EVALUATION OF CURCUMA DOMESTICA LOIR AND ALPINIA GALANGA EXTRACT AS AN ECO-FRIENDLY CORROSION INHIBITOR FOR CARBON STEEL IN 0.5 M HCl MEDIUM

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Abstract. Much effort is being paid to the development of environmentally and ecologically sound or "green" corrosion inhibitors. The study's goal is to determine if the presence or absence of Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) extraction as an eco-friendly corrosion inhibitor in 0.5 M HCl medium affects the corrosion inhibition of low-carbon steel substrates. Weight loss experiments and corrosion rate measurements were used to evaluate the inhibitory performance for immersion times of 7, 14, 21, 28, and 35 days. Energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM) were employed to analyse the surface morphology of all samples and characterise the creation of the protective layer, corrosion products, and localised areas on the carbon steel substrate. After immersion test was revealed that about 85 % of the carbon steel surface was covered by green extract molecules, and the corrosion rate was reduced comparing to the sample exposed to blank solution. According to the study, CDL can inhibit carbon steel in an acidic medium, and the concentration of CDL is connected with the effectiveness of the inhibition. SEM examination of the surface of carbon steel indicated that through the formation of a protective film on the Fe surface, both extracts had an outstanding corrosion-inhibiting effect on the Fe anode. This study provides valuable insight into the development of green corrosion inhibitors for carbon steel.

Keywords: Curcuma domestica loir extraction, alpinia galangal extraction, weight loss, corrosion rate

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Introduction

Metal corrosion results in a disruptive deterioration of the life span of building materials and causes significant financial losses [1]. Low-carbon steel has a distinct potential that makes it preferable for various industrial applications, including pipeline assembly, off- and on-shore structures, pressure vessels, and tanks [1]. These benefits include low cost, excellent formability, ease of welding, and ease of accessibility. In marine settings, such as those used for oil and gas applications, industrial processes, and servicing, low-carbon steel experiences severe corrosion. Either by modifying the original conditions or the metal substrate surface, corrosion prevention can be achieved. The use of corrosion inhibitors is one of the most appropriate, affordable, and promising corrosion protection techniques among the typical corrosion protection new technologies, including the formation of oxide film on metal surfaces, material selection, design and fabrication, coatings, and anodic and cathodic protection techniques [1-3]. With environmentally friendly electrolytes, corrosion inhibitors will reduce or restrict the corrosion reactions of metal substrate surfaces [4,5]. The biodegradability, biocompatibility, and bioaccumulation of toxic chemicals have raised concerns in various industries, especially in the oil and gas industry. These chemical substances are expensive and harmful to the entire ecosphere. Because of the harmful environmental effects, researchers and professionals worldwide are searching for more practical and reliable inhibitors that are also non-toxic and reasonably priced. Recently there has been a growing interest in the development of eco-friendly or bio-based corrosion inhibitors that are environmentally safe and decompose naturally that is comparable to conventional and inorganic corrosion inhibitors.

Natural products have drawn much attention recently as affordable and environmentally friendly corrosion inhibitors [4-6]. Some research has used plant extracts as eco-friendly corrosion inhibitors for environmental products. Plant extracts used as green corrosion inhibitors are usually found in numerous plant portions such as fruit [7], fruit shell [8], leaves [9], stems [10], seeds [11], fruit [12], and flowers [13].

The aim of this study is to use an immersion test to examine the localized corrosion of carbon steel in 0.5 M HCl solution in the presence of the inhibitors Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) extract. The extraordinary fascination with green corrosion inhibitors can probably be attributed to their intriguing capacity to shield metal substrates from corrosive behaviour. Green eco-friendly inhibitors are anticipated to reduce maintenance and cost savings for offshore structures such as pressure vessels and tanks. Kinetic parameters and the type of adsorption mechanism were discussed. The corrosion morphology of carbon steel was examined using SEM/EDS under two different conditions: with and without the presence of corrosion inhibitors. This study provides valuable insight of eco-friendly corrosion inhibitors for carbon steel.

Materials and Methods

The composition of low-carbon steel substrate used in this work is listed in Table 1. Electrical Discharge Machinining (EDM) was used to create round dimension of 25 mm in diameter and 5 mm in thickness in low carbon steel. A layer of paraffin wax is applied on the prevent it from contact with the studied solution. Meanwhile, the top and bottom of the cut surface remain expose.

Table 1: Chemical composition (wt. %) of the substrates.

Alloy element	C	Si	Mn	P	S	Cr	Ni	Cu	Fe
Metal Substrates	0.153	0.175	0.619	0.0265	0.0209	0.112	0.0769	0.222	Balance

To prepare the surfaces of the experimental coupons for the corrosion test, several steps were followed. Firstly, the surfaces were ground with silicon carbide papers of different grit sizes (80, 100, 300, 800, 1000, and 2000) to make them smooth and even. Then, they were rinsed with distilled water to remove any debris or impurities. Next, the surfaces were ultrasonically cleaned in an ethanol bath at room temperature for 20 minutes to remove any leftover particles from grinding. After cleaning, the surfaces were dried and stored in a desiccator to prevent atmospheric corrosion until ready for use in the corrosion test. 4.0 g/L of Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) extract was combined with 500 mL of deionized water to make a green corrosion inhibitor. After blending, the ingredients were transferred to a beaker, and additional deionized water of up to 1000 ml was required. After that, the sample's extract was concentrated using a magnetic stirrer at 50 °C for 1 hour until it was practically dry under reduced pressure. A suction pump and filter paper separated the filtrate from the residue. The extraction juice for both green corrosion inhibitors was warmed in an oven at 50 °C for 96 hours. The oven temperature was then raised to 85 °C and left for 24 hours.

The ASTM G1-03 standard was followed when conducting the immersion tests. All coated and untreated specimens were submerged for 7, 14, 21, 28, and 35 days in a container containing 5 liters of 0.5 M HCl media. After each immersion test, the samples were taken out of the 0.5 M HCl solution, and corrosion products were eliminated by soaking the samples. Photos of the area were cleaned before and after for a visual assessment study. The samples were dried using high-pressure air, washed with acetone, and weighed. The following formula was used to compute the corrosion rate:

$$\text{Corrosion Rate } (C_R) = \frac{K \times W}{A \times T \times D} \quad (1)$$

where *CR* is the corrosion rate (mm/ year), constant, K = 8.76×10^4, W is the mass loss (g), A is the surface area (cm^2), exposed to the corrosive media, T is the exposure time (hour), D is the density (g/cm^3). Scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) were utilized to investigate the corrosion behaviour of substrates in the presence and absence of green corrosion inhibitor extraction.

Results and Discussion

Extraction Properties

Figure 1 displays the turmeric or Curcuma Domestica Loir (CDL) extraction's ATR-FTIR spectrum. The spectrum corresponding to the maximum and minimum peak of the turmeric composition's transmittance over the wavenumber at different frequencies. The sharp peak is at 3346 cm^{-1}, 2943 cm^{-1}, 2832 cm^{-1}, and 2368 cm^{-1}, indicating the sample has

strong O-H stretching. Additionally, this peak indicates that the raw material's chemical composition supports the specimen's resistance to corrosion, demonstrating that the composition contains the optimal inhibitors for causing adsorption toward the specimen to occur. This outcome was consistent with the earlier research by Juhaiman et al. [14]. As a result, the peak for O-H stretching frequency is located at the first peak which is 3346 cm^{-1}. The C-O-C stretching of alkyl aryl ether stretching frequency is at peak of 1026 cm^{-1}.

The highest peak and minimum peak toward the transmittance of the galangal composition across the wavenumber is shown on the graph of ATR-FTIR galangal extraction. In Figure 1, the wavenumbers toward the transmittance of the composition of turmeric are indicated as having the first peak at 3839 cm^{-1}, the second peak at 3400 cm^{-1}, the third peak at 2930 cm^{-1}, the next peak at 2346 cm^{-1}, and the others, but the last peak is at 526 cm^{-1}. Additionally, this finding showed that the raw material's chemical composition supports the specimen's resistance to corrosion, indicating that the composition has the ideal inhibitors for causing adsorption toward the specimen to occur. Additionally, this outcome is consistent with the earlier research by Thirupathi et al. [15]. Moreover, an O-H bond vibration peak at 3400 cm^{-1} is present. For the C=C bond vibration, the stretching frequency of 1638 cm^{-1} is indicated. The peak at 1240 cm^{-1}, in addition, denotes C-O stretching vibration. In conclusion, the ATR-FTIR analysis shows the major characteristic bands corresponding to turmeric and galangal extractions were disappeared, which was an indirect confirmation of protection or shield substrates from corrosion, together with the best inhibitors to prevent adsorption acidic medium onto damaged substrates.

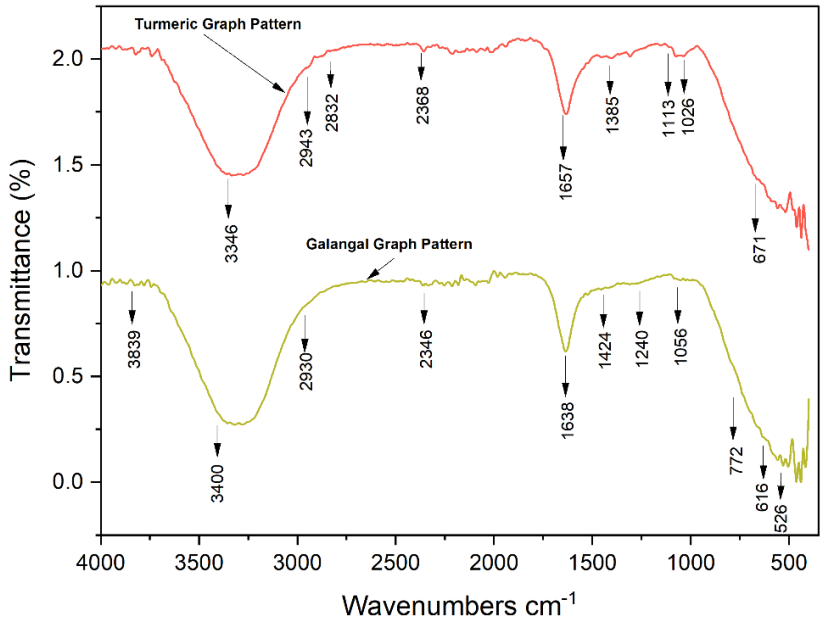


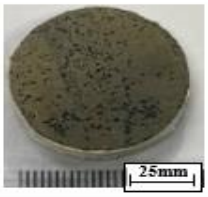
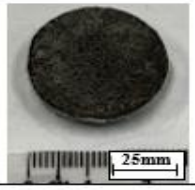
Figure 1: ATR FTIR spectrum of Tumeric and galangal extraction

Visual Inspection After Immersion Test

The immersion test was carried out for 7, 14, 21, 28, and 35 days to evaluate the corrosion behaviour of sample without and with the presence of green corrosion inhibitor. Table 2 shows that there is no protection on the control sample, and it is totally lost indicated that the control sample suffers and extremely poor corrosion protection. While sample inside

the extractions of Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) developed a protection layer for substrates. According to the visual observation results shown in Table 2, the corrosion products were mostly found on the sample in 0.5 M HCl without inhibitor for all the exposure times. This is because the absence of green corrosion inhibitor. The image also shows that the carbon steel substrates allowed the passage of acid, water, oxygen, and other chemicals, which caused corrosion on the metal substrate. While there was less corrosion product visible on the surface of the thin film coated by green corrosion inhibitor. There is no pits, rusting, peeling, or defects any were observed in either green corrosion inhibitor sample [13-15]. This confirm the adsorption of organic Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) extraction molecules onto the substrates surface

Table 2: Sample after immersed in 0.5 M HCl Solution.

Days	0.5 M HCl (Control)	Curcuma Domestica Loir Medium	Alpinia Galangal Medium
7			
14			
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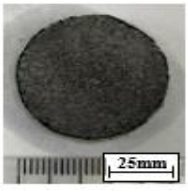
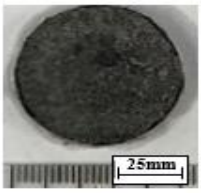
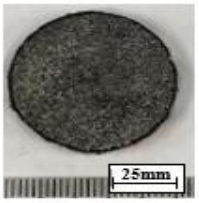
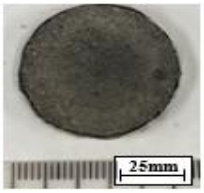
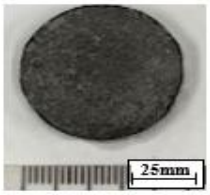
28			
35			

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Visual inspection revealed that both green corrosion inhibitor samples had more chemical penetration on their surfaces than control samples after immersion in 0.5 M HCl medium for 7 to 35 days. The amount of corrosion product observed on the green corrosion

inhibitor shows that not all exposed surfaces were chemically shielded. The reason for this is acidic ions could break the exposed area of the metal substrates after extended exposure.

Weight Loss and Corrosion Rate Measurement

According to earlier research, the remarkable anti-corrosive effectiveness of green corrosion inhibitors on carbon steel substrates is attributed to the excellence adsorption of the inhibitor molecules on the steel substrates, forming a protective layer [3–4]. Figure 2 displays the overall weight loss data of the immersion test as well as the rates of corrosion and effectiveness of the green corrosion inhibitor. Figure 2(a) shows that the weight loss for carbon steel substrates with or without green corrosion inhibitor increases as the immersion period extends from 7 to 35 days. The control sample contributed the higher mass loss, followed by samples inside CDL and AG green corrosion protection. This result shows that the sample was shielded from further corrosion by releasing the inhibitor chemicals. The corrosion product was still evident on the samples after extended contact, even though the weight loss decreased over time because the coating did not cover the whole surface.

The general decrease in corrosion rate is shown in Figure 2(b) as the immersion times increases due to depleting of the acidic ions in the 0.5 M HCl medium. The thin film formed on the carbon steel surfaces also served as a barrier against corrosion. The corrosion rate of the control sample is higher than the green corrosion medium. The least amount of corrosion was observed in CDL, followed by AG samples that were coated with a thin layer of coating. Therefore, compared to AG and control samples, the corrosion rate of CDL samples is lower.

Turmeric has the highest efficiency as an inhibitor (Figure 2(c)). For the first week of the immersion test, the CDL efficiency is 47.20 %, and the AG efficiency is 40.85 %. Next, the value of CDL is 40.34 %, and AG is 30.28 % for the second week, which is day 14 of the period. On day 21, the CDL is worth 35.64 %, while the AG is for 31.35 %. Day 28 of the fourth immersion test week shows that the CDL still has the greatest efficiency score of 35.88 %, followed by the AG at 29.97 %. However, the inhibitor efficiency of CDL is 35.87 % on day 35 of immersion, which is higher than the AG inhibitor efficiency of 30.26 %. Turmeric extract may act as a good corrosion inhibitor with at least one polar unit. These polar units can provide the free electron pairs and p-electrons, also hydroxyl group (–OH), which is an electron donator, moderately activated by virtue of presence of lone pair of electrons on the oxygen (O) atom [14,19-20].

In general, the efficiency of an inhibitor increases with an increase in inhibitor concentration. Mao et al. [3] demonstrate that increasing the concentration of inhibitors can effectively improve inhibition efficiency. This appears because more inhibitor particles could lead to better covered outer layers and, consequently, better inhibition. Corrosion inhibition efficiency of p-phenol derivatives depends on several factors, including electron density on oxygen and hydrogen atoms in hydroxyl group, charge transfer, the energy of interaction, molecular activity, electric dipole moment and Gibbs free energy of the dissolution process. The inhibition efficiency increases with the increase in concentration and decreases with temperature. The maximum inhibition efficiency was found (94.96 %) at 25 °C in the presence of 5 M concentration of the studied compound [19-20].

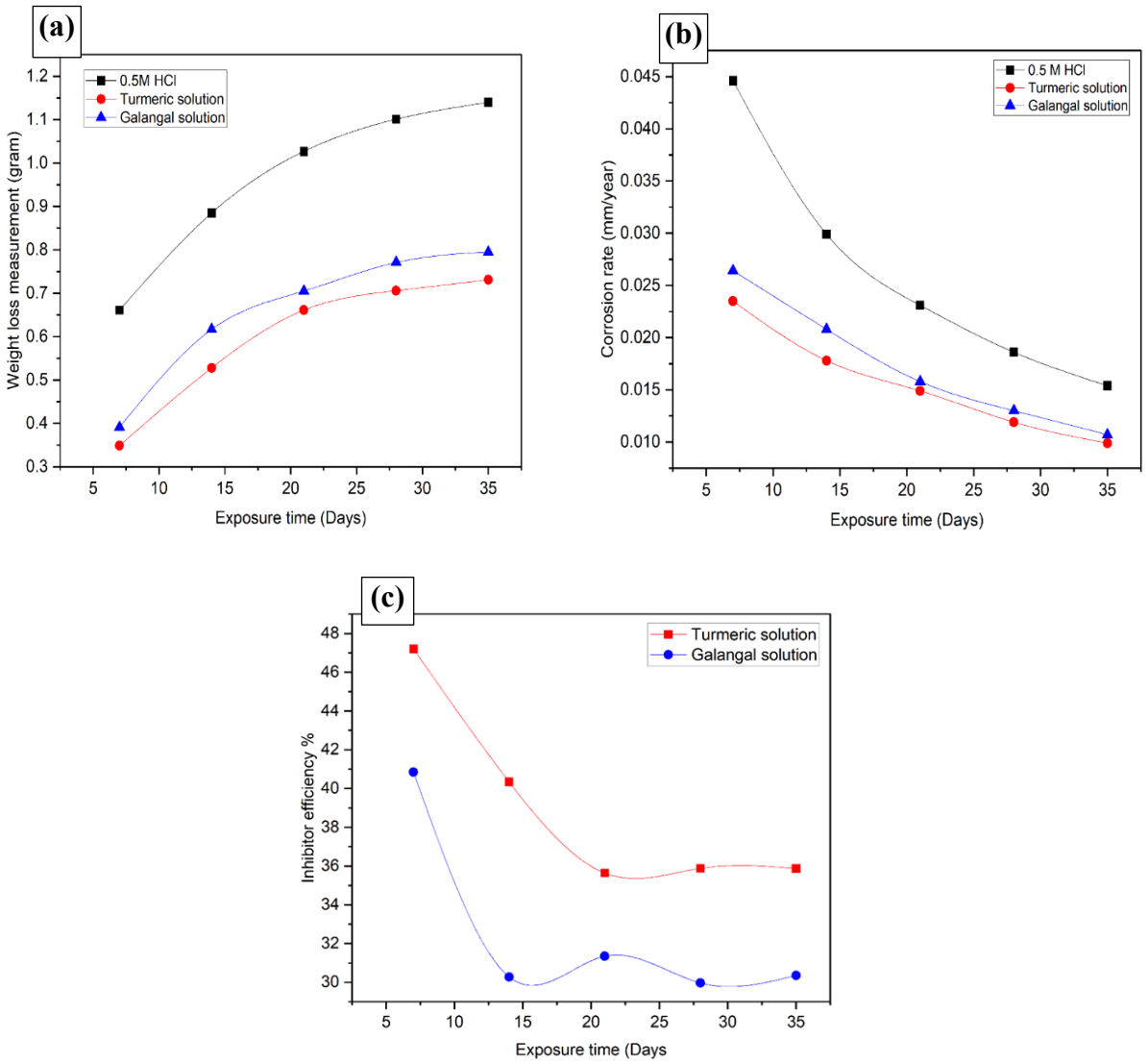

Figure 2: Immersion test results after 7, 14, 21 and 28 days for (a) Weight loss and (b) Corrosion rate measurement for absence and presence of Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) extract in 0.5 M HCl medium

Surface Study by SEM/ EDS

An initial test was conducted to see if the thin film of the coating would function effectively after the corrosion test. After 28 days in 0.5 M HCl media, the samples were subsequently examined using SEM, and the outcomes are presented in Figures 3 and 4. Figure 3(a) illustrates a sample taken prior to an immersion test with no corrosion products on the metal surface. However, without the CDL and AG green corrosion inhibitor, the surface of carbon steel is quite rough, and many corrosion products are visible, as shown in Figure 3(b). The surface is comparatively flat and covered in dense of corrosion products when the medium contains 4.0 g/L CDL and AG (see Figure 3(c) and (d)). At 500× magnification, the edge and surface of the needle-like plates are covered with denser and finer needle-like products (Figure 3(c)). The density and surface smoothness of the mild steel sample was significantly enhanced when the AG was added (Figure 3(d)). As indicated, CDL

and AG in a solution of 0.5 mol/L HCl facilitate the formation of a persistent corrosion-resistant coating on carbon steel substrates. Additionally, CDL and AG may diffuse or adsorb on the surface of the carbon steel substrate. Consequently, corrosion of the carbon steel substrate is effectively prevented.

The acid solutions caused destruction to the carbon steel substrates, leading to irregular surface and small pits [20]. On the other hand, carbon steel substrates demonstrate that extraction of both green corrosion inhibitors in acid solutions considerably reduced corrosion. Furthermore, Ji et al. [20] also concluded that the carbon steel surface, as well as inaccessible metal substrates in acidic solutions, were effectively coated with extract molecules, resulting in the protection of carbon steel against corrosion in an acidic media.

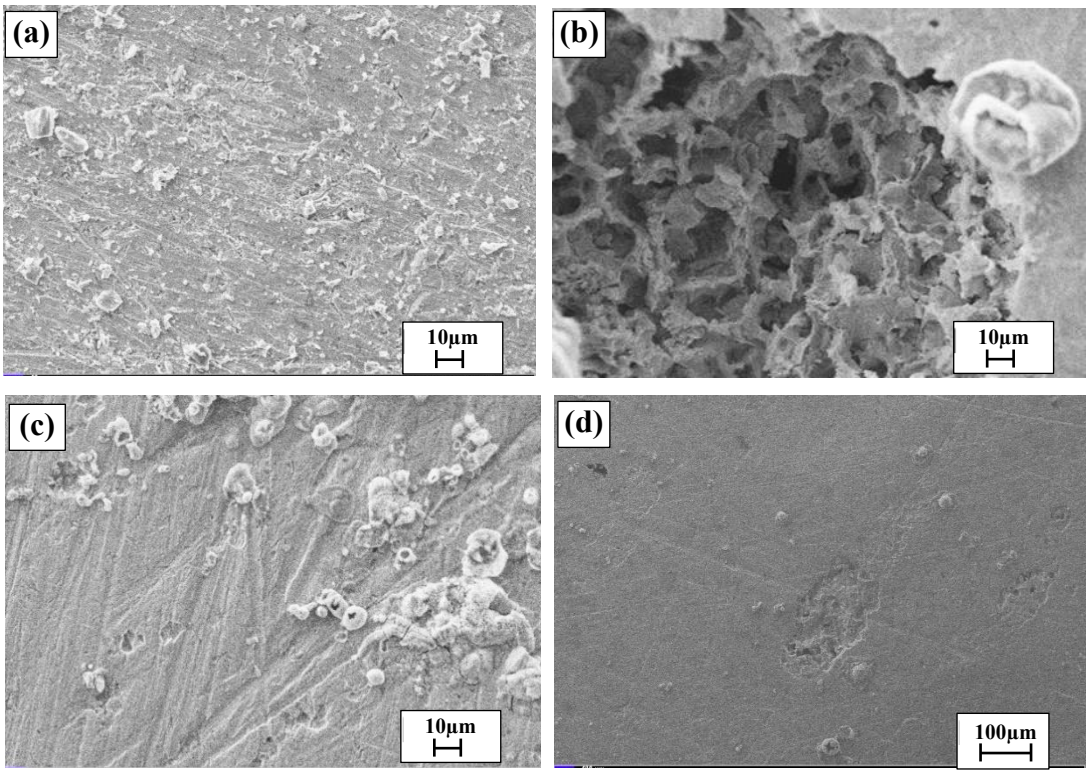

Figure 3: SEM micrographs of (a) sample before immersion test (b) samples without green inhibitor concentration, (c) Curcuma Domestica Loir (CDL) extraction and, (d) sample image Alpinia Galanga (AG) extraction after 28 days in 0.5 M HCl medium.

Figure 4 shows a SEM micrograph and an EDS spectrum for a sample after 35 days in 0.5 M HCl media with and without green corrosion inhibitor. Figure 4(a) depicts the morphology of the absence of green corrosion inhibitor, which confirms the amount of C, O, Si, and Fe for the EDS spectrum and leaves no sign of the composition of the green extraction as shows in Figure 4(b). Figures 4(c) and (d) and 4(e) and (f), on the other hand, depict the SEM morphology and EDS spectrum with CDL and AG, respectively. The C, O, Si, Fe, and Cu were present in the EDS spectrum for CDL extraction and while the C, O, Si, Fe, and Cu were present in AG extraction.

The crucial component is Fe, which indicates that the sample was submerged in a solution containing a green corrosion inhibitor and exhibits the lowest Fe value, 64.68 and 58.69 wt.%, to represent the existence of metal substrates that had been initially protected. To

imitate an exposed area at the metal substrates, the medium without green corrosion inhibitor or pure 0.5 M HCl medium contains a greater value of Fe, which is 90.79 wt.%.

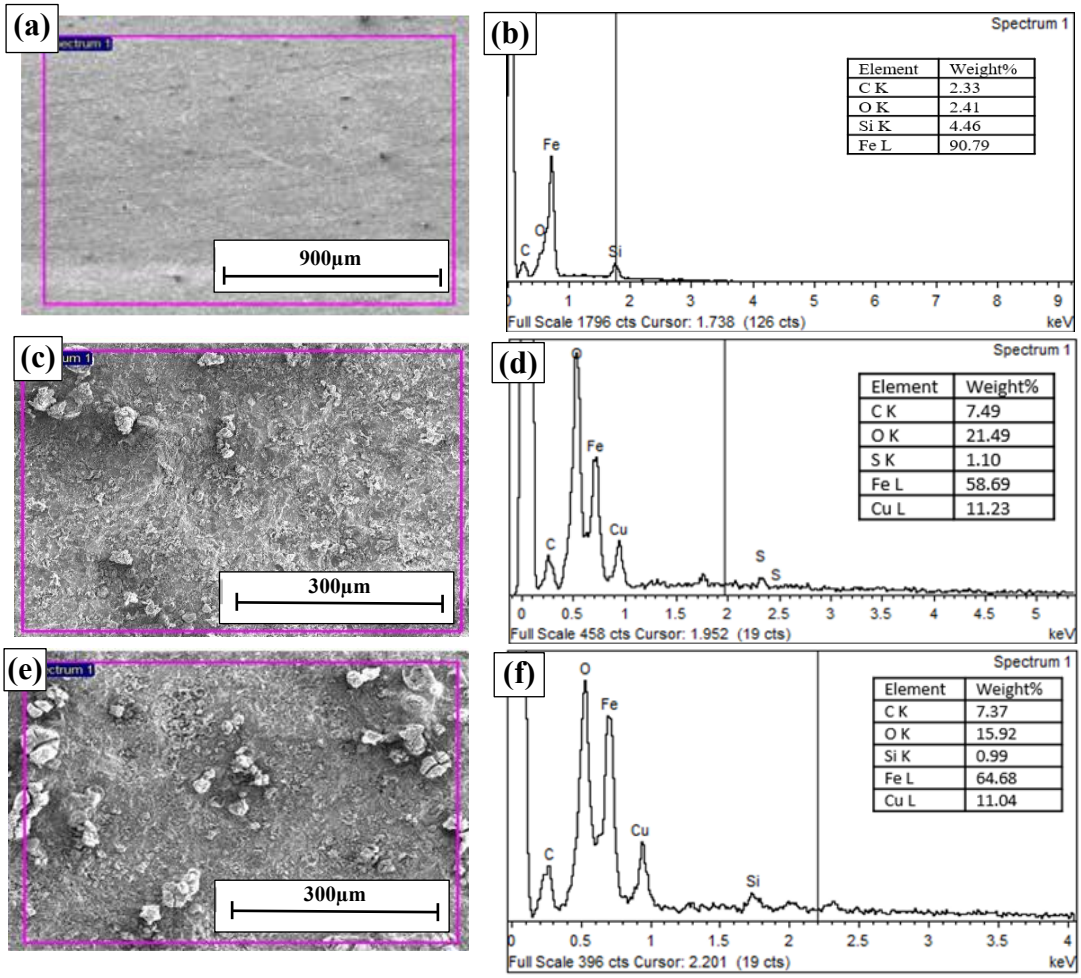

Figure 4: SEM micrograph and EDS spectrum for samples (a) and (b) without green corrosion inhibitor, (c) and (d) presence of CDL extraction and (e) and (f) presence of AG extraction after 35 days exposure in 0.5 M HCl medium.

The findings for this study demonstrate that the majority of their extracts contain essential elements like O, C, N, and Si, which are active in organic compounds and contribute to the adsorption of these compounds on metal substrates to form a film that shields the surface of the substrate and prevents corrosion. The green corrosion inhibitor thus displayed effective corrosion control while safeguarding the substrate. The green inhibitors can adsorb onto metal surfaces by physisorption and/or chemisorption, as claimed by Mao et al. [3]. The chemical adsorption relies on strong interaction by charge sharing of solitary or p electrons from inhibitors with empty d-orbitals of atoms or ions of carbon steel, whereas the earlier adsorption typically relies on ionic interconnection between charged inhibitors and the opposite charges carbon steel surfaces.

Conclusions

Curcuma Domestica Loir (CDL) and Alpinia Galanga (AG) were used to extract a green corrosion inhibitor (AG). This work used 4.0 g/L extraction in 0.5 M HCl to imitate an acidic environment for use in oil and gas applications, demonstrating the possibility of creating a green corrosion inhibitor for corrosion control.

SEM images and EDS spectrum verified an effective organic compound's role in the adsorption of these compounds on metal substrates to produce a coating that shields the surface of substrate and prevents corrosion. Both green corrosion inhibitors formed an effective coating on the metal substrates with satisfactory anticorrosive capabilities during the immersion test for corrosion control.

Consequently, this green corrosion inhibitor greatly enhanced the performance of corrosion control and reduced the corrosion rate of the carbon steel substrates. By confirming that both green corrosion inhibitors have the lowest content of Fe, the green corrosion inhibitor will safeguard the metal substrate.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare

Compliance with Ethical Standards

The work is compliant with ethical standards

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