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Aqueous Extracts of *Santolina Pectinata* lag., Aerial Parts as Green Corrosion Inhibitor for Mild Steel in 1.0 M HCl

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Abstract- The protective effect of the aqueous extracts of *Santolina pectinata* (Lag.) aerial parts (Odorized aqueous extract (AE1) and Deodorized aqueous extract (AE2)) on the corrosion of mild steel (MS) in 1M HCl solution were tested by the weight loss (WL) analysis, potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS) methods. The inhibition efficiency (%IE) is highly raised with increasing of the dose of inhibitors and increased slightly for AE1 but decreased for AE2 with the rise of the temperature media (308-343K). The charge transfer process mainly controls the results of EIS measurements, PDP measurements showed that the studied inhibitors performs as a mixed-type inhibitor. Furthermore, the adsorption on the steel is made according to the Langmuir model of each inhibitor.

Keywords- *Santolina pectinata*; Aqueous extracts; (Z)-heptadeca-10,16-dien-7-one; Mild steel; Corrosion inhibition

1. INTRODUCTION

MS tendency to corrosion is caused by aggressive acids such as hydrochloric and sulphuric acids, which are widely used in the pickling processes of metals [1,2]. Therefore,

tremendous efforts are being made in order to block or delay to the limit the attack of this metal in numerous corrosive media. As a matter of fact, the use of the corrosion inhibitors is viewed as the best way to prevent the corrosion of metal surfaces [3]. Almost all inhibitors of corrosion are synthetic organic compounds [4]. Owing to the high cost, toxicity, and dangerous effects of synthesized corrosion inhibitor [5,6], the search for green alternatives that are eco-friendly and nontoxic to protect health and insure human security is at the present time interesting [7,8]. In our laboratory, a great deal of research has been carried out to study inhibitive effect by means of plant extract on the corrosion of steel in acidic media [9-13]. In this study, our focus is chiefly put on aqueous extracts of *Santolina pectinata (Lag.)* (Figure 1). Almost all constituents from plants that have noted as a corrosion inhibitor are terpenes, steroids, sugars, tannic acid, flavonoids etc. and the formation of the protective film on the surface of steel is improved during the presence of thepolycyclic compounds [14].

Fig. 1. *Santolina pectinata (Lag.)* in its native habitat in south-eastern of Morocco

Santolina pectinata Lag. is, botanically, a synonym of *Santolina rosmarinifolia* subsp. *pectinata* Lag. Maire. It is an endemic herbaceous medicinal aromatic plant originating from North Mediterranean, mainly found in the Iberian System, North Africa and principally in the eastern Balticmountains [15]. In Morocco, this species, known locally as “tayrart”, is a spontaneous plant which often grows, frequently with *Cedrus atlantica* and *Abie spinsapo*, on calcareous substrates in 1500 m above sea level. On the other hand, it is associated with *Quercusilex* and *Q. canariensis* at lower levels [16]. *S. pectinata* Lag.is an infrequently studied Iberian–Maghreb endemic and, to our knowledge, only one study has investigated the chemical composition of essential oil of this plant collected at Pontones (Jakn) from Spain [17]. The phytochemical analysis and biological characteristics of *Santolina* species from various origins have been also widely dealt with [18]. Previous chemical studies have shed the light on the presence of terpenoids, particularly flavonoids and coumarins and other secondary metabolites [19-22]. Many *Santolina* species have been used in traditional

medicine for a long time [18,23,24]. The main objective of the current research is to study the preventive impact of AE1 and AE2 on corrosion of MS in hydrochloric acid solution using WL measurement, PDP, and EIS.

2. EXPERIMENTAL

2.1. Inhibitors

The experimental phase followed in the current study such as Plant material and preparations of the aqueous extract (AE1 and AE2) have been mentioned according to a formerly described experimental procedure in our work [25].

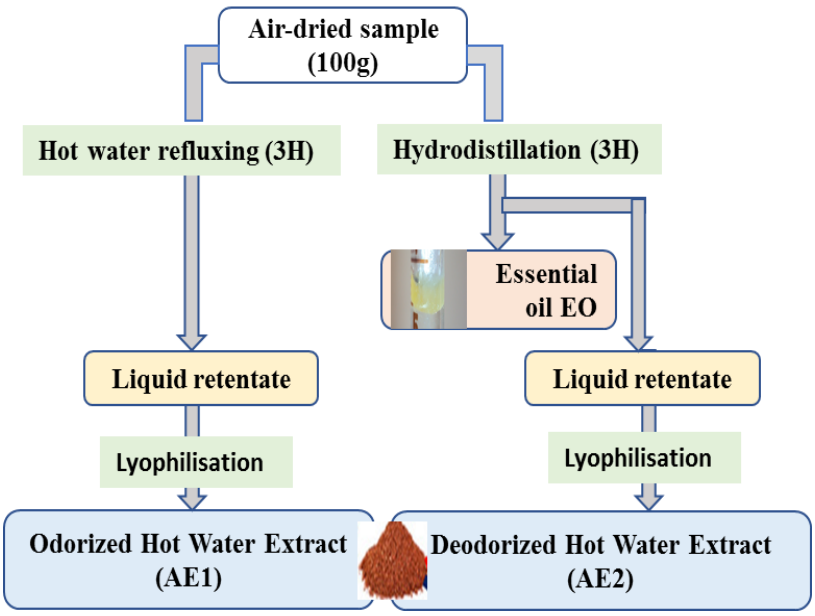

Fig. 2. Scheme of the extraction methods of aqueous extracts from aerial parts of *Santolina pectinata* Lag

2.2. Corrosion test

2.2.1. Preparation of materials

Corrosion tests were realized on the MS segments with dimension of 2 cm×2 cm×0.05 cm; the MS metal presents the subsequent composition with mass percentage (%): P 0.09, Si 0.38, Al 0.01, Mn 0.05, C 0.21, S 0.05 and Fe 99.21. Before each corrosion test, the MS segments were mechanically grazed with sequential grades emery papers (400, 600 and 1200 grit), and ensuing rinsed and degreased with distilled water and acetone respectively, then dried and weighed. The corrosive acid solution is a molar hydrochloric acid (1 M of HCl), was prepared from concentrated commercial acid of HCl (37%) by dilution with distilled water.

2.2.2. Weight loss measurements

The prepared MS segments are weighed; then they are immersed in 1M HCl with and without different concentrations from 0.25 to 3 $g.L^{-1}$ of inhibitors under different temperatures of 308 to 343 K, after 6 h of immersion, the specimens of steel were carefully washed in double-distilled water, dried and then weighed. The rinse removed loose segments of the film of the corroded samples. Inhibitory efficiency (*IE %*) is determined basing on the MS corrosion rates *W* ($mg.cm^{-2}.h^{-1}$) according to the subsequent relationship: (Eqs. 1,2):

$$W=\frac{\Delta m}{S.t} \quad (1)$$

$$E_w\ \%= \frac{W_{corr}- W_{corr(inh)}}{W_{corr}}\times 100 \quad (2)$$

where Δm (mg) is the specimen weight before and after immersion in the tested solution, W_{corr} and $W_{corr(inh)}$ are the values of corrosion weight losses ($mg/cm^2.h$) of MS in uninhibited and inhibited solutions, respectively, S is the area of the MS specimen (cm^2) and t is the exposure time (h). The degree of surface coverage was calculated using:

$$\theta= \frac{W_{corr}- W_{corr(inh)}}{W_{corr}} \quad (3)$$

where θ is surface coverage; $W_{corr(inh)}$ is corrosion rate for steel with of inhibitor, W_{corr} is corrosion rate for steel without of inhibitor.

2.2.3 Electrochemical studies

The working electrode (WE) in the form of disc cut from steel has a geometric area of 1 cm^2 and is embedded inpolytetrafluoroethylene (PTFE). A saturated calomel electrode (SCE) electrode and a disc platinum electrode were used respectively as reference (RE) and counter electrodes (CE), respectively.

The corrosion inhibition efficiency was derived as given below:

$$E_i(\%) = \left(\frac{I_{corr}-I_{corr,inh}}{I_{corr}}\right)\times 100 \quad (4)$$

where I_{corr}, $I_{corr,inh}$ and represent the corrosion current densities not including and by way of the existence of inhibitor.

Electrochemical impedance spectroscopy measurements were achieved at the open circuit potential for the frequency range of 100 KHz to 10 mHz, using a peak-to-peak voltage excitation of 10 mV.

The inhibition efficiency E_{EIS} (%) was calculated from R_t using the following equation:

$$E_{EIS}(\%) = \left(\frac{R'_t - R_t}{R'_t}\right) \times 100 \quad (5)$$

where R_t and R'_t are the charge-transfer resistance values without and with inhibitor respectively. R_t is the diameter of the loop.

The double layer capacitance (C_{dl}) and the frequency at which the imaginary component of the impedance is maximal ($-Z_{max}$) are found determined by Eq. (6):

$$C_{dl} = \frac{1}{2.\pi.f_{max}.R_t} \quad (6)$$

where $\omega = 2\,\pi.\, f_{max}$

f_{max} is the frequency for which the imaginary part of the impedance is maximum.

3. RESULTS AND DISCUSSION

3.1. Effect of both concentration and temperature

In this paragraph, we determine the WL of the MS sample in corrosive solution with and without different concentrations of AE1 and AE2 at different temperatures (308-343K). The values of percentage inhibition efficiency E_w (%) and the corrosion rate (W) obtained are summed up in Table 1.

Table 1. Weight loss results for MS in 1 M HCl with and without different concentrations of aqueous extracts (AE1 and AE2) at different temperatures

	C (g/L)	308 K		313 K		323 K		333 K		343 K	
		W (mg/cm^2.h)	E_w (%)	W (mg/cm^2.h)	E_w (%)	W (mg/cm^2.h)	E_w (%)	W (mg/cm^2.h)	E_w (%)	W (mg/cm^2.h)	E_w (%)
	1M HCl	0.942	……	1.751	……	2.836	……	3.641	……	6.301	……
AE1	0.25	0.121	87.15	0.221	87.37	0.342	87.94	0.434	88.08	0.706	88.79
	0.50	0.070	92.56	0.128	92.68	0.207	92.70	0.261	92.83	0.446	92.92
	1.00	0.067	92.88	0.127	92.74	0.201	92.91	0.255	92.98	0.437	93.06
	2.00	0.065	93.09	0.112	93.60	0.174	93.86	0.218	94.01	0.366	94.19
	3.00	0.055	94.16	0.098	94.40	0.154	94.56	0.187	94.86	0.317	**94.97**
AE2	0.25	0.177	81.21	0.470	73.15	1.113	60.75	1.574	56.77	3.220	48.89
	0.50	0.146	84.50	0.360	79.44	1.047	63.08	1.452	60.12	3.127	50.37
	1.00	0.130	86.19	0.326	81.38	0.904	68.12	1.286	64.68	2.745	56.43
	2.00	0.111	88.21	0.276	84.23	0.643	77.33	1.083	70.25	2.465	60.88
	3.00	0.087	90.76	0.237	86.46	0.560	80.25	0.861	76.35	1.890	**70.00**

The results (Table 1) show that inhibitive efficiency E_w (%) goes up considerably with the rises in concentration of aqueous extracts, indicating that the extent of inhibition depends on the amount of AE1 and AE2. This is due probably to the increase of the surface coverage θ for the studied adsorption; thus could be ensured the apparition of the defensive deposit which limits the dissolution of the MS. Besides, we notice that these findings demonstrate that the effectiveness E_w (%) depends on the temperature (308-343 K). More than that, when the concentration reached to 3 g/L of AE1, the effectiveness (E_w) reached a high value of 94.97 % in 1 M HCl solution at 343 K, which indicates that AE1 the best inhibitor. The distinction between AE1 and AE2 inhibitory effectiveness could be explained by the nature of the molecules of these inhibitors. Such behavior can be explained by adsorption coverage of aqueous extracts on the metal surface, which rises with concentration of inhibitor [26].

3.2. Polarization tests

The PDP curves of MS in 1 M HCl solution without and with a concentration of aqueous extracts at 308 K are given in Fig. 3 and 4. Current density (I_{corr}), corrosion potential (E_{corr}), cathodic and anodic Tafel slopes (βc, βa) are the polarization parameters. These parameters and inhibition efficiency (E_i%) are calculated from the Tafel curves and are summed up in Table 2.

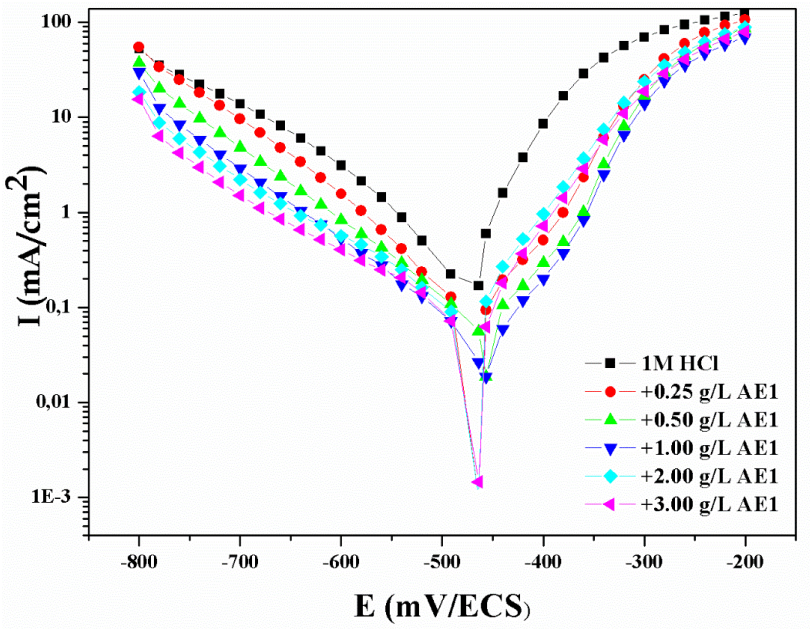

Fig. 3. Polarization curves of MS in 1 M HCl with and without AE1 at various concentrations at 308 K

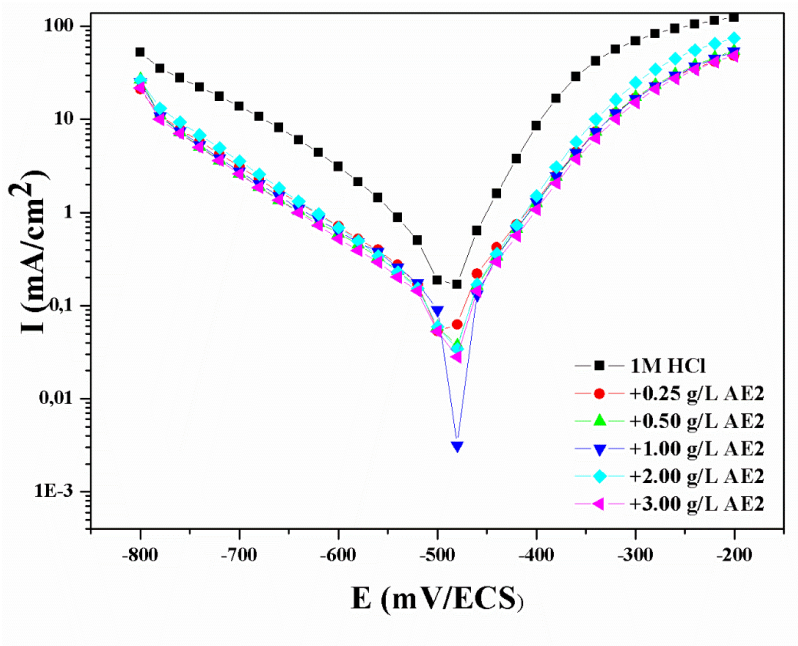

Fig. 4. Polarization curves of MS in 1 M HCl with and without AE2 at various concentrations at 308

From Figs. 3 and 4, we remarked that both anodic and cathodic parts of the polarization curves of each inhibitor shift to lower currents densities by increasing inhibitors concentration. This result can be attributed that there is an inhibition power of AE1 and AE2 to stop oxidative and reductive reactions which could be caused the corrosion phenomenon on the MS surface.

Table 2. Polarization parameters for the MS in 1 M HCl with and without various concentrations of aqueous extracts from *Santolina pectinata* Lag. aerial parts (AE1and AE2)

	C (g/L)	- E_{corr} (mV/SCE)	I_{corr} (mA cm^{-2})	-βc (mV dec^{-1})	βa (mV dec^{-1})	EI_{PDP} %
1M HCl		490.0	0.5779	147.4	74.8	.....
AE1	0.25	490.0	0.0750	139.7	79.0	87.02
	0.50	460.0	0.0700	140.5	78.0	87.88
	1.00	470.0	0.0607	157.1	76.1	89.49
	2.00	470.0	0.0565	155.1	75.0	90.22
	3.00	450.0	0.0390	132.3	74.1	**93.25**
AE2	0.25	460.0	0.1605	198.9	82.4	72.22
	0.50	470.0	0.1294	154.9	73.5	77.60
	1.00	470.0	0.0984	159.9	75.5	82.97
	2.00	490.0	0.0949	141.5	74.4	83.58
	3.00	490.0	0.0848	140.7	78.1	**85.32**

From Table 2 shows that the corrosion current densities (I_{corr}) goes down significantly by increasing AE1 and AE2 concentration. Consequently, the inhibition efficiency EI_{PDP} (%) increases with increasing of inhibitors concentration to reach its maximum values 93.25 and 85.32 % at 3 g/L for the AE1 and AE2 respectively, which indicates that AE1 the best inhibitor. These results suggested that inhibitor is toughly adhered to the MS surface forming a protective layer, which stays electrochemical reactions to occur onto metal surface. Therefore, the maximum displacement in E_{corr} value was 40 mV for AE1 and 30 mV for AE2 which indicates that the aqueous extracts acts as mixed-type [27].

3.3. Electrochemical impedance spectroscopy (EIS)

Nyquist plots of MS in 1M HCl at various concentrations of inhibitors is given in Figs. 5 and 6.

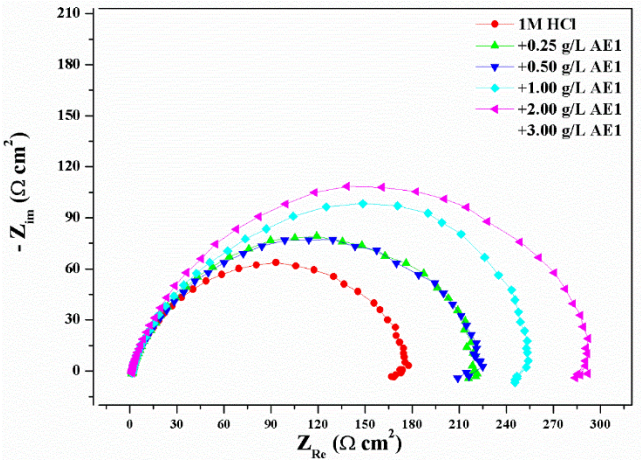

Fig. 5. Nyquist plots of MS in 1 M HCl without and with different concentrations of AE1 oil at 308 K

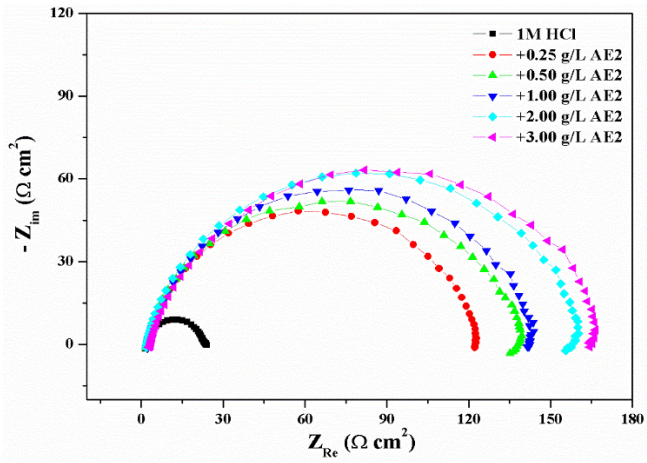

Fig. 6. Nyquist plots of MS in 1 M HCl without and with different concentrations of AE2 oil at 308 K

As exposed in Figs 5 and 6, we perceived that the addition of each inhibitor to the corrosion medium clues to the increase of the size of the capacitive loops. Moreover, the presence of a unique capacitive loop indicated that the studied adsorption is governed through a charge transfer process [28].

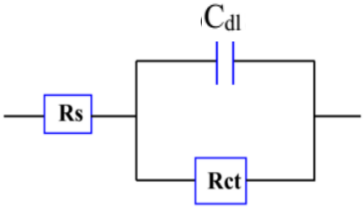

Fig. 7. The equivalent circuit used to fit the EIS experiment data

Table 3. Parameters of EIS of MS in 1M HCl without and with various concentrations of aqueous extracts AE1 and AE2 at 308 K

.	C (g/L)	$-E_{corr}$ (mV/SCE)	R_t (Ω cm^2)	f_{max} (H_Z)	Cdl (μF cm^{-2})	E_{EIS}%
1M HCl		490.1	21.69	100	73.37	.....
AE1	0.25	490.0	178.6	20	44.55	87.85
	0.50	460.0	225.3	20	35.32	90.37
	1.00	470.0	226.7	20	35.10	90.43
	2.00	470.0	254.0	20	31.32	91.46
	3.00	450.0	293.3	20	27.13	**92.60**
AE2	0.25	460.0	123.5	25	51.54	82.43
	0.50	470.0	137.1	25	46.43	84.17
	1.00	470.0	142.3	25	44.73	84.75
	2.00	490.0	159.6	25	39.88	86.40
	3.00	490.0	173.8	25	36.62	**87.52**

What is more is that, these capacitive loops are not the perfect semicircles because of a frequency dispersion effect [29] and has been attributed to roughness and other inhomogeneities of solid surface [30]. The electrochemical parameters of Rt, C_{dl} and f_{max} derived from Nyquist plots and inhibition efficiency E_{EIS} (%) are calculated and listed in Table 3. We can conclude from the data obtained about impedance (Table 3) the increase of inhibitor concentration leads also to the increase Rt values and consequently the inhibitive efficiency (E_{EIS}) goes up to 92.60 and 87.52% at 3 g/L for AE1 and AE2, respectively, AE1 exhibits better inhibitive performance than AE2. Again, AE1 shows itself to be the best aqueous extract of *Santolina pectinata* Lag similar to that obtained for Icorr in this current

research. The goes down significantly in Cdl is due to the adsorption of the AE1 and AE2 on the MS surface leading to the formation of film or complex from acidic solution [31]. The (EIS) findings of these capacitive loops are simulated by the equivalent circuit are given in Fig. 7. In the equivalent circuit, R_s is the electrolyte resistance, R_t the charge transfer resistance and C_{dl} is the double layer capacitance [32].

3.4. Kinetic/Activation parameters

The following study consists to calculate activation parameters of the corrosion reaction such asactivation energy $E°_a$ activated entropy $\Delta S°_a$ and activation enthalpy $\Delta H°_a$ were calculated using the Arrhenius and its alternative formulation called transition state Eqs 7 and 8 [33]:

$$W = A\exp\left(-\frac{E°_a}{R\,T}\right) \tag{7}$$

$$W = \frac{R.T}{Nh}\exp\left(\frac{\Delta S°_a}{R}\right).\exp\left(-\frac{\Delta H°_a}{R\,T}\right) \tag{8}$$

where $E°_a$ is the apparent activation corrosion energy, T is the absolute temperature, R is the universal gas constant, A is the Arrhenius pre-exponential factor, h is the Plank's constant. N is the Avogadro's number, $\Delta S°_a$ is the entropy of activation and $\Delta H°_a$ is the enthalpy of activation.

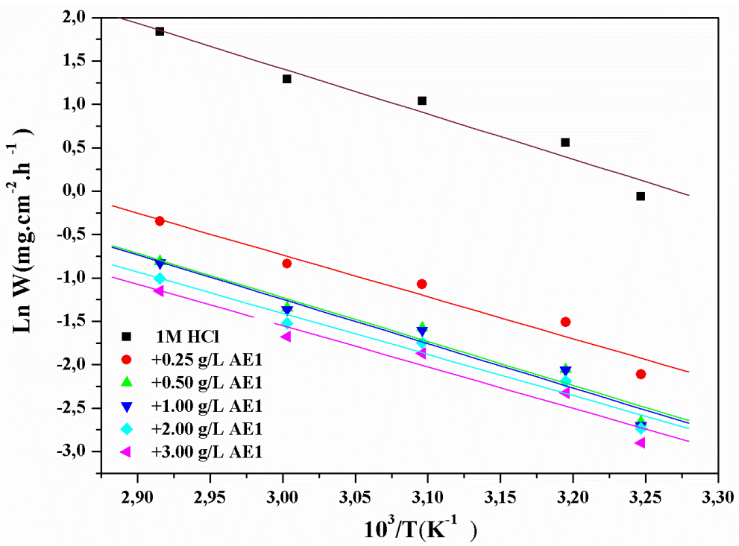

Fig. 8. Arrhenius plots for MS corrosion rates (W) in 1M HCl in the absence and presence of different concentrations of AE1

The activation energies are deduced from the slope ($-E°_a/R$) of the logarithm of the corrosion rate (W) versus reciprocal absolute temperature (Figs. 8 and 9) and their values were reported in Table 4. Using more Eq. (8) plots of Ln (W/T) versus $10^3/T$ (Figs. 10 and 11) gave straight lines with a slope of ($-\Delta H°_a/R$) and an intercept of ($Ln(R/Nh) + (\Delta S°_a/R)$) from which the values of $\Delta H°_a$ and $\Delta S°_a$ were calculated and are summed up in Table 4.

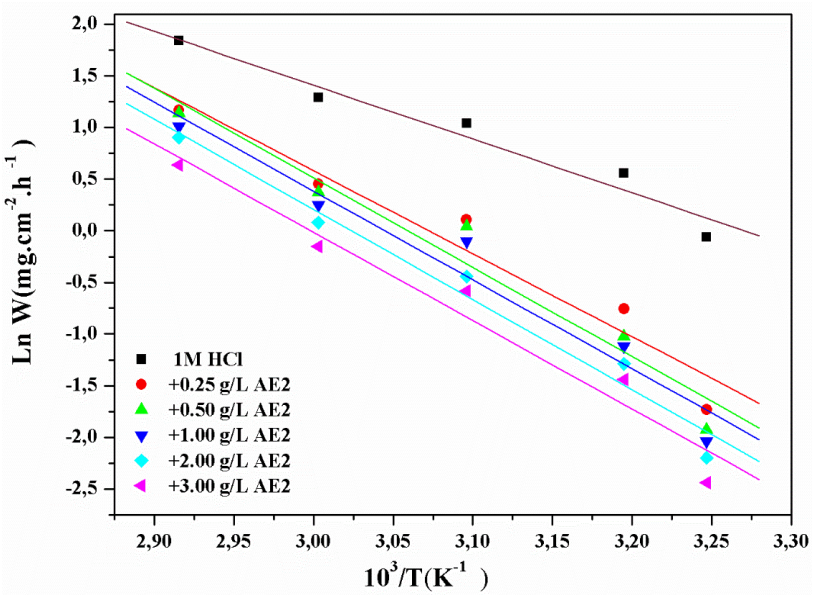

Fig. 9. Arrhenius plots for MS corrosion rates (W) in 1M HCl in the absence and presence of different concentrations of AE2

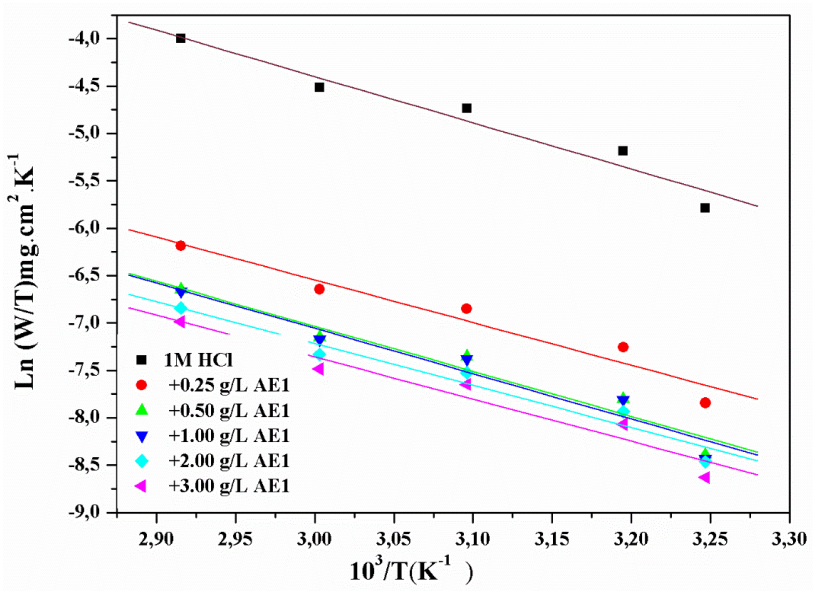

Fig. 10. Transition-state plot for MS corrosion rates (W) in 1 M HCl in the absence and presence of various concentrations of AE1

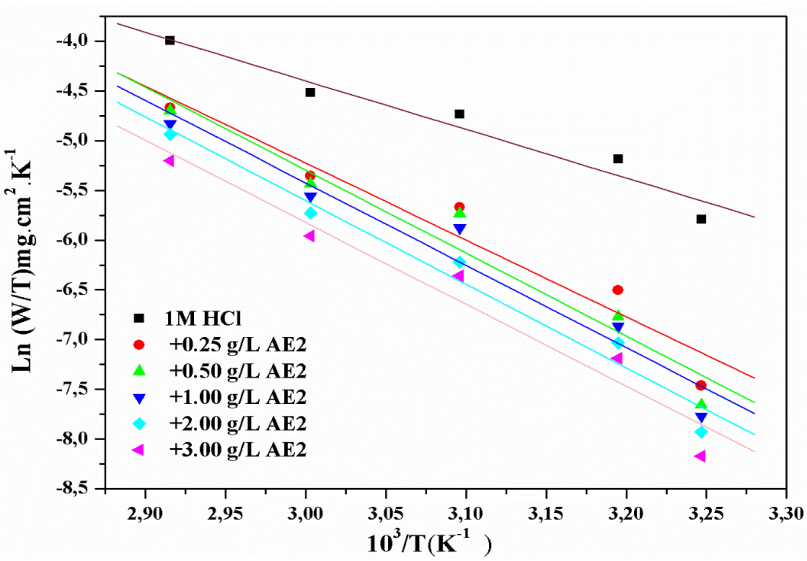

Fig. 11. Transition-state plot for MS corrosion rates (W) in 1 M HCl in the absence and presence of various concentrations of AE2

It is crystal clear from the data in Table 4 that the increase of E_w (%)with temperature and the lower value of $E°_a$ are in favor of chemisorption for AE1.Generally, the increase of E_w and the lower value of $E°_a$ of the corrosion process in an inhibitor's presence when compared to that in its absence is attributed to its chemisorption on the steel surface, while the opposite is the case with physical adsorption [34], which indicates the formation of an adsorption film of physical electrostatic nature for AE2.

Table 4. Activation parameters $E°_a$, $\Delta S°_a$, $\Delta H°_a$ of the dissolution of MS in 1 M HCl without and with various concentrations of AE1 and AE2

C (g/L)		$E°_a$ (KJ. mol^{-1})	$\Delta H°_a$ (KJ. mol^{-1})	$E_a - \Delta H°_a$ (KJ. mol^{-1})	$\Delta S°_a$ (J. mol^{-1}. K^{-1})
AE1	1M HCl	43.35	40.65	2.70	-112.32
	0.25	40.13	37.43	2.70	-139.82
	0.50	42.20	39.50	2.70	-137.32
	1.00	42.46	39.77	2.70	-137.07
	2.00	39.45	36.74	2.70	-147.45
	3.00	39.65	36.95	2.70	-148.03
AE2	0.25	66.96	64.25	2.71	-48.41
	0.50	72.05	69.34	2.71	-33.69
	1.00	71.58	68.88	2.71	-36.18
	2.00	72.64	69.93	2.71	-34.52
	3.00	71.20	68.49	2.70	-40.67

Additionally, the positive value of standard activation enthalpy indicate the endothermic dissolution phenomenon of mild steel [35]. However, the negative values of entropy of activation($\Delta S°_a$) implies that the activated complex in the rate determining step represents an association rather than a dissociation step, meaning that a decrease in disordering takes place on going from reactants to the activated complex [36].

3.5. Adsorption isotherm and thermodynamic parameters

In this work, we evaluated several types of adsorption isotherm (Frumkin, Temkin and Langmuir). Langmuir was found to give the best description on the adsorption of aqueous extracts. Figs. 12 and 13 show straight line ($R^2 \approx 1$) by plotting C/θ with respect to the concentration and the corresponding equation (Eq. (9)) is as follows [26]. Adsorption constant (K_{ads}) value was determined from the intersection of the obtained straight curve and C/θ axis (Table 5):

$$C/\theta=1/K_{ads} +C \quad (9)$$

where C is the concentration of inhibitor (in $mol.L^{-1}$), Θ symbolizes surface coverage and K_{ads} represents the constant of adsorption (in $L.mol^{-1}$).

The equilibrium adsorption constant, K_{ads} is related to the standard Gibb's free energy of adsorption ($\Delta G°_{ads}$) with the following equation [37]:

$$K_{ads}=1/55.5 \exp(-(\Delta G°_{ads})/RT) \quad (10)$$

where R, T, 55.5 are gas constant, absolute temperature of experiment the molar concentration of water in solution in respectively.

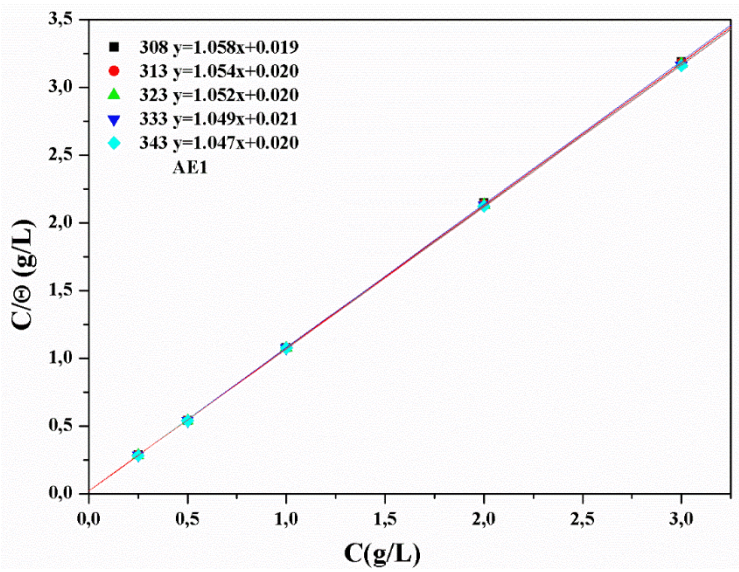

Fig. 12. The Langmuir adsorption isotherm of AE1 on the MS surface in 1 M HCl at different temperatures

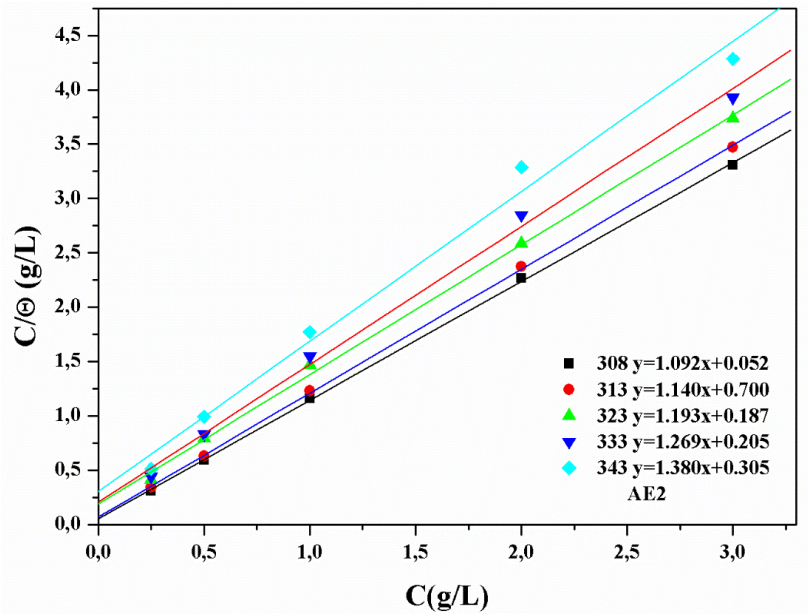

Fig. 13. The Langmuir adsorption isotherm of AE2 on the MS surface in 1 M HCl at different temperatures

We can conclude from the Table 5 that the K_{ads} values goes down with increasing temperature showing that the molecules of AE2 were physically adsorbed on the steel surface, But the K_{ads} remains quasi constant of AE1 with the rise of the temperature media (308-343K).

Table 5. Thermodynamic parameters for adsorption of AE1 and AE2 on MS steel in 1 M HCl solution at various temperatures from Langmuir adsorption isotherm

	T(K)	R^2	K_{ads} (L. g^{-1})	$\Delta G°_{ads}$ (KJ. mol^{-1})
AE1	308	0.999	51.81	-27.82
	313	0.999	48.54	-28.07
	323	0.999	49.57	-29.06
	333	0.999	46.51	-29.77
	343	0.999	48.54	-30.79
AE2	308	0.999	19.27	-25.28
	313	0.999	14.26	-24.91
	323	0.998	5.33	-23.06
	333	0.996	4.87	-23.52
	343	0.989	3.27	-23.09

Table 6. Chemical composition of *S. pectinata Lag.* aerial parts essential oil from south-eastern of Morocco

N [a]	Components [b]	Ir Lit [c]	Ir apo [d]	Ir pol [e]	% [f]
1	Cineole 1,8	1024	1019	1206	0.1
2	Limonene	1024	1021	1199	0.2
3	(Z)-b-Ocimene	1029	1025	1231	1.6
4	(E)-b-Ocimene	1041	1036	1247	0.1
5	Nonanal	1076	1081	1394	0.1
6	Linalool	1086	1083	1544	0.2
7	Cis Sabinene hydrate	1083	1097	1553	0.4
8	β-Thujone	1103	1107	1422	0.4
9	Camphor	1123	1121	1519	0.5
10	Lyratol	1150	1138	1779	0.4
11	Borneol	1150	1149	1689	0.3
12	α-Terpineol	1176	1172	1684	0.2
13	Estragole	1175	1175	1661	0.5
14	Cuminaldehyde	1217	1212	1779	0.9
15	p-Anisaldehyde p	1215	1214	2028	0.6
16	Peryllaldehyde	1248	1248	1768	1.6
17	Lyratyl acetate	1270	1257	1634	0.2
18	E-Anethole	1262	1263	1813	4.1
19	Bornyl acetate	1270	1269	1573	0.8
20	Thymol	1266	1272	2190	0.2
21	Undecan-2-one	1273	1276	1586	0.6
22	Carvacrol	1278	1278	2214	0.6
23	α-Copaene	1379	1371	1489	0.6
24	Methyleugenol	1369	1374	2000	0.2
25	Isocaryophyllene	1409	1403	1570	0.2
26	E-Caryophyllene	1421	1416	1593	6
27	E-β-Farnesene	1446	1447	1661	1.2
28	α-Curcumene	1473	1470	1765	0.3
29	Germacrene D	1479	1475	1701	1.3
30	Spathulenol	1572	1564	2105	1.1
31	Caryophyllene oxyde	1578	1570	1967	3.4
32	Dillapiole	1590	1591	2338	1.2
33	Tau cadinol	1633	1625	2154	1.3
34	**(Z)-heptadeca-10,16-dien-7-one**		**1834**	**2242**	**28**
Total identified					**59.4**
Hydrocarbon monoterpenes					**1.9**
Oxygenated monoterpenes					**6.8**
Hydrocarbon sesquiterpenes					**9.6**
Oxygenated sesquiterpens					**5.8**
Nonterpenic oxygenated compounds					**28.7**
Others					**6.6**

[a] Order of elution is given on apolar coloumn (Rtx-1)
[b] Normalized % abundances of oil are given on the apolar column
[c] Retention indices from literature on theapolar column
[d] Retentionindices on the Rtx-1 apolarcolumn
[e] Retentionindices on the Rtx-wax polarcolumn
[f] Percentage composition is given on the apolar column

AE1 has a greater value indicating its ability to be absorbed easily and strongly [38]. Also, it is clear that, the negative values of $\Delta G°_{ads}$ suggest that the adsorption of inhibitor molecules onto MS surface is a spontaneous phenomenon. Here, the calculated ΔG^0_{ads} values are ranging from -23.06 to -30.79 $kJ.mol^{-1}$; showing that the adsorption mechanism of each inhibitor on MS in 1 M HCl solution at the studied temperatures may be a combination of both electrostatic-adsorption and chemisorption [37].

Molecule adsorption of the AE1 and AE2 at the MS surface can be attributed to the presence of electronegative elements such as oxygen and nitrogen atoms and also to the presence of π-electrons. The high inhibitive performance of AE1 is due probably to the synergic effect of their volatile especially, the non terpenic oxygenated compound (Z)-heptadeca-10,16-dien-7-one which represented the major constituent with 28 % of the essential oil from *Santolina pectinata* Lag. (Figure 14 and Table 6) [39] and non-volatile compounds.

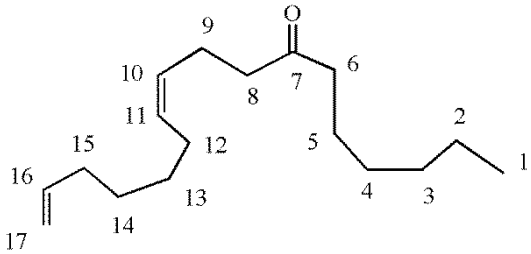

Fig. 14. Chemical molecular structure of (Z)-heptadeca-10,16-dien-7-one

4. CONCLUSION

To sum up, the aqueous extracts of *Santolina pectinata*. Lag showed significant corrosion inhibition activity. PDP curves demonstrate that inhibitors acts as a mixed type inhibitor in 1 M HCl. The inhibition is accomplished by a mixture physical and chemical adsorption of the extract components on the MS surface leading to a reduction in the double layer capacitance as well as an increase in the charge transfer resistance. The adsorption of AE1 and AE2 spontaneous and obeys the Langmuir isotherm. The high protective efficiency of AE1 is due to the synergic Impact of their volatile and nonvolatile molecules. It should be noted that the (Z)-heptadeca-10,16-dien-7-one was identified for the first time and previously undescribed in Santolina species essential oils. In short, this study has given the originality and specificity of S. pectinata from Morocco.

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