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Optimization of Blended Fig and Gmelina (Ficus Polita and Gmelina Arborea) Leaves Extract as Corrosion Inhibitor of Steel in Hydrochloric Acid

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ABSTRACT: The world is currently exploring alternatives that are environmentally friendly in different fields and corrosion engineering has notbeen left out. Numerous plant extracts have been investigated as alternatives to inorganic inhibitors for their potential use as corrosion inhibitors in various industries. Research in this area is receiving a lot of interest in developing inhibitors with promising results as reported by several researchers. This work focused on optimization of combined Ficus polita and Gmelina arborea leaf extracts as corrosion inhibitor for low-carbon steel in 1M%HCI using gravimetric techniques. The leaves extracts were subjected to phytochemical screening and Fourier Transform Infrared Spectroscopy analysis (FTIR). Scanning Electron Microscopy (SEM) was performed on protective layer. Stat-Ease Design Expert was used for design of the experiment and the analysis of the results. Immersion time, Temperature and Inhibitor Quantity were considered as design factors, while the HCI was constant throughout the experiments. Inhibition efficiencies were measured using the IE formula. The results showed that the extracts contained alkaloids, flavonoids, tannins, steroids, saponins, terpenoids, phenols, and functional groups, which were responsible for the corrosion-inhibitory action of the extracts. Scanning Electron Microscopy (SEM) revealed that the surface of low-carbon steel was significantly less corroded in the presence of the blended extracts compared to the control sample. This confirmed the formation of a protective layer on the steel surface. The weight loss results indicated that the blended extract reduced the corrosion rate. The optimal conditions were an immersion time 24h, temperature of 30 ℃, inhibitor ratio of 30:70, inhibitor quantity of 0.6g and Inhibitor Efficiency of 95.08%. These results showed that the blended extract could serve as a good substitute for industrial inhibitors.

KEYWORDS: corrosion rate, ficuspolita leaf extract, gmelina arborea leaf extract, inhibition efficiency, optimization, weight loss

I. INTRODUCTION

Corrosion is a pervasive issue in various industries, particularly the oil, gas, and chemical sectors, where metal equipment and infrastructure are exposed to harsh environments such as hydrochloric acid (HCl). Corrosion not only leads to financial losses due to equipment deterioration but also poses significant safety and environmental risks. To mitigate these concerns, it is imperative to develop effective corrosion prevention techniques (Aslam et al. 2023). Corrosion defined as an irreversible interfacial reaction of a material (metal, ceramic, or polymer) with its environment, which results in the consumption of the material or its dissolution into the material of a component of the environment (Balan, 2018). Knowing that the environment has an important effect on corrosion, one way to manage corrosion is to adjust or modify the environment in which the material is exposed. Several factors contribute to corrosion, including the reactivity of the metal, presence of impurities, presence of air, moisture, gases such as sulfur dioxide and carbon dioxide, and the presence of electrolytes (Chigondo and Chigondo, 2016).

In industries such as petroleum and petrochemical facilities, thousands of kilometers of pipeline, pumps, pressure, and storage vessels are used to process, store, and transport products, which are not only critical to the survival of these industries but also indirectly to the economy of the nation, as they are the mainstay of the world economies. Steel is the most widely used material in this sector (Elyor et al., 2022. Steel used in petrochemical plants is exposed to corrosion as a result of exposure to aggressive conditions such as temperature, pressure, water, oxygen, solvents, and other chemicals (Groysmann, 2017). Low-carbon steel is the most widely used material for construction in the petrochemical industry because of its cost implications compared with other types of metals such as stainless steel. They are also a good material choice for the transport of petrochemicals, particularly because of their low cost.

Over the years, corrosion engineers have developed different methods for controlling and monitoring corrosion depending on the application environment. This starts from the selection of the choice of material for individual applications as a first and usually the most important means of corrosion control. A balance is usually considering between the cost of the material and its specific application. Another means of controlling corrosion is the use of coatings, catholic protection, and corrosion inhibitors, which have become cost-effective and acceptable means of corrosion control, especially in acidic environments found in the petrochemical industries (Groysmann, 2017; Khaled, 2004; Singh, 2016).

Corrosion inhibitors are substances that are added in small quantities either to the metal surface or to the fluid to which the material is exposed to reduce the likelihood of the metal being corroded. Several studies have been carried out on the use of different kind of corrosion inhibitors. These inhibitors operate by the mechanism of reducing the rate of corrosion by blocking the active sites of the metal after being adsorbed on the surface of the metal. This helps displace water molecules and form a compact barrier film on the metal surface (Kumar and Karthikeyan, 2012). The most common inhibitors are inorganic materials that contain sulfur, oxygen, nitrogen, phosphorus, and their functional groups. A major challenge with the use of these inorganic inhibitors for corrosion control is that some of them are toxic, expensive, and result in environmental pollution upon interaction with the environment. As a result of these challenges, scientists have been developing or discovering other substances that could act as good corrosion inhibitors and are cost-effective, non-toxic, and environmentally friendly (Siyi et al., 2020).

In recent years, various green corrosion inhibitors have been reported, including plant extracts (Salleh et al., 2021) (roots, stems, leaves, and seeds), amino acids (Verma, 2022), ionic liquids (Kobzar and Fatyeyeva, 2021), and biopolymers (Shahini et al., 2021), which are primarily used for metal corrosion protection. Among them, plant extracts are the most common green corrosion inhibitors reported in the literature (Alrefaee et al., 2021, Verma, 2022, Verma et al., 2018).

This project aims to investigate and optimize a natural and environmentally friendly corrosion inhibitor derived from blended extracts of Ficus polita and Gmelina arborea leaves. Both these plants have shown promise as potential sources of corrosion-inhibiting compounds in previous studies. By blending their extracts, we sought to enhance their inhibitive properties and create a novel, cost-effective, and sustainable solution for protecting low-carbon steel components from corrosion in hydrochloric acid.

II. MATERIAL AND METHODS

This section explains the methods and the materials used in the study.

2.1 Materials

The following materials were used in this study;

Ficus polita and Gmelina arborea leaves were sourced from Tambari Estate Bauchi, low-carbon steel was sourced from Center for Industrial Studies Abubakar Tafawa Balewa University, Bauchi (ATBU), ethanol, acetone and HCl acid were obtained from Ultra X Medical, Bauchi.

2.2 Equipment/Apparatus:

The equipment used in this work was a 250ml beaker, Heating Mantle, Rotary evaporator, thermostatic water bath, weighing balance and A Cary-630.

2.3 Methods

2.3.1 Sample preparation

Twenty-nine low-carbon steel samples with a surface area of 6.25 cm² were prepared using the method adopted by Akpan et al., (2018). The sheet was mechanically press-cut into dimensions of 2.5 cm × 2.5 cm × 0.3 cm for the gravimetric method and SEM analysis. Mill scales on these coupons were removed by milling and polishing to a mirror finish using milling and polishing machines with a series of silicon carbide abrasive papers (200, 400, and 600 respectively). The coupons were degreased in absolute ethanol, dipped in acetone, air-dried and then stored in a moisture-free desiccator before they were use in corrosion and SEM studies.

2.3.2 Preparation and extraction of plant leaves

Ficus polita and Gmelina arborea leaves were sourced from Tambari Estate Bauchi. Ficus polita and Gmelina arborea leaves were air-dried at room temperature under shed to avoid drying up the phytochemicals present. Air-dried leaves were macerated and ground to increase the surface area. Aqueous extracts were prepared by weighing 100g of each powdered leaf sample in 500 ml of solvent (ethanol) and allowed to soak for 72h. After soaking, the extract was filtered using layered muslin cloth in a beaker. The concentrated extracts were placed in a fume cupboard/hood to remove residual ethanol.

2.3.3 Characterization of fiscus polita and gmelina arborea leaves extract

Characterization of both leaves was carried out at the chemistry laboratory Abubakar Tafawa Balewa University Bauchi to determine their phytochemical compositions such as alkaloids, flavonoids, tannin, glycosides and steroids according to methods reported by (Sin, 2017; Junaid & Patil. 2020 and Hafsat, at el. 2023).

I. Determination of Alkaloids: –Four drops of Mayer‘s reagent were added to 0.5 g of each extract sample in a test tube. The mixture was shaken thoroughly, and a creamy precipitate was observed.
II. Determination of Flavonoids: – Five drops of aqueous NaOH were added to 5ml of each extract in a test tube, and the change in color from greenish/brownish solution to yellowish solution was then observed.
III. Determination of Tannin: –Each extract (0.1g) was dissolved in 1% $FeCl_3$ reagent and stirred. A blue-black coloration was observed.
IV. Determination of Steroids – 10ml of acetic anhydride was added to each extract (0.5g). Concentrated sulphuric acid(1mL) was then added to the tube. A blue/blue-green color was observed.
V. Determination of Saponin: –Each extract (0.5g) was dissolved in 10ml of distilled water. The mixture was shaken vigorously for 30s and allowed to stand for 30min. The honeycomb foam was observed.

Determination of Protein: – Five drops of copper sulfate solution were added to a 0.5g extract in a test tube, four drops of caustic soda solution were added and the solution was shaken thoroughly. The color of the mixture was violet.

2.3.4 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared (FTIR) spectra of the Ficus polita Extract, Gmelina arborea Extract, and corrosion products were carried out separately to determined their functional groups. A Cary-630 Agilent Fourier-transform infrared spectrophotometer was used for this analysis. The analysis was carried out by scanning the sample through a wavenumber range of 500-4000cm^{-1}.

2.4 Scanning Electron Microscopy (SEM/EDX)

A scanning electron microscope (SEM) was used to analyze the morphology of low-carbon steel surface before and after addition of the inhibitor. One piece of low carbon steel coupon was immersed in 1M HCL solution while the second coupon was immersed in a solution of 1M HCL with Ficus polita and Gmelina arborea extracts for 24h. The coupons were rinsed, dried, and subjected to SEM examination.

2.5 Experimental Design

An experimental design was established, involving a Central Composite Design (CCD) of 29 experimental runs, which included three operating variables to study the effect of temperature, immersion time, and inhibitor quantity of the Ficus polita and Gmelina arborea Extract. Nine control experiments conducted, and the expected response of the study was the Inhibition Efficiency. The experiments were performed in a random order to avoid systematic errors, following the approach adopted by Olamide et al. (2018). The factor levels with the corresponding values are listed in Table 1, and the Design Matrix is shown in Table 2. The matrix for the three variables was varied at 3 levels (Minimum -1, Centre 0 and Maximum +1).

Table 1: Independent Variables Experimental Range

Independent variable Symbols Range and Levels					
	Independent variable	Unit	-1	0	+1
1	Inhibitor quantity	(g)	0.2	0.4	0.6
2	Immersion time	(h)	24	48	72
3	Temperature	(^{0}C)	30	40	50

Table 2: Central Composite Design Factors and Level

Std	Run	Inhibitor quantity (g)	Immersion time (h)	Temperature (^{0}C)	Ratio FP:GA
6	1	0.6	24	50	50:50
18	2	0.2	48	40	70:30
9	3	0.6	48	40	60:40
10	4	0.6	48	40	50:50
20	5	0.4	48	40	40:60
8	6	0.6	72	50	60:40
13	7	0.4	48	30	50:50
19	8	0.4	48	50	40:60
7	9	0.2	72	50	40:60
2	10	0.6	24	30	30:70
1	11	0.2	24	30	40:60
12	12	0.4	72	40	60:40
11	13	0.6	24	40	60:40
16	14	0.6	48	40	40:60
3	15	0.4	72	30	60:40
5	16	0.4	24	50	60:40
15	17	0.4	48	40	40:60
4	18	0.6	72	30	50:50
17	19	0.4	48	40	50:50
14	20	0.4	48	56.817	60:40
Control 1	21	--------	24	30	-------
Control 2	22	--------	24	40	-------
Control 3	23	--------	24	50	-------
Control 4	24	--------	48	30	-------
Control 5	25	--------	48	40	
Control 6	26	--------	48	50	-------
Control 7	27	--------	72	30	-------
Control 8	28	--------	72	40	-------
Control 9	29	--------	72	50	-------

2.5.1 Preparation of acidic medium

A corrosive medium containing 1M %HCL was prepared by dissolving 86 cm^3 of concentrated HCl in distilled water and diluting the resulting solution to volume in a 1 dm^3 volumetric flask (Mendham et al. 2000).

2.5.2 Gravimetric method

Twenty-nine cleaned low-carbon steel coupons were weighed using electronic digital weighing balance before the commencement of the experiments. These previously weighed low carbon steel coupons were immersed into different beakers with 100 cm^3 of test solutions containing 1M HCl with various concentrations of the inhibitor ranging from 0.2g to 0.6g. A blank solution containing 100 cm^3 1M HCl without inhibitor was used as the control. The beakers were placed in a water bath, and subjected to various temperatures, ranging from 30^{0}C to 50^{o}C and the immersion times varied from 24h to 72h using the design matrix format for variable interaction. At the end of each run, low-carbon steel coupons were withdrawn from the solution, washed, rinsed with acetone to remove corrosion products, and then reweighed to determine the weight loss from the initial and final weights of the specimens. From the collected weight loss data, the corrosion rate (CR), inhibition efficiency (I.E %) of the inhibitor, and degree of surface coverage (θ) were calculated using equations (1) to (3), respectively.

$$CR\left(\frac{mm}{y}\right) = \frac{87600W}{Apt} \qquad \ldots 1$$

where, CR is corrosion rate, W is the weight loss (g), A is the area of the coupon (cm^2), t is the immersion time (h) and ρ is the density of the coupon (g/cm^3).

$$IE(\%) = \left(1 - \frac{CR_{inh}}{CR_{blank}}\right) \times 100 \qquad \ldots 2$$

where, I. E is the inhibition efficiency, CRi_{nh} and CR_{blank} correspond to the corrosion rates in the presence and absence of the inhibitor, respectively.

Degree of surface coverage θ, at each concentration of inhibitor is computed using the expression;

$$\theta = \left(1 - \frac{CR_{inh}}{CR_{blank}}\right) \quad \ldots 3$$

where θ is the surface coverage and CR_{inh} and CR_{blank} correspond to the corrosion rates in the presence and absence of the inhibitor, respectively

2.5.3 Optimization of the Inhibition Efficiency Using Response Surface Methodology (RSM)

Central Composite Designs as adopted by (Anadebeaet al. 2018) was used to analyzed the response of result of these experiments because it can fit a full quadratic model. They are also used when the design plan calls for sequential experimentation because they can include information from a correctly planned factorial experiment (Olamide, et al. 2018). Response Surface Methodology and graphical analyses of Inhibition Efficiencies were performed. The mathematical models in terms of coded and actual factors were obtained which agrees with (Onukwuli and Omotioma 2016)

III. RESULTS AND DISCUSSIONS

3.1 Results

The results of the research work are as follows:

3.1.1 Phytochemical Test Result

The phytochemical composition of ficuspolita and gmelina arborea extracts contain alkaloid, tannin, flavonoid, phenols, terpenoids, saponins, etc. as shown in Table 3.

Table 3: Phytochemical Component of Ficus Polita and Gmelina Arborea Leaves Extract.

Substance	Ficus Polita	Gmelina Arborea
Steroids	++	+
Tannin	+++	+
Alkaloid	++	+
Flavonoid	+++	++
Phenols	+++	+++
Terpenoids	+	+
Saponins	+	+++
Glycosides	-	+

+++ Highly present
+++ Moderately present
+++ Slightly present

The quantitative phytochemical screening of Ficus Polita and Gmelina Arborea leaves extract are tabulated below.

Table 4: Result Of Quantitative Phytochemical Screening

Phytochemical	Ficus	Gmelina arborea
Alkaloids	12 mg/g	10 mg/g
Flavonoids	20mg/g	25 mg/g
Phenolics	35 mg /g	40 mg /g
Tannins	15 mg/g	18 mg/g
Saponins	10 mg/g	12 mg/g

3.1.2 FTIR test

The peaks in the spectrum of the ficuspolita and gmelina arborea leaf extracts are shown in Figure 1 and 2, whereas the peaks in the spectrum of the corrosion product are shown in Figure 3.

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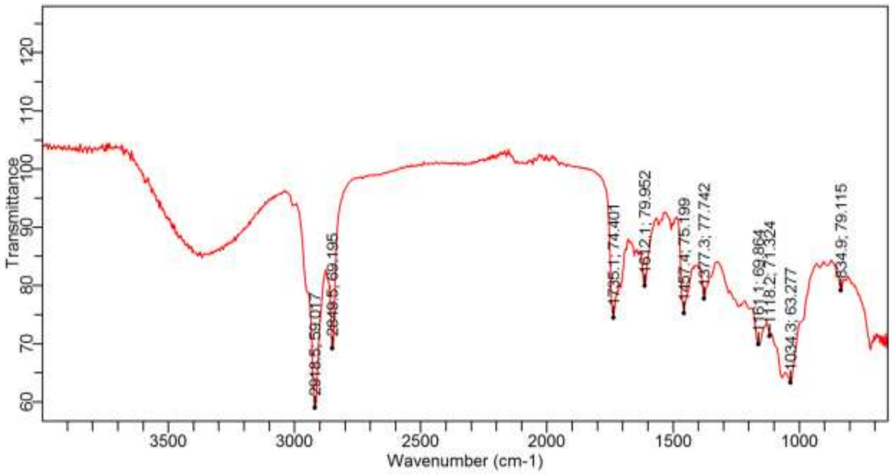

Figure 1: Spectrum of Ficus Polita Leaf Extracts

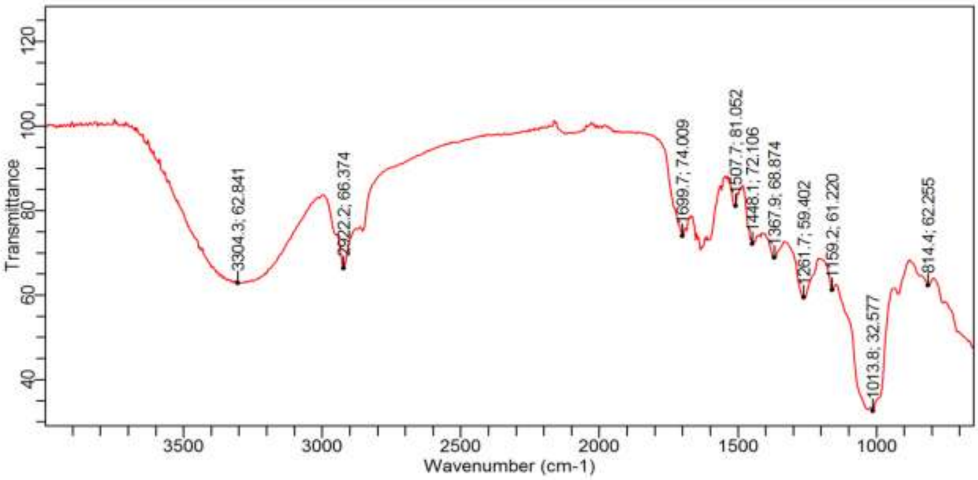

Figure 2: Spectrum of Gmelina Arborea Leaf Extracts

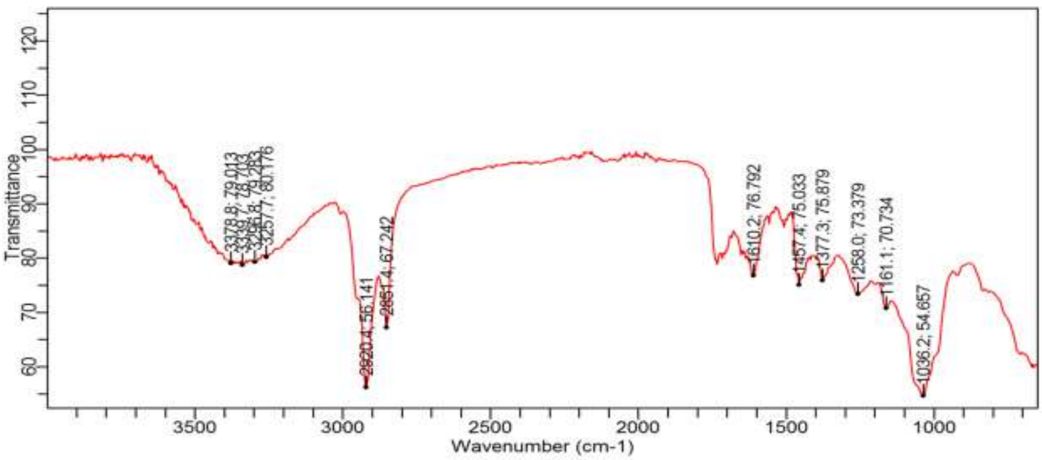

Figure: 3 Spectrum of the Ficus Polita and Gmelina Arborea **Leaf Extracts**

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3.1.3 Weight Loss Result

Table 5 shows the calculated corrosion rate and inhibition efficiencies for blended ficuspolita and gmelina arborea leaves extract.

Table 5: Calculated Corrosion Rate and Inhibition Efficiencies for Blended Ficus Polita and Gmelina Arborea Leaves Extract

Run	Inhibitor quantity (g)	Immersion time (h)	Temperature (^{0}C)	Ratio FP:GA	WI (g)	WF (g)	ΔW (g)	CR (mm/yr.)	IE (%)
1	0.6	24	50	50:50	17.687	17.680	0.0067	0.4984	93.33
2	0.2	48	40	70:30	16.840	16.802	0.0371	1.3763	78.59
3	0.6	48	40	60:40	17.824	17.809	0.0142	0.5282	91.74
4	0.6	48	40	50:50	17.682	17.666	0.0158	0.5273	90.87
5	0.4	48	40	40:60	18.234	18.203	0.0304	1.1285	82.42
6	0.6	72	50	60:40	17.470	17.444	0.0258	0.6420	87.06
7	0.4	48	30	50:50	18.961	18.937	0.0239	0.8905	85.93
8	0.4	48	50	40:60	18.844	18.804	0.0400	1.4908	77.58
9	0.2	72	50	40:60	18.344	18.285	0.0589	1.4621	70.53
10	0.6	24	30	30:70	17.441	17.436	0.0046	0.3474	95.08
11	0.2	24	30	40:60	18.634	18.620	0.0139	1.0371	85.32
12	0.4	72	40	60:40	17.186	17.150	0.0356	0.8843	81.75
13	0.6	24	40	60:40	19.754	19.749	0.0047	0.3563	94.99
14	0.6	48	40	40:60	17.787	17.770	0.0161	0.5988	90.7
15	0.4	72	30	60:40	16.987	16.958	0.0281	0.6985	85.56
16	0.4	24	50	60:40	16.959	16.937	0.0212	1.5794	79.02
17	0.4	48	40	40:60	18.326	18.303	0.0221	0.8221	87.23
18	0.6	72	30	50:50	17.537	17.518	0.0186	0.4634	90.42
19	0.4	48	40	50:50	17.001	16.975	0.0252	0.9373	85.44
20	0.4	48	56.81	60:40	18.408	18.363	0.0443	1.6485	75.21
Cnt1	--------	24	30	-------	18.029	17.934	0.0950	7.3619	
Cnt2	--------	24	40	-------	16.945	16.849	0.0958	7.4239	
Cnt3	--------	24	50	-------	18.160	18.058	0.1012	7.8424	
Cnt4	--------	48	30	-------	17.471	17.300	0.1702	6.5947	
Cnt5	--------	48	40		18.730	18.556	0.1731	6.7071	
Cnt6	--------	48	50	-------	18.376	18.197	0.1788	6.9280	
Cnt7	--------	72	30	-------	17.856	17.660	0.1951	5.0397	
Cnt8	--------	72	40	-------	17.523	17.327	0.1954	5.0474	
Cnt9	--------	72	50	-------	16.979	16.778	0.2001	5.1688	

3.1.4 Result of the Surface Analysis with and without the Inhibitor

Plate 1a: Untreated steel

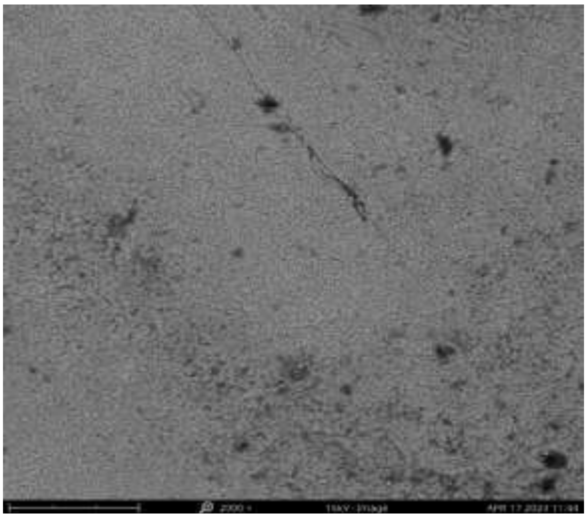

Plate 1b: Treated steel

3.2 Discussions of Results

3.2.1 Analysis of phytochemical result

Table above is the result obtained from phytochemical analysis of the plant extract for ficuspolita and gmelina arborea leaves. It is evident from the result that ficuspolitaextracts were quite high in flavonoids, Phenols and tannin, Moderate in alkaloids and Steroids, lower in saponin and terpenoids. While in gmelina arborea extract, tannin, saponin and Phenols were higher and lower in alkaloids, glycosides and steroids. These properties are largely responsible for the inhibitive ability of the plant, which is in agreement with the findings of Madu, J, O. et al, (2019) and Zakeri, A., et al, (2022). The leaves of ficuspolita and gmelina arborea are highly effective for use as a corrosion inhibitor in metals.

Quantitative analysis is essential in order to identify the quantity of phytochemical constituents in the plant extract. Table 4 shows the quantity of each compound present in the test solution. Ficus polita rich in flavonoids and phenolics provides antioxidant driven corrosion inhibition while Gmelina arborea tannin and alkaloid rich provides very strong adsorption on steel surfaces. The presence of functional groups like Oxygen (0), Nitrogen (N) and Sulphur in molecules of the plant extracts serve as the active centers for the adsorption of the inhibitor on the metal surface as a result of their higher basicity and electron density.

3.2.2 Analysis of FTIR test

The FTIR spectrum of Ficus polita leaf extract displayed a broad O–H stretching vibration around 3340 cm^{-1}, indicative of hydroxyl groups in alcohols and phenols. Peaks at 2922 and 2850 cm^{-1} correspond to aliphatic C–H stretching. A sharp band at ~1712 cm^{-1} was assigned to C=O stretching of carboxylic acids or esters, while strong absorptions at 1610 and 1515 cm^{-1} were attributed to aromatic C=C skeletal vibrations. The C–O and C–O–C stretching bands in the 1270–1020 cm^{-1} range confirmed the presence of phenolic, tannin, and glycosidic functionalities.

The FTIR spectrum of Gmelina arborea leaves extract shows a broad O–H band at ~3330 cm^{-1}, aliphatic C–H stretches at 2924/2853 cm^{-1}, a strong C=O band at ~1716 cm^{-1} (esters/acids), and characteristic aromatic C=C bands at 1604 and 1513 cm^{-1}. The C–O/C–O–C region (1268–1028 cm^{-1}) confirms phenolic and glycosidic functionalities typical of tannins/flavonoids/iridoids.

The FTIR spectrum of the corrosion product formed on mild steel after immersion in 1 M HCl containing blended Ficus polita and Gmelina arborea leaf extracts showed several characteristic shifts and new absorptions compared to the pure extracts. A broad O–H stretching band originally observed at ~3340–3330 cm^{-1} shifted to lower wavenumbers (~3310–3295 cm^{-1}), suggesting strong hydrogen bonding and interaction of hydroxyl groups with Fe surface atoms. The C=O stretching vibration (from phenolic acids/esters at ~1716–1712 cm^{-1}) shifted to ~1698 cm^{-1}, confirming coordination of carbonyl oxygen with Fe^{2+} ions. The aromatic C=C skeletal vibrations at ~1610 and 1515 cm^{-1} were slightly reduced in intensity, indicating involvement of conjugated aromatic systems in adsorption. The C–O/C–O–C stretching bands in the 1270–1020 cm^{-1} range persisted but with diminished intensity, reflecting partial

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consumption/interaction of polyphenolic and glycosidic groups in protective film formation. The variation in the number and nature of the shifts indicates that there was synergy among the functional groups in the corrosion inhibition process Odejobi O. and Akinbulumo, O. 2019.

3.2.3 Analysis of weight loss result

The weight loss results given in table 4 demonstrate the calculated corrosion rate of the low-carbon steel coupons in the absence and presence of the blended inhibitors, as obtained from the experimental data. The corrosion rate of the low-carbon steel was reduced when blended Ficus polita and Gmelina arborea leaf extracts ware introduced in the acidic medium. Design Expert Stat-Ease was used to analyze the results of the experiments and generate an empirical equation. The inhibition efficiencies varied at different concentrations of the extract under different conditions. The experiment yielded the best results with an inhibition efficiency of 95% at 24h and a temperature of 30^{0}C. This was a result of the synergy between the phytochemicals present in the individual extracts. This record is in line with the reports of Nwachukwu et al. 2021.

3.2.3.1 Optimization of the inhibition efficiency using response surface methodology (RSM).

The coded and uncoded values of the test variables were used to optimize the variables, namely, the quantity of inhibitor, immersion time and temperature. The empirical relationship between corrosion Inhibition Efficiency and three variables in coded values to study the effect of the variables on the responses, was given as

$$Y = \beta_0 + \int_{i=1}^{4} \beta_i X_i + \int_{i=1}^{4} \beta_{iI} X_I^2 + \int_{i=1}^{4} \int_{j=i+1}^{4} \beta_{ij} X_i X_{ij} \ldots 4$$

where $\beta_{0,}$ is constant, β_i and β_{ij} are coefficient of ij, Xi, shows independent variables, and X_{ij} shows their relation

Empirical quadratic equation with coefficient is

$$Y_{\text{inhibition efficiency}} = +83.69-0.3999\ A-4.30\ B+5.86\ C-1.01\ D-1.56\ AB-2.25\ AC+0.3954\ AD+3.32\ BC\ +2.70\ BD+1.91CD \ldots\ldots 5$$

Where A is immersion time, B is Temperature, C inhibitor quantity, D is blending ratio

P-values of less than 0.0500 indicate that the model terms ware significant. In this case, A, C^2, B and C ware significant model terms. Values greater than 0.1000 indicated that the model terms were not significant. Therefore, AB, C, AC, BD, CD, A ^{2} and D are insignificant model terms that are not included, resulting in a model reduction and giving Eq. (6) as the improved model.

$$Y_{\text{inhibition efficiency}} = 84.02-1.84\ A-4.57\ B+7.23\ C+0.4558\ D+0.8378\ AB-1.33\ AC+2.93-0.9576BD \quad \ldots 6$$

Equation (6) represents the quantitative effect of the factors (A, B, C, and D) on the response (gravimetric method). Coefficients with one factor represent the effect of that factor, whreas coefficients with more than one factor represent the interaction between those factors. A positive sign in front of the terms indicates a synergistic effect while negative sign indicates an antagonistic effect of the factor. This finding is consistent with the result of previous studies (Nwachukwu et al. 2021). The adequacy of the proposed model was tested using Design Expert sequential model sum of squares and model test statistics. From the statistics test, the regression coefficient (R^2 = 0.9567) is high, and the adjusted RR^2 (0.9252) is in close agreement with the predicted RR^2 (0.8483) value. This shows that the experimental data obtained for the Inhibition Efficiency ware statistically consistent, and the second-order polynomial model selected was suitable for modelling the second-order polynomial equation in the final equation terms of the coded values of the process parameters as shown above. This agrees with the work of (Onukwuliet al.2016).

3.2.3.2 Predicted and actual optimal levels

Figure 4 shows the relationship between the actual and the predicted values where the data points on the plot are reasonably distributed near to the straight line, indicating a good relationship between the experimental and predicted values of the response and that the underlying assumptions of the above analysis were appropriate. The results also suggest that the selected model was adequate for predicting the response variables for the experimental data as reported previously (Nwachukwu et al. 2021).

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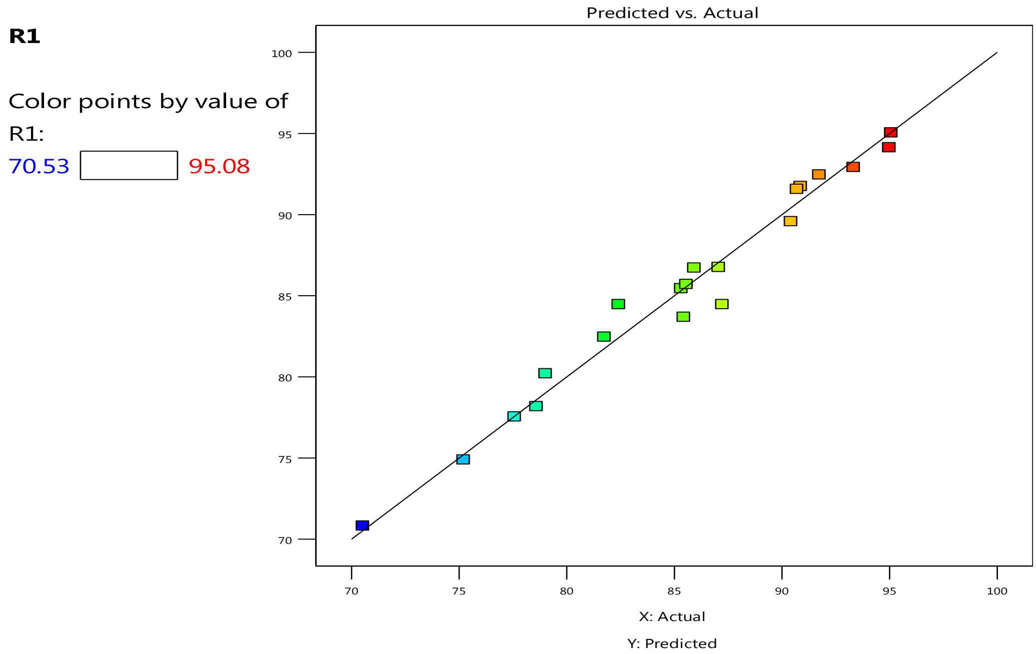

Figure 4: Actual and Predicted Optimal Level

3.2.3.3 Surface response plots for low-carbon steel with blended FP and GA

The interactive effects of the process variables on the corrosion rate were studied by plotting a three-dimensional surface curve against any two independent variables while keeping the other variable constant based on the analysis of the model. The curves are shown in Figures 5– 7. The characteristics of the 3-D surfaces plot imply that there is a complementary relationship between the factors in the corrosion process. Figure 5 shows the effect of exposure time and temperature on the corrosion inhibition efficiency. It was observed that a lower temperature with increased immersion time favored a higher corrosion inhibition efficiency of carbon steel. This also confirmed the synergistic effect of these two variables. Figure 6 depicts the effect of temperature and extract concentration on corrosion inhibition efficiency. It was observed that a lower temperature and higher extract concentration favored an increase in the efficiency of corrosion inhibition on carbon steel. This also affirmed the synergetic effect of the terms on the efficiency of corrosion inhibition of carbon steel. Figure 7 shows the effect of concentration and immersion time on the corrosion inhibition efficiency. inhibition efficiency increased with extract concentration because, as the inhibitor concentration increased, the number of phytochemical compounds adsorbed on the metal surface increased.

Table 8: ANOVA for Quadratic Model (Response: Inhibition Efficiency).

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	835.92	8	104.49	30.39	< 0.0001	Significant
A-Time	11.33	1	11.33	3.29	0.0969	
B-Temperature	196.65	1	196.65	57.19	< 0.0001	
C-quantity	402.47	1	402.47	117.04	< 0.0001	
D-ratio	0.6474	1	0.6474	0.1883	0.6727	
AB	3.06	1	3.06	0.8911	0.3655	
AC	5.26	1	5.26	1.53	0.2417	
BC	25.50	1	25.50	7.42	0.0198	
BD	1.19	1	1.19	0.3456	0.5685	
Residual	37.82	11	3.44			
Lack of Fit	26.26	10	2.63	0.2270	0.9378	
Pure Error	11.57	1	11.57			
Cor Total	873.74	19				

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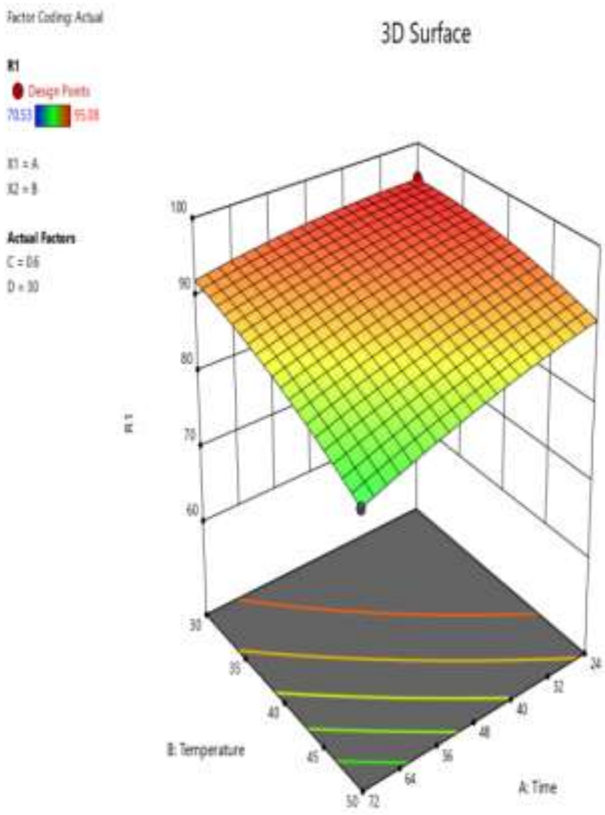

Figure 5: 3D Surface Plot of IE, Temperature and Time.

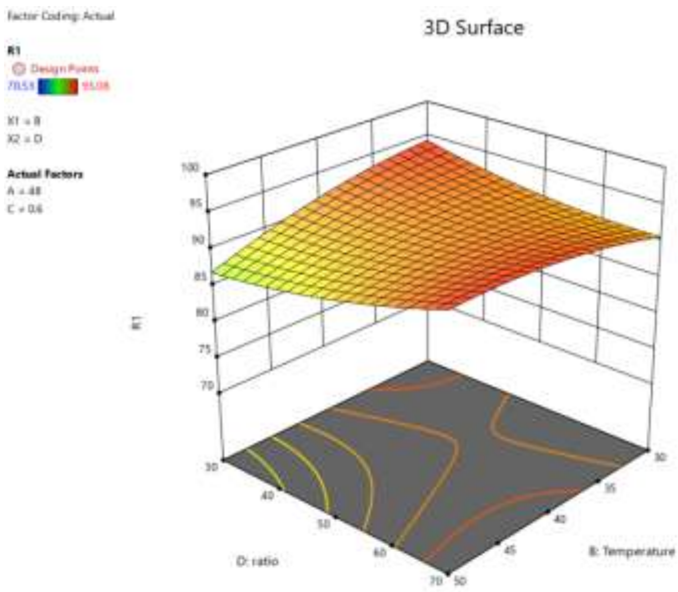

Figure 6: 3D surface plot of IE, Quantity of Inhibitor and Time.

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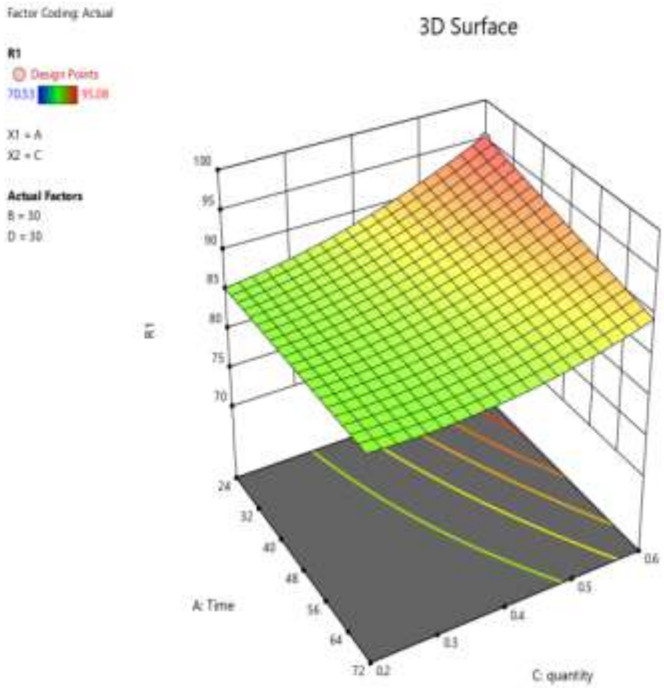

Figure 7: 3D Surface Plot of IE, Quantity of Inhibitor and Time.

3.2.4 Analysis of surface morphology with and without the inhibitor

The surface morphology of low-carbon steel was examined using scanning electron microscopy. It was observed from the surface profile of the untreated steel in Figure 4a, that there were rough surfaces with porous layers full of cracks, the acid easily penetrated the steel, causing it to corrode. However, in the presence of the blended inhibitor, as shown in Figure. 4b, under the same conditions the active corrosion site was blocked by the inhibitor, thereby reducing the rate at which low-carbon steel corroded. The reduction in corrosion rate was due to the formation of a protective layer by the blended FP and GA on the metal surface.

IV. CONCLUSION

The following conclusions were drawn.

Both Ficus polita and Gmelina arborea leaf extracts contained amounts of Phytochemical Phytochemical properties, alkaloids and flavonoids, are highly present indicated by triple plus (+++). Other properties present, but in high amount are saponin and Steroids (++), tannin (+) Terpenoids and Phenols (+). These properties ware responsible for the corrosion-inhibitory action of the extracts.

The weight loss demonstrated that corrosion rates of low-carbon steel when exposed to 1M HCl had value as high as 7.3619mmy^{-1} without blended extract inhibitor. The corrosion rate reduced with addition of blended extract inhibitor to as low as 0.3474mmy^{-1}. Response Surface Methodology (RSM) optimal conditions were as follows: immersion time 24h, temperature 30 ℃; inhibitor ratio of 30:70; inhibitor quantity 0.6g and Inhibitor Efficiency 95.08%. The experimental conditions demonstrate the importance of the inhibitor concentration, immersion time, and temperature on corrosion inhibition efficiency.

Scanning Electron Microscopy (SEM) revealed that the surface of low-carbon steel was significantly less corroded in the presence of the blended extracts than in the control sample. This confirms the formation of a protective layer on the steel surface.

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