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Research article

Exploring *Nymphaeaceae* and *Aloe Barbadenis* Extracts as Corrosion Inhibitors for Mild Steel: Electrochemical Assessment in Acidic medium (H_2SO_4)

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ABSTRACT

Potentiodynamic polarization (PDP) and Fourier transform infrared spectroscopy techniques were used to explore the corrosion inhibition properties of ethanolic extracts derived from *Nymphaea lotus L* and *Aloe barbadensis* plants on mild steel immersed in a 1M H_2SO_4 solution. The compilation of the inhibition performance calculated using PDP method under various conditions was extensively outlined. The Plant extract has shown an effective inhibiting behaviour, with results of up to 80% and 77% for water lily and aloe vera respectively. The concentration of the extracts increased with the inhibitory efficiency. It was shown that the extracts had anodic and cathodic polarisation effects, acting as mixed inhibitors. The results of the study show that in acidic settings, extracts from water lilies and aloe vera can effectively and environmentally protect mild steel from corrosion.

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1. INTRODUCTION

According to (Shehata, Korshed, and Attia 2018), When metals and alloys are exposed to chemicals or come into contact with their surroundings, they naturally want to revert to a stable thermodynamic condition. This process is known as corrosion. Furthermore, corrosion may result from both natural and human activity (Goyal et al. 2018). When certain environmental conditions combine with metals, a natural and unavoidable process called corrosion causes the metal's desired qualities to deteriorate (Umoren et al. 2019). It is frequently determined that corrosion is bad for the environment and for the well-being of individuals. Numerous factors play a role in the corrosion of metals and alloys. These factors, outlined in Figure 1, encompass various elements such as atmospheric moisture, acidic or basic environments, salt exposure, liquid chemicals, potent metal cleaners, and harmful fumes—all of which have the potential to initiate corrosion on metal surfaces (Raja et al. 2016). In addition to the factors illustrated in Figure 1, the ambient temperature also significantly influences corrosion (Goyal et al. 2018). Moreover, specific bacterial species present in a biofilm on steel can accelerate the progression of corrosion (Lin et al. 2012) and create conducive conditions for its further development (Rubio et al. 2006). Potentiodynamic polarization (PDP) is a well-established technique in electrochemistry for studying the corrosion behaviour of metals and alloys. It has been used extensively to investigate the electrochemical reactions and kinetics involved in various corrosion processes. The technique involves sweeping the potential of a working electrode at a controlled rate while monitoring the resulting current response. By analyzing the resulting polarization curve, information about the corrosion potential, corrosion rate, and susceptibility to various forms of corrosion can be obtained (Fattah-alhosseini, Jalali, and Felegari 2015). PDP has been applied in many fields, including materials science, corrosion engineering, and environmental science. It has been used to evaluate the corrosion resistance of materials in various environments, such as seawater, acidic and alkaline solutions, and industrial environments. It has also been utilized for investigating the impacts of diverse factors, including temperature, pH, and alloy composition, on the corrosion characteristics of materials (Yang, Scantlebury, and Koroleva 2012).

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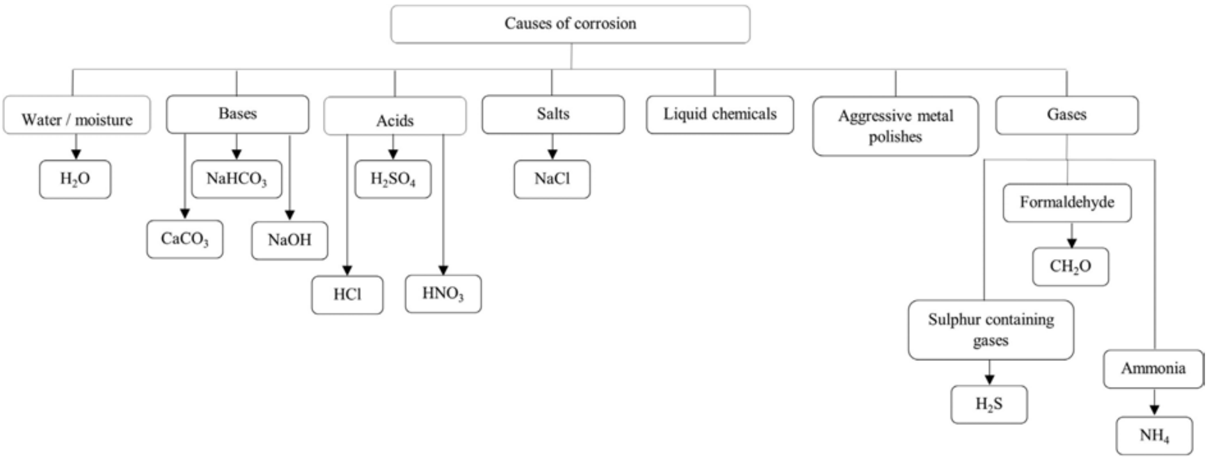


Fig1. Factors that Causes corrosion of metals and alloys (Raja *et al.,* 2016).

PDP (potentiodynamic polarization) the standard procedure entails measuring at different temperatures both with and without particular inhibitor concentrations during specified immersion durations. Typically, this process involves utilizing three electrodes: a working electrode, a counter electrode, and a reference electrode (Popoola 2019). Different electrode materials serve specific functions in the measurement. The counter electrode is commonly constructed of platinum, while the reference electrode typically consists of a saturated calomel electrode. As for the working electrode, it is commonly a low carbon steel alloy (Hamdy and El-Gendy 2013). The effectiveness of Green Corrosion Inhibitors (GCIs) in corrosion prevention can be assessed by comparing the positions of anodic and cathodic current densities to the curve generated in the absence of a Green Corrosion Inhibitor (GCI). This assessment relies on the observed response relative to the applied potential. By varying GCI concentrations, testing temperatures, and investigating different plant conditions, it is possible to investigate the effect of GCIs on corrosion inhibition efficiency.

Previous research has demonstrated that temperature variations and Heterophragma adenophyllum (HA) extract concentrations have a substantial impact on the corrosion behaviour of low carbon steel in 0.5 M HCl (Pahuja et al. 2020). Researchers suggest that the shape of the polarization curve can serve as a means to assess the efficacy of HA in inhibiting corrosion. With higher concentrations of HA, both anodic and cathodic current densities decrease to lower levels, indicating HA's effectiveness as a Green Corrosion Inhibitor (GCI). This outcome indicates that HA is capable of mitigating both cathodic and anodic branch reactions. Additionally, temperature plays a role in the corrosion inhibition effectiveness of HA. Higher temperatures, they found, lessen the inhibitory efficacy of HA because they

encourage the desorption of molecules that make up the protective barrier from surface of the metal (Palaniappan et al. 2020).

2. MATERIALS AND METHODOLOGY

Materials

The mild steel coupons utilized in this investigation were sourced from the Department of Welding and Fabrication at Hassan Usman Katsina Polytechnic in Katsina State.

The Ajiwa water treatment plant, situated in Batagarawa Local Government, Katsina State, is where the Aloe barbadensis plant and Nymphaea lotus L leaves were recovered from the Ajiwa dam site. After then, these specimens were verified by Umaru Musa Yar'adua University's biology research facility in Katsina, Nigeria.

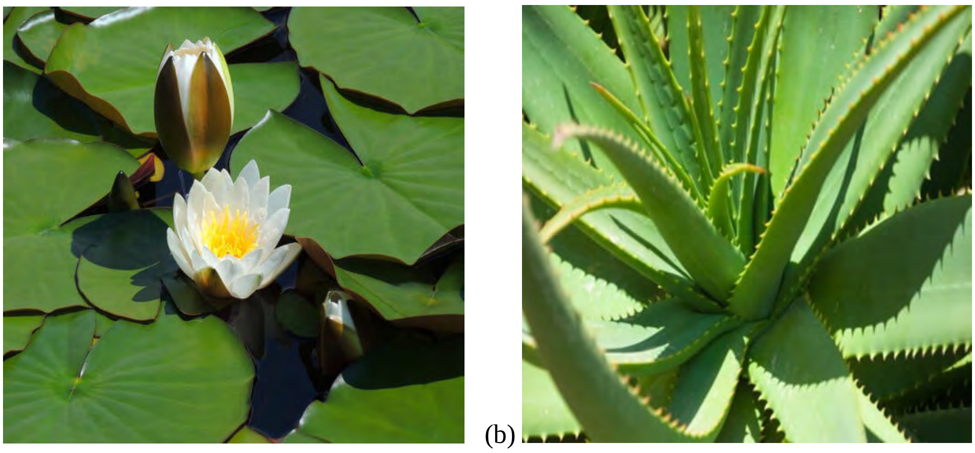
(a) (b)


Fig 2. (a) *Nymphaea lotus L*; (b) *Aloe barbadenis*

Fourier Transform Infrared Spectroscopy (FTIR)

The inhibitor chemical characterization was carried out at Umaru Musa Yaradua central laboratory by Fourier Transform Infrared Spectroscopy (FTIR) which identified the compounds or functional groups present in the water lily and aloe vera powder.

Metal preparation for the experiment

Acetone was used to wash and clean the mild steel components before they were dried. The dried samples were placed in desiccators and weighed using an analytical weighing scale prior to the commencement of the analysis (Okafor et al. 2008).

Potentiodynamic polarization (PDP)

Metal sample for the experiment were cut in the dimension of 3cm by 3cm for electrochemical analysis. These coupons were sealed with epoxy resin in order to exposed only one surface square of the metal. The metal was cleaned by dipping it in acetone, then rinsing it with distilled water and allowing it to air dry. In both unfettered and inhibited media, linear polarisation was measured on the exposed surface at 0.0, 1.0, and 1.5w/v% of the various inhibitors in the corrosive medium, which was H_2SO_4 at 298K in the potential range of -10 to +10 mV and the scan rate of 0.333mV/s (Muhammaed and Iorhuna, 2023).

Electrochemical properties derived from polarisation curves, including anodic and cathodic Tafel slopes (βa and βc), corrosion potential (Ecorr), and corrosion current or density (icorr), were computed using Tafel extrapolation. These parameters are elaborated upon in Tables 1 and 2 provided below. The calculation of Icorr for both uninhibited and inhibited conditions will be conducted using the relationships provided in Equation 1. The percentage inhibition obtained from electrochemical inhibition will be calculated using Equation 2, known as the Stern-Greary equation. The corrosion rate of the process was also measured by using equation 3 as presented below.

$$icorr. = \frac{\beta a \beta c}{2.303(\beta a+\beta c)} \times \frac{1}{Rp} \quad (1)$$

$$IE(\%) = \frac{icorr - i^{\circ}corr}{icorr} \times 100 \quad (2)$$

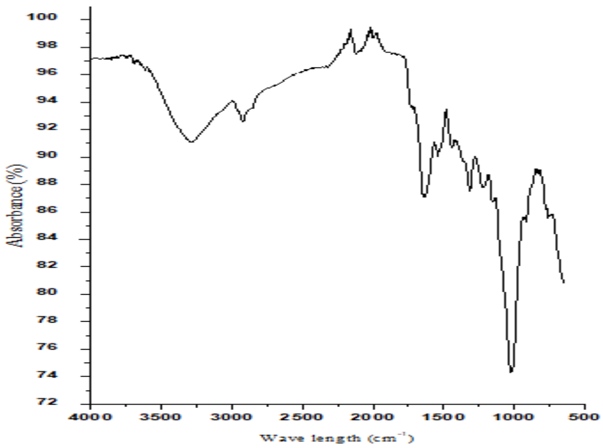
$$CR = 3.27\times10^{-3}\frac{Icorr \times Ew}{\rho} \quad (3)$$

Where, Icorr, I˚corr, βa, βc Rp, Ewand Pare the corrosion current density in (μAcm-2) of uninhibited, inhibited, anodic Tafel plot, cathodic Tafel plot, and polarisation resistance (Ohms), and corresponding weight of the coupons employed ingrammes (Muhammad *et al.,* 2023). E_{corr} and i_{corr} can also be determined from the crossing of anodic and cathodic Tafel slopes of the polarization curves (Olakolegan *et al.,* 2020) using CorrWare software (Badiea & Mohana, 2009) or NOVA software (Pal & Das, 2020).

3. RESULTS AND DISCUSSION

FT-IR spectrum of water lily leaves fine powder.

Fig 3.



FT-IR spectrum of aloe vera fine powder.

Fig 4.

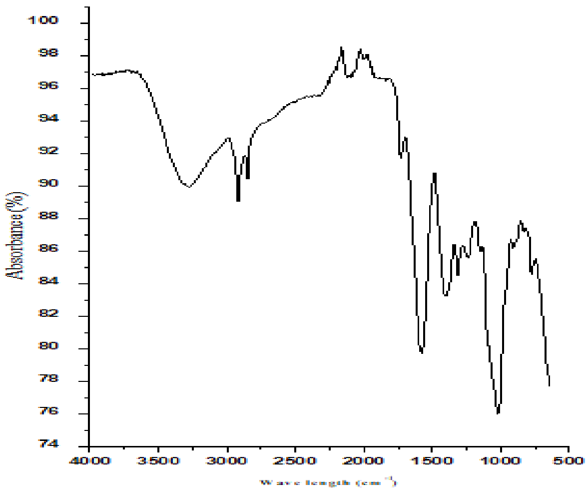


Table 1: Presenting corrosion inhibition on the metal coupons in the absence and presence of water lily leaves extract.

Extract Conc. (Wv^{-1})	i_{corr}(μAcm^{-2})	E_{corr} (mV)	B_a($mVdec^{-1}$)	B_c($mVdec^{-1}$)	C.R ($mmpy^{-1}$) 10^{-3}	%IE
0.0	-1.3228	-0.6472	0.10223	-0.09978	1.0970	-
1.0	-0.3101	-0.6377	0.07046	-0.10127	0.2576	76.56
1.5	-0.2645	-0.6185	0.05536	-0.06476	0.2197	80.00

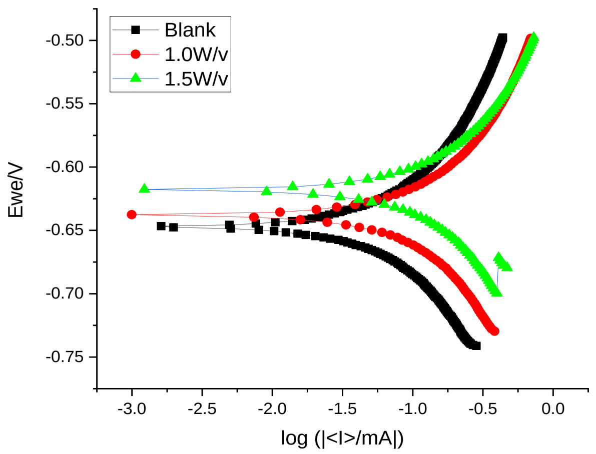


Fig 5. Potentiondynamic polarization curve of mild steel in 1M H_2SO_4 with and without extract of water lily leaves.

Table 2: Showing corrosion inhibition on the metal coupons in the absence and presence of aloe vera extract.

Extract Con. (Wv^{-1})	i_{corr} (μAcm^{-2})	E_{corr} (mV)	B_a ($mVdec^{-1}$)	B_c ($mVdec^{-1}$)	C.R ($mmpy^{-1}$) 10^{-3}	%IE
0.0	-5.5294	-0.6472	0.06736	-0.0898	4.590	-
1.0	-1.3787	-0.6384	0.06406	-0.1001	1.145	75.07
1.5	-1.2481	-0.5997	0.05187	-0.1004	0.183	77.43

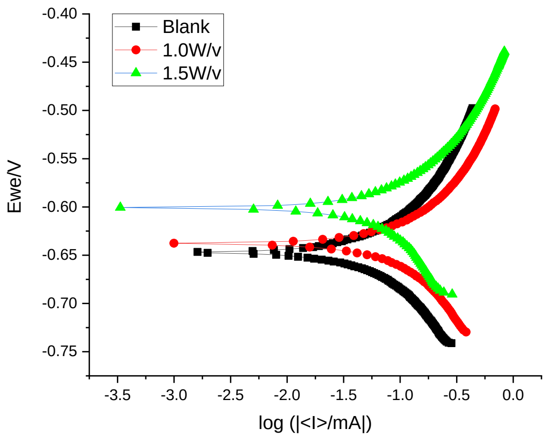


Fig 6. Potentiodynamic polarization curve of mild steel in 1M H_2SO_4 with and without aloe vera extract.

4. Discussion

FTIR result of the water lily leaves fine powder

Fourier The FTIR spectroscopy is a commonly used and powerful method for determining the type of bonding present in organic inhibitors that are adsorbed on the metal surface (Okafor et al. 2008), (Li et al. 2009). The FTIR spectrum of water lily powder depicted in Figure 3 above displays several distinctive features. The stretching vibration of N-H or O-H bonds is responsible for the significant absorption peak at 3600 cm-1, while C-H stretching vibrations are responsible for the band that spans the range of 3000-2900 cm-1. In addition, the stretching vibration of the C=C and C=O bonds is linked to the notable peak at 1643 cm^{-1}. The observed shift of the C=O peak from a higher wavenumber (around 1700 cm^{-1}) to a lower wave number (approximately 1644 cm^{-1}) can be attributed to the conjugation effect of water lily flavonoids, resulting in the superimposition of the C=C and C=O stretching vibration bands (Li et al. 2009). The presence of adsorption bands at 1452 and 1122 cm^{-1} in the spectrum can be attributed to the framework vibration of an aromatic ring. These observations indicate that water lily meets the general structural criteria for serving as a corrosion inhibitor, as it contains functional groups with O and N atoms (such as O-H, N-H, C=C, and C=O) as well as aromatic rings.

FTIR result of the Aloe vera fine powder

The FTIR spectrum for aloe vera leaf fine powder, which spans from 4000 cm^{-1} to 500 cm^{-1}, is displayed in Figure 4. It is evident from the signal at 3280.05 cm^{-1} that there are phenolic -OH groups present in this spectrum. Furthermore, the peaks at 2847.68 and 2918.50 cm^{-1} indicate stretching vibrations of the C-H atom, while the peak at 1733.21 cm^{-1} indicates the presence of the C=O group. C=C bonds can be found in the range of 1580.39 to 1419.11 cm-1, and the –COC group is represented by the peak at 1075.51 cm-1. At the same time absorption bands seem to show the presence of the –NO2 group between 1315.75 cm^{-1} and 1397.75 cm^{-1}. Additionally, the moderate absorption band found at 620.04 cm^{-1}, which may be the result of C-H bending, suggests the presence of polymeric chemicals in aloe vera powder. It's interesting to note that the infrared spectra acquired by other scientists and the FTIR peaks identified almost exactly match (Hamman 2008; Kumar and Mathur 2013; Ray and Aswatha 2013).

Potentiodynamic polarization (PDP)

Polarization resistance measurement was carried on the exposed surface in both uninhibited and inhibited media of the corrodent at 298K in the potential region of -10 to +10 mV at the scan rate of 0.333mV/s (Muhammad et al. 2023). The highest corrosion inhibition of the inhibitors was observed with water lily of about 80.00% when the concentration of the inhibitor was 1.5w/v. The least was 75.05% as recorded on the aloe-vera in Table 2 as presented in figure 6. The table shows that under the presence of individual inhibitors, the icorr reduces significantly and reaches a minimum value. The data presented clearly demonstrate that the additional inhibitors serve as effective inhibitors against mild steel corrosion in 1M H_2SO_4. As evident from the tables, there are no significant changes in the Ecorr values for each inhibitor, indicating that the examined systems operate through a mixed-type corrosion inhibition mechanism (Fekkar et al. 2020). Meanwhile, minimal shifts were observed in the anodic and cathodic Tafel slopes. This observation suggests that the inhibitors being studied effectively function as corrosion inhibitors, hindering both the anodic dissolution and cathodic hydrogen evolution reactions. These inhibitors achieve this by adsorbing onto the mild steel surface, thereby obstructing active sites. Importantly, they achieve corrosion inhibition without altering the mechanism of the corrosion reaction (Fekkar et al. 2020; Myhammad et al. 2023).

5. Conclusion

Following conclusions could be drawn from the experimental findings of this study:

- The FT-IR results indicate that the plant contains functional groups responsible for forming a protective layer on the surface of mild steel.
- The corrosion rate of both inhibitors Water lily and Aloe-vera reduced during the corrosion process giving a significant corrosion rate reduction from 1.0970\times10-3 to 0.2576\times10-3 mmpy-1 for water lily and 4.590 \times 10-3 to 1.145\times 10-3 mmpy-1 for Aloe-vera.
- The distinction suggests that both inhibitors exhibit promising potential for effectively inhibiting low carbon steel corrosion.
- The corrosion potential values (Ecorr) suggest that the plant extracts exhibit a mixed type of mode of inhibition.

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