

Oil of *Ricinus Communis* as a Green Corrosion Inhibitor for Copper in 2 M Nitric Acid Solution

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Abstract— The corrosion behavior of copper in nitric acid with and without the addition of *Ricinus communis* oil at various concentrations was investigated with techniques such as weight loss, measurements of electrochemical polarization and electrochemical impedance spectroscopy (SIE). The results obtained show that the copper corrosion rate decreases with the increase in concentration of *Ricinus communis* oil to 99% to 250 ppm. *Ricinus communis* oil acts as a mixed inhibitor. The effect of temperature on copper corrosion indicates that the effectiveness of inhibition of the natural material remains constant with increasing temperature. The values of inhibition efficiency obtained from weight loss, polarization curves and EIS are in good agreement.

Keywords— corrosion inhibition, copper, *Ricinus communis* oil, adsorption, nitric acid.

I. INTRODUCTION

The growing need for corrosion inhibitors is becoming increasingly necessary to stop or delay maximum attack of a metal in an aggressive solution. The main areas of application are acid pickling, industrial acid cleaning, acid descaling and oil well acidification. Considerable efforts are provided to find suitable compounds to be used as corrosion inhibitors in various corrosive environments. Many studies have been conducted to study the corrosion activity of the extracts of natural substances [1-10]. These organic compounds are generally aromatic plant extracts, spices and medicinal plants. Natural antioxidants are environmentally harmless substances. Their use as corrosion inhibitors was preferred, since it represents the advantage of being economical and environmentally friendly. These benefits have prompted researchers to examine extracts of natural substances as corrosion inhibitors. Menthe [11], *Lippia spicata* [12], thyme [13,14], jojoba oil [15], rosemary oil [16], eugenol [17] bguaine [18], the mugwort [19], have been shown to be very effective corrosion inhibitors for iron and steel in acid. Research has shown that jojoba and bguaine represents a 100 % efficiency for the protection of steel in acidic medium [15-18].

The aim of this study is the study of the inhibition of the corrosion of copper by 2M HNO₃ *Ricinus communis* oil gravimetrically electrochemical polarization methods and electrochemical impedance spectroscopy. The effect of temperature was also studied.

II. MATERIALS AND METHODS

A. Extraction of *Ricinus communis* oil

Ricinus communis was collected in the region of Settat, Morocco. The ripe fruit of the plant are dried in the laboratory in the shade at room temperature for one week to reduce its moisture content. After shelling of fruits recovered seeds were crushed.

The oil was obtained by the method of Soxhlet 3h using hexane as the extraction solvent. The yield of oil was 30%. This oil yield was calculated based on the dry matter.

1) After extraction, a portion of the oil was used for the analysis of the chemical composition Liquid chromatography high performance coupled to mass spectrometry, and the other part was used for the tests of the anti-corrosion activity.

2) After extraction, the oil was recovered and stored in a dark bottle and stored at 4 ° C before use.

B. Preparation of the solution

The solution of HNO₃ 2 M was prepared by dilution of analytical grade HNO₃ 67% with distilled water. Test solutions were freshly prepared before each experiment by adding the oil directly to the etching solution. Experiments were conducted in triplicate to allow determination of reproducibility.

C. Gravimetric measurements

Gravimetric tests were conducted by maintaining the desired temperature of the electrolyte with a thermostat FRIGITHERM mark. The electrolyte volume was 30 mL. The samples are rectangular form surface 9.6 cm². Prior to measurements, they undergo a mechanical polishing with abrasive paper of up to 1200 increasing size, followed by degreasing with acetone, followed by washing with distilled water and drying in air. Each value of the gravimetric test is the average of at least three tests.

D. Measures electrochemical

The electrochemical experiments were performed in a pyrex cell, equipped with a conventional three-electrode: copper as the working electrode in the form of discs cut with a geometric area of 1 cm², platinum as a counter electrode and the electrode ECS as saturated calomel reference electrode. The copper disc was abraded with sandpaper to different

particle size up to 1200, degreased with acetone, rinsed with distilled water and dried before each test water. The measurements are performed with an assembly comprising a potentiostat-galvanostat PGZ100, radiometer type associated with "voltmaster4" software.

The current-potential curve is obtained by potentiodynamic mode, the potential applied to the sample varies continuously with a scanning rate of 30 mV / min. We chose a relatively low rate of scanning to be quasi-steady. Before curve plot, the working electrode is maintained at a potential of -800 mV for 15 minutes.

Chrono amperometric curves were plotted at a potential of 155 mV for 3600 sec.

The measures electrochemical impedance spectroscopy (EIS) were performed with the same electrochemical system. The frequencies between 100 KHz and 10 Hz were superposed on the corrosion potential. The diagrams given in the impedances are Nyquist representation.

E. iodometric titration

Cupric ions Cu^{2+} were determined by an indirect assay (iodometric), which involves two successive reactions.

Reaction 1: $2\text{Cu}^{2+} + 2\text{I}^- \rightarrow \text{I}_2 + 2\text{Cu}^+$ (With potassium iodide solution)

Reaction 2: $\text{I}_2 + 2\text{S}_2\text{O}_3^{2-} \rightarrow \text{S}_4\text{O}_6^{2-} + 2\text{I}^-$ (Assay solution of sodium thiosulfate)

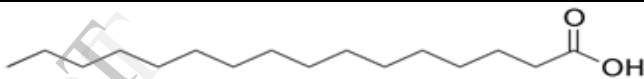
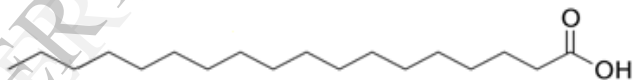
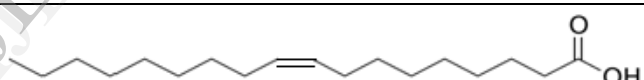
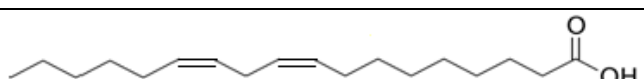
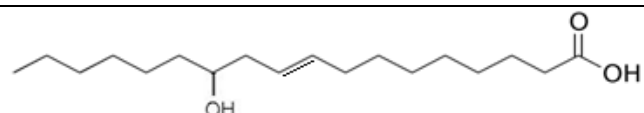
III. RESULTS AND DISCUSSION

A. Analysis of the chemical composition of the oil

The oil of *Ricinus communis* belongs to the botanical family Euphorbiaceae and its main component: ricinoleic acid.

The analysis of the chemical composition of the oil was achieved through Liquid chromatography high performance coupled to mass spectrometry. The retention time and the relative percentage of the various constituents of the oil are shown in Table 1.

Table 1: Chemistry of *Ricinus communis* oil

Compound Name	Retention time (min)	Percentage (%)	Chemical structure
Palmitic acid	10.06	2.55	
Stearic acid	12.53	2.68	
Oleic acid	12.85	7.72	
Linoleic acid	13.57	9.73	
Ricinoleic acid	30.37	75.03	

B. Effect of the concentration

- The potentiodynamic polarization measurements

The figure 1 shows polarization plots of copper cathode and anode immersed in 2 M HNO_3 at 293 K in the absence and presence of various concentrations of inhibitor. The electrochemical data, the corrosion potential (E_{corr}), the cathodic Tafel slopes (β_c) and anode (β_a), the corrosion current density (I_{corr}) are listed in Table 2. The effectiveness of inhibition (%) is calculated by:

$$\text{IE \%} = \frac{I_{\text{corr}} - I'_{\text{corr}}}{I_{\text{corr}}} \times 100 \quad (1)$$

Where I_{corr} I'_{corr} and respectively represent corrosion current densities determined by extrapolation of the straight Tafel corrosion potential with and without addition of inhibitor.

Under the experimental conditions used, the cathodic branch represents the reaction of hydrogen evolution and the anodic branch represents the dissolution of copper. Inspection of these results shows that the corrosion current density (I_{corr}) decreased in the presence of the inhibitor. This behavior reflects its ability to inhibit corrosion of the cook in a solution of 2M HNO_3 . As long as the densities of anodic and cathodic current was reduced (figure 1). It is suggested then that the *Ricinus communis* oil acts as a corrosion inhibitor for copper mixed type in a 2 M solution of HNO_3 [19].

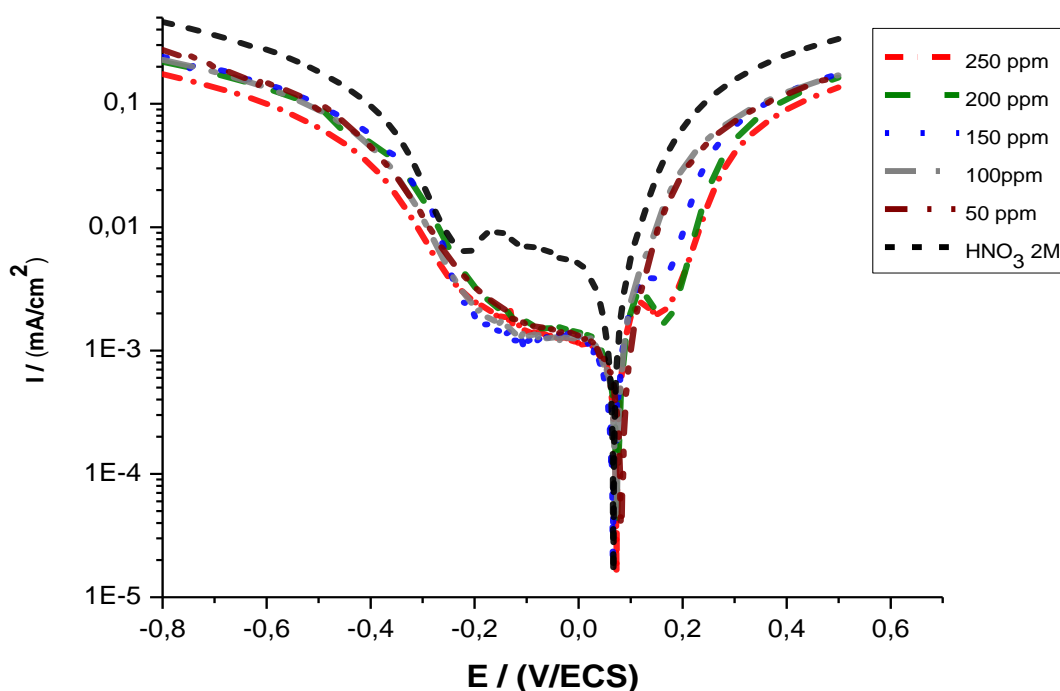


Figure 1. Potentiodynamic polarization curves on copper in 2 M HNO₃ absence and presence of *Ricinus communis* oil at various concentrations at 25 °C.

Table 2. Electrochemical parameters and inhibitory efficacy of copper and with 2M HNO₃ without the addition of *Ricinus communis* oil at various concentrations at 25 °C.

Inhibitor	C _{INH} / (ppm)	E _{Corr} / (mV / SCE)	I _{Corr} / (mA / cm ²)	β _a / (mV)	-B _c / (mV)	IE%
Blank	---	65.2	2.1741	77.0	349.5	---
<i>Ricinus communis</i> oil	50	70.8	1.2074	78.8	1765.1	44.46
	100	64.9	0.7875	71.4	132.7	63.78
	150	71.0	0.3776	49.9	132.3	83.28
	200	64.9	0.1745	28.4	44.9	91.97
	250	72.7	0.0184	34.4	77.3	99.15
	300	71.9	0.0114	56.6	68.1	99.47

From the potentiodynamic polarization curves, one can see that the oil causes a decrease in current density, probably due to the adsorption of organic matter present in the *Ricinus communis* oil in the active sites of the surface electrode. Table 2 shows that the presence of *Ricinus communis* oil, the corrosion potential is slightly shifted. An inhibitor can be classified as anode or cathode, if the difference in corrosion potential is above 85 mV relative to the potential of white corrosion [20]. These results suggest that the *Ricinus communis* oil acts as an inhibitor of the mixed type. These results show that the *Ricinus communis* oil can delay the anodic and cathodic reactions. The current density at the corrosion (I_{corr}) decreases as the concentration of inhibitor increases. The cathodic Tafel slopes (β_c) have significantly changed with the addition of oil (Table 2), indicating that the adsorbed molecules affect inhibiting hydrogen evolution: that is to say, the clearance hydrogen is not only reduced by the effect of locking surface. The results also shown that the anodic Tafel slopes (β_a) vary with the addition of the inhibitor, indicating

modification of the process of dissolution of the metal. Indeed, the shape of the polarization curves recorded in a medium containing less than 150 ppm concentration of *Ricinus communis* oil is similar to that drawn in 2M HNO₃. In the presence of an inhibitor concentration equal to or above 150 ppm, the anodic dissolution of copper is made by oxidation of Cu (0) Cu⁺ and Cu²⁺ ions which react with *Ricinus communis* oil to form a complex that provides a partial protection for copper and leads to a decrease of the anode current to its destruction. Indeed according to Figure 1, it is found that the addition of 150 ppm of *Ricinus communis* oil resulted in the appearance of a slight bearing passivation.

To prove the formation of the complex (oil / copper), it has been a iodometric titration cupric ions to a decreased concentration of 0.0204 mol / l in a solution 2M HNO₃ without inhibitor at a concentration of 0.0162 mol / l a solution containing 150 ppm of *Ricinus communis* oil. Here, three distinct regions may be identified for Cu in a medium containing *Ricinus communis* oil in a concentration

varying from 50 to 250 ppm: the Tafel region extending down to the potential-current density peak due the dissolution of cuprous copper ions, the second region is characterized by the decrease of the current until the minimum is reached due to complex formation (cupric ions + *Ricinus communis* oil), the third area represents an increase the sudden current density following destruction of the complex formed which causes the dissolution of Cu. F.mounir [21] The same shape of the polarization curves of copper in 2M H₃PO₄ in the presence of NaCl.

The efficiency values calculated on Icorr values obtained in the absence and in the presence of *Ricinus communis* oil is 99 % at a concentration of 250 ppm (Figure 2) inhibition.

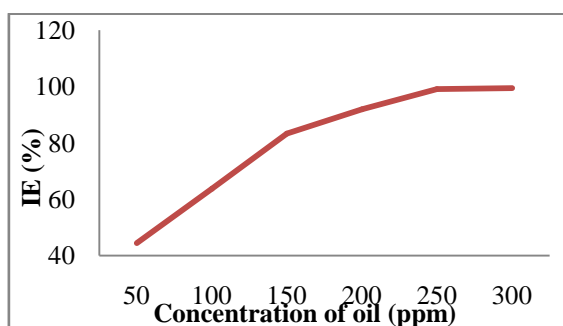


Figure 2. Variation of the efficacy of inhibition of corrosion of copper in 2 M HNO₃ in the presence of *Ricinus* oil at various concentrations at 25 ° C.

- Chronoamperometric current-time (CT)

Experiences chronoamperometric current time were conducted to prove the level of passivation is formed from 150 ppm *Ricinus communis* oil copper in 2M HNO₃ solution. The CT curves measured at 155 mV copper 2M nitric acid containing 150 and 250 ppm of *Ricinus communis* oil are shown in figure 3.

The initial higher current is due to the dissolution of copper in the first cupric cations which in turn reacts with the *Ricinus communis* oil to form a complex. The current then decreases due to the formation of such a layer provides partial protection and does not allow the increase in current. The good efficiency of *Ricinus communis* oil is proven by the very low current value.

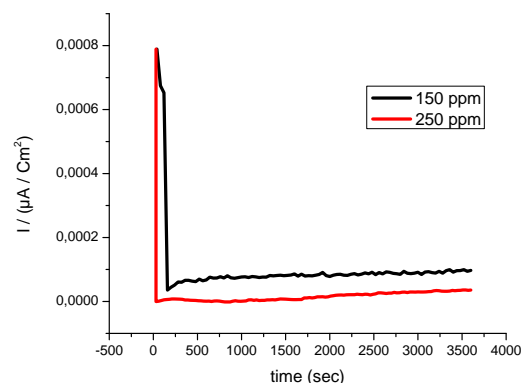


Figure 3. Chronoamperometric curves at 155 mV for copper in 2M HNO₃ containing 150 and 250 ppm of *Ricinus communis* oil.

- Measurements of electrochemical impedance spectroscopy

Representations of Nyquist for copper in 2M HNO₃ solution in the absence and presence of different concentrations of *Ricinus communis* oil are given in Figure 4.

The impedance spectra are simple form semicircles, and the semicircles diameter increases with increasing concentration of inhibitor. The presence of a single half-circle indicates that the charge transfer occurs at the electrode / solution interface, and the process of charge transfer reaction of the copper corrosion inhibitor in the presence of the mechanism does not change its dissolution [22,23]. The dielectric parameters are given in Table 3. Values increase with increase of the concentration of *Ricinus communis* oil while Cdl values decrease. Higher values may suggest the formation of a protective layer on the surface of the electrode [24]. The inhibitory effectiveness was determined by:

$$E \% = \frac{R_T - R_T'}{R_T} \times 100 \quad (2)$$

Where R_T and R_{T'} are respectively the resistance of the charge transfer copper 2M HNO₃ in the absence and presence of inhibitor to E_{corr} = 65 mV / SCE.

The values of charge transfer resistance (RT) were calculated based on the difference in impedance between the upper and lower frequency values.

The double layer capacity (Cdl) and frequency (fmax) at which the imaginary component of the impedance is maximum (-Zmax) are represented by:

$$C_{dl} = \frac{1}{2 \pi f_{max} R_T} \quad (3)$$

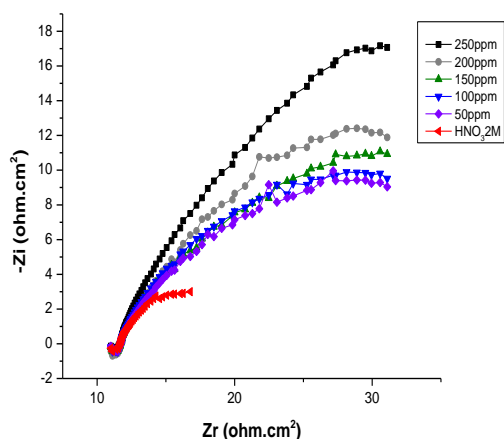


Figure 4. Representation Nyquist copper in 2M HNO₃ at different concentrations of Ricinus communis oil to Ecorr

The Cdl values are considered below those of the blank, thereby confirming the adsorption of inhibitor onto the metal surface forming an electronic double layer [25]. These results are in good agreement with those obtained by polarization where Ricinus communis oil turns out to be a good inhibitor for copper in 2M HNO₃ acid with efficiency of 98%.

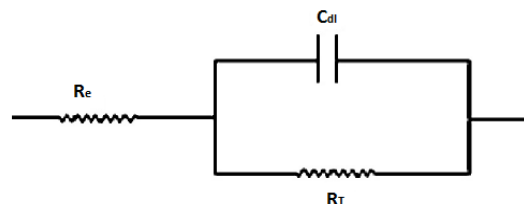


Figure 5. Equivalent circuit used for modeling the impedance diagrams made to potential corrosion.

Table 3. Parameters electrochemical characteristics of impedance diagram of copper with and without addition of inhibitor 2M HNO₃, the corrosion potential.

inhibitor	Concentration in ppm	RT / ohm.cm ²	fm / Hz	Cdl / μF/cm ²	E%
Blank	0	18.71	22.89	371.5	-----
Ricinus communis oil	50	32.06	13.73	361.6	41.64
	100	51.98	10.32	296.7	64.00
	150	101.59	8.46	185.1	81.58
	200	309.75	3.53	145.6	93.96
	250	1600.14	0.77	128.54	98.83
	300	1653.42	0.75	127.89	98.87

The equivalent circuit of said Randles used to study the impedance is given in Figure 5. The resistance Re of the circuit corresponds to the resistance Randles of finite conductivity of the electrolyte. The charge phenomenon of the electrode / solution interface causes the appearance of a capacitive current (shown denoted by the capacitor C_{dl}). The charge transfer resistance R_T is identified in charge transfer resistance [26].

Table 4. Corrosion rate of the copper and inhibitory efficiencies in 2 M HNO₃ without and with addition of Ricinus oil at various concentrations at 25 °C.

	Inhibitor Concentration (ppm)	W (mg/cm ² .h)	EI (%)
blank	0	0.093	-----
Essential oil of Ricinus communis	50	0.062	33.33
	100	0.031	66.66
	150	0.020	77.78
	200	0.010	88.89
	250	0.0053	94.26
	300	0.0053	94.26

3.2.4 Gravimetric measurements

The weight loss measurements were carried out at 293 K in the absence and in the presence of ricinus oil at various concentrations of the samples after immersion in the etching solution of 1h. The efficiency of inhibition, IE (%), and the corrosion rate were calculated using the equations:

$$W = \frac{m_1 - m_2}{A t} \quad (4)$$

$$IE (\%) = \left(\frac{w - w'}{w} \right) \times 100 \quad (5)$$

Where m₁ and m₂ are the weight loss (mg) before and after immersion in the test solutions, A is the sample surface (Cm²), t is the exposure time (h), and w and w' are respectively, Corrosion rates of copper in 2 M HNO₃ medium with and without addition of inhibitor (mg.Cm⁻².h⁻¹). The results of the study are summarized in Table 4.

The values of the efficiency of inhibition, IE (%) obtained by using the method of weight loss for the different concentrations of Ricinus communis oil are summarized in Table 4. It is very clear that the Ricinus communis oil inhibits the corrosion of copper in a solution of 2M HNO₃, since the corrosion rate (W) continuously decreases with increasing inhibitor concentration at 293K, the maximum efficacy (94.26%) was obtained at 250 ppm.

The comparison shows that the three techniques EI (%) obtained by using the impedance technique are comparable, and are parallel to those obtained by the methods of losing weight and polarization (Figure 6).

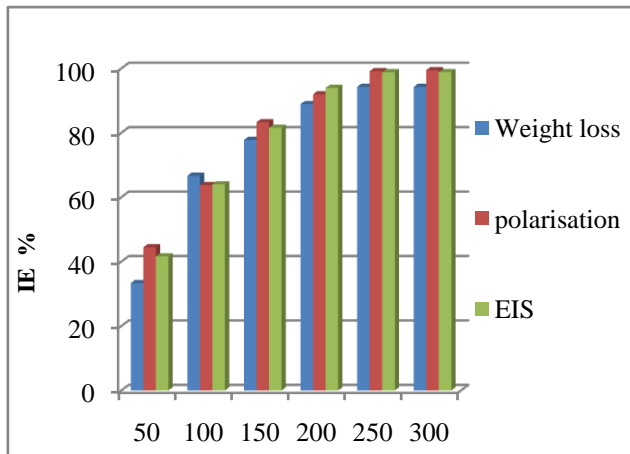


Figure 6. Comparison of the efficiency of the inhibition obtained with the use of weight loss, polarization and impedance measurements

C. Effect of temperature

The temperature is an important condition in the studies on the dissolution of the metal. The rate of corrosion in acidic solutions, for example, increases exponentially with increasing temperature due to the evolution of the hydrogen overvoltage decreasing [27].

The I_{corr} value was obtained by extrapolation of Tafel straight experiments 283, 293, 303, and 313 K. The polarization curves for copper in a solution 2M HNO_3 in the temperature range (273-313 K) are represented Figures 7 and 8, respectively with and without 250 ppm of *Ricinus communis* oil. The various numerical values of the variation of the corrosion current density (I_{corr}), the corrosion potential (E_{corr}), cathodic Tafel slope (β_c), and anodic Tafel slope (β_a) to 250 ppm of inhibitor at all temperatures studied are given in Table 5.

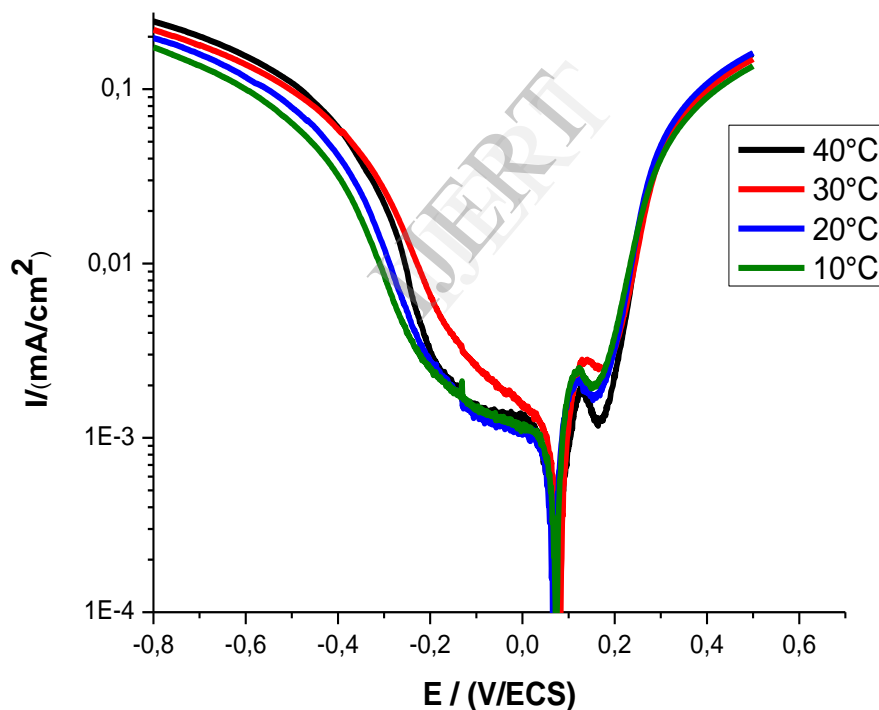


Figure 7. Effect of temperature on the cathode and anode reactions copper in 2M HNO_3

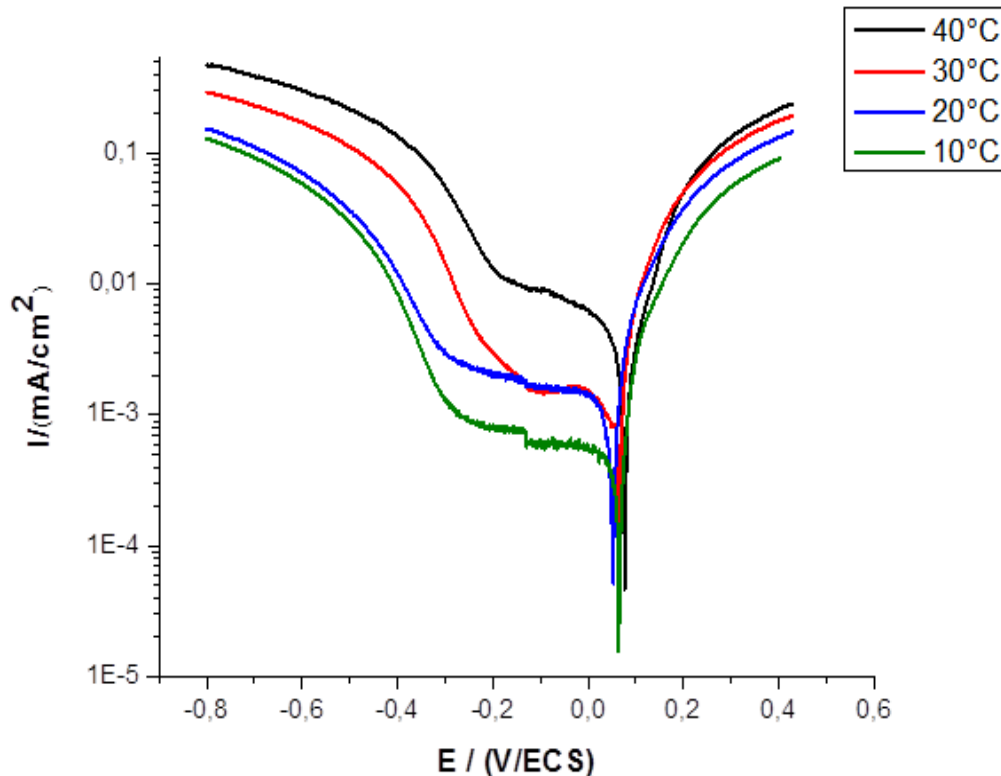


Figure 8. Effect of temperature on the cathode and anode reactions copper with 2M HNO₃ in 250 ppm of Ricinus communis oil.

Table 5. Electrochemical parameters of copper in 2 M HNO₃ without and with 250 ppm of *Ricinus communis* oil, at different temperatures

Inhibitor	Temperature/ (K)	E _{Corr} / (mV / SCE)	I _{Corr} / (mA / cm ²)	β _a / (mV)	-B _c / (mV)	IE%
Blank	283	75.8	1.5387	66.1	77.3	---
	293	64.1	1.9411	126.4	84.5	---
	303	50.3	2.9902	123.1	91.6	---
	313	66.4	3.6507	98.6	65.8	---
Oil of <i>Ricinus communis</i>	283	71.9	0.0114	56.6	68.1	99.26
	293	72.7	0.0296	34.4	77.3	98.48
	303	78.8	0.0557	45.1	78.2	98.14
	313	71.0	0.0978	49.9	132.3	97.31

In the absence of *Ricinus communis* oil, the I_{corr} value increases with increasing temperature, higher than that obtained in its presence. It is obvious that the *Ricinus communis* oil has inhibitory properties at all temperatures studied, and the values of the effectiveness of inhibition remain constant since no decrease more than 2 % with increasing temperature.

This means that the inhibitor is adsorbed on the substrate by chemical bonds (tight binding). This type of non-temperature-sensitive connections effectively fights against corrosion when the temperature increases [28].

In the case of the acid corrosion, many authors [29] use of the Arrhenius equation to account for the effect of temperature (T)

on the rate of corrosion and therefore believe that the logarithm of the speed corrosion W is a linear function of T⁻¹. We can calculate the activation energy from the following relationships:

$$I_{\text{corr}} = K \exp(-E_a / RT) \quad (6)$$

$$I = K' \exp(-E'a / RT) \quad (7)$$

Where k and k' are constants (Arrhenius pre-exponential parameter), and E_a and E'a activation energies, respectively, in the absence and presence of the inhibitor.

Some conclusions on the mechanism of action of the inhibitors may be obtained by comparing measured E_a to both the presence and absence of the corrosion inhibitor. Figure 9 shows the Arrhenius plot of coordinates in the corrosion rate of copper in 2M HNO₃ in the absence and in the presence of *Ricinus communis* oil to 250 ppm.

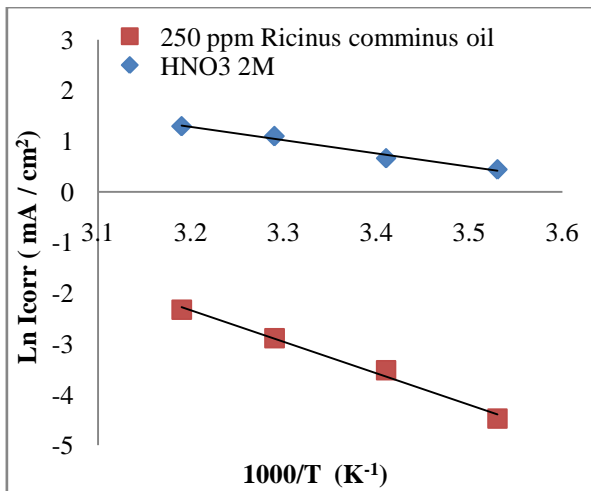


Figure 9. Arrhenius diagram of the dissolution of copper in 2M HNO₃ at different temperatures with and without inhibitor.

The variation of the logarithm of the corrosion current as a function of T^{-1} gives straight indicating that the Arrhenius law is enforced. The values of the activations obtained from these straight energies are given in Table 6.

Table 6. Activation energy of copper dissolution in 2M HNO₃ alone and in the presence of inhibitor.

Sample	Ea / (kJ / mol)
Blank	31.55
Essential oil of <i>Ricinus communis</i>	23.21

From the results of Table 6 it is clear that the presence of inhibitor decreases the activation energy in the presence of inhibitor. This behavior demonstrates the phenomenon of chemisorption of the inhibitor to the metal surface of protective power which increases with temperature.

The values of the activation energy obtained from Arrhenius straight is 31.55KJ. mol⁻¹ in the absence of inhibitor, this value is in agreement with the literature [30], and a 250 ppm concentration of *Ricinus communis* oil, i.e. when the rate of recovery is maximum, the value of the activation in the presence of this oil energy is 13.35 KJ. mol⁻¹. This confirms the chemical adsorption of *Ricinus communis* oil by the formation of an effective protective film.

The kinetic parameters, the enthalpy and entropy of the corrosion process are also estimated from the study of the effect of temperature. An alternative formulation of the Arrhenius equation [31]:

$$I_{\text{corr}} = \frac{RT}{Nh} \times \exp\left(\frac{\Delta S^*}{R}\right) \times \exp\left(-\frac{\Delta H^*}{RT}\right) \quad (8)$$

Where h is Planck's constant, N is the Avagadro number, ΔS^* is the entropy of activation, and the ΔH^* is the activation enthalpy. Figure 10 shows plots of $\ln(I_{\text{corr}} / T)$ versus $1 / T$. The straight lines are obtained with a slope of $-\Delta H^* / R$ and an intercept $(\ln R / Nh + \Delta S^* / R)$, from which the values of ΔS^* and ΔH^* can be calculated, these values are given in Table 7.

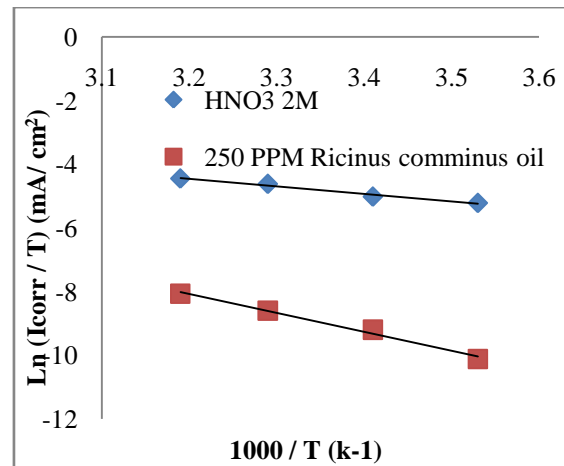


Figure 10. Relationship between $\ln(I_{\text{corr}} / T)$ and $1000 / T$ at different temperatures

Table 7. The values of the activation parameters ΔH^* and ΔS^* of copper in 2M HNO₃ in the absence and presence of 250 ppm of *Ricinus communis* oil to $T = 293\text{K}$

Inhibitor	ΔH^* (KJ / mol)	ΔS^* (J/mole.K)
Blank	3.518	-233.63
<i>Ricinus communis</i> oil (250 ppm)	1.401	-262.24

The positive sign of ΔH^* reflects an endothermic process of adsorption, which is assigned to the chemisorptions [32]. Negative values of entropy ΔS^* , reflects an increase in the disorder that occurs during the formation of metal / adsorbed species complex [33].

More

$$\Delta G^* = -R \times T \times \ln(55.5 \times K) \quad (9)$$

$$K = \Theta / C \times (1 - \Theta) \quad (10)$$

Where R is the universal gas constant, 55.5 is the concentration of water in mol / l, Θ is the degree of coverage of the metal surface, and C is the concentration in ppm of the inhibitor.

The negative value of $\Delta G^* = 38\,064$ kJ / mol at 25°C indicates the spontaneous adsorption process, and the stability of the adsorbed layer on the metal surface [34].

- adsorption isotherm

The adsorption on the surfaces of corrosion has never reached a real equilibrium and tends to reach a state of equilibrium adsorption. However, when the corrosion rate is sufficiently small, the stationary state of adsorption tends to become a quasi-equilibrium state. In this case, it is reasonable to consider that the adsorption thermodynamic quasi-equilibrium isotherms using appropriate balances. [35]

The adsorption behavior provides information on the interaction between the adsorbed molecules and their interactions with the surface of the electrode [36].

It has been reported that the adsorption of the inhibitor molecules depends on a variety of factors, for example the presence of functional groups (or electron donor or withdrawal) steric factors, the distribution of load on the donor

atom the π orbital nature of electron donors, the nature of the metal substrate, and the type of interaction between the organic molecules and the metal surface [37]. The adsorption of Temkin, Frumkin and Langmuir isotherms were used to represent the *Ricinus communis* oil on the surface of copper adsorption. The correlation coefficient, R^2 , was used to choose the isotherm that best matches the experimental data. The recovery rate (θ) at different concentrations for the inhibitor tested in 2M HNO_3 was assessed from measurements of weight loss.

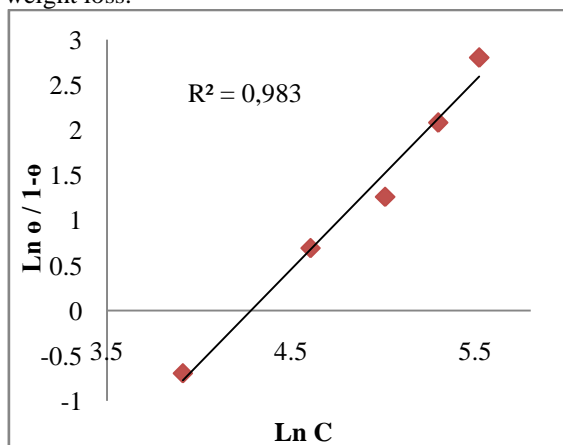


Figure 11. Model Langmuir isotherm for adsorption of *Ricinus communis* oil on the surface of copper in 2 M HNO_3 at 25°C.

The curve representing $\ln(\theta / 1 - \theta)$ as a function of $\ln[C]$, where C is the concentration of inhibitor, is a straight line (Figure 11) indicating that the adsorption of the inhibitor on the surface of the plate Copper is according to the Langmuir model:

$$\ln(\theta / 1 - \theta) = K \ln[C] \quad (11)$$

The strong correlation ($R^2 = 0.983$) for the plot of $\ln(\theta / 1 - \theta)$ versus $\ln[C]$ confirms the validity of this approach.

Based on the Langmuir isotherm, we can put an approach to the representation of adsorption phenomena, which is based on three assumptions, explaining that the adsorption is localized and does not give rise to the formation of a monolayer, and all sites are equivalent and the surface is uniform, and that there is no interaction between the adsorbed molecules (Figure 12). This allows considering constant adsorption energy [38].

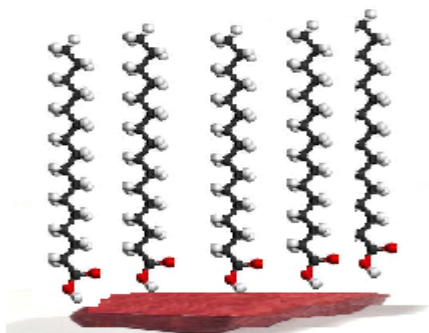


Figure 12. Model adsorption isotherm according to the Langmuir adsorption of *Ricinus communis* oil on the surface of copper in 2 M HNO_3 at 25°C.

IV. CONCLUSION

It appears from this study that:

- *Ricinus communis* oil is an effective inhibitor of the corrosion of copper in a solution of 2M HNO_3 . Efficiency of *Ricinus communis* oil increases with the concentration to achieve 99 % to 250 ppm.

-The results of polarization studies suggest that *Ricinus communis* oil acts as mixed type inhibitor.

- Results from electrochemical impedance spectroscopy indicate that adsorption of *Ricinus communis* oil on the surface of the copper increases the strength and reduces the transfer capacity of the double-layer.

- The adsorption of *Ricinus communis* oil on the copper surface in a solution of 2 M HNO_3 is done according to the Langmuir adsorption isotherm, with a high correlation coefficient. The adsorption process is an endothermic process and spontaneous.

-The efficiency determined by electrochemical polarization inhibitors, Electrochemical impedance spectroscopy, and gravimetric values are in good agreement.

BIBLIOGRAPHIC REFERENCE:

1. A.Y. El-Etr-e, M. Abdallah, Z.E. El-Tantawy, Corros. Sci. 47 (2005) 385.
2. K.O. Orubite, N.C. Oforka, Mater. Let. 58 (2004) 1768.
3. A.Y. El-Etre, Corros. Sci. 45 (2003) 2485.
4. G.O. Avwiri, F.O. Igho, Mater. Let. 57 (2001) 3705.
5. A.Y. El-Etre, M. Abdallah, Corros. Sci. 42 (2000) 731.
6. A.Y. El-Etre, Corros. Sci. 40 (1998) 1845.
7. H. Al-Sehaibani, Mater. Wissen. Werkst. Tech. 31 (2000) 1060.
8. S. Martinez, I. Stern, Appl. Surf. Sci. 199 (2002) 83.
9. R.M. Saleh, A.A. Ismail, A.A. El Hosary, Corros. Sci. 17 (1982) 131.
10. A.A. El Hosary, R.M. Saleh, A.M. Shams El Din, Corros. Sci. 12 (1972) 897.
11. F. Bensabah, S. Houbairi, M. Essahli, A. Lamiri, J. Naja. Portugaliae Electrochimica Acta (2013), 31(4), 195-206.
12. F. Bensabah, S. Houbairi, M. Essahli, A. Lamiri, J. Naja. Journal of Advances in Chemistry. (2014).
13. S. Houbairi, M. Essahli, A. Lamiri, International Journal of Engineering Research & Technology, Vol. 3 Issue 2, February (2014).
14. S. Houbairi, M. Essahli, A. Lamiri, Port. Electrochim. Acta. (2014).
15. A. Chetouani, B. Hammouti, M. benkaddour, Resin Pigment Technol. 33 (2004) 26.
16. E.L. Chaieb, A. Bouyanzer, B. Hammouti, M. Benkaddour, M. Berrabah, Trans. SAEST 39 (2004) 58.
17. E. Azzouyehar, L. Bazzi, M. Essahli, M. Belkhaouda, L. Bammou, A. Lamiri. Journal of Advances in Chemistry. (2013) Vol. 5, No. 3
18. B. Hammouti, S. Kertit, M. Melhaoui, Bull. Electrochem. 11 (1995) 553;
19. S. Houbairi, M. Essahli, A. Lamiri, International Journal of Engineering Research & Technology, Vol. 3 Issue 1, January (2014).
20. A.K. Satapathy, G. Gunasekaran, S.C. Sahoo, K. Amit, P.V. Rodrigues, Corros. Sci. 51 (2009) 2848-2856.
21. F. Mounir, S. El Issami, Lh. Bazzi, R. Salghi, L. Bammou, L. Bazzi, A. Chihab Eddine, O. Jbara. IJRRAS 13 (2) November (2012)
22. L. Larabi, Y. Harek, M. Traisnel, A. Mansri, J. Appl. Electrochem. 34, 833 (2004)
23. X. Li, S. Deng, H. Fu, Corros. Sci. 52, 2786 (2010)
24. M. Behpour, S.M. Ghoreishi, N. Mohammadi, N. Soltani, M. Salavati-Niasari, Corros. Sci. 52, 4046 (2010)
25. K.P. Vinod Kumar, M.S. Narayanan Pillai, G. Rexin Thusnavis, Portugaliae Electrochimica Acta. 28(6), 373-383 (2010)
26. J. Muller, Thèse en Sciences de l'Université Paris Est - Créteil, (2010)

27. A. Popova, E. Sokolova, S. Raicheva, M. Christov, Corros. Sci. 45, 33 (2003)
28. A.S.Fouda, A.K.Mohamed, J.Electrochem. Soc. India 39 (1990) 244.
29. A.B. Mostafa, Corrosion Prevention and Control, vol., June 70, (1980).
30. A.Fiala. Thèse d'état, Universite Mentouri-Constantine. (2007)
31. J.O'M. Bochriss, A.K.N. Reddy, Modern Electrochemistry, vol. 2 (Plenum Press, New York, (1977)
32. N.M. Guan, L. Xueming, L. Fei, Mater. Chem. Phys. 86, 59 (2004)
33. A. Yurt, A. Balaban, S.U. Kandemir, G. Bereket, B. Erk, Mater. Chem. Phys. 85, 420 (2004)
34. M.A. Quraishi, R. Sardar, Ind. J. Chem. Technol. 11 (2004) 103.
35. N. Lahhit, A. Bouyanzer, J.M. Desjobert, B. Hammouti, R. Salghi, J. Costa, C. Jama, F. Bentiss, L. Majidi, Port. Electrochim. Acta. 29, 127 (2011)
36. M. Mahdavian, S. Ashhari, Electrochim. Acta 55, 1720 (2010)
37. R. Hasanov, S. Bilge, S. Bilgic, G. Gece, Z. Kılıc, Corros. Sci. 52, 984 (2010)
38. P.C. Okafor, Y. Zheng, Corros. Sci. 51, 850 (2009)

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