Journal of Basic and Environmental Sciences 2 (2015) 110– 122 **ISSN 2356-6388**

Inhibition of acid Corrosion of Aluminum using Salvadore persica

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Article Information

Received; 5 Nov 2015
In Revised form; 20 Nov. 2015
Accepted; 5 Sep. 2015

Keywords:
Aluminum;
Corrosion inhibition;
Natural product;
Salvadore persica.

Abstract

The inhibitive action of the aqueous extract of Salvadore persica toward acid corrosion of aluminum is tested using weight loss, thermometry, hydrogen evolution, polarization techniques and FTIR spectroscopy. It was found that the extract acts as a good corrosion inhibitor for aluminum corrosion in 2M HCl solution. The inhibition action of the extract was discussed in view of Langmuir adsorption isotherm. It was found that the adsorption of the extract on aluminum surface is a spontaneous process. The inhibition efficiency (η %) increases as the extract concentration is increased. The effect of temperature on the (η %) was studied. It was found that the presence of extract increases the activation energy of the corrosion reaction.

1. Introduction

Aluminum has a remarkable economic and industrial importance owing to its low cost, lightweight, high thermal and electrical conductivity. The most important feature in aluminum is its corrosion resistance due to the formation of a protective film on its surface upon its exposure to atmosphere or aqueous solution. Many researches were devoted to study the corrosion of aluminum in different aqueous solution [1-3]. Hydrochloric acid solutions are used for picking of aluminum or for its chemical or electrochemical etching. It is very important to add a corrosion inhibitor to decrease the rate of aluminum dissolution in such solutions. The inhibition of aluminum corrosion in acidic solutions was extensively studied using organic and inorganic compounds [4-11].

In recent years there is a great attention paid to use naturally substances as corrosion inhibitors. This greatly expanded interest on naturally occurring substances is attributed to the fact that they are cheap, readily available, ecologically friendly, and poses no threat to the environment [12-22].

The present work study the aqueous extract of the Salvadore persica as inhibitor for aluminum corrosion in hydrochloric acid solutions by using weight loss; thermometry, hydrogen evolution, Potentiostatic polarization and Pitting corrosion techniques.

2. Experimental methods

Pure aluminum provided by the ‘‘Aluminum Company of Egypt, Nagh Ammady’’ was used. Aluminum sheets with dimension of (1.3, 1.1, 0.3 cm) were used in weight loss and thermometry experiments. Weight loss measurements were carried out as described elsewhere [23]. The corrosion rate was calculated in millgram per square centimeter.

Inhibition efficiencies at different concentrations of the extract were calculated using the following equation:

$$IE\ \% = r - ri / r .100 \qquad (1)$$

Where r and ri are the rates of corrosion of free and inhibited acid solutions, respectively.

For potentiostatic studies, a cylindrical rod embedded in araldite with exposed surface area of 0.6 cm2, was used. Potentiostatic polarization studies were carried out using Meinsberger potentiostat galvanostat with software zum PS6 remote. Three-compartment cell with a saturated calomel reference electrode (SCE) and a platinum foil auxiliary electrode was used. For potentiodynamic experiments, the working aluminum electrode was held in the test solution for about 15 min before the potential sweep starts, to attain its steady state potential. The inhibition efficiency (IE %) was calculated using the following equation:

$$\text{IE }\% = [1-(\text{icorr}/\text{iocorr})]\,.100 \qquad (2)$$

And the fraction of surface coverage was calculated using equation:

$$\theta = 1-(\text{icorr}/\text{iocorr}) \qquad (3)$$

Where icorr and iocorr are the corrosion current density of aluminum specimen (mA/cm2) in presence and absence of the Salvadore persica extract, respectively.

The reaction vessel used in thermometry experiments was basically the same as described by Mylius [24]. The thermometric experiments were carried out as described elsewhere [18]. The variation in temperature of the system was measured as a function of time. The reaction number (RN) is defined as:

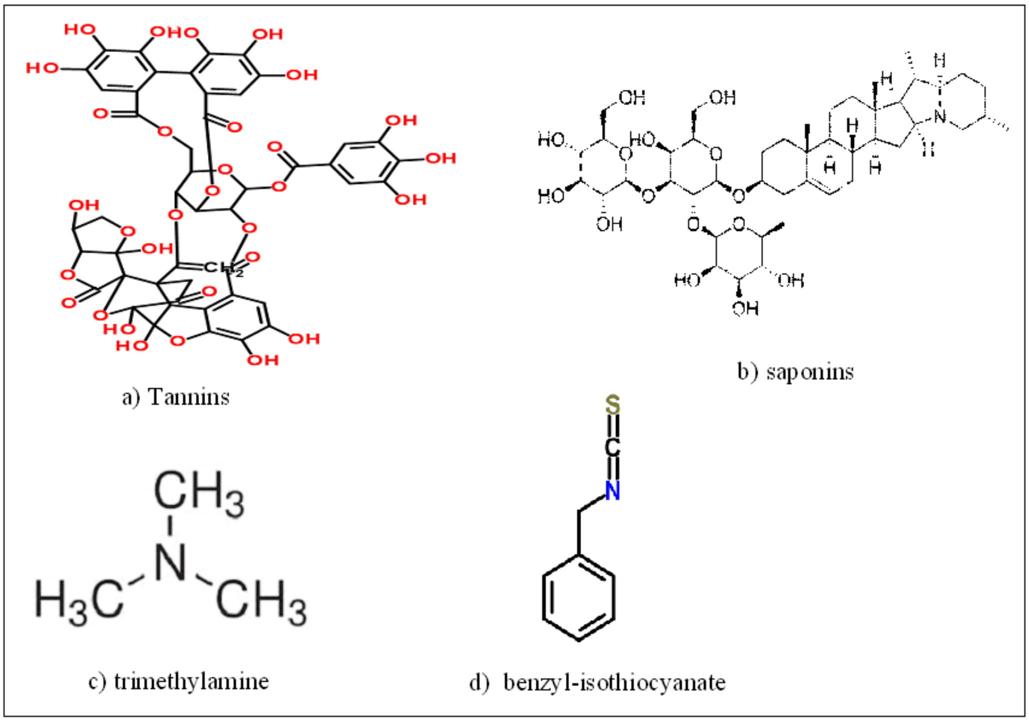
$$\text{RN} = [\text{Tm}-\text{Ti}]/t \qquad (4)$$

Where Tm and Ti are the maximum and initial temperatures, respectively and t is the time in minutes elapsed to reach Tm. IE was calculated as the percent reduction in the RN:

$$\text{IE }\% = [\text{RNf}-\text{RNi}/\text{RNf}]\,.100 \qquad (5)$$

Where RNf and RNi are the RNs of aluminum dissolution in free acid and in presence of inhibitor, respectively. Aluminum sheets with dimensions of (1, 1.4, and 0 .3 cm) were used for hydrogen evolution measurements. The reaction vessel used for hydrogen evolution and the procedure of determination of dissolution rate of aluminum in acid solution were the same as described elsewhere [25].

The Salvadora persica extract was washed thoroughly with distilled water and grinded, then 20 gm of the powder of Salvadora persica extract was boiled in distilled water for four hours. The extract was then filtered and the filtrate was dried in oven at 50oC. The obtained dried residue was used for preparation of the desired concentration of the tested inhibitor. The phytochemical of Salvadora persica root [26] contain benzyl-isothiocyanate, saponins, tannins, silica, a small amount of resin, trimethylamine and a fairly large amount of alkaloidal constituents. Figure (1) represents some component of the extract.


a) Tannins

b) saponins

c) trimethylamine

d) benzyl-isothiocyanate

Fig1: some compounds of Salvadora persica extract a) tannin, b) saponins d) trimethylamine e) benzyl-isothiocyanate

The sheets electrodes were polished with different grades of emery papers, degreased with acetone and rinsed by distilled water. All chemicals used for preparing the test solutions were of analytical grade and the experiments were carried out at room temperature, 25OC.

3. Results and discussion

3.1. FTIR and UV of DSCLE

Fourier transform infra-red (FTIR) spectroscopy of Salvadore persica extract is shown in Fig. 1. The strong absorption band at 3310cm-1is O–H stretching vibration, and that at 2936 cm-1is related to C–H stretching vibration. The strong band at 1614.5cm-1is assigned to C=C and C=O stretching vibration at1404 cm-1 and the band at 1076 cm-1 is assigned to C–O. In this figure the absorption bands below 1000 cm-1 correspond to aliphatic and aromatic C–H group.

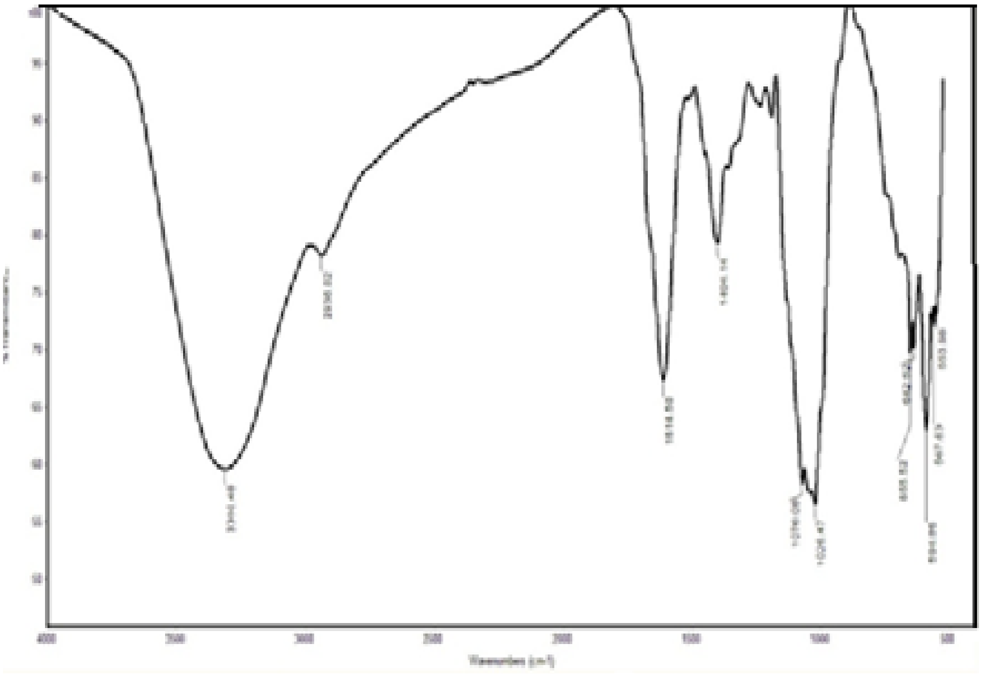


Fig 2: FTIR spectra of Salvadore persica extract

3.2. Weight loss measurements

Weight loss of aluminum, in mg.cm^{-2} was determined at various time intervals in absence and presence of different concentrations of the Salvadore persica extract. The values of the corrosion data obtained from the weight loss measurements are reported in table 1. Inspection of the table reveals that the weight loss increases with increasing exposure time in all tested solutions. However the presence of the extract causes a sharp decrease in the rate of weight loss.

Table (1): data of aluminum corrosion in 2 M HCL solution devoid of and containing different concentrations of Salvadore persica extract at different exposure time.

time h	free	50ppm		100ppm		200ppm		400ppm		600ppm		1000ppm	
	wt-loss mg.cm^{-2}	wt-loss mg.cm^{-2}	IE %	wt-loss mg.cm^{-2}	IE %	wt-loss mg.cm^{-2}	IE %	wt-loss mg.cm^{-2}	IE %	wt-loss mg.cm^{-2}	IE %	wt-loss mg.cm^{-2}	IE %
0.0	-	-	-	-	-	-	-	-	-	-	-	-	-
0.25	2.3	1.06	53.9	1.0	55.6	0.88	61.7	0.37	83.9	0.13	94.3	0.13	94.3
0. 5	10.0	2.1	79.0	2.0	80.0	1.4	86.0	0.69	93.1	0.39	96.1	0.27	97.3
1	42.3	8.2	80.6	6.1	85.7	3.5	91.7	2.0	95.2	0.83	98	0.53	98.7
1.5	58.8	12.9	78.0	8.6	85.3	5.0	91.4	3.0	94.8	1.02	98.7	0.62	98.9
2	66.5	16.3	75.4	12.6	81.0	6.5	90.2	4.1	93.8	1.46	97.8	0.83	98.7
3	89.5	34.4	61.5	28.6	68.0	12.8	85.6	7.3	91.8	3.2	96.4	1.7	98.1
4	101.1	61.0	39.0	58.8	41.8	27.2	73.0	13.6	86.5	6.3	93.7	3.6	96.4
5	112.1	79.6	28.9	78.9	29.6	40.0	64.3	16.8	85.0	7.6	93.2	4.5	95.9
24	222.8	217.9	2.1	210.9	5.3	191.4	14.0	144.2	35.2	79.0	64.5	48.5	78.2

The values of IE of different Salvadore persica extract concentrations are given in Table 1. The tabulated data reveal that, the Salvadore persica extract acts as a good corrosion inhibitor for the acid corrosion of aluminum. The corrosion inhibition increases with increasing extract concentration. Also inspection of table1 reveals that, the inhibition efficiency increase with increasing exposure time up to certain time than decreased at all tested concentrations. This can be attributed to a certain time the adsorption of inhibitor arranged on the aluminum surface competes with the aggressive ions in test solution such as chloride ions. The chloride ions have smaller volume than the extracted molecules, so they push on the electrode surface through the unoccupied sites leading to increasing the corrosion of the electrode surface. In addition, the chloride ions may replace the adsorbed molecules on the aluminum surface.

3.2. Thermometry

Thermometric methods have proved to be of considerable value and help in studying corrosion behaviour of a number of metals and alloys in various corroding environments [27, 28]. The technique is also useful in evaluating the inhibitor efficiency of a number of organic substances [29, 30]. Figure .3.shows the plot of temperature versus time for the corrosion reaction of aluminum in 2M HCl solution in the absence and presence of different concentrations of Salvadora persica. Inspection of the figure revealed that the dissolution of aluminum starts after a certain time from the immersion of the aluminum coupons in the test solution as evident in the constant temperature with time. It may be expected that this time corresponds to the period required by the acid to destroy the pre-immersion oxide film and is known as the 'incubation period'. After the consumption of the pre-immersion oxide film, the temperature of the system rises gradually due to the exothermic corrosion reaction to reach.

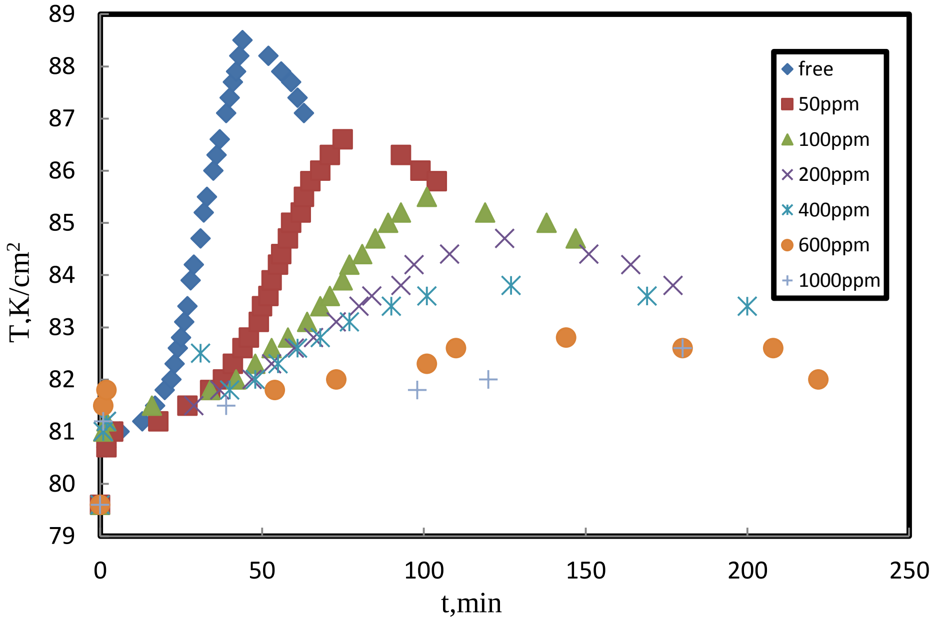


Fig3: Thermometric curves of aluminum in free and inhibited acid solutions.

Table (2): Effect of Salvadore persica concentration on its IE% for aluminum corrosion in 2 M HCl solution as revealed from thermometry technique.

Concentration(ppm)	RN	IE %
free	0.20227	-----
50	0.09	55
100	0.05	75
200	0.04	80
400	0.03	85
600	0.02	90
1000	0.016	92

A maximum value Tm. It is seen from the figure that the maximum temperature Tm was attained at a very short time (t) by the free acid solution. This corresponds to a reaction number (0.20227) of 85oC with 44min (Table 2). Further inspection of the figure revealed that on addition of the Salvadora persica the maximum temperature attained decreased and the time required to reach it increases. This is an indication that the various additives inhibit the corrosion of aluminum in the acidic environment, probably by adsorption on the metal surface; the extent of inhibition depends on the degree of coverage of the metal by the adsorbed molecules. Strong adsorption is noted at higher concentration of Salvadora persica as depicted by decrease in maximum temperature (Tm) attained and a corresponding increase in time (t) taken to reach it, and both factors cause a large decrease in the RN of the system (Table 2). The temperature of all the systems decreases after reaching their maximum values. This could be attributed to decreasing corrodent concentration with increasing reaction time, which in turn decreases the corrosion rate, hence, a decrease in quantity of heat evolved. The results obtained in this study corroborate those of other studies. Table 2 shows the calculated values of reaction number (RN) and the percentage reduction in reaction number (inhibition efficiency) for the various systems investigated. It is very clear from the table that reaction number decreased in the presence of Salvadora persica compared to the blank solution. Also, the percentage reduction in reaction number increases with increase in concentration of Salvadora persica. This assertion is also corroborated by weight loss measurements. Comparing the values of the inhibition efficiencies calculated from weight loss and thermometric methods for the Salvadora persica (Tables 1 and 2), it can be seen that the values obtained for weight loss technique are good agreement by the thermometric method.

3.3. Hydrogen evolution measurements

The volume of hydrogen evolved during the corrosion reaction of aluminum in 2M HCl solutions devoid of and containing different concentrations of Salvadore persica is measured as a function of the reaction time, and the data are represented graphically in Fig 4. Inspection of the figure reveals that, the hydrogen evolution starts after a certain time from the immersion aluminum coupon in the test solution. It may be expected that this time correspond the period needed by the acid to destruct the pre-immersion oxide film, and is known as the incubation period.

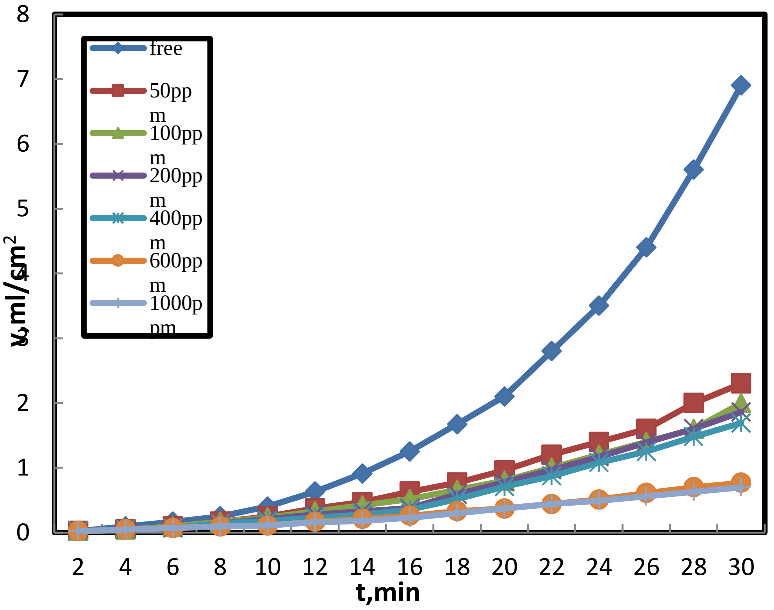


Fig 4:.Hydrogen evolution during corrosion of aluminum in free and inhibited acid.

Table (3): IE % for different concentrations of Salvadore persica toward aluminum corrosion in 2 M HCl solutions, as revealed from hydrogen evolution experiments.

Concentration(ppm)	IE %
50	72.1
100	76
200	77.3
400	79.2
600	91.3
1000	93.1

Further inspection of Fig. 4 reveals linear relationship between the time of reaction and the volume of hydrogen evolved, in all of the tested solutions. However, the presence of the extract decreases, markedly, the slope of the straight line. Since the slope of the line represents the corrosion reaction rate, it could be concluded that the Salvadore persica extract has an excellent ability to inhibit the corrosion of aluminum the acid solution. The values of IE% of different concentrations of the extract are given in Table3. Inspection of Table 3 reveals that the IE % increases as the concentration of the extract is increased. It is of interest to note that the values of IE % of low concentrations are far from those calculated by weight loss and thermometry techniques. On the other hand, the η % of the high concentrations is comparable for the three techniques.

3.4. Potentiostatic polarization

Anodic and cathodic polarization curves, of aluminum in 2MHCl solutions devoid of and containing different concentrations of Salvadore persica, is traced at 5 mV/s. The electrochemical parameters; corrosion potential (Ecorr), corrosion rate (Icorr), anodic Tafel constant (βa), cathodic Tafel constant (βc) and IE% were calculated and given in Table4.

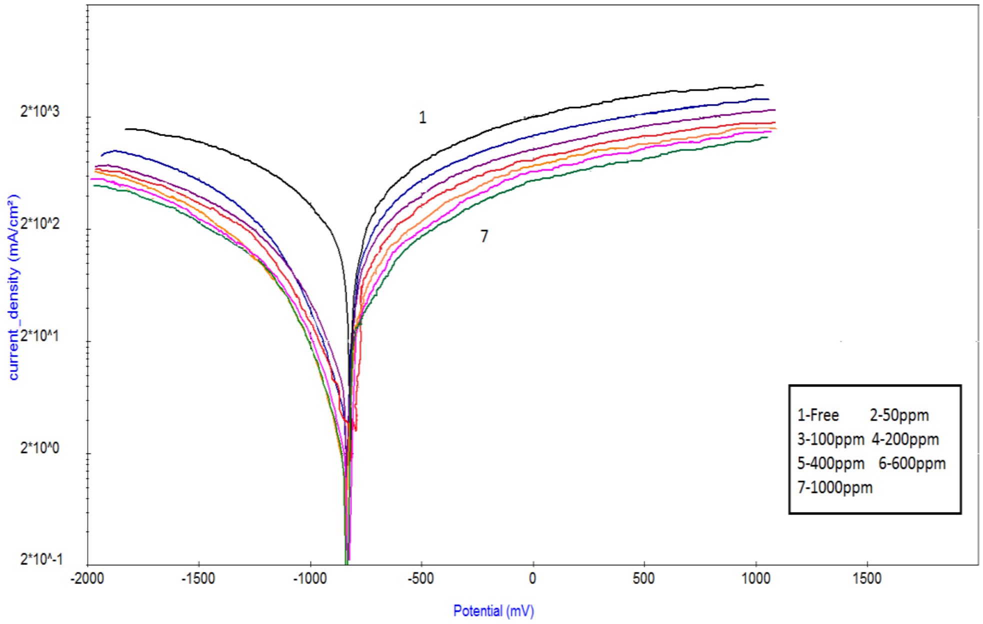


Fig 5: Potentiodynamic polarization curves of aluminum in 2MHCL devoid of and containing different concentration of Salvadore persica at 25o C.

Table (4): Electrochemical parameters of aluminum corrosion in free and inhibited HCl solutions.

Concentration ppm	$-E_{cor}$ mv(S.C.E)	I_{corr} ($mA.cm^{-2}$)	IE %	β_a (mv/dec)	$-\beta_c$ (mv/dec)
0	815	39	-----	195.8	289
50	906	11.9	69.4	182.9	241
100	889	8.1	79.3	167	216
200	859	3.3	91.5	134	209
400	906	2.7	93	108	183
600	867	1.2	96.2	92	180
1000	763	1.1	97.1	65	129

Inspection of Table 4 reveals that the corrosion potential shifts to less negative values upon addition of the inhibitor. Nevertheless, the corrosion potential is almost independent on the inhibitor concentration. On the other hand, the addition of Salvadore persica decreases markedly the corrosion current.This behavior reflects its ability to inhibit the corrosion of aluminum in 2MHCl solution. The IE % increases as the extract concentration is increased. Further inspection of Table 4 reveals also that both the anodic and cathodic Tafel constants decrease upon addition of inhibitor and decrease further with increasing inhibitor concentration. This behavior suggests that the extract inhibits the corrosion of aluminum via the adsorption of its molecules on both anodic and cathodic sites and consequently, it acts as mixed inhibitor. It is important to note that the IE % calculated using polarization method is agreement with the values obtained by the other methods. However, four methods were used in the present work to determine the inhibitive action of Salvadore persica toward corrosion of aluminum in HCl solution. If the techniques which give the highest and the lowest values are excluded, we still have the proof of the excellent inhibitive power of the Salvadore persica.

3.4. Adsorption isotherm

The adsorption of Salvadore persica extract on the metal surface makes a barrier for mass and charge transfers. This situation leads to a protection of the metal surface from the attack of the acid. Determination of the adsorption mechanism can be explained according 2to the applied isotherm with respect to the surface coverage (θ). The values of the surface coverage (θ) were obtained, as a function of the inhibitor concentration from weight loss measurements. Attempts were made to find the best fit of θ values to various isotherms graphically. It was found that the adsorption of tested compound at experimental concentration range on the aluminum surface in 2M HCl follows Langmuir adsorption isotherm as shown in figure.6. The Dependence of the fraction of the surface occupied by the adsorbed molecules (θ) on the inhibitor concentration is presented in figure.6. A plot of C/ θ versus C gives a straight line with approximately unit slope. This result suggests that the adsorption of inhibitor molecules on the aluminum surface follow Langmuir isotherm. Thus, this result suggests that there are no interaction or repulsion forces between the adsorbed molecules. It is of interest to mention here that, the θ values obtained from the potentiostatic polarization technique obeys also the Langmuir adsorption isotherm. Langmuir adsorption isotherm could be represented using the following equations [31, 32]:

$$C_{inh}/ \theta = 1/K_{ads} + C_{inh} \qquad (6)$$

$$K_{ads} = 1/ C_{solvente} – \Delta G_{oads}/ RT \qquad (7)$$

Where ΔGoads is the standard free energy of adsorption where one molecule of water is replaced by one molecule of inhibitor [33] where Csolvent is the concentration of water in solution. The unit of Kads is l mg-1, which results in that the unit of Csolvent is mg l-1 with the value of approximate 1.106.

In general, values of the free energy of adsorption ΔGads, up to -20kJ/ mol seemed to suggest the electrostatic interaction between the charged molecules and the charged metal (physical adsorption), while those higher than -40 kJ/mol involved charge sharing or transfer from the inhibitor molecules to the metal surface to form a co-ordinate type of bond (chemisorption) [34]. The obtained value of ΔG_{ads} equal -27kJ/mol, which suggesting the physical adsorption adsorption mechanism and spontaneous adsorption of Salvadore persica on aluminum surface in 2M HCl.

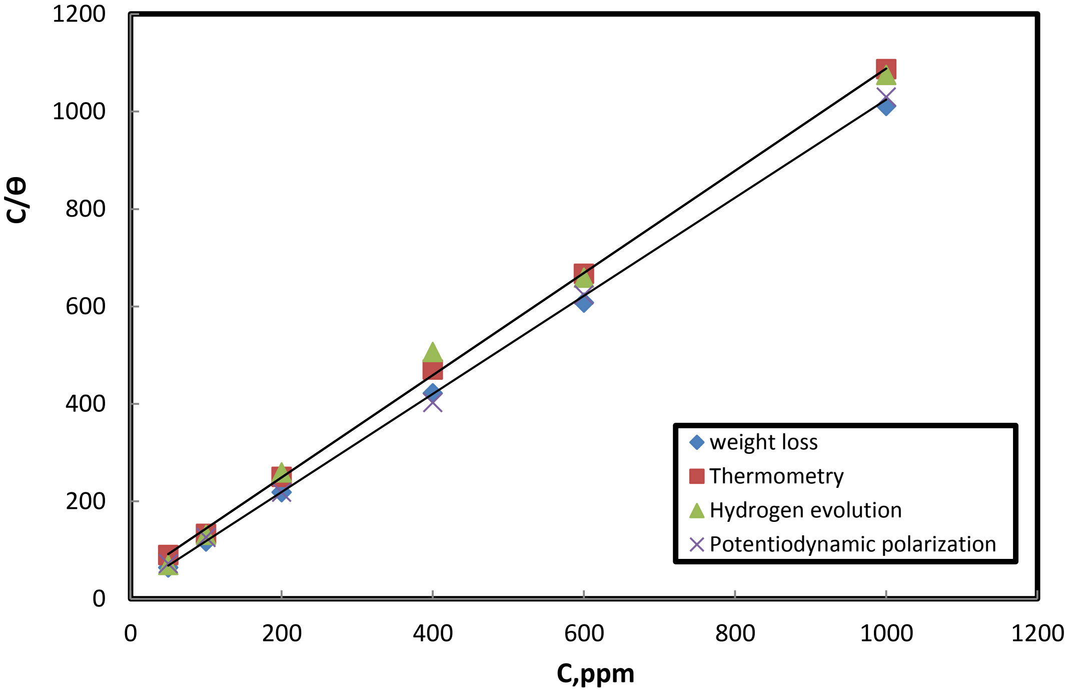


Fig 6: Langmir adsorption drawn using (ppm) concentration of the Salvadore persica extract

The negative sign indicates that the adsorption of the Salvadore persica on aluminum surface is a spontaneous process. Generally, values of ΔG^o_{ads} up to–20 kJmol–1 are consistent with electrostatic interaction between charged molecules and a charged metal (which indicates physical adsorption) while those more negative than –40 kJ mol-1 involves charge sharing or transfer from the inhibitor molecules to the metal surface to form a co-ordinate type of bond (which indicates chemisorption) [35,36]. Physical adsorption is a result of electrostatic attraction between charged metal surface and charged species in the bulk of the solution. Adsorption of negatively charged species is facilitated if the metal is positively charged. Positively charged species can also protect the positively charged metal surface acting with a negatively charged intermediate such as acid anions adsorbed on the metal surface [36]. The value of ΔGoads indicates the physico- chemical adsorption.

Figure.7. shows the plot of log (θ/(1-θ) versus (1/T) curves for aluminum in 2M HCl in presence of 1000ppm of the leaf of Salvadore persica extract gives straight line according to the equation[37]:

$$\text{Log } \theta/1\text{-}\theta = \log A + \log C - (Q_{ads}/2.303RT) \qquad (8)$$

Where A is independent constant. The values of heat of adsorption Qads were obtained from the slope and its values are -74.2KJmol-1. The negative values of heat of adsorption indicate that the degree of surface coverage decreased with rise in temperature, supporting the earlier proposed physiochemical adsorption mechanism, and show the process of adsorption is exothermal.

Thus, by using the following equations, the enthalpy of adsorption ΔHadsas well as entropy of adsorption ΔSads can be calculated using the following equations [36]:

$\Delta G_{ads} = \Delta H_{ads} - T\Delta S_{ads}$ (9)

Where $Q_{ads}/T=\Delta S_{ads}$, The calculated values of the adsorption thermodynamic parameters, ΔS_{ads}, ΔH_{ads} and at 25oC, for the acid solution contains 1000ppm of extract, were found to be -0.24926KJ/molK, 101.48KJ/mol respectively. The negative sign of the thermodynamic parameters indicates that the adsorption process is spontaneous, exothermic. The negative value of ΔS_{ads}, suggests an increase of the orderness due to transition of the molecules from the thermal motion of aqueous phase to the arranged state of the adsorption on the metal surface.

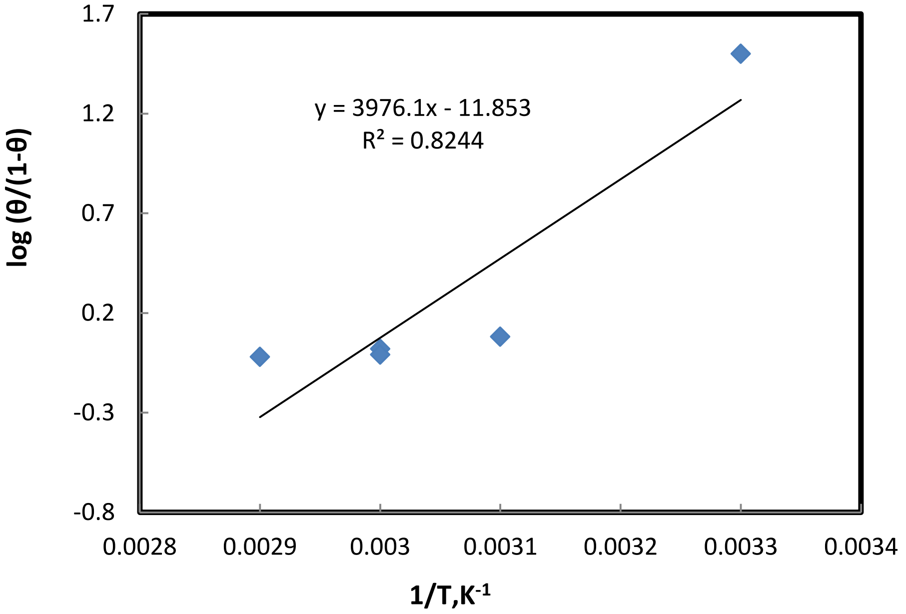


Fig 7: log θ/ (1-θ) -1/T curves for aluminum in 2M HCl in presence of 1000ppm of Salvadore persica extract.

3.5. Effect of temperature

The effect of temperature on the corrosion rate of aluminum in free acid and in presence of 1000ppm inhibitor was studied in the temperature range of 25–70°C, using Potentiostatic polarization measurements. It was found that the rates of aluminum corrosion, in free and inhibited acid solutions, increase with increasing temperature. The aluminum corrosion rate in inhibited solution is affected by the rise of temperature more than that in free acid solution. Consequently, the IE % of the extract decreases with increasing temperature. This result suggests a physical adsorption of the extract compounds on the aluminum surface.

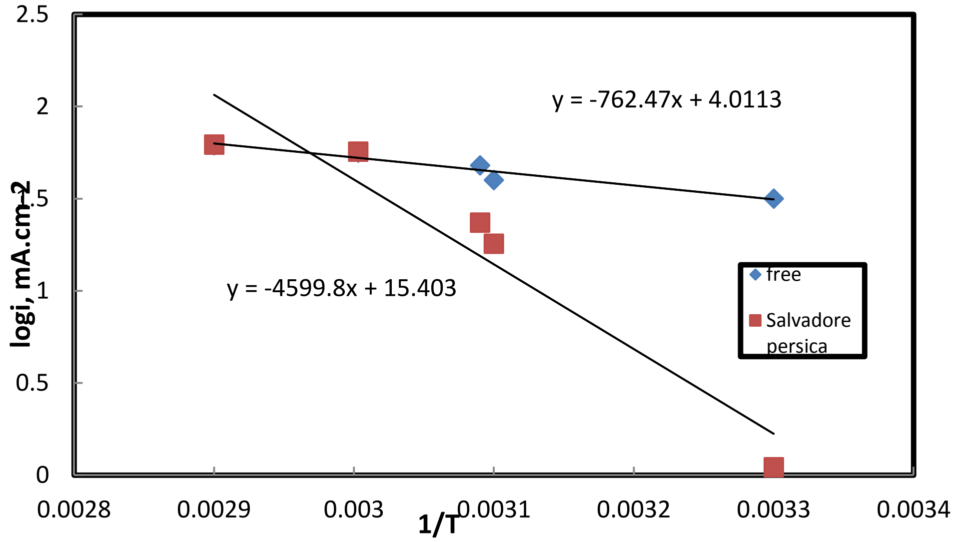


Fig 8: Effect of temperature on aluminum corrosion rate in free and inhibited acid.

The plot of logarithm of the corrosion rate versus the reciprocal of absolute temperature gives straight lines (Fig.8) according to Arrhenius equation [38]:

$$\log I_{corr} = \log A - \frac{E_a}{2.303\,RT} \qquad (10)$$

Where r is the corrosion rate, A is the constant frequency factor and Ea is the apparent activation energy. The values of Ea were calculated and found to be 14.193and 86.187kJ/mol for corrosion reactions in free and inhibited acid, respectively. It is clear that, the activation energy increases in presence of Salvadore persica and consequently the rate of corrosion reaction is decreased.

Thermodynamic parameters for corrosion of aluminum in 2M HCl devoid of and containing 1000ppm of the aqueous extract Salvadore persica extract are calculated from an alternative formula of the Arrhenius equation is the ransition state equation [39]:

R_{corr}= RT/Nh exp(ΔS*/R)exp(-ΔH*/RT) (11)

Where h is planck's constant (6.626176x10-34Js), N is the Avogadro,s number (6.02252x 1023mol-1), ΔS* is the entropy of activation and ΔH* is the enthalpy of activation. Plot of log (rcorr/T) vs. 1/T (Fig.6) give straight lines with slope equal (-ΔH*/2.303R) and an intercept equal (log R/NH+ΔS*/2.303R) from which the values of ΔS* and ΔH* were calculated and tabulated in Table (5).

Table (5): Activation parameters of aluminum corrosion in free and inhibited 2M HCl solutions.

Medium	Ea kJ/mol	ΔH* kJ/mol	ΔS* kJ/mol K	ΔG* (298K) kJ/mol
free	14.599	7.3	-0.1903	64
Salvadore persica	88	68	-0.011	72.3

The data of table (2) show that the values of ΔEa* and ΔH* are higher for the inhibited solutions than for the uninhibited solutions. This indicates that the inhibitive action of the extract is established by increasing the energy barrier for the corrosion process, emphasizing the electrostatic character of the inhibitor’s adsorption on the aluminum surface. In addition, Positive sign of the enthalpies reflects the endothermic nature of the aluminum dissolution process. This result could be interpreted on the basis that aluminum metal always covered by a thin film of oxide. The dissolution of this aluminum oxide layer is endothermic reaction [40]. Small and negative values of entropies show 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 [41, 42]. The change in the activation free energy (ΔG*) of the corrosion process can be calculated at 298K by applying the famous equation:

$$\Delta G^* = \Delta H^* - T\,\Delta S^* \qquad (12)$$

The obtained ΔG* values was also listed in Table 5. The values of ΔG* were positive indicating that the activated complex was not stable and the probability of its formation decreased somewhat with rise in temperature.

3.7. Pitting corrosion

Potentiodynamic curves of aluminum electrode were traced in solutions of 0.6M NaCl devoid of and containing different concentrations of Salvadore persica. The aluminum potential was swept from hydrogen evolution potential toward anodic direction up to the pitting potential, at scanning rate of 1.0 mV/s. No anodic oxidation peaks or any fine structures could be observed in the anodic scan. The pitting potential was taken as the potential at which the current increases sharply to a very high value. The pitting potential values are given in Table 5. Inspection of the data of the table reveals that the presence of Salvadore persica shifts the pitting potential of aluminum to less negative potential. This result suggests that the extract acts as pitting corrosion inhibitor for aluminum.

Table(6): Values of pitting potential E pit of aluminum in free and inhibited 0.6M NaCl solutions.

Concentration(ppm)	0	50	100	200	400	600	1000
EPit (mv)	-689	-681	-676	-663	-655	-650	-642

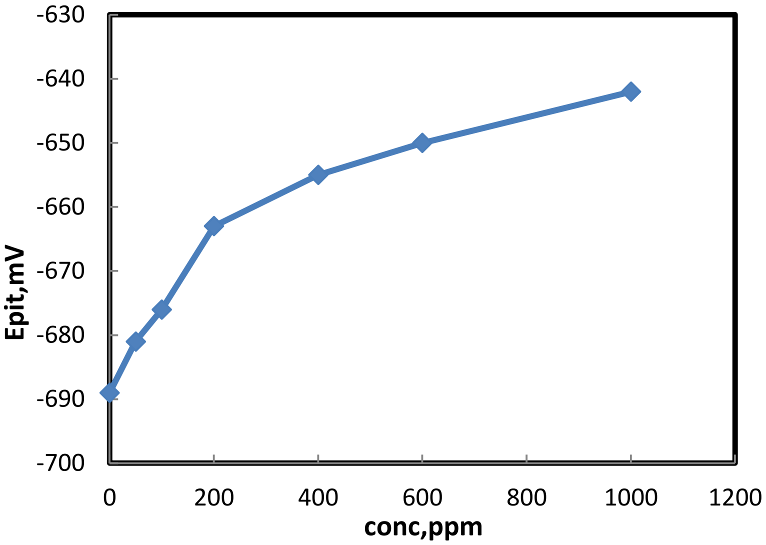


Fig 9: Relationship between extract concentration and E_{pit}.

The shift in the pitting potential increases as the inhibitor concentration is increased. However, the relation between the pitting potential and inhibitor concentration is not linear as shown in Fig. 9. Thus, in relatively high concentrations the extent of the anodic shift in pitting potential decreases.

3.6 mechanism of inhibition

3.6.1 UV visible spectrum studies

Fig. 10 represents the UV visible spectrum of the corrosion product of Salvadore persica extract in the absence and presence of metal of aluminum in 2M HCL. 1000ppm of Salvadore persica extract give the highest inhibition efficiency (98.9%), this means that there is small weight of aluminum metal dissolved in 2M HCL which form complex with this Salvadore persica extract. This has been proved from (uv-vi) spectrophotometer as shown in figure (10). It is shown that the wave length of n ∏* transition of Salvadore persica extract in presence of metal was shifted to higher values (393.5 nm) compared to without metal (390.5nm) this is indicated the formation of complex.

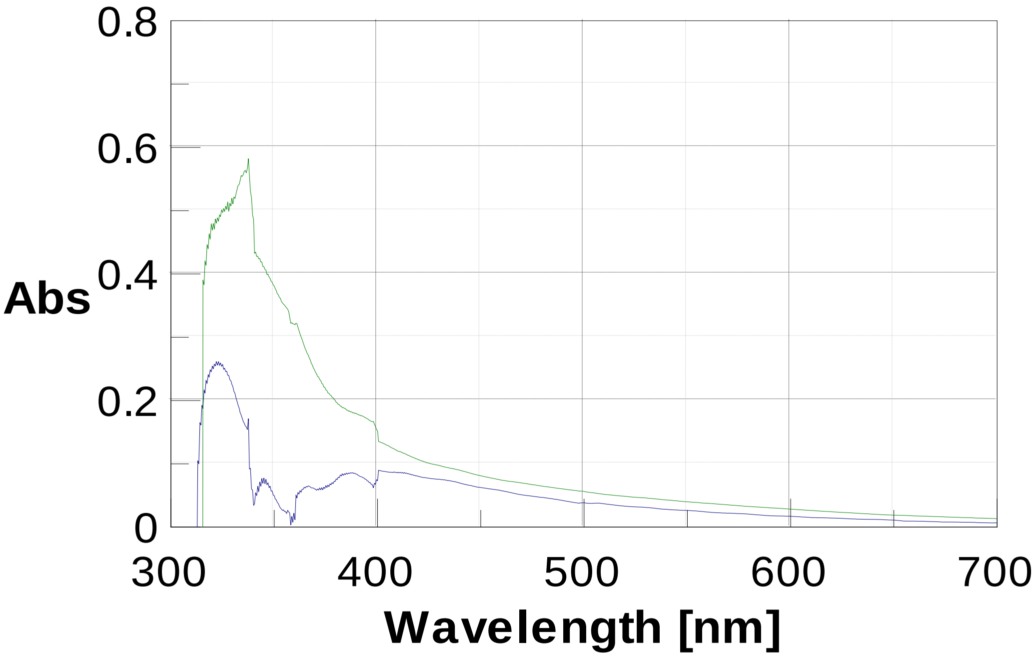


Fig10: UV spectrum for Salvadore persica extract in the absence and presence of metal of aluminum in 2M HCL.

3.6 .2 FTIR studies

FTIR is a powerful technique used to determine the type of bonding between the organic inhibitors and the metal ion. FTIR spectral analysis of the inhibitor film removed mechanically from the aluminum surface was carried out. A comparison of FTIR spectra of pure Salvadore persica extract, and inhibitor film was performed and given in Fig.11. It is seen that the intensity of some peaks are changed which implies that these compounds are coordinated to Al+3 resulting in the formation of a Al+3 – inhibitor complex on the metal surface.

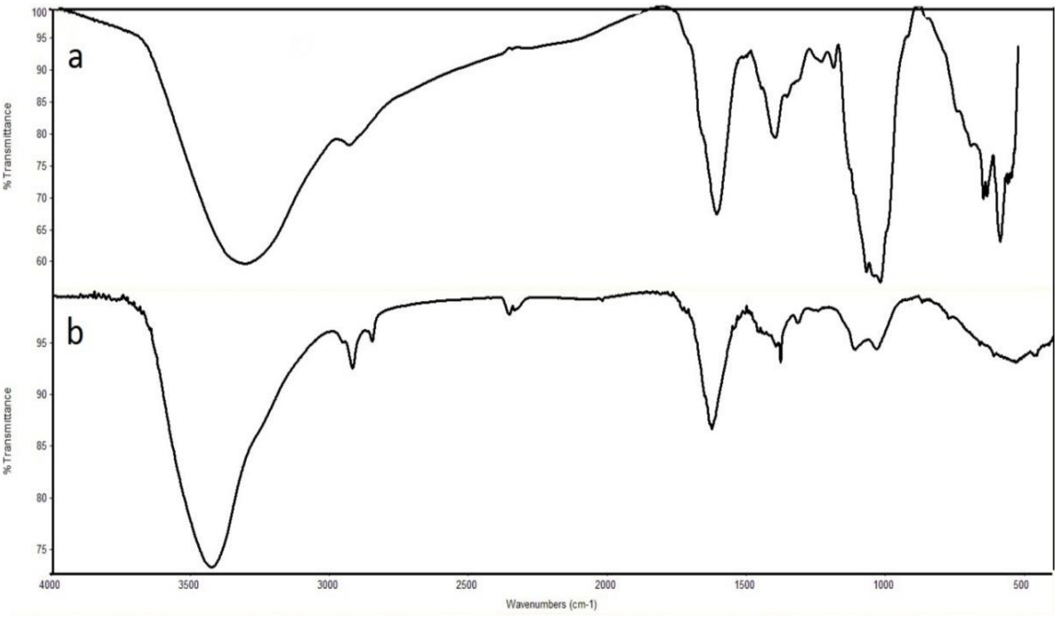


Fig11: FT-IR Spectrum of (a) Salvadore persica extract and (b) the corrosion product on aluminum in the presence of Salvadore persica extract with 2MHCL.

IR spectrum of Salvadore persica extract and the corrosion product on aluminum respectively are given in Table 7. These shifting frequencies may suggest that the formation of barrier film on the metal surface which may confirm the co-ordination between inhibitor molecule and metal surface.

The observed stretching frequency and the corresponding band assignment indicate that the prominent groups which can take part in the complex formation with the aluminum.

Table (7): IR Spectrum of the Corrosion Product on aluminum in the presence of Salvadore persica extract as an Inhibitor in Acid Environment.

Frequency(cm-1)Pure Salvadorepersica extract	Frequency(cm^{-1})extract adsorbed on aluminum	Band assignment
3310	3431.38	O–H in stretching vibration
2936	2924.04	C–H in aliphatic
1614	1631.78	C=O in ester
1404	1384.38	C=C in aromatic ring
1076	1115.79	C–O

4. Conclusion

- The Salvadore persica extract acts as a good inhibitor for corrosion of aluminum in 2.0 M HCl solution. The IE % increases with increasing extract concentration.
- The inhibition action is performed via adsorption of the extract compounds on aluminum surface. The adsorption process is spontaneous and follows Langmuir adsorption isotherm.
- The increase of temperature decreases the IE % of the extract. The adsorption process may be physical in nature.
- The presence of the extract increases the activation energy of the corrosion reaction.
- The Salvadore persica provide some protection against pitting corrosion of aluminum in presence of chloride ions. The degree of protection increases with increasing extract concentration.

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