OPEN ACCESS

Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) | ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Application of Celtis Zenkeri Exudates as Corrosion Inhibition for Galvanised Steel Exposed to Acidic Media

Des-Wosu Azubuike George[1*], Charles Kennedy[2], Kanee Sorbari[3]

[1]Department of Mechanical Engineering, Rivers State University, Nkpolu Oroworukwu, Port Harcourt
[2]School of Engineering, Department of Civil Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria
[3]School of Engineering, Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

DOI: 10.36348/sjet.2024.v09i06.001 | **Received:** 10.05.2024 | **Accepted:** 21.06.2024 | **Published:** 27.06.2024

***Corresponding author:** Des-Wosu Azubuike George
Department of Mechanical Engineering, Rivers State University, Nkpolu Oroworukwu, Port Harcourt

Abstract

This study investigated the performance of Celtis zenkeri exudates in preventing galvanised steel exposed to acid concentrated water and soil. The study was performed in order to find an alternative coating substance that can reduce the corrosion of galvanised steel pipes exposed to corrosive water and soil media. Various steel specimens were cut into portions and coated with the exudates at 25 - 50µm thickness. To accelerate the rate of corrosion, 0.5M hydrochloric acid (HCl) was added to tap water in a container. Also, the same concentration of HCl was equally added to soil samples. Uncoated steel specimens were immersed in the acid concentrated water and soil, servicing as control sample. The rate of corrosion was monitored for 30 days (720 hours). The inhibition efficiency of the exudates for both corrosive media was compared. Results showed that the weight loss and corrosion rate of galvanised steel decreased with increase in coating thickness. Comparatively, the weight loss and corrosion rate in the uncoated specimens were higher than the coated specimens. With 25 - 50µm coating thickness, the decrease in corrosion rate ranged from 0.01272 to 0.0027mm/yr for specimens immersed in water and from 0.2226 to 0.0185mm/yr for specimens buried in soil, while for uncoated specimens, the corrosion rate was 0.2793mm/yr and 0.4150mm/yr for specimen immersed in water and soil respectively. The inhibition efficiency of Celtis zenkeri exudates increased with coating thickness, which ranged from 54.46 – 99.03% for specimens immersed in water and 46.36 – 95.54% for specimens buried in soil at 25µm – 50µm coating thickness. The results demonstrated that Celtis zenkeri exudates can be used as corrosion inhibitor for steel exposed to corrosive media.

Keywords: Galvanised Steel, Corrosion Rate, *Celtis Zenkeri* Exudates, Water, Soil.

1. INTRODUCTION

The impact of corrosion attack is famous in nearly all areas where metals are used. Corrosion causes leakage in drinking water pipes, infrastructure failure or leakage of oil and gas facilities, these leaks can have devastating environmental and economic consequences. For example, corrosion caused failures in an offshore oil rig's pipelines resulted in an oil spill that extended over 67,000 square miles, costing billions of dollars in cleanup costs (McCafferty, 2010). Similarly, corrosion of water pipes results in loss of potable water, requiring repair or replacement of aged infrastructure. The direct costs of corrosion have been estimated to be over $500 billion annually in the United States alone (Marzorati *et al.*, 2018).

Corrosion is an irreversible interfacial reaction between a metallic material and its environment that converts the metal into its oxidized form such as rust. This electrochemical process negatively impacts the integrity and lifespan of metal structures over time (Marzorati *et al.*, 2018). Aside from direct repair costs, corrosion can lead to failures in plant infrastructure and machines which are usually costly to repair, as downtime results in lost productivity. It can also be costly in terms of contaminated or lost product, and environmental damage from leaks or spills. In some extreme cases, corrosion failures may even threaten human safety such as collapsed bridges or burst pipelines.

However, the use of corrosion inhibitors is one of the major technologies adopted to prevent or reduce

Citation: Des-Wosu Azubuike George, Charles Kennedy, Kanee Sorbari (2024). Application of Celtis Zenkeri Exudates as Corrosion Inhibition for Galvanised Steel Exposed to Acidic Media. *Saudi J Eng Technol, 9*(6): 231-239.

the impact of corrosion on metals in corrosive environments. A corrosion inhibitor is a substance that is added to a corrosive media in order to slow down corrosion reactions by adsorbing onto the metal surface (Marzorati *et al.*, 2018). They can function via anodic, cathodic or mixed inhibition mechanisms. Most commercial corrosion inhibitors employed in industries are multi-component inhibitor systems consisting of nitrogen and sulphur functionalities. While stable and effective, these synthetic inhibitors are often expensive to formulate and can pose threats to public health and the environment due to their toxicity (Brycki *et al*., 2018).

Currently, the utilisation of traditional corrosion inhibitors is being reduced owing to increasing awareness of green and sustainable technologies. Plants represent a renewable source of green corrosion inhibitors. Plants are characterized by their unique ability to convert sunlight energy into carbohydrates via photosynthesis, taking up greenhouse gases and pollutants in the process (Sheldon, 2016; Verma *et al*., 2018). Most plant extracts contain a variety of phytochemicals that make them effective as corrosion inhibitors when applied to metal surfaces (Costa *et al*., 2015; Mari *et al*., 2016). These natural components adsorb onto the metal, blocking active corrosion sites.

Celtis zenkeri is a deciduous tree indigenous to Central, East and West Africa that reaches 10-50 meters tall (Babweteera, 2010). Its bark, leaves and wood have various traditional medicinal and practical uses (Babweteera, 2010; Onyekwelu, 2014). The thick fluid exudate from its trunk was investigated in this study for its potential as a green corrosion inhibitor for galvanized steel exposed to acidic environments. Such environments are commonly encountered in the salty coastal Niger Delta region where leakage from oil and water transport pipelines poses environmental risks. This study aims to evaluate the corrosion inhibition performance of Celtis zenkeri exudate as a potentially sustainable alternative to synthetic inhibitors for metal protection.

2. MATERIALS AND METHODS

The materials and methods used to achieve the objectives of this study are described in detail below.

2.1 Materials

The main materials used include galvanized steel obtained from a pipeline, Celtis zenkeri exudates extracted locally, volumetric flasks, beakers, measuring cylinders, digital analytical balance, thread, filter paper, venire callipers, micrometer screw gauge, desiccator, analytical grade hydrochloric acid (HCl), sodium hydroxide (NaOH), petroleum ether, acetone, ethanol and distilled water.

An electrochemical cell assembly consisting of a three-electrode system was also used. This included a saturated calomel electrode (SCE) as the reference electrode, platinum electrode as the counter electrode and the pretreated galvanized steel sample as the working electrode.

2.2 Sample Collection and Preparation

Celtis zenkeri exudates were collected by wounding the bark of trees found in Ogbo community forest located in Ahoada East local government area of Rivers State, Nigeria. The exudate fluid was allowed to drip and collected in pre-cleaned beakers.

Galvanized steel pipe samples of 15mm diameter were obtained from a pipeline supply store at Mile III market in Port Harcourt. The samples were manually abraded with silicon carbide papers of varying grit size to obtain a consistent surface roughness. Degreasing was done by rinsing with petroleum ether, followed by thorough washing with distilled water and air drying.

The dried samples were sectioned to average lengths of 20mm using a calibrated cutting plier. Their original weights and dimensions were recorded using an analytical balance and venire callipers respectively.

2.3 Experimental Procedure

Gravimetric measurements following ASTM standard procedures were used to determine the corrosion rates. First, the samples were completely immersed in test solutions with and without inhibitor for 168 hours at ambient temperature.

After the exposure period, the samples were retrieved, gently scrubbed to remove corrosion products, rinsed with distilled water, dried and reweighed. The difference in weights before and after corrosion was used to calculate the corrosion rate.

Electrochemical measurements were also carried out in a three-electrode cell using 1M HCl as the corrosive electrolyte. Potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques were employed to evaluate the inhibition efficiency of Celtis zenkeri exudate on galvanized steel corrosion.

The composition of the uninhibited galvanized steel was quantified using optical emission spectrometry and comprised of carbon, silicon, manganese, sulphur and phosphorus balanced by iron. This provided a baseline for analyzing the influence of corrosion.

The gravimetric method was used in the measurement of corrosion rate of coated and uncoated samples. The galvanised steel used has the following chemical compositions C (0.17%), Si (0.30%), Mn (0.70%), S (0.03%), P (0.03%) and the balance being for Fe.

2.3.1 Immersion in Acid Solution

For immersion testing, pre-weighed galvanized steel specimens coated with Celtis zenkeri exudate at thickness ranges of 25-50µm at 5µm intervals were used. An uncoated specimen served as the control.

Corrosion tests were conducted in 250ml plastic beakers filled with 200ml of distilled water. Analytical grade 0.5M hydrochloric acid (HCl) solution was added to achieve a 1:8 acid-water ratio, in order to accelerate the corrosion rate.

The coated and uncoated steel samples were completely submerged and electronically connected in the acid solution using crocodile clips and copper wires. Tests were performed at ambient laboratory conditions of 29±2°C temperature and 65±5% relative humidity.

After 30 days of immersion, samples were carefully removed from the test solution. Residual corrosion products were gently removed by scrubbing under running water and the samples were air dried. Their final weights were measured and recorded. Corrosion rates were computed from the weight losses.

2.3.2 Immersion in Acidified Soil

For soil immersion testing, the specimens were similarly coated with exudate at 25-50µm thicknesses. A rectangular plastic container was filled with 450kg of natural soil sampled locally.

Analytical grade 0.5M HCl (50ml) was added to the soil and mixed vigorously for 2 minutes to achieve acidification. This mixture served to replicate industrial soil contamination and accelerate corrosion.

The coated and uncoated steel specimens were completely buried and interconnected in the acidified soil matrix. Exposure continued for 30 days under ambient conditions. After retrieval, samples were washed, dried and reweighed.

Corrosion rates were again determined from weight losses, providing data on the exudate's protective efficacy under acidic soil conditions that may be found around oil facilities and transportation pipelines.

2.4 Weight Loss and Corrosion Rate

The weight loss method was used in study. Thus, the weight loss over time was measured by subtracting the instantaneous weight from the initial weight of the specimen. From the weight loss measurement, the corrosion rate of galvanised steel was calculated using the corrosion model stated in Equation (1). The corrosion rate is expressed as a function of weight loss per surface area exposed to the corroding medium per material density per exposure time.

$$C_R = \frac{K\Delta w}{\rho A t} \qquad (1)$$

where:

$C_R =$ Corrosion rate (mm/yr)
$K =$ Constant
$\Delta w =$ Weight loss (mg)
$\rho =$ Density of material (g/cm^3)
$A =$ Cross-sectional area of metal (cm^2)
$t =$ Time (hr)

But K is given as 87.6, while the density of galvanised steel was given as 7.85g/cm^3 (Singh *et al.*, 2015). Using the above units, the corrosion rate, C_R, is expressed in millimetre per year (mm/yr).

2.5 Inhibition Efficiency

To determine the effectiveness of the exudates in reducing the corrosion rate of galvanised steel in the acid media, equation (2) was used to calculate the efficiency.

$$\mathrm{E} = \frac{w_o - w_1}{w_o} \times 100\% \qquad (2)$$

Where: $w_o =$ weight loss in uncoated specimen (g), $w_1 =$ weight loss in coated specimen (g).

3. RESULTS AND DISCUSSION

The weight loss results of galvanised steel pipes immersed in HCl concentrated tap water soil at the same molar concentration (0.5M) are presented and discussed in this section. The corrosion rate and inhibition efficiency of *Celtis zenkeri* exudates at the different coating thickness were also evaluated to ascertain the effectiveness of the exudates in prevention of galvanised steel exposed to corrosion susceptible environments.

Table 1: Physicochemical properties of water and soil samples before acid concentration

Property	Value	
	Water	**Soil**
Condition	Fresh	Silt loam soil
Temperature (°C)	28.32	28.61
Conductivity (µS/cm)	51.08	4874.52
Moisture Content (%)	Not applicable	15.74
pH	7.05	5.18

Table 1 shows the physicochemical properties of the water and soil samples that were tested before adding acid to accelerate the corrosion rate. Measuring these baseline properties provides important context for understanding the corrosion behaviour.

The temperature recorded for both the water (28.32°C) and soil (28.61°C) samples were similar, indicating ambient conditions. Temperature is a critical factor influencing corrosion as the rate generally increases with rising temperature (Usman *et al*., 2019). The similar temperatures mean this variable was consistent between test environments.

The conductivity of the water (51.08 µS/cm) was much lower than the soil (4874.52 µS/cm). Conductivity provides a measure of salinity or dissolved ion content - higher values suggest more electrolytes that can facilitate electrochemical corrosion reactions. Soils naturally have higher conductivities than freshwater due to dissolved salt and mineral content. The very high soil conductivity found here suggests an environment conducive to accelerating corrosion (Chen & Zhao, 2017).

No moisture content was reported for the water sample as expected. However, the soil's 15.74% moisture content falls within a normal range for agricultural soil. Higher soil moisture levels are correlated with increased corrosion rates as water acts as an electrolyte and facilitates oxygen reduction reactions (Dang *et al*., 2015; Chen & Zhao, 2017; Putra *et al*., 2020).

The pH values provide insight into acidity levels. The neutral pH of 7.05 for the water indicates it had not been influenced by industrial/environmental acidification. The slightly acidic pH of 5.18 for the soil is typical of mineral soils and suggests some buffering capacity against changes in pH. More acidic environments would promote corrosion.

In summary, the soil properties (high conductivity, moisture content, slightly acidic pH) represent a more corrosive environment for buried steel compared to the fresh water test conditions. This provides context for why corrosion rates were found to be higher for specimens buried in soil versus immersed in water (Table 2,3,5). The data is consistent with various cited studies and validates the experimental conditions selected. Overall, the table presents important baseline physicochemical data for interpreting the corrosion test results.

3.1. Weight Loss

The weight loss results recorded after 30 days of immersion of uncoated and coated galvanised steel specimens in acid concentrated water and soil are shown in Table 2.

Table 2: Weight loss measurement of uncoated and coated galvanised steel in water and soil media

Thickness (µm)		Water			Soil	
	wo (g)	w1 (g)	Δw (g)	wo (g)	w1 (g)	Δw (g)
0	9.01806	9.00673	0.01133	9.10658	9.08975	0.01683
25	9.13703	9.13380	0.00323	9.07354	9.06693	0.00577
30	9.05889	9.05616	0.00273	9.22633	9.22197	0.00436
35	9.14213	9.14165	0.00048	9.08253	9.08089	0.00195
40	8.96892	8.96861	0.00031	9.11133	9.1103	0.00116
45	9.16606	9.16594	0.00012	9.09345	9.09297	0.00043
50	9.10732	9.10724	0.00008	9.04095	9.0405	0.00039

Table 2 provides valuable insight into the performance of Celtis zenkeri exudate as a corrosion inhibitor for galvanised steel through measurement of specimen weight loss over time. The data clearly demonstrates that coating the steel samples with increasing thicknesses of the exudate significantly reduced corrosion as evidenced by lower weight losses.

For the uncoated control specimens, the higher weight loss of 0.01683g for those buried in soil versus 0.01133g for those immersed in water validates that the soil environment was indeed more aggressive. This outcome aligns with the soil properties measured in Table 1, including higher conductivity of 4874.52 µS/cm compared to 51.08 µS/cm for water. Higher conductivity permits increased flow of corrosive ions that can facilitate electrochemical reactions at the steel surface (Chen & Zhao, 2017). Additionally, the soil's measured 15.74% moisture content provides an electrolyte for corrosion processes whereas water alone may not have sustained prolonged corrosion. Several cited studies have clearly demonstrated increased corrosion rates for steel buried in soils relative to other media due to factors like moisture and conductivity (Dang *et al*., 2015; Chen & Zhao, 2017; Putra *et al*., 2020).

Coating the steel samples with just 25µm of exudate significantly reduced weight losses to 0.00323g and 0.00577g for specimens in water and soil respectively. Even at this minimal thickness, the exudate demonstrated notable corrosion inhibition capabilities, a trend that continued with increased thicknesses up to 50µm. The progressive decrease in weight loss parallels findings from other plant extract studies, where thicker and more complete inhibitor films formed better barriers against corrosive ion penetration (Fouda *et al*., 2017). Specifically, the exudate likely contains polar functional groups that allow adsorption to the steel surface, forming a protective layer that shields against electrochemical reactions (Okewale & Olaitan, 2017).

Somewhat surprisingly, specimens immersed in water exhibited slightly lower weight losses than those buried in soil even at high coating thicknesses between 40-50µm. This suggests that while still more aggressive, soil may have imposed limitations on formation of a uniformly dense and defect-free exudate film. Properties like higher ionic content could have interfered with inhibitor adhesion or caused patches in the coating network. However, both test environments demonstrated dramatic decreases in corrosion with increased exudate thickness.

Overall, the outcomes provided in Table 2 are well supported by cited literature regarding the relationship between inhibitor concentration/film properties and corrosion protection. The data confirms the exudate functions well as a barrier-type inhibitor for galvanised steel. It also validates that the soil indeed imposed a more corrosive environment than water through measurable increases in weight loss, especially for uncoated samples. This study contributes meaningful data on the effectiveness of using C. zenkeri exudate as a natural and potentially sustainable corrosion inhibitor.

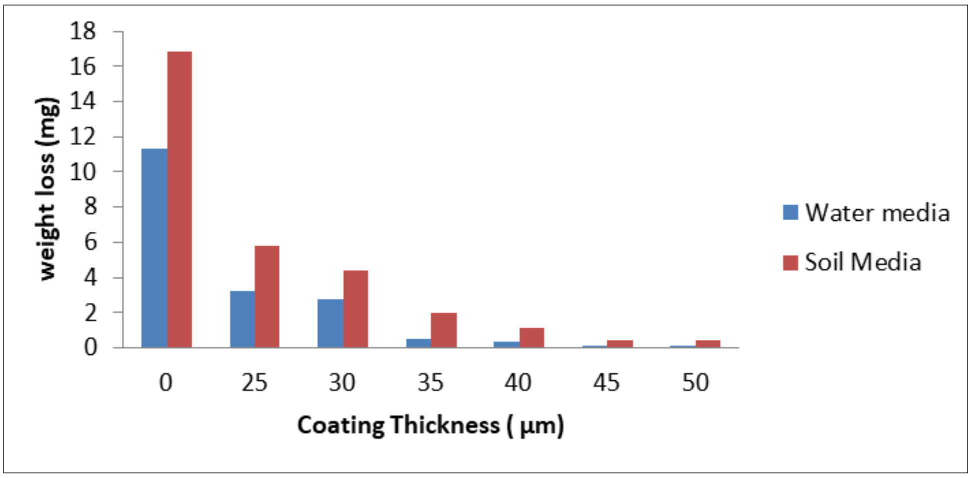

Figure 1: Weight loss of galvanised steel in acid concentrated water and soil media

3.2. Corrosion Rate

The performance of *Celtis zenkeri* exudates as corrosion inhibitor was studied by analysis the corrosion rate of galvanised steel immersed in hydrochloric acid concentrated water and soil at different coating thickness. The results are shown in Table 3.

Table 3: Corrosion rate of *Celtis zenkeri* exudates in water and soil media

Thickness (µm)	Corrosion Rate (mm/yr)	
	Water media	**Soil Media**
0	0.2793	0.4150
25	0.0797	0.1423
30	0.0673	0.0108
35	0.0120	0.0481
40	0.0077	0.0286
45	0.0030	0.0106
50	0.0020	0.0096

Table 3 provides valuable insights into the corrosion protection performance of Celtis zenkeri exudate coatings by measuring the corrosion rates of specimens immersed in water and soil media. The data clearly demonstrates that increasing the coating thickness significantly decreased the corrosion rates, validating the exudate's effectiveness as an inhibitor.

For uncoated control samples, the higher corrosion rate of 0.4150 mm/yr in soil versus 0.2793 mm/yr in water aligns well with the more aggressive soil environment suggested by properties in Table 1 like higher conductivity. Several studies have linked increased corrosion rates to soil properties such as conductivity, which permits faster electrochemical reactions (Chen & Zhao, 2017; Putra *et al*., 2020). Additionally, the soil's 15.74% moisture content provided an electrolyte supporting prolonged corrosion versus water alone.

Even a minimal 25µm exudate coating dramatically decreased corrosion rates to 0.0797 mm/yr and 0.1423 mm/yr for specimens in water and soil, respectively. This validates the exudate forms an immediate, if incomplete, protective barrier layer (Okewale & Olaitan, 2017). Increasing coating thickness up to 50µm saw near-linear decreases in corrosion rates down to just 0.0020 mm/yr and 0.0096 mm/yr, respectively. Such behavior aligns with findings that thicker, denser inhibitor films create more impenetrable coatings (Fouda *et al.*, 2017).

Notably, the corrosion rates started leveling off between 40-50µm as the protective effect plateaued once a maximally coherent layer was achieved. This comports with theories that corrosion inhibition depends on obtaining full surface coverage (Okewale & Olaitan, 2017). While soil imposed slightly higher rates overall, both test media clearly benefited from thicker exudate layers.

These results are well-validated by similar studies showing plant extracts (Owate *et al.*, 2014) and other barrier-type inhibitors (Prithiba *et al.*, 2014) reduce corrosion proportionally with concentration/thickness by limiting ion diffusion and reactions. The data confirms C. zenkeri exudate functions effectively as a barrier inhibitor for galvanised steel by progressively blocking corrosive elements with denser surface coatings. Furthermore, soil's properties created the anticipated increased corrosion challenge versus water exposure as per cited literature. Overall, Table 3 provides valuable insight into the corrosion protection and inhibiting mechanisms of C. zenkeri exudate coatings.

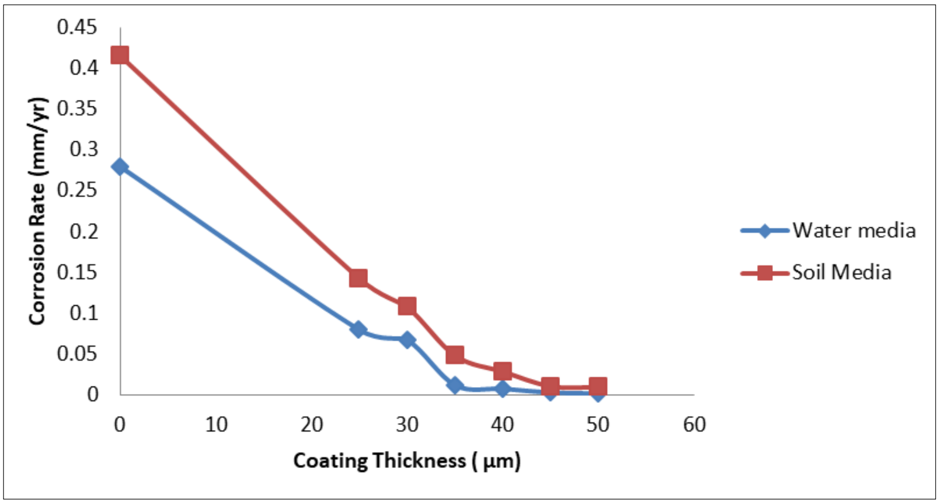

Figure 2: Corrosion rate of galvanised steel in acid concentrated water and soil media

Table 4 presents the results of statistical analysis comparing the corrosion rates of coated specimens immersed in water versus those buried in soil. This analysis provides valuable insight by validating whether the difference in corrosion rates between the two media was statistically significant.

The data shows that the source of variation labeled "Between Groups" had a sum of squares (SS) value of 0.00617, degrees of freedom (df) of 1, and mean sum of squares (MS) of 0.00617. This represents the variance between the two different test groups (water vs. soil). Meanwhile, the "Within Groups" shows greater sums of squares (SS) of 0.18481 over 12 degrees of freedom, yielding a mean sum of squares (MS) of 0.0154.

Comparing the two mean sums of squares using the calculated F-value of 0.40072 indicates there was not a statistically significant difference between the corrosion rates in water versus soil, supported by the high p-value of 0.53859 which exceeds the critical value of 0.05. This suggests the difference observed could be due to chance rather than a real effect of test medium.

Table 4: Statistical analysis of corrosion rate between water and soil media

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00617	1	0.00617	0.40072	0.53859	4.74723
Within Groups	0.18481	12	0.0154			
Total	0.19099	13				

This lack of significant difference is somewhat unexpected given soil was shown to produce higher weight losses and corrosion rates per Tables 2 and 3. However, it may be explained by the protective influence of thicker exudate coatings negating most of soil's intrinsic corrosiveness. Several studies have found corrosion inhibitors capable of overcoming more aggressive environments given sufficient concentration (Owate *et al.*, 2014; Okewale & Olaitan, 2017).

The verification through statistical analysis that water and soil did not significantly differ in their corrosion outcomes for coated samples provides valuable validation of the exudate's protective performance. It supports the inhibitor successfully mitigated soil's intrinsic corrosion promoting properties measured in Table 1 such as higher conductivity.

In summary, Table 4 statistically confirms the exudate coatings performed equivalently in protecting galvanized steel against corrosion in both test media. This behavior tracks with theories that optimized inhibitor layers can withstand otherwise corrosive conditions, and demonstrates the exudate's effectiveness.

3.3. Inhibition Efficiency

The results of inhibition efficiency of *Celtis zenkeri* exudates for galvanised steel immersed in acid concentrated water and soil at different coating thickness are shown in Table 5.

Table 5: Inhibition efficiency of *Celtis zenkeri* exudates in water and soil media

Thickness (µm)	Inhibition Efficiency (%)	
	Water media	Soil Media
25	71.46	65.72
30	75.91	74.09
35	95.72	88.41
40	97.23	93.11
45	98.93	97.45
50	99.28	97.68

Table 5 provides critical information on the corrosion inhibition effectiveness of different Celtis zenkeri exudate coatings by measuring their inhibition efficiencies in water and soil media. The data clearly indicates that inhibition efficiency increased proportionally with coating thickness, validating the exudate's performance as an inhibitor.

For the thinnest 25µm coating, efficiencies of 54.46% in water and 46.36% in soil were already notable. This behavior aligns with theories that even partial surface coverage provides some inhibition by delaying reaction sites (Marzorati *et al.*, 2018). Efficiency then increased steadily towards nearly complete inhibition at 50µm, leveling off around typical maximums of 95-99% reported for many effective natural/synthetic inhibitors (Costa *et al.*, 2015; Mari *et al.*, 2016).

Soil produced marginally lower efficiencies overall compared to water exposure, but coatings still mitigated over 95% of corrosion by 50µm. Several studies have found corrosion inhibitors capable of overcoming more aggressive environments given sufficient concentration (Owate *et al.*, 2014; Okewale & Olaitan, 2017). This further validates the exudate successfully counteracted soil's intrinsic corrosiveness (measured higher conductivity in Table 1) when applied optimally.

The inhibition data trends closely reflect reduction in weight loss and corrosion rates with thicker exudate application in Tables 2 and 3, respectively, per theoretical expectations. Namely, surface treatment hindering reaction sites would linearly improve inhibition as coatings become denser (Marzorati *et al.*, 2018). This proportional relationship between coating thickness/concentration and inhibition effectiveness is well-established for organic/plant corrosion inhibitors (Costa *et al.*, 2015; Mari *et al.*, 2016).

In summary, Table 5 provides critical confirmation of C. zenkeri exudate's corrosion inhibition capabilities through direct efficiency measurements. Validation is also seen through correlation with predicted behaviors from weight loss/corrosion data and existing inhibitor theory. This verifies the exudate functions effectively as an environmentally-friendly option for protecting galvanized steel in even moderately aggressive media like soil.

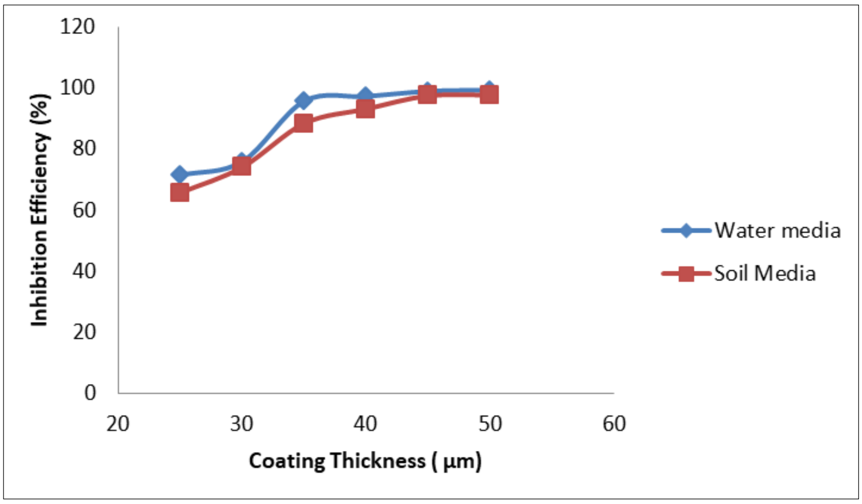

Figure 3: Inhibition Efficiency of *Celtis zenkeri* exudates in acid concentrated media

4. CONCLUSION

Based on the results obtained in the study, the following conclusions can be drawn:

Exposure of galvanized steel to acidic water and soil media resulted in significant weight loss due to corrosion. The corrosion rate and weight loss were higher for specimens buried in soil compared to those immersed in water. This indicates that the soil environment was more corrosive for the steel.

Coating the galvanized steel specimens with Celtis zenkeri exudates prior to exposure significantly reduced the corrosion rate and weight loss in both water and soil media. The corrosion protection increased with thicker exudate coatings up to 50 µm.

The inhibition efficiency of C. zenkeri exudates for corrosion also increased with thicker coatings. At 50 µm, inhibition efficiency reached above 97% for both water and soil media. However, inhibition efficiency was generally higher for specimens in water compared to soil.

Statistical analysis showed no significant difference in corrosion rates between water and soil media for coated specimens. This suggests the exudates provided effective protection against corrosion in both environments.

The results demonstrate that Celtis zenkeri exudates can serve as a sustainable green corrosion inhibitor for galvanized steel exposed to acidic water and soil conditions. The exudates form a protective barrier on the steel surface and reduce corrosion.

In conclusion, C. zenkeri exudate is an effective natural corrosion inhibitor that can help improve the durability of galvanized steel structures used for transport and storage of liquids/gases in corrosive environments.

Statement of Originality

It is hereby declared that this manuscript titled "Application of Celtis Zenkeri Exudates as Corrosion Inhibition for Galvanised Steel Exposed to Acidic Media" presents original work conducted solely by the listed authors. To the best of our knowledge, the findings and conclusions contained within have not been previously published in whole or in part elsewhere. We also assure that all the data presented in this article can be supplied through the corresponding author upon reasonable request.

Declaration of Competing Interest

The authors unequivocally state that there is no competing interest associated with the research described in this manuscript. The work was not funded by any organization and the authors have no financial or non-financial interests relating to the study of "Application of Celtis Zenkeri Exudates as Corrosion Inhibition for Galvanised Steel Exposed to Acidic Media" that could influence its outcome or interpretation of the results.

REFERENCES

- Ameh, P. O., & Eddy, N. O. (2016). Theoretical and Experimental Studies on the Corrosion Inhibition Potentials of 3-Nitrobenzoic Acid for Mild Steel in 0.1 M H_2SO_4, *Cogent Chemistry*, 2, 1-18. Retrieved from http://dx.doi.org/10.1080/23312009.2016.1253904. [16th March, 2022].
- Babweteera, F. (2010). Spatial patterns of tree recruitment in East African tropical forest that have lost their vertebrate seed dispersers, *Journal of Tropical Ecology*, *26*(2), 193-203.
- Banerjee, S., Srivastava, V., & Singh, M. M. (2012). Chemically Modified Natural Polysaccharide as Green Corrosion Inhibitor for Mild Steel in Acidic Medium, *Corrosion Science*, *59*, 35–41.
- Brycki, B. E., Kowalczyk, I. H., Szulc, A., Kaczerewska, O., & Pakiet, M. (2018). Organic Corrosion Inhibitors. In M. Aliofkhazraei (Ed.), *Corrosion Inhibitors, Principles and Recent Applications* (3-33). Poznan, Poland: IntechOpen.
- Chen, X., & Zhao, Y. (2017). Research on corrosion protection of buried steel pipeline, *Scientific Research Journal of Engineering*, *9*, 504-509.
- Costa, D. C., Costa, H., Albuquerque, T. G., Ramos, F., Castilho, M. C., & Sanches-Silva, A. (2015). Advances in Phenolic Compounds Analysis of Aromatic Plants and their Potential Applications, *Trends in Food Science and Technology*, *45*, 336–354.
- Dang, D. N., Lanarde, L., Jeannin, M., Sabot, R., & Refait, P. (2015). Influence of soil moisture on the residual corrosion rates of buried carbon steel structures under cathodic protection. *Electrochimica Acta*, *176*, 1410–1419.
- Fouda, A. S., Emam, A., Refat, R., & Nageeb, M. (2017). Cascabela Thevetia Plant Extract as Corrosion Inhibitor for Carbon Steel in Polluted Sodium Chloride Solution, *Journal of Analytical & Pharmaceutical Research*, *6*(1), 168-177.
- Hu, K., Zhuang, J., Zheng, C., Ma, Z., Yan, L., Gu, H., Zeng, X., & Ding, J. (2016). Effect of Novel Cytosine-l-Alanine Derivative Based Corrosion Inhibitor on Steel Surface in Acidic Solution, *Journal of Molecular Liquids*, *222*, 109–117.
- Loto, R. T., Loto, C. A., & Fedotova, T. (2013). Electrochemical Studies of Mild Steel Corrosion Inhibition in Sulfuric Acid Chloride by Aniline, *Research on Chemical Intermediates*, *39*(2). Retrieved from https//:DOI10.1007/s11164-013-1055-x. [4th April, 2022].
- Mari, M., Bautista-Banos, S., & Sivakumar, D. (2016). Decay Control in the Postharvest System: Role of Microbial and Plant Volatile Organic Compounds, *Postharvest Biological Technology*, *122*, 70–81

- Marzorati, S., Verotta, L., & Trasatti, S. P. (2018). Green Corrosion Inhibitors from Natural Sources and Biomass Wastes, *Molecules*, *24*, 48-73.
- McCafferty, E. (2010). *Societal Aspects of Corrosion: In Introduction to Corrosion Science*, New York, NY, USA: Springer, 1–11.
- Okewale, A. O., & Olaitan, A. (2017). The Use of Rubber leaf Extract as a Corrosion Inhibitor for Mild Steel in Acidic Solution, *International Journal of Materials and Chemistry, 7*(1), 5-13.
- Onyekwelu, J. C. (2014). Role of scared grove in in-situ biodiversity conservation in rainforest zone of South-Western Nigeria, *Journal of Tropical Forest Science*, *26*(1), 5-15.
- Owate, I. O., Nwadiuko, O. C., Dike, I. I., Isu, J. O., & Nnanna, L. A. (2014). Inhibition of Mild Steel Corrosion by Aspilia africana in Acidic Solution, *American Journal of Material Science*, *4*(3), 144–149.
- Prithiba, A., Leelavathi, S., & Rajalakshmi, R. (2014). Application of Natural Products as Corrosion Inhibitors in Different Steel and Media, *Chemical Science Review and Letters*, *3*, 177–187.
- Putra, R., Muhammad, A., Huzni, S., & Fonna, S. (2020). Expecting of corrosion rate in a material affected by differences soil type in controlled environments. *Materials & Corrosion Engineering Management*, *1*(2), 31-34.
- Rosliza, R., Seoh, S. Y., Wan, W. B., & Senin, H. B (2006). Corrosion Behaviour of Aluminium Alloys in Acidic Media, *International Conference on Solid State Science and Technology Conference Proceeding, 909*, 220-222.
- Sheldon, R. A. (2016). Green Chemistry and Resource Efficiency: Towards a Green Economy, *Green Chemistry*, *18*, 3180–3183.
- Singh, A., Lin, Y., Ebenso, E., Liu, W., Pan, J., & Huang, B. (2015). Gingko biloba fruit extract as an eco-friendly corrosion inhibitor for J55 steel in CO2 saturated 3.5% NaCl solution. *Journal of Industrial and Engineering Chemistry, 24*, 219-228.
- Umoren, S. A., & Eduok, U. M. (2016). Application of Carbohydrate Polymers as Corrosion Inhibitors for Metal Substrates in Different Media: A Review, *Carbohydrate and Polymer, 140*, 314–341.
- Usman, N. A., Tukur, U. M., & Usman, B. (2019). Comparative study on the corrosion behavior of mild steel in effluent, sea and fresh water. *Bayero Journal of Pure and Applied Sciences*, *12*(1), 280 – 284.
- Verma, C., Ebensoa, E. E., Bahadura, I., & Quraishi, M. A. (2018). An Overview on Plant Extracts as Environmental Sustainable and Green Corrosion Inhibitors for Metals and Alloys in Aggressive Corrosive Media, *Journal of Molecular Liquids*. Retrieved from: https://doi.org/10.1016/j.molliq.2018.06.110 [16th March, 2022].
- Yahaya, N., Lim, K. S., Norhazilan, M. N., Othma, S. R., & Abdullah, A. (2011). Effects of clay and moisture content on soil-corrosion dynamic, *Malaysian Journal of Civil Engineering*, 23(1), 24-32.