A Natural Extract as Corrosion Inhibitor for Copper Surface in Acid Solution

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***Abstarct-* Electrochemical methods, impedance and polarization were performed for the evaluation and comparison of the corrosive power of copper in 2M HNO_3 environment, with the essential oil of Thymus satureoides and secondly with its major componen, borneol. The inhibition efficiency increases with the concentration to reach 89.04% at 1200 ppm in the presence of the essential oil and 69.72% at 1600 ppm in the presence of Borneol. The polarization curves indicate that they act as a mixed type inhibitor with a predominant cathodic character for the essential oil. The results obtained from potentiodynamic polarization and impedance measurements are in good agreement.**

Keywords: Essential oil of Thymus satureoides; Borneol; Inhibition; Corrosion, Copper, Nitric Acid.

1. INTRODUCTION

Copper is widely used in industry because of its outstanding physical and mechanical properties. For example, it is often used in heating and cooling thanks to its excellent conductivity thermique [1].
It is known that the corrosion products cause a reduction in the efficiency of heating equipment copper. Therefore, the pickling operation is necessary. Why acidic solutions, which unfortunately are often aggressive media for copper are used. Thus, the use of organic inhibitors which play an important role in controlling the corrosion of copper and the kinetics of the hydrogen evolution reaction. It is established that compounds containing nitrogen or oxygen or sulfur are of interest individual [2]. In this context, the azoles are used as corrosion inhibitors for copper and its alloys acide medium [3-11]. Furthermore, Fouda et al. [12-14] examined the inhibitory effect of the corrosion of copper by nitric acid medium few nitrile compounds.

However, the most used against copper corrosion inhibitors are benzotriazole, benzimidazole and tétrazole [15-20]. However, benzotriazole and its derivatives are highly toxiques [21] compounds [22]. Thus, the restrictions due to environmental protection require limiting their utilization [22].

In this context, we are interested in the application of the Moroccan essential oil of *Thymus satureoides*. Which represents the advantage of being a non-toxic natural products as corrosion inhibitors. These products are used as extracts or as essential oils.

From nature and generated by it, that non-toxic natural gasoline, also gave satisfactory regarding the corrosion inhibition of iron in HCl medium 1M [23, 24] results.

In this work, we are interested in studying the behavior of copper in 2M HNO_3 and determine the inhibitory efficacy of the Moroccan essential oil *Thymus satureoides* and to compare its activity with respect to its major product the Borneol. Electrochemical polarization measurements and impedance were carried out for this study.

2. EXPERIMENTAL CONDITIONS

2.1 Inhibitor

2.1.1 Extraction of essential oil

The essential oil was obtained from thyme belonging to the botanical family lipped, by steam distillation of water using a Clevenger-type distiller for 2h30. The yield of essential oil of *Thymus satureoides* is 1.1%. This means essential oil yield was calculated based on the dry matter.
After extraction, a portion of the oil was used for the analysis of the chemical composition, the other part was used for the tests of the anti-corrosion activity. The oil, after extraction, was recovered and stored in a dark bottle and stored at 4 ° C before use.

The Borneol was provided to us by the company SOMAPROL.

2.1.2 Study of the chemical composition of the oil

The thyme essential oil was analyzed by chromatography Gas chromatography coupled to mass spectrometry.

2.2 Corrosive solution

This is a solution of acid 2M HNO_3 nitric obtained by diluting concentrated acid 67% Sigma-Aldrich brand with distilled water. The medium is not deaerated.

2.3 Electrochemical measurements

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 cm^2, 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 use. The measurements are performed with an assembly comprising a potentiostatgalvanostat PGZ100, radiometer type associated with "voltamaster4" 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.

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 potential for corrosion and various other potential points. The diagrams given in the impedances are Nyquist representation.

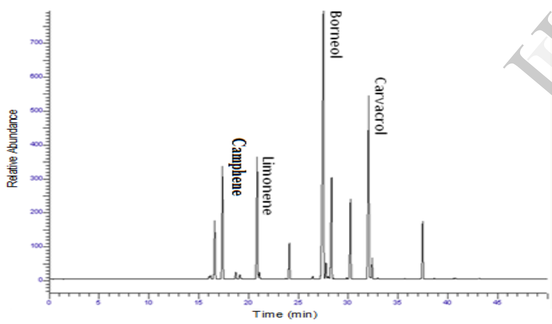
The various tests were carried out maintaining the temperature at 25°C±1.1°C of the electrolyte with a thermostat FRIGITHERM mark.

3. RESULTS AND DISCUSSION

3.1 Analysis of the chemical composition of the essential oil

The essential oil of *Thymus satureoides's* main components: borneol (35.9%) (Fig.1), Carvacrol (17.8%), camphene (10.2%), α-thujone (2.4%). α-terpineol (0.6%), analysis of the chemical composition of the essential oil was performed by gas chromatography coupled to mass spectrometry. The chromatogram obtained is shown in Fig. 2 The retention time and the relative percentage of the various constituents of the essential oil are shown in Table 1.

Fig.



1.Chemical structure of Borneol.

Fig. 2.Chromatogram of the essential oil of Thymus satureoides.

Table 1.Constituents of the essential oil of thyme.

Time (min)	Area%	Compound
16609	0.30	thujene (alpha)
17390	10.20	Camphene
20871	11.19	limonene
24106	2.43	alpha-thujone
27524	35.89	Borneol
27780	0.55	alpha terpineol
28348	9.26	pinanone
30238	6.68	thymoquinone
32067	17.81	Carvacrol
32416	1.04	isomenthyl acetate
37472	4.06	Himachalene

3.2 Potentiodynamic polarization curves

The measurement of the corrosion potential and the transient curves plotted intensities-potential indicates the type of inhibitor (cathode-anode) in the direction of deflection of the potential relative to the potential measured in the absence of inhibitors, while distinguishing the influence of the inhibitor on each of the individual reactions, anodic and cathodic , to the electrode, it can also use the linear portion of the semi-logarithmic transformation E = f (log I), allow us firstly to access the value of the corrosion current density and other share the values of the slopes of the Tafel.

Figures 3,4 and 5 show the curves of cathodic and anodic polarization of copper in HNO3 media,without inhibitor (Fig. 3), with the addition of the essential oil of Thymus satureoides (Fig. 4), and then with the addition of Borneol (Fig. 5) at different concentrations. The electrochemical parameters derived from these curves are shown in Table 2.

The inhibitory effectiveness of tested compounds% IE is defined by equation:

$$\% \text{ EI} = \frac{I_{corr} - I'_{corr}}{I_{corr}} \times 100$$

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

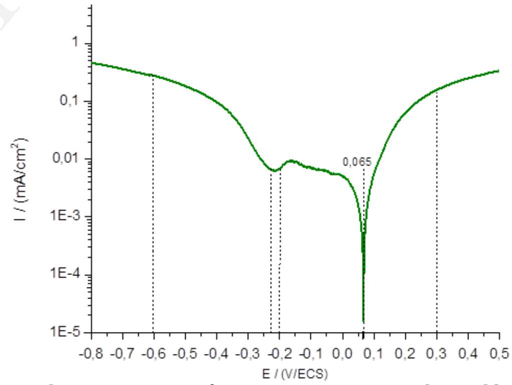


Fig. 3. Polarization curves of copper in 2M HNO_3 without addition of inhibitor at 25°C.

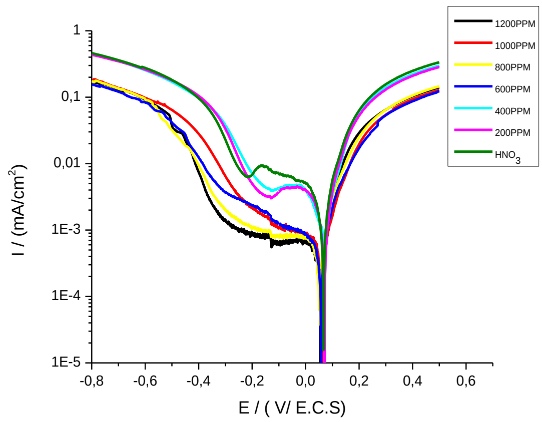


Fig. 4. Polarization curves of copper in 2M HNO_3 without and with addition of the essential oil of *Thymus satureoides* at different concentrations to 25°C.

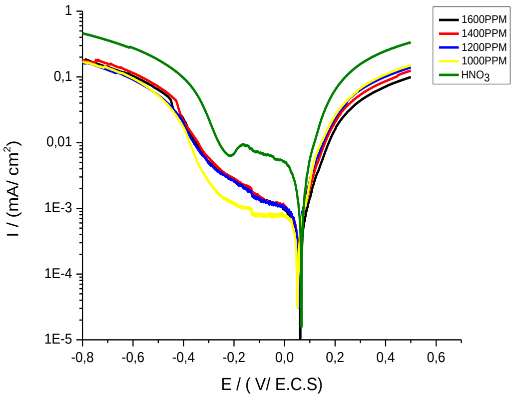


Fig. 5. olarization curves of copper in 2M HNO3 without and with addition of different concentrations Borneol to 25 ° C.

2M nitric acid

In the control medium (white) in the cathodic branch, there are four areas of potential: the first area is observable at more negative voltages (less than a) where'there is an intensive gassing due to the reduction reaction of protons which coincides with that of'nitric acid. The second range between -600 mV / SCE and -240 mV / ECS is characterized by a linear growth of the logarithm of current versus potential. It corresponds to the reduction of'nitric acid on the surface of'electrode.

The third area, on a current plateau between -200 mV / SCE where'there is the'cessation of gas evolution. Showing a considerable decrease in current density for this part of the curve.

Table 2. Electrochemical parameters and inhibitory efficacy of copper in 2M HNO_3 without and with adition of the essential oil of Thymus satureoides Borneol and at various concentrations at 25 °C.

Inhibitor	CINH / (ppm)	Corr / (mV / SCE)	Corr / (mA / cm2)	βa / (mV)	βc / (mV)	IE%
Blank	---	65.2	2.1741	77.0	-349.5	---
the essential oil of *Thymus satureoides*	200	68.9	1.8560	75.9	-206.1	14.63
	400	70.4	1.4906	72.0	-165.8	31.44
	600	56.3	1.3529	126.2	-21.4	37.77
	800	50.9	1.2059	106.0	-21.4	44.53
	1000	59.2	0.7500	93.6	-877.6	65.50
	1200	56.5	0.2387	42.9	-96.5	89.02
	1400	57.3	0.2383	40.8	-148.0	89.04
Borneol	1000	50.7	1.7141	121.5	-18.1	21.16
	1200	53.9	1.3742	112.2	-22.7	36.79
	1400	57.4	0.8851	95.7	-821.4	59.29
	1600	60.4	0.6584	95.1	-466.0	69.72
	1800	33.0	0.6561	123.8	-279.4	69.82

This allowed us to conclude that the low current density associated with this area is due to the reduction of'oxygen dissolved in the solution. Finally, the fourth field from -200 mV / ECS up'the corrosion potential (65 mV / SCE). This part of the curve corresponds to the reduction of'HNO2 [25]. In the anodic branch, there are two potential areas: the first area is from the corrosion potential and the beginning of the linear portion to an equal potential value of 300 mV / SCE where gas evolution is observed. It is probably due to the'oxidation'a species produced by the reduction of'(likely NO) nitrous acid where'it was found that the continuous release to occur. The second area in which the current density increases continuously with the potential'electrode reflects the anodic dissolution of cuivre [25].

Addition of inhibitor

Addition of this inhibitor in a nitric medium (2M) results in a corrosive significant decrease in corrosion rate. Furthermore the hydrogen overvoltage may decrease or increase depending on the nature of the metal, the hydrogen overvoltage of copper is much greater in the presence of the inhibitor. On the other hand, the influence of the inhibitor on the corrosion potential of ennobling result of accelerating the formation of the protective layer in the nitric medium.

Case of the essential oil of Thymus satureoides

Examination of Fig. 4 and the data in Table 2, we can see that the addition of the test compound causes a slight shift of the corrosion potential but with a tendency towards the cathode values. This displacement is accompanied by a net decrease of the densities of the anodic and cathodic current which is more marked when the concentration of inhibitor increases until a critical concentration at which value of 0.2387 mA / cm^2 is obtained corresponding to an efficiency of 89.02%.

This decrease of the current bit to be explained by the inhibiting action of this inhibitor, the adsorption of chemical compounds in the essential oil on the surface of active electrode sites, creating a barrier that slows the dissolution of metallic copper in the anodic sites and blocking the

release of hydrogen in the reduction of the blocking on cathodic hydrogen sites [26].
In the light of these results we noted the mixed nature of the inhibitor used with predominant cathodic effectiveness.
On the other hand the addition of inhibitor varies slightly the values of Tafel slopes, but this does not necessarily mean a change in the mechanism of the reaction. Indeed, when the recovery rate increases with the concentration of inhibitor, the active air electrode is reduced and the adsorbed film can have an ohmic behavior, manifested by a change in the value of βa and βc. So although the inhibitor has an inhibitory efficacy makes good slow corrosion of copper, there is the reduction reaction of nitric acid and thus release of dihydrogen that the dissolution of copper following the same mechanism in the absence inhibitor on free sites metal [27].

Case Borneol

The analysis of Fig. 5 and Table 2 shows that the addition of the inhibitor leads to a small movement of the corrosion potential. This displacement is accompanied by a decrease in the anodic and cathodic current is due to the inhibitory action of a mixed character Borneol but still much less influential than in case of the essential oil.

Comparison of electrochemical results obtained in this study show that the addition of essential oil *Thymus satureoides* a still more pronounced effect than that of its major product, Borneol alone. Where it is found that the maximum efficiency of 89.02% is achieved at 1200 ppm to the total oil while it is only 69.72% of a higher concentration of 1600 ppm in the case of Borneol.
On the other hand, always with the same concentrations, the corrosion current in the presence of Borneol decreases to a value of 0.6561 mA / cm^2 a value which remains substantially higher than that obtained with the total essential oil and which is of the order of 0.2383 mA/cm^2.

Transient electrochemical measurements

The electrochemical impedance measurement technique is particularly suitable for determining the mode of inhibitor action, evaluation of dielectric properties of the film formed and follows their evolution as a function of many parameters.
It also helps to explain the chemical or electrochemical process developing through the films formed. Thus, we applied this technique to study the influence of the addition of the essential oil Thymus Sautreoides on the electrochemical behavior of the interface of copper / 2M HNO_3, while comparing this activity with that of Borneol.
These measurements were made at various points of the current-potential curve in the absence and presence of inhibitor.

Allure of the diagram corrosion potential.

The Fig. 6 shows the diagram of electrochemical impedance of copper obtained in 2M HNO_3 with and without addition of inhibitors. The dielectric parameters of the metal / solution interface from this diagram are collected in Table 3.

The inhibitory effectiveness was determined by equation:

$$E\,\% = \frac{R_T' - R_T}{R_T'} \times 100$$

Where R_T and R_T' are respectively the resistance of the charge transfer copper 2M HNO_3 in the absence and presence of inhibitor to E = 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 (C_{dl}) and frequency (fmax) at which the imaginary component of the impedance is maximum are shown in Equation:

$$C_{dl} = \frac{1}{2\pi\, fmax\; RT}$$

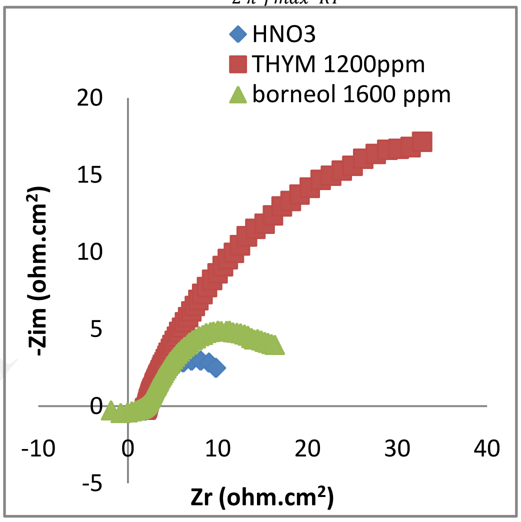


Fig. 6. Electrochemical impedance diagram of copper with and without the addition of inhibitors to the corrosion potential in 2M HNO_3.

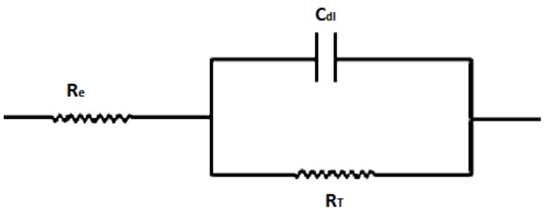
Table 3. Parameters electrochemical characteristics of impedance diagram of copper with and without addition of inhibitors 2M HNO_3, the corrosion potential.

Inhibitor concentration / ppm	R_T / ohm.cm^2	fm / Hz	Cdl / µF/cm^2	E%
Blank	18.71	22.89	371.5	-----
Essential oil Thymus satureoides 1200 ppm	154.70	6.25	164.6	87.9
Borneol 1600 ppm	61.67	10.00	258.0	69.66

This diagram is used to distinguish in the case of the white vertical bar is formed as a semicircle at high frequencies characterizing the charge transfer in the presence of these inhibitors diagrams keep pace even more flattened at least characterizing the formation of a protectrice layer [28], they do not close on the real axis reflecting a capacitive interface behavior.
The equivalent circuit of said Randles used to study the impedance is given in Fig. 7. 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 Rt is identified in charge transfer resistance [29].

Fig. 7.Equivalent circuit used for modeling the impedance diagrams made to potential corrosion.



The value of RT password 18.70 ohm.cm^2 in the case of witness 154.70 ohm.cm^2 1200 ppm of essential oil of *Thymus satureoides* and a value of 61.67ohm.cm^2 to 1600 ppm of Borneol.

Higher values of R_T inhibitors for higher concentrations, indicating the resistance against charge transfer reactions, responsible for corrosion process, for forming a protective film on the metal-substrate interface acid.

The C_{dl} values are considered below those of the blank, thereby confirming the adsorption of inhibitor onto the metal surface forming a double layer électronique [30].

These results are in good agreement with those obtained by the polarization Borneol which proves to be a good inhibitor for copper in 2M HNO_3 acid with an efficiency of 69.99%, but there is less effective than in the case of the total essential oil which represents an inhibitory efficacy of 87.9%, which shows that the inhibitory action of *Thymus satureoides* Moroccan is not due to its major product.

Influence of cathodic overvoltage

This study was performed in the potentiostatic mode potential increasingly along the cathode polarization curve. Electrochemical impedance diagrams are shown in Fig. 8 for the essential oil of *Thymus satureoides* and Fig. 9 for Borneol.

The parameter values associated with these measures are summarized in Table 4 for the essential oil of *Thymus satureoides* and in Table 5 for Borneol.

Case of the essential oil of *Thymus satureoides*

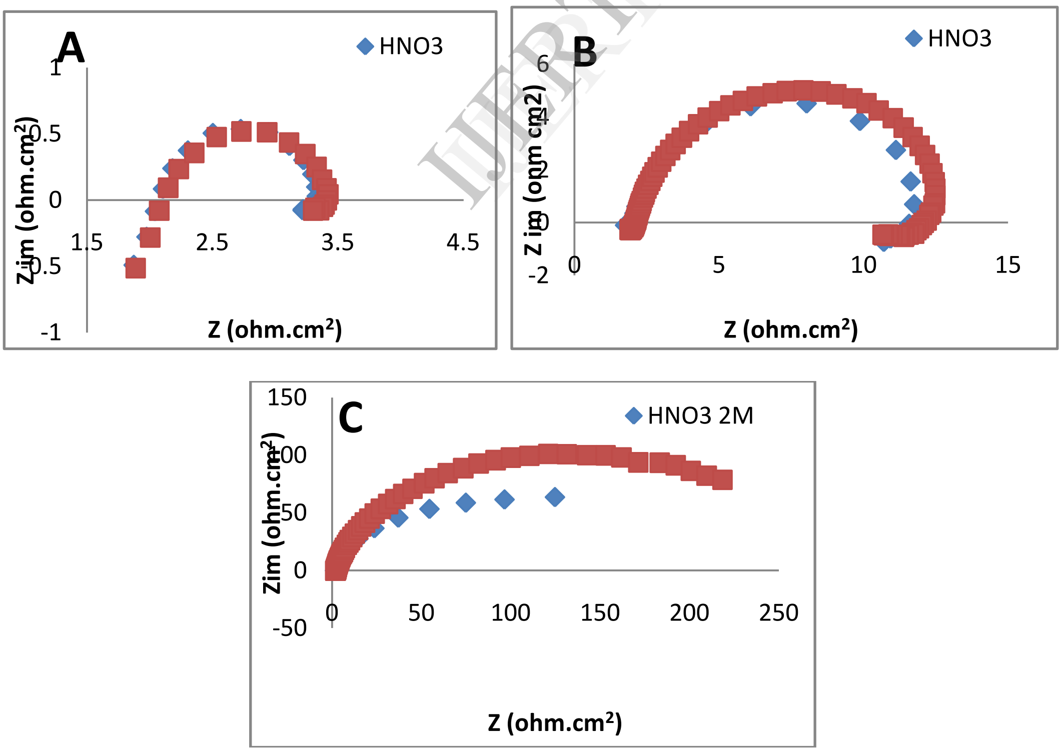


Fig. 8. Diagram of electrochemical impedance determined at different cathode voltage, the copper in 2M HNO_3 with and without addition of the essential oil of *Thymus satureoides* to 1200 ppm.

A. E = -600 mV / ECS B. E = -400 mV / ECS C. E = -200 mV / ECS

Table 4. Characteristics derived from the impedance diagrams obtained under cathodic polarization with and without addition of the essential oil Thymus satureoides 1200 ppm of copper in 2M HNO_3.

Inhibitor	E / mV / ECS	R_T / ohm.cm^2	fm / Hz	C_{dl} / µF/cm^2
Blank	-600	1340	4091.36	29.03
	-400	8202	837.84	23.16
	-200	47.32	157.02	21.42
Essential oil of *Thymus satureoides* 1200 ppm	-600	1370	3850.56	30.17
	-400	9620	615.25	26.89
	-200	264.4	11.28	53.36

A (E = -600 mV / ECS)

The electrochemical impedance diagrams plotted in potentiostatic mode, the potential to -600 mV / SCE, which is within a characteristic field transpassivity. The results obtained are consistent with those found by Keddam andYU [31-33].

The diagram shows a portion of a capacitive semicircle connected to the high frequency of the double layer capacity. The resistor corresponds to an associated charge transfer resistance. On the other hand an inductive loop is apparent in the frequency range of 10 Hz to 10 MHz.

B (E = -400 mV / ECS)

The impedance plots diagrams to -400 mV / SCE show a capacitive high frequency which can be attributed to the charge transfer followed by an inductive loop loop.

The analysis of the impedance values reveals a decreased charge transfer resistance and an increase in frequency, compared with the corresponding diagram obtained at -200 mV / SCE. This may mean that the process for the charge transfer, diffusion, adsorption include several slow steps in A than B. proposed at this stage the reaction mechanism contains several successive elementary steps. This change in resistance is quite compatible with the existence of a plateau in the curves polarization [34].

C (E = -200 mV / ECS)

The two diagrams are with and without inhibitor consisting of a high-frequency arc which can be attributed to charge transfer. It is noted that these diagrams are not close to the real axis, which reflects a capacitive interface behavior.

Discussion

In general, in the presence of thyme impedance values are greater than those of copper in 2M HNO_3 alone. This result reflects the influence of the cathodic electrochemical behavior of the interface Cu / 2M HNO_3.

Indeed impedance diagrams of this inhibitor is characterized by the increase

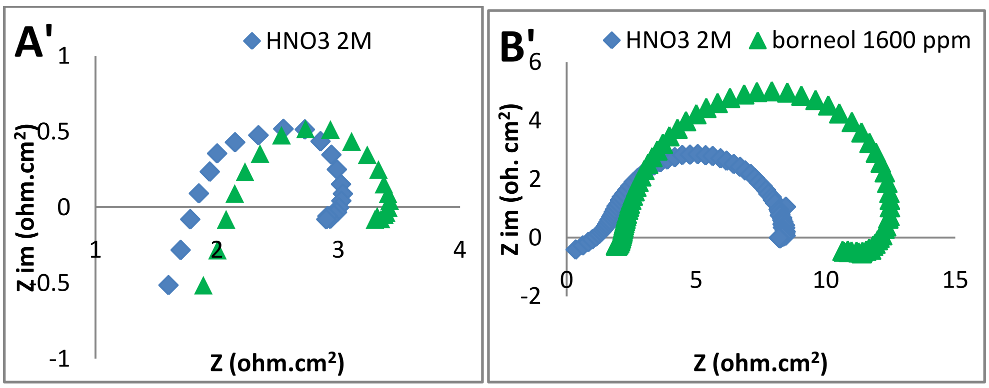
in charge transfer resistance and the double layer capacity, and the decrease of the frequency.

The results of the influence of power surges on the cathode of the electrochemical impedance with and without copper inhibitor in addition to medium acid diagrams HNO_3 2M, may be divided into two parts:

-For a voltage -200 mV / ECS there has been a capacitive arc which does not close on the real axis, indicating a charge transfer with a reduction mechanism consists of several successive elementary steps involving adsorbed compounds H_{ads} like.

-For the potential of -400 and -600 mV / SCE. In this area the impedance diagrams are characterized by the presence of a capacitive charge transfer loop followed by a inductive loop. The resistance value of the load transfer to -600 mV / SCE decreases reflecting acceleration of the electrochemical process or a change of mechanism [35].

Case of Borneol.



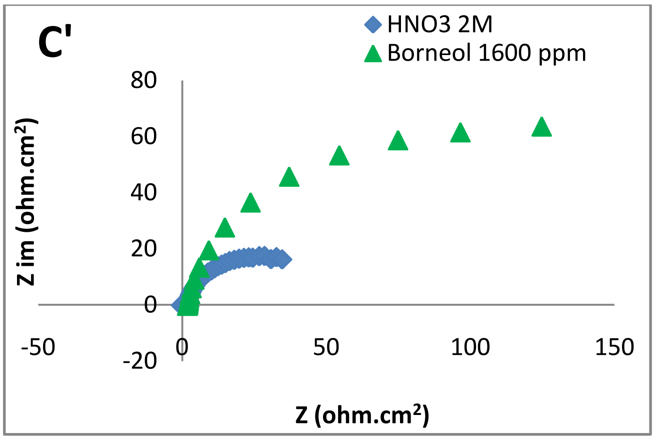


Fig. 9.Diagram electrochemical impedances determined at different cathode overvoltages, on the copper in 2 M HNO3 without and with addition of 1600 ppm Borneol.

A '. E = -600 mV / ECS B '. E = -400 mV / ECS C '. E = -200 mV / ECS

Table 5. Characteristics derived from the impedance diagrams obtained under cathodic polarization with and without addition of Borneol to 1600 ppm of copper in 2M HNO_3.

Inhibitor	E / mV / ECS	R_T / ohm.cm^2	fm / Hz	C_{dl} / µF/cm^2
Blank	-600	1340	4091.37	29.03
	-400	8202	837.84	23.16
	-200	47.32	157.02	21.42
Borneol 1600 ppm	-600	1356	1650.78	71.10
	-400	9350	1208.08	14.09
	-200	188.4	47.29	17.86

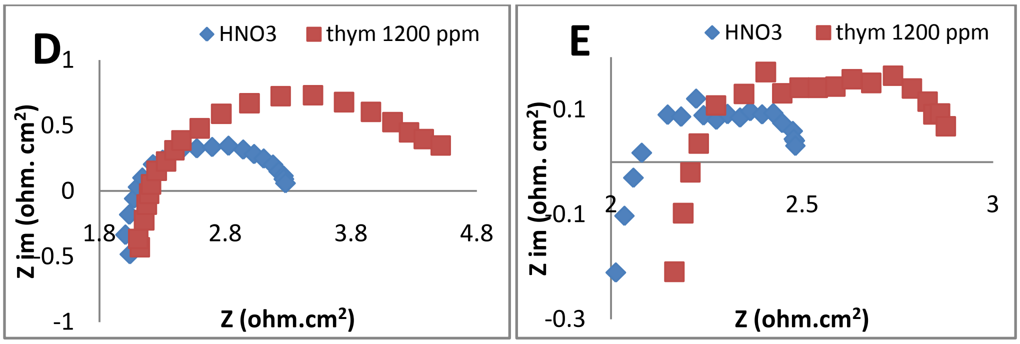
The influence of cathodic overvoltage was performed in potentiostatic mode along the current-potential curve at 1600 ppm Borneol. The shape of the corresponding impedance diagrams is similar to that obtained with the essential oil of *Thymus satureoides* where we see the emergence of a capacitive loop followed by an inductive loop.
Deviations perfect circular shape are often refereed to frequency dispersion of interfacial impedance. This unusual phenomenon can be attributed to the heterogeneity of the surface of the electrode resulting from the surface roughness or phenomena interface [36, 37].
The R_T values are lower compared to those obtained under the same conditions with the thyme. These results demonstrate the effect more pronounced cathodic thyme compared to Borneol.

Influence of the anodic overvoltage

All experimental results were obtained in potentiostatic mode. The imposed potentials are 100, 200, 400 mV / SCE. Electrochemical impedance diagrams are shown in Fig. 10 for the essential oil of *Thymus satureoides* and Fig. 11 for Borneol.

The parameter values associated with these measures are summarized in Table 6 for the essential oil of *Thymus satureoides* and in Table 7 for Borneol.

Case of the essential oil of *Thymus satureoides*.



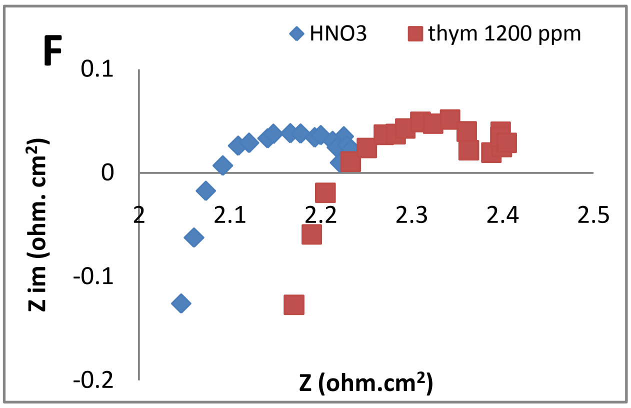


Fig. 10.Diagram of electrochemical impedance determined at different anode voltages, the copper in 2M HNO_3 with and without addition of the essential oil of *Thymus satureoides* to 1200 ppm.

D. E = 100 mV / ECS E. E = 200 mV / ECS F. E = 400 mV / ECS

Table 6. Characteristics derived from the impedance diagrams obtained under anodic polarization with and without addition of the essential oil *Thymus satureoides* 1200 ppm of copper in 2M HNO_3.

Inhibitor	E / mV / ECS	R_T / ohm.cm^2	fm / Hz	C_{dl} / µF/cm^2
Blank	100	1228	314.04	412.7
	200	0.5102	400.08	779.7
	400	0.3478	10.00	45740
Essential oil of *Thymus satureoides* 1200 ppm	100	5841	132.98	204.9
	200	1756	161.36	561.7
	400	0.4064	8.89	44030

D (E = 100 mV / ECS)

In the case of white, the impedance diagram obtained shows a capacitive loop. The same was observed with the addition of thyme, a loop diagram falls due to charge transfer and speaker at the interface Cu / 2M HNO_3.

E (E = 200 mV / SCE) and F (E = 400 mV / ECS)

The records for the 200 and anode overvoltage impedance 400 mV / SCE copper in 2M HNO_3 diagrams are characterized by two loops relatively poorly defined. The first high frequency loop is a rapid process, which is associated with the first step of electronically transferring the adsorbed copper ions (Cu^+_{ads}) to the metal surface according to the following reaction:

$$Cu \rightleftarrows Cu^+_{ads} + e^-$$

The second loop mid-frequency corresponds to the second step of the electrochemical reaction that is to say the charge transfer because the slower the frequency decreases with increasing voltage, these results are in good agreement with those found by Kanouni and Wayne [35-38].

$$Cu^+ \rightleftarrows Cu^{2+} + e^-$$

DISCUSSION

Examination of the various values associated with each impedance diagram copper 2M HNO_3 acid alone for the various anodic overvoltage characteristics shows that the capacity of each loop believe with increasing voltage, however the resistance decreases. These variations reflect the increase in the dissolution of copper by increasing the active surface of the electrode.

The introduction of the essential oil of *Thymus satureoides* shows a higher value of the charge transfer resistance at the same time and a decrease in capacitance associated with the capacitive device, which is probably due to the blocking of surface of the working electrode by forming a protector film [35].

Case of Borneol.

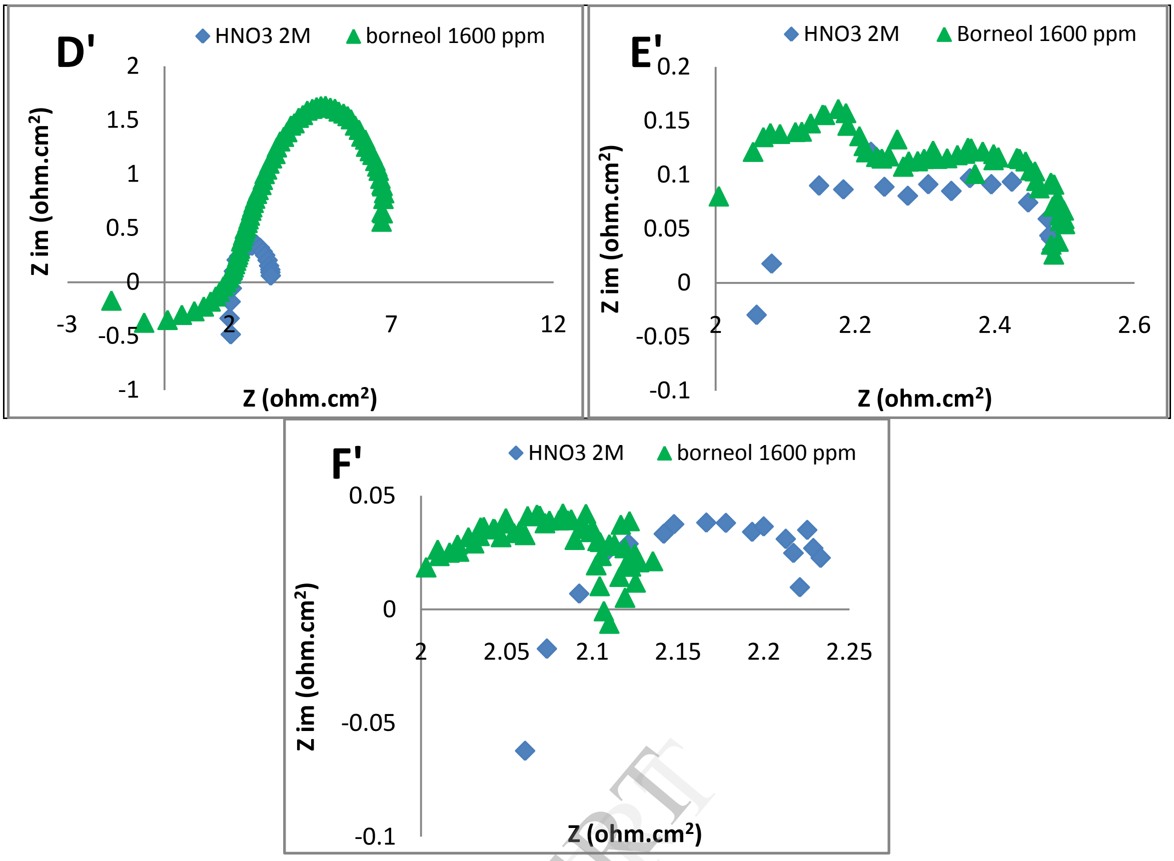


Fig. 11. Diagram impedances determined at different electrochemical anodic overvoltages, on the copper in 2 M HNO_3 without and with addition of 1600 ppm Borneol.

D '. E = 100 mV / ECS E '. E = 200 mV / ECS F '. E = 400 mV / ECS

Table 7. Features derived from the impedance diagrams obtained under anodic polarization with and without addition of Borneol to 1600 ppm of copper in 2M HNO_3.

Inhibitor	E / mV / ECS	R_T / ohm.cm^2	fm / Hz	C_{dl} / µF/cm^2
Blank	100	1228	314.04	412.7
	200	0.5102	400.08	779.7
	400	0.3478	10.00	45740
Borneol 1600 ppm	100	2436	206.45	316.47
	200	0.7082	354.64	633.68
	400	0.3453	10.23	45051.72

Like the case of thyme, electrochemical impedance diagrams of the anodic overvoltage Borneol to 1600 ppm, showed a change in these diagrams as a function of applied potential.
This trend is manifested by the appearance at the beginning to 100 mV / ECS a capacitive arc, 200 mV / SCE and the arc followed by a loop at low frequencies which is ill-defined at 400 mV / ECS reflecting step dissolution, but with higher values of resistance, on the other hand we notice that the values R_T' resembles that of R_T with the changing potential.
The effect of the addition does not appear Borneol significantly affect the anodic process anodic overvoltages higher than 200 mV / SCE.

CONCLUSION

Based on the above results, the following conclusions can be drawn:

- The essential oil of *Thymus satureoides* proved an effective inhibitor for the corrosion of copper in 2M HNO_3. The study also showed that this activity is mainly due to a synergy between these different chemical compounds and not just its major product (Borneol) alone.
- The efficiency increases with the inhibitor concentration to reach 89.02% at 1200 ppm for the essential oil of *Thymus satureoides* and 69.72% at 1600 ppm for the major component alone.

- The values of βa and βc slopes polarization curves show that the tested inhibitors act as a mixed inhibitor, with a predominant cathodic efficiency for the essential oil.
- The electrochemical impedance measurements conducted with copper in 2M HNO_3 in the presence of the essential oil of *Thymus satureoides* Borneol and show that the addition of such compounds increases the corrosion resistance of copper.
- Inhibitors act primarily by a simple reduction of the active area without changing the mechanism of anodic and cathodic processes.

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