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Evaluating the Corrosion Inhibition Properties of *Burkea Africana* Extract on Mild Steel in Acidic Media

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Abstract

This study investigates the corrosion inhibition properties of *Burkea africana* leaf extract on mild steel in hydrochloric acid (HCl) solution. The extract was obtained through Soxhlet extraction using methanol, and its inhibitory effects were evaluated using weight-loss measurements, thermodynamic analysis, and adsorption isotherms. The results demonstrate that *Burkea africana* extract significantly reduces the corrosion rate of mild steel, with inhibition efficiency increasing with the extract concentration. The inhibition efficiency reached 68.57% at 0.8 ppm, indicating a high potential for this natural extract as a corrosion inhibitor. Thermodynamic analysis, using Langmuir and Freundlich adsorption models, reveals spontaneous adsorption with both isotherms supporting a physisorption mechanism. The negative Gibbs free energy values obtained from both models indicate a spontaneous and favourable adsorption process. The phytochemicals present in *Burkea africana*, such as tannins, flavonoids, and saponins, are believed to play a significant role in the inhibition mechanism by forming a protective barrier on the steel surface. These findings highlight *Burkea africana* as a promising green corrosion inhibitor for industrial applications, offering an environmentally friendly alternative to synthetic inhibitors.

Keywords: *Burkea africana*, corrosion inhibition, Freundlich isotherm, hydrochloric acid, Langmuir isotherm, mild steel

Introduction

Corrosion, the degradation of a material, usually a metal, resulting from a chemical or electrochemical interaction with its surroundings [1], poses a critical challenge in industrial processes. Mild steel, favoured for its mechanical properties and affordability [2], is particularly vulnerable to corrosion in acidic environments, such as hydrochloric acid (HCl), used in cleaning, pickling, and descaling. Corrosion results in significant economic losses, structural failures, and safety risks [3].

Corrosion inhibitors mitigate material degradation by reducing the corrosion rate. Synthetic inhibitors are widely used for their effectiveness but are often environmentally hazardous and expensive [4]. This has spurred interest in plant-based inhibitors as green alternatives. Derived from natural sources, these inhibitors are biodegradable, eco-friendly, and often cost-effective [5].

Burkea africana, is a plant abundant in tannins, flavonoids, and saponins [6], and so should be promising as a green corrosion inhibitor [7]. These phytochemicals interact with metal surfaces, forming protective films that impede corrosion [8]. This study investigates the effectiveness of *Burkea africana* extracts in inhibiting mild steel corrosion in acidic environments, with adsorption behavior evaluated through Langmuir and Freundlich isotherms.

Materials and Methods

- Mild Steel Coupons: Rectangular samples measuring 2 cm × 2 cm × 0.2 cm.
- Chemicals: Analytical-grade methanol (purity: 99.9%) and 37% Hydrochloric acid, reagent grade. Both chemicals obtained from Sigma Aldrich.
- Equipment: 250ml Soxhlet extractor (Guangzhou Reacware Co, China), BK-RE-1A rotary evaporator (BIOBASE Corporation, China), Ohaus AX423 digital analytical balance (Ohaus Corporation, USA), and Pyrex CGW3121-250 Desiccator (Corning Inc, USA).

Preparation of *Burkea africana* Extract

Fresh *Burkea africana* leaves were collected, cleaned, and air-dried at room temperature for 10 days. The dried leaves were ground into powder and extracted using methanol in a Soxhlet apparatus at 65°C. This method is consistent with previous studies on plant extracts that have shown that Soxhlet extraction is effective for obtaining bioactive compounds [9], [10]. The concentrated extract was stored in an airtight container at 4°C until use.

Weight-Loss Measurements

The weight loss measurement was adapted from ASTM G31-21 [11]. Mild steel coupons were polished with emery paper, degreased in acetone, rinsed with distilled water, and dried. Coupons were weighed and immersed in 100 mL of 1 M HCl containing various concentrations (0.1 to 0.8 ppm) of *Burkea africana* extract at 30°C (303k) for 24 hours. Post-immersion, the coupons were cleaned, dried, and reweighed. This procedure aligns with standard practices for evaluating corrosion inhibition where weight loss measurements are commonly used to assess the effectiveness of inhibitors [12,13]. The weight loss, corrosion rate and inhibition efficiency were calculated as follows:

The weight loss of each specimen was calculated using the formula:

$$\boldsymbol{W = W_{initial} - W_{final}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

where:

- W_{initial} is the initial weight of the specimen,
- W_{final} is the final weight after immersion.

$$\boldsymbol{Corrosion\ Rate} = \frac{\boldsymbol{Weight \times 87.6}}{\boldsymbol{Area \times Time}} \quad \dots\dots\dots\dots\dots\dots\dots\dots.(\mathbf{2})$$

$$Inhibition\ Efficiency\ (\%IE) = \frac{(\text{Weight Loss}_{blank} - \text{Weight Loss}_{inhibitor})}{\text{Weight Loss}_{blank}} \times 100 \quad \dots.(3)$$

Langmuir and Freundlich Isotherms

A variety of adsorption isotherm models can be applied to understand how corrosion inhibitors interact with metallic surfaces [14]. Among these, the Langmuir and Freundlich isotherms were specifically chosen in this study because they offer complementary insights into the adsorption mechanism. The Langmuir model is particularly suitable for systems where monolayer adsorption on homogeneous surfaces is expected, making it ideal for evaluating inhibitors that form a uniform protective layer over the metal surface [15]. Conversely, the Freundlich model accounts for heterogeneous surfaces and the possibility of multilayer adsorption, making it appropriate for corrosion systems where the surface energy varies across different sites [16].

Alternative models such as the Temkin and Dubinin–Radushkevich isotherms were not employed because they are typically more appropriate for systems involving significant adsorbate-adsorbate interactions or adsorption on microporous materials, neither of which is the primary focus of this study [17]. By using both Langmuir and Freundlich isotherms, a broader understanding of the adsorption behaviour, surface uniformity, and inhibitor efficiency could be obtained.

In this study, the surface coverage, Θ, was first determined from inhibitor efficiency (%IE) according to:

$$\boldsymbol{\Theta} = \frac{(\%\mathbf{IE})}{\mathbf{100}} \quad \dots\dots\dots\dots\dots\dots\dots\dots.(\mathbf{4})$$

To assess whether the inhibitor molecules form a **monolayer** on homogeneously distributed adsorption sites, the **Langmuir isotherm** model (Equation (5)) is used. Here, a plot of C/Θ versus C (where C is the inhibitor concentration) allows determination of the **adsorption equilibrium constant**, K:

$$\frac{C}{\Theta} = \frac{1}{K} + C \quad \dots\dots\dots\dots\dots\dots\dots\dots.(5)$$

From K, the **Gibbs free energy of adsorption**, ΔG_{ads}, was calculated via:

$$\Delta G_{ads} = -RT\ln(K) \quad \dots\dots\dots\dots\dots\dots\dots\dots(6)$$

However, if the surface is **heterogeneous** - offering sites of varying energies and if **multilayer** adsorption is plausible, the **Freundlich isotherm** (Equation (7)) may better represent the experimental data. In this case, a plot of log(Θ) against log(C) yields the **Freundlich adsorption constant**, K_f, and an exponent n that reflects adsorption intensity:

$$\log(\Theta) = \log(K_f) + n\log(C) \quad \dots\dots\dots\dots...(7)$$

Analogous to the Langmuir model, the **Gibbs free energy** was determined using:

$$\Delta G_{ads} = -RT\ln(K_f) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Results and Discussion

Corrosion Reaction

The corrosion of mild steel in hydrochloric acid is represented as:

$$Fe(s)\ 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g) \ldots\ldots\ldots\ldots (9)$$

This reaction involves the dissolution of iron into the solution with the release of hydrogen gas. *Burkea africana* extracts are presumed to reduce the corrosion rate by forming a protective barrier on the steel surface, likely through the adsorption of phytochemical constituents, such as flavonoids, tannins, and alkaloids, onto the steel surface. Previous studies have reported that natural extracts, particularly those containing tannins and flavonoids, can effectively inhibit corrosion by adsorbing onto metal surfaces and forming a protective film [18], [19], [20]. The phytochemicals present in *Burkea africana*, such as tannins and flavonoids, may contribute to this protective effect, as suggested by related findings in the literature [21]. While no direct evidence of this adsorption mechanism was obtained in the present study, the observed reduction in corrosion rate in the presence of *Burkea africana* extracts aligns with the corrosion inhibition behaviour reported for plant extracts in similar studies [18], [20].

Weight-Loss Data

Table 1: Weight loss, corrosion rate, and inhibition efficiency for mild steel in 1 M HCl with varying concentrations of *Burkea africana* extract

Concentration (ppm)	Average Weight Loss (g)	Corrosion Rate (mm/year)	Inhibition Efficiency (%)
0.0 (Blank)	0.308	0.035	–
0.1	0.214	0.025	28.57
0.2	0.17	0.019	45.71
0.4	0.134	0.015	57.14
0.6	0.123	0.014	60
0.8	0.102	0.011	68.57

The results demonstrate a concentration-dependent increase in inhibition efficiency reaching 68.57% at 0.8 ppm of *Burkea africana* extract. This trend aligns with findings from other studies indicating that the effectiveness of natural extracts as corrosion inhibitors increases with concentration [22]. Comparisons with neem and moringa extracts highlight the extract's competitive efficacy as a green inhibitor; similar studies have reported high inhibition efficiencies for these extracts in acidic media [23]. The observed reduction in weight loss and corrosion rate suggests that ***Burkea africana* extract forms** a protective layer on the steel surface effectively mitigating the corrosive effects of the acidic environment [24].

Langmuir Isotherm

From the Linear plot of C/ Θ vs C (figure 1), K was determined to be 3.91 L/mol. The Gibbs free energy was calculated using ΔG_{ads} = -RTln(K) and this yielded a value of −3.43kJ/mol kJ /mol. The negative value of $\Delta G_{ads} < 0$ indicates that the adsorption process is spontaneous [25].

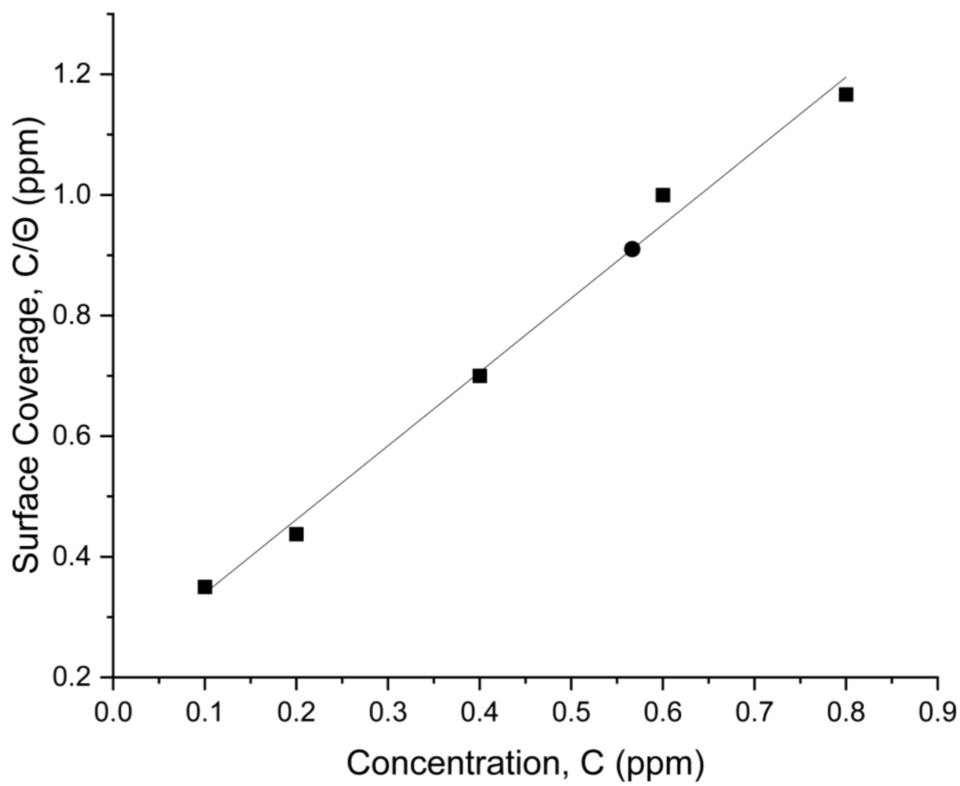

Figure 1: Linear plot of C/ Θ vs C

Freundlich Isotherm

From the linear plot of log(Θ) vs log C (figure 2), K_f was to be equal to 3.92, The Gibbs free energy was calculated using: $\Delta G_{ads} = -RT\ln(K_f)$. This yields $\Delta G_{ads} = -3.44$kJ/mol. This value also indicates a spontaneous adsorption process further supporting the effectiveness of *Burkea africana* extracts as corrosion inhibitors in acidic media [3].

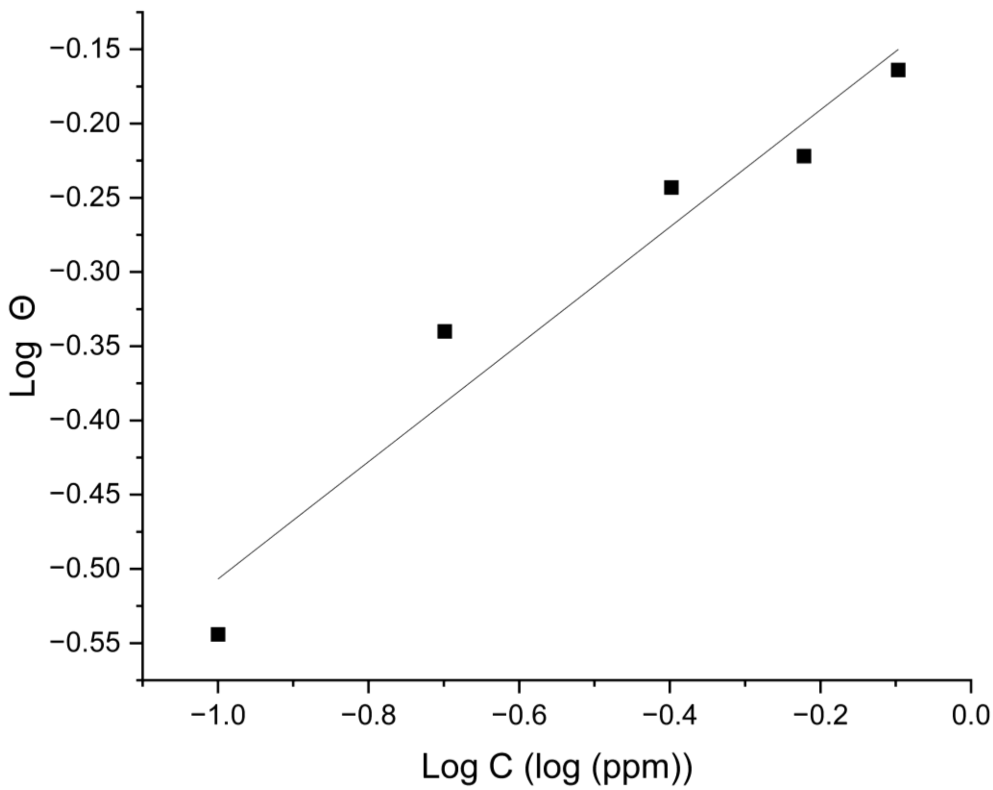

Figure 2: linear plot of log(Θ) vs log C

Implications of the Isotherm Calculations

The results obtained from the isotherm calculations and analysis indicate that both isotherms suggest spontaneous adsorption (ΔG_{ads} < 0). However, both the Langmuir and Freundlich models yielded ΔG_{ads} values much higher than -20kJ/mol indicating physisorption [26]. Physisorption has been reported in many studies of plant extracts as corrosion inhibitors [23], [27], [28]. Physisorption, characterized by weak van der Waals forces, leads to the formation of a protective film on the metal surface. This film acts as a barrier, reducing the metal's exposure to corrosive agents and thereby decreasing the corrosion rate. However, because physisorption involves weaker interactions, the protective film may be less stable under varying environmental conditions, such as changes in temperature or pressure, potentially affecting its long-term effectiveness [29]. The linear plots of the Langmuir and Freundlich yield R^2 values of 0.9963 and 0.95534 respectively, indicating that the Langmuir isotherm is a better fit. However, that the linear plots of both the Langmuir and Freundlich yield similar figures (3.91 L/mol and 3.92 respectively) implies both single and multilayer adsorption were taking place at nearly the same rate [30]. Literature suggests that tannins form chelates with iron ions while flavonoids scavenge radicals; saponins reduce surface tension collectively creating a protective barrier that inhibits corrosion [31], [32], [33]. This synergistic action enhances the overall protective effect of *Burkea africana* extracts against corrosion in acidic environments.

Conclusion

This study on the corrosion inhibition properties of *Burkea africana* leaf extract on mild steel in hydrochloric acid (HCl) solution indicated that *Burkea africana* extract significantly reduces the corrosion rate of mild steel, with inhibition efficiency increasing with the extract concentration. The inhibition efficiency (68.57% at 0.8 ppm) evident a high potential of this natural extract as a corrosion inhibitor. Therefore, the findings position *Burkea africana* as a promising green corrosion inhibitor, and can be tapped for national development.

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