The Effect of Mangosteen Peel Extract Concentration as a Corrosion Inhibitor on Low Carbon Steel in NaCl Media

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Abstract. *This study aims to investigate the effectiveness of mangosteen peel extract as a corrosion inhibitor on low carbon steel in a NaCl environment. Corrosion of low carbon steel is a significant issue in the industry, especially in chloride-containing environments. The weight loss method was used to measure the corrosion rate, while the form of corrosion was examined using the photomacro method with a digital microscope. The research was conducted by immersing low carbon steel specimens in a NaCl solution. The experimental research method involved corrosion testing on mild steel plates in a NaCl 3% solution with varying concentrations of mangosteen peel extract (100 ppm, 200 ppm, 300 ppm, 500 ppm, 600 ppm). The results show that the mangosteen peel extract is effective in reducing the corrosion rate, with a concentration of 200 ppm showing the highest inhibition efficiency. Analysis indicates an increase in corrosion resistance, suggesting the formation of a protective layer by the extract on the steel surface. The conclusion of this study is that mangosteen peel extract has potential as an environmentally friendly and effective corrosion inhibitor for the protection of low carbon steel in chloride-containing media. Further research is recommended to optimize the formulation and application of the extract on an industrial scale.*

Keywords: *mangosteen peel, corrosion, inhibitor, low carbon steel*

1. INTRODUCTION

Corrosion is a detrimental phenomenon that causes the degradation of metal surfaces, resulting in substantial maintenance and replacement costs. In cooling system installations within industries and power plants, corrosion can lead to the shutdown of production machinery or power generation equipment. This process is driven by cooling water, whether fresh or brackish, which contains oxygen and hydrogen ions. These ions react with the steel metal in the cooling machinery, leading to chemical and electrochemical reactions that culminate in corrosion.

Corrosion in cooling systems is induced by cooling water, either fresh or brackish, that contains oxygen and hydrogen ions. These ions react with the steel metal of the cooling machines, triggering chemical and electrochemical reactions that ultimately lead to the corrosion process.

One effective method to mitigate corrosion is by using inhibitors added to the cooling water. These inhibitors function to hinder the corrosion reaction. In pursuit of more environmentally friendly solutions, the development of natural inhibitors has become increasingly important. Natural inhibitors are typically derived from plant extracts containing antioxidants.

Tannins are among the components in plant extracts that have shown potential as corrosion inhibitors. Therefore, it is necessary to conduct research to evaluate the performance of tannins as corrosion inhibitors.

This research aims to evaluate the performance of mangosteen peel extract as a corrosion inhibitor for low carbon steel in a 3% NaCl water environment. This study is expected to provide an effective and environmentally friendly solution to reduce corrosion in industrial cooling systems.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Corrosion is a major issue affecting the longevity and integrity of metallic structures, particularly in industrial settings. The use of natural inhibitors for corrosion protection has garnered significant interest due to their environmental friendliness and potential effectiveness. Mangosteen (Garcinia mangostana L.), renowned for its rich phytochemical profile, particularly in its peel, has been explored as a potential natural inhibitor. This literature review aims to summarize current research on the inhibitory effects of mangosteen peel extract on corrosion, focusing on its effectiveness, mechanisms of action, and practical applications. The mangosteen peel is rich in various bioactive compounds, notably xanthones, flavonoids, tannins, and anthocyanins. Xanthones, such as α-mangostin, γ-mangostin, and garcinone E, are the primary compounds responsible for the peel's antioxidant and antimicrobial properties. These compounds also play a crucial role in corrosion inhibition by forming a protective layer on metal surfaces.

Several studies have demonstrated the efficacy of mangosteen peel extract in inhibiting corrosion. The primary bioactive compounds in the peel, such as xanthones, flavonoids, and tannins, are believed to contribute to its inhibitory properties. A study by Al Juhaiman et al. (2018) investigated the effect of mangosteen peel extract on the corrosion of mild steel in acidic environments. The results indicated a significant reduction in corrosion rate, suggesting the extract's potential as an effective corrosion inhibitor. Similarly, research by Kumar et al. (2017) showed that mangosteen peel extract could inhibit the corrosion of aluminum in chloride media.

The primary mechanism of corrosion inhibition by mangosteen peel extract is the adsorption of its bioactive compounds onto the metal surface. This adsorption is facilitated by the presence of polar functional groups in the xanthones and flavonoids, which interact with the metal atoms. The adsorption can be described using adsorption isotherms, such as the Langmuir isotherm, which suggests monolayer adsorption of the inhibitor molecules., highlighting its versatility.

Electrochemical studies provide insights into the inhibitory mechanisms. Polarization studies indicate that mangosteen peel extract acts as a mixed-type inhibitor, reducing both anodic and cathodic reactions. Electrochemical Impedance Spectroscopy (EIS) studies further reveal increased charge transfer resistance and decreased double-layer capacitance in the presence of the extract, suggesting effective barrier formation that impedes corrosion processes.

Surface analysis techniques, such as Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM), have been used to study the morphology of metal surfaces treated with mangosteen peel extract. These studies confirm the formation of a uniform and adherent protective layer, which reduces surface roughness and prevents direct contact of the metal with the corrosive environment.

Industrial Applications

The application of mangosteen peel extract as a corrosion inhibitor has shown promising results in various industrial settings. Trials in cooling water systems, oil pipelines, and storage tanks have demonstrated its efficacy in protecting metallic surfaces from corrosion, thereby reducing maintenance costs and extending equipment lifespan. The use of mangosteen peel extract aligns with the principles of green chemistry and sustainability, offering an eco-friendly alternative to synthetic inhibitors.

Environmental and Economic Benefits

The use of natural inhibitors like mangosteen peel extract offers significant environmental benefits. Unlike synthetic inhibitors, which can be toxic and non-biodegradable, mangosteen peel extract is biodegradable and non-toxic. Additionally, utilizing agricultural waste products such as mangosteen peel contributes to waste valorization and circular economy, adding economic value to otherwise discarded materials.

Challenges and Future Directions Standardization and Optimization

One of the challenges in the practical application of mangosteen peel extract is the standardization of extraction methods and inhibitor formulations. Variations in extraction techniques and raw material sources can lead to inconsistencies in inhibitor performance. Optimizing extraction processes to maximize the yield and purity of bioactive compounds is crucial for consistent and effective corrosion inhibition.

Long-term Stability and Performance

Long-term studies are needed to evaluate the durability and effectiveness of mangosteen peel extract under various environmental conditions. Factors such as temperature fluctuations, exposure to UV radiation, and varying pH levels can affect the performance of the inhibitor. Research should focus on improving the stability and resilience of the protective film formed by the extract.

Synergistic Formulations

The development of synergistic formulations, combining mangosteen peel extract with other natural or synthetic inhibitors, could enhance the overall inhibitory efficiency and broaden the range of applicable environments. Such formulations could leverage the strengths of different inhibitors, providing comprehensive protection against corrosion.

Mangosteen peel extract exhibits significant potential as a natural corrosion inhibitor due to its rich phytochemical content and environmentally friendly nature. The bioactive compounds in the peel, particularly xanthones, play a crucial role in forming protective films on metal surfaces, thereby inhibiting corrosion. While current research provides a strong foundation for its application, further studies are needed to address the challenges and fully realize its potential in industrial applications. The shift towards natural corrosion inhibitors like mangosteen peel extract aligns with global efforts to promote sustainable and eco-friendly practices in industrial processes.

This section contains a literature review which is used to support the research concept. Literature studies are not limited to theory alone, but also empirical evidence. The research hypothesis (if any) must be built from theoretical concepts and supported by empirical studies (previous research). [Times New Roman, 10, normal].

3. RESEARCH METHODS

A. Experimental Methods

This study employs an experimental method to evaluate the effectiveness of mangosteen peel extract as a corrosion inhibitor for low carbon steel. The experimental setup involves the use of weight loss analysis to determine the corrosion rate. The process is detailed as follows:

1) Specimen Preparation: Low carbon steel specimens are prepared with uniform dimensions. Each specimen is cleaned, polished, and weighed to obtain the initial weight.
2) Corrosion Testing: The specimens are immersed in a 3% NaCl solution, both with and without the addition of mangosteen peel extract as the inhibitor. The corrosion tests are conducted for a specified duration under controlled conditions to ensure consistency.
3) Weight Loss Measurement: After the corrosion test period, the specimens are removed, cleaned to remove corrosion products, and dried. The final weight of each specimen is measured. The weight loss is calculated by subtracting the final weight from the initial weight.
4) Corrosion Rate Calculation: The corrosion rate is determined by dividing the weight loss by the exposure time. This provides a quantitative measure of the corrosion process.
5) *Inhibition Efficiency Evaluation (IEE)* : The inhibition efficiency of the mangosteen peel extract is calculated using the formula:

$$IEE = \left(\frac{CR\ control - CR\ inhibited}{CR\ Control}\right) x100$$

where Corrosion Rate control is the corrosion rate of the specimen in the 3% NaCl solution without the inhibitor, and Corrosion Rate inhibited is the corrosion rate of the specimen in the presence of the mangosteen peel extract.

6) *Data Analysis*: The collected data is statistically analyzed to assess the effectiveness of the mangosteen peel extract in reducing the corrosion rate. Comparative analysis is performed between the inhibited and non-inhibited conditions to determine the significance of the results

B. Experimental Procedure

This experiment aims to evaluate the effectiveness of various concentrations of an inhibitor in reducing the weight loss of metal samples immersed in a 3% NaCl solution. The study involves preparing metal samples, exposing them to different inhibitor concentrations, and measuring the resultant weight loss to determine the optimal inhibitor concentration.

1. *Materials and Methods:*

a. Sodium Chloride (NaCl) 3% solution
b. Inhibitor (concentrations: 0 ppm, 100 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm, 600 ppm)
c. Metal samples (preferably steel or other corrosion-prone material)
d. Distilled water

2. *Equipment:*

a. Analytical balance (accuracy: 0.001 g)
b. Glass beakers (100 mL capacity)
c. Magnetic stirrer
d. Thermometer
e. pH meter
f. Pipettes and pipette fillers
g. Labels
h. Timer or stopwatch

3. *Procedure:*

a. Sample Preparation:
- Clean the metal samples thoroughly using distilled water and dry them with a lint-free cloth.
- Accurately weigh each metal sample and record the initial weight.

b. Solution Preparation:
- Prepare a 3% NaCl solution by dissolving NaCl in distilled water.
- Dispense the NaCl solution into several glass beakers, labeling each beaker according to the inhibitor concentration to be tested (0 ppm, 100 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm, 600 ppm).

c. Inhibitor Addition:
- Add the appropriate amount of inhibitor to each beaker to achieve the desired concentration.

- Use a magnetic stirrer to mix the solution thoroughly, ensuring uniform dispersion of the inhibitor.

d. Sample Exposure:

- Immerse each metal sample in the corresponding beaker containing the inhibitor solution.
- Ensure that all samples are fully submerged in the solution.
- Allow the samples to remain in the solution for a period of 240 hours.

e. Final Weight Measurement:

-After 240 hours, remove the metal samples from the solution and rinse them with distilled water.
- Dry the samples using a lint-free cloth.
- Weigh each sample again and record the final weight.

f. Data Analysis:

- Calculate the weight loss for each sample by subtracting the final weight from the initial weight.
-Plot a graph of weight loss (mg) versus inhibitor concentration (ppm).

8 Safety Considerations:

- Wear appropriate personal protective equipment (PPE), including gloves and safety goggles, throughout the experiment.
- Maintain a clean and organized workspace.
- Handle all chemicals according to standard laboratory safety protocols.

9. Repetition and Accuracy:

- Repeat the experiment multiple times to ensure the accuracy and reliability of the results. Record any variations in the data and analyze potential factors influencing the outcomes.

C. Outlines

The experimental data should reveal the relationship between inhibitor concentration and weight loss, indicating the most effective concentration for reducing corrosion in a 3% NaCl solution.

This procedure outlines the steps required to assess the effectiveness of different inhibitor concentrations in minimizing weight loss due to corrosion. The findings contribute to the understanding of corrosion inhibition in saline environments, providing valuable insights for industrial applications.

By adhering to this detailed experimental protocol, researchers can replicate the study and compare results to establish robust conclusions regarding the optimal inhibitor concentration for corrosion prevention.

4. RESULTS AND DISCUSSION

A. Sample Uniformity Analysis Using Minitab

The uniformity of the low carbon steel samples was analyzed using Minitab statistical software. Descriptive statistics, including the mean, standard deviation, and range, were calculated for the initial weights of the samples to assess their consistency. A low standard deviation and narrow range would indicate a high level of uniformity among the samples.

Additionally, an Analysis of Variance (ANOVA) test was performed to determine if there were any significant differences in the initial weights of the samples. A high p-value (typically greater than 0.05) from the ANOVA test would suggest that there are no statistically significant differences, confirming the uniformity of the samples.

The I-Chart, as shown in Figure 1, confirms the consistency and stability of the initial weights of the low carbon steel samples, further supporting the reliability of the dataset for subsequent experimental analysis.

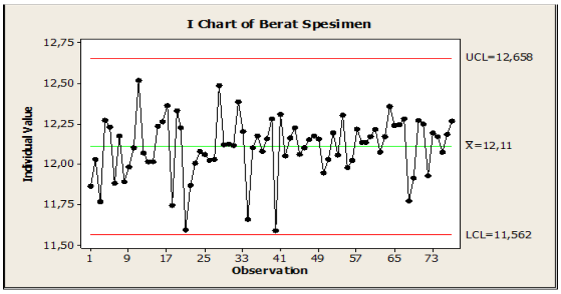

Figure 1. The initial weights of the low carbon steel samples were recorded and used as the dataset for the I-Chart.

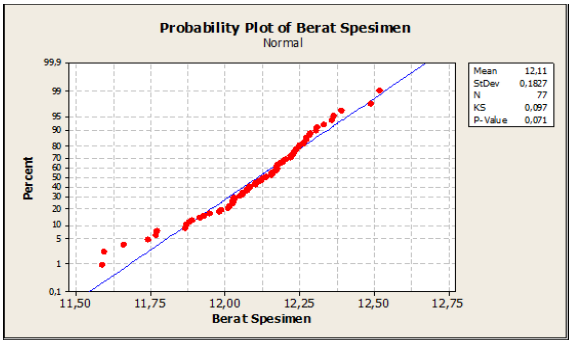

Figure 2. The normality of the initial weights of the low carbon steel samples was assessed using Minitab statistical software.

To evaluate whether the data follows a normal distribution, a probability plot (Q-Q plot) and the Anderson-Darling test were employed , the normality is shown in Figure 2.

Steps in I-Chart Analysis

1) *Data Collection*: The initial weights of the low carbon steel samples were recorded and used as the dataset for the I-Chart.Chart Construction:
2) *The I-Chart was plotted* : displaying each individual sample weight along the y-axis against the sample number along the x-axis. Control limits (upper and lower) and the centerline (mean) were calculated and displayed on the chart.

Interpretation:

1) *Control Limits*: The control limits represent the expected range of variation within a stable process. Any data point falling outside these

limits indicates a potential out-of-control condition.

2) *Centerline*: The centerline represents the average initial weight of the samples.

Variation Analysis:

The chart was examined for any points outside the control limits or patterns within the control limits that could suggest non-random variation.

Analysis Results:

1) Consistency: All data points fell within the control limits, indicating that there were no significant outliers or unusual variations in the initial weights of the samples.
2) Stability: The pattern of the data points did not display any trends or cycles, suggesting that the process of weighing the samples was stable over time.

B. Data And Results

1).Weightloss

Description of data displayed in Figure 3, the graph shows the relationship between the concentration of an inhibitor (in ppm) and the weight loss (in mg) in a solution with 3% NaCl.

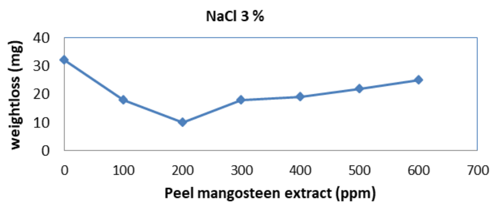

Figure 3. The graph, Weight Loss is measured along the y-axis, and the concentration of the inhibitor is measured along the x-axis.

Detailed Analysis:

a. Initial Observation (0 ppm): At 0 ppm of inhibitor, the weight loss is highest, around 38 mg. This indicates significant corrosion or reaction taking place in the absence of the inhibitor.
b. Decrease in Weight Loss (100 - 200 ppm): As the inhibitor concentration increases to 100 ppm, the weight loss decreases sharply to approximately 20 mg. At 200 ppm, the weight loss further decreases to around 10 mg, showing the effectiveness of the inhibitor in reducing weight loss significantly at low concentrations.
c. Minimum Weight Loss (200 ppm): The lowest weight loss is observed at 200 ppm, suggesting this might be the optimal concentration for the inhibitor in this specific setup.
d. Gradual Increase (300 - 600 ppm): Beyond 200 ppm, as the inhibitor concentration increases to 300 ppm, 400 ppm, 500 ppm, and 600 ppm, the weight loss starts to increase gradually.

The weight loss values for these concentrations hover between 10 mg to 20 mg. This indicates a possible saturation point where adding more inhibitor does not further reduce the weight loss and might even slightly reduce its effectiveness.

2) Efficiency Inhibitor

The graph illustrates the relationship between the concentration of mangosteen peel extract (in ppm) and the inhibition efficiency (in %) in a 3% NaCl solution. The inhibition efficiency is plotted on the y-axis, and the concentration of the mangosteen peel extract is plotted on the x-axis.

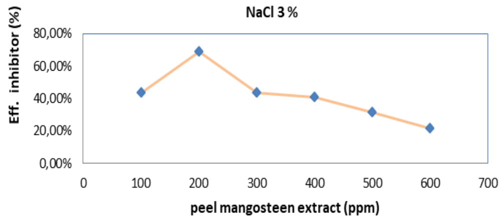

Figure 4. The graph, eff. inhibitor is measured along the y-axis, and the concentration of the inhibitor is measured along the x-axis.

Detail Analysis :

a. Initial Observation (0 ppm): At 0 ppm of mangosteen peel extract, the inhibition efficiency is at its lowest, close to 0%. This indicates that without the extract, there is negligible inhibition of the corrosion process in the NaCl solution.
b. Increase in Inhibition Efficiency (100 - 200 ppm): As the concentration of the mangosteen peel extract increases to 100 ppm, the inhibition efficiency rises significantly, reaching approximately 60%. At 200 ppm, the inhibition efficiency peaks at around 70%, indicating this concentration provides the highest level of corrosion inhibition in the solution.
c. Decrease in Inhibition Efficiency (300 - 600 ppm): Beyond 200 ppm, the inhibition efficiency starts to decline. At 300 ppm, the efficiency drops to around 50%.
d. As the concentration increases further to 400 ppm, 500 ppm, and 600 ppm, the inhibition efficiency continues to decrease, with the values approximately being 45%, 40%, and 35%, respectively.

3)Photomacro

Thin corrosion is a form of corrosion where the corrosion product layer formed is very thin and uniform. Nevertheless, this layer can protect the metal from further damage. The use of natural inhibitors such as mangosteen peel extract aims to form an effective and environmentally friendly protective layer to prevent corrosion on low carbon steel in NaCl media.

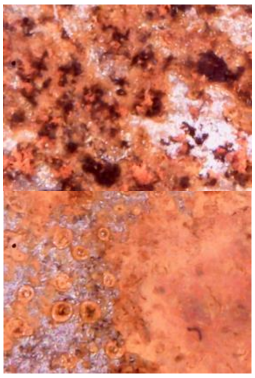

Figure 5. The photomacro of specimen, left without inhibitor ,and right with inhibitor 200 ppm, the surface attack display different, the right looks thinner than left.

C. General Trend

The graph shows a clear trend where the inhibition efficiency increases with the concentration of mangosteen peel extract up to a certain point (200 ppm), after which the efficiency decreases as the concentration continues to rise.

The graph indicates that the mangosteen peel extract is most effective as a corrosion inhibitor in a 3% NaCl solution at a concentration of around 200 ppm. Increasing the concentration beyond this point does not improve the inhibition efficiency and actually results in a gradual decrease. This suggests that there may be an optimal concentration for the extract's effectiveness, and higher concentrations could lead to diminishing returns or potential negative interactions affecting its performance.

5. CONCLUSION

The graph indicates that the inhibitor is most effective at around 200 ppm for reducing weight loss in a 3% NaCl solution. Increasing the concentration beyond this point does not significantly enhance the inhibitor's effectiveness and might even be counterproductive.

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