates that the inhibitor does not reduce steel dissolution but it retards the cathodic hydrogen evolution reaction. Electrochemical parameters obtained from the polarization curves are shown in **Table 2**, where R_p was calculated by using the Stern-Geary equation. From this table it is seen that as the *Salvia hispanica* increases, the E_{corr} is slightly shifted towards more cathodic values and the corrosion current density value decreases, except at 800 ppm, where both E_{corr} and I_{corr} values were very similar to those obtained in the uninhibited solution. On the other hand, the I_{pas} and E_{pit} values remained more or less unaffected with a further increase in the inhibitor concentration; however, the lowest I_{pas} and highest E_{pit} values were obtained with the addition of 1000 ppm of inhibitor. Anodic Tafel slopes were not affected by the inhibitor whereas cathodic slopes were lowered by the addition of the inhibitor, indicating that Salvia *hispanica* is acting as a cathodic type of inhibitor. Finally, polarization resistance value, R_p increased with increasing the inhibitor concentration. Thus, by addition of the inhibitor to the solution, the change in the mechanism of corrosion process and an improvement in corrosion behavior are obvious. This could be mainly attributed to the adsorption process of active molecules, which additionally form protective layer on steel surface.

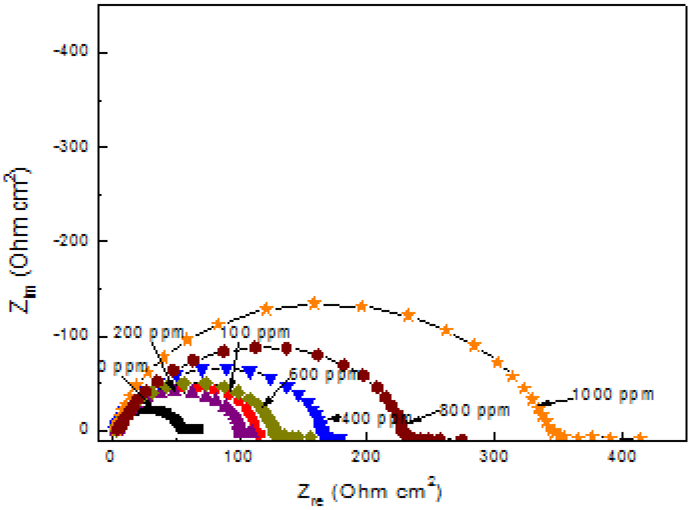

Figure 4 Effect of *Salvia hispanica* in the Nyquist diagrams for carbon steel in 0.5 M H_2SO_4.

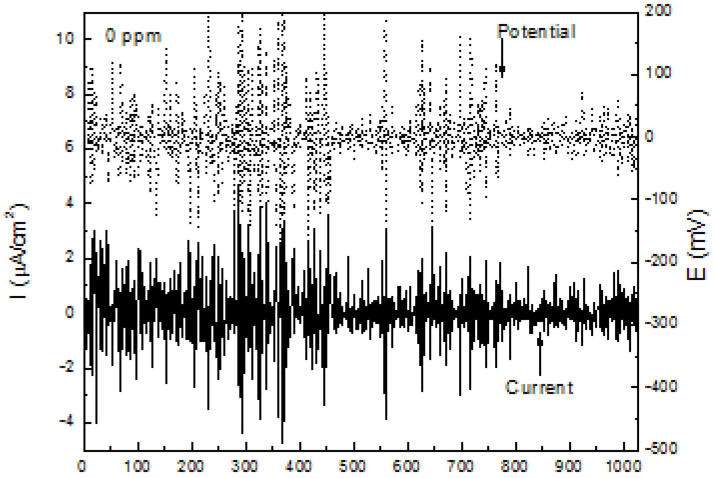

Figure 5 Noise time transients in current and in potential for carbon steel in uninhibited 0.5 M H_2SO_4 solution.

Nyquist diagrams for carbón steel in 0.5 M H_2SO_4 in the absence and presence of different concentrations of Salvia *hispanica* are shown in **Figure 4**. This figure shows that Nyquist diagram significantly changed with the addition of the inhibitor at its different concentrations since the semicircle diameter increases with the inhibitor concentration, thus, lowering the corrosion rate. Impedance data describe a single, depressed, capacitive-like semicircle, indicating that the corrosion process is charge transfer controlled [32].

Table 3 Electrochemical parameters obtained from the Nyquist diagrams for carbon steel in 0.5 M H_2SO_4 with different *Salvia hispanica* concentrations

C_{inh} (ppm)	R_{sol} (Ohm cm^2)	R_{ct} (Ohm cm^2)	Y_0 (Ohm^{-1} cm^{-2})	C_{dl} (μF cm^{-2})	n	I.E. (%)
0	5	47	0.00062	61.4	0.88	
100	4	116	0.00041	36.4	0.87	57
200	4	108	6.5×10^{-5}	26.8	0.83	54
400	2	177	4.4×10^{-5}	32.8	0.87	71
600	4	152	3.5×10^{-5}	27.7	0.88	67
800	5	270	1.7×10^{-5}	21.5	0.85	82
1000	5	409	8.3×10^{-6}	14.2	0.83	88

Stochastic fluctuations of potential or current occurring at the electrode/solution interface could be described using a generic term called electrochemical noise (EN). Since no external perturbation is required to be applied to corroding electrodes, EN would seem to be ideally suited to most fields of corrosion studies [33-34]. The time records of electrochemical current noise and potential for the carbon steel specimens after 1 h of immersion in 0.5M H_2SO_4 without *Salvia hispanica* after their trend removal are shown in **Figure 5**. Both time series show high frequency transients with a sudden increase in their intensity and a rapid decay in this value. Also, some low amplitude high frequency noise oscillations are present in the signals shown. The anodic, increase in the current value indicates a rupture of the passive film, whereas the slow decay in the current value indicates the rebuilding of the passive film. Thus, these transients indicate passive film rupture-repassivation events. Uruchurtu and Dawson have mentioned that passivation and breakdown on the corroding surface are responsible for occurrence of these irregular transients [35]. However, as soon as 100 ppm of Salvia *hispanica* are added to the acidic solution, **Figure 6a**, the intensity of the current transients are decreased at least one order of magnitude. Cheng et al. [36] and Hernandez et al. [37] have reported that an increase in the current is attributed either to film rupture or to the nucleation of pits, while the subsequent decrease in the current is attributed to the recovery of a passive film without propagation of pits. Similarly, Breslin and Rudd [38], Goellner et al. [39], Vazquez et al. [40] and Hladky and Dawson [41] have established that the positive or negative current transients indicates the preferential anodic dissolution of one of the two identical working electrodes

When 200 ppm of Salvia *hispanica* are added, **Figure 6b**, the intensity of the transients is decreased even more, almost three orders of magnitude, but now most of the transients show similar intensity, indicating that the steel is undergoing a uniform type of corrosion. The decrease in the current transients intensity could be attributed to a lower dissolution rate of carbon steel in acid solution. With a further increase in the inhibitor concentration up to 800 ppm, **Figure 6c**, brings an increase in the transients intensity up to 0.2 μA/cm^2 after 500 s of immersion in the solution. As it has been previously mentioned, every rise and drop of current might be associated with a possible breakdown and recovery of passive film on the surface of carbon steel. Sudden and sharp rise and drop of current in **Figure 6** (a and c) for the samples dipped in the solution with Salvia *hispanica* extract were recognized. It could be noted that the emergence and disappearance of these transients associated with breakdowns and the repassivation happens in very few seconds which might indicate the dynamic nature of passivation process on the corroding surface of the carbon steel [42]. However, the presence of Salvia *hispanica* extract even in small percentages significantly reduces the transients' intensity and frequency, indicating the hindrance of ongoing corrosion process on the passive layer. In the case of solution with 200 ppm of extract, it could be seen that the corrosion process (rupture of passive film on top of carbon steel) could be prevented properly and the steel shows susceptibility towards uniform type of corrosion. However, with the addition of 1000 ppm of Salvia *hispanica* extract, **Figure 6d**, both the intensity and frequency of the transients are decreased once again considerably, indicating a great reduction in both the corrosion rate and susceptibility to pitting corrosion.

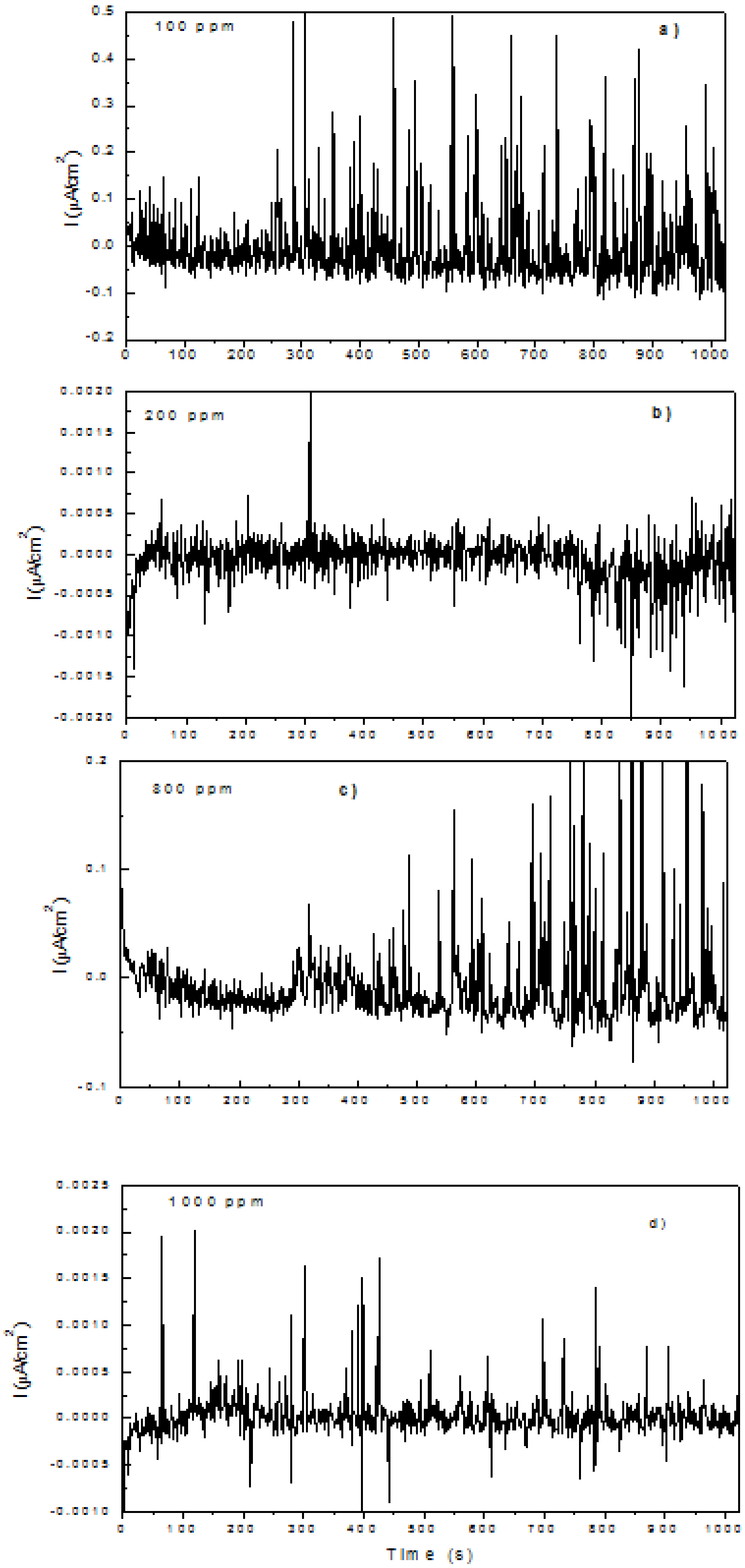

Figure 6 Noise time transients in current for carbon steel in uninhibited 0.5 M H_2SO_4 solution containing a) 100, b) 200, c) 800 and d)1000 ppm of *Salvia hispanica*

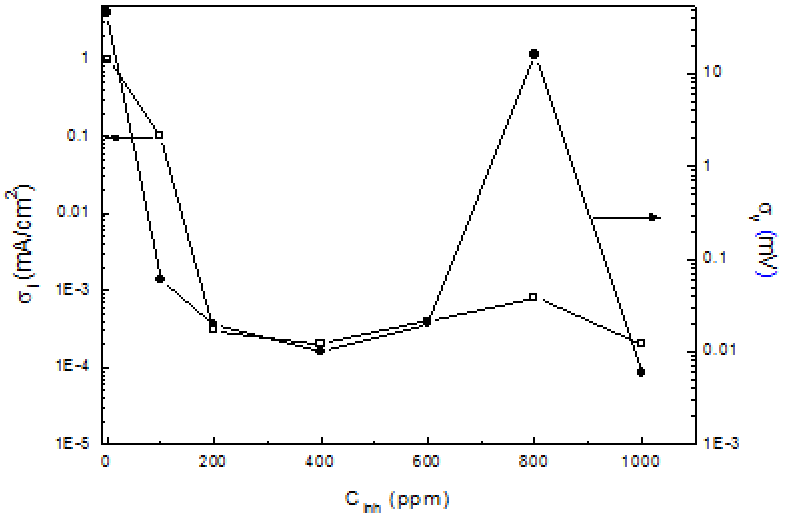

Figure 7 Effect of *Salvia hispanica* concentration in the potential noise standard deviation, σ_v, and current noise standard deviation, σ_i

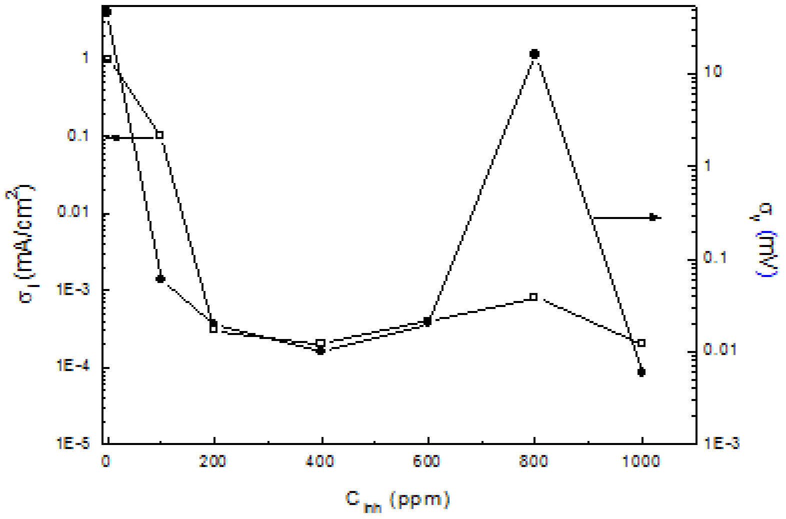

Figure 8 Effect of *Salvia hispanica* concentration in the R_p, R_{ct} and R_n values

To see the effect of inhibitor concentration in the noise transients intensity, **Figure 7** shows the variation of the standard deviation in current and in potential as a function of the Salvia *hispanica* extract concentration. It can be seen in this figure that a big decrease in the noise transients, both in current and in potential, as the inhibitor concentration increases, except when 800 ppm of inhibitor are added, where an increase in the noise transients exits. The noise data indicated that in absence of the inhibitor, transients data were present indicating film rupture/repasivation events. When the inhibitor was present, the frequency of these transients was decreased except at 800 ppm, where the frequency of these transients was similar to that obtained with uninhibited solution. Thus, the beneficial effect of Salvia *hispanica* in hindering not only the susceptibility towards uniform but to localized type of corrosion of carbon steel in acidic solution is obvious.

In order to see the agreement with the results obtained from DC polarization and EIS measurements and the EN data, **Figure 8** shows the variation of R_p, R_{ct} and R_n. Generally speaking, there is a good agreement between the different techniques, showing a trend to increase the resistance values as the inhibitor concentration increases, indicating a decrease in the corrosion rate with the addition of Salvia *hispanica*, obtaining the lowest corrosion rate with the addition of 1000 ppm of inhibitor, which is in agreement with the weight loss tests. The inhibitive behavior might be connected to adsorption of organic inhibitor molecules on the samples surface.However, at the highest inhibitor concentrations, the R_n values is almost one order of magnitude higher than those for R_p and R_{ct}. This could be due to the fact that R_n is related with localized corrosion events wheras R_p and R_{ct} are related with uniform corrosion events.

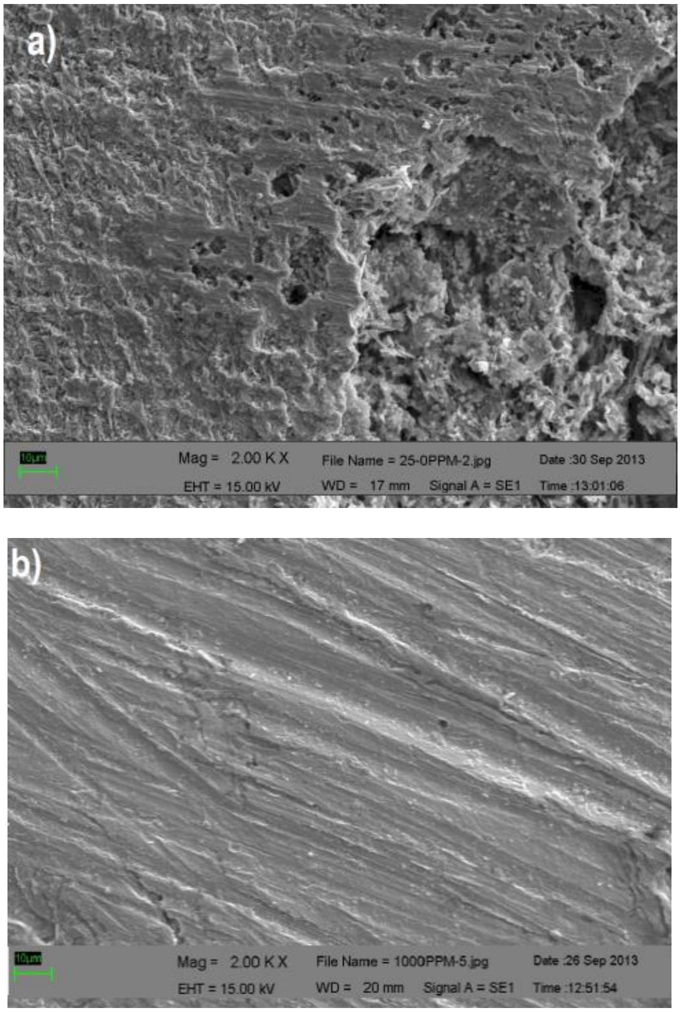

Figure 9 SEM micrograph of corroded specimen in 0.5 M H_2SO_4 solution containing a) 0 and b) 1000 ppm of *Salvia hispanica*

Micrographs of corroded specimens in absence and in presence of 1000 ppm of *Salvia hispanica* are shown in Fig. 9. Specimen corroded in the uninhibited solution, **Figure 9a**, shows a porous film on the external steel surface. It is clear from **Figure 9a** that the surface of carbon steel was strongly damaged in the H_2SO_4 solution without *Salvia hispanica* extract. Results show a severe dissolution of carbon steel in exposure with H_2SO_4 solution without inhibitor.

However, the visual performance of the steel surface exposed to H_2SO_4 solution was significantly changed in the presence of *Salvia hispanica* extract. It can be seen from **Figure 9b** that *Salvia hispanica* extract reduced dissolution rate of carbon steel considerably and more compact corrosion products, with a much less amount of porous were formed on the metal surface in presence of inhibitor. This finding can be understood from the smooth surface and protective film formation on the metal surface.

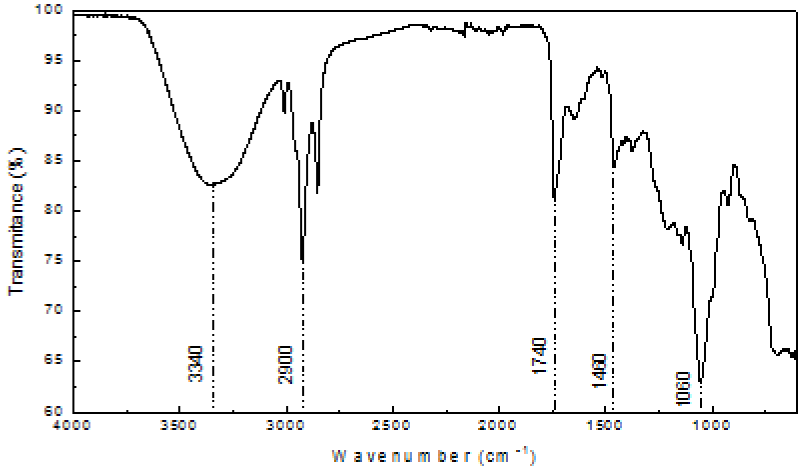

Figure 10 Infrared spectrum of the *Salvia hispanica* spectrum.

Corrosion inhibition by *Salvia hispanica* extract can be attributed to its active components adsorption on the surface of carbon steel and the formation of a barrier film which isolates the surface from corroding environment. Several active components such as myricetin, quercetin, kaemperol, caffeic acid, as well as highly unsaturated fatty acids (FA), with their main components being linoleic and α-linolenic acid with potent antioxidant activity, amino acids, proteins and vitamins have been identified from the *Salvia hispanica* extract [25-27]. An infrared spectrum of pure *Salvia hispanica* extract is shown in **Figure 10**, where it can be seen that the wide peak observed at 3340 cm^{-1} has been assigned to the OH group, whereas that observed at 2900 cm^{-1} has been assigned to the C-H group; the signal observed at 1460 cm^{-1} corresponds to the C=C group, that at 1050 cm^{-1} corresponds to the C-O group, and finally, the peak observed at 1740 cm^{-1} was assigned to the C=O group, all of them present in the linoleic and α-linolenic acids structure as shown in **Figure 10**.

Corrosion inhibition of a *Salvia hispanica* extract can be attributed to its active components adsorption on the surface of carbon steel and the formation of a barrier film which isolates the surface from corroding environment. Polarization curves have shown that the passive film formed on inhibited solution is improved when *Salvia* hispanica extract is added to the environment, whereas SEM micrographs have shown the presence of this film. Infrared data have indicated that linoleic and α-linolenic acids present in *Salvia hispanica* could be the responsible for the protection given to carbon steel. The organic molecules of inhibitors can be adsorbed on the carbon steel surface both through chemical and physical interactions. Results given above showed a pfysical type of adsorption.

The mechanism of action of corrosion inhibitor depends on the electron density and polarizability of the functional groups present in the molecule. Such determination of inhibition mechanism for *Salvia hispanica* is complicated by the fact that most of the constituents of laurel oil such as myricetin, quercetin, kaemperol, and caffeic acid etc. inhibit the corrosion reaction in different ways.

But, taking into account that the chemical composition of Salvia hispanica [17] reveals that linoleic and α-linolenic acids are the major compound (76.0%), it is plausible to consider that these compound are largely responsible for the corrosion inhibition. Owing to the adsorption of the inhibitor onto the surface of carbon steel, a thin film is formed on the metals surface to retard the corrosion.

Thus, in this case, active molecules such as linoleic and α-linolenic acids worked as filming inhibitors to control the corrosion rate of carbon steel. In wide range of inhibitors, π electrons and heteroatoms (e.g., O, N) are responsible for the inhibitors molecules adsorption on the metal surface and corrosion protection [8-11,43]. Moreover, inspection of these chemical structures reveals that these compounds can be adsorbed on the metal surface inside oxide layer via the lone pairs of electrons present on their oxygen, OH and COOH atoms. Instead of reacting with or removing an active corrosive species, the filming inhibitors act by a physical, according to a Langmuir type of adsorption, and decrease the attack by creating a barrier between the metal and its environment [44].

Conclusions

A study has been carried out on the use of *Salvia hispanica* as green inhibitor for carbon steel in sulfuric acid. Weight loss results showed that *Salvia hispanica* reduces the corrosion rate of carbon steel with its efficiency increasing with the inhibitor concentration due to a physical adsorption according to a Langmuir type of isotherm adsorption. Polarization curves showed that *Salvia hispanica* forms a passive layer on carbon steel with a passive current density value lower than that obtained for uninhibited solution for more than two orders of magnitude. EIS measurements showed that the corrosion process for carbon steel does not change with the addition of *Salvia hispanica* and is under charge transfer control. EN results indicated that the addition of *Salvia hispanica* decreased the pitting corrosion susceptibility of carbon steel. Finally, it was shown that the most important active elements of *Salvia hispanica* responsible of the decrease in the corrosion rate due to the formation of a protective, passive film are linoleic and α-linolenic acids.

References

[1] AH. Ostovari, SM. Peikari, SR. Shadizadeh, SJ. Hashemi, Corros. Sci. 51 (2009) 1935-1943.
[2] A. Ousslim, A. Aouniti, K. Bekkouch, A. Elidrissi, B. Hammouti, Surf. Review and Letters. 16 (2009) 787-791.
[3] M. Benabdellah, M. Benkaddour, B. Hammouti, M. Bendahhou, A. Aouniti, Appl. Surf. Sci. 252 (2006) 6212–6217.
[4] P.B. Raja, M.G. Sethuraman, Mater. Lett. 62 (2008) 113–116.
[5] L. Wang, J. Pu, H. Luo, Corros. Sci. 45 (2003) 677–683.
[6] A.Y. EL-Etre, Corros. Sci. 40 (1998) 1845–1850.
[7] I. Radojcic, K. Berkovic, S. Kovac, J. Vorkapic-Furac, Corros. Sci. 50 (2008) 1498–1504.
[8] UJ. Ekpe, EE. Ebenso, UJ. Ibok, J. W. Afr. Sci. Assoc. 39 (1994) 13-18.
[9] EE. Ebenso, UJ. Ibok, Discov. Innov. 10 (1998) 52-58.
[10] S. Martinez, I. Stern, J. Appl. Electrochem. 31 (2001) 973-979.
[11] A. Popova, M. Christov, S. Raicheva, E. Sokolova, Corros. Sci. 46 (2004) 1333-1341.
[12] KC. Emregul, M. Hayvali, Mater. Chem. Phys. 83 (2004) 209-215.
[13] EE. Oguzie, EE. Ebenso, Pigment Resin Technol. 35 (2006) 30-36
[14] EE. Oguzie, Corros. Sci. 50 (2008) 2993-3001.
[15] Subhadra Garai, Saraswati Garai, Parasuraman Jaisankar, J.K. Singh, Adirajan Elango, Corros. Sci. 60 (2012) 193–204.
[16] Jasna Halambek, Katarina Berkovi, Jasna Vorkapic-Fura, Mat. Chem. Phys. 137 (2013) 788-795.
[17] M. Behpour, S.M. Ghoreishi, M. Khayatkashani, N. Soltani, Mater. Chem. Phys. 131 (2012) 621-628.
[18] A. Khadraoui, A. Khelifa, H. Boutoumi, H. Hamitouche, R. Mehdaoui, B. Hammouti, S.S. Al-Deyab, Int. J. Electrochem. Sci., 9 (2014) 3334 - 3348.
[19] Pandian Bothi Raja, Ahmad Kaleem Qureshi, Afidah Abdul Rahim, Hasnah Osman, Khalijah Awang, Corros. Sci. 69 (2013) 292–301.
[20] A. A. Bushway, P. R. Belyea, R. J. Bushway, J. Food Sci. 46 (1981)1349-1350.
[21] R.Ayerza, J. Am. Oil Chem. Soc. 72 (1995) 1079–1081.
[22] M.S. Taga, E.E. Miller, D.E. Pratt, J. Am. Oil Chem. Soc. 61 (1984) 928–931.
[23] C.W. Weber, H.S. Gentry, E.A. Kohlhepp, P.R. McCrohan, Ecol. Food Nutr. 26 (1991), 119–125.

[24] B.Heuer, Z. Yaniv , I. Ravina, Ind. Crops and Products 15 (2002) 163–167.
[25] Z. Yaniv, D. Schafferman, M. Zur, I. Shamir, Ind. Crops and Products 6 (1997) 285–289.
[26] O.O. Xomet, N.V. Likhanova, M.A.D. Anguilar, E. Arce, H. Dorantes, P.A. Lozada, Mat. Chem. Phys. 110 (2008) 344–351.
[27] S. V. Ramesh, A. V. Adhikari, Mater. Chem. Phys. 115 (2009) 618-627.
[28] A. Popova, M. Christov, Corros. Sci. 48 (2006) 3208-3215.
[29] Y. Chen and M. Gopal, Corrosion/99, paper No. 197 (Houston, TX, NACE, 1999), Paper No.509.
[30] R.Moshrefi, M. Ghassem Mahjani, A.Ehsani, M.Jafarian, Anti Corros. Meth. Mat., 58 (2011) 250-257.
[31] J. C. Uruchurtu **,** J. L. Dawson, Corrosion, 43, (1987) 19-26.
[32] Y. F. Cheng, M. Wilmott, J. L. Luo, Corros. Sci. 41 (1999) 1245-1256.
[33] M.A. Hernandez, F.J. Rodriguez, J. Genesca, E. Garcia, F.J. Boerio, Corrosion/99, paper No. 197 (Houston, TX, NACE, 1999) Paper No, 197..
[34] C.B. Breslin, A.L. Rudd, Corros. Sci. 42 (2000) 1023-1039.
[35] J. Goellner, A. Burkert, A. Heyn, J. Hickling, H.U. Vogler, Corrosion/2000, paper No. 430 (Houston, TX, NACE, 2000) p. 430/1-430/14.
[36] R.C. Vazquez, G. Rios, A. Trejo, R.E. Rincon, J. Uruchurtu, J.M. Malo, Corrosion/2000, paper No. 696 (Houston, TX, NACE, 2000) p. 696/1-696/11.
[37] K. Hladky, J.L. Dawson, Corros. Sci. 22 (1982) 231-237.
[38] T. Anita, M.G. Pujar, H. Shaikh, R.K. Dayal, H.S. Khatak, Corros Sci 48 (2006) 2689–2710.
[39] S. Safak, B. Duran, A. Yurt, G. Turkoglu, Corros. Sci. 54 (2012) 251–259.
[40] R. Rosliza, A. Nora'aini, W.B. Wan Nik, J. Appl. Electrochem. 40 (2010) 833-839.

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