

***Ammodaucus Leucotrichus* Cosson & Durieu fruits essential oil as corrosion inhibitor of tinplate in 0.5M oxalic acid medium and its thermodynamic properties.**

A. Boumezzourh^(a), M. Ouknin^(a), A. Bouyanzer^(b), J. Costa^(c), L. Majidi^{(a)*}

^(a)Laboratory of Natural Substances & Synthesis and Dynamics Molecular, Faculty of Sciences and Techniques, Moulay Ismail University, 52000 Errachidia, Morocco.

^(b)Laboratory of Applied Analytical Chemistry, Materials and Environment, Faculty of Sciences, University Mohammed Premier, P. O. Box 4808, 60046 Oujda, Morocco.

^(c)Laboratory of Chemistry of Natural Products, UMR CNRS 6134, Faculty of Sciences and Techniques, University of Corse, France..

Abstract

The anticorrosion proprieties of *Ammodaucus leucotrichus* Cosson & Durieu essential oil (ALEO) against the corrosion of tinplate in 0.5M oxalic acid medium was studied in the interest to improve the corrosion resistance of cans in interaction with food contains. For this, the gravimetric test, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques were used. The different corrosion test used show that the ALEO has an anticorrosion effect with an inhibition efficiency of 83.83% at 4g.L⁻¹, this can be pertained to the chemical composition of the studied essential oil. The essential oil behavior at rang temperature (303-373K) show that ALEO exhibits good inhibition even at moderate to high temperatures. The estimation of the corrosion activation parameters reveal that the essential oil shows good inhibitor characteristics with a physisorption mechanism. By using the scanning electron microscopy and energy dispersive X-rays (SEM-EDX), it is clear that the surface is remarkably improved in the presence of ALEO compared with that exposed to the acid medium without essential oil.

* Corresponding author:

lmajidi@yahoo.fr

Received 02 Dec 2018,

Revised 23 March 2019,

Accepted 24 March 2019

Keywords: *Ammodaucus leucotrichus*; tinplate; corrosion inhibitor; essential oil; food.

1.Introduction

Many problems related to food product can limit the shelf life of the food conserved, such as stress corrosion cracking, sulphide black corrosion and occasionally discoloration on the product surface. The iron dissolution is related to pitting corrosion at fractures or pores of coating and the filiform corrosion with the rust formation on the external surface of metal container [1,2]. Tinplate is one of the dominant materials used for food cans, it is used for its appearance, nontoxicity and its corrosion resistance. However, the high level of tin solved in food product can produce serious digestive disturbances [3]. Many studies were carried out in order to increase the resistance corrosion of tinplate and to prevent its corrosion by food media, such as lacquers or the passivation treatment [4]. However, the use of non-toxic inhibitors called green inhibitors is one of the possible solutions used to prevent the corrosion of the material and to keep the quality of food conserved [5]. Natural plants have been added as extracts, oils or pure compounds, and may play major roles to keep the environment healthier, safe and under pollution control. Recently, the uses of green inhibitor such as essential oil and plant extract against steel and tinplate corrosion has been the aim of many studies [6-12]. The oxalic acid is as a natural antioxidant [13], it is used as purification agent in pharmaceutical industry [14]. This natural acid is found in many fruits and vegetable especially the canned ones [15-17], the addition of the oxalic acid to canned fruits is recommended to increase the tartness and enhance the flavor of the fruit canned [18]. However, the high acidity of oxalic acid can be a source of cans corrosion [19-21]. In previous paper [22], we have reported that *Ammodaucus leucotrichus* Cosson & Durieu essential oil revealed significant antifungal activity against three phytopathogenic fungi causing sever diseases in apple. The genus *Ammodaucus* appertain to the Apiaceae family, this genus includes two endemic subspecies *Ammodaucus leucotrichus* Cosson & Durieu subsp. *Leucotrichus* and *Ammodaucus leucotrichus* Cosson & Durieu subsp. *nanocarpus*. The first one inhabits the sub-saharan countries of North Africa, Morocco, Algeria and Tunisia, extending to Egypt and tropical Africa. The second subspecies grows in the Canary Islands, Spain [23]. The *Ammodaucus leucotrichus* is known for its medicinal proprieties. It is used to treat indigestion, gastralgia and gastric-intestinal pain, as a powder or in a decoction [24]. Many studies conducted to evaluate different biological activities of *Ammodaucus leucotrichus* revealed that, this plant shows an antimicrobial and antioxydante activities [25–27]. It is also reported that the formation and nucleation of calcium oxalate monohydrate crystals also the growth and aggregation phases of calcium oxalate crystallization are inhibited in the presence of *Ammodaucus leucotrichus* aqueous extract [28]. Essential oil and aqueous extract of *Ammodaucus leucotrichus* are also found to be active against the corrosion of mild steel in 1M HCl solution [29, 30]. The present work attempts to evaluate the *Ammodaucus leucotrichus* essential oil (ALEO) as inhibitor of tinplate corrosion in oxalic acid ($C_2H_2O_4$) and how this element reduces the dissolution of tin. For this reason, the corrosion parameters were determined using the gravimetric method, electrochemical impedance spectroscopy and electrochemical polarization measurements. The surface morphology is characterized by using scanning electron microscopy spectroscopy and energy dispersive X-rays (SEM-EDX).

2. Materials and methods

2.1. Essential oil

The *Ammodaucus leucotrichus* Cosson & Durieu fruits essential oil was extracted by hydrodistillation using Clevenger apparatus by our team and analyzed using CG and CG-MS analysis [31], this oil is found as source of Perillaldehyde (73.5%), Limonene (12.5%) and Methyl perillate (1.8%) as reported in our previous paper [22].

2.2. Gravimetric test

The weight loss measurement is effectuated under total immersion of tinplate of 1.5*1.5 cm² with the chemical composition Sn (51.49%), Fe (47.23%), Co (0.88%) and Al (0.41%), in 50 ml of 0.5M H₂C₂O₄ solution in the presence and the absence of different concentration of ALEO. The sheets were abraded with emery pepper graduate 1200, rinsed with distilled water, digressed with ethanol than derided and weighted before their immersion in aggressive medium. After 6h of immersion at 303K, the samples were rinsed, dried and weighted. To study the temperature influence on the inhibitor efficiency. Also, to evaluate the thermodynamic parameters, same tests were carried out in a range temperature 303 to 374 k for 2h of total immersion in corrosive medium with different concentration of essential oil. The rate corrosion W (mg.cm⁻².h⁻¹) is calculated according to the equation (1):

$$W = \frac{m_0 - m_{inh}}{m_0} \quad (1)$$

With, m_0 and m_{inh} represent the sheets weight before and after immersion, S (cm²) represent simple surface and t duration of immersion. The inhibition efficiency $E\%$ is determined according to the equation (2):

$$E\% = \frac{W_0 - W_{inh}}{W_0} \cdot 100 \quad (2)$$

W_0 and W_{inh} represent the corrosion rate in the absence and presence of inhibitor, respectively.

2.3. Electrochemical tests

The electrochemical parameters were evaluated using a Volta lab (Tacussel- Radiometer PGZ 100) connected to cell with three electrodes, a saturated calomel electrode and platinum electrode were used as reference and auxiliary electrode. The same material used in weight loss measurement constructed the working electrode (WE). The potentiostate is controlled by Tacussel corrosion analysis software model (Voltamaster 4). The exposed surface area (0.5 cm²) of WE was rinsed with distilled water, degreased with ethanol then dried before its immersion in test solution. After the immersion of the working electrode into the test solution with babbling nitrogen gas in order to eliminate the oxygen, the potential of the electrode was determined by allowing the open circuit potential (OCP) for 30 min to rich its stable value [32].

2.4. Electrochemical impedance spectroscopy (EIS)

After determination of OCP, the EIS experiments were performed at the rest potential, in the frequency range varying between 100 kHz and 10mHz, with 10 points per decade by applying 10 mV ac voltage peak-to-peak. The impedance diagrams were given in the Nyquist presentation. The inhibition efficiency obtained from the charge transfer resistance is calculated following the equation (3):

$$E\% = \frac{R_{inh} - R_0}{R_{inh}} \cdot 100 \quad (3)$$

R_0 and R_{inh} represent charge transfer in the presence and absence of the essential oil, respectively.

2.5. Potentiodynamic measurement

The potentiodynamic curves were recorded at scan rate of 1mV/s from the corrosion potential E_{corr} , the current density value were obtained by Tafel extrapolation method. The inhibition efficiency is calculated according to the following equation (4):

$$E\% = \frac{I_{corr} - I_{inh}}{I_{corr}} \cdot 100 \quad (4)$$

I_{corr} and I_{inh} represent respectively the corrosion current densities in the absence and presence of essential oil.

2.6. Scanning electron microscopy and energy dispersive X-rays (SEM-EDX)

The morphology of the corrosion products formed on the surface of the tinplate in 0.5M H₂C₂O₄ solution in the absence and presence of 4g.L⁻¹ ALEO were examined by SEM-EDX using a TESCAN VEGA 3 EDAX instrument at an accelerating voltage of 20 kV. After the immersion of the tinplate samples in 0.5M H₂C₂O₄ solution in the presence and absence of 4g.L⁻¹ ALEO for 6h. Before, the analysis using SEM-EDX, samples undergo a washing with double distilled water and then drying.

3. Results and Discussions

3.1. Gravimetric results

The gravimetric method is one of the most widely used methods to give an idea on the effect of corrosion inhibition. The data gathered in Table 1 and represented in Figure 1 show that the corrosion rate of tinplate in oxalic acid depend on the concentration used of essential oil. By increasing the concentration, the rate corrosion decreases and the inhibition efficiency increases to reach its high value 83.83% at 4g.L⁻¹ of ALEO. This behavior can be due to the increase of essential oil molecule number adsorbed on the tinplate surface. The ALEO is found reach on monoterpenes oxygenated with oxygen atom in their functional groups, those are known for their anticorrosion characteristics [33], and this activity can be attributed to the peryllaldehyde or the synergy between its compounds.

Table 1. ALEO concentration effect against the corrosion rate of tinplate in 0.5M H₂C₂O₄.

C (g.L ⁻¹)	W(mg/cm ² .h)	E%	Θ
0.5M C ₂ H ₂ O ₄	0.56	--	--
0.125	0.42	24.19	0.24
0.25	0.40	28.01	0.28
0.5	0.28	50.01	0.50
1	0.22	60.41	0.60
2	0.18	68.01	0.68
3	0.13	76.94	0.77
4	0.09	83.83	0.84

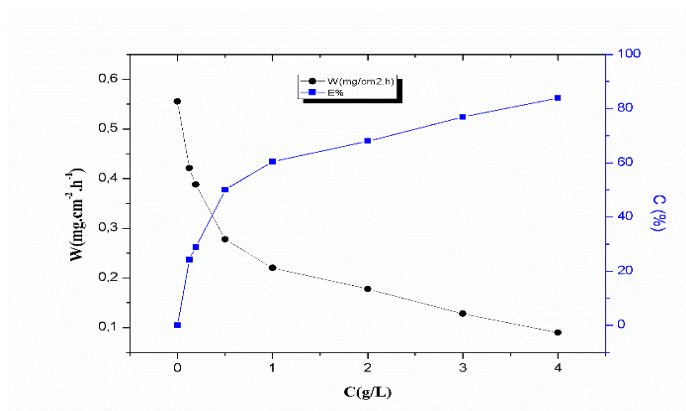


Figure 1. Variation of the inhibition efficiency (E%) and the corrosion rate (W) of Tinplate in 0.5 M H₂C₂O₄ in the presence of ALEO.

3.2. The temperature effect on the corrosion inhibition and thermodynamic parameters

The temperature has great effect on the corrosion, the rate corrosion increases with the rise of temperature, the gravimetric method is used in order to determine the behavior of ALEO against the tinplate corrosion in 0.5 M H₂C₂O₄ medium in temperature range 303 to 374 K, for 2h of immersion. This study allowed us to determine the thermodynamic parameters as the activation energy E_a , enthalpy ΔH_a and entropy ΔS_a activation of the tinplate corrosion in oxalic acid medium. The data gathered in Table 2 after 2h of immersion show that the rate tinplate corrosion is more pronounced in the absence of ALEO. The Figure 2 shows that the inhibition efficiency decreases with the increase of temperature. A decrease of the corrosion rate is observed by increasing the concentration of essential oil. On the other hand, an increase of temperature induces rate corrosion increase.

Table 2. Temperature effect (298-318 K) of tinplate corrosion in 0.5M H₂C₂O₄ in the presence and absence of ALEO.

	303K		313K		323K		343K		374K	
C(g.L ⁻¹)	W(mg/cm ² .h)	E%	W(mg/cm ² .h)	E%	W(mg/cm ² .h)	E%	W(mg/cm ² .h)	E%	W(mg/cm ² .h)	E%
0.5M H ₂ C ₂ O ₄	0.56	--	0.80	--	1.00	--	1.50	--	2.00	--
0.125	0.42	24.19	0.62	22.10	0.80	20.01	1.20	19.87	1.67	16.70
0.25	0.40	28.01	0.59	26.25	0.78	22.23	1.20	20.01	1.60	19.90
0.5	0.28	50.01	0.46	43.05	0.60	39.80	1.02	31.87	1.45	27.28
1	0.22	60.41	0.42	47.22	0.58	42.43	0.95	36.71	1.36	32.12
2	0.18	68.01	0.37	53.28	0.49	51.12	0.81	45.86	1.12	43.94
3	0.13	76.94	0.29	63.38	0.38	61.62	0.63	58.25	0.89	55.56
4	0.09	83.83	0.18	77.89	0.24	75.76	0.41	72.39	0.63	68.69

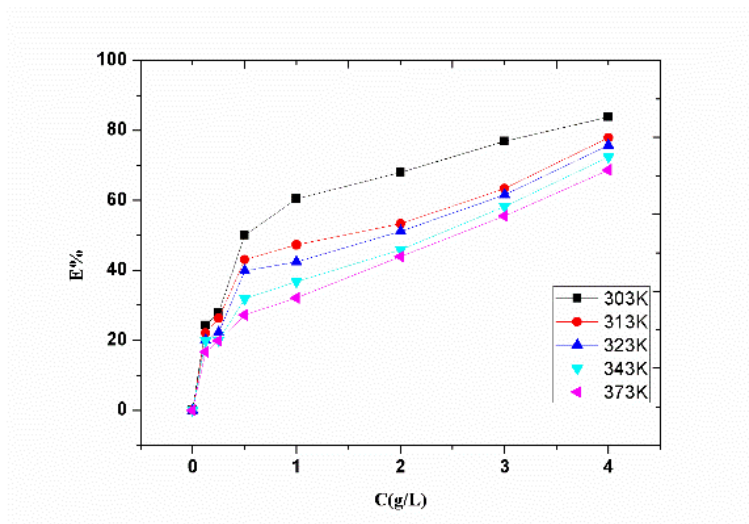


Figure 2. The temperature effect against the essential oil efficiency

The Arrhenius equation is used to determine the activation energy, accounting the effect of temperature on the corrosion rate according to the followed equations (5):

$$W_{corr} = A. \exp \frac{-E_a}{RT} \quad (5)$$

$$\ln(W_{corr}) = \frac{-E_a}{RT} + \ln A \quad (6)$$

The enthalpy (ΔH_a) and the entropy of activation are calculated using the Arrhenius equation transition (7).

$$W_{corr} = \frac{RT}{Nh} \exp\left(\frac{\Delta S_a}{R}\right) \cdot \exp\left(-\frac{\Delta H_a}{RT}\right) \quad (7)$$

With W_{corr} is rate corrosion, R the gas constant, T the absolute temperature, N Avogadro's number and h is Plank's constant. The logarithm of the corrosion rate ($\ln(W_{corr})$) versus the temperature ($1000/T$) is shown in Figure 3 the plot of $\ln(W_{corr})$ in function of ($1000/T$) are linear, linear curves obtained obey to the Arrhenius law. The slope of the Arrhenius curve represents $(-E_a/R)$. Respectively, $(-\Delta H_a/R)$ and $[\ln(R/Nh) + (\Delta S_a/R)]$ represent the slope and intersection with the y-axis of the curves representing the variation of $\ln(W_{corr}/T)$ versus ($1000/T$), represented in Figure 4. The Table 3 shows the activation parameters calculated from Arrhenius lines.

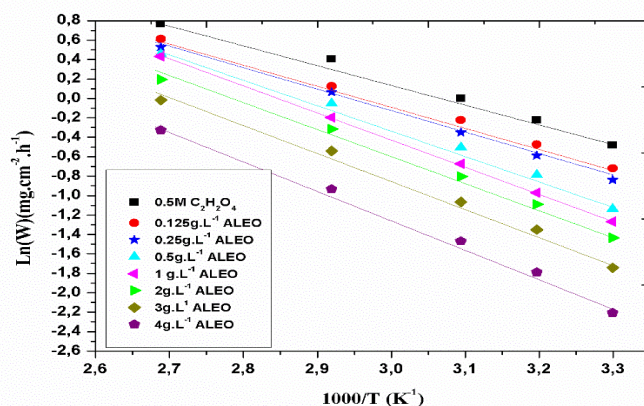


Figure 3. Arrhenius plot of tinplate in the absence and presence of different concentration of ALEO.

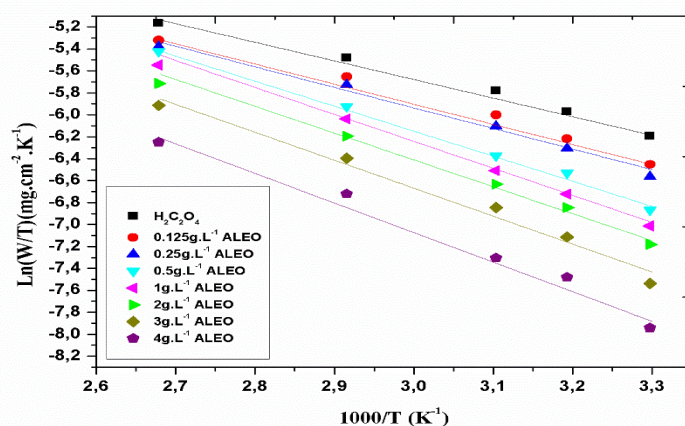


Figure 4. Arrhenius transition plot of tinplate in the absence and presence of different concentration of ALEO.

The values of the activation energy E_a in the presence of ALEO are higher than the one obtained in oxalic acid. The last increase by increasing the concentration of essential oil used. The increase in the activation energy in presence of essential oil is attributed to the physisorption of the essential oil molecule [33]. The data in the Table 3 shows that ΔH_a values of dissolution reaction tinplate in the presence of ALEO are higher than that in the absence of ALEO. The positive signs of ΔH_a reflect the endothermic nature of the dissolution process of tinplate [34], which reflect that the essential oil adsorbed on most active adsorption sites (having the lowest energy) and the corrosion take place on the active sites (having higher energy) [35]. The value of the $E_a - \Delta H_a$ is 2.79 kJ mol^{-1} , is approximately equal to the average value of RT (2.69 kJ mol^{-1}) at the average temperature approximately 331K of the domain studied. This result agrees that the corrosion process is a unimolecular reaction as described by the known of perfect gas [36]. The negative value

of ΔS_a in the absence and presence of essential oil indicates that the activated complex in the rate determining step represents an association rather than dissociation, which means that a decrease in disordering takes place in going from reactants to the activated complex [36].

Table 3. Thermodynamic parameters of tinplate corrosion in 0.5M $H_2C_2O_4$ in the presence and absence of ALEO.

C(g.L ⁻¹)	E _a (kJ.mol ⁻¹)	ΔH _a (kJ.mol ⁻¹)	ΔS _a (kJ.mol ⁻¹)	E _a -Δ H _a (kJ.mol ⁻¹)
0.5M H ₂ C ₂ O ₄	16.9	14.1	-211.64	2.8
0.125	18.04	15.25	-212.79	2.79
0.25	18.38	15.85	-213.12	2.53
0.5	21.76	18.97	-216.51	2.79
1	23.15	20.35	-217.89	2.8
2	23.23	20.44	-217.98	2.79
3	23.98	21.18	-218.72	2.8
4	25.21	22.42	-219.96	2.79

3.3. Isotherm adsorption

The adsorption of inhibitors on the metal surface depends on several conditions such as its electronic characteristics, the metal surface nature, temperature and the varying degrees of surface-site activity. However, the adsorption of inhibitor molecules can be considered as a quasi-substitution process, between the inhibitor in the aqueous phase and water molecules on the electrode surface [37]. To describe the adsorption process of the inhibitor on the metal surface the adsorption isotherms are used. Langmuir, Frumkin and Temkin adsorption isotherms were applied in order to explain the adsorption process of ALEO on the tinplate surface:

$$\text{Langmuir : } C_{inh}/\theta = 1/k + C_{inh} \quad (8)$$

$$\text{Temkin : } \ln (C_{inh}/\theta) = \ln K - g\theta \quad (9)$$

$$\text{Frumkin : } \ln [C_{inh} * (\theta/(1 - \theta))] = \ln K + g\theta \quad (10)$$

Langmuir adsorption isotherm reflect the physisorption or chemisorption phenomenon while Temkin adsorption isotherm gives an explanation about the heterogeneity formed on the metal surface. Chemisorption is attributed to Temkin isotherm [38]. The dependence of the coverage surface θ (E%/100) as function of inhibitor concentration was graphically tested for a different adsorption isotherms

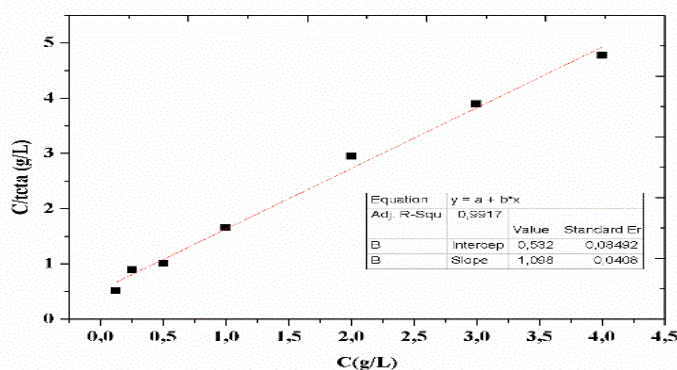


Figure 5. Langmuir isotherm adsorption.

From the Figure 5 representing the graphical representation of (C/Θ) versus the essential oil concentration $C(g.L^{-1})$, the graphical presentation was found to be linear with correlation coefficient R^2 (0.9917) almost equal to unity and the slope value 1.098 is less than 1.4. Which means that the essential oil adsorb on the tinfole flowed the Langmuir adsorption.

3.4. Electrochemical tests

The Figure 6 presents the variation of open circuit potential (OCP) of tinfole in 0.5M $H_2C_2O_4$ in function of time in the presence and absence of ALEO. According to the Figure 6, it is observed that the OCP in function of time presents two domains, the transition domain and stable domain. In the presence of ALEO minimize time transitional domain (0 to 100s) at $4g.L^{-1}$. However, in the absence of the ALEO (0 to 200s) is large than the one observed on the presence ALEO. By addition of different concentration of ALEO the OCP shifts to noble values than those observed without ALEO. The OCP value depends on the concentration used of ALEO.

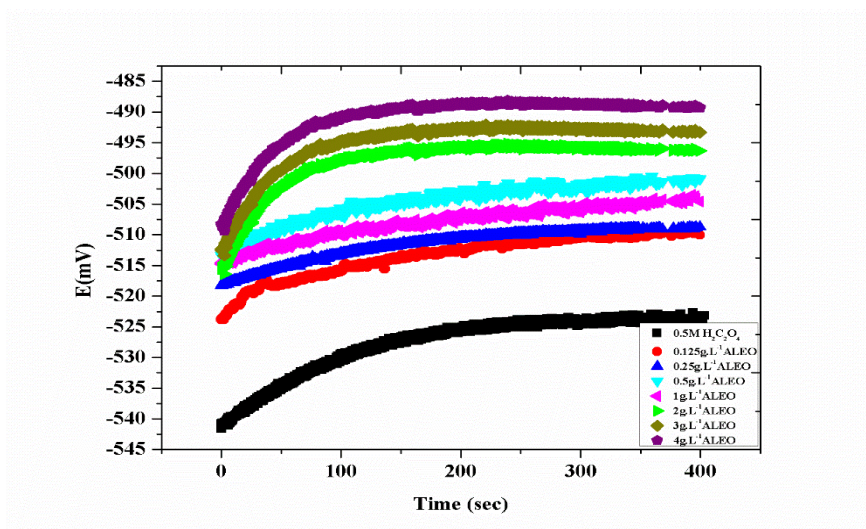


Figure 6. OCP of tinplate in 0.5M oxalic acid in the presence and absence of different concentration of ALEO.

3.5. Electrochemical impedance spectroscopy

The effect of ALEO against the tinplate corrosion in 0.5M $H_2C_2O_4$ was studied using EIS at 303K. The Nyquist plots of tinplate corrosion in the presence and the absence of ALEO are represented in Figure7. The efficiency E% and the EIS parameters such as R_t and C_{dl} are listed in the Table 4.

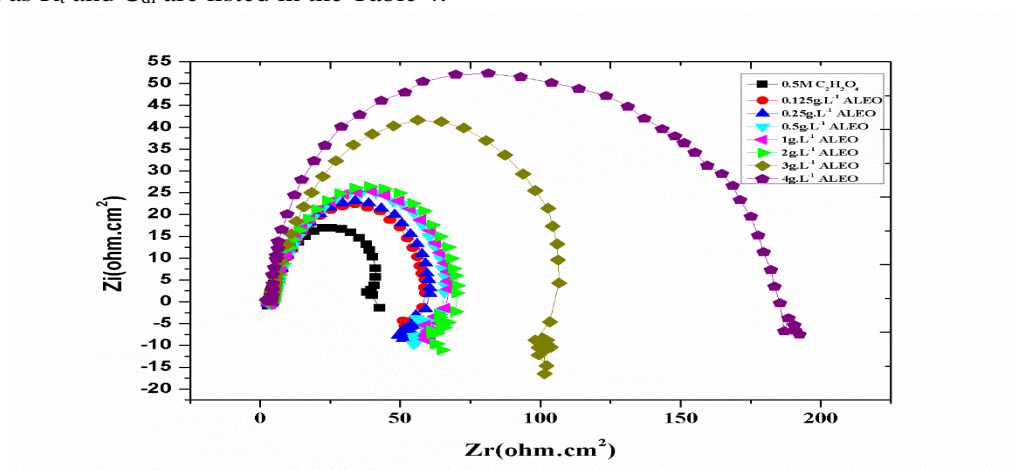


Figure 7. Nyquist plots of tinplate in 0.5M $H_2C_2O_4$ with and without a different concentration of ALEO.

Table 4. Electrochemical parameters for tinplate in 0.5M H₂C₂O₄ in presence and absence of various concentrations of ALEO.

C(g.L ⁻¹)	C _{dl} (μF.cm ²)	R _t (ohm.cm ²)	E%
0.5M H ₂ C ₂ O ₄	90.2	40	
0.1	63.41	55.96	28.52
0.25	61.75	56.96	29.78
0.5	71.04	62.12	35.61
1	68.06	63.89	37.39
2	51.49	66.98	40.28
3	63.68	104.8	61.83
4	36.06	191.88	79.15

The recorded EIS spectrum for tinplate in 0.5M H₂C₂O₄ shows one single capacitive loop. The same trend is observed in the presence of various concentration of ALEO, which indicates that the corrosion mechanism does not change with the addition of essential oil, the presence of one loop indicates that the corrosion of tinplate is controlled by the charge transfer process [39]. Also, it is clear that the obtained impedance diagrams are not perfect semicircles this can be attributed to roughness and other inhomogeneities of solid surface [34]. The inspection of the data in Table 4 shows that R_t increases and C_{dl} decreases by the addition of essential oil. The decrease of C_{dl} can be attributed to the increase of either thickness protective layer or the decrease of the local dielectric constant of the film or both [40]. A large charge transfer resistance is related to a slower corroding system. The increase in charge transfer resistance values could be attributed to the adsorption of the ALEO compounds at the tinplate-acid interface, blocking the active sites on tinplate surface and hence enhances the corrosion resistance of the tinplate in acid medium, by increasing the concentration of essential oil the surface coverage increases as consequence the inhibition efficiency of ALEO against the corrosion of tinplate in 0.5M H₂C₂O₄ increase to reach 79% at 4g.L⁻¹ of ALEO.

3.6. Potentiodynamic measurement

The polarization curves of tinplate in 0.5M H₂C₂O₄ at 303K are presented in Figure 8. The Table 5 brings together different electrochemical parameters related to the potentiodynamic polarization also the ALEO inhibition efficiency.

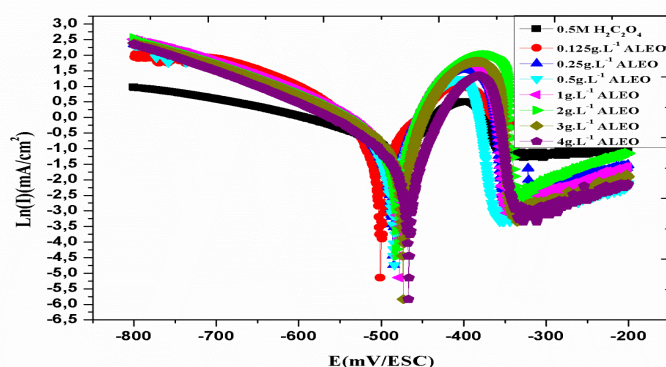


Figure 8. The anodic and cathodic polarization curves of tinplate in 0.5M H₂C₂O₄ with and without various concentration of ALEO.

Table 5. Polarization parameters for tinplate in 0.5M H₂C₂O₄ with and without various concentration of ALEO.

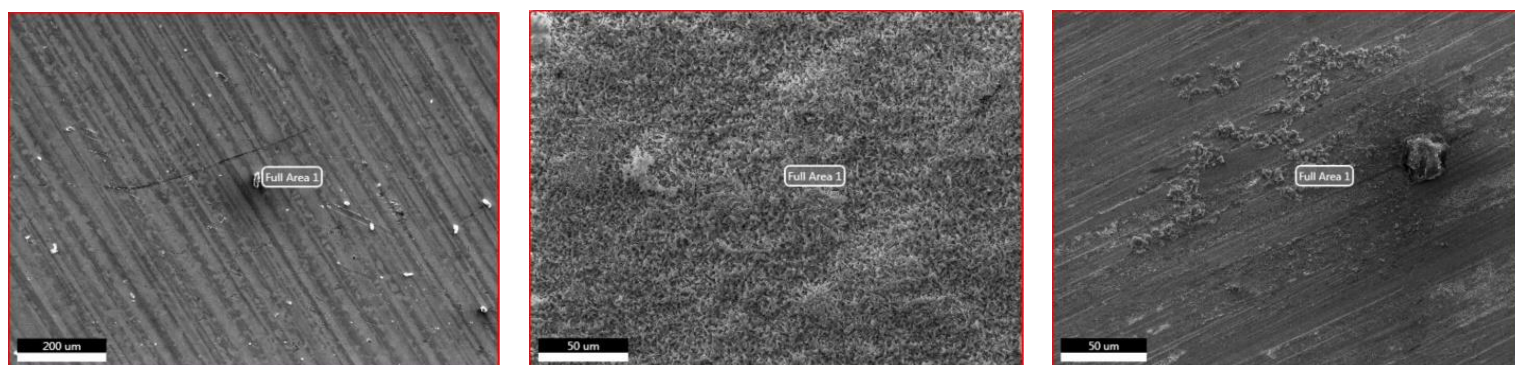
C(g.L ⁻¹)	E _i =0	β _a	β _c	I _{corr}	E%
-----------------------	-------------------	----------------	----------------	-------------------	----

	(mV/SCE)	(mV/dec)	(mV/dec)	(m A/cm ²)	
0.5M H₂C₂O₄	-553.5	159.1	-250	1.1164	--
0.1	-487	78	-240.7	0.8044	27.95
0.25	-486	57.6	-236.7	0.729	34.70
0.5	-479.9	54.7	-230.6	0.6849	38.65
1	-486	52.3	-228.7	0.5252	52.96
2	-475	49.3	-218.8	0.4258	61.86
3	-482.1	43.5	-216.2	0.2781	75.09
4	-468.3	39.3	-214.2	0.2127	80.95

The analysis of the polarization curves show that the anodic current densities decrease in the presence of ALEO. The Figure 8 shows that the presence of ALEO modifies both the mechanism of cathodic hydrogen evolution and the anodic dissolution of tinplate in 0.5M H₂C₂O₄. From the Table 5 it is clear that the current corrosion density decreases with increasing the ALEO concentration used. The inhibition efficiency of ALEO increases to reach its high value 80.95% at 4g.L⁻¹. The change of the value of the β_a in the presence of ALEO indicates that essential oil molecules are pore adsorbed on the anodic sites resulting an inhibition of the anodic reaction of the tinplate in oxalic acid medium [41]. An anodic active-passive transition is observed in the presence and absence of essential oil. This phenomenon can be attributed to the formation of an oxide film on Sn(II), the increase in the anodic current density is attributed to the oxidation of Sn(II)-Sn(IV) [12,42]. The E_{corr} displacement value is 85.2 mV greater than 85 so the ALEO is as anodic or cathodic inhibitor type [43].

3.7. Scanning electron microscopy (SEM)

In order to evaluate the morphology of tinplate surfaces in contact with oxalic acid solution. Samples were imaged using the SEM.



(A) (B) (C)
Figure 9. SEM micrographs of tinplate samples at 308 K (A) tinplate surface before immersion, (B) after immersion in 0.5M oxalic acid without inhibitor, (C) after immersion in 0.5M oxalic acid and 4g.L⁻¹ of ALEO.

Figure 9 shows the SEM of tinplate samples after 6h of exposure to 0.5M H₂C₂O₄ and exhibiting changes that occurred during corrosion process in the presence and absence of essential oil. In the presence of ALEO, it is clear that the

surface is remarkably improved compared with that exposed to the acid medium without ALEO, this indicates that the ALEO compounds forms a protective film which is responsible for the corrosion inhibition [44].

3.8. Energy dispersive X-rays (EDX)

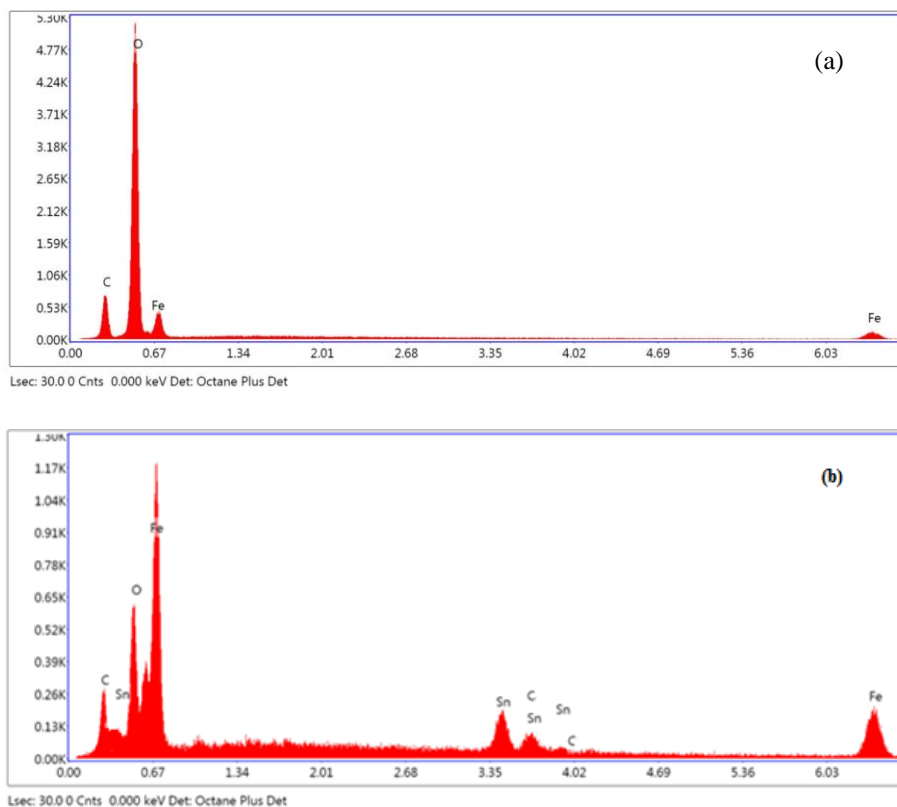


Figure 10. EDX spectra of tinplate surfaces in 0.5M $\text{H}_2\text{C}_2\text{O}_4$ in the absence (a) and presence 4g.L^{-1} of ALEO (b).

The analysis of the Figure 10 ((a) and (b)) shown the EDX spectra in the absence and the presence of ALEO after 6hs of immersion. The EDX spectrum in the absence of ALEO (a) shows the absence of Sn. However, in the presence of 4g.L^{-1} the EDX shows the presence of Sn, this result confirms that the ALEO reduces the dissolution of tinc in oxalic acid.

4. Conclusion

From the present study, it is clear that ALEO shows a good inhibition against tinplate corrosion in 0.5M $\text{H}_2\text{C}_2\text{O}_4$. The inhibitive action of ALEO increases with the concentration to attain 83.83% at 4g/L . However, its efficiency decreases with the increase of temperature. The activation energy increases with the ALEO concentration, the adsorption of the inhibitor adsorption is well described by Langmuir isotherm model. The OCP test shows that OCP shift to noble values in presence of ALEO. The EIS measurement shows that the inhibition of corrosion on tinplate is due to the formation of protective film on metal surface the R_i increase by the increase of ALEO concentration used. The results of potentiodynamic polarization curves indicate that ALEO is anodic type inhibitor. The SEM-EDX it is clear that the tinplate surface is remarkably improved in the presence of ALEO. Those results could be attributed to the chemical composition of ALEO. The obtained results confirm that the ALEO could be used to improve corrosion resistance of cans and to keep the quality of food conserved.

References

- [1] M. G. Kontominas, M. I. Prodromidis, E. K. Paleologos, A. V. Badeka, D. Georgantelis, *Food. Chem.*, 98 (2006) 225-230.
- [2] J. I. Martins, *Eng. Fail. Anal.*, 26 (2012) 258-265.
- [3] D. Xia, S. Song, J. Wang, H. Bi, Y. Jiang, Z. Han, *Trans. Nonferrous Met. Soc. China.*, 22 (2012) 717-724.
- [4] R. Catalá, M. Alonso, R. Gavara, E. Almeida, J. M. Bastidas, J. M. Puente, *Food Sci. Technol. Int.*, 11 (2005) 223-227.
- [5] L. Bammou, M. Mihit, R. Salghi, A. Bouyanzer, S. Al-Deyab, L. Bazzi, B. Hammouti, *Int. J. Electrochem. Sci.*, 6 (2011) 1454-1467.
- [6] A. Salhi, A. Bouyanzer, I. El Mounsi, H. Bendaha, A. Chetouani, H. Amhamdi, A. Zarrouk, B. Hammouti, J. M. Desjobert, J. Costa, *Mor. J. Chem.*, 4 (2016) 1037-1051.
- [7] L. El Hattabi, J. Costa, J. M. Desjobert, A. Guenbour, M. Tabyaoui, *Mor. J. Chem.*, 4 (2016) 862-875.
- [8] A. Salhi, A. Bouyanzer, A. Chetouani, S. El Barkany, H. Amhamdi, I. Hamdani, A. Zarrouk, B. Hammouti, J. M. Desjobert, J. Costa, *Mor. J. Chem.*, 5 (2017) 59-71.
- [9] Y. El Ouadi, A. Beladjila, A. Bouyanzer, Z. Kabouche, H. Bendaif, F. Youssfi, M. Berrabah, R. Touzani, A. Chetouani, B. Hammouti, *Mor. J. Chem.*, 5 (2017) 139-152.
- [10] A. Batah, A. Anejjar, M. Belkhaouda, L. Bammou, R. Salghi, L. Bazzi, B. Hammouti, A. chetouani, *Mor. J. Chem.*, 5 (2017) 404-416.
- [11] M. G. Al-Mazaideh, A. S. Al-Quran, *Mor. J. Chem.*, 6 (2018) 195-202.
- [12] L. Bammou, B. Chebli, R. Salghi, L. Bazzi, B. Hammouti, M. Mihit, H. Idrissi, *Green Chem. Lett. Rev.*, 3 (2010) 173-178.
- [13] T. Kayashima, *Biochim. Biophys. Acta.*, 1573 (2002) 1-3.
- [14] A. M. Fekry, *Electrochimica. Acta.*, 54 (2009) 3480-3489.
- [15] M. R. Moßhammer, F. C. Stintzing, R. Carle, *Innov. Food Sci. Emerg. Technol.*, 7 (2006) 275-287.
- [16] A. C. Rice, C.S. Pederson, *J. Food Sci.*, 19 (1954) 106-114.
- [17] J. C. Sherlock, S. C. Britton, *Br. Corros. J.*, 7 (1972) 180-183.
- [18] E. Edward Colby, Cincinnati, Ohio, assignor to The Procter & Gamble Company, Cincinnati, Ohio, a corporation of Ohio, Filed Jan. 29, 1962, Ser. No. 169,631.
- [19] J. L. Camalet, J.C. Lacroix, S. Aeiach, K. Chane-Ching, P.C. Lacaze, *Synth. Met.*, 93 (1998) 133-142.
- [20] V. N. Lambeth, M. L. Field, J. R. Brown, E. S. Regan, D. G. Blevins, *Food Technol.*, 22 (1969) 132.
- [21] C. Mannheim, N. Passy, A. L. Brody, *Food Sci. Nutr.*, 17 (1983) 371-407.
- [22] M. Manssouri, M. Znini, A. El Harrak, L. Majidi, *J. App. Pharm.*, 6(2016) 131-136.
- [23] A. Velasco-Negueruela, M. J. Pérez-Alonso, P. L. Pérez de Paz, J. Palá-Paúl, J. Sanz, *J. Chromatogr. A.*, 1108 (2006) 273-275.
- [24] J. Bellakhdar, *La Pharmacopée Marocaine Traditionnelle*. Ibiss Press, (1996) 358.
- [25] M. H. Abu Zarga, H. I. Al-Jaber, Z. Y. Baba Amer, L. Sakhril, M. A. Al-Qudah, J. Y. G. Al-humaidi, I. F. Abaza, F. U. Afifi, *J. Biol. Act. Prod. Nat.*, 3 (2013) 224-231.
- [26] D. Dahmane, T. Dob, S. Krinat, A. Nouasri, H. Metidji, A. Ksouri, *J. Essent. Oil. Res.*, 29 (2017) 48-55.
- [27] Z. Louail, A. Kameli, T. Benabdelkader, K. Bouti, K. Hamza, S. Krinat, *J. Mater. Env. Sci.*, 7 (2016) 2328-2334.
- [28] M. Beghalia, S. Ghalem, H. Allali, A. Belouatek, A. Marouf, *Med. Plants – Int. J. Phytomedicines Relat. Ind.*, 1 (2009) 37.
- [29] M. Manssouri, Y. El Ouadi, M. Znini, J. Costa, A. Bouyanzer, J. M. Desjobert, L. Majidi, *J. Mater. Env. Sci.*, 6 (2015) 631- 646.
- [30] M. Manssouri, M. Znini, A. Ansari, A. Bouyanzer, Z. Faska, L. Majidi, *Der. Pharma. chemica.*, 6 (2014) 331-345.
- [31] M. Ouknin, A. Romane, J. Costa, L. Majidi, *Nat. Prod. Res.*, 32 (2018) 1478-6427.
- [32] N. Mechbal, Y. Karzazi, F. Abridach, F. El-Hajjaji, B. Hammouti, *Mor. J. Chem.*, 4 (2016) 876-890.
- [33] L. Majidi, Z. Faska, M. Znini, S. Kharchouf, A. Bouyanzer, B. Hammouti, *J. Mater. Env. Sci.*, 1 (2010) 219-226.

- [34] G. Cristofari, M. Znini, L. Majidi, A. Bouyanzer, S. S. Al-Deyab, J. Paolini, B. Hammouti, J. costa, *Int. J. Electrochem. Sci.*, 6 (2011) 6699-6717.
- [35] A. Ghazoui, N. Bencat, S. S. Al-deyab, B. Hammouti, M. Ramdani, M. Guenbour, *Int. J. Electrochem. Sci.*, 8 (2013) 2272-2292.
- [36] L. Majidi, M. Znini, A. Ansari, B. Hammouti, C. Jama, J. Costa, J. Paolini, *Int. J. Electrochem. Sci.*, 8 (2013) 7381-7393.
- [37] I. B. Obot, N. O. Obi-Egbedi, *Port. Electrochimica. Acta.*, 27 (2009) 517-524.
- [38] F. Darriet, M. Znini, L. Majidi, A. Muselli, B. Hammouti, A. Bouyanzer, J. costa, *Int. J. Electrochem. Sci.*, 8 (2013) 4328-4345.
- [39] M. Behpour, S. M. Ghoreishi, N. Mohammadi, N. Soltani, M. Salavati-Niasari. *Corros. Sci.*, 52 (2010) 4046-4057.
- [40] Y. ELouadi, F. Abridach, A. Bouyanzer, R. Touzani, O. Riant, B. El Mahi, A. El Assyry, S. Radi, A. Zarrouk, B. Hammouti, *Der. Pharma. Chemica.*, 7 (2015) 265-275..
- [41] M. Znini, G. Cristofari, L. Majidi, A. Ansari, A. Bouyanzer, J. Paolini, J. Costa, B. Hammouti, *Int. J. Electrochem. Sci.*, 7 (2012) 3959-3981.
- [42] S. S. Abdel Rehim, S. M. Sayyah, M. M. El Deeb. *Mater. Chem. Phys.*, 80 (2003) 696-703.
- [43] A. K. Satapathy, G. Gunasekaran, S. C. Sahoo, K. Amit, P. V. Rodrigues, *Corros. Sci.*, 51 (2009) 2848-2856.
- [44] M. Ouknin, A. Romane, J. Costa, P. Ponthiaux, L. Majidi, *Mor. J. Chem.*, 6 (2018) 557-568.