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# Corrosion Inhibitor for X70 Steel using Banana Leaves Extract

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**Abstract**

Corrosion of X70 steel remains a significant challenge across industries, necessitating the exploration of effective and eco-friendly inhibitors. This study investigates the corrosion inhibition properties of banana leaves water extract (BLWE) for X70 steel immersed in a NaCl solution. Several analysis methods were used including FTIR, SEM-EDX and EIS. FTIR was employed to identify the functional groups present in the BLWE. SEM-EDX was used to characterise the elemental composition and morphological structure of the X70 steel surface. Comparison of morphology structure and elemental composition on the sample surface were performed between the pre-immersion test, using raw X70 steel samples, and the post-immersion test, where samples were immersed into different ratios of NaCl solution with BLWE inhibitor. The corrosion rate of the X70 steel samples was evaluated and compared using EIS. FTIR analysis revealed the presence of several functional groups in the BLWE, including hydroxyl (-OH) stretching and carbonyl (C=O) stretching, which contribute to its potential as a an organic anti-corrosion barrier. SEM-EDX analysis showed that the 70% NaCl solution mixed with 30% BLWE inhibitor was the most effective, as evidenced by a high percentage of iron (82.34%) and a low percentage of oxygen (11.51%) after the immersion test. EIS results, Tafel and Nyquist plots, demonstrated that the 70% NaCl solution mixed with 30% BLWE inhibitor provided the best corrosion protection, as indicated by a shift in the Tafel plot to a greater potential applied (V) and Nyquist plot to higher resistance values. These findings confirm that the 70% NaCl solution mixed with 30% BLWE inhibitor is the optimal choice for protecting X70 steel samples.

## 1. Introduction

X70 steel is a high-strength low-alloy steel commonly used in the petroleum and natural gas industries for pipeline construction. Its excellent mechanical properties, such as high tensile strength, make it ideal for withstanding harsh environments [1,2]. However, X70 steel is prone to corrosion, particularly in aggressive conditions involving humidity, temperature fluctuations, and corrosive substances, which can significantly affect its durability and performance [1].

Corrosion is the deterioration of metal due to chemical reactions with its environment, and in X70 steel, it can lead to material loss and structural failure [3]. Common types of corrosion include uniform corrosion, pitting corrosion, galvanic corrosion, and stress corrosion cracking, with pitting corrosion being particularly problematic for pipelines due to its localized damage and the formation of holes in the material [3].

Corrosion inhibitors are used to mitigate these effects and can be categorized into synthetic and natural types. Synthetic inhibitors, such as alloying and galvanization, are effective at forming protective layers on metal surfaces but can have environmental drawbacks due to their toxicity [4,5]. Natural inhibitors, derived from plant or animal sources, are more eco-friendly and biodegradable, offering a sustainable alternative to synthetic chemicals [6].

Plant extracts, including harmal, Falcaria vulgaris, and Areca, have demonstrated effective corrosion protection [6]. Banana leaves, in particular, are rich in bioactive compounds like polyphenols, flavonoids, and alkaloids, making them a promising natural corrosion inhibitor [7]. This study investigates the potential of banana leaf extract as a corrosion inhibitor for X70 steel. Given the rich presence of bioactive compounds such as polyphenols, flavonoids, and alkaloids in banana leaves, these compounds are believed to contribute to corrosion protection [8,9]. The research aims to evaluate the effectiveness of banana leaf extract in reducing corrosion rates and enhancing the durability of X70 steel in aggressive environments.

## 2. Materials and Methods

### 2.1 Sample Preparation for Organic Inhibitor

Fresh banana leaves were collected and washed to remove surface contaminants. The leaves were then sliced into thin strips for uniform drying. The sliced banana leaves were subjected to a drying process in a laboratory drying oven set at 70°C for 24 hours to ensure complete removal of moisture. Once dried, as shown in Fig. 1, the banana leaf strips were sealed in aluminium foil tray and covered to prevent contamination and preserve it for subsequent processing.

**Fig. 1** Banana leaf strips after drying process

### 2.2 Sample Preparation for X70 Metal Pieces

The X70 steel samples were prepared by cutting them into dimensions of 10 mm × 10 mm × 3 mm using a Sodick AP250L EDM Wire Cut Machine. The cut samples were then polished using sandpaper of progressively finer grades (80, 180, 320, and 600) to achieve a smooth surface finish suitable for subsequent analysis as shown in Fig. 2.

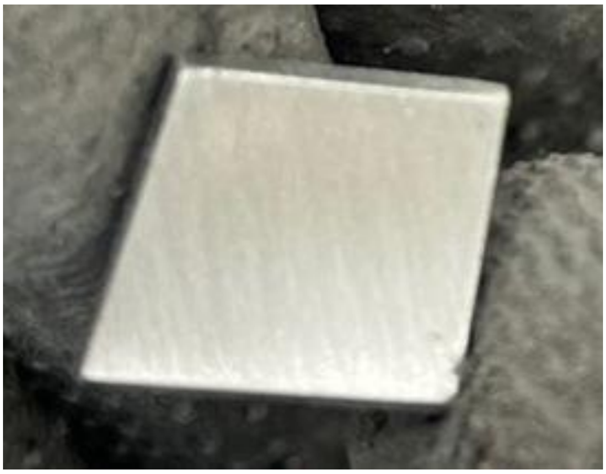

**Fig. 2** X70 steel samples after being polished

The banana leaf strips underwent several preparation processes. First, the dried banana leaf strips were blended using a juice blender (Fig. 3(a)) and then sieved with a 200-micron sieve (Fig. 3(b)) to obtain a fine powder. A total of 50 g of the powdered banana leaves was measured using an analytical balance and added to a beaker containing 200 mL of ethanol and 50 mL of distilled water to create the solvent mixture. The mixture was heated and stirred on a magnetic stirrer set to 550 RPM at 45°C for 3 hours in a fume hood, as shown in Fig. 3(c). The resulting solvent was filtered using filter paper to separate the solid residue from the liquid extract (Fig. 3(d)). Finally, the extract was processed using a rotary evaporator (Fig. 3(e)) to remove ethanol, operating at a rotation speed of 70 RPM and a water bath temperature of 50°C for one hour. The final extract was transferred to an essential oil bottle for storage.

(a)

(b)

(c)

(d)

(e)

**Fig. 3** The sample preparation of banana leaves extract, including (a) the blending of banana leaf strips using a juice blender, (b) the sieving of banana leaves process, (c) the heating and stirring process of the solvent. (d) the filtering solvent process and (e) the filtering process using rotary evaporator

For the preparation of the NaCl solution, 30 g of NaCl powder was weighed and dissolved in 500 mL of distilled water. The solution was stirred thoroughly and transferred to a volumetric flask to prepare a 1 mol/L NaCl solution, which was used as the corrosion agent for the immersion tests.

## 2.3 Immersion Test

The immersion test was conducted using a total of 100 mL of NaCl solution, divided into four test tubes. Each test tube contained 25 mL of NaCl solution mixed with banana leaves water extract (BLWE) inhibitor according to the ratios shown in Table 1.

**Table 1** Ratios and volumes of NaCl solution with BLWE inhibitors for each of the test tube

| Test tube | Ratio of NaCl solution (%) | Volume of NaCl solution (mL) | Ratio of BLWE inhibitor (%) | Volume of BLWE inhibitor (mL) |
|---|---|---|---|---|
| 1 | 100 | 25.0 | 0 | 0.0 |
| 2 | 90 | 22.5 | 10 | 2.5 |
| 3 | 70 | 17.5 | 30 | 7.5 |
| 4 | 50 | 12.5 | 50 | 12.5 |

The first test tube contained 25 mL of NaCl solution, representing the 100% NaCl solution without inhibitor. In the second test tube, 22.5 mL of NaCl solution was mixed with 2.5 mL of BLWE to create a ratio of 90% NaCl to 10% BLWE. The third test tube contained 17.5 mL of NaCl solution mixed with 7.5 mL of BLWE inhibitor, following the ratio of 70% NaCl to 30% BLWE. Lastly, the fourth test tube consisted of 12.5 mL of NaCl solution mixed with 12.5 mL of BLWE inhibitor, forming a 50% NaCl to 50% BLWE ratio. Four samples of X70 steel were immersed into each test tube for 24 days to evaluate the corrosion inhibition performance of the BLWE inhibitor, as shown in Fig. 4. The test tubes were labelled according to their percentages of NaCl solution and BLWE inhibitors, sealed and stored in a controlled environment and regular observations were conducted to monitor changes in the solution and the appearance of the samples.

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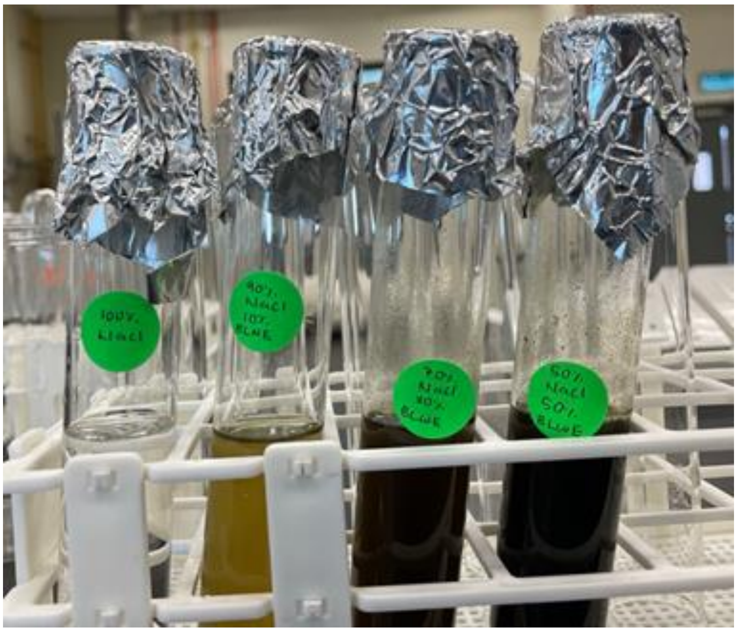


**Fig. 4** Immersion of X70 steel samples inside of the different percentages NaCl solution and BLWE inhibitor in the test tubes

## 2.4 Preparation of Samples for EIS Corrosion Rate Analysis

The preparation of X70 steel samples for Electrochemical Impedance Spectroscopy (EIS) involved multiple steps. First, nichrome wire was soldered to the surface of each X70 steel sample to create a secure electrical connection. The samples were then embedded in resin and hardener, called epoxy mounting process. A 1:1 ratio of resin to hardener was used and stirred for 3 minutes, and the mixture was poured into a square molding case for epoxy with dimensions of 25 mm × 25 mm × 25 mm. The X70 steel samples were positioned inside the molding case, and the resin-hardener mixture was poured over them to fully encapsulate the samples, the epoxy was left to dry for 24 hours to achieve complete curing. Fig. 5 displays the sample of the X70 steel sample after the drying epoxy mounting process. The bottom surface of the molded X70 steel samples was intentionally left exposed to allow direct contact with the electrolyte solution during the EIS analysis. During the EIS test, the molded X70 steel samples were immersed in beakers containing different percentages of NaCl solution and BLWE inhibitors, as outlined in Table 1 before.

**Fig. 5** X70 steel samples after the epoxy mounting and drying process

## 2.5 Sample Characterisation

FTIR was used to identify the functional groups present in the banana leaves water extract (BLWE). The results were compared in a superimposed spectrum of BLWE and distilled water to highlight the unique functional groups available in the BLWE. SEM-EDX analysis was performed to examine both the morphological structure and the elemental composition of the X70 steel samples. A raw X70 steel sample was analysed as a baseline to observe the original composition and surface morphology, acting as a control sample to compare against the post-immersion samples. Electrochemical Impedance Spectroscopy (EIS) was employed to determine the corrosion rate of the X70 steel samples in different percentages of NaCl and BLWE as in Table 1. The analysis involved Tafel and Nyquist plots.

## 3. Results and Discussion

### 3.1 FTIR Analysis of Banana Leaves Water Extract (BLWE) and Distilled Water

Fourier-transform infrared spectroscopy (FTIR) was employed to identify the functional groups present in the banana leaves water extract (BLWE) and compare them with distilled water. The superimposed FTIR spectrum of BLWE and distilled water is shown in Fig. 6.

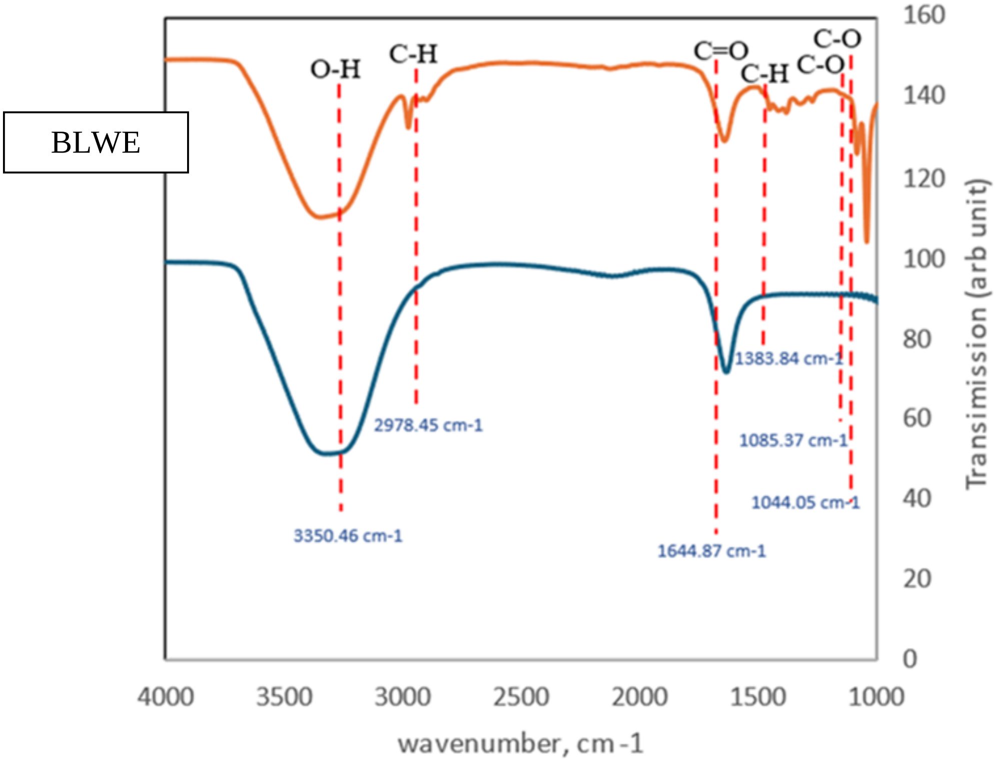


**Fig. 6** superimposed FTIR spectrum of BLWE and distilled water

In the BLWE spectrum, distinct peaks corresponding to key functional groups were observed. At 3350.46 $cm^{-1}$, a peak associated with hydroxyl (-OH) stretching vibration was identified. This group is commonly found in alcohols and phenolic compounds, which are known to form hydrogen bonds with the steel surface. This interaction aids in the formation of a protective film, reducing corrosion by blocking active sites. Another notable feature is the presence of peaks at 2978.45 $cm^{-1}$ and 1383.84 $cm^{-1}$, corresponding to C-H stretching vibrations. These groups are typically present in alkanes and aromatic compounds, which play a role in enhancing the hydrophobicity of the steel surface. Increased hydrophobicity reduces the interaction of the steel with water and corrosive ions, thereby inhibiting corrosion. Additionally, a peak at 1644.87 $cm^{-1}$ was attributed to carbonyl (C=O) stretching vibrations, characteristic of aldehydes, ketones, or carboxylic acids. Carbonyl groups are known for their ability to form coordination bonds with metal surfaces, creating a stable and protective layer that minimizes corrosion.

A comparison between BLWE and distilled water spectrum indicate that observed in the BLWE spectrum, such as 3350.46 $cm^{-1}$, 2978.45 $cm^{-1}$, 1383.84 $cm^{-1}$, and 1644.87 $cm^{-1}$, are absent in the distilled water spectrum. These peaks represent functional groups unique to BLWE, including hydroxyl (-OH), carbon-hydrogen (C-H), and carbonyl (C=O) groups, which are indicative of the bioactive compounds present in BLWE. In contrast, the spectrum of distilled water exhibits only broad absorption bands related to water molecules, lacking the specific functional groups found in BLWE. This comparison confirms that the corrosion inhibition properties of BLWE are attributed to these bioactive compounds, which are not present in distilled water.

### 3.2 SEM-EDX Analysis of X70 Samples Pre- and Post-Immersion Test

SEM-EDX was employed to examine the morphological structure and elemental composition of X70 steel samples before and after immersion in NaCl solutions with varying concentrations of Banana Leaves Water Extract (BLWE) inhibitor over 24 days. Fig. 7 illustrates the surface appearance of the X70 steel for the (a) raw sample, (b) sample immersed in 100% NaCl, (c) sample immersed in 90% NaCl and 10% BLWE, (d) sample immersed in 70% NaCl and 30% BLWE, and (e) sample immersed in 50% NaCl and 50% BLWE. The elemental composition results, presented in Table 2, further detail the atomic percentages of key elements such as iron and oxygen for each condition.

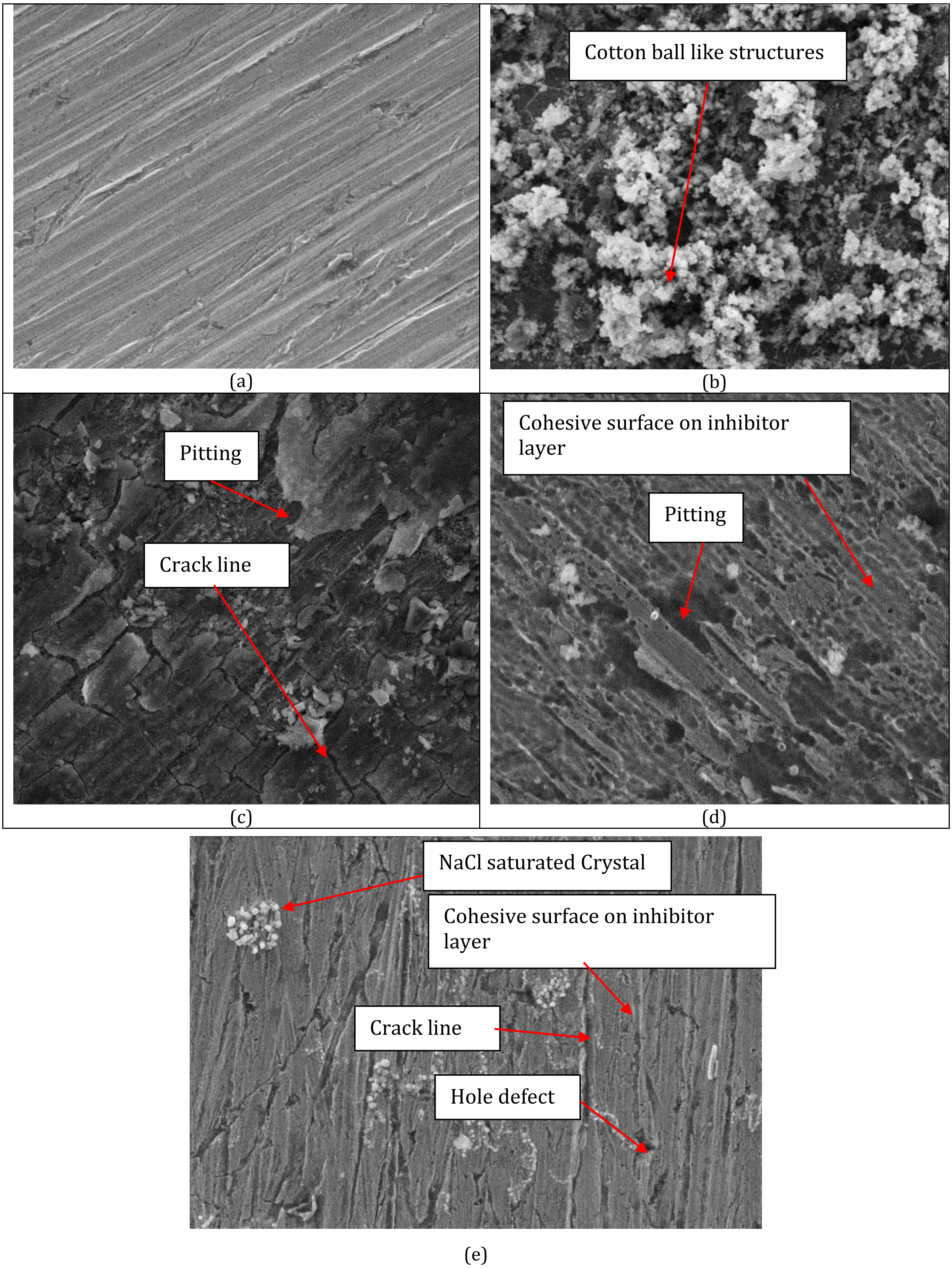


**Fig. 7** The appearance of iron on X70 steel surface for (a) Raw sample, (b) 100% NaCl immersion, (c) 90% NaCl 10% BLWE, (d) 70% NaCl 30% BLWE, and (e) 50% NaCl 50% BLWE

**Table 2** Atomic percentage of raw sample and samples of X70 steel at the different percentages of NaCl solution and BLWE inhibitor

| Element | Atomic % | | | | |
|---|---|---|---|---|---|
| | Raw sample | 100% NaCl | 90% NaCl, 10% BLWE | 70% NaCl, 30% BLWE | 50% NaCl, 50% BLWE |
| Fe | 97.78 | 45.24 | 40.65 | 82.34 | 56.92 |
| O | 0.00 | 47.28 | 43.05 | 11.51 | 40.90 |
| Cl | 0.00 | 1.12 | 0.50 | 0.68 | 0.31 |
| Si | 2.55 | 0.11 | 0.96 | 0.47 | 0.71 |
| C | 0.00 | 6.32 | 14.70 | 4.83 | 1.36 |
| **Total** | 100 | 100 | 100 | 100 | 100 |

The comparison of iron and oxygen atomic percentages in Table 2 samples reveals distinct differences based on the immersion conditions. For the raw X70 steel sample (Fig. 7(a)), which serves as the control sample, the iron percentage is remarkably high at 97.78%, accompanied by trace elements such as silica (Si) at 2.55%, with 0% oxygen since the sample was not exposed to a corrosive environment. In contrast, the X70 steel sample immersed in 100% NaCl (Fig. 7(b)) exhibits the highest oxygen percentage at 47.28% and a reduced iron percentage of 45.24%. The SEM image reveals a cotton ball-like structure, indicative of goethite (α-FeOOH) formation on the surface after exposure to the acidic environment for 24 days [10]. The sample immersed in a 90% NaCl solution mixed with a 10% BLWE inhibitor (Fig. 7(c)) shows a slightly improved condition with 40.65% iron and 43.05% oxygen. However, the SEM image highlights the presence of crack lines and pitting, signalling moderate corrosion activity. For the sample immersed in a 70% NaCl solution mixed with 30% BLWE inhibitor (Fig. 7(d)), the results demonstrate the most effective corrosion inhibition. The iron percentage significantly recovers to 82.34%, while the oxygen percentage drops to the lowest value of 11.51%. The SEM image displays a smooth surface with minimal pitting, indicating effective protection. Lastly, the sample immersed in a 50% NaCl solution mixed with 50% BLWE inhibitor (Fig. 7(e)) shows a less effective inhibition compared to the 30% BLWE sample. The iron percentage is 56.92%, and the oxygen percentage increases to 40.90%. The SEM image reveals a slightly rougher surface, with noticeable saturated NaCl crystals and hole defects caused by corrosion.

The SEM-EDX analysis demonstrated that the 70% NaCl solution mixed with 30% BLWE inhibitor provided the most effective corrosion protection for X70 steel after 24 days of immersion. This sample exhibited the highest iron content (82.34%) and the lowest oxygen content (11.51%), indicating minimal oxidation and corrosion. The corresponding SEM image showed a smooth surface with minimal pitting, confirming the effective formation of a protective layer.

## 3.3 3.3 EIS Analysis of Corrosion Rates for X70 Steel Samples

Electrochemical Impedance Spectroscopy (EIS) is employed to evaluate the corrosion rates of X70 steel samples immersed in varying percentages of NaCl solution and BLWE inhibitor. To analyse and differentiate the corrosion behaviour, both Tafel and Nyquist plots are utilized. The superimposed Tafel plot displayed in Fig. 8, highlights the potential applied during the electrochemical reactions while the superimposed Nyquist plot, as shown in Fig. 9, provides a comparative analysis of resistance for the samples to corrosion by analysing the impedance ranges.

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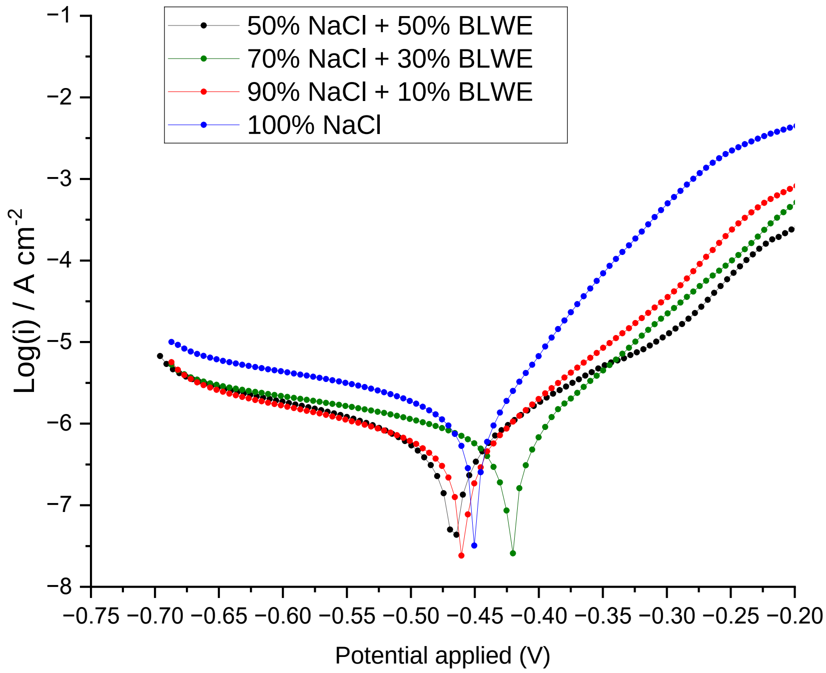
(a)




(b)

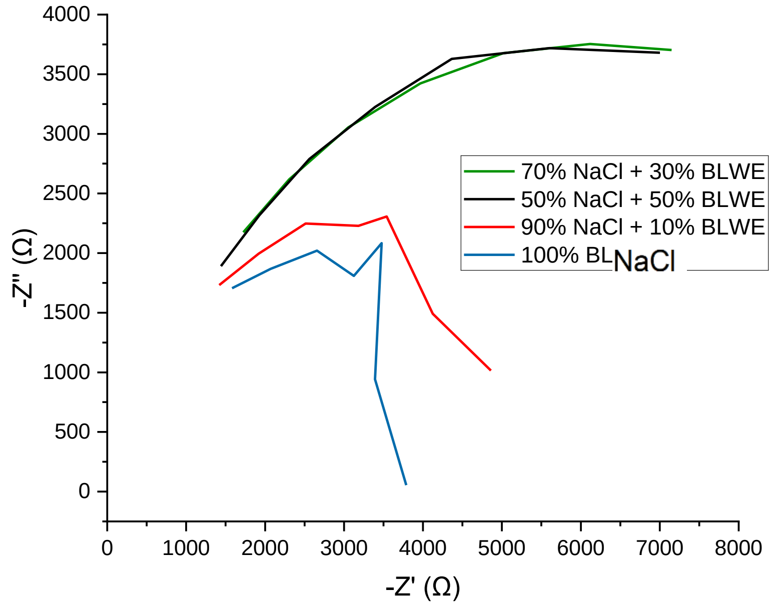



**Fig. 8** Superimposed of EIS analysis for various inhibitor concentration from (a) Tafel and (b) Nyquist plot

The superimposed Tafel plot (Fig. 8) demonstrates the relationship between the potential applied (V) and the logarithm of the current density (log(i)) for X70 steel samples immersed in different NaCl and BLWE mixtures. Among the curves, the green curve corresponding to the 70% NaCl solution mixed with 30% BLWE inhibitor condition exhibits the highest potential applied. This indicates the most positive shift in corrosion potential, suggesting that the 70% NaCl + 30% BLWE mixture offers the best anodic protection. The higher potential implies that the inhibitor effectively reduces the anodic reaction rate, forming a protective barrier on the steel surface that prevents metal dissolution.

The superimposed Nyquist plot (Fig. 9) shows the impedance response (-Z'') versus the real resistance (-Z') for the X70 steel samples. The semicircle diameter reflects the charge transfer resistance (Rct), which is inversely proportional to the corrosion rate. The 70% NaCl solution mixed with 30% BLWE inhibitor (green curve) condition exhibits the largest semicircle diameter compared to other curves, indicating the highest charge transfer resistance. This demonstrates that the BLWE at 30% concentration provides an effective barrier, reducing the electron flow required for corrosion. The enhanced Rct in the Nyquist plot corresponds to the ability of the BLWE to inhibit corrosion by forming a dense and stable protective film on the steel surface.

Both the Tafel and Nyquist plots confirm that the 70% NaCl solution mixed with 30% BLWE inhibitor is the most effective combination for corrosion inhibition. The Tafel plot highlights its anodic protection through the highest potential applied, while the Nyquist plot shows its efficiency in increasing charge transfer resistance.

## 4. Conclusion

FTIR identified key functional groups in BLWE, including hydroxyl (-OH), carbonyl (C=O), and carbon-hydrogen (C-H), which contribute to its corrosion inhibition properties by forming protective layers on the steel surface. SEM-EDX analysis confirmed that the 70% NaCl solution mixed with 30% BLWE inhibitor provided the best corrosion protection, with the highest iron content (82.34%) and the lowest oxygen content (11.51%) after immersion. The surface morphology showed minimal pitting and a smooth protective layer, indicating effective corrosion inhibition. Electrochemical Impedance Spectroscopy (EIS) results, including Tafel and Nyquist plots, further supported the performance of the 70% NaCl solution with a 30% BLWE mixture. The Tafel plot demonstrated the highest applied potential for the green curve, indicating the strongest anodic protection, while the Nyquist plot showed the largest charge transfer resistance, confirming the inhibitor's efficiency. 70% NaCl solution mixed with 30% BLWE inhibitor proved to be the optimal choice for reducing corrosion in X70 steel, showcasing the potential of BLWE as an eco-friendly and effective corrosion inhibitor.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Amirul Imran Mohammad, Zaidi Embong, Khawarizmi Jafery, Siti Maisarah Rahim, Mohamad Sidiq Mohd Basir;* ***data collection:*** *Amirul Imran Mohammad, Khawarizmi Jafery, Siti Maisarah Rahim, Mohamad Sidiq Mohd Basir;* ***analysis and interpretation of results:*** *Amirul Imran Mohammad, Zaidi Embong, Khawarizmi Jafery, Siti Maisarah Rahim;* ***draft manuscript preparation:*** *Amirul Imran Mohammad, Zaidi Embong. All authors reviewed the results and approved the final version of the manuscript.*

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