Exploiting the Anticorrosion Effects of *Vernonia Amygdalina* Extract for Protection of Mild Steel in Acidic Environments

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ABSTRACT

The corrosion protection of mild steel in 1 M HCl and 0.5 M H₂SO₄ solutions by ethanol extract of *Vernonia amygdalina* (VA) was studied using a combination of experimental and computational methods. The obtained results revealed that VA reduced the corrosion of mild steel in both environments and inhibition efficiency increased with VA concentration but decreased with prolonged exposure. Electrochemical results showed that the extract functioned via mixed corrosion inhibiting mechanism by adsorption of some organic constituents of the extract on the metal/acid interface. Findings from infrared spectroscopy and electron microscopy all confirmed that VA retarded mild steel corrosion in both 1 M HCl and 0.5 M H₂SO₄ through an adsorption process. The adsorption behavior of selected constituents of the extract was modeled using density functional theory computations.

Keywords : Corrosion inhibition, Adsorption, *Vernonia amygdalina*(VA), Fourier transform infrared spectroscopy, Density functional theory

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1. Introduction

The corrosion dissolution of iron and steel surfaces during acid cleaning, descaling and pickling can normally be controlled by introduction of appropriate corrosion inhibiting additives, to hinder the corrosion reaction and suppress the corrosion rate. Some organic compounds are known to be applicable as corrosion inhibitors for mild steel in acidic media [1-6]. Many materials of plant origin have been successfully used to reduce metal corrosion in the past [7-11]. The extracts from seeds, barks, leaves, and root of these plant materials have been tested for their corrosion inhibiting properties and some have been reported to successfully inhibit metal corrosion in acidic media [12-23].

The present research investigates the ethanol

extract of *Vernonia amygdalina* (VA) as anticorrosion additives for mild steel exposed in acidic environments. *Vernonia amygdalina* is a small shrub that grows in the tropical Africa. Because of its bitter taste, it is often called bitter leaf in English. Some natural constituents that are found in the leaves include flavonoids (luteolin, luteolin 7-O-glucosides and luteolin 7-O-glucuronide) [24], tannins [25] and sesquiterpene lactones containing vernodalol, vernodalol and 11, 13-dihydrovernodalol [26]. The electronic structures of some of these constituents (Figure 1) are comparable to those of regular organic corrosion inhibitors [27]. *Vernonia amygdalina* has of course been previously investigated for corrosion inhibiting efficacy [27-30]; but not in sufficient detail to yield the mechanistic insights envisaged in the present study, accomplished via a combination of experimental and computational techniques.

Gravimetric and electrochemical measurements were used for monitoring corrosion; Fourier trans-

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Fig. 1. Some active chemical constituents of *Vernonia amygdalina* (VA).

form infrared spectroscopy was employed for characterization of the additives and corrosion product, while scanning electron microscopy was used for surface morphology examinations. Density functional theory (DFT) computations enabled assessment of molecule-metal interactions for selected organic constituents of VA extract.

2. Experimental Section

2.1 Material preparation

Mild steel specimens with weight percentage composition (C = 0.05, Mn = 0.06, P = 0.36, Si = 0.3 and the balance Fe) were used for the experiments. The acid solutions used were respectively 1 M HCl and 0.5 M H₂SO₄, made from analytically grade reagents, the plant material used was *Vernonia amygdalina* (VA) prepared in the concentration range of 50-1500 mg/L. Stock solutions of the plant material were made by refluxing 20 g of the dried and ground VA powder for 3 h in 96% ethanol. The solutions were left to cool and then filtered. The extracted material was quantified by subtracting the weight of the residue from the weight of the material before extraction. Test solutions were made in the desired concentrations by diluting the stock solution with 1 M HCl and 0.5 M H₂SO₄ respectively.

2.2 Gravimetric experiments

Mild steel coupons of dimension 3 cm x 3 cm x 0.14 cm were used for the gravimetric experiments. The coupons were abraded under running water with silicon carbide abrasive paper (from grade #400 - #1000), rinsed in distilled water, dried with acetone and warm air, weighed and kept in a moisture-free desiccator prior to use. Tests were performed in aerated conditions, with the metal specimens fully immersed in 300

ml of the test solutions at 303 K. Coupons were retrieved and cleaned at 24h intervals continuously for 120h, as well as after 216h. Cleaning involved immersion in 20% sodium hydroxide solution containing zinc dust to quench the corrosion reaction, and scrubbing under running water. All the tests were run in quadruplicate and the data showed good reproducibility.

2.3 Electrochemical experiments

The electrochemical experiments were performed with mild steel coupons of dimensions 1 cm x 1 cm x 0.14 cm. The coupons were encapsulated in polytetrafluoroethylene (PTFE) rods using epoxy resin, to leave only one surface of area 1 cm² exposed. The exposed surface was cleaned as described earlier. Electrochemical measurements were conducted in a conventional three-electrode glass cell of capacity 400 ml using a VERSASTAT 400 complete DC Voltammetry and corrosion system with V3 studio software [31]. The working electrode was mild steel; the counter electrode was a graphite rod and a saturated calomel electrode (SCE) was the reference electrode. The SCE was connected via a Luggin's capillary.

Electrochemical Impedance spectroscopy experiments were made at corrosion potential (E_{corr}) over a frequency range of 100 kHz – 10 mHz, using a signal amplitude of perturbation of 5 mV. Potentiodynamic polarization measurements were performed in the potential range of ± 250 mV versus corrosion potential at a scan rate of 0.333 mV/s. All the experiments were performed in quadruplicate to ensure good reproducibility of results. Experimental temperature was 303 K.

2.4 Fourier Transform Infrared Spectroscopy

A Nicolet Magna-IR 560 FTIR spectrophotometer was used for all FTIR (KBr) recording. A frequency range of 4000-400 cm⁻¹ was used. The instrument recorded the spectra of VA powder and also that of the adsorbed surface films removed from the surface of the mild steel coupons after 24 hours immersion in 1 M HCl and 0.5 M H₂SO₄ containing 1500 mg/L VA. The adsorbed surface films were carefully removed using a sharp object, mixed with KBr and then the pellet was made [21].

2.5 Scanning Electron Microscopy Examination

Morphological studies of the mild steel electrode surface were done by SEM examinations of electrode surfaces exposed to different test solutions using a

Fig. 2. Variation of weight loss with time for mild steel corrosion in the uninhibited and inhibited (a) 1 M HCl and (b) 0.5 M H_2SO_4 .

Fig. 3. Inhibition efficiency of ethanol extract of VA on mild steel corrosion in (a) 1 M HCl and (b) 0.5 M H_2SO_4 solutions.

Shimadzu SSX-550. Mild steel coupons of size $15 \times 10 \times 2$ mm were cleaned as previously described in the gravimetric section and immersed for 3-h in 1 M HCl and 0.5 M H_2SO_4 solutions without and with 1500 mg/L VA at 30 ± 1 °C, and then dipped in distilled water, left to dry in acetone, and examine with SEM machine [31].

2.6 Theoretical Considerations

Quantum chemical calculations and molecular dynamics simulations in the framework of density functional theory (DFT) were performed using the DFT electronic structure programs VAMP and DMol3 as contained in the Materials Studio 4.0 software [32].

3. Results and Discussion

3.1 Gravimetric Results

The gravimetric technique was used to evaluate the

corrosion rates of mild steel coupons exposed to acidic conditions in the absence and presence of VA as an anticorrosion additive. Figure 2 shows the obtained plots of weight loss vs. time in (a) 1M HCl and (b) 0.5 M H_2SO_4 respectively. The results indicate that VA effectively hindered the corrosion reaction.

The effectiveness of the anticorrosion/inhibiting effect of VA was quantified by evaluating the inhibition efficiency as follows:

$$IE(\%) = \left(1 - \frac{\Delta W_{\text{inh}}}{\Delta W_{\text{blank}}}\right) \times 100 \quad (1)$$

Where ΔW_{blank} is the weight loss in the absence and ΔW_{inh} is the weight loss in the presence of VA extract.

Fig. 3 shows the plot of inhibition efficiency vs. time for mild steel corrosion in (a) 1 M HCl and (b) 0.5 M H_2SO_4 . The results show that inhibition effi-

Fig. 4. Potentiodynamic polarization curves for mild steel corrosion in (a) 1 M HCl and (b) 0.5 M H₂SO₄ solutions without and with VA ethanol extract.

ciency increased with concentration and decreased with time. Similar trends have been reported elsewhere [33-35].

3.2 Potentiodynamic Polarization Results

Potentiodynamic polarization experiments were performed to find out the effect of VA on the anodic dissolution reaction of mild steel and cathodic hydrogen ion reduction. Typical potentiodynamic polarization plots for mild steel corrosion in (a) 1 M HCl and (b) 0.5 M H₂SO₄ in the absence and presence of VA are given in Fig. 4, while the potentiodynamic polarization parameters derived from the polarization curves are shown in Table 1.

The results show that VA modified both the anodic and cathodic reactions, and displaced the corrosion potential (E_{corr}) slightly towards cathodic values in 1 M HCl and slightly towards the anodic values in 0.5 M H₂SO₄ while reducing both the cathodic and anodic current densities as well as the reaction current density (i_{corr}). VA thus functioned as a mixed-type corrosion inhibitor in both 1 M HCl and 0.5 M H₂SO₄ [36-37]. The inhibition efficiency (IE) from the potentiodynamic polarization experiments was quantified as:

$$\text{IE}(\%) = \left(\frac{i_{\text{corr}(\text{bl})} - i_{\text{corr}(\text{inh})}}{i_{\text{corr}(\text{bl})}} \right) \times 100 \quad (2)$$

Where $i_{\text{corr}(\text{bl})}$ and $i_{\text{corr}(\text{inh})}$ represent the corrosion current density in the absence and presence of the inhibitor, respectively.

From Table 1, VA reduced the i_{corr} values from 1745.0 $\mu\text{A}/\text{cm}^2$ in 1 M HCl to 95.3 $\mu\text{A}/\text{cm}^2$ on addi-

Table 1. Potentiodynamic polarization parameters for mild steel in 1 M HCl and 0.5 M H₂SO₄ with and without VA

Inhibitor concentration (mg/L)	E_{corr} (mV vs SCE)	i_{corr} ($\mu\text{A}/\text{cm}^2$)	IE (%)
0 (1 M HCl)	-442.8	1745.0	
50 mg/L VA	-449.6	1003.0	42.5
200 mg/L VA	-476.0	117.2	93.3
800 mg/L VA	-476.1	95.3	94.5
0 (0.5 M H ₂ SO ₄)	-485.9	4059.0	
50 mg/L VA	-450.3	2265.0	44.2
200 mg/L VA	-473.9	601.2	85.2
800 mg/L VA	-462.2	139.1	96.6

tion of 800 mg/L of VA ethanol extract. Also, the i_{corr} values reduced from 4059.0 $\mu\text{A}/\text{cm}^2$ in 0.5 M H₂SO₄ to 139.1 $\mu\text{A}/\text{cm}^2$ on adding 800 mg/L VA ethanol extract indicating that the extract effectively reduced mild steel corrosion in both acid solutions. The results are in good agreement with that reported by [38]. The maximum values of the inhibition efficiency in both acid solutions were comparable; 94.5% (in 1 M HCl) and 96.6% (in 0.5 M H₂SO₄).

3.3 Electrochemical Impedance Spectroscopy Results

Electrochemical impedance spectroscopy (EIS) experiments were undertaken to ascertain the effect of VA ethanol extract on the kinetics of the reaction at the metal/acid solution interface in the presence and absence of VA [39]. Fig. 5 gives the (a) Nyquist (b) Bode phase and (c) Bode modulus plots for mild

Fig. 5. Electrochemical impedance spectra of mild steel corrosion in 1 M HCl solution without and with VA ethanol extract (a) Nyquist (b) Bode phase and (c) Bode modulus plots.

steel corrosion in 1 M HCl without and with VA and Fig. 6 gives the corresponding plots in 0.5 M H₂SO₄ solution. The electrochemical parameters derived

Fig. 6. Electrochemical impedance spectra of mild steel corrosion in 0.5 M H₂SO₄ solution without and with VA ethanol extract (a) Nyquist (b) Bode phase and (c) Bode modulus plots.

from the impedance responses are given in Table 2. The Nyquist plots show single capacitive semi-circles in the high frequency region, corresponding to

Table 2. Impedance parameters for mild steel in 1 M HCl and 0.5 M H₂SO₄ without and with VA

Inhibitor concentration (mg/L)	$R_{ct}(\Omega\text{-cm}^2)$	$Q_{dl}(\mu\Omega^{-1}\text{S}^n\text{cm}^{-2}) \times 10^{-4}$	IE (%)
0 (1 M HCl)	14.50	2.40	
50 mg/L VA	19.35	1.25	24.9
200 mg/L VA	203.90	0.25	92.9
800 mg/L VA	338.40	0.22	95.7
0 (0.5 M H ₂ SO ₄)	8.02	2.09	
50 mg/L VA	11.90	1.41	32.6
200 mg/L VA	37.14	0.46	78.4
800 mg/L VA	262.8	0.40	96.9

Fig. 7. Equivalent circuit used to model the impedance data R_s = solution resistance, R_{ct} = charge transfer resistance and CPE = constant phase element.

just one time constant as observed in the Bode plots. The high frequency intercept with the real axis is called the solution resistance (R_s) while the corresponding low frequency intercept with the real axis is the charge transfer resistance (R_{ct}) [33]. The impedance data given in Table 2 were gotten by fitting into an equivalent circuit model $R_s(Q_{dl}R_{ct})$ shown in Fig. 7, which has been used by other researchers to model the impedance response for the mild steel/acid system [31,40-42].

From the equivalent circuit, the solution resistance is seen to be shorted by a constant phase element called (CPE) which was placed in parallel to the charge transfer resistance (R_{ct}). The capacitor was replaced with the CPE to account for deviations from ideal dielectric behavior.

The inhibition efficiency calculated from the impedance data ($IE_R\%$) was quantified by the formula:

$$IE(\%) = \left(\frac{R_{ct,inh} - R_{ct,bl}}{R_{ct,inh}} \right) \times 100 \quad (3)$$

Where $R_{ct,bl}$ is the charge transfer resistance without VA and $R_{ct,inh}$ represent the charge transfer resistance when VA was added.

Addition of VA improved the R_{ct} values but decreased the C_{dl} values. The former effect describes the anticorrosion action of VA, whereas the latter effect points towards adsorption of some organic constituents of the extract onto the metal/solution interface. According to the Helmholtz equation:

$$C_{dl} = \epsilon \epsilon_0 A / d \quad (4)$$

Reduction in C_{dl} values could result from either an increase in d (interfacial thickness) or a reduction in ϵ (dielectric constant). ϵ_0 (vacuum permittivity) and A (electrode area) are constant. Reduction in ϵ values indicates that some adsorbed water molecules have been replaced by organic species, which have lower dielectric constants than water, while higher d values indicates that something is adsorbed on the interface. Either way, it is reasonable to assume that lower C_{dl} values in the presence of VA implies that some

organic constituents of VA have been adsorbed on the corroding metal surface [43].

3.4 Adsorption Isotherms

In order to characterize the net adsorption of VA on the mild steel surface, the gravimetric data after 24h of immersion was fitted into different adsorption isotherms, with the Langmuir adsorption isotherm (Eqn. 5) giving the best fit.

$$C/\theta = 1/b + C \quad (5)$$

Here C represents the inhibitor concentration, b is the equilibrium constant and θ the degree of surface coverage ($\theta = IE/100$) [44] (6) which shows the fraction of the surface that is covered by the adsorbed constituents.

Fig. 8 shows the Langmuir plots to be linear for VA extract in (a) 1 M HCl and (b) 0.5 M H₂SO₄ solutions respectively. The values of the slopes are close to unity, confirming that the data fits the Langmuir adsorption isotherm. The deviation from unity may be due to interaction between adsorbed constituents and also changes in the heat of adsorption as the surface coverage increases which had been ignored while deriving the Langmuir adsorption isotherm [45-46].

3.5 Fourier Transform Infrared Spectroscopy Results

Fourier Transform Infrared spectroscopy was

Fig. 8. Langmuir adsorption isotherms for VA ethanol extract on mild steel in 1 M HCl and 0.5 M H₂SO₄ solutions.

undertaken to identify the functional groups involved in the adsorption of VA constituents on the mild steel surface. The spectra of VA powder (1) and that of the surface scrapings removed from the mild steel surface after 24h immersion in 1 M HCl (2) and 0.5 M H₂SO₄ (3) containing 1500 mg/L VA were recorded and the results are presented in Fig.9. The multiplicity of peaks observed for VA powder shows that the extract contained a complex mixture of constituents. Interestingly, most of the peaks for VA powder also appeared on the spectra for the surface films on the mild steel, some of the peaks observed in the surface films are OH-stretching frequencies around 3330 cm⁻¹, C-H stretching around 2850 cm⁻¹, C=C stretch frequency around 1625 cm⁻¹ and C-C skeletal frequency around 1100 cm⁻¹ showing that they may have been involved in the adsorption process [47]. The peak for C-H stretch bonding around 2935 cm⁻¹ apparently disappeared, implying that this was somehow not involved in the adsorption process.

3.6 Scanning Electron Microscopy Results

The surface microstructure of mild steel specimens after 3h of immersion in uninhibited 1M HCl and 0.5 M H₂SO₄ solutions at 30°C was visualized using SEM and then compared with surfaces corroded in the presence of VA under similar conditions. Fig. 10 shows the SEM image of the pristine, uncorroded mild steel surface before in the acidic solutions, while Fig. 11 shows the corresponding images for the mild steel surface after 3h immersion

Fig. 9. FTIR spectra of VA powder (1) and the surface film on mild steel specimens immersed in 1 M HCl (2) and 0.5 M H₂SO₄ (3) solutions containing VA ethanol extract.

in 1 M HCl without (Fig. 11a) and with (Fig. 11b) 1500 mg/L of VA. Fig. 12 presents similar images for 0.5 M H₂SO₄ without (Fig. 12a) and with (Fig. 12b) 1500 mg/L of VA.

The results show rigorously corroded surfaces for specimens immersed in uninhibited 1M HCl and 0.5 M H₂SO₄ solutions respectively, which is due to the rapid degradation of the mild steel surfaces by the

acids [48]. With the addition of VA, the corrosion damage became much subdued due to the protective effect of the adsorbed extract constituents.

3.7 Computational Results

The experimental results already show evidence that the corrosion inhibiting efficacy of VA ethanol extract was achieved via adsorption of some organic constituents of VA on the surfaces of the corroding mild steel specimens. Such adsorption has been shown to involve the overlap of frontier orbitals: the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) and can be modeled by means of quantum chemical calculations and molecular dynamic simulations in the frame work of density function theory (DFT).

Calculations were performed to illustrate the involvement and contributions of some major chemical constituents of VA, including vernodalin and luteoline [24,26] to the corrosion inhibition process. This was achieved using the Materials Studio 4.0 software (BIOVIA Inc.) Electronic structure modeling

Fig. 10. SEM image of mild steel surface before corrosion in acidic solutions.

Fig. 11. SEM images of mild steel surface after 3 h at 30°C in 1 M HCl (a) without VA ethanol extract and (b) with 1500 mg/L VA ethanol extract.

Fig. 12. SEM images of mild steel surface after 3 h at 30°C in 0.5 M H₂SO₄ (a) without VA extract and (b) with 1500 mg/L VA extract.

Table 3. Calculated quantum chemical properties for the most stable configurations of vernodalin, and luteolin

Property	Vernodalin	Luteolin
E _{HOMO} (eV)	-4.134	-5.386
E _{LUMO} (eV)	-4.081	-4.151
E _{LUMO-HOMO}	0.0531	1.235
η	0.0265	0.618
X	4.1080	4.769
ΔN	54.566	1.805
Σ	37.736	1.619
Adsorption energy (kcal/mol)	-175.6	-142.9

was achieved in DMol³ workspace, using a Mulliken population analysis, the DND basis set and the Perdew-Wang (PW) local correlation density functional [31,49-50]. Details of the simulation are as described in [51]. Fig. 13 shows the HOMO and LUMO orbitals, Fukui functions for nucleophilic (f^-) and electrophilic (f^+) attack and electron density for vernodalin and luteolin respectively. Table 3 lists the associated quantum chemical parameters, including HOMO energy (E_{HOMO}), LUMO energy (E_{LUMO}), energy gap (E_{LUMO-HOMO}), absolute hardness (η), absolute electronegativity (χ), electron charge transfer, (ΔN) absolute softness (σ), and the adsorption energies. Interestingly, the obtain values fall within the range reported for some organic inhibitors [34,51].

The f^- functions of the two constituents correspond with the HOMO locations, showing that these are the sites where the constituents can be adsorbed on the mild steel surface, and f^+ correspond with the LUMO locations, showing sites through which the constituents could interact with the non-bonding electrons in the metal. The electron density shows charge distribution saturated all around each molecule; which is suitable for flat-lying adsorption orientations. High values of E_{LUMO} indicate better opportunity for the constituents to donate electrons to the mild steel surface. Accordingly, E_{HOMO} for vernodalin shows that it has a better disposition to donate electron to the mild steel surface than luteolin. This is further confirmed by the lower value of (E_{LUMO-HOMO}). confirms its adsorption on the mild steel surface. I and A are related to E_{HOMO} and E_{LUMO} according to the equation:

$$I = -E_{\text{HOMO}}, A = -E_{\text{LUMO}} \quad (7)$$

The absolute electronegativity (χ), absolute hardness (η) and softness (σ) of the molecules were calculated using the equation:

$$X = \frac{I + A}{2} \quad (8)$$

$$\eta = \frac{I - A}{2} \quad (9)$$

$$\sigma = \frac{1}{\eta} \quad (10)$$

Electron charge transfer, (ΔN) from the adsorbate to the adsorbent was calculated using the equation:

$$N = \frac{X_m - X_i}{2(\eta_m + i)} \quad (11)$$

Where X_m and X_i are the absolute electronegativity of the adsorbent and adsorbate molecule, respectively, while η_m and η_i represent the corresponding absolute hardness. The values of ΔN that are shown in Table 3 were calculated using theoretical values of 7 eV/mol and 0 eV/mol for X_m and η_m respectively [52]. ΔN values have been reported to correlate well with inhibition efficiency [53].

Molecular dynamics simulations were employed for assessment of the non-covalent interactions between single molecules of vernodalin and luteolin and a model Fe surface at the molecular level. The simulation was performed using Forcite quench molecular dynamics to scan the adsorption configurations of lowest energy and identify the low energy minima [31,54]. The COMPASS force field and the Smart algorithm were used to perform the calculations, done in a simulation box of dimensions 30 Å × 25 Å × 29 Å, with the vacuum layer of thickness 20 Å. The Fe surface was cleaved along the (110) plane. Simulation temperature was 303K and time step 1 fs. Quenching of the system was done every 250 steps. Fig. 14 shows representative snapshots of the different adsorption couples and show the constituent molecules to maintain flat lying orientations, to optimize contact with the metal surface.

Atom legend: white = H; gray = C; red = O; blue = N. The blue and yellow isosurfaces depict the electron density difference: the blue regions show electron accumulation, while the yellow regions show electron loss.

The adsorption energy E_{ads} was quantified as follows;

	VERNODALIN	LUTEOLIN
HOMO Orbital
LUMO Orbital
f^- Function
f^+ Function
Electron density

Fig. 13. Electronic properties of vernodaline, and luteoline.

$$E_{\text{ads}} = E_{\text{total}} - (E_{\text{cons.}} + E_{\text{Fe}}) \quad (12)$$

Where E_{ads} corresponds to the adsorption energy, E_{total} , $E_{\text{cons.}}$ and E_{Fe} are the total energies of the constituent, Fe slab and the adsorbed const/Fe (110) couple respectively in the gas phase. The obtained values of

adsorption energies for vernodaline (-175.6 kcal/mol) and luteoline (-142.9 kcal/mol) are all negative suggesting that these constituents are strongly adsorbed on the mild steel surface. The trend in adsorption energy is related to the trend in the molecular size hence the larger constituent (vernodaline) interacted

Fig. 14. Representative snapshots of (a) vernodalin and (b) luteolin adsorbed on the mild steel surface.

more strongly with the metal surface. The strong adsorption of the extract constituents on the Fe surface accounts for the good corrosion inhibition efficiencies notice in the experimental section for VA.

4. Conclusions

The results obtained from this study showed that *Verninia amygdalina* (VA) ethanol extract effectively inhibited the corrosion of mild steel in both 1 M HCl and the 0.5 M H₂SO₄. The gravimetric results revealed that inhibition efficiency increased with increase in VA concentration and decreased with increase in exposure time. The potentiodynamic polarization result showed that VA ethanol extract is a mixed type corrosion inhibitor for mild steel in the aggressive acid environments which was confirmed by the electrochemical impedance spectroscopy to be achieved by the adsorption of the extract constituents on the mild steel surface.

The Langmuir adsorption isotherm, Fourier transform infrared spectroscopy, scanning electron microscopy and theoretical modeling results all confirmed the adsorption of VA constituents on the surface of the mild steel which resulted in the corrosion inhibition of the extract for mild steel in both 1 M HCl and 0.5 M H₂SO₄ solutions.

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