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Effect of Tannin-based Natural Corrosion Inhibitors from Biomass Wastes on Carbon Steel: A Review

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Abstract-- Corrosion of carbon steel frames is a major concern in the automotive industry, especially for motorcycles that are often exposed to harsh environments. As an eco friendly alternative to synthetic chemical-based corrosion inhibitors, This paper reviews the evaluation of the effectiveness of corn husk extract as a natural, tannin-based inhibitor. Corn husks were selected due to their abundant availability as agricultural waste and their active compounds with potential anti-corrosion properties. The extract was obtained using maceration, reflux, and ultrasonic methods, and tested in corrosive solutions of NaCl, HCl, and H_2SO_4. The inhibitor's effectiveness was assessed using weight loss measurements and surface morphology analysis. Results showed that corn husk extract reached up to 100% inhibition efficiency at a 600 ppm concentration, particularly in NaCl solution. The tannins and phenolic compounds in the extract played a crucial role in forming a protective layer on the carbon steel surface. These findings highlight the strong potential of corn husks as a green base material for corrosion inhibitors, while also promoting the use of biomass waste in developing sustainable corrosion protection technologies for the automotive industry.

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1. INTRODUCTION

Corrosion is a material degradation phenomenon that occurs due to chemical reactions between metals and their surrounding environment [1][2][3][37][39]. In the automotive industry, corrosion is a serious challenge, especially in motorcycle components that are often exposed to extreme conditions such as high humidity, rainwater, and pollutants [38]. Corrosion not only causes a decrease in the aesthetics of the vehicle, but also contributes to a decrease in the performance and service life of the components, thus increasing maintenance and replacement costs [4].

One of the most important things on a motorcycle is the frame. The motorcycle frame is a structure that supports almost all motorcycle components, such as the engine, front and rear suspension, fuel tank, and other components [5][6]. The growth of vehicle sales and production has decreased since 2020, this is due to the corrosion of automotive steel plates in the form of low carbon steel stored in warehouses [7]. There is a problem related to the use of frames on motorcycles that have production defects. Frames that have been introduced as design innovations in the motorcycle industry. However, in some cases, damage to the frame occurs, which can cause accidents and losses to consumers [8][40].

Various methods have been developed to reduce the impact of corrosion, including the use of protective coatings, corrosion-resistant materials, and chemical inhibitors [9][10][50][51]. Corrosion inhibitors serve to slow down or stop the corrosion reaction by forming a protective layer on the metal surface. However, many conventional inhibitors based on synthetic chemicals have a negative impact on the environment and human health [11][43][44]. Therefore, research into eco friendly corrosion inhibitors is growing as a safer and more sustainable alternative. A comprehensive review revealed that plant-based corrosion inhibitors, including corn husk extract, are increasingly in demand due to their affordable, biodegradable, and safe-to-use properties. However, challenges such as limited solubility and performance variability still need to be addressed through modifications and advanced formulations [12][13][14][42]. In addition, recent studies have shown that bioactive compounds from biomass waste, such as 5- hydroxymethylfurfural (5-HMF), can be used as a base material for the synthesis of efficient and eco friendly corrosion inhibitors, without involving toxic chemical reagents [15]. One group of natural compounds that show promise as corrosion inhibitors are tannins. Tannins are polyphenolic compounds that are found in many plants, such as bark, leaves, and seeds. These compounds have strong antioxidant properties and are able to form complexes with metal ions, thus inhibiting the corrosion process [16][17][18][19][20][21]. In several studies, tannins have been shown to be effective in reducing the corrosion rate of various types of metals, including carbon steel which is commonly used in motorcycle components [46][47][48][49]. This research aims to review various studies that have been conducted related to corrosion, the effectiveness of eco friendly inhibitors, and the potential use of tannins in corrosion inhibition. By understanding the mechanism of action and advantages of tannins, it is hoped that this research can provide insights for the development of more sustainable corrosion protection technologies.

2. METHODOLOGY

There are several methods used in making this natural inhibitor, starting from the extraction method used, the media used, the materials used, and testing the inhibitor to determine its corrosion efficiency. All methods will be compared which one is better in the process of making natural inhibitors so that it can be a recommendation for further research.

2.1 Corn Husk (Zea Mays Linnaeus)

Corn husk is an agricultural waste that is rich in phenolic compounds such as *flavonoids, saponins, alkaloids, tannins*, and *phenols* [22]. Extraction of active compounds was carried out using the maceration method, and NaCl solution was used as a corrosive medium to simulate the marine environment. Tests carried out include the mass loss method to determine the corrosion rate and surface characterization with Scanning Electron Microscopy - Energy Dispersive X-ray (SEM-EDX) to analyze the morphology and elemental composition on the surface of metal specimens.

2.2 Jackfruit Seeds (Artocarpus Heterophyllus)

Tannins in jackfruit seeds have great potential as corrosion inhibitors due to their ability to form complexes with Fe(III) ions on the metal surface, thereby reducing reactivity and slowing down the oxidation rate [23]. The extract was made through maceration and mixed into 3% HCl solution. Tests were conducted using the weight loss method, followed by SEM for visual observation of the metal surface after treatment.

2.3 Cocoa Fruit Peel (Theobroma Cacao)

Cocoa pods contain polyphenolic compounds such as *catechins, leukoanthocyanidins*, and *anthocyanidins* which include flavonoids and condensed tannins. The combination of these compounds is able to suppress the corrosion process by forming a passive layer over the steel surface [24]. The corrosive medium used was seawater, and observations were made through weight loss measurements, as well as observations of the macro and micro structure of the metal surface.

2.4 Mangosteen Fruit Peel (Garcinia Mangostana)

Indonesia is one of the countries with high mangosteen production. Mangosteen rind contains 16.8% tannins, which makes it a strong candidate as an organic inhibitor [25][26]. After drying and pulverizing, mangosteen peels were extracted through maceration method with NaCl solvent. Corrosion tests were conducted by weight loss method as well as potentiodynamic to understand the dynamics of redox reactions on the metal surface.

2.5 Guava Leaf (Psidium Guajava)

Guava leaves are known to contain tannins between 9-12%. The extraction process is carried out using the reflux method with NaCl solution media, and the effectiveness of inhibition is determined through mass loss testing. The active compounds in these leaves work by forming a protective film that inhibits the rate of metal ion release [27][28].

2.6 Pineapple Peel (Ananas Comosus)

Pineapple peel contains active compounds such as *steroids, saponins, flavonoids, phenols,* and *alkaloids* that contribute to anticorrosion activity [29][30]. Processing was done through maceration using methanol solvent, which is effective in extracting polar and semi-polar compounds. Evaluation was done through weight loss, FTIR (Fourier- transform infrared spectroscopy) for functional group identification, and SEM to see the characteristics of the metal surface.

2.7 Ketapang Leaf (Terminalia Catappa)

Ketapang leaves contain various secondary metabolites such as *flavonoids, saponins, triterpenes, diterpenes, phenolics*, and *tannins* [31]. The extraction process was carried out by the socletation method using a mixed solvent of ethanol: water (3:2), accompanied by ultrasonic processing to accelerate the release of active compounds. The extraction results were then tested through weight loss method and analysis of iron content on the surface with SEM-EDX.

2.8 Mahogany Bark (Swietenia Mahagoni)
Mahogany wood, which is widely used in the furniture industry, has bark containing *tannins* [32]. The bark powder was extracted with 96% ethanol through maceration method. Tests were conducted using the mass loss method, showing effectiveness as a natural inhibitor.

2.9 Acacia Bark (Acacia Mangium)
Waste from the wood processing industry, such as acacia bark powder, has potential as a source of *tannins* [33]. A total of 200 grams of powder was extracted through maceration, then tested using the weight loss method to determine its effectiveness as an inhibitor.

2.10 Soursop Leaf (Annona Muricata)
Soursop leaves are also known to contain high tannins [34]. Extraction was carried out through maceration using seawater as a medium to simulate a corrosive environment. Assessment was done through weight loss method and surface analysis with SEM, which showed positive results towards corrosion rate inhibition.

Table 1. Natural Inhibitors of Tannins

INHIBITOR	METHOD	MEDIA	TEST	REFERENCES
Corn Husk	Maceration	NaCl	Weight Loss - SEM - EDX	[22]
Jackfruit Seed	Maceration	NaCl	Weight Loss - SEM	[23]
Cocoa Fruit	Maceration	Sea Water	Weight Loss - SEM	[24]
Mangosteen	Maceration	NaCl	Weight Loss - Potentiodynamic	[25]
Guava Leaf	Refluks	NaCl	Weight Loss - SEM	[27]
Pineapple	Maceration	NaCl, H2SO4	Weight Loss - SEM - Electrochemistry	[29]
Ketapang Leaf	Ultrasonic	H2SO4	Weight Loss - SEM - EDX	[31]
Mahogany	Maceration	NaCl	Weight Loss - Electrochemistry	[32]
Acacia	Maceration	H2SO4	Weight Loss	[33]
Soursop Leaf	Maceration	Sea Water	Weight Loss	[34]

3. RESULT AND DISCUSSION

The following are the results of all research on the manufacture of natural inhibitors

3.1 Corn Husk (Zea Mays Linnaeus) [22]
In testing the corrosion rate in 3% NaCl corrosive solution with immersion time for ten days, there is a difference between steel samples added and without added corn husk extract inhibitor solution. The inhibitor acts to slow down the reaction that occurs between the steel and the given corrosive medium. At the various concentrations of inhibitor solution given, there was an indication of a reduction in the corrosion rate after adding the inhibitor solution. Inhibition efficiency is expressed as a percentage reduction in the corrosion rate of steel without the use of inhibitors.

Based on the research, it is concluded that the largest corrosion rate at a concentration of 0 ppm (without inhibitor) is 88.08 mpy, while the lowest corrosion rate is at a concentration of 600 ppm which is 0 mpy. The greatest corrosion inhibitor efficiency occurred at a concentration of 600 ppm by 100%.

3.2 Jackfruit Seeds (Artocarpus Heterophyllus) [23]
This test uses the initial mass and final mass. The first step is to weigh the mass of the sample before the immersion process so that the initial mass is known. Putting the sample in the medium of 3% HCl corrosive solution without inhibitor then allowed to stand for 10 days (sample A), 20 days (sample B), and 30 days (sample C), where each sample is in a different beaker.
Putting the samples in the medium that has been added with inhibitors with a concentration of 400 ppm, then allowed to stand for 10 days (sample D), 20 days (sample E), and 30 days (sample F), where each sample is in a different beaker.The inhibitor efficiency of jackfruit seed extract can be categorized as a very efficient inhibitor to inhibit the corrosion rate of high carbon steel. where the inhibition efficiency values obtained at 10, 20, and 30 days of immersion are 72.62%, 85.40%, and 89.47%, respectively.

3.3 Cocoa Fruit Peel (Theobroma Cacao) [24]

The inhibition efficiency tends to increase for each addition of inhibitor concentration. The inhibition efficiency of cocoa fruit peel extract produced varies depending on the inhibitor concentration and corrosive media. It can be seen that the inhibition efficiency in seawater corrosive media can reach 83.37% at an inhibitor concentration of 2000 ppm, this is because in these conditions the Fe-tanine complex compound is formed perfectly and covers the entire steel surface.

3.4 Mangosteen Fruit Peel (Garcinia Mangostana) [25]

The efficiency value of mangosteen peel extract inhibitor against St-37 steel corrosion from each inhibitor concentration. This difference depends on the concentration of inhibitor used. The graph shows that the highest inhibitor efficiency value is 26.05% with an inhibitor concentration of 2%, while the lowest efficiency occurs in the addition of 10% inhibitor with a value of 11.8%. The graph also shows that the concentration of inhibitor solution works effectively up to 8% concentration. At 10% concentration, it is no longer effective to protect the steel surface from corrosion.

3.5 Guava Leaf (Psidium Guajava) [27]

The addition of this inhibitor concentration results in an increased ability to prevent corrosion characterized by a decrease in the corrosion rate. The smallest corrosion rate and the largest IE percent were obtained by adding guava leaf extract inhibitor with an optimum concentration of 130 ppm with a corrosion rate of 0.045 mg/cm2/day with an efficiency of 38.36%.

3.6 Pineapple Peel (Ananas Comosus) [29]

From the analysis of the data obtained, the inhibition efficiency value on day 10 in H2SO4 solution was 57.71% and in NaCl solution was 66.25%. This is due to the time that greatly affects the immersion of steel so that the longer the time, the better the pineapple peel extract to inhibit corrosion in steel.

The results showed that the corrosion rate of steel in H2SO4 corrosion medium was greater than that of NaCl in immersion for 10 days, namely 0.37 mg/cm2h. For the inhibition efficiency value, namely the value that shows the ability of pineapple peel extract to inhibit steel corrosion, which is 57.71% in H2SO4 0.75 M and 66.25% in NaCl 1 M.

3.7 Ketapang Leaf (Terminalia Catappa) [31]

The utilization of tannins as a *coating* material is expected to be a safer alternative for the environment. Tannins were obtained using ultrasonic extraction method with 95% ethanol solvent and the resulting tannin yield was 4.85%. The synthesis of bio-inhibitors from *waterglass* and tannins extracted from ketapang leaves can be used as an alternative material for corrosion inhibitors on *pipelines*. Making the *coating* material by combining silica from *waterglass* and tannin from ketapang leaves, then flowing the corrosion medium on the iron pipe. The composition of silica with tannin from ketapang.

Leaves used was 50:50 with a concentration of 50% *waterglass*. The results of this study show the effect of tannin and *waterglass coating* formula on the *coating* material causes a smaller corrosion rate, which is 171.77 mmpy.

3.8 Mahogany Bark (Swietenia Mahagoni) [32]

It can be seen that the effectiveness of tannin inhibitor from mahogany bark tends to increase with the length of immersion. This happens because the longer the immersion time, the more layers will be formed so that the protection on the iron surface will increase.

The highest efficiency was achieved at an inhibitor concentration of 250 ppm with an immersion time of 1680 hours. The highest inhibitor efficiency value was recorded at a concentration of 250 ppm, reaching 39.45%.

3.9 Acacia Bark (Acacia Mangium) [33]

Acacia bark extract from methanol:water (80:20) solvent contains tannins. Tannins present in acacia bark extract can act as inhibitors where the corrosion rate of HQ 760 steel in sulfuric acid with the addition of tannins is smaller than the corrosion rate of HQ 760 steel in sulfuric acid without tannins. The corrosion rates of softened steel with and without acacia bark extract in 0.5 M sulfuric acid medium for 3 days were 0.0089 and 1.013503 mg/m2.h, respectively.

3.10 Soursop Leaf (Annona Muricata) [34]

The highest corrosion rate that occurred on the metal was the 0% variation (without inhibitor) at the 24-hour test which amounted to 0.8435 mmpy, while the lowest corrosion rate was experienced by specimens with the addition of 20% inhibitor at the 216-hour immersion time which amounted to 0.2778 mmpy.

Efficiency data that occurs in specimens in seawater media. The table shows that the highest efficiency was obtained from the addition of 20% inhibitor in 216 hours, which amounted to 52.1% and the lowest efficiency occurred in the addition of 10% inhibitor at 72 hours test time, which amounted to 9.6%.

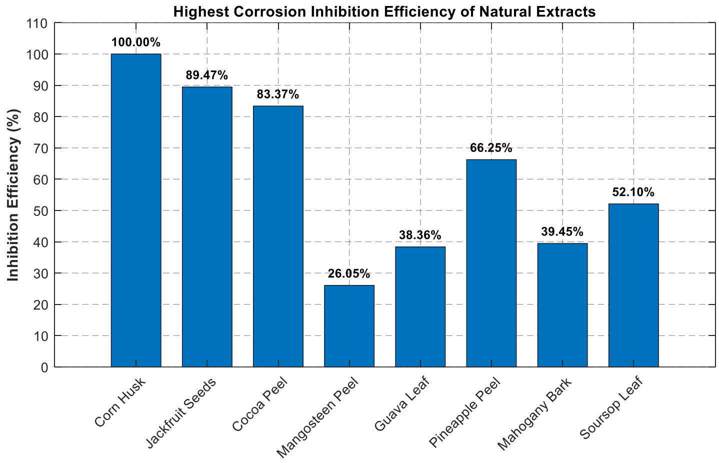

Figure 1. Efficiency of Natural Inhibitors references : [22][23][24][25][27][29][32][34]

Various studies have demonstrated the high effectiveness of tannin extract from corn husks as a corrosion inhibitor for carbon steel, achieving an inhibition rate of up to 100% at a concentration of 600 ppm in a NaCl medium [22]. However, the real-world application of this finding in the automotive context particularly for protecting motorcycle frames remains very limited. Previous studies have typically been conducted in laboratory settings using flat steel plates in static corrosive media [36], which do not accurately represent the actual conditions faced by motorcycle frames in the field. These frames are not only exposed to corrosive environments like seawater or high humidity, but also experience mechanical stress such as vibration, impact, high temperatures due to engine heat, and contact with lubricants and complex airborne pollutants [38][45]. These factors can affect the stability of the protective layer formed by natural inhibitors. Therefore, the effectiveness of corn husk extract under such dynamic conditions still needs to be thoroughly tested.

Moreover, despite the corn husk extract showing great potential as a highly effective inhibitor [35], no research has yet developed a commercially viable, stable formulation compatible with automotive coating systems, including the paints and primers commonly used on motorcycle frames. This remains a barrier to the direct application of this technology in the automotive industry. In addition, the economic aspects and production scalability of corn husk extract as a corrosion inhibitor have yet to be evaluated though these are crucial factors for the sustainable use of biomass-based inhibitors in automotive manufacturing. Hence, further research that tests the corn husk extract under simulated motorcycle operational conditions, develops an industrial ready inhibitor formulation, and conducts economic and environmental analysis is essential to bridge the gap between lab results and real world applications. By addressing this gap, corn husk extract could become not only an eco friendly and technically effective solution, but also a practical and economically feasible option for corrosion protection of motorcycle frames in the future.

4. CONCLUSION

Based on the analysis of various reviewed studies, it can be concluded that the effectiveness of natural corrosion inhibitors on carbon steel is influenced by several key factors, namely the type of extract, solution concentration, type of corrosive medium, and immersion duration. Among the natural materials tested, corn husk extract demonstrated the most outstanding performance as a corrosion inhibitor. At a concentration of 600 ppm in a 3% NaCl solution, corn husk extract achieved an inhibition efficiency of 100%, effectively halting the corrosion process entirely [22]. This indicates a strong chemical interaction between active compounds in the corn husk such as tannins and polyphenols and the metal surface, resulting in the formation of a protective layer against corrosion.

Meanwhile, other extracts such as jackfruit seeds, cocoa peel also showed positive contributions in reducing the corrosion rate but did not match the protective capability exhibited by corn husk. This difference underscores the importance of the unique chemical characteristics of each plant material in determining its effectiveness as an inhibitor. Therefore, corn husk extract can be considered the most promising candidate for the development of eco friendly, cost-effective, and sustainable natural corrosion inhibitors [35][36][41]. These findings also open up broader opportunities for utilizing biomass waste to support metal protection technologies, particularly in the automotive industries reliant on carbon steel.

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