

Jackfruit peel extract as environmentally safe inhibitor for carbon steel protection in acidic solution

Ira Kusumaningrum*, Rudy Soenoko, Eko Siswanto, Femiana Gapsari,

Mechanical Engineering Department, Faculty of Engineering, MT Haryono 167 Malang, 65145 Indonesia

Corresponding Author Email: ira210371@gmail.com

ABSTRACT

The addition of corrosion inhibitors into the acidic environment is an environmental modification to control the rate of corrosion. Organic compound inhibitors become an environmentally friendly alternative. In this study, research and analysis have been carried out on jackfruit peel extract as a corrosion inhibitor for AISI 1037 carbon steel protection in 1M HCl solution. Variation of inhibitor concentration is 200-3000 ppm. Corrosion rate measurements were performed by applying weight loss and potential polarization methods. The addition of inhibitor concentrations up to 1000 ppm increased the inhibitor efficiency up to 90.98%, but the efficiency decreased at concentrations of 2000 ppm and 3000 ppm. The adsorption inhibitors that occurred in this study was physical adsorption. It followed the Langmuir isothermal adsorption. The functional group of the film layer on the carbon steel surface indicated that the jack fruit peel extract compounds was adsorbed on the steel surface.

Keywords: Corrosion, inhibitor, adsorption, thermodynamic parameter

Received: November 2-2021 **Accepted:** January 05-2022

<https://doi.org/10.14447/jnmes.v25i1.a07>

1. INTRODUCTION

Corrosion is the destruction of a metal because it reacts with the environment [1]. Corrosion cannot be prevented but can be controlled. This can extend the life of the metal structure or components. Corrosion control can be done by selecting the right design and material, applying protective coating, cathodic or anodic protection and modifying the environment. The addition of corrosion inhibitors into the electrolyte solution is one of the modifications to the environment. Corrosion inhibitors are chemicals that are added to the corrosion system with low concentration. The addition aims to reduce the rate of corrosion without significantly altering the concentration of corrosive substances [2]. The use of inorganic inhibitors can have a detrimental effect on the environment and humans because it contains toxic substances. Therefore, organic compound-based inhibitors are the right choice and environmentally friendly.

Organic inhibitors are adsorbed type inhibitors. This type of inhibitor can reduce the rate of corrosion. It forms an adsorbent layer that is able to protect the metal surface from its corrosive environment. This is due to inhibitory compounds having heteroatomic structures such as N, O, P, S, and atoms having free electron pairs [3]. Elements with free electron pairs as ligands form complex compounds with metals.

Organic inhibitors were widely used to control corrosion. This had been proven by many studies that use plants as corrosion inhibitors. Research was done on all parts of the plant. *Thymus vulgaris* [4], parsley/*Petroselinum sativum* [5], *Hyptis suaveolens* [6], *Dryopteris cochleata* [7], bamboo leaf [8], *Urtica dioica* [9], *Sida acuta* [10], *Nicotiana tabacum* [11], and *Retama monosperma* [12] is a plant whose leaves are used as corrosion inhibitors. Studies using fruits as corrosion inhibitors such as in *Ginkgo Biloba* [13], *Chinese Gooseberry* [14], *Aqueous citrullus lanatus* [15], *Moroccan ammodavcus leucotrichus* [16], red apple [17] and *Myristica fragrans* [18] were also conducted. Plant waste such as *peels of lychee* [19],

melon [20], *Musa paradisica* [21], watermelon [22] and orange [23] were also used as corrosion inhibitor.

Utilizing fruit waste was an attempt to increase the role of nature in industry. This attempt can increase the economic value of the fruit waste. The watermelon peel extract had been used as corrosion inhibitor on mild steel in 1 M HCl solution and 0.5 M H₂SO₄. Concentrations vary from 0.1 g/l to 2.0 g/l [22]. Corrosion rate was tested using potentiodynamic polarization method and electrochemical impedance spectroscopy method. The same patterns were shown by both methods. The inhibitor efficiency increased as the concentration of watermelon peel extract was increased. Corrosion inhibition on mild steel was investigated where the melon peel extract was added into 1 M HCl with varied concentration between 0.05 g/l to 0.5 g/l and at varied temperatures of 295°K to 333°K [20]. The highest inhibitor efficiency was shown by the addition of 0.5 g/l into 1 M HCl solution.

Jackfruits (*Artocarpus heterophyllus*) are tropical fruit that grow in South Asia countries and Florida. In those countries, jackfruits are more popular as garden plants rather than plants for commercial plantation [24]. In Indonesia, jackfruits are eaten when both ripe or nearly ripe. However, the waste of the fruit has not been utilized maximally. Jackfruit peel contains some antioxidant compounds such as protocatechuic acid, chlorogenic acid, isovitexin, feruloyl derivative, artocarpin and luteolin [25]. In this study, jackfruit peel extract (JPE) was used as an environmentally friendly inhibitor. The JPE contains some antioxidant compounds which are able to inhibit oxidation reaction in corrosion process. This expected to reduce corrosion rate on AISI 1037 carbon steel. The inhibitor efficiency was investigated by performing corrosion rate test using both potentiodynamic polarization and weight loss methods.

The interaction between and surface of the steel and the inhibitor molecule can be understood using the adsorption isotherm. There are some types of adsorption isotherm equation which are often met as the adsorption pattern of a corrosion

inhibitor. They are adsorption isotherm of Langmuir, Freundlich, Temkin and Frumkin. Determining adsorption isotherm model was conducted with linear curve plot based on the adsorption isotherm equations [26]

Langmuir equation:

$$K_{ads} = \theta / (1 - \theta) C_{inh}$$

Frumkin equation:

$$\text{Log} \frac{\theta}{1 - \theta C_{inh}} = \text{Log} K_{ads} + b\theta \dots\dots\dots(1)$$

Freundlich equation:

$$\text{Log} \theta = \text{log} K_{ads} + n \text{Log} C_{inh} \dots\dots\dots(2)$$

Temkin equation:

$$\exp(-2\alpha\theta) = b \times C_{inh} \dots\dots\dots(3)$$

θ is the fraction of surface coverage, K_{ads} is balance constant of adsorption-desorption, C_{inh} is inhibitor concentration and b is interaction parameter which can be calculated using slope of the linear regression equation. The value of b which is more than zero indicates attraction of the adsorbed species. The resistance is indicated by the value of a which is less than zero. Based on the value of each R2 determinant coefficient, the adsorption isotherm pattern is appropriated.

Inhibition mechanism of an organic compound on carbon steel surface can be reviewed through thermodynamic parameters which are the changes in adsorption free energy (ΔG°_{ads}), enthalpy of adsorption (ΔH°_{ads}) and entropy of adsorption (ΔS°_{ads}). The thermodynamic parameter for the higher JPE inhibitor efficiency was shown in table 3. The adsorption energy of inhibitor on the steel surface can be evaluated from the following equation [27]:

$$\Delta G^{\circ}_{ads} = -R T \text{Ln}(K_{ads} \times A) \dots\dots\dots(5)$$

where R is the constant of gas ($8.314 \text{ J.K}^{-1}\text{mol}^{-1}$), T is the absolute temperature ($^{\circ}\text{K}$) and A is the concentration of water in the acidic solution (55.5 in Molar or 1000 in g/L). If the value of around -20 kJ mol^{-1} ; it indicate physisorption. However, around -40 kJ mol^{-1} , respectively indicate chemisorption [36]. The negative of enthalpy ΔH°_{ads} signifies exothermic adsorption. The absolute magnitude of ΔH°_{ads} for chemisorption is greater than physisorption. The of ΔH°_{ads} estimation is illustrated below through the Langmuir isotherm and calculated using Van't Hoff equation [27]:

$$\text{Ln} K_{ads} = -\Delta H^{\circ}_{ads} / RT \dots\dots\dots(6)$$

where T is the absolute temperature, and ΔH°_{ads} is the enthalpy of adsorption. If $\Delta S^{\circ}_{ads} < 0$, that signifies the adsorption process occurrence. The greater of ΔS°_{ads} value indicates the higher the adsorption will be. Its value can be calculated using equation:

$$\Delta G^{\circ}_{ads} = \Delta H^{\circ}_{ads} - T \Delta S^{\circ}_{ads} \dots\dots\dots(7)$$

The adsorption process of inhibitor can be observed by activation parameters such as the activation energy (E_a), the activation enthalpy ($\Delta H^{\#}$) and the activation entropy ($\Delta S^{\#}$) for corrosion in the absence and presence of inhibitor. the activation energy (E_a) were calculated from Arrhenius equation [28]:

$$i_{corr} = A \exp \frac{E_a}{RT} \dots\dots\dots(8)$$

Where i_{corr} is the density of corrosion current, A is the constant of Arrhenius, and R is the constant of universal gas. The transition state equation was presented:

$$i_{corr} = \frac{RT}{Nh} \exp \left(\frac{\Delta S^{\#}}{R} \right) \exp \left(\frac{-\Delta H^{\#}}{RT} \right) \dots\dots\dots(9)$$

Where N is constant of Avogadro, h is the constant of Planck.

2. EXPERIMENTAL

2.1 The Materials

The material protected in the experiment was AISI 1037 carbon steel with chemical composition of 0.37% C, 0.17%-0.37%Si, 0.35%-0.65% Mn, 0.025% P, 0.020% S, 0.25% Cr, 0.25% Ni, 0.25% Cu and Fe as the rest. The specimen dimension was 10 mm x 40 mm x 5 mm. It was abraded consecutively using emery paper with grade size of 600 to 1200.

1 M HCl solution was used as the electrolyte in the study. It was prepared by dissolving 83 ml of 38% HCl from Merck with aquades to obtain 1000 ml solution. JPE inhibitor was added into 1M HCl solution with varied concentration.

JP extraction was started by cleaning process of the peel from contaminants. Next, the clean JP was dried and ground to produce fine powder. The extraction stage was performed by maceration method using ethanol solvent. Filtrate from the extraction result was filtered and put into Erlenmeyer. Next, the filtrate was evaporated using rotary vacuum evaporator to produce thick extract.

2.2 Characterization of JP extract

Then, the functional group of the JPE was identified using Fourier transform infra red (FTIR) spectroscopy of Shimadzu 8400 S. After that, the JP powder was mixed with KBr salt to form pellets and later was used as test sample. The main compound identification was performed using mass spectrometer of triple quadrupole TSQ Quantum Access Max with ionization of ESI source (electrospray ionization) and operated using positive mode ionization. The condition of ESI ionization covered spray voltage of 3 kV and evaporation temperature of 275 $^{\circ}\text{C}$.

2.3 The Test Method

The corrosion rate measurement using weightloss method was performed by weighing the specimen before and after immersion process. The specimen was dipped into 250 ml corrosive media of 1 M HCl solution and was added by varied concentrations of inhibitor: of 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm. The specimen was immersed with variation of time of 1 hour to 96 hours (4 days). Corrosion rate (CR) in this method was calculated by applying weightloss data of the specimen during corrosion test [22] using the following equation:

$$CR = 87600 W / \rho A T \dots\dots\dots(10)$$

where : CR is corrosion rate and W is lost weight. The inhibitor efficiency (EI) was calculated using equation:

$$EI = ((CR_{blank} - CR_{inh})/CR_{blank})100\% \dots\dots\dots(11)$$

The weight of the specimen was measured using moisture balance Shimadzu MOC-120H with maximum capacity of 120 gram and readability of 0.001 gram.

Corrosion rate was also measured using potentiodynamic polarization. The test was performed with Autolab PGSTAT 204 N and software Nova 1.11 Autolab to measure corrosion rate of AISI 1037 carbon steel in 1 M HCL with and without JPE inhibitor. JPE added into 1 M HCl was varied: 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm. Previously, the unexposed specimen surface was coated with epoxy resin previously.

The working electrode was AISI 1037 carbon steel, the conter electrode was platinum and the reference electrode was Ag | AgCl. The scan rate was set at 0.100 V/s. The value of Open Circuit Potential (OCP) ranged from -0.44 V to -0.46 V using average OCP value. From the data, the inhibition efficiency value (%EI) [27] was calculated using the equation:

$$EI = ((i_{corr} - i_{corr}i)/i_{corr})100\% \dots\dots\dots(12)$$

2.4 Surface Analysis

The surface morphology of AISI 1037 carbon steel before and after immersion for 4 days in 1M HCl solution, without or with JPE inhibitor was analyzed using a scanning electron microscope (SEM) FEI Quanta FEG 650. Sample was sprinkled on top of the stub with double sided carbon tape without sputter coating.

3. RESULT AND DISCUSSION

3.1 Characterization of JP Extract

The identification of JPE functional group using FTIR produced some peaks with certain wavelength values. It is presented in Figure 1.

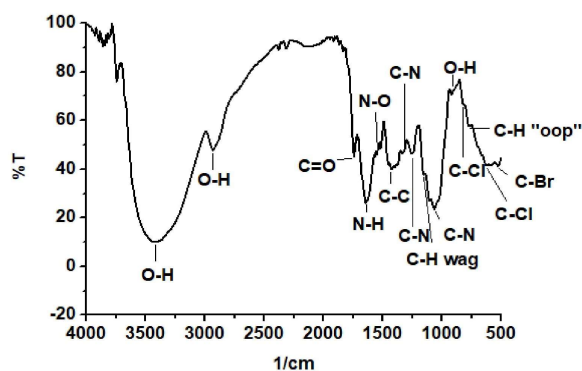


Figure 1 The results of Fourier transform infrared (FTIR) test on JPE functional group

Based on IR chart[29], the functional group bond of JPE was functional group of alkyl halides with C-Br stretch bond in wavenumber range of 690-515 cm^{-1} with intensity of 41.26% and C-Cl stretch in wavenumber range of <600-840 cm^{-1} with intensity of 66.22%. The alkenes fungsional group with =C-H stretch group can read in wavenumber range 995-685 cm^{-1} and

intensity of 70.69%. Aromatic functional group was found with C-H bond and wavenumber range of 900 - 675 cm^{-1} with intensity of 57.64% and C-C stretch bond in wavenumber range of 1500-1400 cm^{-1} and intensity 39.77 %. Besides that, aromatic functional group was found with C-N stretch bond in wavenumber range of 1335-1250 cm^{-1} and intensity of 46.33% or known as aromatic amines functional group. In range of 1250-1020 cm^{-1} and intensity of 23.61%, it was found aliphatic amines functional group with C-N stretch bond. alcohols functional group was found at wave range of 3500-3200 cm^{-1} and intensity of 10%.

The characteristics of compounds which are potential as antioxidant in JPE was identified using spectrometer MS, shown in spectrogram as presented in table 1. In the spectrogram, the compound with the highest abundance is artocarpin with molecule structures [28] shown in Figure 2.

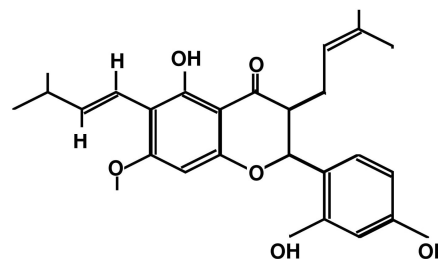


Figure 2 Molecule structures of Artocarpin

3.2 Inhibitor Performance

Inhibition performance could be observed from the inhibitor's ability to inhibit corrosion rate on AISI 1037 carbon steel. Based on the weight loss test, there was decrease in corrosion rate as the inhibitor concentration was increased. However, this happened only until the concentration of 1000 ppm. Above 1000 ppm, (at concentration of 2000 ppm and 3000 ppm) the corrosion rate increased. Thus, the inhibitor was efficient by the increase of the concentration up to 1000 ppm. The inhibitor became less efficient when the concentration was increased up to 2000 ppm and 3000 ppm such as shown by the graph in figure 3. It can be caused by the saturation binding conditions between the steel surface and the inhibitor molecules. The other cause was the removal of the protective layer due to interactions between the inhibitor with HCl or with the inhibitor itself [30]. It can called the competitive adsorption [31].

Increasing the concentration up to 1000 ppm had significantly reduced the dimension of the metal surface which had electrochemical reaction. The addition of JPE inhibitors into the HCl solution caused the adsorption of the inhibitor molecules on the metal surface by forming a protective layer. The metal was protected by this layer from its aggressive environment and the corrosion was fails [31].

Table 1 Identification of JPE compounds

No. Peak	Observed m/z	Calculated m/z	Formula	Compound
1	95,13	95,12	C ₆ H ₆ O; C ₆ H ₅ OH	Phenol
2	155,05	155,13	C ₇ H ₆ O ₄	Protocatechuic acid
3	309,07	309,23	C ₁₅ H ₁₀ O ₆	Luteolin
4	325,12	325,12	C ₁₅ H ₁₀ O ₇	Morin
5	335,09	335,32	C ₁₆ H ₁₄ O ₆	Artocarpanone
6	437,15	437,51	C ₂₆ H ₂₈ O ₆	Artocarpin
7	511,06	511,40	C ₂₁ H ₂₀ O ₁₀	Isovitexin

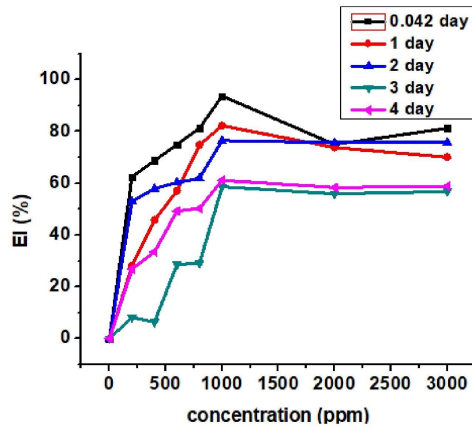


Figure 3 The JPE inhibitor efficiency on AISI 1037 carbon steel in 1 M HCl solution

Increasing the concentration up to 1000 ppm had significantly reduced the dimension of the metal surface which had electrochemical reaction. The addition of JPE inhibitors into the HCl solution caused the adsorption of the inhibitor molecules on the metal surface by forming a protective layer. The metal was protected by this layer from its aggressive environment and the corrosion was fails [31].

The performance of JPE inhibitor was also shown by the result of potentiodynamic polarization test such as presented in Figure 4 and Table 2. The method was conducted to strengthen the data obtained from the weightloss method. The Tafel plot of AISI 1037 carbon steel with or without JPE inhibitor in 1 M HCl solution is displayed in Figure 5. The plot illustrates the significant shift of E_{corr} with and without inhibitor. It is shown in values of 16.3 mV, 8.29 mV, 19.24 mV, 28.31 mV, 7.7 mV, 1.1 mV and 7.75 mV at the concentration of 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm. The values of E_{corr} shift which are less than 85.0 mV confirm that the inhibitor is mixed [27]. This is also supported by the shift of the values of anodic.

Tafel slope (β_a) or cathodic Tafel slope (β_c), with or without inhibitor, where β_a was at range of 110.85 mV/dec up to 407.32 mV/dec and β_c was at range of 63.89 mV/dec to 135.21 mV/dec. The biggest shift was found at β_a which indicates mixed inhibitor. However, the inhibitor tends to be anodic [32].

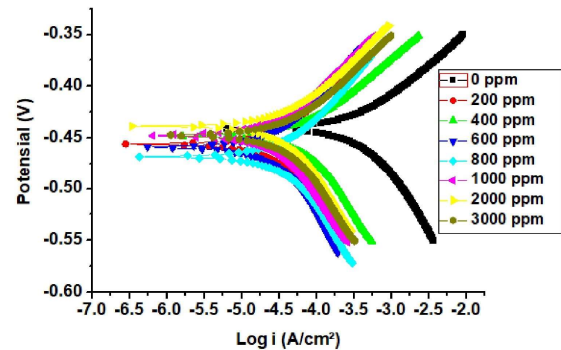


Figure 4 The Tafel plot of AISI 1037 carbon steel in 1 M HCl solution with or without the addition of JPE inhibitor

The two test methods of inhibitor performance show that there is the same trend of inhibition such as shown by the graph in figure 5. It illustrated the efficiency of JPE inhibitor in 1 M HCl solution at varied concentrations to protect AISI 1037 carbon steel using potentiodynamic polarization or weightloss method.

In the image, there was trend similarity in which the inhibition efficiency increases as the concentration increases up to 1000 ppm. However, the efficiency decreases at the concentration of 2000 ppm and 3000 ppm. Inhibitor efficiency in weightloss method is lower than that in the potentiodynamic polarization method even though it has the same trend.

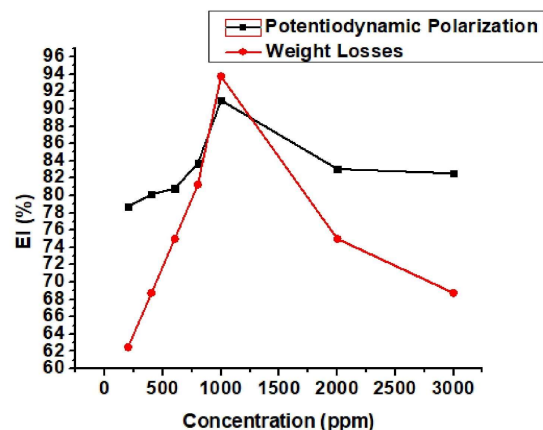


Figure 5 Diagram of JPE inhibitor efficiency on AISI 1037 carbon steel in 1 M HCl solution

This showed that during corrosion, the mass changes was equivalent to the change of current [33].

Table 2. The Result of Potentiodynamic Polarization Test on AISI 1037 Carbon Steel in 1 M HCl Solution With or Without The Addition of JPE Inhibitor

Concentration	Tafel slope		E _{corr} (V)	I _{corr} (A)	Corrosion rate (mm/year)	EI (%)
	ba (V/dec)	bc (V/dec)				
Blank	0.098	0.069	-0.440	0.000382		
200 ppm	0.407	0.135	-0.456	0.000081	0.94	78.73
400 ppm	0.111	0.064	-0.448	0.000076	0.88	80.15
600 ppm	0.310	0.153	-0.459	0.000073	0.85	80.82
800 ppm	0.168	0.106	-0.468	0.000062	0.72	83.71
1000 ppm	0.116	0.078	-0.447	0.000034	0.40	90.98
2000 ppm	0.198	0.089	-0.439	0.000065	0.75	83.07
3000 ppm	0.199	0.089	-0.447	0.000067	0.77	82.55

3.3 Adsorption Isotherm and Activation Energy

Table 3. Thermodynamic Parameters of Inhibitor Adsorption of JPE Inhibitor for The Higher Inhibitor Efficiency

Concentration Ppm	K _{ads}	ΔG_{ads} KJ mol ⁻¹	ΔH°_{ads} KJ mol ⁻¹	ΔS°_{ads} KJmol ⁻¹ °K ⁻¹
1000	10.089	-22.995	-5.765	0.058

The corrosion inhibition mechanism of JPE can be defined by discovering the adsorption isotherm adsorption model on the steel surface. The linear curve plot of the inhibitor concentration of 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm is displayed in Figure 6. Langmuir adsorption isotherm pattern is displayed in curve (a) Freundlich, (b) Temkin and (c) Frumkin. The adsorption isotherm equations are as follows. Based on the value of each R² determinant coefficient, the appropriate adsorption isotherm pattern at the concentration of 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm is Langmuir where it has C_{inh} big influence on the adsorption isotherm which is shown by R² value reaching 0.988.

The thermodynamic parameter for the higher JPE inhibitor efficiency was shown in table 3. In Table 3, it shown that at the concentration of 1000 ppm was around -20 KJ/mol. This indicated that there was interaction between inhibitor molecules with adsorbed chlorin ion on carbon steel surface which forms protective layer through the physical adsorption [22]. The positive value of enthalpy indicated that the

adsorption process of JPE was endothermic process and there

was a regularity of energy, so that the corrosion process was slowed down [34].

Table 4 was shown activation parameters for both corrosion in the absence inhibitor and corrosion inhibition at 1000 ppm JPE inhibitor between 298°K – 318°K. The addition of JPE inhibitor in HCl 1 M solution decreased the reaction rate and it was needed higher energy of activation to trigger the reaction [35]. The increase of energy of activation could be observed from the physisorption occurrence. This was confirmed by the decrease in inhibitor efficiency if the temperature was increased [6].

Table 4 was shown activation parameters for both corrosion in the absence inhibitor and corrosion inhibition at 1000 ppm JPE inhibitor between 298°K – 318°K. The addition of JPE inhibitor in HCl 1 M solution decreased the reaction rate and it was needed higher energy of activation to trigger the reaction [35]. The increase of energy of activation could be observed from the physisorption occurrence. This was confirmed by the decrease in inhibitor efficiency if the temperature was increased [6].

Table 4 Activation Parameters for Both Corrosion in The Absence and Present JPE Inhibitor

Concentration (ppm)	T °K	i _{corr} (A/cm ²)	E _a (KJ/mol)	ΔS° KJ/mol°K	ΔH° KJ/mol
Blank	298	0.00038	31.52	-0.27	28.97
	308	0.00082			
	318	0.00084			
1000	298	0.00004	102.66	-0.05	100.12
	308	0.00021			
	318	0.00046			

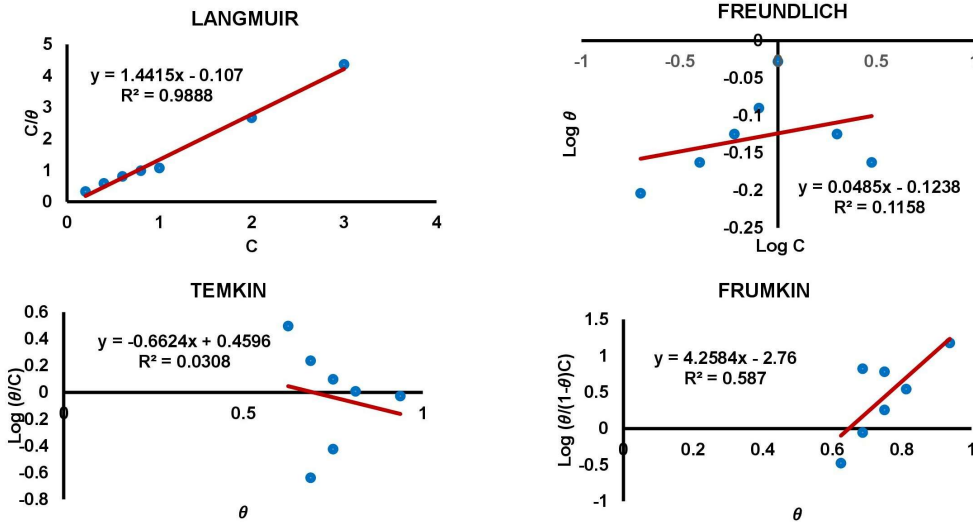


Figure 6 The linear curve plot of Langmuir, Freundlich, Temkin and Frumkin adsorption patterns at the concentration of 200 ppm, 400 ppm, 600 ppm, 800 ppm, 1000 ppm, 2000 ppm and 3000 ppm

3.4 Inhibitor Adsorption Mechanism

The adsorption of JPE inhibitor on the carbon steel surface can occur through physical, chemical or both mechanisms. Based on the result of potentiodynamic polarization and the thermodynamic parameters, the inhibitor adsorption of JPE on the carbon steel surface indicated physical adsorption. It was illustrated in Figure 7. This illustration described the way of JPE molecules could adsorb on the steel surface and prevent the corrosion.

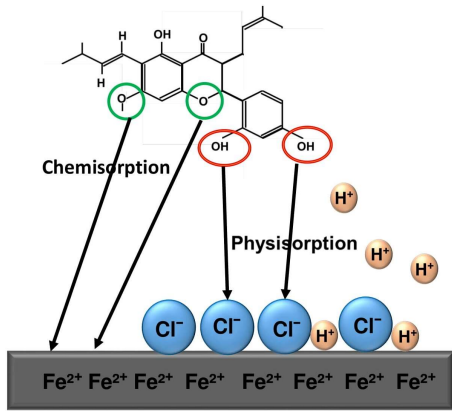
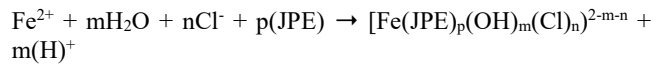


Figure 7 Illustration of inhibition of JPE

In the physisorption, Chloride ions present in the corrosive solution can be adsorbed onto the positively charged carbon steel surface due to their electrostatic interactions. The active substances in the JPE, such as artocarpin, protonated and reacted to chlorine ions that have been absorbed on the carbon steel surface. The transformation from the low stable chloro iron complex to a higher stable iron-inhibitor complex was the causes.

The formed of complex based on interactions of donor acceptor like interaction between O atoms of neutral species and p electrons. Besides that, the interaction between π electrons on cation species and the d orbital that vacant of iron was the other ones. The soluble of iron complex that formed was depended on the the hydroxyl group and inhibitor molecule. Subsequently, the hydroxyl group was replaced by

the molecule of inhibitor. Thus, the mechanism of JPE inhibitor adsorption followed this react:



The formation of FeOH^+ and $[\text{FeClOH}]^-$ intermediates was the first reaction. The next, FeOH^+ and $[\text{FeClOH}]^-$ was convert to $\gamma\text{-Fe}_2\text{O}_3$ and $\gamma\text{-FeOOH}$ and formed oxide layer. The inhibitor molecules were reacting with $[\text{FeClOH}]^-$ at the pores of oxide layer, and formed the stable complex $[\text{Fe}(\text{JPE})_p(\text{OH})_m(\text{Cl})_n]^{2-m-n}$. The complex formed would adsorb at the surface of carbon steel and reduce corrosion rate.[36].

3.5 Adsorption Layer

The characteristics of the adsorption layer on the specimen surface can be studied through its functional groups. Based on the comparison between the IR spectra of the JPE and the IR spectra of the adsorption layer, the characteristics of the adsorption layer were almost the same as the characteristics of the JPE. However, the wavenumber of functional groups of the adsorption layer shifted from the wavenumber of functional groups of JPE. This shown in figure 8.

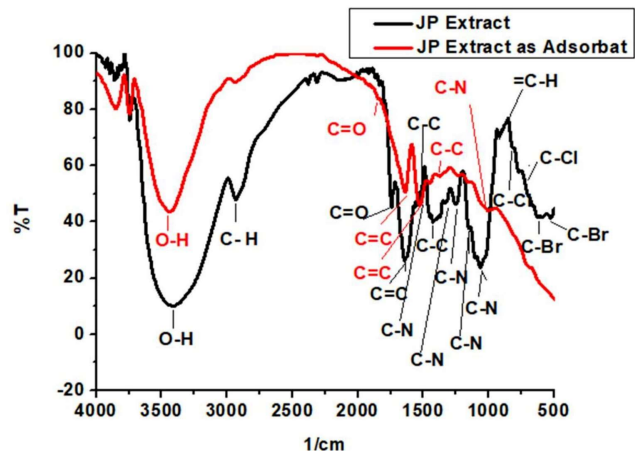


Figure 8 The shift of the wavenumber of functional group of JPE until it was adsorbed on AISI 1037 carbon steel surface

The aromatic wavenumber shifted from of 1426.06 cm^{-1} to 1449.2 cm^{-1} and from 1518.64 cm^{-1} to 1526.35 cm^{-1} . The alcohols wavenumber shifted from of 3414.5 cm^{-1} to 3439.6 cm^{-1} . The shifts also occur in the wavenumber of the carboxylic acid, anhydrides, and alkenes fungsi functional groups. The wavenumber of the carboxylic acid shifted from 2932.36 cm^{-1} to 2942 cm^{-1} , the anhydrides wavenumber shifted from 1742.36 cm^{-1} to 1846.51 cm^{-1} , and the alkenes wavenumber shifted from 1644 cm^{-1} to 1638.21 cm^{-1} . The shift of wavenumber did not change the functional groups because it was still in the wavenumber range.

3.6 The Analysis of Metal Surface

The Surface morphology of AISI 1037 carbon steel before and after immersion in 1 M HCl without or with JPE inhibitor was provided by SEM result. The change of surface morphology was shown at figure 9 presented the smooth surface before the process of corrosion (Figure 9 a). Pits and cracks appear after immersion in 1 M HCl (Figure 9 b). They decrease after the addition of an inhibitor (figure 9 c-f). This shown that the addition of JPE inhibitor in acidic environment caused a reduction of corrosion rate.

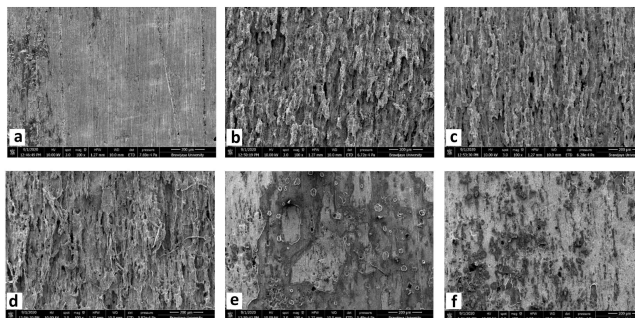


Figure 9 The images of Scanning Electron spectroscopy of AISI 1037 carbon steel surface in 250x before corrosion (a), after immersion in 1 M HCl (b), after immersion in 1 M HCl with JP extract inhibitor 200 ppm (c), after immersion in 1 M with JPE inhibitor 600 ppm (d), after immersion in 1 M HCl with JPE inhibitor 1000 ppm (e), after immersion in 1M HCl with JPE inhibitor 3000 ppm

3.7 The Comparison on Inhibitor Efficiency

The other fruit peel extract as corrosion inhibitors was used to compare the inhibitory ability of JPE compared to other fruit peel extracts. This can be observed from the inhibitor efficiencies. Some of them were garlic peel [38], garcinia indica peel [39], Musa paradisia peel [21], calamansi peel [40], grapefruit peel [41], cumcumber peel [42], pumpkin peel [43], carica papaya peel [44], punica granatum peel [45], aqueous brown onion peel [46], musa acuminate fruit peel [47], banana peel [48], lemon peel [49], longan peel [50], lychee peel [19], mangifera indica peel [51], almond peel [52], mango peel [53], orange peel [53], musa sapientum peel [54], sweet melon peel [20], green pea peel [55], mangosteen peel [56] and watermelon peel [22]. The comparison is shown in the figure 10.

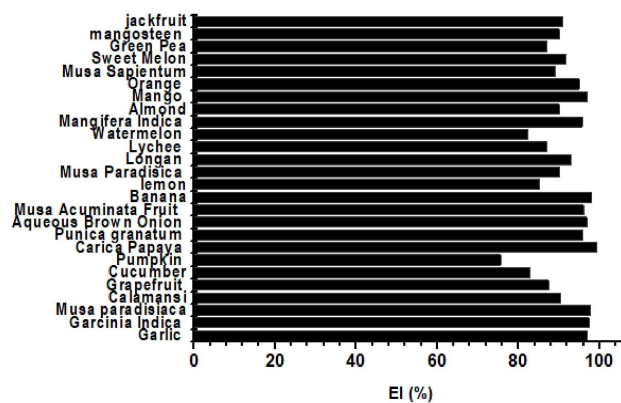


Figure 10 The comparisson of inhibition efficiency of JPE and the others

4. CONCLUSION

JPE could be used as environmentally friendly inhibitor for AISI 1037 carbon steel in HCl solution. The functional groups in antioxidant compound molecules could be identified through FTIR spectrum of the extract. The result of mass spectroscopy indicated antioxidant compounds where the highest abundance was found in artocarpin. In this study, the most efficient inhibitor was found when the inhibitor concentration of 1000 ppm was added into 1 M HCl solution. The inhibitor efficiency achieved 90.98% using potentiodynamic polarization method. Adsorption occurred at concentration of 200 ppm up to 3000 ppm followed Langmuir pattern. The value of free energy and the activation energy indicated physical adsorption. The IR spectra of protective layer formed by the inhibitor indicated that the JPE was maybe adsorbed on the surface of AISI 1037 carbon steel.

5. REFERENCES

- [1] P. R. Roberge and R. Pierre, *Handbook of Corrosion Engineering Library of Congress Cataloging-in-Publication Data.*
- [2] C. Monticelli, *Corrosion inhibitors*. Elsevier, 2018.
- [3] Z. Tang, "A review of corrosion inhibitors for rust preventative fluids," *Curr. Opin. Solid State Mater. Sci.*, vol. 23, no. 4, pp. 1–16, 2019.
- [4] A. Ehsani, M. G. Mahjani, M. Hosseini, R. Safari, R. Moshrefi, and H. M. Shiri, "Journal of Colloid and Interface Science *Evaluation* of Thymus vulgaris plant extract as an eco-friendly corrosion inhibitor for stainless steel 304 in acidic solution by means of electrochemical impedance spectroscopy , electrochemical noise analysis and ," *J. Colloid Interface Sci.*, vol. 490, pp. 444–451, 2017.
- [5] M. Benarioua, A. Mihi, N. Bouzeghaia, and M. Naoun, "Mild steel corrosion inhibition by Parsley (Petroselinum Sativum) extract in acidic media," *Egypt. J. Pet.*, 2019.
- [6] P. Muthukrishnan, B. Jeyaprabha, and P. Prakash, "Mild steel corrosion *inhibition* by aqueous extract of Hyptis Suaveolens leaves," *Int. J. Ind. Chem.*, vol. 5, no. 1, pp. 1–11, 2014.
- [7] R. S. Nathiya and V. Raj, "Evaluation of Dryopteris cochleata leaf extracts as green inhibitor for corrosion of aluminium in 1 M H₂SO₄," *Egypt. J. Pet.*, 2017.
- [8] X. Li, S. Deng, and H. Fu, "Inhibition of the corrosion of

- steel in HCl, H₂SO₄ solutions by bamboo leaf extract," *Corros. Sci.*, vol. 62, pp. 163–175, 2012.
- [9] M. Ramezanzadeh, G. Bahlakeh, Z. Sanaei, and B. Ramezanzadeh, "Studying the Urtica dioica leaves extract inhibition effect on the mild steel corrosion in 1 M HCl solution: Complementary experimental, ab initio quantum mechanics, Monte Carlo and molecular dynamics studies," *J. Mol. Liq.*, vol. 272, pp. 120–136, 2018.
- [10] S. A. Umoren, U. M. Eduok, M. M. Solomon, and A. P. Udoh, "Corrosion inhibition by leaves and stem extracts of *Sida acuta* for mild steel in 1 M H₂SO₄ solutions investigated by chemical and spectroscopic techniques," *Arab. J. Chem.*, vol. 9, pp. S209–S224, 2016.
- [11] J. Bhawsar, P. K. Jain, and P. Jain, "Experimental and computational studies of *Nicotiana tabacum* leaves extract as green corrosion inhibitor for mild steel in acidic medium," *Alexandria Eng. J.*, vol. 54, no. 3, pp. 769–775, 2015.
- [12] N. El Hamdani, R. Fdil, M. Tourabi, C. Jama, and F. Bentiss, "Alkaloids extract of *Retama monosperma* (L.) Boiss. seeds used as novel eco-friendly inhibitor for carbon steel corrosion in 1 M HCl solution: Electrochemical and surface studies," *Appl. Surf. Sci.*, vol. 357, pp. 1294–1305, 2015.
- [13] A. Singh, Y. Lin, E. E. Ebenso, W. Liu, J. Pan, and B. Huang, "Ginkgo biloba fruit extract as an eco-friendly corrosion inhibitor for J55 steel in CO₂ saturated 3.5% NaCl solution," *J. Ind. Eng. Chem.*, vol. 24, pp. 219–228, 2015.
- [14] 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*, vol. 282. Elsevier B.V, 2019.
- [15] A. Dehghani, G. Bahlakeh, B. Ramezanzadeh, and M. Ramezanzadeh, "A combined experimental and theoretical study of green corrosion inhibition of mild steel in HCl solution by aqueous *Citrullus lanatus* fruit (CLF) extract," *J. Mol. Liq.*, vol. 279, pp. 603–624, 2019.
- [16] M. Manssouri *et al.*, "Adsorption properties and inhibition of mild steel corrosion in HCl solution by the essential oil from fruit of Moroccan *Ammodaucus leucotrichus*," *J. Mater. Environ. Sci.*, vol. 6, no. 3, pp. 631–646, 2015.
- [17] S. Umoren, I. B. Obot, Z. Gasem, and N. A. Odewunmi, "Experimental and Theoretical Studies of Red Apple Fruit Extract as Green Corrosion Inhibitor for Mild Steel in HCl Solution," *J. Dispers. Sci. Technol.*, vol. 36, no. 6, pp. 789–802, 2015.
- [18] R. Haldhar, D. Prasad, and A. Saxena, "Myristica fragrans extract as an eco-friendly corrosion inhibitor for mild steel in 0.5 M H₂SO₄ solution," *J. Environ. Chem. Eng.*, vol. 6, no. 2, pp. 2290–2301, 2018.
- [19] L. L. Liao, S. Mo, H. Q. Luo, and N. B. Li, "Corrosion protection for mild steel by extract from the waste of lychee fruit in HCl solution: Experimental and theoretical studies," *J. Colloid Interface Sci.*, vol. 520, pp. 41–49, 2018.
- [20] M. T. Saeed, M. Saleem, S. Usmani, I. A. Malik, F. A. Al-Shammari, and K. M. Deen, "Corrosion inhibition of mild steel in 1 M HCl by sweet melon peel extract," *J. King Saud Univ. - Sci.*, vol. 31, no. 4, pp. 1344–1351, 2019.
- [21] G. Ji, S. Anjum, S. Sundaram, and R. Prakash, "Musa paradisica peel extract as green corrosion inhibitor for mild steel in HCl solution," *Corros. Sci.*, vol. 90, pp. 107–117, 2015.
- [22] N. A. Odewunmi, S. A. Umoren, and Z. M. Gasem, "Watermelon waste products as green corrosion inhibitors for mild steel in HCl solution," *J. Environ. Chem. Eng.*, vol. 3, no. 1, pp. 286–296, 2015.
- [23] N. M'hiri, D. Veys-Renaux, E. Rocca, I. Ioannou, N. M. Boudhrioua, and M. Ghoul, "Corrosion inhibition of carbon steel in acidic medium by orange peel extract and its main antioxidant compounds," *Corros. Sci.*, vol. 102, no. 2016, pp. 55–62, 2016.
- [24] A. Saxena, A. S. Bawa, and P. S. Raju, *Jackfruit (Artocarpus heterophyllus Lam.)*. Woodhead Publishing Limited, 2011.
- [25] M. N. H. Daud, A. Wibowo, N. Abdullah, and R. Ahmad, "Bioassay-guided fractionation of *Artocarpus heterophyllus* L. J33 variety fruit waste extract and identification of its antioxidant constituents by TOF-LCMS," *Food Chem.*, vol. 266, pp. 200–214, 2018.
- [26] 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*, vol. 277. Elsevier B.V, 2019.
- [27] F. Gapsari, K. A. Madurani, F. M. Simanjuntak, A. Andoko, H. Wijaya, and F. Kurniawan, "Corrosion inhibition of honeycomb waste extracts for 304 stainless steel in sulfuric acid solution," *Materials (Basel)*, vol. 12, no. 13, 2019.
- [28] B. S. Prathibha, H. P. Nagaswarupa, P. Kotteeswaran, and V. Bheemaraju, "Inhibiting effect of Quaternary ammonium compound on the corrosion of mild steel in 1M Hydrochloric acid solution, its adsorption and kinetic characteristics," *Mater. Today Proc.*, vol. 4, no. 11, pp. 12245–12254, 2017.
- [29] S. Table and S. Table, "IR Tables, UCSC Table 1. Characteristic IR Absorption Peaks of Functional Groups * Vibration Alkanes," pp. 1–6.
- [30] F. Gapsari, R. Soenoko, A. Suprpto, and W. Suprpto, "Bee Wax Propolis Extract as Eco-Friendly Corrosion Inhibitors for 304SS in Sulfuric Acid," *Int. J. Corros.*, vol. 2015, 2015.
- [31] M. G. Hosseini, M. R. Arshadi, T. Shahrabi, and M. Ghorbani, "Synergistic influence of benzoate ions on inhibition of corrosion of mild steel in 0.5 M sulphuric acid by benzotriazole," *IJE Trans. B*, vol. 16, no. 3, pp. 255–264, 2003.
- [32] M. H. Hussin, A. A. Rahim, M. N. Mohamad Ibrahim, and N. Brosse, "Improved corrosion inhibition of mild steel by chemically modified lignin polymers from *Elaeis guineensis* agricultural waste," *Mater. Chem. Phys.*, vol. 163, pp. 201–212, 2015.
- [33] W. Suprpto, R. Soenoko, and F. Gapsari, "Comparison of the analytical and experimental models of 304SS corrosion rate in 0.5 M H₂SO₄ with bee wax propolis extract," *Eng. Rev.*, vol. 38, no. 2, pp. 182–188, 2018.

- [34] A. O. Yüce and G. Kardaş, "Adsorption and inhibition effect of 2-thiohydantoin on mild steel corrosion in 0.1M HCl," *Corros. Sci.*, vol. 58, pp. 86–94, 2012.
- [35] W. Huang, L. Hu, C. Liu, J. Pan, Y. Tian, and K. Cao, "Corrosion inhibition of carbon steel by lepidine in HCl solution," *Int. J. Electrochem. Sci.*, vol. 13, no. 11, pp. 11273–11285, 2018.
- [36] A. K. Satapathy, G. Gunasekaran, S. C. Sahoo, K. Amit, and P. V. Rodrigues, "Corrosion inhibition by *Justicia gendarussa* plant extract in hydrochloric acid solution," *Corros. Sci.*, vol. 51, no. 12, pp. 2848–2856, 2009.
- [37] M. Noori, "Inhibitive Assesment of Stearamide as a Corrosion Inhibitor for Mild Steel in HCl Solution," *Int. J. Eng.*, vol. 25, no. 2 (C), pp. 119–126, 2012.
- [38] B. E. A. Rani and B. B. J. Basu, "Green inhibitors for corrosion protection of metals and alloys: An overview," *Int. J. Corros.*, vol. 2012, no. i, 2012.
- [39] A. Thomas, M. Prajila, K. M. Shainy, and A. Joseph, "A green approach to corrosion inhibition of mild steel in hydrochloric acid using fruit rind extract of *Garcinia indica* (Binda)," *J. Mol. Liq.*, vol. 312, p. 113369, 2020.
- [40] G. C. E. Arguelles, M. C. D. Torres, B. J. U. Wu, J. G. Olay, and R. C. Ong, "(Calamansi) Citrofortunella Microcarpa Rind Extract As Plant Derived Green Corrosion Inhibitor for Mild Steel in 1.0M Hcl," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 778, no. 1, 2020.
- [41] A. Batah, A. Anejjar, L. Bammou, M. Belkhaouda, R. Salghi, and L. Bazzi, "Carbon steel corrosion inhibition by rind and leaves extracts of grapefruit in 1.0 M hydrochloric acid," *J. Mater. Environ. Sci.*, vol. 8, no. 9, pp. 3070–3080, 2017.
- [42] G. M. Al-senani, "Corrosion Inhibition of Carbon Steel in Acidic Chloride Medium by Cucumis Sativus (cucumber) Peel Extract," *Int. J. Electrochem. Sci.*, vol. 11, no. 1, pp. 291–302, 2016.
- [43] R. Anaee, "Corrosion Inhibition by Pumpkin Peels Extract in Petroleum Environment," *Am. Chem. Sci. J.*, vol. 5, no. 1, pp. 32–40, 2015.
- [44] S. E. Agarry, K. M. Oghenejoboh, O. A. Aworanti, and A. O. Arinkoola, "Biocorrosion inhibition of mild steel in crude oil-water environment using extracts of *Musa paradisiaca* peels, *Moringa oleifera* leaves, and *Carica papaya* peels as biocidal-green inhibitors: kinetics and adsorption studies," *Chem. Eng. Commun.*, vol. 206, no. 1, pp. 98–124, 2019.
- [45] M. Behpour, S. M. Ghoreishi, M. Khayatkashani, and N. Soltani, "Green approach to corrosion inhibition of mild steel in two acidic solutions by the extract of *Punica granatum* peel and main constituents," *Mater. Chem. Phys.*, vol. 131, no. 3, pp. 621–633, 2012.
- [46] K. C. R. Ferreira *et al.*, "Corrosion Inhibition of Carbon Steel in HCl Solution by Aqueous Brown Onion Peel Extract," *Int. J. Electrochem. Sci.*, vol. 11, no. 1, pp. 406–418, 2016.
- [47] N. Gunavathy and S. C. Murugavel, "Corrosion inhibition studies of mild steel in acid medium using *Musa acuminata* fruit peel extract," *E-Journal Chem.*, vol. 9, no. 1, pp. 487–495, 2012.
- [48] M. Sangeetha, S. Rajendran, J. Sathiyabama, and P. Prabhakar, "Eco friendly extract of Banana peel as corrosion inhibitor for carbon steel in sea water," *J. Nat. Prod. Plant Resour.*, vol. 2, no. 5, pp. 601–610, 2012.
- [49] K. Agarwal, "Fenugreek leaves and lemon peel as green corrosion inhibitor for mild steel in 1M HCl medium," *J. Mater. Sci. Surf. Eng.*, vol. 1, no. 2, pp. 44–48, 2014.
- [50] L. L. Liao, S. Mo, H. Q. Luo, and N. B. Li, "Longan seed and peel as environmentally friendly corrosion inhibitor for mild steel in acid solution: Experimental and theoretical studies," *J. Colloid Interface Sci.*, vol. 499, pp. 110–119, 2017.
- [51] O. O. Ogunleye, O. A. Eletta, A. O. Arinkoola, and O. O. Agbede, "Gravimetric and quantitative surface morphological studies of *Mangifera indica* peel extract as a corrosion inhibitor for mild steel in 1 M HCl solution," *Asia-Pacific J. Chem. Eng.*, vol. 13, no. 6, pp. 19–21, 2018.
- [52] S. Pal, H. Lgaz, P. Tiwari, I. M. Chung, G. Ji, and R. Prakash, "Experimental and theoretical investigation of aqueous and methanolic extracts of *Prunus dulcis* peels as green corrosion inhibitors of mild steel in aggressive chloride media," *J. Mol. Liq.*, vol. 276, pp. 347–361, 2019.
- [53] J. C. Da Rocha, J. A. Da Cunha Ponciano Gomes, and E. D'Elia, "Aqueous extracts of mango and orange peel as green inhibitors for carbon steel in hydrochloric acid solution," *Mater. Res.*, vol. 17, no. 6, pp. 1581–1587, 2014.
- [54] N. R. Rosli, S. M. Yusuf, A. Sauki, and W. M. R. W. Razali, "*Musa sapientum* (Banana) peels as green corrosion inhibitor for mild steel," *Key Eng. Mater.*, vol. 797, pp. 230–239, 2019.
- [55] M. Srivastava, P. Tiwari, S. K. Srivastava, A. Kumar, G. Ji, and R. Prakash, "Low cost aqueous extract of *Pisum sativum* peels for inhibition of mild steel corrosion," *J. Mol. Liq.*, vol. 254, pp. 357–368, 2018.
- [56] A. Ngatin and R. P. Sihombing, "Utilization of mangosteen extract as a corrosion inhibitor of carbon steel in acid environment (HCl)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 830, no. 2, 2020.