EFFECT OF COCONUT SHELL ON THE ELECTROCHEMICAL BEHAVIOR OF AUSTENITIC STAINLESS STEEL AISI 316 IN ACID SOLUTION: CHEMICAL, ELECTROCHEMICAL AND SURFACE CHARACTERIZATION STUDIES

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ABSTRACT

In recent times, efforts have been made widely to replace toxic inhibitors with eco-friendly materials. Agricultural waste with their inimitable features has been identified as a high potential material in achieving high demanding goals. In this study, the electrochemical performance of AISI 316 austenitic stainless steel was studied in 0.5 M H₂SO₄ medium at various inhibitor concentrations in the absence and presence of coconut shell (CS). Gravimetric and electrochemical procedures were used in investigating the electrochemical behavior of stainless steel. Adsorption of the CS at the steel surface was further supported by scanning electron spectroscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). The results obtained showed that the inhibitor retards both active and pitting attack to an extent depending on the time of exposure and inhibitor concentration. Potentiodynamic results show that CS slows down the rate of cathodic and anodic corrosion reactions by forming a protective layer on the surface of the stainless steel and its adsorption fits the Langmuir adsorption isotherm model. It was also concluded that the CS performed as mixed type inhibitor by decreasing cathodic and anodic corrosion densities. This was concluded by comparison of the changes in the value of the cathodic and anodic Tafel slope. The inhibition efficiency of 88.45% was achieved using this inhibitor in 0.5M H₂SO₄ solution. An increase in the CS concentration leads to a decrease in the corrosion rate values. This signifies an excellent adsorb-ability of coconut shell on the stainless steel surface. Reasonable consistency was found between the methods used.

KEYWORDS: Acid corrosion inhibition, AISI 316 austenitic stainless steel, Coconut shell, H₂SO₄, Adsorption isotherm

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INTRODUCTION

Stainless steel is used widely in a variety of services owing to the passive film stability which forms on its surface [1, 2]. The amount of chromium present in this iron alloy hinders the formation of rust in certain environment. Despite its wide use, corrosion failures are often reported in an acidic environment [3, 4]. Acids are commonly used for stainless steel in different technological processes in the industry, for instance, oil well acidizing, industrial acid cleaning, acid descaling, and acid pickling. Also, in the technical cracking of petroleum, acid appears due to the salts hydrolysis and may have a negative consequence on the equipment. Acid corrosion is an expensive problem in the petroleum refining unit and it signifies a major loss due to lost production, cost of corrosion control, ineffective operation, and high maintenance [5]. An attempt was made by researchers to develop high resistant alloy to acid environments to prevent acid corrosion attack. The major drawback of this new alloy is its high cost compared with

conventional stainless steel, because of the high percentage of alloying elements for instance Mo, Ni, and Cr plus the fabrication process complexity. The positive consequence of these alloying elements on the pitting resistance is characterized with either the formation of a protective passive surface layer containing these elements, or the adsorption of soluble products of these elements [1]. Also, the metallic corrosion rate could be restrained by the metal surface modification via organic molecules. Given this, organic inhibitor is known in affecting the metal corrosion rate by decreasing the rate of both or either the cathodic oxygen reduction and the anodic metal dissolution. Therefore, it is of interest to investigate the possibility of increasing the corrosion resistance of one of the most widely used stainless steel, namely 316, by adding the inhibitor to the electrolyte medium. The inhibitive properties of some inhibitors in the acidic medium have been reported by different researchers [6-13]. O, S, and N atoms act as active center for the organic molecule adsorption onto the surface of the metal. The inhibitor efficiency depends on the characteristics of the environment in which it acts, the nature of the metal, and other experimental circumstances. The reason why these substances provide good protection when adsorbed and the nature of the chemical bond at the metal surface have been carried out by different researchers. Organic inhibitor molecule adsorption is generally over the surface of the metal and the effective adsorption film leads to a barrier defending the metal from corrosion [14]. This indicates that molecule structure, hydrophobicity, electron density, dispersibility, and solubility are the main factors in selecting an inhibitor molecule. Additionally, it is argued that the inhibitor molecule could be adsorb onto the metal surface by either physical adsorption, chemisorptions, or sporadically through both simultaneously [15-17]. Physisorption is an electrostatic interface between the charged metal surface and inhibitor molecules while chemisorptions is transference or sharing of inhibitor charge molecule to the metal surface resulting in the formation of a coordinate bond. Various researches have been carried out to study the corrosion properties of stainless steel and appropriate chemical corrosion inhibitors in acidic environments. However, most of the compound has damaging effect on the environment and health; with limited use as corrosion inhibitor due to their poor solubility in the electrolytic solutions and high volatility. Due to the limitations above, inhibitors selection could be controlled by its cost, environmental acceptability and its ability to protect the surface of the metal.

Agricultural waste is one of the most promising cost-effective inhibitors of the future with a strong ability to absorb over electrolyte/metal interface areas amid the numerous interesting properties that make them environmental benign and effective inhibitor for corrosion of metal. In contributing to the available information in the open literature on the inhibitory effect of waste materials, the aim of the present study is to evaluate the inhibitory property of coconut shell on stainless steel in sulphuric acid solutions. Our research team studied the inhibitive property of agricultural wastes [18-23] for the corrosion of stainless steel in different corrosive environments. Due to the high corrosion inhibitory tendency of waste materials, in this study, we, therefore, investigate the inhibitory property of coconut shell. The novelty of this study lies on the fact that literature on agro waste-based inhibitor is scarce and they are commercially available heterocyclic aromatic organic compound, which can mitigate corrosion of stainless steel AISI 316 surface. The inhibitive performance of coconut shell has been studied via electrochemical (Potentiodynamic polarization), chemical (gravimetric), and surface (SEM and EDX) methods.

2. EXPERIMENTAL DETAIL

2.1. Material and Preparation

Stainless steel AISI 316 with the chemical compositions (in wt. %): 0.022 C, 0.001 S, 0.024 P, 1.28 Mn, 0.48 Si, 10.1 Ni, 2.09 Mo, 0.04 N, 16.6 Cr, and Fe (balance) was used in this study. The molecular structure of the inhibitor used in this

study is shown in Figure 1. The corrosive medium of 0.5 M H_2SO_4 was set-up by diluting analytical grade H_2SO_4 with distilled water. Water was distilled first and after that deionized by a Millipore water purification system. For the electrochemical and gravimetric techniques, the specimen surface pre-treatment was carried out by grinding the samples mechanically with 220 to 1000 emery papers, degrease with acetone and rinse with distilled water before the tests. For each test, a fresh solution was prepared and used.

Figure 1: Chemical structure of coconut shell

2.2. Gravimetric Tests

The gravimetric method was used in calculating the corrosion rate value. Before each test, the stainless steel samples used were ground with different emery papers. Then, the sample was washed severally with distilled water afterward with ethanol and dried in air. After weighing accurately, the sample was immersed in a container, with 250 ml of 0.5M H_2SO_4 with the absence and presence of various concentrations of coconut shell powder (2, 4, 6, 8 and 10 g). At 24 hours interval, the samples were taken out, washed, dried, and accurately weighed. To show good reproducibility, the experiment was carried out in triplicate. The data obtained was used to achieve the best adsorption isotherm.

2.3. Electrochemical Measurement

Electrochemical measurement was studied in a three-electrode conventional glass cells using Autolab potentiostat (PGSTAT 30 computer controlled) with a NOVA software version 1.8. A platinum rod was used as counter electrode and a saturated Ag/AgCl as reference electrode. The working electrode was made from a commercially produced 316 stainless steel and surrounded in epoxy resin with a 1 cm^2 surface area. The sample was then stringed for electrical contact and connection. The surface of the electrode was mechanically polished with a metallurgical paper of different grade, the surface of the electrode was further polished with alumina paste $0.3\mu\text{m}$ dispersed on a soft cloth paper to obtain a scratch-free surface. The sample was then rinsed with distilled water, degreased in ethanol, and air-dried. Before polarization scanning, the stainless steel sample was dipped in the test solution to reach a steady-state potential. CS was added to freshly prepared 0.5 M H_2SO_4 medium in the concentration range of 2 to 10 g. The extrapolation of the linear Tafel area of the cathodic and anodic curve was used to obtain the anodic (β_a), cathodic (β_c) Tafel slopes, corrosion potential (E_{corr}), and corrosion current density (i_{corr}).

2.4. Scanning Analysis (SEM, AND EDX)

Analysis to examine and characterize the surface morphology of the stainless steel specimen after 168 hours of exposure to 0.5 M H_2SO_4 solution in the absence and presence of CS was carried out using A Joel high resolution scanning electron microscope (JSM – 7600F). Also, the film adsorbed on the specimens was examined using the energy dispersive X-ray spectroscopy (EDX).

3.EXPERIMENTAL RESULTS

3.1. Gravimetric Method

The weight loss, corrosion rate, surface coverage degree (θ), and the inhibition efficiency (IE) of the stainless steel were calculated using equations 1 to 4.

$$W = W_o - W_{F_1}$$

Where W is weight loss (mg), W_o is initial weight (mg) and W_f is final weight (mg)

The corrosion rate was determined in millimeter per year (mm/yr) using the expression:

$$Corrosionrate(CR) = \left(\frac{87.6W}{DAT} \right)_2$$

Where W is weight loss (mg), D is specimen density (g/cm³), A is specimen area (cm²), T is exposure time (hour).

The degree of surface coverage (θ) at each inhibitor concentration was calculated using:

$$\theta = \frac{CR_o - CR}{CR_o}_3$$

Where CR and CR_o are corrosion rates of the specimen in the presence and absence of inhibitor.

The percentage inhibition efficiency (IE%) was calculated using the relationship:

$$IE (\%) = \frac{CR_o - CR}{CR_o} \times \frac{100}{1}_4$$

It is obvious that the IE value increased and the corrosion rate value of the stainless steel decreased when the inhibitor concentration was increased. The observed performance could be attributed to the surface area increase covered by the molecules of the inhibitor adsorbed with the concentration increase [24].

Figure 2: Weight loss of stainless steel in free and inhibited acid solutions.

Figure 3: Corrosion rate of stainless steel in free and inhibited acid solutions.

Figure 4: Degree of surface coverage of stainless steel in inhibited acid solutions.

Figure 5: Inhibition efficiency of stainless steel in inhibited acid solutions.

Figure 6: Variation of inhibition efficiency IE (%) as a function of the inhibitor concentration.

As clearly seen in Figure 6 the inhibitor efficiency increases with increase in the CS concentration. The observed increase in inhibition efficiency values could be as a result of the blocking effect of the stainless steel surface by the adsorption of CS film, thereby decreasing the attacked area. The high IE showed by the inhibitor could be accredited to the CS adsorption on the metal surface via polar group and the double bond π -electron, leading to better coverage of the metal surface [25]. The gravimetric result indicates that the coconut shell performs as a good inhibitor for stainless steel in acid solutions at the studied concentrations. To have a better understanding on the effect of the CS concentration on the AISI 316 stainless steel corrosion in H_2SO_4 medium, assume the stainless steel corrosion rate against the inhibitor concentration fits the kinetic relationship given in equation (5) [26]:

$$\text{LogCR} = \text{Log}k + B\text{Log}C_{inh} \quad (5)$$

Where C_{inh} is the concentration of the coconut shell, CR is corrosion rate, k is the rate constant and B is the reaction constant. Figure 7 shows the curve of Log CR versus Log C_{inh} . The obtained straight line shows that the kinetic

parameter (B and k) could be calculated via Equation 5, and the corresponding results are listed in Table 1.

Figure 7: Variation of Log CR with log Cinh for stainless steel corrosion in 0.5 M H₂SO₄.

Table 1: Kinetic parameter for the corrosion of stainless steel in 0.5 M H₂SO₄ medium containing coconut shell

Temperature (°C)	B	k (mm/year)
30	-0.7379	0.0349

The negative sign of B (reaction constant) values indicate that the process of corrosion rate is inversely proportional to the CS concentration, signifying that the CS is highly effective at increased concentration. Therefore, when the changes in corrosion rate with inhibitor concentration become steep (constant B high negative value), this denotes the good inhibitory performance of the inhibitor [26].

3.2. Potentiodynamic Behavior

This section explores the electrochemical behavior of stainless steel samples with and without the different concentrations

of the coconut shell in the acid medium. Potentiodynamic polarization experiment of stainless steel AISI 316 in 0.5M H_2SO_4 medium in the presence and absence of CS is shown in Figure 8. The following observation could be drawn from the data:

Figure 8: Potentiodynamic polarization experiment of stainless steel AISI 316 in 0.5M H_2SO_4 in free and inhibited acid solutions.

- The corrosion potential (E_{corr}) calculated, with the presence of coconut shell is -0.36881 V coupled with corrosion current (i_{corr}) value of $1.53E-06A$. The equivalent values without the presence of the CS are -0.40501V and $4.27E-04 A$, respectively. Comparing E_{corr} and i_{corr} values show that the presence of CS leads to the shift in E_{corr} to the -ve site with a clear decrease in the values of the corrosion current densities. The polarization resistance value was $4.27E-04 \Omega$ and 1328.5Ω for the solution without and with inhibitor, respectively. The current density values were lowered and the polarization curves move to more negative potential with the addition of inhibitor. This performance reveals the inhibitive action of CS which could be ascribed to its adsorption on the stainless steel surface. The parallel Tafel curves showed that the reduction mechanism was not affected and the hydrogen evolution was activation controlled with the presence of the CS.
- Comparing the anodic (β_a) and cathodic constant (β_c), result in values of 0.15706 and $0.10754 Vdecade^{-1}$ and 0.011184 and $0.008022Vdecade^{-1}$ without and with CS, respectively. As a result, it is concluded that the CS is mixed type in nature. In contrast, the hydrogen evolution rate is distorted by the layer adsorbed due to the presence of the inhibitor. Also, the tendency of the studied inhibitor to adsorb at the stainless steel surface reduce the oxygen diffusion to the surface of the stainless steel and entrap the ion on the steel surface resulting in reduced dissolution rate and aids to produce passive films in the anodic potentiodynamic curve.
- Corrosion rate values calculated showed that at 10 g CS, the minimum corrosion rate and the highest polarization resistance values was obtained. This observation can be clarified based on the fact that a significant CS concentration is attained in the acid medium which caused the optimal CS efficiency. It was mentioned earlier that at low CS concentration in the acid solution, the molecule surface coverage adsorbed is low to result in a total

coverage in preventing stainless steel corrosion. Also, [2] ascribed this occurrence to the sulfur compound hydrolysis to produce corrosion-promoting specie. Another possible means for the results observed at 10 g CS could be clarified due to an increase in the solution acidity by the inhibitor carboxylic functionality. The obtained result pointed that CS showed a normal increase in its efficiency reaching a stable value at high concentration. This stage could be explained due to the thin layer formation at the stainless steel surface owing to the CS polymerization [2].

- The current density value reduces with the existence of inhibitor which indicates that the inhibitor adsorbs on the surface of the steel, and as a result, the stainless steel corrosion rate decreases with an increase in the CS concentration. This occurs due to the conjugated π - electron adsorption of aromatic ring of the inhibitor, overlapping with the vacant d-orbital of the stainless steel with donating p-orbital of inhibitor which results in $d\pi-\pi\pi$ interface. Figure 8 shows that both active and pitting attack of the stainless steel is retarded to an extent depending on the inhibitor concentration. The experimental value of related electrochemical data's such as anodic and cathodic Tafel slope values in V/dec (β_a and β_c), corrosion potential (E_{corr} values in V), corrosion current density (I_{corr} values in A/cm^2), and corrosion rate (CR in mm/year) were obtained from the polarization curve and are tabulated in Table 2.

Table 2: Electrochemical data's of AISI 316 stainless steel in free and inhibited acid solutions

	β_a (V/dec)	β_c (V/dec)	E_{corr} , Calc (V)	E_{corr} , Obs (V)	i_{corr} (A)	Corrosion rate (mm/year)	Polarization resistance (Ω)
Control	0.157	0.108	-0.405	-0.392	4.27E-04	4.965	64.879
2g	0.065	0.057	-0.359	-0.367	1.46E-04	1.692	90.970
4g	0.019	0.048	-0.394	-0.399	9.60E-05	1.115	61.984
6g	0.032	0.044	-0.379	-0.383	5.52E-05	0.641	145.290
8g	0.008	0.025	-0.587	-0.590	1.62E-06	0.019	1576.900
10g	0.012	0.008	-0.369	-0.381	1.53E-06	0.018	1328.500

The nature of the CS can be estimated by the shift in E_{corr} values with the inhibitor Tafel curves to the curve without the inhibitor. The values of E_{corr} obtained in this study is within the range of ± 85 mV, the cathodic and anodic reaction was affected concurrently and no regular shift was spotted, which denotes that CS is a mixed-type. The observed irregularity in the anodic and cathodic Tafel slope values also indicates that not only one mechanism is involved for the stainless steel inhibition in the acid solution. The likely ways could be: via the anions involvement; adsorption and synergistic effects.

3.4. Adsorption Studies

The adsorption isotherm provides the basic information on the interaction between the metal surface and the adsorbed molecules. Supposing that inhibition effect is mainly as a result of the metal adsorption at the solution interface, the inhibition effectiveness can be used for estimation of the surface coverage. Necessary information on the interaction between the stainless steel surface and the inhibitor can be given by the adsorption isotherm. The degree of surface coverage (θ) at various inhibitor concentrations in acid medium has been estimated from the gravimetric measurement. The inhibition performance of a composite is established by its adsorptive tendency on the corroding sample surface. Also, corrosion inhibition nature can be inferred from the adsorption features of the inhibitor. The degree of surface coverage (θ)

for the various CS concentrations was graphically evaluated by fitting to an appropriate adsorption isotherm. We examined several adsorption isotherm equations relating the CS concentration and the surface coverage. Given this, an attempt was made to fit the values to different isotherms; Temkin, Flory-Huggins, Langmuir, Frumkin, and Freundlich. The regression coefficient for Langmuir adsorption isotherm was approximately unity (0.97562) than other isotherms (Figure 9b -d). Thus, Langmuir adsorption isotherm demonstrates the best possible adsorption model for the CS molecule onto the stainless steel AISI 316 surface in the 0.5 M H_2SO_4 medium. As a result, we assume that the CS forms a monolayer on the stainless steel surface, and there is no interface between the species adsorbed on the sample surface and the adsorption energy is independent on the surface coverage.

Figure 9: Langmuir (a), Freundlich (b), Temkin (d), and Frumkin (d) adsorption isotherm of the CS onto stainless steel surface in 0.5M H_2SO_4 medium.

3.5. Inhibition Mechanism

Research has made known that an inhibitor molecule inhibitive performance is a function of its molecular geometrical structure and molecular electronic structure[27,28]. CS is a heterocyclic compound having heteroatom of N. This atom acts as an active center at the surface of the metal. The bond strength adsorption is established by the atom acting electron density on the reaction center and the group polarizability. In reality, the process of inhibition is understood to take place through the adsorption of the inhibitor because of the lone pair of electron of the hetero nitrogen atom. The nonbonding electron in the nitrogen atom in the CS molecule is the reactive site for a donor-acceptor interface between the empty d-orbital of the Fe atom and CS molecule. Based on the obtained results in this work and literature, it can be hypothesized that the CS inhibits stainless steel corrosion by slowing down the cathodic and anodic reactions. The CS can be regarded as a good inhibitor for stainless steel in sulphuric acid solutions. It was found that the adsorption process takes place by the substitution of the corrosive agent with the inhibitor molecule on the stainless steel surface.

3.6. Surface Characterization

The surface morphology of the AISI 316 stainless steel electrode with and without inhibitor after gravimetric test in 0.5 M H_2SO_4 medium is shown in Figures 10 (a) and (b). The SEM image (Figure 10a) denotes a strong corrosive attack (pitting and uniform corrosion) via sulphuric ion because of the high dissolution of steel with the absence of CS and thus confirmed by the EDX result (Figure 10a). The SEM image shows that the corrosion process does not occur homogeneously on the surface of the stainless steel sample in the 0.5 M H_2SO_4 medium whereas Figure 10 (b) demonstrates a film formed on the steel surface which could be the reason for the inhibition process. Due to the presence of the CS, the morphology of the stainless steel surface appears better. On the other hand, the surface of the protected pits become visible and the stainless steel kinetic dissolution reduced significantly with the presence of the CS film on the stainless steel surface after the buildup of protector in the acid solution. From the electrochemical and gravimetric data, it was concluded that the CS is a potential effective inhibitor for AISI 316 stainless steel sample in a 0.5 M H_2SO_4 medium. It is known that in inhibiting acid corrosion, the first stage is the adsorption of the inhibitor onto the surface of the metal. Because of the electrostatic attraction, the coconut shell molecule is adsorbed, and high inhibition efficiency is expected.

Figure 10: SEM and EDX images of stainless steel AISI 316 after gravimetric test in 0.5 M H_2SO_4 (a) without and (b) with 6 g inhibitor.

4. CONCLUSIONS

The results obtained proved that the CS compound exhibited good corrosion inhibition for stainless steel AISI 316 in 0.5M H₂SO₄ solution. The inhibitive performance was observed to improve with an increase in the compound concentrations and decrease as the exposure time increases to reach a maximum value of 88.45% at 10 g. This could be due to improved film repair conditions. The potentiodynamic polarization measurement results showed that the CS under investigation is mixed-type in nature. The CS adsorption on the stainless steel surface fits the Langmuir adsorption isotherm, signifying that the major inhibition process takes place via adsorption, and the adsorption of this compound results in the formation of a monolayer on the stainless steel surface. Mechanistic details of the inhibition could be ascribed to the organic molecule surface coverage on the surface of the stainless steel. The SEM and EDX examination revealed minor corrosion products on the surface of the stainless steel with CS confirming the active role of the CS in the corrosion inhibition process. The obtained results from the gravimetric method were in good agreement with electrochemical measurement.

REFERENCES

1. H. El Dahan, "Pitting corrosion inhibition of 316 stainless steel in phosphoric acid-chloride solutions Part I Potentiodynamic and potentiostatic polarization studies," *Journal of Materials Science*, vol. 34, pp. 851-857, 1999.
2. A. Galal, N. Atta, and M. Al-Hassan, "Effect of some thiophene derivatives on the electrochemical behavior of AISI 316 austenitic stainless steel in acidic solutions containing chloride ions: I. Molecular structure and inhibition efficiency relationship," *Materials Chemistry and Physics*, vol. 89, pp. 38-48, 2005.
3. A.-E. A. Hermas, A. M. Elnady, and R. M. Ali, "Corrosion inhibition of stainless steel in sulfuric acid solution containing sulfide ions," *Anti-Corrosion Methods and Materials*, 2019.
4. A. Abdel-Gaber, B. Abd-El-Nabey, E. Khamis, R. Salman, H. Rahal, and Z. El Morr, "Electrochemical synthesis and corrosion behaviour of polyaniline on stainless steel in sodium hydroxide solutions," *Chemical Engineering Communications*, pp. 1-10, 2020.
5. N. Tantawy, "Evaluation of new cationic surfactant as corrosion inhibitor for carbon steel in a metal working fluid," *Parameters*, vol. 30, p. 50oC, 2005.
6. L. A. C. Matos, M. C. Taborda, E. d. P. Banczek, E. D'Elia, and P. R. P. Rodrigues, "Aqueous Agro-Industrial Waste as Corrosion Inhibitor for Stainless Steel AISI 304 in Acidic Media," *Materials Research*, vol. 22, 2019.
7. F. Gapsari, K. A. Madurani, F. M. Simanjuntak, A. Andoko, H. Wijaya, and F. Kurniawan, "Corrosion Inhibition of Honeycomb Waste Extracts for 304 Stainless Steel in Sulfuric Acid Solution," *Materials*, vol. 12, p. 2120, 2019.
8. A. Fouda, S. Abd El-Maksoud, A. El-Hossiany, and A. Ibrahim, "Corrosion protection of stainless steel 201 in acidic media using novel hydrazine derivatives as corrosion inhibitors," *Int. J. Electrochem. Sci*, vol. 14, pp. 2187-2207, 2019.
9. R. Kerkour, S. Chafaa, N. Maouche, O. Moumeni, and N. Chafai, "Corrosion inhibition of stainless steel N304 by dihydroxy benzyl phosphonic acid in 0.5 M H₂SO₄: Experimental and theoretical studies," 2019.
10. M. Abdallah, M. Alfakeer, A. M. Alonazi, and S. S. Al-Juaid, "Ketamine Drug as an Inhibitor for the Corrosion of 316 Stainless Steel in 2M HCl Solution," *INTERNATIONAL JOURNAL OF ELECTROCHEMICAL SCIENCE*, vol. 14, pp. 10227-10247, 2019.
11. M. Boudalia, R. M. Fernández-Domene, M. Tabyaoui, A. Bellaouchou, A. Guenbour, and J. Garcia-Anton, "Green approach to corrosion inhibition of stainless steel in phosphoric acid of *Artemisia herba alba* medium using plant extract," *Journal of*

- Materials Research and Technology*, vol. 8, pp. 5763-5773, 2019.
12. O. Sanni, O. S. I. Fayomi, and A. P. I. Popoola, "Eco-friendly Inhibitors for Corrosion Protection of Stainless steel: An Overview," in *Journal of Physics: Conference Series*, 2019, p. 042047.
 13. N. Goudarzi and H. Farahani, "Investigation on 2-mercaptobenzothiazole behavior as corrosion inhibitor for 316-stainless steel in acidic media," *Anti-Corrosion Methods and Materials*, 2014.
 14. E. Cano, J. Polo, A. La Iglesia, and J. Bastidas, "A study on the adsorption of benzotriazole on copper in hydrochloric acid using the inflection point of the isotherm," *Adsorption*, vol. 10, pp. 219-225, 2004.
 15. Y. Qiang, S. Zhang, B. Tan, and S. Chen, "Evaluation of Ginkgo leaf extract as an eco-friendly corrosion inhibitor of X70 steel in HCl solution," *Corrosion Science*, vol. 133, pp. 6-16, 2018.
 16. H. Tian, W. Li, B. Hou, and D. Wang, "Insights into corrosion inhibition behavior of multi-active compounds for X65 pipeline steel in acidic oilfield formation water," *Corrosion Science*, vol. 117, pp. 43-58, 2017.
 17. X. Li, S. Deng, T. Lin, X. Xie, and X. Xu, "Inhibition action of triazolyl blue tetrazolium bromide on cold rolled steel corrosion in three chlorinated acetic acids," *Journal of Molecular Liquids*, vol. 274, pp. 77-89, 2019.
 18. O. Sanni and O. Fayomi, "Electrochemical analysis of austenitic stainless steel (Type 904) corrosion using egg shell powder in sulphuric acid solution," *Energy Procedia*, vol. 157, pp. 619-625, 2019.
 19. O. Sanni and O. Fayomi, "The inhibitive study of egg shell powder on uns n08904 austenitic stainless steel corrosion in chloride solution," *Defence Technology*, vol. 14, pp. 463-468, 2018.
 20. O. Sanni and A. P. I. Popoola, "Data on environmental sustainable corrosion inhibitor for stainless steel in aggressive environment," *Data in brief*, vol. 22, pp. 451-457, 2019.
 21. O. Sanni, A.P.I Popoola and A. Kolesnikov, "Constitutive modeling for prediction of optimal process parameters in corrosion inhibition of austenitic stainless steel (Type 316)/acidic medium," *Materials Research Express*, vol. 5, p. 106513, 2018.
 22. O. Sanni, "Assessment of Concentration, Temperature and Exposure Time Effect on Waste Product as a Sustainable Inhibitor for Stainless Steel Corrosion: Optimization Using Response Surface Method," *Journal of Bio-and Tribo-Corrosion*, vol. 5, p. 46, 2019.
 23. O. Sanni, A.P.I Popoola and O. Fayomi, "Temperature Effect, Activation Energies and Adsorption Studies of Waste Material as Stainless Steel Corrosion Inhibitor in Sulphuric Acid 0.5 M," *Journal of Bio-and Tribo-Corrosion*, vol. 5, p. 88, 2019.
 24. N. Goudarzi, M. Peikari, M. Reza Zahri, and H. Reza Mousavi, "Adsorption and corrosion inhibition behavior of stainless steel 316 by aliphatic amine compounds in acidic solution," *Archives of Metallurgy and Materials*, vol. 57, pp. 845-851, 2012.
 25. B. Ariwahjoedi, "The correlation between structure and corrosion inhibition activity of 4, 5-diphenyl-1-vinylimidazole derivative compounds towards mild steel in 1% NaCl solution," *Int. J. Electrochem. Sci*, vol. 3, pp. 154-166, 2008.
 26. M. N. Rahuma, F. M. Al-Sonosi, and A. M. Al-Frjany, "Corrosion inhibition of 316 stainless steel in 20%(W/W) HCl solution using Dithizone," *American J. Appl. Chem*, vol. 2, pp. 1-5, 2014.
 27. A. Singh, K. R. Ansari, M. A. Quraishi, and Y. Lin, "Investigation of Corrosion Inhibitors Adsorption on Metals Using Density Functional Theory and Molecular Dynamics Simulation," in *Corrosion Inhibitors*, ed: IntechOpen, 2019.
 28. L. Guo, R. Zhang, B. Tan, W. Li, H. Liu, and S. Wu, "Locust Bean Gum as a green and novel corrosion inhibitor for Q235 steel in 0.5 M H₂SO₄ medium," *Journal of Molecular Liquids*, p. 113239, 2020.