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Comparative Study of the Inhibitive Effects of the Leaves and Seeds of *Moringa Oleifera* on Mild Steel in Acidic and Basic Media

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Abstract: The comparative study of the inhibition characteristics of leaves and seeds of *Moringa oleifera* has been investigated. Uniform mild steel coupons were immersed in 0.5 M and 1.0 M of H_2SO_4 and NaOH containing 5 ml, 10 ml, 15 ml and 20 ml of *Moringa oleifera* leaf and seed extracts obtained by reflux method and allowed to stand for 672 hours with a coupon withdrawn from each beaker at 168 hourly interval for characterization. The results obtained showed the normal corrosion behavior for passivating metals, with an initial steep rise in corrosion rate which decreased with increasing exposure time. On media concentration, the corrosion rates were observed to decrease as the concentration of the media increased. Curiously, an unusual behavior was noticed in the seed extract in 0.5 M NaOH at 504 hours and 1.0 M NaOH at 336 hours, which is attributed to the breakdown of the passive film due to possible system agitation. Comparatively, the leaf extract had better corrosion inhibition potentials in the acid than the seed, while in the base, the seed extract manifested better inhibition efficiency than the leaf. In conclusion therefore, both *Moringa oleifera* leaves and seeds can serve as veritable green corrosion inhibitors.

1. Introduction

Corrosion is defined as an irreversible interfacial reaction of a material (metal, ceramic and polymer) with its environment which results in consumption of the material or in dissolution into the material of a component of the environment (Elmsellem *et al.*, 2014). Corrosion is generally viewed as a universal phenomenon (Fernandez *et al.*, 2015). Several types of corrosion are distinguished, amongst which are: uniform, galvanic, pitting, crevice, intergranular, fretting, erosion, high-temperature, selective leaching and stress corrosion cracking (Harsimran, 2021). In general, corrosion is a slow process that damages industrial machines, metallic equipment and reduces the overall value of that product. On annual basis, total economic loss due to various types of corrosion in India is nearly US $6500 million, while in the USA, total direct wastage is estimated about 3.2% of domestic product (Kumar *et al.*, 2018). Corrosion is therefore one of the major problems that must be confronted for the safety of our environment and for economic reasons (Finsgar *et al.*, 2014; El Mouaden *et al.*, 2018), making the investigation of metallic corrosion a subject of immense conceptual and practical concern that has expectedly received a substantial amount of interest (Chukwukere *et al.*, 2020). Unfortunately, the age old and vexing problem of corrosion continues to attract research attention, not only because it continues to cost our society very dearly, but also for its bearings on the applications of new technologies (Raman, 2018). The key to control corrosion is its proper awareness and by adapting, suitable and timely measures (Palanisamy, 2018). One of such control measures happens to be the use of corrosion inhibitors, which in recent times has shifted from the conventional inorganic and synthetic inhibitors to the eco-friendlier green inhibitors (Okafor *et al.* 2010; Ben Hmamou *et al.* 2012; Barouni *et al.* 2014; Ouachikh *et al.* 2009).

The corrosion inhibition efficiency of plant parts vary. According to Justine (2021), the flower extract of Roselle (green variety) offered higher inhibition efficiency compared to the leaves extract of the same plant. The inhibitive action of the leaves (LV), root (RT) and seeds (SD) extracts of Neem on mild steel in acidic media followed trend. SD > RT > LV (Okafor *et al.* 2010). According to Uwah *et al.*, (2010), the ethanol extract of the leaves of *Nauclea latifolia* was more variant as an inhibitor compared to the ethanol extracts of the bark and roots of the same plant.

However, the corrosion inhibition variability of others plant parts have not been compared. One of such plants is *Moringa oleifera*, therefore the need for this work. In essence therefore, this work focuses on the comparative analysis of the inhibitive variations of the leaves and seed extracts of *Moringa oleifera* on mild steel in acid media and base media.

2. Methodology

2.1 Materials

The materials used for the study were: mild steel rod, sieve, plastic containers, bowls, dry leaves and seeds of Moringa oleifera, emery paper, distilled water, filter papers, tetraoxosulphate (VI) acid (H_2SO_4) and sodium hydroxide base (NaOH) solution, cello tape, nylon thread, electronic weighing balance (Tapson's Scientific Instruments Co. Model=TAPT 3000 G), hack saw and hand file beakers, measuring cylinder, hacksaw and blades, vernier caliper and measuring tape**.**

2.2 Material preparation of mild steel and leaf extracts

The leaves and seeds of Moringa oleifera were obtained from a market in Jalingo, Taraba State. The leaves and seeds were thoroughly washed in water to remove dust and sand particles. The leaves and seeds were shade dried separately for 96 hours, so as to enrich the active principles in them by reducing their moisture content (Saratha *et al*., 2009). The dried leaves and seeds were converted to powder by pounding using a mortar and pestle. The powdered samples were sieved with a sieve (150 µm mesh size). The sieved samples of leaves and seeds of Moringa oleifera were stored in polythene bags until needed for corrosion studies. Extraction of active ingredients in the leaves and seeds of Moringa oleifera plant were done using the Reflux method (Nwigbo *et al*., 2012, Fouda *et al*., 2017).

Photo 1: Moringa oleifera leaf and seed

30 grams each of the powdered leaves and seeds of Moringa oleifera plant were measured using an electronic balance into four round bottom flasks. 1.0M H_2SO_4, 0.5M H_2SO_4, 1.0M NaOH and 0.5M

NaOH solution were respectively added to each of the measured samples in the four flasks. The resulting mixtures were boiled for 90 minutes, on a gas burner. The content of each flask was filtered using a filter paper. The filtrates were taken as the stock solution. Mild steel coupons were produced from mild steel rod. The mild steel rod was cut into one hundred and forty-four test specimens, each of dimensions (10mm x 5mm x 5mm). The surfaces of the test specimens were polished with abrasive paper to produce smooth surface and to remove any trace of contaminants. The test specimens were degreased in ethanol, washed thoroughly in deionized water and rinsed with acetone. The washed specimen was air dried (Eddy *et al*., 2011, Ehujuo *et al*., 2014) to remove any moisture that might be present on the test specimens.

The inhibitors were accurately weighed and dissolved in the prepared 0.5 M H_2SO_4, 1.0 M H_2SO_4, 0.5 M NaOH, 1.0 M NaOH solution to obtain different inhibitor(s) concentrations (5 ml, 10 ml, 15 ml and 20 ml). The corrosion rates and inhibition efficiencies of the extracts were determined using weight loss methods. The Weight Loss Method of corrosion measurement was adopted for evaluating the corrosion rates of mild steel samples. The inhibitors were accurately weighed and dissolved in the prepared 0.5 M H_2SO_4, 1.0 M H_2SO_4, 0.5 M NaOH, 1.0 M NaOH solution. The experiment was conducted in four sets and at room temperature. In each of the set of weight loss measurements, nine beakers were arranged on a table in the Hydraulic Laboratory of the Department of Mechanical Engineering, Taraba State University, Jalingo. 70 ml of 0.5 M H_2SO_4, 1.0 M H_2SO_4, 0.5 M NaOH, 1.0 M NaOH solution was measured and poured into each of the labeled beakers in each set. The required concentration of the extract (5 ml, 10 ml, 15 ml and 20ml) were respectively measured from the stock solution of leaves and seeds of the Moringa oleifera plant. Thereafter, the measured extracts (leaves and seeds of Moringa oleifera plant) were respectively added to each of the beakers containing the corrodent in each set. No inhibitor was added to the first beaker in each set. Four pre-weighed specimens were tied with nylon string, coded and totally immersed in each of the beakers containing both the corrodent and the extracts. After every 168 hours, one sample was withdrawn from the corrodent, observed and washed with distilled water rinsed in ethanol to remove corrosion products, air dried and re-weighed. The procedure is repeated after 336 hours, 504 hours and 672 hours. The difference in weight of the coupon was taken as the weight loss. The inhibition efficiencies (IE%) of the inhibitors were computed using **Eqn.1.**

$$IE\% = \left(\frac{CR_a - CR_p}{CR_a}\right) \times 100 \qquad \textbf{Eqn.1}$$

CR_p = Corrosion rate in the presence of inhibitor and CR_a = Corrosion rate in the absence of the inhibitor.

The corrosion rates in mm/yr were computed using **Eqn.2.**

$$CR = \frac{87.6W}{\rho A t} \qquad \textbf{Eqn.2}$$

Where W = weight loss (mg); ρ = density of specimen (g/cm^3), A = area of specimen (cm^2) and t = period of immersion (hours).

3. *Results and Discussion*

The results obtained are represented in **Figure 1-16** as follows. Variation of corrosion rate with exposure time for the corrosion of mild steel in the two media with the differing extracts as obtained from weight loss are presented in **Figure 1-8.** A cursory look at the **Figures** shows that the general corrosion trend for passivating metals was obeyed, starting with an initial steep rise in the corrosion rate, followed by a progressive decline as the exposure time increased. Specifically, **Figure 1-4** revealed that the corrosion rates of mild steel in all the media in the absence of the extracts were found to be higher compared to the corrosion rates in the presence of the extracts. This is indication that the extracts had inhibited the corrosion rates of mild steel in both media.

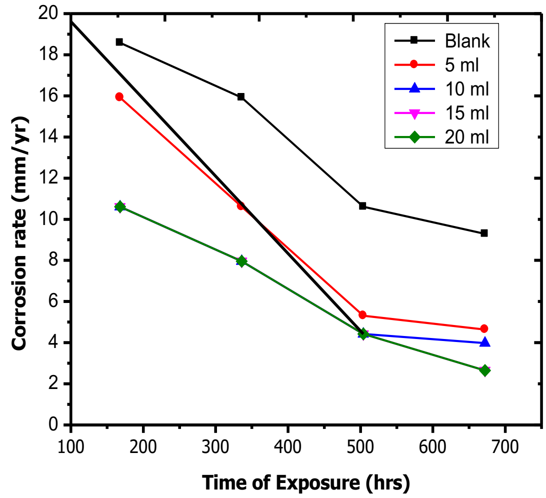


Figure 1. Corrosion rate of mild steel against exposure time for *Moringa oleifera* leaf extract in 0.5M H_2SO_4.

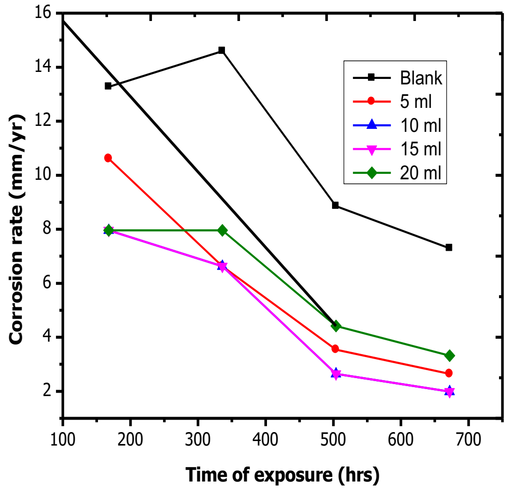
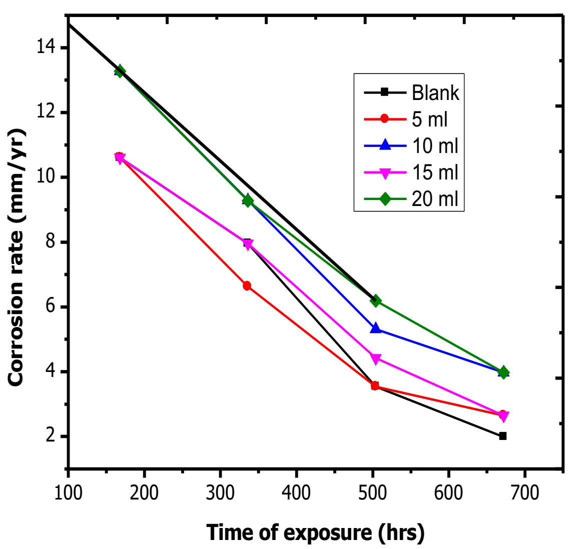


Figure 2. Corrosion rate of mild steel against exposure time for *Moringa oleifera* seed extract in 0.5M H_2SO_4.



gure 3. Corrosion rate of mild steel against exposure time for *oringa oleifera* leaf extract in 1.0 M H_2SO_4.

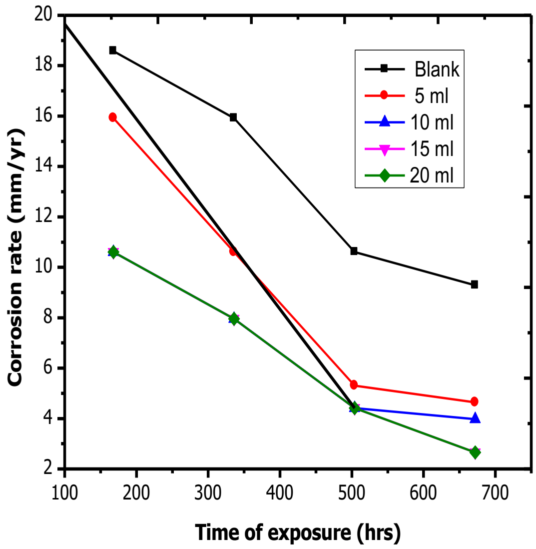


Figure 4. Corrosion rate of mild steel against exposure ime for *Moringa oleifera* seed extract in 1.0 M H_2SO_4.

The corrosion rates declined as exposure time increased from first day of immersion to the last day of withdrawal at concentrations of 5 ml, 10 ml, 15 ml and 20 ml. The observed decrease in corrosion rates is believed to be due to the formation of a thin film of passivating corrosion complexes that created a barrier between the metal and the acidic environment (Odiongenyi *et al.,* 2008 ; Loto *et al.,* 2011 ; Owate *et al.,* 2014).

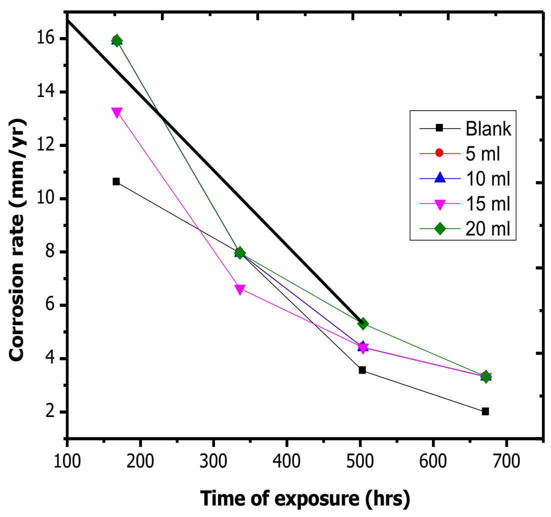


Figure 5. Corrosion rate of mild steel against exposure time for *Moringa oleifera* leaf extract in 0.5 M NaOH.

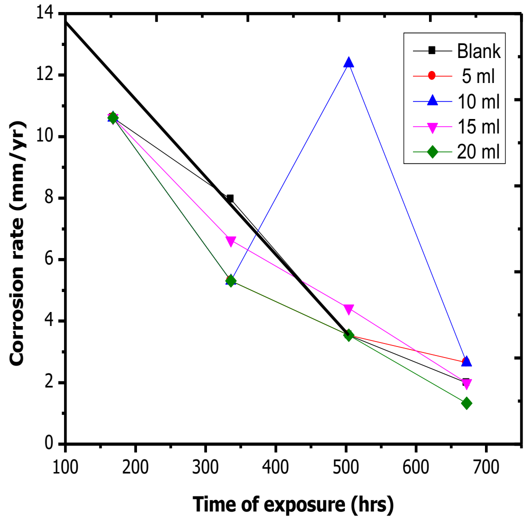


Figure 6. Corrosion rate of mild steel against exposure time for *Moringa oleifera* seed extract in 0.5 M NaOH.

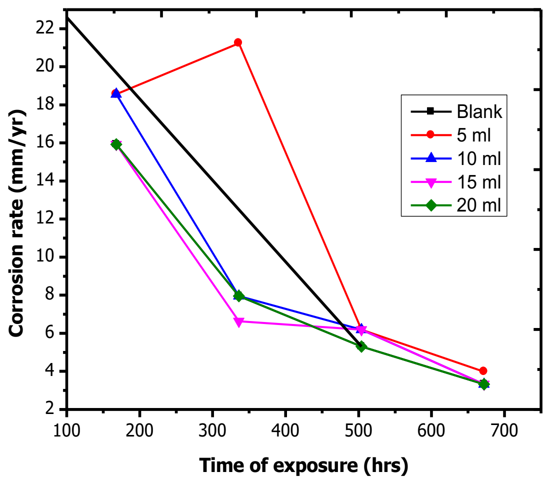


Figure 7. Corrosion rate of mild steel against exposure time for *Moringa oleifera* leaf extract in 1.0 M NaOH.

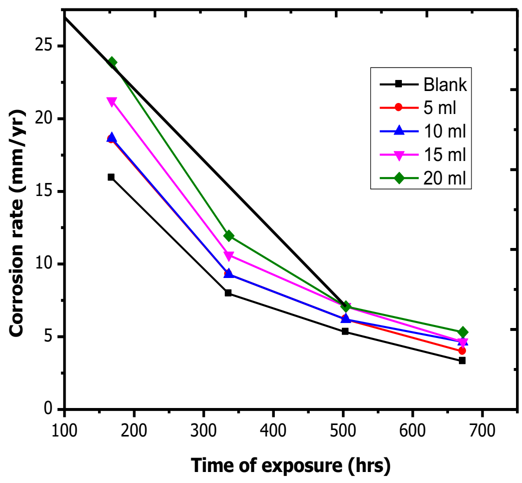


Figure 8. Corrosion rate of mild steel against exposure time for *Moringa oleifera* seed extract in 1.0 M NaOH.

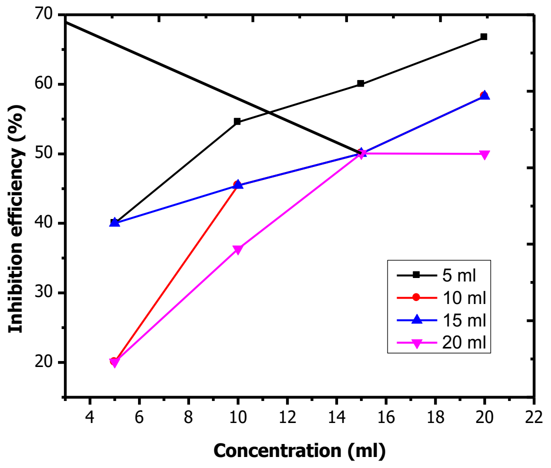


Figure 9. Inhibition efficiency against concentration of *Moringa oleifera* leaf extract on the mild steel in 0.5 M H_2SO_4

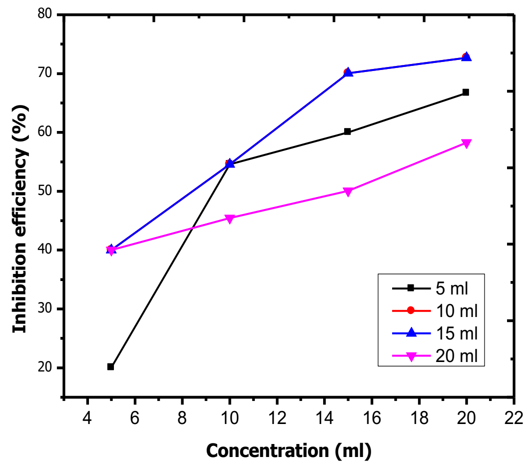


Figure 10. Inhibition efficiency against concentration of *Moringa oleifera* seed extract on the mild steel in 0.5 M H_2SO_4

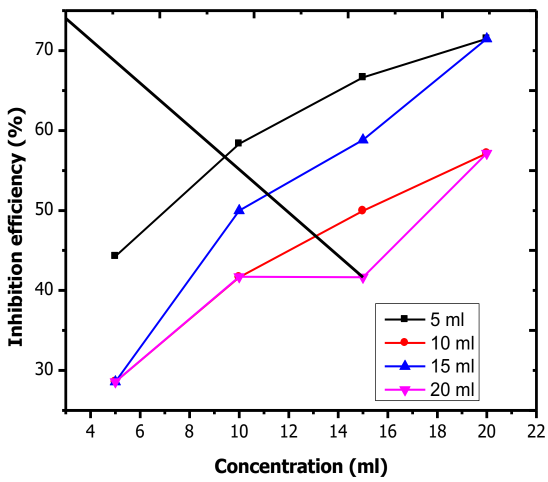


Figure 11. Inhibition efficiency against concentration of *Moringa oleifera* leaf extract on the mild steel in 1.0 M H_2SO_4.

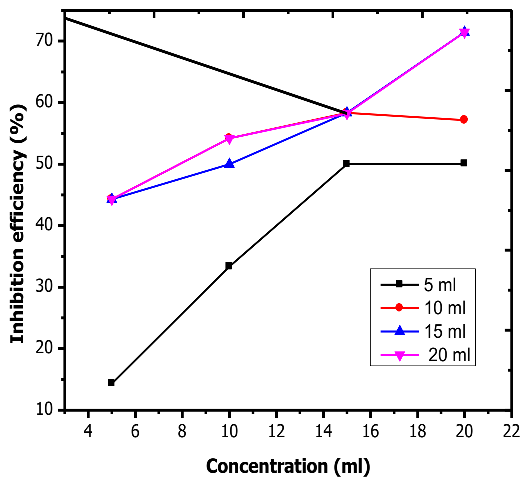


Figure 12. Inhibition efficiency against concentration of *Moringa oleifera* seed extract on the mild steel in 1.0 M H_2SO_4

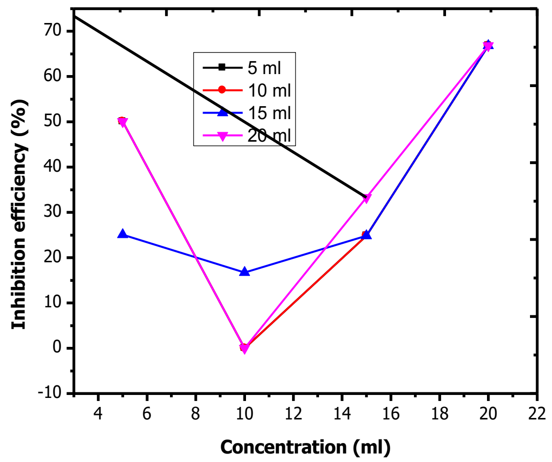


Figure 13. Inhibition efficiency against concentration of *Moringa oleifera* leaf extract on the mild steel in 0.5 M NaOH.

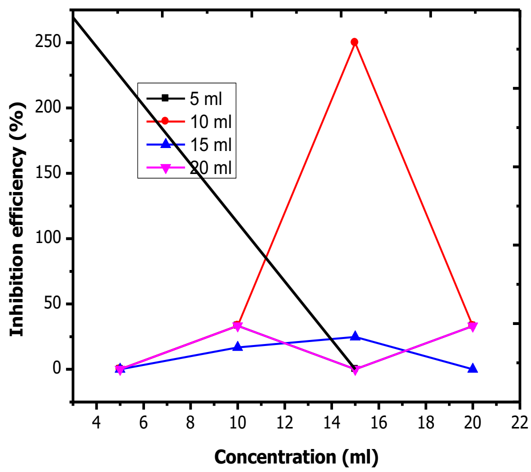


Figure 14. Inhibition efficiency against concentration of *Moringa oleifera* seed extract on the mild steel in 0.5 M NaOH

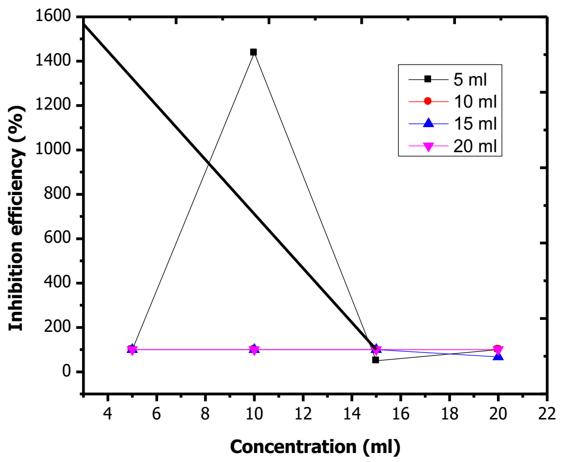


Figure 15. Inhibition efficiency against concentration of *Moringa oleifera* leaf extract on the mild steel in 1.0 M NaOH.

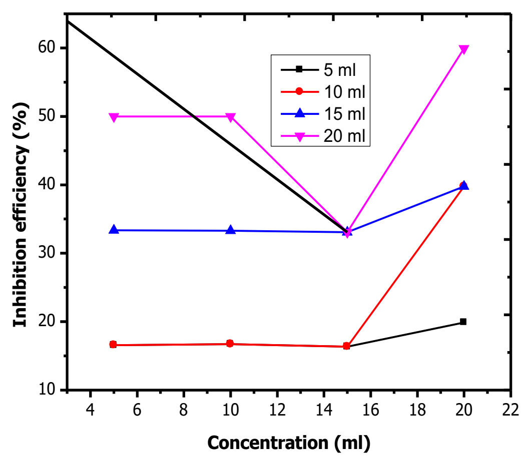


Figure 16. Inhibition efficiency against concentration of *Moringa oleifera* seed extract on the mild steel in 1.0M NaOH

Figures 5-8 represent the corrosion rates of mild steel in all the basic media. It is observed that the corrosion rates declined as exposure time increased at extract concentrations of 5 ml, 10 ml, 15 ml and 20 ml respectively. Curiously, in the absence of the extracts, the corrosion rates were found to be lower compared to the corrosion rates in the presence of the extracts. This behavior is believed to be due to weight gain by the coupon in the presence of NaOH instead of weight loss. The weight gain appears to be from the strong adsorption of the passivating corrosion complex on the metal surface. **Figures 9-16** represent the inhibition efficiencies of the extracts in all the corrosion media. It can be seen from the graphs that inhibition efficiency increased as concentrations of each of the leaf and seed extracts increased. It is noticed that there is an indirect relationship between corrosion rate data and inhibition efficiency. It is confirmed from this work that in a given corrosion-inhibitor medium, the higher the corrosion rate values the lower the inhibition efficiency (Omotosho, 2016).

In a marked surprising deviation from the norm, we curiously notice an unusual behavior in the corrosion rates of the seed extract at 0.5 M and 1.0 M NaOH, where at the exposure times of 504 hours for 0.5 M NaOH and 336 hours for 1.0 M NaOH, there was a sudden sporadic rise in corrosion rates. This behavior is attributed to a possible system agitation that caused the fragile protective passive film to break down thereby exposing the mild steel to a more grievous attack by the corrosion media, irrespective of the presence of the inhibitors. Relationship between inhibition efficiency and extract concentrations for the corrosion of mild steel are presented in **Figure 9-16**. When critically observed, it can be seen that the normal phenomenon of linear relationship between inhibition efficiency and media concentration is obeyed. There is a linear increase in inhibition efficiency as the concentration of extracts increased in the acidic corrosion media. In the basic corrosion media, an unusual behavior is noticed. However, there was no clearly defined observation of this linearity phenomenon at 10 ml of seed extract and 20 ml of leaf extract concentrations in 0.5 M NaOH and at 20 ml of seed extract and 5 ml of leaf extract concentrations in 1.0 M NaOH respectively. These deviations from the norm are a consequence of possible collapse of the protective films due to unintended system agitations in the course of the experimentation.

The results obtained by Natsir *et al.,* (2019) show that *M. oleifera* leaves contained 18 types of amino acids included threonine, lysine, leucine, isoleucine, phenylalanine, valine, methionine, tryptophan while non-essential amino acids include histidine, proline, tyrosine, aspartate acid, glycine, arginine, alanine, glutamate acid, serine, cysteine. In other work, indicated the presence of these compounds Decanoic acid, 17-Octadecynoic acid near 12 types of essential and non-essential amino acids. Extraction of phenolic compound showed presence of quercetine and kaemferal. Also, Vitamin C content in fresh samples of leaves of *M. olifera* was characterized Khalaf *et al.,* (2021).

The presence of the numerous components rich in aromatic rings, doble and triple bonds as well as heteroatoms as S, N, O… favorized the adsorption on the metal surface. The inhibition process is generally interpreted by the synergistic intermolecular effect of the various molecules contained in the leaf and seed extracts as stated by Ezeh *et al.,* (2023) and Lrhoul *et al.,* (2023).

Conclusion

From the foregoing discussions, we summarize that the corrosion rates of mild steel containing the seed and leaves extract of *Moringa oleifera* generally obeyed the already established phenomenon of corrosion behavior of passivating metals. There was an initial steep rise in the corrosion rate, which progressively decreased as exposure time increased. When compared, we observe that the leaf extract had better corrosion inhibition potentials in the acid than the seed. There also exists an established direct linear relationship between inhibition efficiency and media concentration. Accordingly, both leaf and seed extracts obeyed this phenomenon. However, in comparative terms, in the base, the seed extract manifested better inhibition efficiency than the leaf. We therefor conclude that both *Moringa oleifera* leaves and seeds can serve as alternative green inhibitors to the conventional inorganic and synthetic inhibitors currently in use in the oil and gas, and food processing industries.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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