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The Effectiveness of a Combination of Lime (*Citrus aurantifolia*.), Lerak (*Sapindus rarak*) and Jasmine Flower (*Jasminum nudiflorum*) Extracts as and Environmentally Friendly Corrosion Inhibitor

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Abstract: Corrosion can also be defined as the forced destruction of metal by the surrounding medium which is usually a liquid (corrosive agent). Corrosion prevention processes can be carried out, including by coating the metal surface, cathodic protection, adding corrosion inhibitors and so on. Several types of inhibitors that have been widely used in industrial applications are synthetic chemical inhibitors. However, the compounds of inhibitors are environmentally unfriendly, toxic and expensive. To overcome this problem, it is necessary to develop an environmentally friendly alternative corrosion inhibitor or better known as a green inhibitor. This research aims to test the effectiveness of using a combination of lime (*Citrus aurantifolia*.), Lerak (*Sapindus rarak*) and jasmine flower (*Jasminum nudiflorum*) extracts as an environmentally friendly corrosion inhibitor. The results obtained were inhibitors in the form of a combination which were added to the corrosive medium HCl which could reduce the rate of aluminum corrosion. This research also shows that time and concentration influence the corrosion rate. A higher concentration (200 ppm) has a greater inhibitory power than a concentration of 100 ppm. The best inhibitory power is found in 200 ppm inhibitor with a soaking time of 20 minutes.

Keywords: Corrosion; Inhibitor; Jasmine flower; Lerak; Lime

Introduction

Corrosion is an event of damage or reduction in the quality of a metal material caused by a reaction with the environment. Corrosion can also be defined as the forced destruction of metal by the surrounding medium which is usually a liquid (corrosive agent). Corrosion usually begins on the surface of the metal and damage, or degradation of the metal can then spread to the interior of the material. Organisms can also contribute to the corrosion of building materials, apart from that, corrosion can also be interpreted as a decrease in the quality of metal caused by electrochemical reactions between the metal and the surrounding environment (Irmaya et al., 2020; Najem et al., 2022). Factors that influence the rate of corrosion include inhibitor concentration, temperature, and exposure time. The greater the inhibitor concentration value given, the corrosion rate value will decrease, and the inhibition efficiency value will be higher. The inhibitor's ability to inhibit is measured by its efficiency. The efficiency value depends on the inhibitor concentration used. This happens because the inhibitor acts as a barrier to the rate of corrosion.

Corrosion prevention processes can be carried out, including by coating the metal surface, cathodic protection, adding corrosion inhibitors and so on. A corrosion inhibitor itself is defined as a substance which, when added in small amounts to the environment, will reduce the environmental corrosion attack on metal.

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Generally, corrosion inhibitors come from organic and inorganic compounds that contain groups that have lone pairs of electrons, such as nitrite, chromate, phosphate, urea, phenylalanine, imidazoline, and amine compounds. So far, several types of inhibitors that have been widely used in industrial applications are synthetic chemical inhibitors. These inhibitors are generally made from compounds containing silicates, phosphates, borates, dichromats, molybdates, chromates, tungstate and arsenates (Gangopadhyay et al., 2018; Izadi et al., 2018; Kadhim et al., 2021). However, these compounds are environmentally unfriendly, toxic and expensive. To overcome this problem, the development of an environmentally friendly alternative corrosion inhibitor or better known as a green inhibitor has been widely carried out. Basically, green inhibitors contain the elements P, S, N, O, and elements that have lone electron pairs (Akbar, 2019; Mahidashti et al., 2018; Zunita et al., 2024).

Among various types of inhibitors, polyphenols have emerged as promising candidates due to their favorable characteristics, including cheap, biodegradable, renewable, and most importantly, safe for the environment and humans. Its performance as a sustained corrosion inhibitor has prompted numerous electrochemical experiments as well as theoretical, mechanistic, and computational studies, with many papers reporting inhibition efficiencies of over 85%. Polyphenols have very promising potential for use as environmentally friendly and powerful corrosion inhibitors; therefore, further investigations, both experimental and computational, are still needed to realize higher inhibition efficiency up to 100% (Gabsi et al., 2023).

Research on green inhibitors using gelatin on steel in an HCl solution has been reported (Farag et al., 2020). Research through the manufacture of N-isonicotinamido-3- methoxy-4-hydroxybenzalaldimine (IM) based on vanillin and isoniazid, can resist corrosion with inhibitor efficiency reaching 93% at 120 mg/L (Haruna et al., 2018). Then, the use of black pepper as a corrosion inhibitor for metal has also been carried out. Black pepper extract contains nitrogen elements from the alkaloid group (Hu et al., 2018). Other research shows that water extract of henna leaves (*Lawsonia inermis*) has been used as an inhibitor in controlling corrosion of mild steel in well water (Devi et al., 2020).

Lavender essential oil can also be used as a natural corrosion inhibitor for EN AW-2011 aluminum alloy in 1M H2 SO4 and 1M HCl. A gravimetric and electrochemical study was carried out to determine the inhibitory effect of Lavender oil. The gravimetric test results show that the optimum inhibitory effect of Lavender oil on 1M H2 SO4 is 85.3%, while on 1M HCl it is only 47.8%. As the concentration of Lavender oil increases, its inhibitory effect on both acids increases. Lavender essential oil is a better natural corrosion inhibitor for the EN AW-2011 alloy in 1M H2 SO4 than when the alloy is soaked in 1M HCl (Kamarska, 2019). Therefore, the use of inhibitors that are safe, easy to obtain, biodegradable, low cost and environmentally friendly is very necessary (Chauhan et al., 2023; Grassino, 2021).

A corrosion inhibitor is defined as a substance which, when added to the environment, will reduce the environmental corrosion attack on metal. The development of environmentally friendly corrosion inhibitors is a topic that is widely studied by researchers from within and outside the country. Studies have shown that extracts from various plants and fruits are believed to be able to act as corrosion inhibitors because they contain long chain organic molecules which are able to settle on metal surfaces, thereby inhibiting the metal's interaction with its environment (Kadhim et al., 2021). Research has been carried out previously, namely examining the use of natural extracts as corrosion inhibitors.

The research results of Gonzales et al. (2023) showed that the corrosion inhibition of a liquid extract based on Citrus is environmentally friendly. Swastika et al. (2017) also stated that tannin is one of the substances found in lime peel which can function as an environmentally friendly corrosion inhibitor. Research by Nurrosyidah et al. (2023) stated that lerak (*Sapindus rarak*) meets the physical quality requirements according to SNI, namely pH in the range of 8-11 and foam stability in the range of 13-200 mm. The detergent from lerak also has a distinctive aroma and homogeneous color and is able to clean oil stains and plant sap. Previous research also stated that lerak solution is an effective cleaning agent for silver metal, where the level of cleanliness and brilliance of the metal increases with the length of soaking time. Like silver metal, bronze metal can also be cleaned with a leach solution with a soaking time of 24 hours. Meanwhile, the use of lerak solution for ferrous metals is less effective if soaked for 24 hours (Fatmawati, 2014).

Research by Deng et al. (2012) used jasmine leaf extract (*Jasminum nudiflorum Lindl*) to inhibit the rate of aluminum corrosion in a 1 M HCl solution. The inhibition efficiency increased as the inhibitor concentration increased, namely 90% with an immersion time of 2 hours. Jasmine flowers contain tannin which has acidic properties because there are phenol groups in it. Tannin has a tart taste. Apart from that, tannin also functions as a substance used to inhibit corrosion rates (Sanjaya et al., 2018). So far there has been no research regarding the use of a combination extract of lime (*Citrus aurantifolia*.), Lerak (*Sapindus rarak*) and jasmine flower (*Jasminum nudiflorum*) as an environmentally friendly corrosion inhibitor. Therefore, in this case the researchers want to conduct a study on this combination extract as a potential green inhibitor.

Method

The method used in this research consists of several stages.

Making Lime, Lerak and Jasmine Flower Extracts

Making extracts as inhibitors was carried out using maceration and evaporation methods. The material to be used to make the extract is dried for 3 days then crushed using a chopper. The material was then weighed 100 grams using an analytical digital scale. The ingredients are soaked for 5 days using 96% alcohol in a ratio of 100 grams each in 1000 ml of alcohol. The soaking results are filtered using filter paper and evaporated for distillation at a temperature of around 70 °C to separate the extract from the solvent.

The results in the form of lime (*Citrus aurantifolia*.), lerak (*Sapindus rarak*) and jasmine (*Jasminum nudiflorum*) flower extracts were obtained and treated according to the experimental design, namely a combination extract of 3 ingredients with concentrations of 100 ppm and 200 ppm.

Corrosion Testing

This research used a corrosive medium in the form of a 1 M HCl solution. The test object used was aluminum with a thickness of 0.01 cm which was cut to a size of 5 cm long and 2 cm wide. The test object is first cleaned of dirt and dust attached to it and then weighed as the initial weight. Each test object was soaked in 1 M HCl solution without inhibitors and with inhibitors with varying substance concentrations and soaking times (Table 1). After soaking for the specified time, the specimens were removed, washed under a stream of water and acetone to remove corrosion products, then dried using a stream of hot air. Once completed, the final mass weighing is carried out.

Table 1. Corrosion Test Immersion Treatment

Time Variation Treatment (minutes)	Time Variation Treatment (minutes)
HCl 1M without inhibitor	10′, 20′, 30′, 40′
HCl 1M with 100 ppm combination extract inhibitor	10′, 20′, 30′, 40′
HCl 1M with combination extract inhibitor 200 ppm	10′, 20′, 30′, 40′

Measurement of Corrosion Rate and Inhibition Power

The quantities measured and analyzed in this research are the corrosion rate and inhibitory power (efficiency) of the inhibitor with the following formula:

The corrosion rate

$$L = (m1-m2)/(l \times t) \tag{1}$$

L = the corrosion rate (mg/cm^2 hour)
m1 = initial aluminum mass (mg)
m2 = final aluminum mass (mg)
l = aluminum area (cm^2)
t = soaking time (hour)

Inhibitory Power (efficiency)

$$E = (Ro-Ri)/Ro \times 100\% \tag{2}$$

E = efficiency of adding inhibitor substances (%)
Ro = mass of aluminum after immersion with addition of inhibitors (mg)
Ri = mass of aluminum after immersion without inhibitor added (mg)

Result and Discussion

Effect of Immersion Time on Corrosion Rate

The effect of immersion time on corrosion rates can vary depending on the type of metal or material involved, the type of corrosive environment, and other conditions. In general, the corrosion rate tends to increase with increasing immersion time in a corrosive environment. Immersion time can be quite an important factor in determining the corrosion rate of a material. The longer a material is exposed to an environment that causes corrosion, the more likely corrosion is to occur. This is because time will provide more opportunities for chemical reactions between the material and the corrosive agent to occur.

The effect of immersion time on the corrosion rate can be seen by observing immersion using 1M HCl without inhibitors. The results obtained from these observations can be seen in Table 2. The chemical reaction between the material and the corrosive agent can vary depending on the type of material and the chemical properties of the corrosive agent.

Table 2. Immersion Test Results for Aluminum Metal in HCl Solution without Inhibitors

Time (minutes)	Mass initial (mg)	Mass Final (mg)	Mass corroded (mg)	Corrosion Rate (mg/cm^2 hour)
10	150.88	140.83	10.05	3.01
20	155.43	134.43	21	3.15
30	155.53	123.46	32.07	3.21
40	153.55	110.34	43.21	3.24

The corrosion rate without the addition of inhibitors shows that the longer the aluminum is exposed to the HCl solution, the higher the corrosion rate. Chemical reactions that cause corrosion in aluminum will tend to form an oxide layer which protects itself from corrosion. Increasing the soaking time in the 1M HCl solution will cause the aluminum to become more abrasive and dissolve into 2 $AlCl_3$ (aq) and 3 H_2 (g) (Graedel, 1989). The hydrogen gas produced during the reaction can be seen from the bubbles produced during immersion. The reaction is as follows:

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

Environmental conditions, such as humidity, temperature, and the presence of other materials, can influence the chemical reaction of corrosion. Over time, interactions between materials and corrosive agents will result in physical and chemical changes that can damage the material.

Effect of Inhibitor Concentration on Corrosion Rate

Corrosion inhibitors are chemical compounds added to corrosive environments to reduce or prevent corrosion of metals. The effect of the inhibitor concentration can be seen in Figure 1. The higher the inhibitor concentration, the more the mass of aluminum corroded decreases, so the corrosion rate also decreases. The corrosion rate using a combination extract inhibitor with a concentration of 100 ppm can be seen in Table 3, while the corrosion rate using a combination extract inhibitor with a concentration of 200 ppm can be seen in Table 3.

Table 3. Results of the Immersion Test for Aluminum Metal in HCl Solution with a Combination Extract Inhibitor of 200 ppm

Time (minutes)	Mass initial (mg)	Mass Final (mg)	Mass corroded (mg)	Corrosion Rate (mg/cm² hour)
10	154.55	153.32	1.23	0.738
20	155.21	152.71	2.5	0.75
30	155.44	148.12	7.32	1.464
40	155.11	138.33	16.78	2.517

Increasing the inhibitor concentration can increase its effectiveness in protecting metals from corrosion. This is because inhibitors work by interacting with metal surfaces and forming a protective layer that inhibits corrosion reactions. Based on the data, it can be seen that soaking aluminum without using inhibitors will cause the corrosion process to occur more quickly. The longer the soaking time, the more corrosion will occur as evidenced by the decreasing final mass of aluminum. Inhibitors will reduce the rate of corrosion. Indicators with higher ppm produce lower corrosion power. There are limits to increased concentration. Too high or low inhibitor concentration and soaking time can reduce efficiency. In this study, the best inhibitory power (indicated by a low corrosion rate) was found in HCl immersion with an inhibitor in the form of a combined extract with a concentration of 200 ppm at a soaking time of 20 minutes (Figure 1).

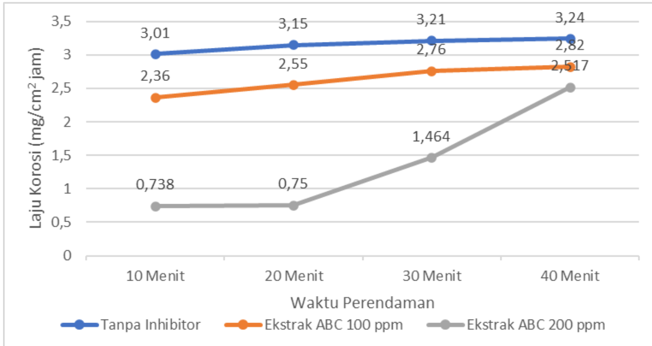

Figure 1. Comparison of corrosion rates using 1M HCl without inhibitor, HCl with inhibitor concentration of 100 ppm and HCl with inhibitor concentration of 200 ppm

Inhibitory Power (efficiency)

Analysis of inhibitory power (efficiency) showed that the longer the soaking time, the greater the inhibitory power (Figure 2).

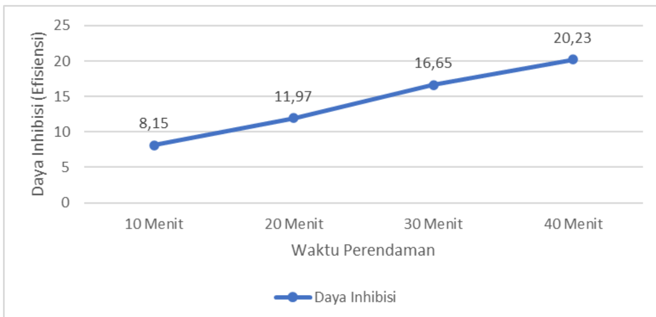

Figure 2. Inhibitory power (Efficiency) of combination extract of lime *(Citrus Aurantifolia.)*, lerak *(Sapindus Rarak)* and jasmine flower *(Jasminum Nudiflorum)* concentration 200 ppm

The increase in inhibitory power with immersion time may indicate that the inhibitor takes longer to spread and adhere to the metal surface effectively. This could be caused by the adsorption process of the inhibitor onto the metal surface which requires a certain time. Inhibitors will form an effective protective layer on metal surfaces over time. This coating can isolate the metal from the corrosive environment, reducing the corrosion rate. The reaction between inhibitor and metal can reach an optimal balance after a certain time. In some cases, the inhibitory effect may become more stable and efficient after some time. Changes in environmental conditions over time, such as changes in pH or temperature, can also affect inhibitory power. This can occur with results that are not always linear because many factors can influence the interaction between the inhibitor and the metal. Therefore, further experiments and testing are needed to understand more deeply the mechanisms and factors that contribute to the increase in inhibitory power over time.

Conclusion

The conclusion of the research that has been carried out is that an inhibitor in the form of a combination extract of lime (*Citrus aurantifolia*.), lerak (*Sapindus rarak*) and jasmine flower (*Jasminum nudiflorum*) added to the corrosive medium HCl can reduce the rate of aluminum corrosion. A higher concentration (200 ppm) has a greater inhibitory power than a concentration of 100 ppm. The best inhibitory power is found in 200 ppm inhibitor with a soaking time of 20 minutes.

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This research team contributed to the writing of this scientific work, namely: ideas, conception, data collection, analysis and interpretation of results, manuscript preparation, article writing, revision process and funding of this research

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Conflicts of Interest
The authors declare no conflict of interest.

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