The Effectiveness of *Musa Paradisiaca* as Green Inhibitor for Mild steel in Marine Corrosion

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Abstract. Corrosion is characterized as metal and alloy degradation or destruction due to a chemical or electrochemical response to the surrounding environment or medium. Different metals corrode at different rates. Many organic and inorganic compounds have been investigated in the control of corrosion by adding the corrosive fluids as they are readily accessible, inexpensive, sustainable and environmental friendly. This research evaluates the effectiveness of *Musa paradisiaca* as an organic inhibitor of mild steel in marine corrosion. The gravimetric and linear polarization methods were applied to study the corrosion behaviour of mild steel. All the parameters analysed showed good inhibitory characteristics against the corrosion of mild steel in solution being tested, and their efficiency was found to increase with the inhibitor concentration. After a varied immersion duration, the gravimetric and electrochemical measurements for mild steel in seawater showed that the presence of *Musa paradisiaca* significantly reduces the corrosion densities ($i_{corr}$) of $0.44 \times 10^{-6}$ A cm$^{-2}$ and corrosion rates of 0.00507 mm/year, as the polarization resistance ($R_p$) of 2536.6 and inhibition efficiency (IE) of 99.38 % are synchronously increased.

1. Introduction

Mostly, the industries are relying on the metal properties as it is hard, high density, high tensile strength which is mostly used for production, storage and transportation of the energy product. In the marine industry, pier piling is one of the concerns in marine corrosion as the steel piling will corrode due to the reaction in the marine environment which environment is air saturated seawater. Due to this issue, corrosion may devote to contamination which can lead to the slowdown of production of the main product that also leads to the reduction of the expected company’s profit. Therefore, preventing corrosion is an essential part of industrial and critical cleaning processes.

A corrosion inhibitor is one of the corrosion prevention methods in which a material is added to a metal to decrease the rate of corrosion. The inhibition mechanism can be very complex as it is adsorbed and stifles the corrosion current on anodic and cathode sites. Some of them will also impact the redox reaction, while others will enable the creation of protective films on the surface of the metal. In addition, inhibitors may be mixed into a protective coating or a primer for the primer. Along the years, many commodious efforts have been utilized to obtain the applicable corrosion inhibitors of natural products in order to decrease or eliminate the corrosion rate of the materials used but no published analysis is available on banana leaves and stem (*Musa paradisiaca*) as a corrosion inhibitor for any metal [1-5]. The corrosion inhibitor becomes essential to protect the metal in the aggressive solution. Research has been done to find an acceptable natural product to be used as...
corrosion inhibitor in adaptation to different corrosion media [6-12]. The Musa extraction will provide captivating possibilities to be a corrosion inhibitor because it is renewable, low cost, safe use and availability. The goal of this research is to report on the evaluation of the inhibitive effect of gravimetric and potentiodynamic polarisation (PP) measurements on marine corrosion of mild steel immersed in seawater. In this study, a review of the inhibition mechanism was also performed. The marine and petrochemical industries have allowed mild steel to meet or exceed the minimum strength requirements for normal strength steel currently used in pipelines, especially in delivery of liquid or gas, because mild steel can withstand the weather and other outdoor consequences. Mild steel also applied in steel frame building as it is incredibly high strength and cannot be damaged by insects and is impervious to both rot and fire. The properties of the banana trees have been evaluated and proved that it carries the beneficial to marine industrial utilization. Plus, banana trees can be formed at any type of agricultural scale. Moreover, the potential usages of banana trees that have been appraised in this research are linear with the green technology as it is renewable.

2. Methodology

2.1 Material
The material used was mild steel (AISI/SAE 1020) with subsequent chemical composition (wt); C (0.25-0.29%), Cu (0.20%), Fe (98%), Mn (1.03%). The samples were mechanically polished using 400, 500 and 600 emery papers (30 x 24 x 4 mm coupons) and lubricated using distilled water. The polished samples were cleaned with acetone, washed using distilled water, dried in air and processed until use in humidity free desiccators. Seawater collected from Pantai Teluk Kalong, Kemaman, Terengganu was the test solution used for the investigation. Musa paradisiaca extracts were the inhibitor used and the concentration range of the inhibitor employed ranged from 200 ppm to 1000 ppm. The chemical composition of banana leaves and stem [1] shown in Table 1.

| %       | Cellulose | Hemicellulose | Lignin | Starch | Pectin |
|---------|-----------|---------------|--------|--------|--------|
| Banana stem | 39.12     | 72.71         | 10.78  | -      | 0.27   |
| Banana leaves | 37.3      | 12.4          | 13.3   | 8.4    | -      |

2.2 Extraction Procedure
Musa paradisiaca leaves were dried in an oven at 70°C for 6 hours and ground into powder and 10 grams of Musa paradisiaca powder was refluxed for 1 hour in 100 mL double distilled water. The plant extract has been prepared by evaporating the filtrate [7]. The solution concentrations were prepared from solid residue obtained by evaporating the filtrate in reflux system and varied in 0, 200, 400, 600, 800 and 1000 ppm Musa extracts in seawater. All the tests used a fresh seawater solution and conducted at room temperature (25°C). The triplicate specimens for each concentration of the inhibitor were submerged for 30 minutes in a 100 mL beaker containing the respective solution. As shown in Figure 1, all electrochemical experiments were performed with an Autolab frequency response analyzer (FRA) coupled to an Autolab potentiostat connect to a computer. The cell used is a traditional three electrode with a saturated calomel electrode (SCE) and a platinum wire counter electrode (CE) as a reference to which all potential is referred to. In the shape of square cut, the working electrode (WE) was such that the flat surface of the electrode was the only surface. The exposed area to the test solution was 3.75 cm². The WE was first submerged in the test solution and the electrochemical measurements were performed after establishment a steady state open circuit potential.
The potentiodynamic current-potential curves were reported by automatically changing the electrode potential from -250 mV to +250 mV, with the scanning rate of 5 mV s\(^{-1}\) related to the open circuit potential. From the intersection of the linear anodic and cathodic branches of the polarization curves, corrosion current densities (\(i_{\text{corr}}\)) and corrosion potential (\(E_{\text{corr}}\)) were assessed as Tafel plots. The measurements of the polarization resistance (\(R_p\)) were performed at -10 mV to +10 mV.

The corrosion rate was calculated by using the following equation:

\[
\text{Corrosion rate (mmpy)} = \frac{[87.6 \times W]}{pAT} \quad (1)
\]

mmpy is millimetre per year, \(W\) is weight loss (mg), \(p\) is density (gm/cm\(^3\)), \(A\) is the area of the specimen (cm\(^2\)) and \(T\) is a time in hours. The inhibition efficiency (%\(IE\)) was calculated by using the following equation:

\[
\%IE = \frac{(W_i - W_f)}{W_i} \times 100 \quad (2)
\]

The corrosion rates in the absence and presence of the inhibitor are \(W_1\) and \(W_2\). The inhibition efficiency (%\(IE\)) was estimated using the following equation:

\[
\%IE_{RP} = \frac{\left(\frac{R_{P2}}{R_{P1}} - 1\right)}{\frac{R_{P2}}{R_{P1}}} \times 100 \quad (3)
\]

\(R_{P2}\) and \(R_{P1}\) are polarization resistance in the presence and absence of inhibitor, respectively.

### 3. Result and Discussion

The immersion of mild steels in seawater with different concentration of *Musa* extracts for weight loss measurement have been evaluated and the results clearly indicated that there are differences between the samples of mild steel that exposed directly to seawater with and without inhibitor. The data shown mild steel samples which immersed without the presence of inhibitor undergo increment in weight loss, while the mild steel samples which immersed with the presence of inhibitor undergo the decrement in weight loss as shown in Figure 2.

The weight loss of samples of mild steels is decreased with the increase in concentration of *Musa* extracts, which increases the corrosion resistance by the concentration. The pattern due to the concentration of *Musa* extracts leading to the creation of thin layer and isolated from seawater medium, the amount of adsorption and the coverage of *Musa* extracts on the mild steel increases.
It was found that the increase in inhibition efficiency of Figure 3 and the decrease in corrosion rate of Figure 4 were correlated with an increase in the inhibitor concentration, suggesting that the inhibitor was adsorbed on the mild steel surface or at the solution interface, raising its concentration and providing wider surface coverage. The previous research of potato peel as an extract on corrosion has reported 66.19% of \%IE from the measurement of weight loss after 35 days immersion [8], while Musa extracts recorded 86.51 % of \%IE from the measurement of weight loss after 36 days of immersion.

Figure 2. The overall graph of weight loss versus immersion time for all solutions.

Figure 3. The overall graph of \%IE for all solutions.
The polarization measurement has been developed in order to determine the essence of the inhibition mechanism. The corrosion current density ($i_{corr}$), corrosion potential ($E_{corr}$), cathodic and anodic Tafel slopes ($b_c$ and $b_a$), corrosion rates and the polarization resistance were evaluated by the data record from polarization measurement. The addition of Musa extracts to the seawater solution has lowered the existing corrosion current density ($i_{corr}$).

As shown in Figure 5, the transition in cathodic and anodic Tafel slopes ($b_c$ and $b_a$) indicates that the adsorption of Musa extracts modifies the anodic dissolution process as well as the evolution of cathodic hydrogen. It is clear that both cathodic and anodic reactions are inhibited and as the inhibition increases in acid media, the inhibition increases. In addition, it is clear that in the presence of different concentration of Musa extracts in seawater solutions, there is no definite trend in the change of $E_{corr}$ values. This finding suggests that Musa extracts can be classified as a mixed type of inhibitor in seawater solutions [9].
The breakdown of mild steel and depletion of dissolved oxygen as a result of anodic and cathodic processes of mild steel corrosion in seawater are:

\[
\begin{align*}
Fe & \rightarrow Fe^{3+} + 3e^- \quad (4) \\
3O_2 + 6H_2O + 12e^- & \rightarrow 12OH^- \quad (5)
\end{align*}
\]

Then, Fe3+ reacts with OH- to form ferum hydroxide near the mild steel surface as below

\[
4Fe + 6H_2O + 3O_2 \rightarrow 4Fe(OH)_3 \quad (6)
\]

And the hydroxide precipitates on the surface due to its low solubility product. Ferum hydroxide changes gradually to ferum oxide resulting in the passive film formation.

\[
2Fe(OH)_3 \rightarrow Al_2O_3 + 3H_2O \quad (7)
\]

Figure 6 also indicates that inhibition efficiency for polarization resistance undergo the increment from 200 ppm till 1000 ppm of Musa extracts which reflects that the inhibitor is capable to show the efficiency of the inhibitor by various concentration of Musa extracts. From the previous research of evaluation tapioca starch as an inhibitor, it has documented 93.38 % of maximum value % IE of \(i_{corr}\) while Musa has recorded 99.38 % of maximum value % IE of \(i_{corr}\).

\[
\text{Figure 6. The graph of } \% \text{IE of } R_p \text{ for all solutions}
\]

Based on the data obtained, the seawater that has the presence of the inhibitor undergo the minimum results in of conductivity, salinity and TDS compared to the absence of the inhibitor. Not only that, the graph also indicates that 1000 ppm is the best result which has the lowest result in conductivity, salinity and TDS.

Decreases in conductivity, salinity and TDS parameters are due to the salinity of the solution (Figure 7). Since salinity is a measure of conductivity of water, TDS and electrolyte increase, and galvanic corrosion in an electrolytic solution requires dissimilar metals, salinity and corrosion rate are directly related.
The salinity decrease provides minimum free electrons to serve as an escape path for the metal to corrode. Corrosion is the transfer of electrons from one substance to another so less salt in water limits water’s ability to transmit electrons by redox reactions. Finally, it clearly indicates that there is less DO in the presence of the inhibitor than in absence of the inhibitor. As DO is capable removing the protective hydrogen film that can form several metals and oxidise dissolved ions into insoluble form, low dissolved oxygen can delay the corrosion process.

4. Conclusion
Mild steel corrosion inhibition studies have been performed using seawater at room temperature and the results have shown that *Musa* extracts can be regarded as a source of relatively inexpensive, eco-friendly, biodegradable and effective corrosion inhibitors. The findings of weight loss showed that the application of *Musa* extracts specifically minimizes the weight loss and abridged mild steel dissolution in seawater. As the corrosion inhibitor concentrate increases, weight loss decreases. It also shows that the addition of inhibitor, the $R_p$ values increase while the corrosion rate values decrease, suggesting the formation of a surface film. The active molecule present in the *Musa* extract effectively prevented the corrosion of mild steel by creating a protective barrier layer in natural seawater. The adsorbed extract organic matter inhibited the corrosion process through a mixed-inhibition mechanism from the potentiodynamic polarization measurements, influencing both the anodic metal dissolution reaction and the evolution reaction of cathodic hydrogen. The measurement of the study of inhibitor mechanism analysis for all solutions from 0 ppm to 1000 ppm of *Musa* extracts shows a decrease in outcome based on the conductivity, salinity, TDS and dissolved oxygen parameters as low free electrons transmit in the redox reactions that clearly affect the corrosion behaviour.

Acknowledgement
The authors fully acknowledged the University College TATI for the approved fund which makes this important research viable and effective.

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