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# Inhibition of aluminum corrosion in 0.1 M $Na_2CO_3$ by *Ricinus communis* oil

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**Abstract**: The study was carried out using potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) technique. The inhibition efficiency was found around 87 % with 1600 ppm of inhibitor. The efficiency was accentuated with the increase of the concentration while it decreased with the rise of the temperature. Analysis of the polarization curves revealed that the Ricinus communis oil is considered as a mixed inhibitor. The Influence of the temperature was also studied, the values of the activation energy showed that the inhibition occurred by physisorption.

**Keywords:** Aluminum; corrosion; inhibition; $Na_2CO_3$; *Ricinus communis* oil

## Introduction

Aluminum is currently the focus of many scientific researches in view of its extensive industrial uses, especially in the food industry, which uses $Na_2CO_3$ as a food additive (E500i). The solubility of aluminum oxide film formed on its surface increases beyond the limits of a pH range from 4 to 9 [1]. The inhibition of materials corrosion by non-toxic organic inhibitors and heavy metal free is an encouraging solution that can effectively replace the use of chemical inhibitors [2-4]. The mechanism action of organic inhibitors is explained by physical and / or chemical adsorption on the metal surface [3, 5-7]. This inhibitive action depends on the physicochemical properties of the inhibitor atoms such as the functional group and the aromaticity as well as the presence of the heteroatoms [8-10], without forgetting the nature of the surface, the temperature and the pressure of the reaction [11].

In light of the good anticorrosive performance of green inhibitors several plant extracts have been used to protect aluminum and these alloys against corrosion in various aggressive media, S.A.Umoren et al [12] used *Raphia hookeri* gum to inhibit The aluminum corrosion in 2M HCl, they found that the addition of 0.5 g / l ensures an efficiency of 56.3% at 30 ° C, E.E. Oguzie [13] found that *Sansevieria trifasciata* leaf extract protects aluminum against corrosion in two aggressive media (2M HCl and 2M KOH), J. Alambek et al [14] studied the effect of the *Lavandula angustifolia* extract on Al-3Mg in 3% NaCl, the polarization results show that this extract provides a good efficiency of 99% with a concentration of 20 ppm, G.O.Avwiri et al [15] tested *Vernonia amygdalina* extract on aluminum alloys in two two acidic mediums (0.1M HCl and 0.1M $HNO_3$), the extract of this plant gave good results in the medium 0.1 M $HNO_3$. S. Geetha et al [16] evaluated the inhibitory efficacy of *Vitex Negundo* leaf extract in 1M NaOH, based on the polarization results a concentration of 1.5g / l of the extract ensures an efficacy of 78% at 30 ° C.

The oil of *Ricinus communis* is well known for its benefits and uses in cosmetics, in this work we will concentrate on the evaluation of its ability to inhibit aluminum corrosion in 0.1M $Na_2CO_3$.

## Experimental Section

Extraction of *Ricinus communis* oil:

The oil was obtained by the soxhlet method for 3 hours using hexane as a solvent. The oil samples were stored and protected from light. The analysis of the chemical composition was carried out by high performance liquid chromatography coupled with mass spectrometry.

Polarization and Impedance

The electrochemical tests were carried out in a three electrodes cell with a saturated calomel reference electrode and platinum electrode as an

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auxiliary. The working electrode was an aluminum disk with a surface area of 1 $cm^2$. The polarization tests were carried out in a potential range between -1600 mV and -1200 mV with a scanning speed of 0.5 mV / sec. The corrosion inhibiting efficiency was calculated by equation (1), where $I'_{cor}$ and $I_{cor}$ represent respectively the current density with and without inhibitor.

$$E(\%) = \frac{I_{cor} - I'_{cor}}{I_{cor}} \times 100 \qquad (1)$$

The curves were realized by the device potentiostat / galvanostats PGZ100 associated with the software "Volta master 4". Impedance spectroscopy (EIS) measurements were carried out using the same electrochemical system. Frequencies between 100 KHz and 10 Hz were superimposed on the corrosion potential. The inhibitory efficiency by impedance method was obtained by formula (2), where $R_T$ and $R'_T$ are respectively the charge transfer resistance of aluminum in 0.1 M $Na_2CO_3$ with and without the presence of the inhibitor.

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

Preparation of the solution

The corrosive environment was obtained by dissolving sodium bicarbonate in distilled water. Before each electrochemical test the solutions are prepared.

## Results and Discussion

Analysis of *Ricinus communis* oil

Analysis of the composition of *Ricinus communis* oil in table 1 [17] shows that the extract is very rich in fatty acid and especially in ricinoleic acid with a percentage of 75.03%.

**Table 1.** The constituents of *Ricinus communis* oil.

| Compound Name | Retention time (min) | Percentage (%) |
|---|---|---|
| **Palmitic acid** | 10.0 | 2.55 |
| **Stearic acid** | 12.5 | 2.68 |
| **Oleic acid** | 12.8 | 2.72 |
| **Linoleic acid** | 13.5 | 9.73 |
| **Ricinoleic acid** | 30.5 | 75.03 |

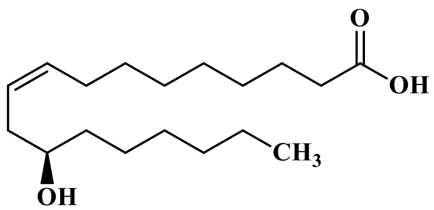


**Figure 1.** Chemical structure of Ricinoleic acid

Effect of concentration

*Polarization*

Fig.2 shows the polarization curves with and without addition of the inhibitor. The electrochemical parameters grouped in Table 2 are obtained by extrapolating the linear parts of the anodic and cathodic polarization curves.

The analysis of Table 2 shows that the current intensity decreases from 171.16 µA / $cm^2$ to 20.24 µA / $cm^2$ in the presence of the inhibitor, which means that the corrosion inhibition of aluminum in $Na_2CO_3$ is carried out by an adsorption mechanism [18]. The anodic and cathodic slopes of Tafel have greatly decreased with the gradual addition of the inhibitor, this reduction refers to the mixed type of *Ricinus communis* oil [19]. The polarization curves in the presence and absence of the inhibitor have the same shape, indicating that the mechanisms of the anodic and cathodic reactions do not change. This extract ensures an efficiency of 86, 83 % with a concentration of 1600 ppm. *Ricinus communis* oil also gave good results for other metals such as copper in nitric acid [17] with a 99% efficiency for a concentration of 250 ppm, besides the leaves extract of *Ricinus communis* ensures a good protection of the mild steel in NaCl [20] with an efficacy of 84% for the addition of 300 ppm.

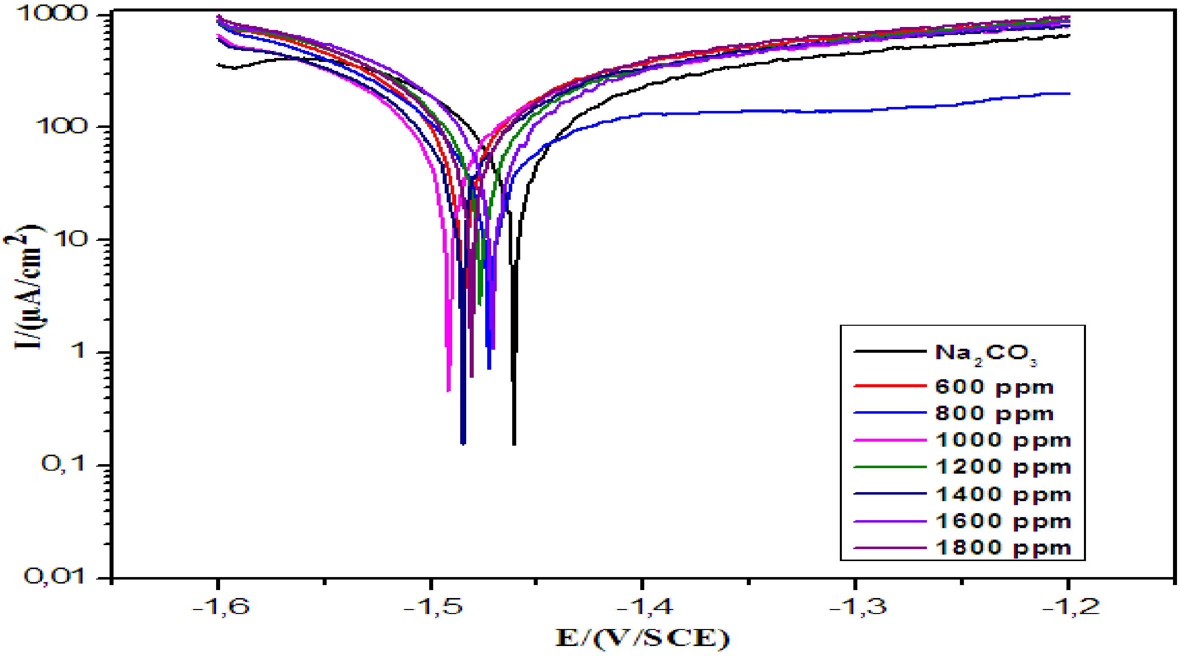


**Figure 2.** Polarization curves of aluminum in 0.1 M $Na_2CO_3$ with and without inhibitor at 25 ± 0.1 ° C.

**Table 2.** Electrochemical parameters of aluminum in 0.1 M $Na_2CO_3$ with and without addition of *Ricinus communis* oil at different concentrations.

| $C_{inh}$ (ppm) | $E_{cor}$ (mV/SCE) | $I_{cor}$ (µA/cm$^2$) | $\beta_a$ (mV) | $\beta_c$ (mV) | E (%) |
|---|---|---|---|---|---|
| Blank | -1462 | 171.16 | 353.8 | -248.6 | ------ |
| 600 | -1487 | 72.30 | 87.1 | -67.4 | 57.75 |
| 800 | -1474 | 58.31 | 190.6 | -83.9 | 65.93 |
| 1000 | -1493 | 46.09 | 66.6 | -53.8 | 73.07 |
| 1200 | -1477 | 30.55 | 35.9 | -33.1 | 82.14 |
| 1400 | -1488 | 26.40 | 38.3 | -33.3 | 84.57 |
| 1600 | -1472 | 22.52 | 27.6 | -23.3 | 86.83 |
| 1800 | -1483 | 20.24 | 21.4 | -19.9 | 88.17 |

*Electrochemical impedance spectroscopy*

The Nyquist diagrams of aluminum in 0.1 M $Na_2CO_3$ without and with the addition of the inhibitor at different concentrations are given in Fig. 3. The electrochemical impedance parameters are grouped in Table 3.

Most spectra have the same shape (Fig.3) with only one loop, indicating that geometric blocking is the inhibition mode of the oil [21]. From Table 3 the $R_T$ values increase from 45.51 ohm.cm$^2$ to 203.7 ohm.cm$^2$ with the gradual addition of the inhibitor while $C_{d1}$ decreases this is due to a decrease in the local dielectric constant and / or an increase in the thickness of the electric double layer [22] due to the formation of a protective layer on the aluminum surface [23]. In the equivalent electrical circuit given in Fig. 4, with $R_1$ is the resistance of the electrolyte, $R_2$ is the charge transfer resistor, $R_3$ is the resistance of passivation layer, $Q_1$ double layer capacity and $Q_2$ Passivation layer capacity.

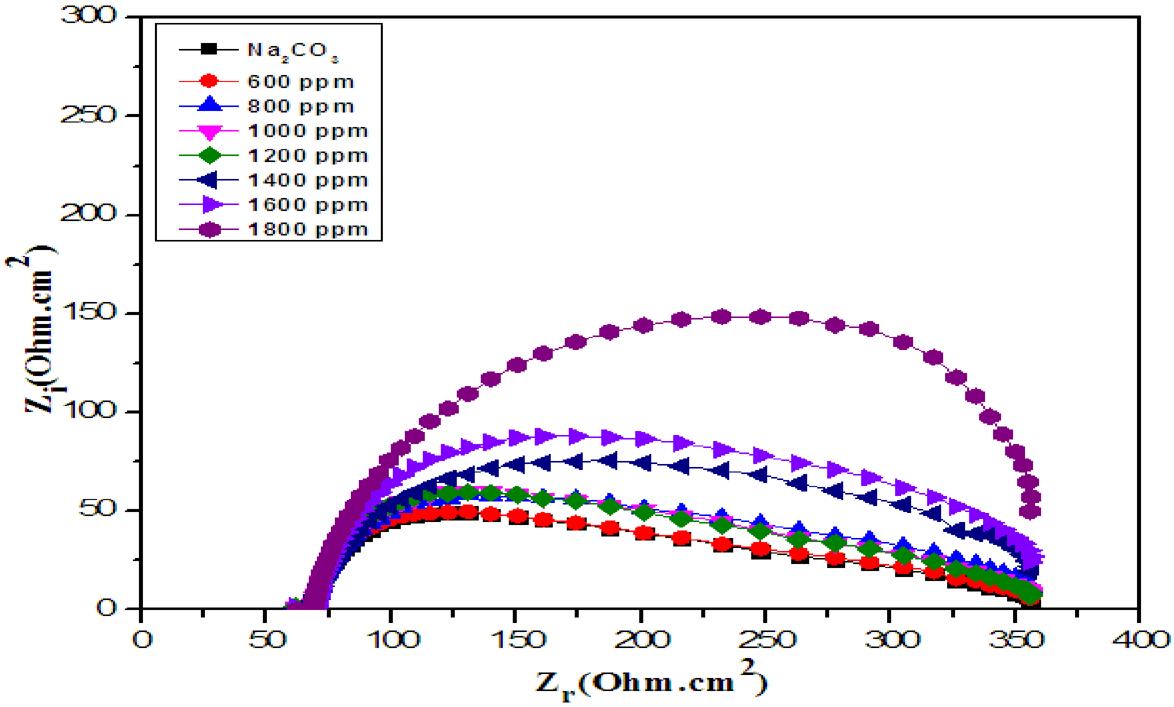


**Figure 3.** Nyquist curves of aluminum in $Na_2CO_3$ with and without addition of the inhibitor at 25 ± 0.1 ° C.

**Table 3.** Electrochemical parameters of the impedance diagram of aluminum in 0.1 M $Na_2CO_3$ with and without addition of inhibitor.

| $C_{inh}$ (ppm) | $R_T$ (ohm.cm$^2$) | $C_{dl}$ (µF/cm$^2$) | E(%) |
|---|---|---|---|
| **Blank** | 46.51 | 21.62 | --- |
| **600** | 113.7 | 20.49 | 59.09 |
| **800** | 133.6 | 18.73 | 65.18 |
| **1000** | 134.2 | 18 | 65.34 |
| **1200** | 139.6 | 17.63 | 66.68 |
| **1400** | 173.9 | 17.49 | 73.25 |
| **1600** | 203.7 | 16.66 | 77.16 |

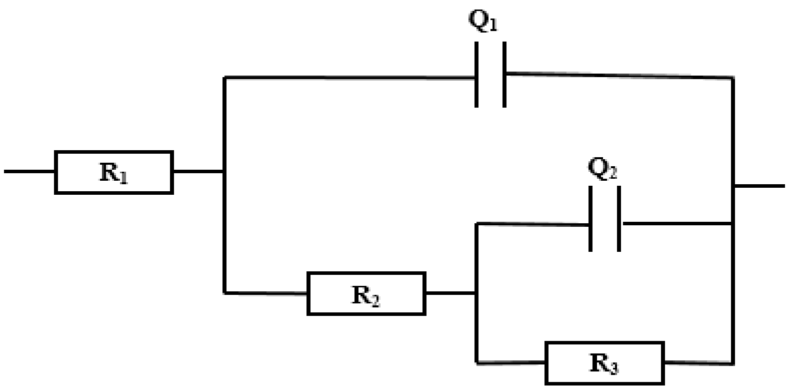


**Figure 4.** Equivalent circuit model for electrochemical impedance measurements.

Effect of temperature

*Polarization*

The polarization curves at different temperatures with and without the addition of the inhibitor are given in Figs. 5 and 6. Table 4 shows the temperature effect on the electrochemical parameters taken from the polarization curves with and without addition of 1600 ppm of *Ricinus communis* oil.

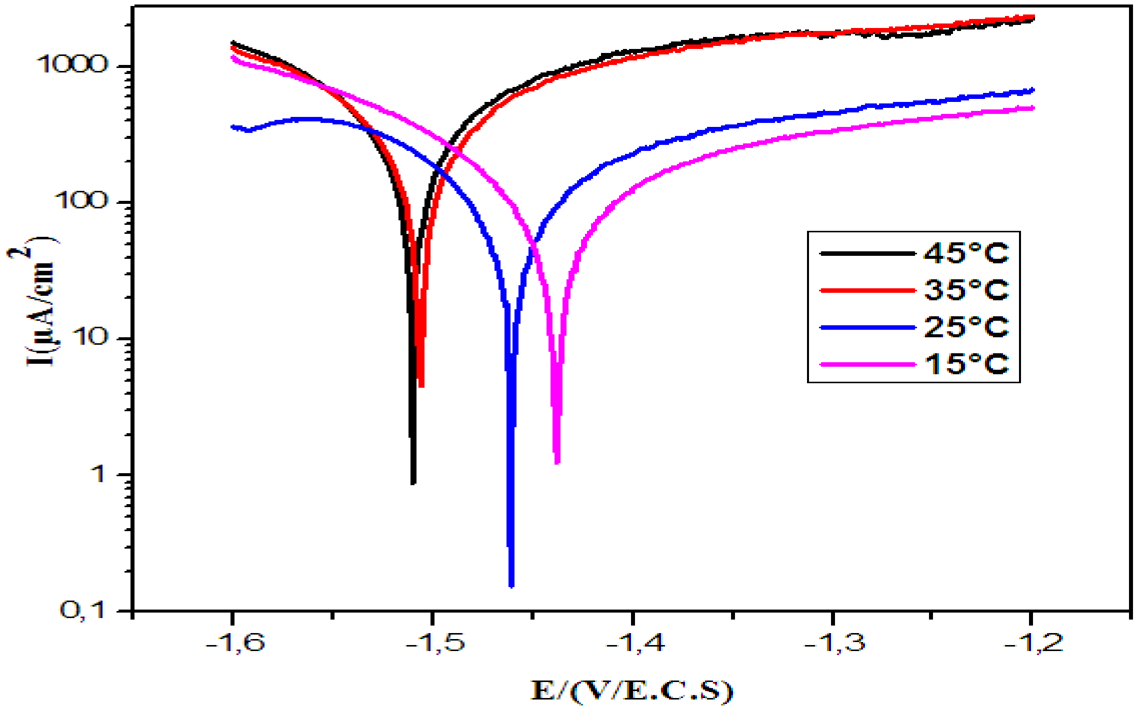


**Figure 5.** Polarization curves of aluminum in 0.1 M $Na_2CO_3$ without inhibitor at different temperatures.

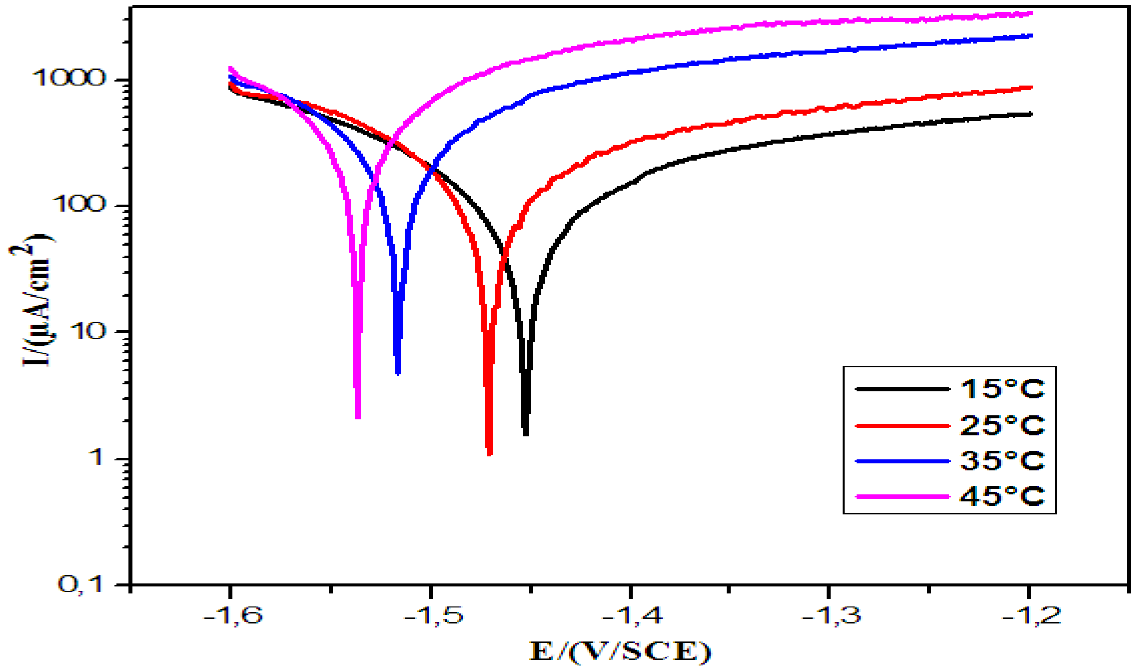


**Figure 6.** Polarization curves of aluminum in 0.1 M $Na_2CO_3$ with the presence of 1600 ppm of the inhibitor at different temperatures.

The results of Table 4 show that as the temperature increases the intensity of current increases with and without addition of 1600 ppm of inhibitor and consequently the inhibition efficiency decreases, this is explained by the physical adsorption of *Ricinus communis* oil molecules on the surface of aluminum [24].

**Table 4:** Electrochemical parameters of aluminum in a 0.1 M $Na_2CO_3$ solution with and without 1600 ppm of the inhibitor at different temperatures.

| $C_{inh}$ (ppm) | T(K) | $I_{cor}$ (µA/cm$^2$) | $E_{cor}$ (mV/SCE) | E (%) |
|---|---|---|---|---|
| Blank | 288 | 103.32 | -1439 | ---- |
| | 298 | 171.16 | -1462 | ---- |
| | 308 | 197.93 | -1509 | ---- |
| | 318 | 258.03 | -1536 | ---- |
| 1600 ppm | 288 | 12.03 | -1455 | 88.34 |
| | 298 | 22.52 | -1472 | 86.83 |
| | 308 | 62.44 | -1518 | 68.44 |
| | 318 | 84.73 | -1538 | 67.15 |

*Electrochemical impedance spectroscopy*

The impedance curves obtained at different temperatures with and without the addition of the inhibitor are given respectively in Figs. 7 and 8. The electrochemical impedance parameters are listed in Table 5.

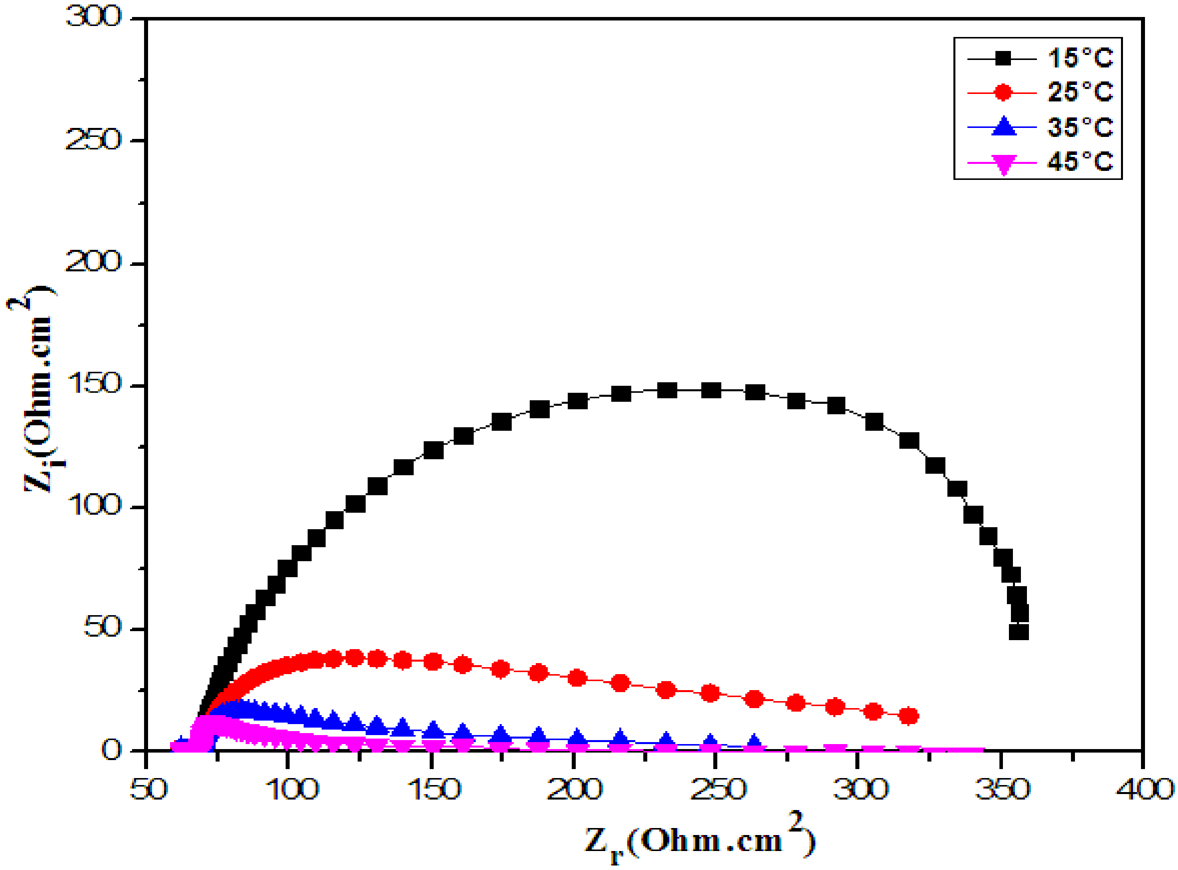


**Figure 7.** Nyquist curves of aluminum in 0.1 M $Na_2CO_3$ without inhibitor at different temperatures.

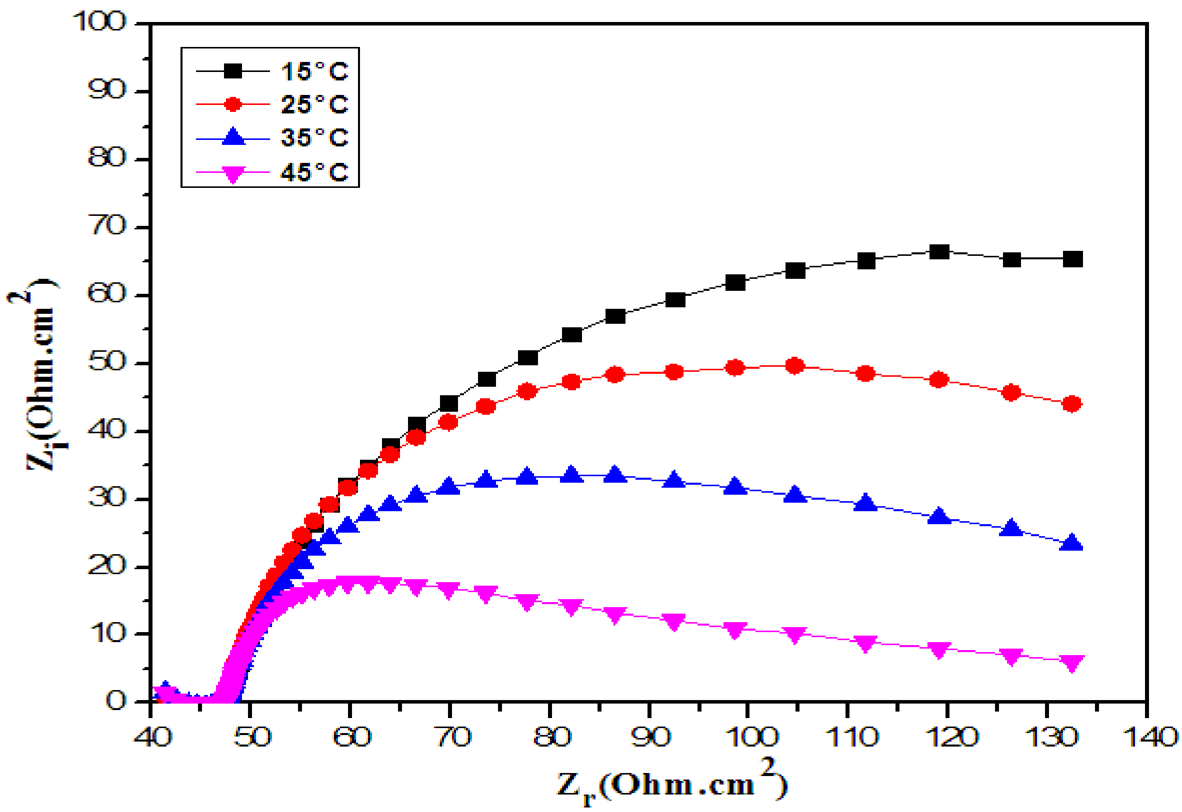


**Figure 8.** Nyquist curves of aluminum in 0.1 M $Na_2CO_3$ with 1600 ppm of the inhibitor at different temperatures.

From the inspection of Table 5, the values of the transfer resistance as well as the inhibition efficiency decreased with increasing temperature. These results of impedance correspond to those obtained by polarization ensuring that the increase in temperature negatively influences the inhibition process by *Ricinus communis* oil.

**Table 5.** Electrochemical parameters of aluminum impedance diagram with and without inhibitor at different temperatures.

| $C_{inh}$ (ppm) | T(K) | $R_T$(ohm.cm$^2$) | E (%) |
|---|---|---|---|
| **Blank** | 288 | 55.67 | ---- |
| | 298 | 46.51 | ---- |
| | 308 | 39.72 | ---- |
| | 318 | 22.3 | ---- |
| **1600 ppm** | 288 | 353.8 | 84.26 |
| | 298 | 203.7 | 77.16 |
| | 308 | 153.9 | 74.19 |
| | 318 | 74.19 | 69.94 |

*Determination of activation energy*

The activation energy is calculated by equation (4), with K the corrosion rate, A Arrhenius factor and Ea the activation energy. Fig. 9 illustrates the Arrhenius lines in the presence and Absence of the inhibitor. The calculated values of activation energy increase from 21.82 Kj /mol to 52.43 Kj /mol in the presence of the inhibitor, which means that the corrosion inhibition of aluminum in $Na_2CO_3$ is carried out by physical adsorption [24-27].

$$K = Ae^{-E_a/RT} \qquad (4)$$

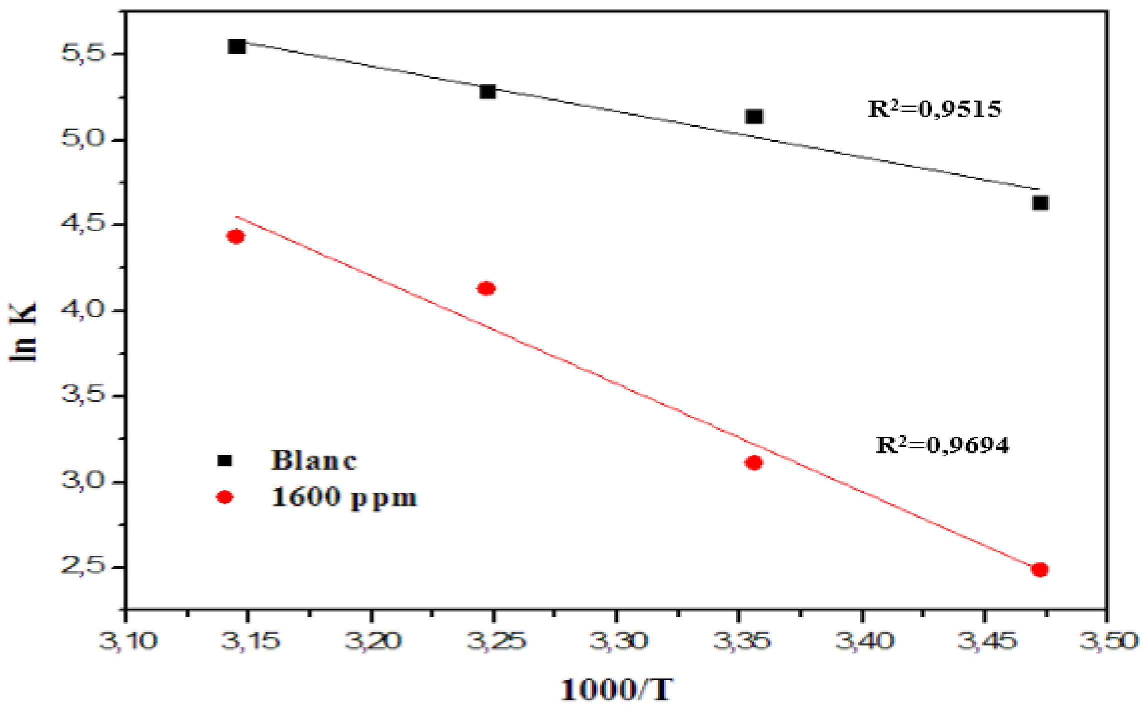


**Figure 9.** Arrhenius Curves of aluminum in 0.1 M $Na_2CO_3$ with and without inhibitor

## Conclusion

*Ricinus communis* oil provides a good anticorrosive protection of aluminum in 0.1 M $Na_2CO_3$, this inhibition is achieved by physical adsorption of its molecules to the aluminum surface. This extract acts as a mixed inhibitor, its inhibitory power increases with the increase of the concentration whereas it decreases with the rise of the temperature.

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