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CORROSION RESISTANCE EVALUATION: A COMPARATIVE STUDY OF *ALOE VERA* AND *ELAEIS GUINEENSIS* OILS IN REFRIGERATION SYSTEMS

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ABSTRACT

The primary issue with the corrosion of copper tubes utilized in refrigeration systems within highly salt-contaminated environments is gas leakage. This gas leakage not only reduces the equipment's lifetime and efficiency but also increases energy consumption. Furthermore, it has environmental implications since air conditioning equipment employs greenhouse gases. Consequently, the aim of this study is to assess the corrosion inhibition potential of an organic varnish with various concentrations of Aloe vera and Elaeis Guineensis oils applied to the surfaces of copper tubes employed in air conditioning coils. Additionally, to evaluate the corrosion rate of both coated and uncoated copper tubes. To achieve these objectives, it were conducted electrochemical impedance spectroscopy and potentiodynamic polarization tests within an environment containing 3.5% sodium chloride (NaCl). After the tests, the samples that exhibited the best results were selected to compare the efficiency against corrosion. The highest level of efficiency, standing at 99.60%, was observed when using Elaeis guineensis oil at a concentration of 150 ppm. Following closely behind was Aloe vera oil at 100 ppm, showing an efficiency of 99.26%.

Keywords: *Corrosion, Copper, Cooling system, Aloe vera, Elaeis guineensis.*

INTRODUCTION

Copper is considered a noble metal, possessing a crystalline structure and properties similar to gold and silver. Its combination of characteristics, including high electrical and thermal conductivity, resistance to corrosion, and mechanical properties, has established copper as one of the most important metals in the commercial sector. Copper has numerous industrial applications, including electricity generation and transmission, the production of solar panels, artistic sculptures, etc. [2-4].
Corrosion in copper in highly salted environments leads to the following reactions [5-7]:

$$Cu \rightarrow Cu^{+} + e^{-} \tag{1}$$

$$Cu^{+} + Cl^{-} \rightarrow CuCl \tag{2}$$

$$CuCl + Cl^{-} \rightarrow CuCl_2^{-} \tag{3}$$

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \tag{4}$$

Equation (1) illustrates the initial oxidation reaction of copper, leading to the formation of Cu^{+} ions. When exposed to chloride ions (Cl^{-}), these copper cations react, resulting in the creation of a soluble CuCl layer on the metal surface, as depicted in Equation (2). It's important to note that this CuCl layer is unstable and continues to react with chloride ions, forming the ion complex described in Equation (3) [2-5]. Equation (4) represents the oxygen reduction reaction in this context [4-6].
To prevent or minimize corrosion in copper, corrosion inhibitors can be employed. These substances have the capacity to extend the lifetime of the metal by adhering to its surface, effectively preventing contact with the corrosive environment. This protective mechanism involves the bonding of nitrogen, phosphorus, sulfur, triple bonds, and aromatic rings to the metal surface, thereby impeding the corrosive effects [8-10].
However, traditional inhibitors are known to be toxic to both human health and the environment, in addition to being very expensive. This has led the exploration of alternative substances, particularly those derived from plants, which offer the advantages of being low-cost, renewable, and environmentally friendly [11-13].
Aloe vera, a medicinal plant widely employed in the pharmaceutical industry, presents itself as a promising corrosion inhibitor. The extract from *Aloe vera* comprises elements with substantial molecular weight, featuring heterocyclic structures and atoms of oxygen and nitrogen. Examples of these constituents include aloeresin A, aloeresin B, aloins, aloesin, and aloe emodin, all of which play an important role in conferring the inhibitory effect [14].
Elaeis guineensis, commonly known as palm, finds numerous applications, including food, cosmetics, and biodiesel production. Palm oil contains a significant component known as lignin. Lignin is characterized by a complex molecular structure comprising C_6-C_3 molecules and functional groups, rendering it highly hydrophobic in nature [15].
Therefore, the primary objective of this study is to evaluate the corrosion inhibition effectiveness of an organic varnish, supplemented with varies concentrations of Aloe vera and Elaeis Guineensis oils, when applied to the surfaces of copper tubes utilized in air conditioning coils. These assessments are conducted within an environment containing 3.5% sodium chloride (NaCl). To measure the inhibition efficiency, electrochemical impedance spectroscopy and potentiodynamic polarization tests were systematically carried out.

MATERIALS AND METHODS

Sample preparation

The samples used in this study were 3/8” diameter copper tubes, typically employed in air conditioning applications. These tubes had a chemical composition in accordance with NBR 7541 standards, consisting of 99.90% copper content and a phosphorus content ranging from 0.015% to 0.040%. They were cut from tubulation, each measuring 2.00 cm in length, and then subjected to a sanding process using abrasive papers. Subsequently, they were cleaned with distilled water and dried using compressed air.
The varnish was chosen based on several factors, including cost-effectiveness, use and application, low toxicity, and ease of preparation. The selected varnish possesses the following properties: a density of 1.02 g/cm^3, a flash point of 100 °C, a pH of 9, and a kinematic viscosity of 404.50 mm^2/s.
Aloe vera and *Elaeis Guineensis* oils exhibited dynamic viscosities of 52.79 mPas and 213.60 mPas, respectively. These measurements were obtained using a BROOKFIELD DV III ULTRA viscometer, with a shear rate of 58 s^{-1} and rotation speed of 200 RPM. Additionally, both oils registered a pH level of 5, as determined by pH test strips.

The varnish was prepared in accordance with the producer's instructions, which involved dilution in water at a ratio of 5 parts varnish to 1 part water. After this dilution, the oils were added to achieve concentrations of 50, 100, and 150 ppm [16].
The samples were coated with each solution and allowed to dry for 24 hours before conducting the corrosion tests. Fig. 1 illustrates the samples following the painting process. For the sake of comparison, one sample was exclusively coated with the varnish, while another sample was left untreated, lacking the protective layer.

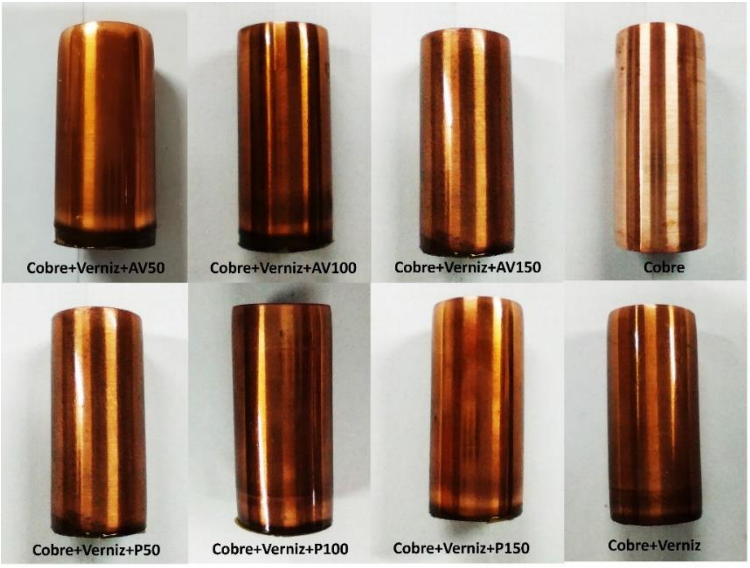

Fig. 1 - Copper samples.

Potentiodynamic Polarization and EIS tests

Potentiodynamic polarization and Electrochemical Impedance Spectroscopy (EIS) tests were conducted using an AUTOLAB PGSTAT302N instrument. The electrochemical cell employed in this study comprised three electrodes: a reference electrode consisting of calomel (Hg|Hg2Cl2|KCl(3M)), a platinum counter electrode, and a copper working electrode. The exposed area of the working electrode to the 3.5% NaCl solution was 0.449 cm², and it was securely held in place with a custom-made rubber adapter.
Initially, the open circuit potential was allowed to stabilize for 3600 seconds, after which Electrochemical Impedance Spectroscopy (EIS) measurements were performed. The test parameters included an amplitude of 10 mV, with 10 measurement points per decade, and a frequency range from 100 kHz to 1 mHz [4, 7, 17].
Following the test, an equivalent circuit was configured, and a fitting curve was generated to determine the resistance values. These values were then used to calculate the inhibition efficiency using Equation (5).

$$EI\ (\%) = \left[\frac{R_p - R_p{}'}{R_p}\right] x\ 100 \tag{5}$$

where R_P and R_P’ represent the polarization resistance with and without inhibitor, respectively. Polarization tests were conducted with a sweep rate of 1 mV/s, covering a range of ± 3 mV from the open circuit potential (V_{OCP}) [17]. Following the measurements, data were analyzed using Tafel extrapolation to determine the corrosion current density. The inhibition efficiency was subsequently calculated using Equation (6).

$$EI\ (\%) = \left[\frac{I_0 - I_{varnish}}{I_0}\right] x\ 100 \tag{6}$$

where I_0 and $I_{varnish}$ are the corrosion current densities of the copper samples without and with varnish, respectively.

RESULTS AND DISCUSSION

Electrochemical Impedance Spectroscopy

Through impedance tests, we were able to generate Nyquist and Bode plots. Fig. 2 displays the Nyquist diagram for both *Aloe vera* and *Elaeis guineensis* samples, alongside copper samples with and without varnish, for comparative analysis.
From Fig. 1a, it is evident that the sample coated with a varnish solution containing *Elaeis guineensis* at a concentration of 150 ppm exhibited the largest semicircle diameter, indicating a more substantial impedance variation and superior inhibitory properties [17]. Among the *Aloe vera* samples, the best performance was observed at the 100 ppm concentration. Nevertheless, the semicircle diameter was smaller compared to that of the 50 ppm *Elaeis guineensis* sample.

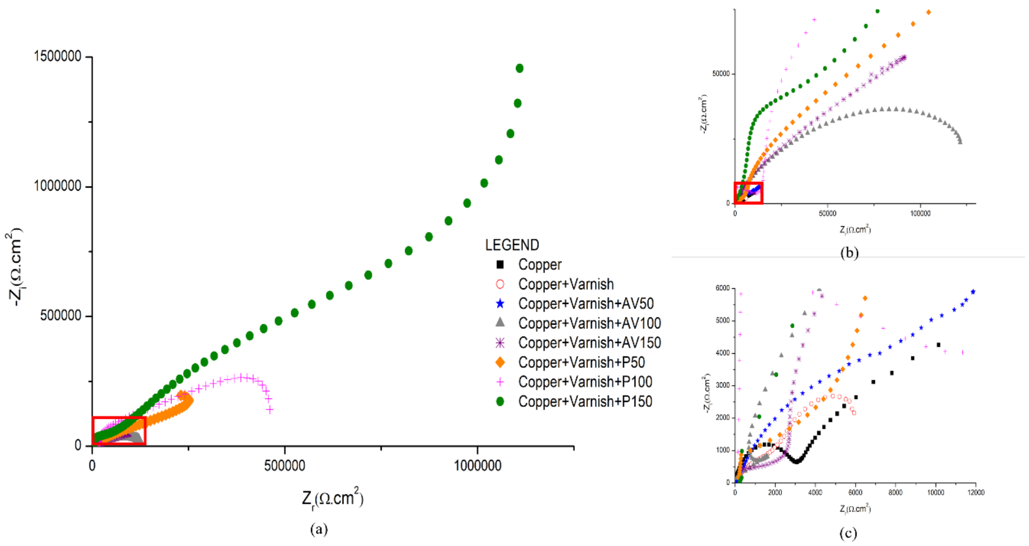

Fig. 2 – (a) Nyquist plots for uncoated and coated samples with varnish, and solutions of varnish and *Aloe vera* and *Elaeis guineeses* oils. Magnified view of the area highlighted (b) in "a" and (c) in "b".

To enhance comprehension of the Nyquist plots and facilitate the derivation of the equivalent circuit and fitting curve required for calculating inhibition efficiency, it is essential to examine the Bode plots, shown in Fig. 3.
The plots confirm that the optimal performance is achieved with the 150 ppm *Elaeis Guineensis* sample. Furthermore, in Fig. 3a, it is evident that all the samples exhibit a high-frequency time constant (f > 100 Hz), suggesting that the coating offers resistance to corrosion. Additionally, there is dispersion in the low-frequency region (f < 1 Hz), indicating the presence of a diffusion process, which is typical of corrosion [1, 18]. In Fig. 3b, it is noticeable that no plateau is formed in the high-frequency region, indicating that the impedance is frequency-dependent due to the adsorption of the coating on the metal surface, which retards corrosion [18].

Potentiodynamic Polarization

Fig. 4 presents polarization curves for copper samples, including those coated with varnish and *Aloe vera* and *Elaeis Guineensis* oils, along with copper samples both with and without varnish coating.

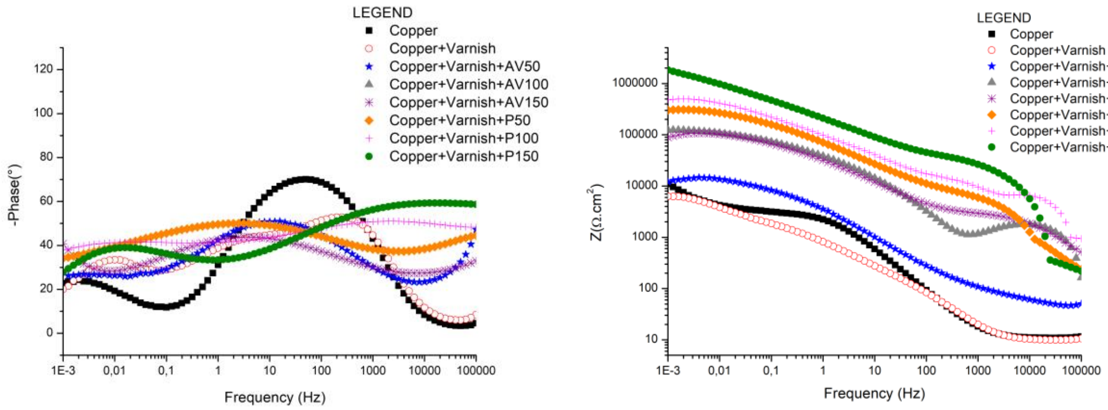

Fig. 3 – Bode (a) phase and (b) impedance plots for uncoated and coated samples with varnish, and solutions of varnish and *Aloe vera* and *Elaeis guineeses* oils.

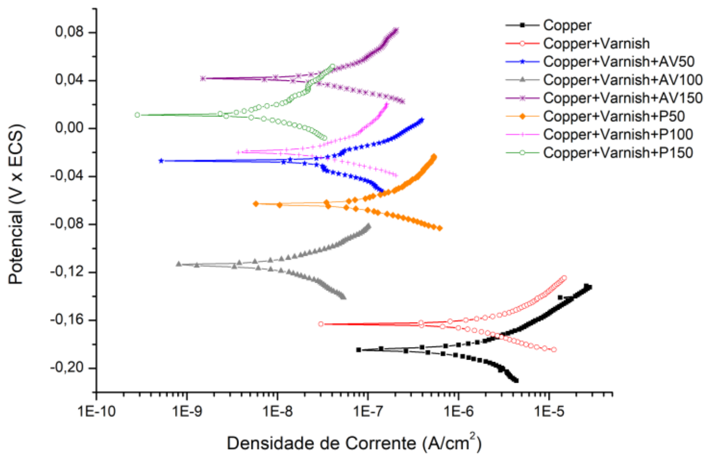

Fig. 4 – Polarization curves for uncoated and coated samples with varnish, and solutions of varnish and *Aloe vera* and *Elaeis guineeses* oils.

From the curves, it is evident that the inclusion of natural extracts in the varnish shifted the curves to the left, signifying a reduction in copper dissolution and, consequently, an increase in corrosion inhibition. Notably, the sample with the lowest corrosion current density corresponds to the 150 ppm concentration of *Elaeis Guineensis*, reaffirming the results obtained from EIS. This behavior suggests that both *Aloe vera* and *Elaeis Guineensis* oils have a substantial impact on controlling the cathodic reduction of oxygen [14, 16, 19].

Fig. 5 shows diagrams comparing the inhibition efficiency obtained using Equations (5) and (6). Consistent with the findings from EIS and polarization tests, the sample exhibiting the highest performance is the one coated with varnish and *Elaeis guineensis* oil at a concentration of 150 ppm, showcasing an inhibition efficiency of 99.73% for EIS and 99.60% for polarization tests. Among the *Aloe vera* samples, the most favorable results were observed with a concentration of 100 ppm, registering inhibition efficiencies of 97.55% for EIS and 99.26% for polarization.

The inhibitory behavior observed in *Aloe vera* and *Elaeis guineensis* oils can be attributed to their molecular structures, which consist of aromatic rings bonded to radicals such as CH_3 and heteroatoms like P, N, O, and Cl. *Elaeis guineensis* exhibited superior results due to the presence of lignin and its highly hydrophobic nature [11-13, 14, 19].

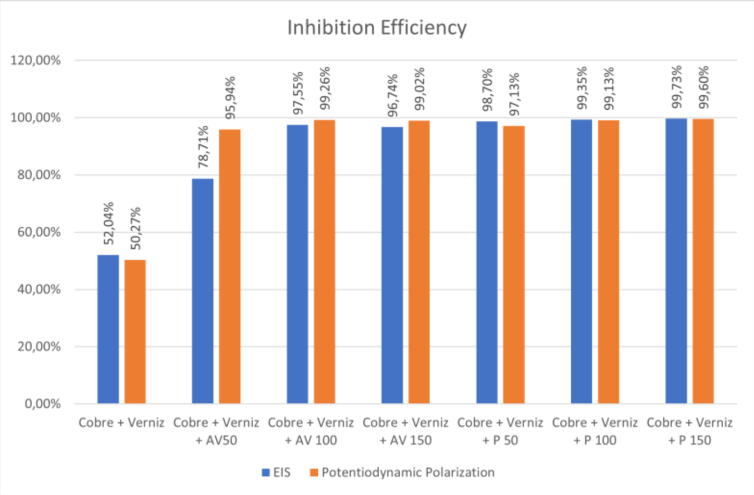

Fig. 5 – Inhibition efficiency for uncoated and coated samples with varnish, and solutions of varnish and *Aloe vera* and *Elaeis guineeses* oils.

CONCLUSIONS

Based of the investigation of the inhibition performance of *Aloe vera* and *Elaeis Guineenses* oils added to varnish for copper exposed to 3.5% NaCl environment, the following conclusions can be drawn:

- Impedance plots demonstrated an increased resistance to corrosion for samples coated with *Aloe vera* and *Elaeis Guineensis* oils compared to samples without varnish and those with varnish alone. This indicates that the oils act as inhibitors, with a predominant cathodic inhibition mechanism.
- Potentiodynamic tests revealed a reduction in the corrosion current density for samples coated with varnish and *Aloe vera* and *Elaeis Guineensis* oils.
- The sample exhibiting the highest inhibition efficiencies in both impedance and polarization tests was the one with 150 ppm Elaeis Guineensis, displaying an efficiency of 99.73% for the EIS test and 99.60% for polarization.

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