LAUTECH Journal of Engineering and Technology 18 (2) 2024: 80-92
10.36108/laujet/4202.81.0270

Corrosion inhibitory performance of hybridized rice-husk extract and biopolymer waste on food-compatible mild steel in acidic media

Adeoye B. K.

[1]*Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology Akure, Ondo State, Nigeria.*

Article Info

Article history:

Received: April 6, 2024
Revised: May 29, 2024
Accepted: June 2, 2024

Keywords:

Chitosan
Corrosion,
Metal-alloy,
Inhibition,
Rice-husk

.

Corresponding Author:
bkadeoye@futa.edu.ng

ABSTRACT

Metal corrosion is frequently the outcome of the reactive interaction between food's corrosive components and metal alloy during processing and packaging. This study used gravimetric and depth of attack methodologies to examine the performance of hybridized rice husk extract and chitosan, as a corrosion inhibitor for mild steel in 1 M HCl. Rice husk was subjected to phytochemical screening to choose the best material combination. Gas chromatography-mass spectrometry was then used to characterize the extract. Fourier transform infrared spectroscopy was used to characterize the corrosion film solution and chitosan synthesized from residual biopolymer fish scale. The rate at which the coupon corroded with and without rice husk extract and chitosan was assessed in relation to temperature, concentration, and time. The formation of a film over the metal surface was facilitated by the presence of polycyclic chemicals, tannins, and cellulose, thus aiding corrosion. The inhibition efficiency increased with an increase in temperature and concentration of rice husk extract. Kinetic parameters showed that Langmuir isotherm is the best fit because the R^2 value is close to unity. The addition of a 5:1 ratio of rice husk to chitosan shows a great difference as the inhibition efficiency increases with increasing temperature to 80% inhibition efficiency

INTRODUCTION

Metal corrosion is frequently the consequence of the reactive interaction between a metal or metal alloy and its surroundings (Awad *et al*., 2018). The food manufacturing industries are very concerned about food contaminations resulting from such corrosion since food products frequently have low pH values or include corrosive chemicals, which increases the likelihood of failure due to local corrosion. It has been demonstrated that some dietary organic fatty acids can cause widespread surface erosion when they corrode steels devoid of molybdenum (Halambeka *et al*., 2020. These include the acids tartaric, lactic, citric, and acetic, which, because most commercial food preparation involves heating, often results in widespread corrosion at temperatures above 70 to 80 °C. Moreover, this surface attachment frequently influences the release of metal in the form of ions, wear particles, or bigger pieces, which can immediately stop a process or cause it to fail (Alaneme, Olusegun and Alo, 2016). The effect of this process is the declassification of food products to unmarketable articles because of organoleptic changes, vacuum loss, hydrogen swelling and metal concentration above the legal limit or perforation damages of the food line and containers (Halambek, Cindrića and Grassinob., 2020).

Many strategies have been developed to address this issue of stabilizing the metallic surface and preventing food contamination by metal ions.

Corrosion inhibition is one of the most well-known strategies for minimizing the ensuing issues related to safety, economy, and the environment (Luo et al., 2017). Corrosion inhibitors are compounds that, when added in modest concentrations to mild steel (MS), greatly lower the rate of its corrosion when in corrosive environments. The inhibitory mechanisms are adsorption on a metal surface that displaces a water molecule, which creates protective barriers on the MS surfaces against corrosive chemicals, or oxidation, which results in the formation of protective oxide layers. (Abiola, Otaigbe and Kio, 2009; Yildiz *et al*., 2014). According to reports, these inhibitors, which may be found in both organic and inorganic forms, can be employed to successfully shield MS surfaces from corrosive substances (Umoren and Eduok., 2011; Wang *et al*., 2015). The structural, physical, and chemical characteristics of the material determine an organic inhibitor's efficacy (Rani and Basu, 2012; Torres *et al*., 2014). Although efficient, many of them are hazardous for humans and the natural environment, and their synthesis is highly costly. The development of a green class of inexpensive, environmentally friendly corrosion inhibitors that are easily obtainable from a variety of plant sources is now underway. Research conducted by Abiola *et al.* (2009) and Matthaus and Özcan (2012) on plant extracts has verified the existence of several organic chemicals that can create protective coatings on metal surfaces and impede corrosion. Mangifera indica peel extract was investigated gravimetrically and quantitatively by Ogunleye *et al*., 2016 as a corrosion inhibitor for mild steel in a 1 M HCl solution. Yadav et al. (2013) investigated how copper and aluminium behaved when exposed to an HCl solution that contained fruit extract from *Ziziphus mauritiana*. Using the weight loss approach, the corrosion potentials of apricot juice for MS in a 1 M H_3PO_4 solution were investigated at various temperatures. Abdallah *et al*., 2017 used methods including weight loss measures and galvanostatic and potentiodynamic anodic polarization to assess the inhibitory potentials of curcumin, parsley, and cassia bark extracts for the corrosion of carbon steel in 0.5 M H_2SO_4 solution.

Given the advantages to consumer health and environmental concerns, MS is widely used in most industries, and the issues arising from low corrosion resistance make it imperative that MS be continuously and urgently protected from corrosion. To assess inhibitory efficiency, the majority of published investigations have consistently used weight loss and electrochemical approaches. The latter typically calls for a high level of equipment and knowledge, which are frequently out of reach for many researchers. Thus, using quantitative surface morphological approaches, this work determined the kinetic and thermodynamic parameters that maximized the effectiveness of spent rice husk and extracted chitosan from wasted fish scales as a green inhibitor for MS in a hydrochloric acid media.

MATERIALS AND METHODS

Materials

The MS coupon used for these studies was procured from the Engineering workshop of the Federal University of Technology, Akure, Nigeria and sectioned into 3.5 cm × 3.0 cm × 0.3 cm with a 0.5 cm-diameter hole located 1.0 cm from one of its ends. The hole was used for hanging the coupon to attain uniform exposure during immersion. Emery paper of 800 grit was used to polish the surface of the coupons and then washed thoroughly with deionized water. They were then subjected to chemical treatments by storing them inside a dusting powder prior to the time of use. The mild steel sample was degreased by immersion in acetone and then dried with a clean cloth before using them for each analysis. Rice husks were obtained from a local market in Akure, Nigeria. All other chemicals and reagents are of analytical grades.

Preparation and characterization of Rice Husk Extract (RHE)

This was done using the modified method described by Ogunleye *et al*. (2018). The rice husks were thoroughly sorted, screened and thereafter dried and then pulverized using a blender after initial size reduction with a mortar. Oil was extracted from the husk by Soxhlet extraction and the solvent used was ethanol. The ethanol in the extract was evaporated using a rotary evaporator while the concentrated rice husk extract was transferred into bottles and stored for use. The extracted oil obtained was analysed for its composition using gas chromatography-mass spectrometry (GC–MS; Agilent 5789A), and functional groups of the extract were later characterized using Fourier transform infrared (FTIR) spectroscopy. Phytochemical was done on the extract obtained by following the method described by Abdulkadir et al. (2016)

Extraction and characterization of chitosan from biopolymer waste

Chitosan was extracted from the shrimp shell waste as described by Adeoye *et al*., 2022. The basic processes involved were pulverization using a Rocklabs mill, deproteinization using 0.1 M sodium hydroxide, decolourization in pure acetone, demineralization using 0.5 M hydrochloric acid and deacetylation by boiling in 0.2 M sodium hydroxide. Characterization of the extracted chitosan was carried out using Fourier Transform Infrared Spectroscopy (FTIR).

Phytochemical screening of rice husk

Phytochemical screening was conducted on rice husk to determine the inhibitory bioactive substance. Determination of alkaloid, saponin, tannin, phlobatannin, anthraquinone, flavonoid, steroid, terpenoid and cardiac glycosides were performed to enhance the selectivity of the material to be used either as sole or in combination with other active materials.

Experimental procedure

The inhibition experiment was conducted by following the method described by Ogunleye *et al*. (2018)

Weight loss experiment

The sample was weighed before immersion and again after a predetermined amount of time, according to the usual weight loss procedure. With an analytical balance of sensitivity ± 0.0001 g, OHAUS AX124 was used to quantify the weights of MS coupons. 100 cm^3 beakers with and without different inhibitor concentrations were used to completely immerse a previously weighed metal in 50 ml of acid solution in an open beaker.

After that, each sample was taken out of the test solution, cleaned with distilled water, dried completely, and weighed. It was then submerged in the test solutions with different concentrations of rice husk extract inhibitors (0, 0.2, 0.4, 0.6, 0.8, and 1.0 g/L), including blank solution without inhibitors at four temperatures (30, 40, 50, and 60 °C), maintaining an immersion time of 2 h for the temperature dependence experiments described by Gowraraju *et al*. (2017)

To determine the weight loss, the mass measured before the experiment was deducted from the mass measured afterwards. The corrosion rate, inhibitor efficiency, and surface coverage could all be ascertained when the weight loss data was acquired (Ogunleye *et al.,* 2018). The weight reduction was determined by calculating the difference in weight. An analytical balance was used to measure the weight of mild steel specimens both before and after immersion. The experiment was conducted to investigate time and temperature dependence.

Analysis conducted on Coupons

The data obtained were used to calculate different parameters as follows:

i) *Inhibition Efficiency (%I) and Surface Coverage (θ)*: Inhibition Efficiency I.E (%), which gives information about the performance of the inhibition, was calculated using the formula in Equation 1 (Eddy and Odomelan, 2012).

$$I.E.\,(\%) = \frac{(W_0 - W)}{W_0} \times 100 \qquad (1)$$

Where W_o is the initial weight and W is the final weight of the coupon after retrieval, and I.E (%) is the inhibition efficiency.

The degree of surface coverage (θ) was calculated by the use of Equation 2 (Khadom *et al.*, 2010).

$$\theta = \left(1 - \frac{W_f}{W_i}\right) \qquad (2)$$

Where W_i and W_f are the initial and final weights of the mild steel.

ii) Corrosion Rate: The Corrosion Rate, CR, in grams per cm square per hour of mild steel in the corrodant was obtained using Equation 3 (Kumar, Pillai and Thusnavis, 2011)

$$CR = \frac{W_L}{A \cdot t} \qquad (3)$$

Where W_L is the weight loss in grams, A is the surface area of the coupon in cm^2 and t is the exposure time in hours (a constant immersion time of 3 h was maintained).

iii) Adsorption Studies: Adsorption isotherms are used to investigate the model of adsorption and the adsorption characteristics of an inhibitor are represented in Equations 4 – 7 as described by (Umoren and Eduok, 2016)

Langmuir
$$\frac{C}{\theta} = \frac{1}{K_L} + C \qquad (4)$$

Freundlich
$$\log\theta = \log K_F + n_F \log C \qquad (5)$$

Frumkin
$$\log\frac{\theta}{1-\theta} = \log K + \frac{2a\theta}{2.303} \qquad (6)$$

Temkin
$$\log\theta = -\log K - \frac{2a}{2.303} \qquad (7)$$

K is the equilibrium constant of the adsorption-desorption process in all cases. Higher values of K in each indicate more favourable adsorption, while lower values indicate more favourable inhibition. The initial stages of an inhibitor's action on a metal surface in an acidic solution.

Equation 8 describes how the organic molecules in the aqueous solution are substituted for water molecules on the metal surface, signifying adsorption.

$$Org_{(soln)} + nH_2O_{(ads)} \rightarrow Org_{(ads)} + nH_2O_{(soln)} \qquad (8)$$

Where $Org_{(soln)}$ and $Org_{(ads)}$ are the organic molecules in an aqueous solution and that is adsorbed on the metal surface, respectively, $H_2O_{(ads)}$ is water molecules on the metal surface and n is the size ratio representing the number of water molecules replaced by one molecule of organic adsorbate (Khadom *et al.*, 2010).

Mass loss measurement

At 24-hour intervals, the weight loss of every coupon was calculated by removing the samples from the solution, cleaning them with acetone, and then reweighing them. By dividing each sample's weight loss by the coupon's surface area, the mass loss for each was calculated.

RESULTS AND DISCUSSION

Phytochemical screening

Extraction, screening, and identification of the physiologically active compounds present in plants are referred to as phytochemical screening processes. Plants may contain flavonoids, alkaloids, carotenoids, tannin, antioxidants, and phenolic compounds, to name a few bioactive chemicals. A variety of phytochemical constituents, including tannins, saponins, flavonoids, hydroxyl groups, and amino groups, are contained in the extract as indicated by Table 1. According to research by Eddy et al. (2012), the majority of these elements in the extract are well-known corrosion inhibitors of mild steel in acidic media. The inhibitory actions of the rice husk extract combined with chitosan are primarily responsible for the mild steel's decreased rate of corrosion in the presence of the inhibitor.

Table 1: Phytochemical constituent of rice husk

Phytochemical constituents	Ethanol
Saponin	+
Tannin	+
Lieberman test	-
Flavonoid	+
Steroid	-
Terpenoid	+
Alkaloid	-
Keller kiliana test	+
Salkwoski test	+

Key Present = + Absent = -

FTIR spectroscopy of the extract and corrosion product

FTIR, or Fourier transformation infrared spectroscopy, is a highly versatile technique for materials examination that can be employed to identify both organic and some inorganic compounds that may be the cause of malfunctions or product contamination. The FTIR spectra of the RH extract containing chitosan and the adsorbed corrosion film on the mild steel surface following immersion in 1 g/L of 1 M HCl corrosion are displayed in Figure 1 - 3. Identical bands appear in the infrared spectra of the rice husk extracts with HCl solutions. The broad band obtained at 3312 and 3640 can be assigned to OH stretching band. The frequency of 2064.45 corresponds to C≡C stretching. The frequency at 1643.84 cm-^{1} corresponds to C=C, while the ones at 2080 and 2102.85 belong to C-H stretching. When comparing the spectra of the solid corrosion product (Figure 2 and 3) and the rice husk extracts from the acidic media, frequency shifts are seen. The spectra's shifts show that the functional groups contained in the extracts were what allowed them to interact with mild steel.

Furthermore, it is confirmed that the functional group and Fe^{2+} generated on the metal surface coordinated to develop an extract complex of Fe^{2+} on the metal surface, which facilitates the inhibition of the target metal. The distinctive band of C=O in the amine peptide group was the absorption at 1610 cm^{-1}. Additionally, the absorption at 2370 cm^{-1} was a distinctive band of the carboxylic group's O=H stretch.

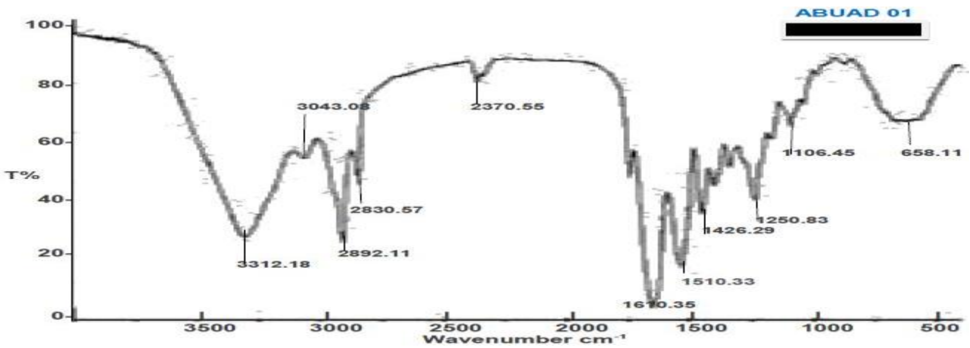

Figure 1: IR spectrum of HCl extract of rice husk mixed with chitosan and metal.

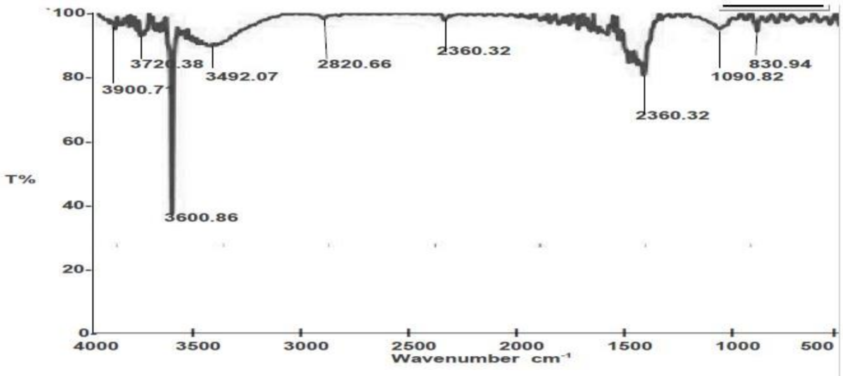

Figure 2: IR spectrum of HCl extract of rice husk mixed with chitosan

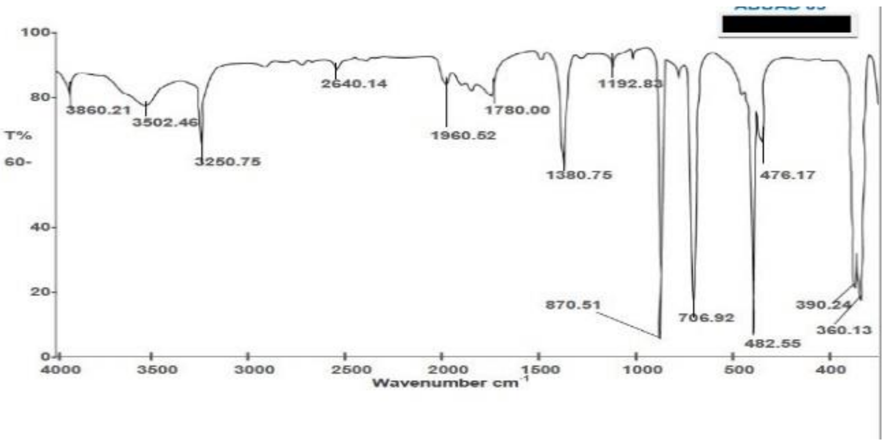

Figure 3: IR spectrum of metal

The protective film that formed on the surface of MS in HCl solution was caused by O–H, C≡C, C-C, C–H, C–O, and C=O, which suggests that this group may be a possible inhibitor of metallic corrosion (Fekry *et al*., 2010; Ogunleye *et al*., 2017).

According to this finding, RHEC may be a mixed-type inhibitor of MS surface corrosion in HCl solutions.

Mass loss measurement

Figure 4 illustrates the change in mass loss in an acidic medium with and without extracts. In the absence of extract, an increase in exposure time was associated with a mass loss. In addition, compared to the blank solution, the mass loss of the mild steel substrate was significantly reduced upon the addition of the extract from HCl solution. It has been demonstrated that using chitosan extract alone results in low inhibitory efficiency (Fekry *et al*., 2010). The efficiency is increased by the inclusion of husk. The phytochemical components (Table 1) that are contained in the extract have been found to adsorb on the surface of the metal, as suggested by Saratha *et al*. (2010). This creates a barrier for mass and charge transfer, which reduces the interaction between the metal and the corrosive environment.

Effect of temperature on the inhibition efficiency and corrosion rate

Figure 5 shows the influence of temperature on inhibitory efficiencies (IE) for mild steel substrates in HCl solution, as well as without the extract in an acidic medium.

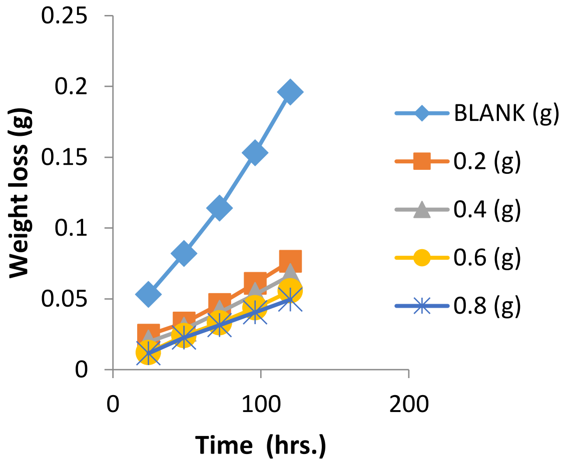

Figure 4*:* Effect of time on the weight of the metal

It has been noted that as temperature rises, so does the inhibition efficiency. Alaneme *et al*., (2013) explained this behaviour by pointing to partly reversible inhibitor adsorption from the metal surface at a higher temperature as well as an enhanced rate of mild steel dissolution. This may be explained by the process of chemisorption and is caused by the addition of chitosan to the extract. Table 2 presents a measurement of the corrosion rate at various temperatures and extract concentrations. As can be seen in Figure 6, the corrosion rate increases both in the presence as well as the absence of extracts as the temperature rises, which is expected because rising temperatures accelerate the rate of reaction by increasing the average kinetic energy of the reacting molecules (Nwabanne *et al*., 2011). However, the value of the corrosion rate decreases as the extract concentration rises.

Effect of concentration of extract on inhibition efficiency

Figure 5 illustrates the value of inhibition efficiency determined by weight loss across different inhibition concentrations in 1 M HCl solutions at 303–333K. A higher dosage of rice husk extract combined with chitosan boosted the inhibitory efficacy. This behaviour may be explained by the extract's increased adsorption at the mild steel/acid interface as the concentration of rice husk extract combined with chitosan increases.

Weight Loss versus Time

Table 2 illustrates how the weight loss varies over time for mild steel corrosion at various concentrations of pure ethanol extract from rice husk extract combined with chitosan at various temperatures. Generally, it was found that as concentration increased, the metal sample's weight loss decreased. Nevertheless, the extract's addition to the corrodant lessened the weight loss.

Adsorption Isotherms of Corrosion Inhibition of RHCE

An organic compound's ability to effectively suppress corrosion is mostly based on its capacity to be adsorbed on the metal surface, which involves substituting water molecules at the interface where corrosion occurs (Obot *et al*., 2009). The kind of electrolyte, the inhibitor's chemical makeup, the metal's charge and nature, and the distribution of charges inside the molecule all affect the inhibitor's ability to adsorb (Obot *et al*., 2009). According to Lebrini *et al*. (2011), an extract is typically a mixture of many substances with an unknown molecular mass, so using thermodynamic characteristics to merely characterize the adsorption behaviour of extracts has limitations. The characterization of plant extract adsorption for metal corrosion reaction prevention depends heavily on data gathered from adsorption isotherms.

The surface coverage (θ) values increased with an increase in RHCE concentration, indicating that the RHCE inhibits corrosion by adsorption onto MS in HCl solution. The weight loss and corrosion rate studies in Table 2 allowed for the evaluation of the adsorption isotherm when θ is determined as a function of the concentration at a constant temperature. Some of the most well-known

$$\frac{C}{\theta}=\frac{1}{K}+C \qquad (4)$$

Where K is the equilibrium constant of adsorption.

When C/θ was plotted against C, a straight line with an intercept of $1/K_L$ was obtained (Umoren *et al*., 2011). The Langmuir plot for the adsorption of rice husk ethanol extract combined with chitosan on a mild steel surface is displayed in Figure 6. The Langmuir isotherm suggests that adding rice husk ethanol extract combined with chitosan raises the unconstrained system's free energy significantly. According to Sivaraja and Kannan (2010), these findings indicate an isotherm model including Langmuir, Freundlich, and Temkin, where the surface coverage fraction (θ) is given as a function of reaction temperature. The data about the adsorption of rice husk extracts combined with chitosan and absolute ethanol extract onto a mild steel surface were examined using these isotherms. In circumstances when there is no interaction between the adsorbed molecules and the surface, the Langmuir adsorption isotherm is the best for both physical and chemical adsorption on a flat surface. Equation 4 applies if it is considered that the adsorption of rice husk extract combined with chitosan on mild steel surfaces proceeds following Langmuir adsorption (Emregul et al., 2005).

Monolayer of adsorption with little to no contact and significant inhibitor adsorption on the mild steel surface. Since the R^2 value is almost equal to unity, the Langmuir isotherm provides the best fit. The concentration dependence data of ethanol extract of rice husk mixed with chitosan on mild steel surface was also tested according to Freund lich isotherm earlier described expression in Equation 8.

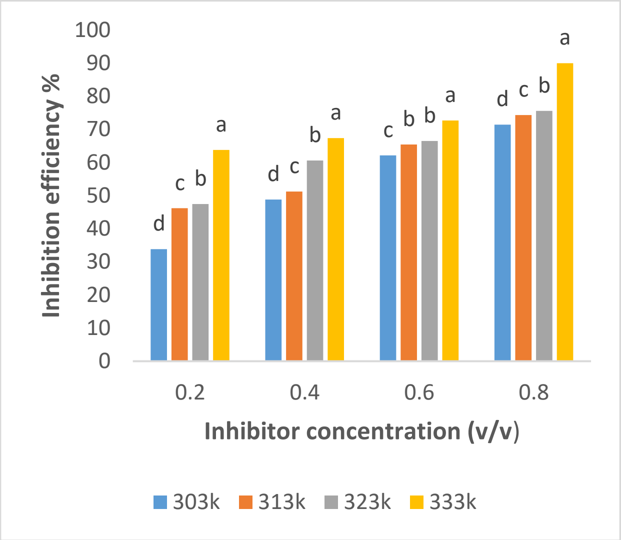

Figure 5: Effect of temperature on inhibition efficiency

$$Log\theta = LogK_F + n_F \log C \qquad (5)$$

Here, n_F, which is correlated with the adsorption intensity and changes depending on the material's heterogeneity, and K_F, the Freundlich adsorption isotherm constant, indicate the degree of adsorption. Based on the report of Khadom *et al*. (2010), the value of n_F is consistently positive and does not correspond to an integer. So, assuming the isotherm is followed, a plot of Log θ against log C should result in a straight line with an intercept equal to log K_F (Bentiss *et al*., 1999). The Langmuir plot for the adsorption of pure ethanol extract from rice husk combined with chitosan on a mild steel surface is displayed in Figure 7. The fact that the reported n_F values do not approach 0.6 suggests that the extract's adsorption process was not heterogeneous. Favorable adsorption is indicated by positive values of n_F and K_{ads}. Finally, for Temk in the adsorption isotherm, Equation 9 relates the amount of surface coverage (θ) to the inhibitor concentration (C) in the bulk electrolyte (Yurt *et al*., 2005).

$$e^{(-2a\theta)} = K \cdot C \qquad (9)$$

Where K is the equilibrium constant of adsorption, Rearranging and taking the logarithm of Equation 11 yields Equation 10.

$$\theta = \frac{-\ln K}{2a} - \frac{\ln C}{2a} \qquad (10)$$

With the validity of Temkin isotherm assumptions, a plot of θ versus lnC from Equation 12 should be linear. Greater adsorption efficiency and, thus, higher inhibition efficiency are generally implied by higher K values. The pattern in the K values' temperature variation that has been observed therefore supports the physical adsorption mechanism. (Umoren *et al.*, 2008a; Umoren and Ebenso, 2007; Yurt *et al.*, 2005) Positive values for "a" indicated the inhibitor's appealing behaviour.

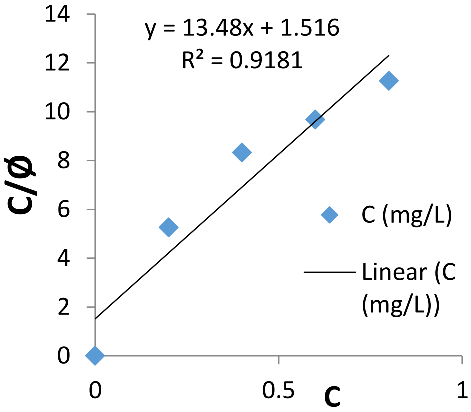

Figure 6: Langmuir isotherm for the adsorption of absolute ethanol extract of rice husk extract mixed with chitosan on mild steel at room temperature

Table 2: Corrosion parameters for mild steel in 1 M HCl containing various concentrations of extract at different temperature values.

T(K)	Concentration	W_L(g)	CR(g/cm^2/h)	I.E. (%)	*θ*
303	Blank	0.0151	5.0271x10^{-6}	0.0	0.0
	0.2	0.0090	3.3273x10^{-6}	33.82	0.038
	0.4	0.0071	2.5721x10^{-6}	48.83	0.048
	0.6	0.0060	1.9058x10^{-6}	62.09	0.062
	0.8	0.0042	1.4367x10^{-6}	71.42	0.071
313	Blank	0.0231	8.7128x10^{-6}	0.0	0.0
	0.2	0.0135	4.6889x10^{-6}	46.18	0.046
	0.4	0.0117	4.2470x10^{-6}	51.26	0.051
	0.6	0.0088	3.0214x10^{-6}	65.43	0.065
	0.8	0.0061	2.2402x10^{-6}	74.29	0.074
323	Blank	0.0422	1.5531x10^{-5}	0.0	0.0
	0.2	0.0217	8.1292x10^{-6}	47.41	0.047
	0.4	0.0182	6.0995x10^{-6}	60.54	0.061
	0.6	0.0147	5.1757x10^{-6}	66.52	0.067
	0.8	0.0108	3.7801x10^{-6}	75.55	0.076
333	Blank	0.0931	3.6508x10^{-5}	0.0	0.0
	0.2	0.0392	1.3214x10^{-5}	63.81	0.064
	0.4	0.0352	1.1948x10^{-5}	67.34	0.067
	0.6	0.0293	9.9747x10^{-6}	72.68	0.073
	0.8	0.0104	3.6579x10^{-6}	89.98	0.90

I.E (%) = Inhibition efficiency; θ = Degree of surface coverage; CR = Rate of corrosion in (kg/cm2/h).

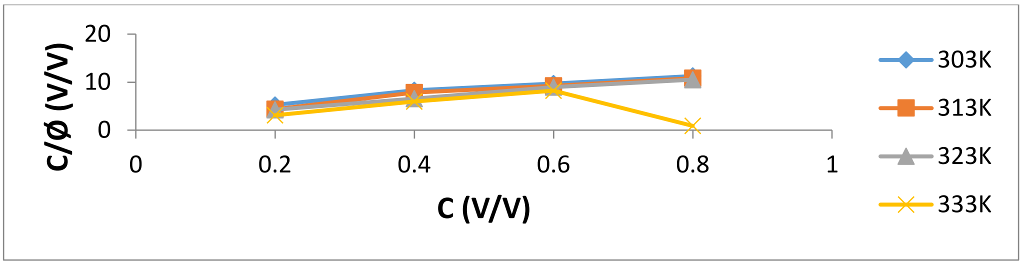

Figure 7: Langmuir adsorption isotherm plots for the adsorption of HCl extracts of rice husk mixed with chitosan at 303-333K

Table 3. Effect of time on the weight of the metal

Conc./Time(hr.)	24	48	72	96	120
BLANK	0.0530	0.0820	0.1140	0.1530	0.1960
0.2	0.0245	0.0330	0.0460	0.0610	0.0765
0.4	0.0195	0.0285	0.0405	0.0530	0.0665
0.6	0.0120	0.0240	0.0330	0.0435	0.0555
0.8	0.0115	0.0225	0.0315	0.0405	0.0495

Synergy effect of hybridized Rice Husk and Chitosan

The food production industry operates at high temperatures, making it possible that a single study's findings won't be enough to determine the total impact of a material combination synergy. The results demonstrate that adding rice husk in a 5:1 ratio to chitosan makes a significant difference, as the inhibition efficiency increases to almost 80% at higher temperatures. This outcome is consistent with the research done by Alaneme *et al.* (2014), who studied the corrosion inhibition and adsorption properties of rice husk extract on mild stills submerged in 1M HCl to determine the relationship between efficiency and temperature variations. Around 98% efficiency was attained, with efficiency declining as temperature rises.

Analogous research conducted on chitosan by Verma *et al.* (2018) and Gupta *et al.* (2018) shows that the addition of an inorganic substance such as potassium iodide (KI) enhances the inhibitory efficiency of chitosan alone. whose effectiveness reduces as the temperature rises.

CONCLUSIONS

In this study, we investigate the impact the kinetic and thermodynamic parameters that maximized the efficiency of wasted rice husk and extracted chitosan from wasted fish scales as a green inhibitor for MS in a hydrochloric acid medium using quantitative surface morphological techniques. The analyses of the results showed that the inhibition efficiency increased with an increase in concentration of the inhibitor and also increased with temperature. The development of added value waste as an inhibitor makes it more applicable in the food industry since the processing of food is at high temperatures.

The chemical adsorption mechanism of the inhibition process was in conformation with the data obtained, and Langmuir and Freundlich's models were best fitted into the obtained results. The corrosion inhibition activity in these extracts was due to the presence of heterocyclic constituents like alkaloids, and flavonoids. The presence of tannins, cellulose and polycyclic compounds enhances the film formation over the metal surface, thus aiding corrosion. Extracting these compounds from waste products like Rice husks and Shrimp is the best way to manage food waste, thereby reducing environmental pollution. Obtained results could serve as an eye-opener for relevant stakeholders by providing them with relevant information required in the adoption of green corrosion prevention technology. We suggest that policymakers should increase awareness of the potential benefit inherent in the use of plant-based corrosion inhibitors, especially those easily assessed wasted food constituting pollution in the environment. The findings could serve as beneficial inputs for assessing food-compatible inhibitors for corrosion prevention in food industries.

REFERENCES

Abdulkadir, A. R., Zawawi, D. D. and Jahan, M.S. (2016). 'Proximate and phytochemical screening of different parts of Moringa oleifera', *Russian Agricultural Sciences*, 42(1), pp. 34–36. Available at: https://doi.org/10.3103/s106836741601002.

Abdallah, M., Altass, H. M., AL Jahdaly, B. A. and Salem M. M. (2018). Some natural aqueous extracts of plants as green inhibitors for carbon steel corrosion in 0.5 M sulfuric acid. *Green Chem Letters and Review*. 11(3):189-196

Abiola, O. K., Otaigbe, J. O. E. and Kio, O. J. (2009). Gossypium hirsutum L. extracts as green inhibitor for aluminum in NaOH solution. Corrosion Science; 51:1879-1881.

Abiola, O. K. and Ofurka, N. C. (2005). Corrosion inhibition effect of coco nucifera juice on mild steel in5% hydrochloric acid solution, *Scientia Africana*. 2; 82-90

Adeoye, B. K., Aransiola, E. F., Alebiowu, G. and Osungunna, M. O, (2023). Flow and compaction properties of excipients developed from biopolymer waste snail shell and influencing factors. *Journal of the Nigerian Society of Chemical Engineers*. 38 (2), 34-41

Alaneme, K. K., Olusegun, S. J. and Alo, A. W. (2016). Corrosion inhibitory properties of elephant grass (*Pennisetum purpureum*) extract: effect on Mild steel corrosion in 1 M HCl solution. *Alex Engineering Journal*; 55:1069–1076.

Awad, T. S, Asker, D. and Hatton, B. D. (2018). Food-safe modification of stainless-steel food processing surfaces to reduce bacterial biofilms. *Applied Materials and Interfaces*.14,27-35. 10.1021/acsami.8b03788

Bashir, S., Sharma, V., Lgaz, H., Chung, I. M., Singh, A. and Kumar, A. (2018). The inhibition action of analgin on the corrosion of mild steel in acidic medium: a combined theoretical and experimental approach. Journal of Molecular Liquids. 263:454-462.

Chaouiki A., Lgaz H. and Chung I. M. (2018). Understanding corrosion inhibition of mild steel in acid medium by new benzonitriles: insights from experimental and computational studies. *Journal of Molecular Liquids* ;266:603-616.

Chatterjee, S., Bhattaharjee, K. and Kumar, A (2009). A simple and robust algorithm for micro array data clustering based on gene population variance ratio metric. Biotechnology Journal 4(9): 57-61

Eddy, N. O. and Odomelan, S. A (2012). Inhibition of corrosion of mild steel in acidic medium usingethanol extracts of aleo vera. *Pigment and resin technology*. 38; 111-115

Emergul, K. C, Akay, A. A. and Atakol, O. (2005). The corrosion inhibition of steel with schiff based compound in 2M HCL. *Material chemistry and physics*. 93; 325-329.

Fares, M. M., Maayta, A. K., and Al-Qudah, M. M. (2012). Pectin as promising green corrosion inhibitor of aluminium in hydrochloric acid solution. Corrosion Science, 60, 112–117.

Fery, A. M. and Ameer, M. A. (2010). Corrosion inhibition of mild steel in acidic medium using newlysynthesized heterocyclic organic molecules. *International journal of hydro energy*. 7641-7651.

Fioro-Bimbi, M., Alvarez, P. E., Vaca, H. and Gervasi, C. A. (2015). Corrosion inhibition of mild steel in HCl solution by pectin. *Corrosion Science*, 92, 192–199.

Gowraraju, N. D., Jagadeesan, S., Ayyasamy, K., Olasunkanmi, L. O., Ebenso, E. E. and Chitra, S. (2017). Adsorption characteristics of Iota-carrageenan and Inulin biopolymers as potential corrosion inhibitors at mild steel/sulphuric acid interface. *Journal of Molecular Liquids*, 232, 9–19.

Gupta, N., Joshia, P., Srivastavaa, V., and Quraishia, A. (2018).Chitosan: A macromolecule as green corrosion inhibitor for mild steel in sulfamic acid useful for sugar industry. *International Journal of Biological Macromolecules* (106) 704–711.

Halambeka, J., Cindrića, I. and Grassinob, A, N. (2020). Evaluation of pectin isolated from tomato peel waste as natural tin corrosion inhibitor in sodium chloride/acetic acid solution. Carbohydrate Polymers. 234, 115940

Harborne, J. B. (1980) Phytochemical methods: a guide to modern technique on plant analysis, Chapman and Hall, London, 302.

Khadom, A. A, Musa, A. Y, Kadhum, A. A. H., Mohamad, A. B. and Takriff, M. S. (2010). Adsorption kinetics of 4 amino-5-phenyl-4H-1, 2, 4-triazole-3-thiol on mild steel surface. *Port Electrochim Acta*. 28: 221–230.

Kumar, K. P. V., Pillai, M. S. N. and Thusnavis, G. R. (2011). Green corrosion inhibitor from seed extract of*Arecacatechu* for mild steel in hydrochloric acid medium. *Journal of Mater Science*. 46: 5208–5215.

Luo, X, Pan, X., Yuan, S., Du, S., Zhang, C. and Liu, Y. (2017) Corrosion inhibition of mild steel in simulated seawater solution by a green eco-friendly mixture of glucomannan (GL) and bis-quaternary ammonium salt (BQAS). *Corrosion Science*; 125:139-151.

Marciales, A., Haile, T., Ahvazi, B., Ngo, T. D. and Wolodko, J. (2018). Performance of green corrosion inhibitors from biomass in acidic media. *Corrosion Reviews*, 36, 239–266.

Marzorati, S., Verotta, L. and Trasatti, S. (2019). Green corrosion inhibitors from natural sources and biomass wastes. *Molecules*, 48, 1–24.

Obot, I. B., Obi-Egbedi, N. O. and Umoren, S. A. (2009). Adsorption characteristics and corrosion inhibitive properties of clotrimazole for aluminium corrosion in hydrochloric acid. *International Journal Electrochemical Science*; 4: 863–877.

Ogunleye, O. O., Eletta, O. A., Arinkoola, A. O., Agbede, O. O. (2018). Gravimetric and quantitative surface morphological studies of Mangifera indica peel extract as a corrosion inhibitor for mild steel in 1 M HCl solution. Asia-Pacific Journal of Chemical Engineering. 13 (6);e2257. https://doi.org/ 10.1002/apj.2257

Rani, B. E. A. and Basu, B. B. J. (2012). Green inhibitors for corrosion protection of metals and alloys: An overview. *International Journal of Corrosion*.;1:1-15

Saratha, R., Priya, S. V. and Thilagavathy, P. (2009). Investigation of *Citrus aurantiifolia* leaves extract as corrosion inhibitor for mild steel in 1 M HCl. *Journal of Chemistry*; 6: 785–795.

Torres, V. V., Rayol, V. A. and Magalhães, M. (2014). Study of thioure as derivatives synthesized from a green route as corrosion inhibitors for mild steel in HCl solution. *Corrosion Science*.;79:108-118

Umoren, S. A., Ebenso, E. E., Okafor, P. C., Ekpe, U. J. and Ogbobe O. (2006). Effect of halides on the corrosion inhibition of mild steel in alkaline medium using polyvinyl alcohol. *Journal Applied Polymer Science*. 103:2810–2816.

Umoren, S. A and Eduok, U. M. (2016). Application of carbohydrate polymers as corrosion inhibitors for metal substrates in different media: a review. *Carbohydrate Polymer*. 140: 314–341.

Wang, Y. N., Dong, C. F., Zhang, D. W., Ren, P. P., Li, L. and Li, X .G. (2015), Preparation and characterization of a chitosan-based low-pH-sensitive intelligent corrosion inhibitor, International Journal of Mineral Metallurgical and Materials. 22, No. 9, 998.

Yadav, S., Choudhary, G. and Sharma, A. Green approach to corrosion inhibition of aluminum and copper by *Ziziphus mauritiana* fruit extract in hydrochloric acid solution. *International Journal Chemical Technology* Resources. 2013;5(4):1815-1823.

Yildiz, R., Döner, A., Dogan, T. and Dehri, I. (2014). Experimental studies of 2-pyridinecarbonitrile as a corrosion inhibitor for mild steel in hydrochloric acid solution. *Corrosion Science*. ;82: 125-132.