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Performance of Salak *(Salacca zalacca)* Seed Extract to GreenCorrosion Inhibitor on AISI 1040 Steel

Muhammad Rifani[1,a], Daffa Irsyad D.[2,b], Ade Wahyu Yusariarta[3,c], Jatmoko Awali[4,d], Fredy Kurniawan[5,e], Masato Tominaga[6,f], Yusairie Mohd[7,g], YunitaTriana[8,h*]

[1,2,3,4,8]Department of Material and Metallurgical Engineering, Institut Teknologi Kalimantan, Balikpapan 76127, Indonesia

[5]Department of Chemistry, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia

[6]Department of Chemistry and Applied Chemistry, Graduate School of Science and Engineering, Saga University, 840-8502

[7]Faculty of Applied Science, Universiti Teknologi MARA, Shah Alam, Selangor 40450, Malaysia

[a]06191042@student.itk.ac.id, [b]06191017@student.itk.ac.id, [c]adewahyu27@lecturer.itk.ac.id, [d]jatmoko.awali@lecturer.itk.ac.id, [e]fredy@chem.its.ac.id, [f]masato@cc.saga-u.ac.jp, [g]yusairie@uitm.edu.my, [h]nita@lecturer.itk.ac.id

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Abstract. This study aimed to determine the effect of concentration and immersion time of Salak *(Salacca zalacca)* Seed extract as a green inhibitor on the corrosion inhibition efficiency and corrosion rate of AISI 1040steel in a 1M HCl environment. The chemical composition of AISI 1040 steel was confirmed using OES testingto verify its compliance with AISI 1040 chemical standards. The antioxidant activity of the salak *(Salacca zalacca)* seed extract was determined through the 1,1-Diphenyl-2-Picrylhydrazyl (DPPH) test yielding an IC50 value of 192.55 ppm, indicating weak antioxidant activity. Qualitative phytochemical analysis confirmed the presence of flavonoids and tannins in the extract, as verified by Fourier Transform Infrared (FTIR) testing. The study explored concentration variations ranging from 100 to 500 ppm and immersion time variations of 10 to 30 days were used. The highest inhibition efficiency was obtained at 500 ppm concentration, whilethe lowest was at 100 ppm, with values of 40.26% and 18.90% respectively. Additionally, the corrosion rate was reduced to 0.035 mm/year at the highest concentration of 500 ppm. These findings demonstrated the potential of salak *(Salacca zalacca)* seed extract as an eco-friendly, effective corrosion inhibitor for AISI 1040 steel.

Introduction

Corrosion in a chloride-containing acidic environment is a major issue for steel structures, leading to degradation and material failures [1], [2]. This problem is particularly critical for industries utilizing steel in environments exposed to hydrochloric acid (HCl)[3]. Traditional methods, such as cathodic protection [4], coating [5], and corrosion inhibitors [6], are widely employed to mitigate corrosion. However, many conventional inhibitors, especially inorganic compounds, are toxic, costly, and harmful to the environment [7–10]. This has spurred interest in the development of green corrosion inhibitors, which are non-toxic, readily available, and eco-friendly.

Nowadays, organic corrosion inhibitors are intensively used as steel corrosion inhibitor in different aggresive media such as acidic environment [11–15]. Chemically, natural organic inhibitors contain S, N, O, P, and ring structures of heterocyclic compounds [16]. Green inhibitors can be sourced from plants or seeds, which usually contain tannins, organic acids or amino acids, and alkaloids, all of which are known for their ability to inhibit corrosion [17],[18]. Several studies have been conducted using plant extracts as natural product-based corrosion inhibitors. These plant extracts are usually obtained from various parts of the plant parts such as leaves [19], seeds [20], fruit shell [21], stems [22], root bark [23], fruit [24], and flowers [25].

Salak *(Salacca zalacca)* is a plant native to Indonesia with a high nutritional content [26]. However, not all parts of this plant are utilized properly [27]. Solid waste from salak *(Salacca zalacca)* seeds hasnot been processed much and only becomes organic waste. Even though salak *(Salacca zalacca)* seeds contain flavonoids and tannins. These compounds have been widely studied and can be used as materials to inhibit the process of corrosion [28], [29]. Salak *(Salacca zalacca)* seed as a corrosion inhibitor has been shown to be effective in inhibiting the release of Ni ions in stainless steel orthodentic wires [30].
In this study, salak *(Salacca zalacca)* seeds extracted will then be applied to the surface of AISI 1040 steel in 1M HCl environment. The composition of AISI 1040 steel is confirmed using OES testing toprove the conformity of the composition to the AISI 1040 chemical standard. The test used 1,1- Diphenyl-2-Picrylhydrazyl (DPPH) to determine the antioxidant activity of salak *(Salacca zalacca)* seed extract. The content of secondary metabolites in the extract will be confirmed by using Fourier Transform Infra Red (FTIR) technique. Various concentrations were used from 100 to 500 ppm and variations in immersion time from 10 to 30 days. These variations were carried out to determine the optimum concentration and the effect of soaking time of salak *(Salacca zalacca)* seed extract on the corrosion rate. Then the observation of the corrosion rate per year is studied through the weight loss method and polarization measurement. Additionaly, microstructural analysis was conducted using Scanning Electron Microscope(SEM) to examine the surface morphology and assess the extent of corrosion damage.

ExperimentalMaterials

The metal specimen used in this study was AISI 1040 steel. The size of AISI 1040 steel was used to investigate the corrosion protection efficiency of the extract in 1 M HCl is a rectangular steel piece measuring 2 cm x 2 cm x 0.3 cm. The chemical composition testing using Optical Emission Spectroscopy (OES) was conducted to verify the compatibility of the sample composition with the AISI 1040 chemical standard.

Inhibitors

The salak *(Salacca zalacca)* seeds, collected from the KM. 21 Karang Joang, North Balikpapan, Balikpapan City, were first cleaned to remove any dirt and then sun-dried for 7 days. After that, the seeds were ground into a fine powder before being soaked in 2000 mL of 96% ethanol for three consecutive days (3×24 hours). Then, the ethanol extract was separated from the solid residue through filtration and then evaporated at 45–50°C for five hours to obtain the concentrated extract. The resulting solid extract was weighed and homogenized with 1M HCl to prepare inhibitor solutions of 100, 200, 300, and 500 ppm.

Antioxidant Activity Analysis

The DPPH (2,2-diphenyl-1-picrylhydrazyl) test was chosen for its simplicity and accuracy in measuring free radical scavenging activity, which is a key indicator of antioxidant potential. This method is widely recognized for providing reliable quantitative data on the antioxidant activity of natural extracts, making it an ideal choice over other methods like ABTS or FRAP in this study. The results were expressed as the IC50 value, representing the concentration required to inhibit 50% of free radicals, with an IC50 value of 192.55 ppm indicating weak antioxidant activity. Phytochemical testing was carried out to identify the secondary metabolites found in the extract of salak *(Salacca zalacca)* seeds. The ingredients tested are flavonoids, tannin, alkaloid, and saponin. On the other hand, 2,2-diphenyl-1-picrylhydrazyl (DPPH) is a testing method to determine the antioxidant activity in salak *(Salacca zalacca)* seed extract.

Characterization

Characterization testing was carried out to determine the content of functional groups contained in salak *(Salacca zalacca)* seeds extract using Fourier Transform Infra-Red (FTIR). FTIR testing was conducted at the Material Characterization Laboratory, Integrated Laboratory of Kalimantan

Institute of Technology.The FTIR test was performed using an FTIR spectrophotometer (Shimadzu) with the KBr pellet method. SEM-EDX test was also conducted to see the damage on the surface of the specimen. The macrostructural changes of the AISI 1040 steel surface after the weight loss corrosion test were compared with and without the addition of an inhibitor, considering various variations of immersiontime and concentration.

Weight Loss Method

This test was conducted to determine the weight loss in the sample when immersed in a corrosive medium (1M HCl), as shown in Figure 1. Various inhibitor concentrations (0 ppm, 100 ppm, 200 ppm, 300 ppm, 400 ppm, and 500 ppm) and immersion times (10 days, 20 days, and 30 days) were selected based on existing literature and preliminary studies, which indicate that these concentration ranges are optimal for observing the inhibition efficiency of plant-based extracts in acidic environments [31,32]. The concentration range was designed to capture both low and high inhibitor efficiencies, while the immersion times allowed for the assessment of both short-term and long-term performance of the extract [33]. Corrosion testing with the weight loss method was repeated three times to ensure the accuracy and reproducibility of the results.

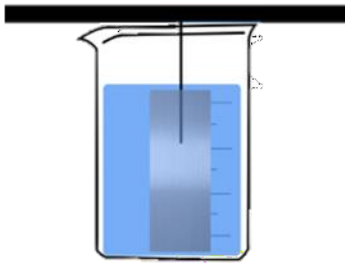


Fig. 1. Illustration of Weight Loss Method

Electrochemical Experimental

To determine the corrosion rate per year on the specimen used with open circuit potential (OCP) test. OCP testing was carried out using a potentiostat/galvanostat (Figure 2) and tafel curve analysis using the software Origin 2020. In the potentiodynamic polarization method, there are three electrodes, namely the Ag/AgCl reference electrode, platinum auxiliary electrode, and AISI 1040 steel working electrode. Corrosion rate calculation from Icorr in the polarization curve is calculated by:

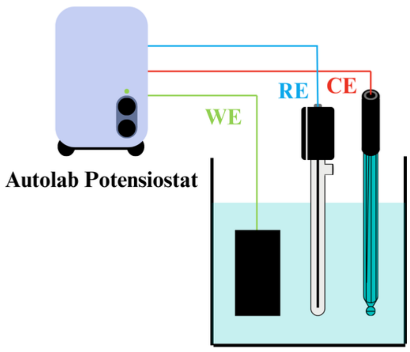


Fig. 2. Electrochemical cell circuit

Result and Discussion

Analysis of Organic Inhibitor Compounds of Salak *(Salacca zalacca)* Seed Extract Determination of Antioxidant Properties of Salak *(Salacca zalacca)* Seed Extract

The results of the linear regression equation from the plot of the percentage of antioxidant activity of salak *(Salacca zalacca)* seed extract is y = 0.2645x – 0.9303 with R2 = 0.9822. After the value of 50is substituted for the y value, x will be obtained as the IC50 value. The IC50 value obtained was af 192.55 ppm (Table 1). From the IC50 value, the salak *(Salacca zalacca)* extract exhibited weak antioxidant activity (IC50 = 192.55 ppm) because the IC50 value is in the range of 150 ppm – 200 ppm. The weak antioxidant activity (IC50 = 192.55 ppm) indicates that the extract's ability to neutralize free radicals is limited, suggesting that its corrosion inhibition performance primarily relies on the adsorption of compounds like flavonoids and tannins onto the metal surface, rather than oxidative protection. Despite weak antioxidant capacity, these compounds can still form a protective barrier, reducing metal exposure to corrosive agents. This mechanism has been similarly observed in other plant-based inhibitors, where surface adsorption plays a more significant role than antioxidant effects in corrosion inhibition [20, 34].

Table 1. Results of Measurement of Antioxidant Activity of Salak *(Salacca zalacca)* Seed Extract using the DPPH Method

Concentration	% Antioxidant Activity	IC50 (ppm)
12,5	0,8759	192,55
25	7,8832	
50	11,825	
100	29,343	

These results differ from previous research conducted by [29] which showed that the 70% ethanol extract of salak *(Salacca zalacca)* seeds has an antioxidant activity of 229.27 ppm. Then in the research conducted by [41], it was shown that the ethanol extract of salak *(Salacca zalacca)* seeds has an antioxidant activity of 293.8 ppm. The difference in the value of the antioxidant activity obtained can be influenced by various reasons including the type of solvent, differences in drying methods andvarieties so that it has a real effect on the content of the extract and antioxidant activity [37], [38].

Qualitative Analysis of Secondary Metabolites of Salak *(Salacca zalacca)* Seed Extract

Condensed extract of Salak *(Salacca zalacca)* seeds was tested for the content of secondary metabolites using a color reaction. The results indicated that the salak *(Salacca zalacca)* seed extract contains flavonoids and tannins. As seen on Table 2, for alkaloids and saponins, the results were negative, meaning that these compounds were not detected. The absence of alkaloids and saponins may reduce the overall inhibition efficiency, as alkaloids are known for their ability to donate electrons, enhancing adsorption onto metal surfaces, while saponins can form protective films. However, the presence of flavonoids and tannins, both rich in functional groups like hydroxyl and carbonyl, remains sufficient to provide effective corrosion inhibition through strong adsorption and the formation of a barrier layer on the steel surface [34, 35].

Table 2. Results of Phytochemical Tests on Salak *(Salacca zalacca)* Seed Extract

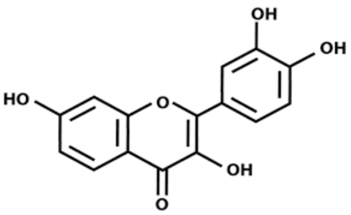
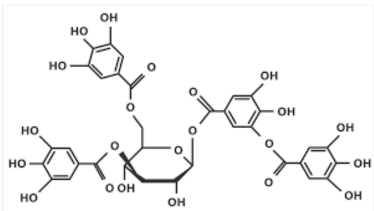
Compound	Reactor	Results
Flavonoid	NaOH 1% + HCl 1%	+
Tannin	(CH3COO)2 Pb 1%	+
Alkaloid	HCl + Dragendorff	-
Saponin	Aquades + HCl	-

* (+) = Detected
(-) = Not Detected

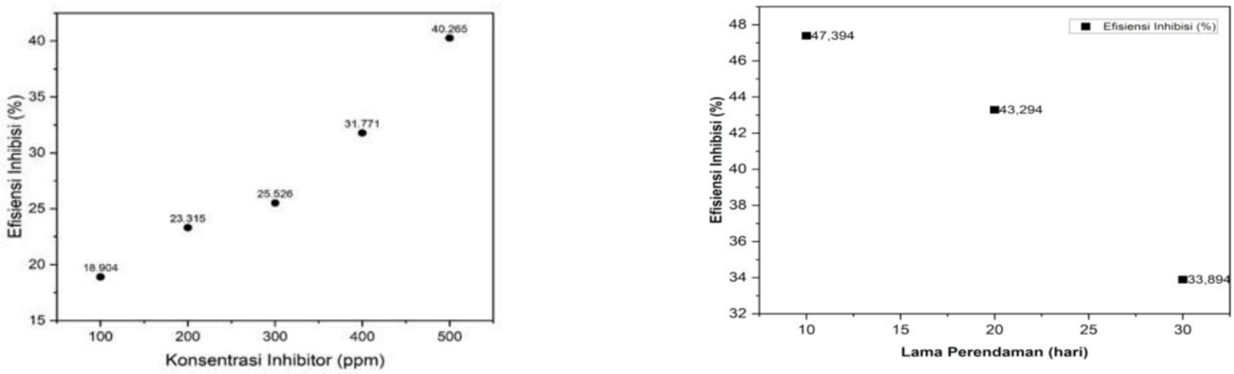
Functional Group Analysis of Salak *(Salacca zalacca)* Seed Extract

The IR spectrum of the isolated compound shows information that there is an absorption peak of the hydroxyl group at wave number 3288.72 cm-1. The hydroxyl group is stretched –OH bonded (can be hydrogen bonded), and the bonded OH is visible by forming a widening band and a strong intensity. This hydroxyl group is strengthened by –C-O- stretching at wave 1102.42 cm-1. The absorption band at wave number 2930.18 cm-1 shows the presence of aliphatic C – H stretching and is reinforced by the appearance of absorption at wave number 1409.45 cm-1 indicating the presence of C – H stretching. The absorption band at wave number 1627.88 cm-1 showed the presence of alkene groups and was strengthened by the appearance of alkene groups at wave numbers 987.03 cm-1 and 923.15 cm-1. In the frequency area 1180 – 1360 cm-1 Two amine/amide groups were found each at wave number 1261.09 cm-1 and 1102.42 cm-1. Then in the frequency area of 690 – 900 cm-1 C – H aromatic ring group was obtained at wave numbers 865.45 cm-1 and 830.42 cm-1 with great intensity. The presence of electronegative atoms such as N and O as well as double bonds in alkene groups gives the extract potential as a corrosion inhibitor [39]. These findings are consistent with studies of other plant-based corrosion inhibitors, where tannins and flavonoids, with their hydroxyl and carbonyl groups, play a crucial role in adsorption onto metal surfaces [9, 20]. The presence of electronegative atoms (N and O) and double bonds in alkene groups strengthens the potential of the extract as an effective corrosion inhibitor, similar to findings in other plant-derived inhibitors [10, 35]. Based on the results of the FTIR test, it is indicated that the compounds contained are tannins and flavonoids as seen on Table 3.

Table 3. Organic Compounds in Salak *(Salacca zalacca)* Seed Extract

Organic Compound	Molecular Structure	Annotation
Flavonoid		Flavonoids possess various functional groups, including double bond C=O, double bond C=C, single bond C-O, single bond C-H, and single bond O-H. Based on the results of FTIR analysis, it indicates the presence of flavonoid compounds
Tannin		Tannins have phenolic (-OH) groups and exhibit colloidal properties. Other functional groups present include aliphatic C-H and aromatic double bond C=C. Based on the results of FTIR analysis, it is indicated that the compoundpresent is tannin.

Performance Analysis of Corrosion InhibitorsDetermination of Inhibition Efficiency



(a) (b)

Fig. 3. Effect of (a) Concentration and (b) Immersion Time on Inhibition Efficiency

Based on Figure 3a, it is shown that the lowest inhibition efficiency in specimens soaked for 20 days with various concentrations was at a concentration of 100 ppm with an efficiency value of 18.904%. While the highest inhibition efficiency was obtained at a concentration of 500 ppm with an inhibition efficiency value of 40.265%. Moreover, based on Figure 3b of variations in immersion time, it is shown that the lowest inhibition efficiency was found in specimens soaked with a concentration of 500 ppm in various immersion times at 30 days with an efficiency value of 33.894%. Meanwhile, the highest inhibition efficiency was obtained for ten days of immersion with an inhibition efficiency value of 47.394%. These results indicate that the inhibition efficiency of Salak *(Salacca zalacca)* seed extract decreases over time, suggesting potential limitations in its long-term performance. Variability in efficiency may be influenced by factors such as concentration, immersion time, and the gradual degradation of the protective layer formed by the extract.

Determination of Corrosion Rate

Measurement was conducted using the potentiodynamic polarization method. This method involves a series of 3 electrodes, with AISI 1040 steel as the working electrode, Ag/AgCl as the reference electrode, and platinum as the auxiliary electrode. Measurements were performed with a scan rate of 1 mV/s and a potential of -100 mV to 100 mV. The testing was performed based on variations in concentration and immersion time. Inhibitors can be classified as anodic inhibitors or cathodic inhibitors if the shift in corrosion potential (Ecorr) is greater than 85 mV from blank to the anodic or cathodic direction [6]. In the Tafel curve shown in Figure 4a, it can be seen that there is a shift in thecorrosion potential of 114 mV towards the anodic so it can be said that the extract is classified as ananodic inhibitor. Anodic inhibitors have a mechanism to reduce the corrosion rate by forming or facilitating the formation of a film layer which will inhibit the reaction of dissolving the anode metal. The test data also show indications of adsorption on the steel surface and control of the anodic dissolution process.

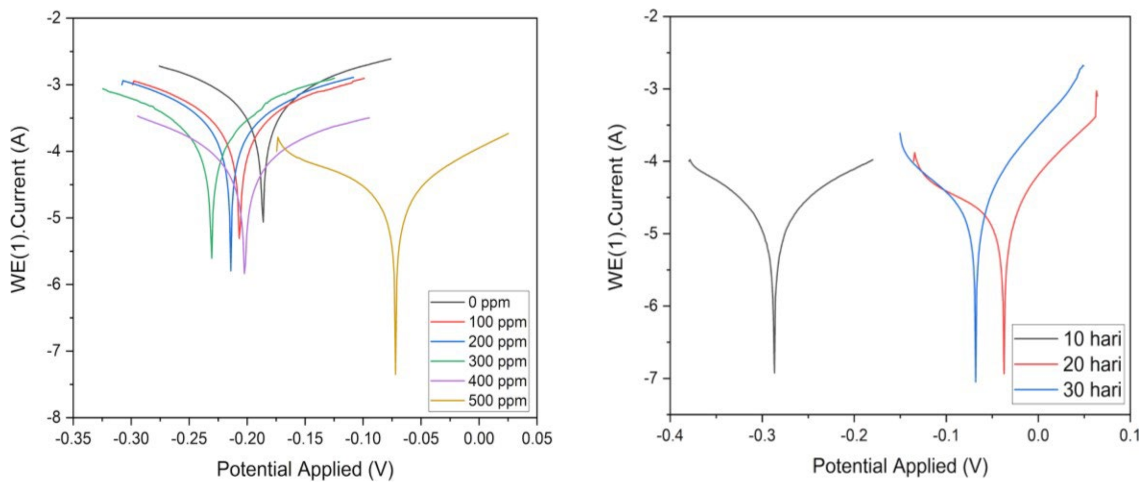
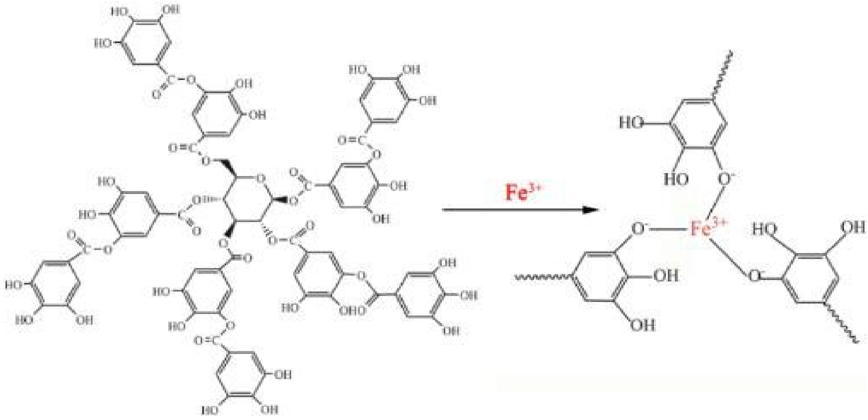


Fig. 4. Tafel Curve with Variation (a) Concentration and (b) Immersion Time ofSalak *(Salacca zalacca)* Seed Inhibitor

The steel added with the inhibitor of salak *(Salacca zalacca)* seed extract decreased the corrosion rate to 0.035 mm/year at an inhibitor concentration of 500 ppm. The corrosion rate on the specimen decreased with the addition of inhibitor extract concentration. In addition, it can be seen that the value of the corrosion current (Icorr) is directly proportional to the corrosion rate. The higher the corrosion current, the higher the value of the corrosion rate in the material. And then, the steel with the addition of 500 ppm inhibitor which is immersed in various variations of immersion time experiences an increase in the corrosion rate. The longer the steel is immersed in corrosive media, the higher the measured corrosion rate will be. The lowest corrosion rate value was obtained at ten days of immersion time while the highest corrosion rate value was obtained at 30 days of immersion (Figure4b).

Inhibition Mechanism

The organic inhibitor from salak *(Salacca zalacca)* seeds has the ability to inhibit the corrosion rate due to the presence of secondary metabolite compounds such as flavonoids and tannins. These compounds have their own mechanisms in protecting metals from corrosion. Flavonoids, according to [40], have free electron pairs and double bonds in their molecular structure, which serve as a medium for the inhibitor to react with iron metal. Flavonoids are also known as antioxidant compounds because they can capture free radicals by releasing hydrogen atoms from their hydroxyl groups. On the other hand, tannins will form complex compounds with iron ions, forming ferric tannate on the metal surface.



Fe^{2+} + Tanin → Fe-tanin Fe-tanin + O2 → Fe-Tanat

Fig. 5. Mechanism of Formation of Tannin Complexes with Fe^{3+} [36]

Tannin compounds can form complex compounds with iron (II) and iron (III). The iron (II) - tannin complex compound is colorless and has properties that are easily soluble and oxidized. In the presence of oxygen, this complex compound transforms into iron (III) - tannin complex known as tannate. The Fe-tannate complex compound acts as a barrier and coats the metal, preventing direct contact between the solution and the iron metal [42].

The two compounds will form a thin barrier layer on the metal surface as illustrated in Figure 6. In many studies (including acidic media), the adsorption of inhibitor molecules tends to be initiated using a physical adsorption mechanism and then propagated using a chemical adsorption mechanism which is called the physiochemical mechanism of adsorption [43].

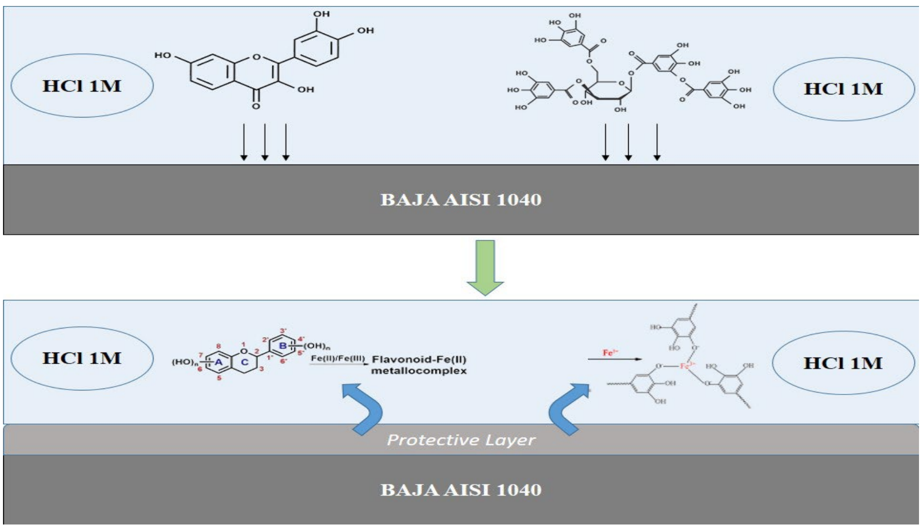


Fig. 6. Illustration of Inhibition Mechanism

The indications of the formed layer on the metal surface can be observed based on the results of the Scanning Electron Microscopy (SEM) test shown below.

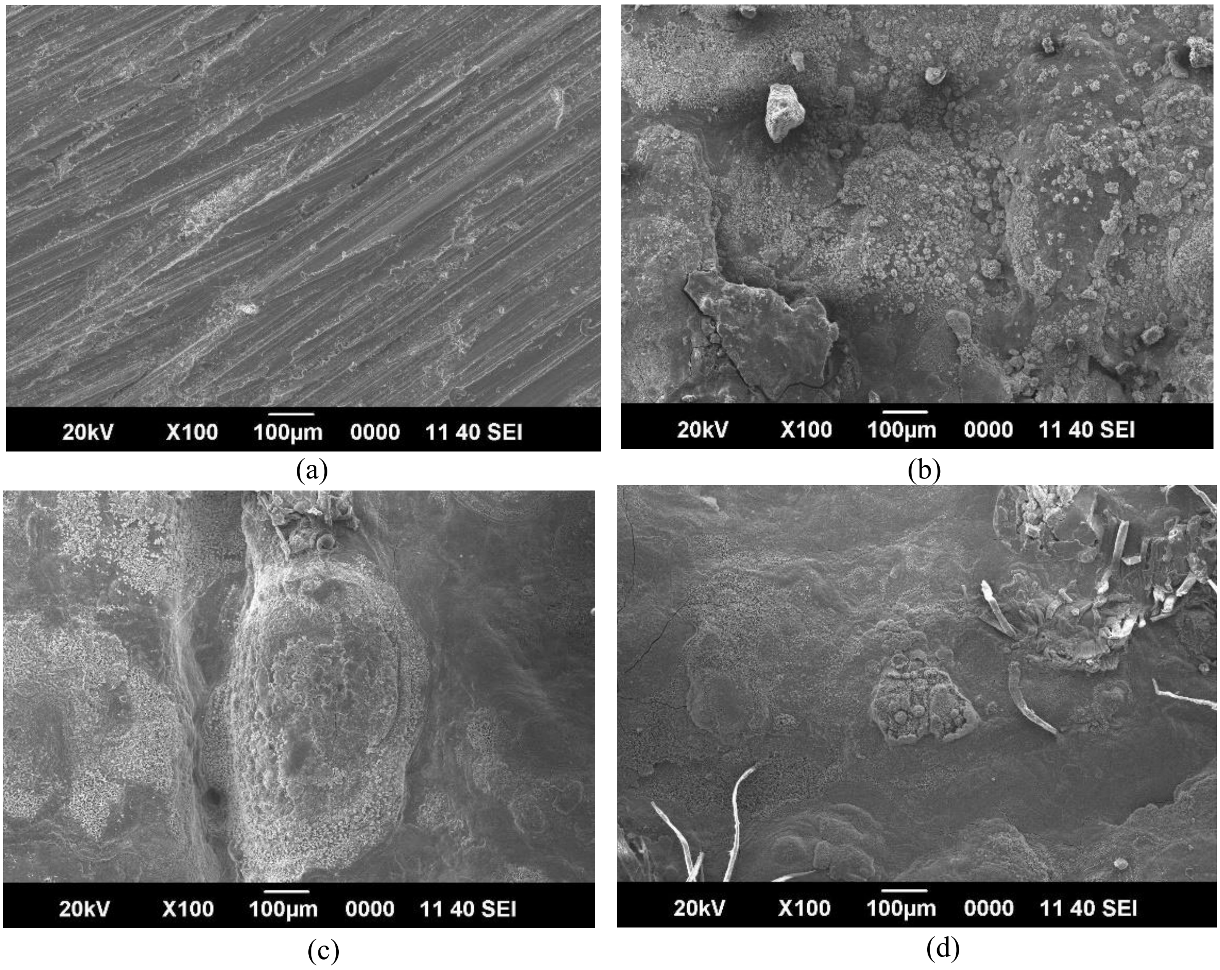


Fig. 7. The Morphology Observation Results of AISI 1040 Steel Surface: (a) Untreated Specimen, (b) Specimen with 0 ppm Inhibitor and 20 Days of Immersion, (c) Specimen with 500 ppmInhibitor and 20 Days of Immersion, (d) Specimen with 500 ppm Inhibitor and 10 Days of Immersion

Fig. 7 illustrates the comparison of surface morphology between specimens with and without the addition of an inhibitor. The observation results indicate that the specimen immersed without the addition of an inhibitor (Figure 7b) exhibits a rougher and more damaged surface due to metal erosion caused by oxidation reactions during immersion. It can be observed that the specimen is indicated to undergo uniform corrosion and pitting corrosion on its surface. By adding an inhibitor (Fig. 7c-d), the metal dissolution process can be minimized through the formation of a passive layer that acts as a barrier in preventing the metal from acting as an anode in a corrosive environment.

Conclusion

The optimal inhibitor concentration was 500 ppm, achieving an efficiency of 40.26% and a corrosion rate of 0.035 mm/year. The highest inhibition efficiency was observed after 10 days of immersion, but the efficiency declined over time, indicating potential limitations in long-term performance. These findings suggest that salak *(Salacca zalacca)* seed extract is a viable, eco-friendly corrosion inhibitor for short-term applications, but its long-term stability requires further improvement. Future research should explore the synergistic effects of combining salak *(Salacca zalacca)* seed extract with other natural inhibitors to enhance durability and performance over extended periods. Additionally, studies on the extract's behavior in other corrosive environments and on different metal types would provide a more comprehensive understanding of its potential industrial applications.

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References

[1] Y. Song, G. Jiang, Y. Chen, P. Zhao, and Y. Tian, "Effects of chloride ions on corrosion of ductile iron and carbon steel in soil environments," Sci. Rep., vol. 7, no. 1, pp. 1–13, 2017, doi: 10.1038/s41598-017-07245-1.

[2] R. Fan, W. Zhang, Y. Wang, D. Chen, and Y. Zhang, "Metal Material Resistant to HydrochloricAcid Corrosion," J. Phys. Conf. Ser., vol. 1732, no. 1, 2021, doi: 10.1088/1742-6596/1732/1/012134.

[3] Trethewey K.R & Chamberlain, Korosi untuk Mahasiswa dan Rekayasawan. Jakarta: PT. Gramedia Pustaka Utama, 1991.

[4] N. Azisah, D. Paroka, and W. Wahyuddin, "Analisa Penempatan Dan Kebutuhan Proteksi Katodik Pada Sistem Pipa Gas Bawah Laut Offshore Dari Pulau Pemping Ke Tanjung Uncang Batam," Zo. Laut J. Inov. Sains Dan Teknol. Kelaut., vol. 2, no. 3, pp. 57–63, 2020, doi: 10.20956/zl.v1i3.11978.

[5] F. Krzyzanowski, M., Beynon, J. H. and R. B. J., D. C., Revie, R. W., Kreysa, G., Sch¨ utze, M.,Roberge, P. R., Revie, R. W., Ghali, E., Sastri, V. S., Elboujdaini, M., Heimann, Oxide Scale Behavior in High Temperature Metal Processing Corrosion and Corrosion Control Corrosion Handbook - Corrosive Agents and Their Interaction with Materials Corrosion Inspection and Monitoring Corrosion Prevention and Protection Plasma Spray Coati. 2012.

[6] S. Prifiharni et al., "Extract sarampa wood (Xylocarpus Moluccensis) as an eco-friendly corrosion inhibitor for mild steel in HCl 1M," J. Indian Chem. Soc., vol. 99, no. 7, p. 100520, 2022, doi: 10.1016/j.jics.2022.100520.

[7] et al Azis, "Pengaruh Konsentrasi Inhibitor Suplemen Vitamin C (Asam Askorbat) terhadap Laju Korosi Baja Api 5I Grade B pada Lingkungan 3,5% NaCl yang Mengandung Gas CO2," J. Tek.POMITS, vol. Vol. 2, No, 2013.

[8] N. Chaubey, Savita, A. Qurashi, D. S. Chauhan, and M. A. Quraishi, "Frontiers and advances ingreen and sustainable inhibitors for corrosion applications: A critical review," J. Mol. Liq., vol. 321,p. 114385, 2021, doi: 10.1016/j.molliq.2020.114385.

[9] R. Kusumastuti, R. I. Pramana, and J. W. Soedarsono, "The use of morinda citrifolia as a green corrosion inhibitor for low carbon steel in 3.5% NaCl solution," AIP Conf. Proc., vol. 1823, 2017, doi: 10.1063/1.4978085.

[10] J. W. Soedarsono, M. N. Shihab, M. F. Azmi, and A. Maksum, "Study of curcuma xanthorrhizaextract as green inhibitor for API 5L X42 steel in 1M HCl solution," IOP Conf. Ser. Earth Environ. Sci., vol. 105, no. 1, 2018, doi: 10.1088/1755-1315/105/1/012060.

[11] Y. L. Kobzar and K. Fatyeyeva, "Ionic liquids as green and sustainable steel corrosion inhibitors:Recent developments," Chem. Eng. J., vol. 425, no. April, p. 131480, 2021, doi: 10.1016/j.cej.2021.131480.

[12] M. R. Vinutha and T. V. Venkatesha, "Review on mechanistic action of inhibitors on steel corrosion in acidic media," Port. Electrochim. Acta, vol. 34, no. 3, pp. 157–184, 2016, doi: 10.4152/pea.201603157.

[13] A. S. Amarasekara, “Acidic Ionic Liquids,” Chem. Rev., vol. 116, no. 10, pp. 6133–6183, 2016,doi: 10.1021/acs.chemrev.5b00763.

[14] W. E. S. Hart, J. B. Harper, and L. Aldous, “The effect of changing the components of an ionic liquid upon the solubility of lignin†,” Green Chem., vol. 17, no. 1, pp. 214–218, 2015, doi:10.1039/c4gc01888e.

[15] C. Verma, I. B. Obot, I. Bahadur, E. S. M. Sherif, and E. E. Ebenso, “Choline based ionic liquidsas sustainable corrosion inhibitors on mild steel surface in acidic medium: Gravimetric, electrochemical, surface morphology, DFT and Monte Carlo simulation studies,” Appl. Surf. Sci., vol. 457, pp. 134–149, 2018, doi: 10.1016/j.apsusc.2018.06.035.

[16] S.F.A,A.E. M, and E. A, “Eco-friendly chalcones derivatives as corrosion inhibitors for carbon steel in hydrochloric acid solution,” African J. Pure Appl. Chem., vol. 7, no. 10, pp. 337–349, 2013,doi: 10.5897/ajpac2013.0520.

[17] Fatkhurohmat, “Aplikasi Ekstrak Kulit Jeruk Nipis (Citrus Aurantifolia) Sebagai Inhibitor Organik Pada Baja Api 5L Grade B Media Larutan H2SO4 1M,” (Doctoral Diss. Inst. Teknol. Sepuluh Nop., 2017.

[18] A. Zakeri, E. Bahmani, and A. S. R. Aghdam, “Plant extracts as sustainable and green corrosion inhibitors for protection of ferrous metals in corrosive media: A mini review,” Corros. Commun., vol.5, pp. 25–38, 2022, doi: 10.1016/j.corcom.2022.03.002.

[19] T. Yunita, A. W. Putri Kusuma, S. E. Novita, and Sulistijono, “Effect of Addition Tahongai Leaf Extract (Kleinhovia hospita Linn.) As Organic Inhibitor on 1040 AISI Steel,” IOP Conf. Ser. Mater.Sci. Eng., vol. 547, no. 1, 2019, doi: 10.1088/1757-899X/547/1/012006.

[20] A. H. Al-Moubaraki, A. Al-Judaibi, and M. Asiri, “Corrosion of C-steel in the red sea: Effect of immersion time and inhibitor concentration,” Int. J. Electrochem. Sci., vol. 10, no. 5, pp. 4252–4278,2014.

[21] A. Dehghani, G. Bahlakeh, and B. Ramezanzadeh, “A detailed electrochemical/theoretical exploration of the aqueous Chinese gooseberry fruit shell extract as a green and cheap corrosion inhibitor for mild steel in acidic solution,” J. Mol. Liq., vol. 282, pp. 366–384, 2019, doi: 10.1016/j.molliq.2019.03.011.

[22] N. H. J. Al Hasan, H. J. Alaradi, Z. A. K. Al Mansor, and A. H. J. Al Shadood, “The dual effect of stem extract of Brahmi (Bacopamonnieri) and Henna as a green corrosion inhibitor for low carbon steel in 0.5 M NaOH solution,” Case Stud. Constr. Mater., vol. 11, p. e00300, 2019, doi: 10.1016/j.cscm.2019.e00300.

[23] A. Singh et al., “Plant derived cationic dye as an effective corrosion inhibitor for 7075 aluminum alloy in 3.5% NaCl solution,” J. Ind. Eng. Chem., vol. 20, no. 6, pp. 4276–4285, 2014, doi: 10.1016/j.jiec.2014.01.033.

[24] Y. Triana, P. R. Utami, A. D. Laksono, J. Awali, G. U. N. Tajalla, and Sulistijono, “The Effect of Addition Organic Inhibitor Bintaro Fruit Extract (Cerbera Manghas) to Inhibition Eficiency and Corrosion Rate on JIS G3131 Steel in 0,1 M H2so4 Environment,” J. Phys. Conf. Ser., vol. 1803, no.1, 2021, doi: 10.1088/1742-6596/1803/1/012013.

[25] A. Dehghani, G. Bahlakeh, B. Ramezanzadeh, and M. Ramezanzadeh, “Potential of Borage flower aqueous extract as an environmentally sustainable corrosion inhibitor for acid corrosion of mild steel: Electrochemical and theoretical studies,” J. Mol. Liq., vol. 277, pp. 895–911, 2019, doi: 10.1016/j.molliq.2019.01.008.

[26] R. Setyawaty, J. Farmasi, F. Farmasi, A. Farmasi Kusuma Husada, J. Karangbenda Raya - Berkoh, and R. B. Aptuning, “Pharmaceutical Journal Of Indonesia Preliminary Studies on the Content of Phytochemical Compounds On Skin of Salak Fruit (Salaccazalacca),” Pharm. J. Indones.,vol. 6, no. 1, pp. 1–6, 2020.

[27] I. G. A. S. Dhyanaputri, I. W. Karta, and L. A. W. Krisna, "Analisis Kandungan Gizi Ekstrak Kulit Salak Produksi Kelompok Tani Abian Salak Desa Sibetan Sebagai Upaya Pengembangan Potensi Produk Pangan Lokal I Gusti Ayu Sri Dhyanaputri 1 , I Wayan Karta 2 , Luh Ade Wilan Krisna 3," Meditory, vol. 4, no. 2, pp. 93–100, 2016.

[28] F. & Andriani, "Screening of antioxidant activities and their bioavailabilityof tropical fruit By products from Indonesia," Int. J. Pharm. Pharm. Sci., pp. 95–100, 2016.

[29] I. W. Karta, L. A. N K Eva Susila, I. N. Mastra, and P. G. A. Dikta, "Kandungan Gizi Pada Kopi Biji Salak *(Salacca zalacca)* Produksi Kelompok Tani Abian Salak Desa Sibetan yang Berpotensi Sebagai Produk Pangan Lokal Berantioksidan dan Berdaya saing," J. Virgin, Jilid, vol. 1, no. 2, pp. 123–133, 2015.

[30] E. Erwansyah and C. Pratiwi, "The effect of snakefruit extract *(Salacca zalacca)* in inhibiting the release of chromium (Cr) and nickel (Ni) ion from stainless steel orthodontic wire to saliva," Int. J. Appl. Pharm., vol. 11, no. 4, pp. 33–36, 2019, doi: 10.22159/ijap.2019.v11s4.35286.

[31] Khan, M. A., & Ahmad, S. Evaluation of Plant Extracts as Green Corrosion Inhibitors for Carbon Steel in Acidic Media. *Corrosion Science*, 170, 107522, 2020. https://doi.org/10.1016/j.corsci.2020.107522

[32] Singh, R., & Kumar, V. Green Corrosion Inhibition of Mild Steel in 1M HCl Using Neem (Azadirachta indica) Leaf Extract. *Journal of Molecular Liquids*, 289, 110874, 2019. https://doi.org/10.1016/j.molliq.2019.110874

[33] Zhang, Y., Li, X., & Wang, S. Investigation of Plant-Derived Corrosion Inhibitors for Steel in Acidic Environments. *International Journal of Electrochemical Science*, 16(3), 2543-2558, 2021. https://doi.org/10.3190/IJES201615031254

[34] C. Verma, I. B. Obot, E. E. Ebenso, M. A. Quraishi, and I. Bahadur, "Choline-based ionic liquids as sustainable corrosion inhibitors on mild steel surface in acidic medium: Gravimetric, electrochemical, surface morphology, DFT, and Monte Carlo simulation studies," *Appl. Surf. Sci.*, vol. 457, pp. 134–149, 2018, doi: 10.1016/j.apsusc.2018.06.035.

[35] S. A. Umoren, M. M. Solomon, "Synergistic corrosion inhibition effect of metal cations and mixtures of organic compounds: A review," *J. Environ. Chem. Eng.*, vol. 5, no. 3, pp. 246–257, 2017, doi: 10.1016/j.jece.2017.02.024.

[36] S. Werdyani, P. Jumaryatno, and N. Khasanah, "Antioxidant Activity of Ethanolic Extract and Fraction of Salak Fruit Seeds (Salacca Zalacca (Gaertn.) Voss.) Using Dpph (2,2-Diphenyl-1-Picrylhydrazyl) Method," J. Eksakta, vol. 17, no. 2, pp. 137–146, 2017, doi: 10.20885/eksakta.vol17.iss2.art5.

[37] F. Z. Nisa, M. Astuti, S. M. Haryana, and A. Murdiati, "Antioxidant Activity and Total Flavonoid of Carica papaya L. Leaves with Different Varieties, Maturity and Solvent," agriTECH, vol. 39, no. 1, p. 54, 2019, doi: 10.22146/agritech.12813.

[38] S. Ariviani and N. H. R. Parnanto, "Kapasitas Antioksidan Buah Salak (Salacca Edulis Reinw) Kultivar Pondoh, Nglumut Dan Bali Serta Korelasinya Dengan Kadar Fenolik Total Dan Vitamin C," Agritech, vol. 33, no. 3, pp. 324–333, 2013, [Online]. Available: https://journal.ugm.ac.id/agritech/article/view/9555/7130

[39] N. O. Eddy, S. A. Odoemelam, E. C. Ogoko, R. A. Ukpe, R. Garg, and B. Anand, "Experimental and quantum chemical studies of synergistic enhancement of the corrosion inhibition efficiency of ethanol extract of Carica papaya peel for aluminum in solution of HCl," Results Chem., vol. 4, no. August 2021, p. 100290, 2022, doi: 10.1016/j.rechem.2022.100290.

[40] N. Subekti, J. W. Soedarsono, R. Riastuti, and F. D. Sianipar, “Development of environmental friendly corrosion inhibitor from the extract of areca flower for mild steel in acidic media,” Eastern- European J. Enterp. Technol., vol. 2, no. 6–104, pp. 34–45, 2020, doi: 10.15587/1729- 4061.2020.197875.

[41] Y. M. Li et al., “Iron-tannic acid nanocomplexes: Facile synthesis and application for removal ofmethylene blue from aqueous solution,” Dig. J. Nanomater. Biostructures, vol. 11, no. 4, pp. 1045– 1061, 2016.

[42] W. Xu, E. H. Han, and Z. Wang, “Effect of tannic acid on corrosion behavior of carbon steel in NaCl solution,” J. Mater. Sci. Technol., vol. 35, no. 1, pp. 64–75, 2019, doi: 10.1016/j.jmst.2018.09.001.

[43] L. Chen, D. Lu, and Y. Zhang, “Organic Compounds as Corrosion Inhibitors for Carbon Steel in HCl Solution: A Comprehensive Review,” Materials (Basel)., vol. 15, no. 6, pp. 1–59, 2022, doi: 10.3390/ma15062023.