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GRAVIMETRIC AND ELECTROCHEMICAL TEST OF *ETLINGERA ELATIOR* INFLORESCENCE EXTRACT AS GREEN CORROSION INHIBITOR

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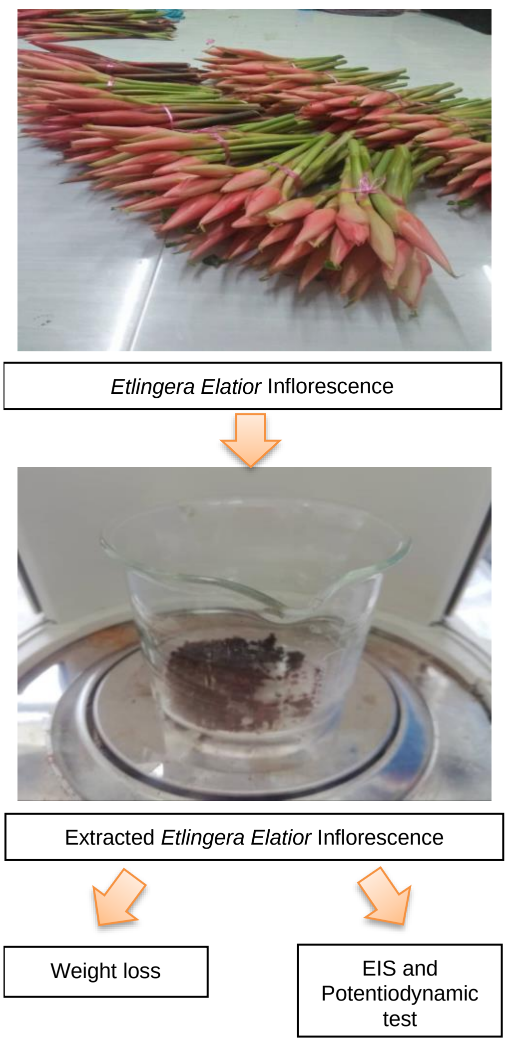
Graphical abstract



Abstract

At present, organic corrosion inhibitors which are commonly used such as silicate and phosphate have a high level of toxicity. It has prompted the search for green corrosion inhibitors because of its eco-friendly properties and has a lower level of toxicity. Therefore, this study has been conducted to investigate the inhibition efficiency (IE%) and corrosion rate of mild steel in 0.5 M HCl acidic medium. The data obtained through weight loss and the electrochemical method at various concentrations and temperatures. The surface morphologies was observed using Scanning Electron Microscope (SEM). Different experimental conditions were also used such as electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization curves (PPC). EIS findings revealed that the addition of studied inhibitors prevented the degradation of mild steel in HCl solution, hence leading to a high value of polarization resistance compared to the blank solution. Besides that, the PPC results suggested that the tested samples had a mixed-type effect which decreased the anodic and cathodic corrosion reactions. Surface characterization by SEM illustrated a notable decrease in surface roughness of mild steel after the addition of inhibitors. Outcomes from the present study indicates that the *Etlingera Elatior* inflorescence extract acts as a good corrosion inhibitor for mild steel sample in HCl solution with IE% value above 93.63 %. Formation of the protective layer becomes weaker as the temperature raises.

Keywords: *Etlingera Elatior* Inflorescence Extract, Corrosion Test, Mild Steel, Corrosion Rate, HCl Acid Solution

Abstrak

Pada masa kini, perencat kakisan organik yang biasa digunakan seperti silikat dan fosfat mempunyai tahap ketoksikan yang tinggi maka ia telah mendorong kepada pencarian perencat kakisan hijau kerana sifatnya yang mesra alam dan ketoksikan yang rendah. Justeru, kajian ini telah dibuat untuk mengkaji kecekapan perencatan dan kadar kakisan keluli lembut dalam medium berasid 0.5M HCl. Dapatan diperoleh melalui kaedah kehilangan berat dan elektrokimia pada pelbagai kepekatan dan suhu. Morfologi permukaan diperhatikan menggunakan Mikroskop Imbasan Elektron (SEM). Keadaan eksperimen yang berbeza juga digunakan seperti Spektroskopi Impedans Elektrokimia (EIS) dan Lengkung Polarisasi Potensiodinamik (PPC). Penemuan EIS mendedahkan penambahan perencat yang dikaji menghalang kemerosotan keluli lembut dalam larutan HCl, justeru membawa kepada nilai rintangan polarisasi yang tinggi berbanding dengan larutan tanpa perencat kakisan.

Selain itu, daripada keputusan PPC mencadangkan sampel yang diuji mempunyai kesan jenis campuran, mengurangkan tindak balas kakisan anodik dan katodik. Pencirian permukaan oleh SEM menggambarkan penurunan ketara dalam kekasaran permukaan keluli lembut selepas penambahan perencat. Hasil daripada kajian ini menunjukkan bahawa ekstrak Etlingera Elatior bertindak sebagai perencat kakisan yang baik untuk sampel keluli lembut dalam larutan HCl dengan nilai kecekapan melebihi 93.63%. Pembentukan lapisan pelindung menjadi lemah apabila suhu meningkat.

Kata kunci: Ekstrak Kuntum Etlingera Elatior, Ujian Kakisan, Keluli Lembut, Kadar Kakisan, Larutan Asid HCl

1.0 INTRODUCTION

Mild steel (MS) is a material which has various applications especially in oil and gas industry. It has been widely used in petroleum production, refining, chemical processing, metal processing equipment and constructions [1]. Because of its adequate mechanical properties such as ease of availability and fabrication, economic considerations despite of low cost has made mild steel as the material choice in pipeline systems [2]. However, the disadvantages of mild steels include poor resistance to corrosion in aggressive acid solutions and it might extensively suffer when its surface is unprotected.

Hydrochloric acid is a mineral acid broadly applied in many industrial processes such as removing rust on metal, steel pickling, acid descaling, cleaning of boiler tubes, oil well acidizing, and petroleum processing up to 60 ˚C in temperature [3]. Acidic solution applications led to corrosion attacks on surfaces of metal substrate [4]. Several approaches have been utilized to defeat the corrosion process. One of the most common and effective yet economic way to prevent the corrosion of metals in acidic medium is inhibitor [5]. Inhibitors consumption as corrosion preventers has increased over the years.

Aqueous extracts and oils found in barks, leaves, seeds, fruits and roots of most plants have been used as corrosion inhibitors in acidic medium with no adverse effects [6-12]. Introduction of green corrosion inhibitors from plant extracts and biological materials as a green alternative are extensively fascinated by the great attention from academic and industrial chemists [13].

Naturally occurring substances such as tomato peels [14], *Zenthoxylam alatum* extract [15], *Phyllantus amarus* extract [16], *Eclipta alba* [17], *Henna* extract [18], *Justicia gendarussa* plant extract [19], *Sida* acuta [20], *Sebania sesban* extract [21], *Mollugo cerviana* [22], *Elaeis guineesis* frond lignin [23], *Tinospora* extract [24], *Griffonia simplicifolia* extract [25], *Chromolaena* extracts [26], *Melia azedarach* [27], *Areca* fat [28] has been used as corrosion inhibitors at various environmental conditions, including various tannin extracts such as chestnut tannin [29], *Rhizophora apiculata tannin* [30], Black wattle tannin [31], *Rhizophora racemosa* [32].

The kantan plant (*Etlingera Elatior*) is known as a perennial herbaceous plant belonging to the *Zingiberacea* family [33]. The inflorescence of *Etlingera Elatior* possesses a unique flavor and aroma. It grows up to 5-6m tall forming clumps and the inflorescences are large and very attractive with showy bracts with a color of pink to red and sometimes white. It is used traditionally as flavouring and medicine. Moreover, there has been an increasing amount of literature in antioxidants and phytochemistry. *Etlingera Elatior* inflorescence is high in antioxidant properties. These antioxidant properties which occur naturally in the plant include flavonoid and polyphenols.

One of the parameters that influences the adsorption of corrosion inhibitor is temperature. The effect of temperature will alter the formation of protective layers formed on metal surface. To be clearer, the aim of this study is to investigate the effectiveness of *Etlingera Elatior* inflorescence extract as green corrosion inhibitor on the mild steel surface using the gravimetric (weight loss) and electrochemical test (EIS and potentiodynamic polarization curves) technique.

2.0 METHODOLOGY

2.1 Plant Material

Etlingera Elatior samples used in this study was purchased from local suppliers in Jenaris, Kajang, Selangor.

2.2 Extraction of Etlingera Elatior

The plant petals were first thoroughly washed under tap water in order to remove impurities. They were then cut into small parts and dried to ambient temperature. After the end of the exposure process within 14 days or after all the dried petals became rot, they were grounded using a blender to form a fine powder and stored in a universal glass bottle which was then placed in the refrigerator. For the extraction of *Etlingera Elatior* inflorescence, 25 g of powder with some modifications was extracted using 200 ml of 50

% ethanol type of solvent for 2 hours at temperature of 65 ˚C [34]. The solution had been evaporated using a rotating evaporator for 45 minutes at a temperature of 90 ˚C. The extract stored in the universal glass bottle and placed in the refrigerator. For the preparation of corrosion inhibitor stock solution, 2 g of extracted *Etlingera Elatior* was diluted with 0.5 HCl to prepare a series of inhibitor stock solutions with numerous concentrations of 250, 450, 650, 950, 1050 ppm for weight loss measurement. The concentrations of stock solution of corrosion inhibitor were different for the electrochemical test which were 150, 350, 550, 750, 950, 1150 and 1350 ppm.

2.3 Mild Steel Specimen and Medium

The various experiments were done using mild steel SAE/AISI grade 1015 metal samples. The specimens have compositions of C (0.15%), Mn (0.40%), P (0.02%), S (0.03%) and Fe (99.4%). The specimens were machined into pieces measuring 2 × 2 × 0.2 cm^3. Then, their surfaces were mechanically polished with silicon-carbide paper with 120-1200-grit. Finally, they were gently washed using distilled water and degreased with acetone before use. The mild steel sample was then thoroughly cleaned using distilled water, dried and used for weight loss studies. For electrochemical studies, only 1 cm^2 of surface area was exposed and another 1cm^2 of surface area was covered using an electrical tape. The test solution of 0.5 M HCl was prepared by diluting analytical grade HCl (Chemiz).

2.4 Chemical Compound in Etlingera Elatior Extract

Chemical compound presented in *Etlingera Elatior* extract was analyzed using gas chromatography mass spectroscopy (GC-MS). The gas chromatograph mass spectrometer (GC-MS) analysis was performed on an Agilent 7890A gas chromatograph (GC) directly coupled to the mass spectrometer system (MS) of an Agilent 5975C inert MSD with triple-axis detector. All peaks from raw GC chromatogram were identified by using MSD Chemstation. A library search was carried for all the peaks using the NIST/EPA/NIH version 2.0. The results were then combined in a single peak table.

2.5 Weight Loss Method

Performance of the corrosion of mild steel in 0.5 M HCl was determined by weight loss measurements at 0 ˚C, 15 ˚C, 25 ˚C, 45 ˚C, 65 ˚C. Previously, weighed mild steel coupons were immersed in 50 ml of 0.5 M HCl solution containing varying amounts of inhibitor concentrations (250 ppm, 450 ppm, 650 ppm, 950 ppm and 1050ppm) for 168 hours at room temperature. The mild steel specimen immersed in 0.5 M HCl without the presence of inhibitor performed as blank. After 168 hours, the coupons were taken out, washed with water, cleaned with acetone, dried and the samples were weighed before and after immersion in a corrosive medium. The equation of weight loss is as shown in equation (1).

$$\text{Weight loss } (\Delta w) = \text{Wi} - \text{wf} \quad (1)$$

The corrosion rate and inhibition efficiencies of the flower extracts were then calculated using the equations (2) and (3) respectively.

$$Cr(\text{mmy}^{-1}) = \frac{8.76\times10^4\times\Delta W}{\rho TA} \quad (2)$$

where ΔW is the difference between initial and final weights of mild steel (mg), ρ is the density of mild steel (g cm^{-3}) and A is the surface area of mild steel (cm^2). The immersion time per hour (h) denoted as T.

$$\text{IE\%} = \left(\frac{Crblank - Crinh}{Crblank}\right) \times 100\% \quad (3)$$

where Cr_{blank} and Cr_{inh} are the corrosion rate values with the presence and absence of *Etlingera Elatior* flower extract, respectively.

2.6 Electrochemical Measurements

The electrochemical measurements (EIS and potentiodynamic polarization) were supplied direct to a software. The instrument used was Gamry 3.2 potentiostat (model: ZRA Reference-3000). The observations were made using a traditional three electrode setup at 25˚C and atmospheric pressure. The reference electrode was a mild steel specimen placed in cold mounting with a 1 cm^2 exposed surface area, whereas the auxiliary and reference electrodes were a saturated calomel electrode (SCE) and a platinum rod, respectively. The measurements were taken by the absence and presence of various concentrations of *Etlingera Elatior* inflorescence extracts. To achieve stability, the mild steel electrode was submerged in the test solution for 30 minutes prior to taking the measurements.

For electrochemical impedance spectroscopic (EIS) measurements, a sinusoidal voltage of potential amplitude 10mV and the frequency range from 10 kHz to 0.1 Hz were implemented. All experiments were carried out at room temperature of 25 ˚C. The purpose of the EIS test was carried out was to provide an understanding of the kinetic and quality of electrochemical procedures for mild steel in acidic media. Electrochemical impedance spectroscopy (EIS) was imposed at the open circuit with 10 points and a max ac voltage amplitude of 10V. The impedance measurements were represented as Nyquist and bode. The inhibition efficiencies (IE%) and corrosion rate, Cr (mmy^{-1}) in the absence and presence of *Etlingera Elatior* extracts inhibitor were calculated from the equation:

$$IE\% = \frac{Rct - Rct\prime}{\text{Rct}} \times 100 \quad (4)$$

Where R_{ct}' and R_{ct} are the charge transfer resistance at the presence and absence of *Etlingera Elatior* in the acidic medium respectively.

$$IE\% = 1 - \left(\frac{Icorr}{I'corr}\right) \times 100 \qquad (5)$$

Where I_{corr} and I'_{corr} denote the current densities at the presence and absence of *Etlingera Elatior* in 0.5 M HCl solution.

2.7 Surface Analysis of Specimen (SEM)

The surface morphology of mild steel was examined when immersed in 0.5 M HCl solution. Mild steel samples with coupon size 2×2×0.2 cm^3 was exposed into the 0.5 M HCl solutions in the presence and absence of 950 ppm *Etlingera Elatior* corrosion inhibitor 168 h at 65 ˚C. Images captured from SEM were recorded using a MERLIN model scanning electron microscope (SEM; ZEISS, Oberkochen, Germany). The location is in the Centre of Research and Instrumentation Management (i-CRIM) laboratory, Universiti Kebangsaan Malaysia (UKM). The SEM experiments were performed at a voltage of 10 kV, using 1.0 k magnification. Meanwhile, the size of each image was fixed at 100 µm.

3.0 RESULTS AND DISCUSSION

3.1 GC-MS Analysis of Etlingera Elatior Extract

The chemical constituents of *Etlingera Elatior* as obtained from the GC-MS chromatographs is represented in Figure 1. A total of 20 peaks at different retention time (RT) were identified. The main components consisted of N-hexadecanoic acid (12.49 %) at RT (42.24 min) peak no. 9, cyclododecane (11.81 %) at RT (32.60 min) peak no. 3, 9,12-octadecanoic acid (Z,Z)- at RT (46.10 min) peak no. 11 and dodecanoic acid (7.71 %) at RT (31.76 min) peak no. 2, among many others. Most of these detected components were known corrosion inhibitors for mild steel in acidic medium.

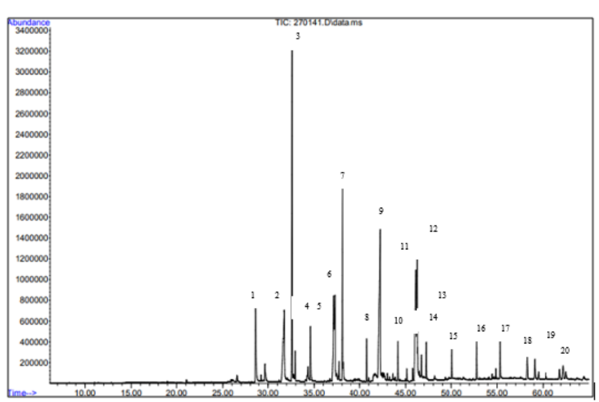


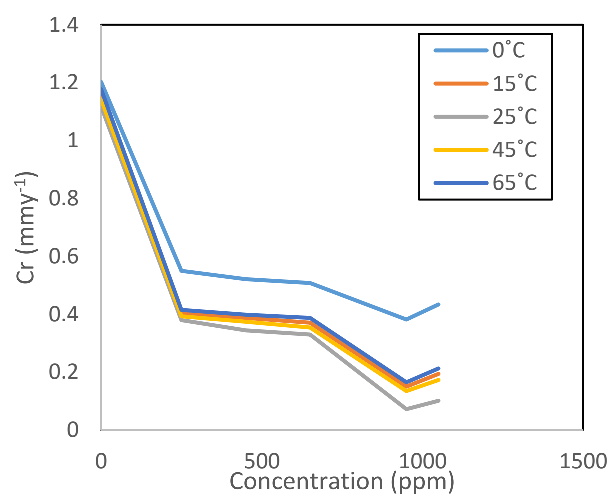
Figure 1 GC-MS chromatographs of *Etlingera Elatior* extract

3.2 Weight Loss Measurements

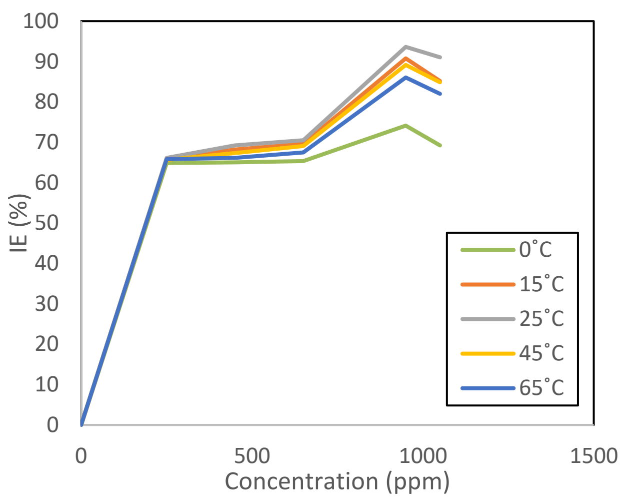
The immersion process was carried out for 168 h at 0 ˚C, 15 ˚C, 25 ˚C, 45˚ C and 65 ˚C in this study. Immersion was investigated out to develop *Etllingera Elatior* inhibitor performance as an environmentally friendly inhibitor in corrosive media with 0.5 M HCl solution at several temperatures. The result of the immersion time at various temperatures illustrated in Figure 2 (a) and (b) indicates the values of corrosion rate (Cr) and inhibition efficiency (IE%) obtained via weight loss measurement.

An entire graph shown in Figure 2 portrays the increase of corrosion rate and the decrease of the IE% value for temperatures of 0 ˚C, 15 ˚C, 45 ˚C and 65 ˚C. At different concentrations for every temperature, IE% increases until 950 ppm and then decreases. This might be the result of absorbed inhibitor molecules desorbing at a higher temperature. Hence, the surface for active corrosion was exposed resulting it to be easily corroded. Immersion time causes the corrosion rate to increase. The longer the length of immersion time, the protective layer that has been formed will be reduced because of the influence from the lengthy interaction with the corrosive media.

From Table 1, it clearly shows that the temperature plays an important role in the corrosion process. The inhibitor's inhibitory efficiency was observed to be most efficient at 25 ˚C with the IE% value stated at 93.62 %. At temperature lower than 25 ˚C, the inhibitor molecules were not active and most of them were at static arrangement. Meanwhile, at temperature higher than 25 ˚C, the inhibitor molecules did not achieve stability because of the kinetic energy among them. As the temperature increases up to 65 ˚C, the mechanism of adsorption of the inhibitor molecule on the mild steel surface obey physical adsorption because physical the value of IE% decreases with temperature [35].



(a)



(b)

Figure 2 *Etlingera Elatior* flower concentrations with corrosion rate (Cr) and IE% at various temperature

Table 1 Cr and IE% results at various temperature in the absence and presence of *Etlingera Elatior* flower extract

Temperature (˚C)	Concentration (ppm)	Cr (mmy^{-1})	IE%
0	0.5M HCl	1.2023	-
	250	0.5498	64.83
	450	0.5201	64.99
	650	0.5076	65.31
	950	0.3811	74.12
	1050	0.4334	69.20
15	0.5M HCl	1.1524	-
	250	0.4009	66.00
	450	0.3868	68.20
	650	0.3696	69.61
	950	0.1492	90.77
	1050	0.1927	85.19
25	0.5M HCl	1.1176	-
	250	0.3789	66.10
	450	0.3437	69.25
	650	0.3297	70.50
	950	0.0713	93.62
	1050	0.1004	91.02
45	0.5M HCl	1.142	-
	250	0.3922	65.66
	450	0.3734	67.30
	650	0.3536	69.04
	950	0.1239	89.15
	1050	0.1727	84.88
65	0.5M HCl	1.1769	-
	250	0.4139	65.83
	450	0.3982	66.17
	650	0.3862	67.49
	950	0.1642	86.05
	1050	0.2121	81.98

3.3 Electrochemical Measurements

3.3.1 Electrochemical Impedance Spectroscopic Studies (EIS)

Electrochemical impedance spectroscopy measurements for mild steel in 0.5 M HCl was evaluated with and without *Etlingera Elatior* inflorescence extract at 25 ˚C (Figure 3). From Figure 3, R_{ct}, R_s and constant phase element (CPE) were shown in equivalent circuit model. The results obtained are represented as Nyquist and bode plot in Figure 4 and Figure 5 respectively. From Table 2, the data obtained for the present study showed in concentrations up to 950 ppm with the highest R_{ct} value of 812.4 Ω cm^2. However, the IE value decreased at 1150 ppm and 1350 ppm which are 30.96 % and 6.94 % respectively. This happened due to the occurring of ion diffusion. The desorption process occurred when an adsorbed substance was released from the interface after having steric hindrance, repulsive force, weak van der waals effect and ionic bond interaction. These lead to low values of inhibition efficiency for both 1150 ppm and 1350 ppm concentrations. Hence, demonstrating a minimum distribution value of charge storage and ohmic contact of the molecules with substrates.

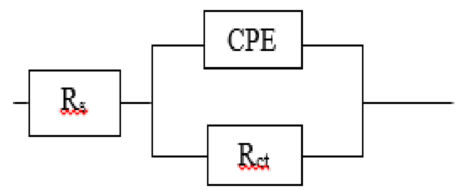


Figure 3 Model of equivalent circuit used to illustrate experimental data

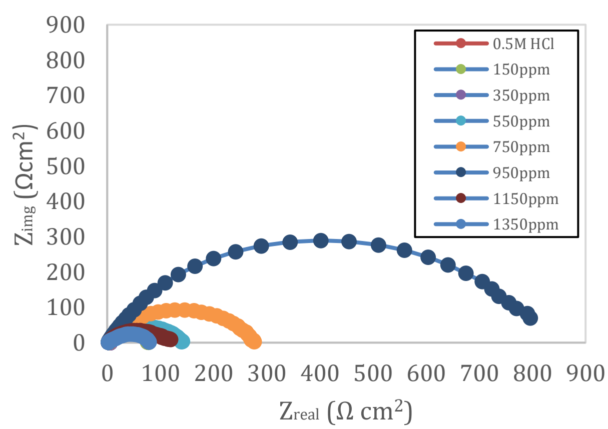


Figure 4 Nyquist plot for mild steel in 0.5 M HCl solution at 25 ˚C in the absence and presence of various concentrations of *Etlingera Elatior* inflorescence extract

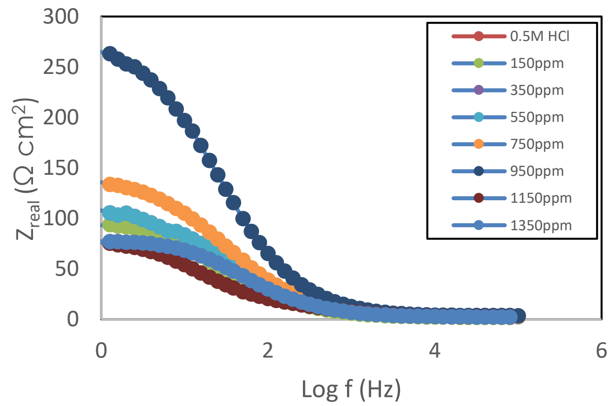


Figure 5 Bode plots for mild steel in 0.5 M HCl solution in the absence and presence of various concentrations of *Eltingera Elatior* inflorescence extract

Table 2 The value obtained from fitted EIS curves for corrosion of mild steel with the presence and absence of *Elingera Elatior* extract in 0.5 M HCl

Concentrations (ppm)	R_{ct} (Ω cm²)	Rs (Ω cm²)	θ	IE %
0	77.19	2.04	0	0.00
150	95.20	1.58	0.1892	18.92
350	82.68	4.88	0.3368	33.68
550	136.9	2.50	0.4362	43.62
750	273.3	3.32	0.7176	71.76
950	812.4	2.03	0.9050	90.50
1150	111.8	2.12	0.3096	30.96
1350	82.95	1.86	0.0694	6.94

3.3.2 *Potentiodynamic Polarization Studies*

The potentiodynamic polarization curves for mild steel in 0.5 M HCl at 25 ˚C in the absence and presence of *Etlingera Elatior* in florescence extract are portrayed in Figure 6 Electrochemical parameters such as corrosion potential (E_{corr}), corrosion current density (I_{corr}), corrosion rate (Cr) and cathodic Tafel constant (βa) were computed from the polarization curves and are listed in Table 3. The percentage of inhibition efficiency (IE%) of the inhibitor determined using equation (5) is also included in the table. From Table 3, it is clearly seen that increasing the inhibitor concentration will reduce the corrosion current density value meanwhile the inhibition efficiency increases up to 950 ppm. The decreasing of corrosion current density is because of the inhibitor molecules act by adsorption on the surface of mild steel, hence producing an efficacious protection layer against corrosion.

The attentive observation of the tafel plots in Figure 6 reveals that both anodic and cathodic curves are influenced by the presence of inhibitor. Thus, with the present of *Etlingera Elatior* inflorescence extract minimizes the cathodic hydrogen evolution. Categorization of an inhibitor as cathodic or anodic can be done if the E_{corr} value is bigger than 85 mV. Based on present study, 30 mV is the highest displacement value observed for E_{corr} at 950 ppm. This indicates that inhibitor behaves as a mixed type of inhibitor.

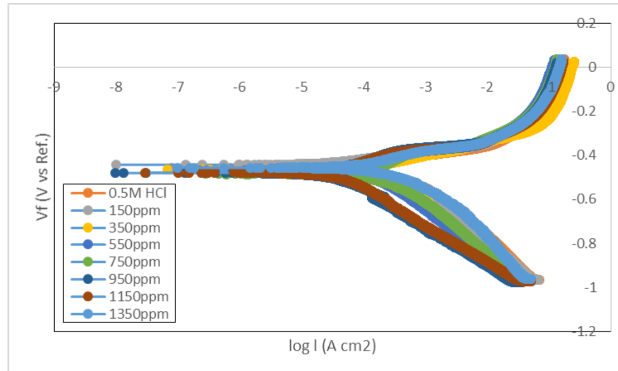


Figure 6 Tafel polarization curves for mild steel in 0.5M HCL at 298.15K in the presence and absence of *Etlingera Elatior* inflorescence extracts

Table 3 Potentiodynamic polarization data for mild steel corrosion in 0.5M HCl at a numerous concentration of *Etlingera Elatior* inflorescence extract as green corrosion inhibitor

Concentration of inhibitor	E_{corr}(mV)	β_{a}(mV/dec)	B_{c}(mV/dec)	I_{corr}(mA cm²)	CR (mm/year)	IE%
0	455.0	181.0	273.5	0.395	0.184	0
150	457.0	171.5	267.0	0.389	0.180	1.52
350	464.0	170.7	236.4	0.333	0.154	15.70
550	470.0	159.3	223.6	0.179	0.115	54.68
750	481.0	151.0	222.4	0.148	0.083	62.53
950	485.0	132.5	185.7	0.048	0.022	87.85
1150	483.0	150.8	231.4	0.113	0.052	71.40
1350	443.0	127.7	193.7	0.141	0.065	64.30

3.4 Adsorption Studies

Corrosion inhibition mechanism can be perfectly explained by using adsorption isotherms. There are 4 types of adsorption isotherms which are Langmuir, Frumkin, Temkin and Freundlich isotherms. In this study, Langmuir adsorption isotherm model was found out to be the most suitable model. The surface coverage θ (IE%/100) for mild steel in 0.5 M HCl with and without the presence of corrosion inhibitor was calculated at 25 ˚C, 45 ˚C and 65 ˚C. Figure 7 indicated that the Langmuir adsorption isotherm is obeyed at all temperatures following the equation, as shown by a linear relationship of C_{inh}/θ versus C_{inh} with R^2 close to unity.

$$C_{inh}/\theta = 1/K_{ads} + C_{inh} \quad (6)$$

C_{inh} denotes the inhibitor's concentration. The adsorption equilibrium constant K_{ads} is estimated using the intercept of Langmuir plot lines.
The free energy of adsorption (ΔG_{ads}) can be calculated using the equation below:

$$\Delta G_{ads} = -RT \ln (1000 * K_{ads}) \quad (7)$$

Where K_{ads} represents as adsorption equilibrium constant. When G_{ads} has a negative value, it indicates that a spontaneous response has occurred. That shows that there is a strong interaction existing between the absorbed molecules and the mild steel surface.

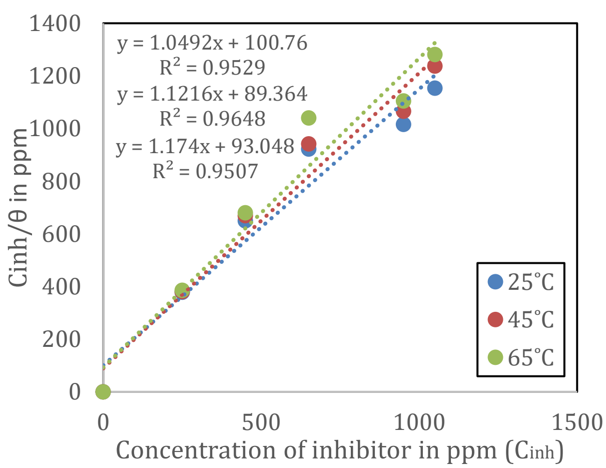
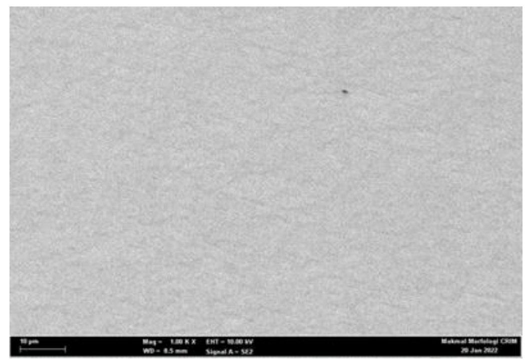


Figure 7 Langmuir adsorption isotherm for mild steel sample in 0.5 M HCl with certain concentrations of *Etlingera Elatior* inflorescence extracts at various temperatures

3.5 Scanning Electron Microscopy (SEM) Analysis

The interaction between the inhibitor and mild steel surface was captured using the Scanning Electron Microscopy (SEM). Figures 8 and 9 represents SEM images produced under magnification of 1.0k x of the mild steel surface (a) the polished sample of mild steel using silicon-carbide paper acts as reference, (b) after immersed within 168 hours in 0.5 M HCl solution and (c) after immersed within 168 hours in 0.5 M HCl solution with 950 ppm of *Etlingera Elatior* corrosion inhibitor at temperatures of 25 ˚C and 65 ˚C. The surface morphology of polished sample in Figure 2(a) creates a smooth surface with no obvious signs of corrosion occurrence. After immersing the sample in 0.5 M HCl solution, the corrosion sign started to occur as can be seen in Figure 2(b). The tested sample became deteriorate and rust. The sample after immersed in 0.5M HCl solution containing 950ppm of *Etlingera Elatior* corrosion inhibitor portrayed some positive result in preventing rust by forming a protective layer. The surface was observed to be relatively smooth as presented in Figure 2(c). When the temperature rises above 25 ˚C, the tested surface protection on the mild steel become weak. Figure 9 can be referred to observe the protective layer form with and without *Etlingera Elatior* corrosion inhibitor. This situation occurred because the surface kinetic energy was high to eliminate and remove these degradable short molecular weight segments of *Etlingera Elatior*, hence minimal of surface coverage was obtained. As a sequence, minimum value of inhibition efficiency was obtained. The outcome shows that with the presence of *Etlingera Elatior*, it was found to be an effective inhibition mechanism of metal corrosion but at a certain temperature.

(a)



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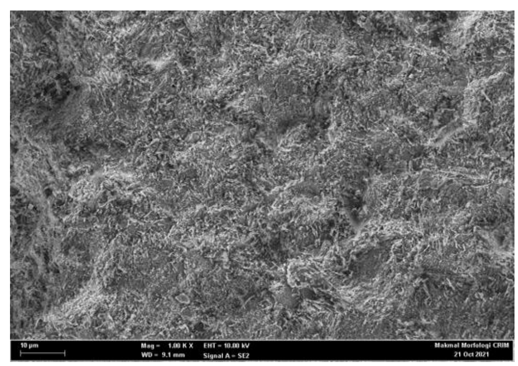

(c)

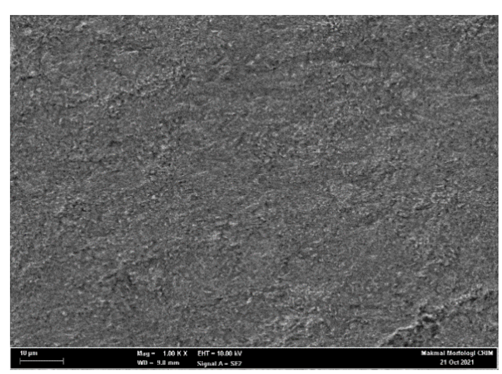

Figure 8 Surface morphology by using SEM of mild steel (a) polished sample, (b) 0.5M HCl and (c) 950ppm of *Etlingera Elatior* at 25˚C

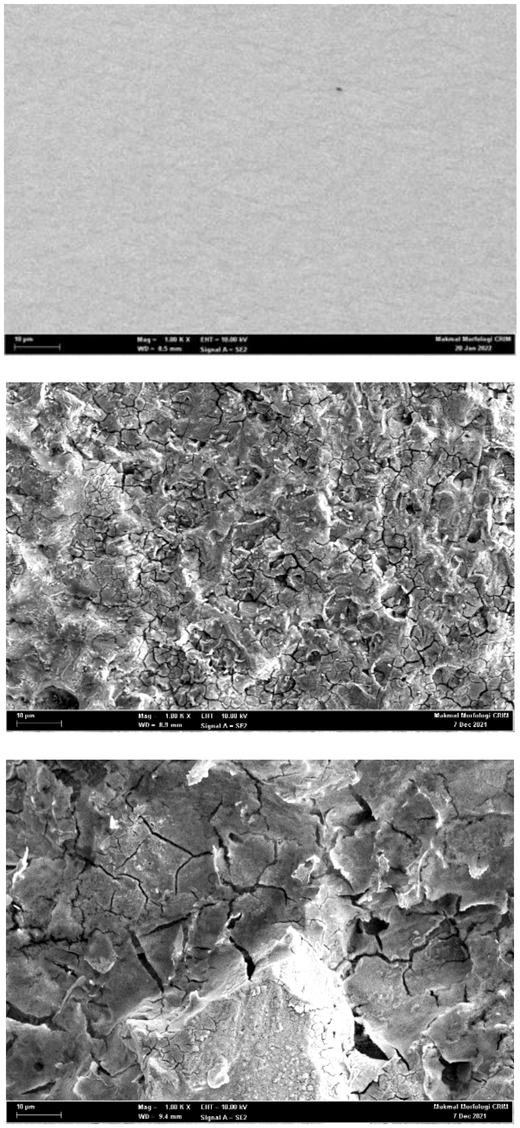

Figure 9 Surface morphology by using SEM of mild steel (a) polished sample, (b) 0.5M HCl and (c) 950ppm of *Etlingera Elatior* at 65˚C

4.0 CONCLUSION

Etlingera Elatior inflorescence extract reacts as a green corrosion inhibitor of mild steel with the highest inhibition efficiency of 93.62 % at 25 ˚C and at an optimum inhibitor concentration of 950 ppm when tested using the weight loss method. For experiments using EIS and Potentiodynamic Polarization Curves (PPC) at the same concentration, the findings stated that the highest inhibitory efficiency was at 950 ppm concentration with 90.50 % for EIS and 87.85 % for potentiodynamic polarisation also at 25 ˚C. The higher the temperature above 25 ˚C and lower than 25 ˚C, the lower the inhibition efficiency (IE%) but higher the corrosion rate. The inhibitor obeys the Langmuir isotherm type of adsorption isotherm by producing a monolayer onto the metal. Statistical analysis illustrates that the corrosion rate is affected by temperature and inhibitor concentrations. The SEM image suggested that the corrosion mechanism inhibition occurred through the adsorption process, which supported confirmatory results.

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