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A Study of the Corrosion Behavior of Engineering Mild Steel in Acidified and Hydrolyzed Extracts *of Zingiber Officinale* (Ginger)

Nwangbo T. N[1], Idenyi N. E[2], Idu K. H[3*]
[1]Scientific Equipment Development Institute, Enugu, Federal Ministry of Science and Technology, Abuja, Nigeria
[2]Department of Mechanical and Bioresources Engineering, Ebonyi State University, Enugu - Abakaliki Rd, 481101, Abakaliki, Ebonyi, Nigeria
[3]Department of Physics, Taraba State University, ATC, 660213, Jalingo, Nigeria

Abstract: We report the use of weight loss technique in the study of the corrosion behaviour of engineering mild steel in acidified and hydrolysed corrosion media using *Zingiber officinale* (Ginger) extracts. Cylindrical steel rods were cut into corrosion coupons of predetermined dimensions of 15 mm by 10mm diameter. The coupons were then weighed before being suspended in situ in fours into beakers containing 10 mL, 15 mL and 20 mL of the extracts in 0.5 M and 1.0 M concentrations of H_2SO_4 and NaOH respectively. These setups were allowed to stand for a period of 28 days with a coupon withdrawn from each beaker after every 7 days, processed according to standard procedures before reweighing. The data of the weight loss were recorded and computations of the corrosion penetration rate using the formula; $\mathrm{CPR} = \frac{K\Delta W}{\rho A \Delta t}$ were calculated. Plots of corrosion penetration rate against time, inhibition efficiency against concentration of extract and Langmuir adsorption isotherms were then plotted. The results obtained revealed that the corrosion rate profiles for passivating metals in which there is an initial sharp rise in corrosion rate, followed by a progressive decline as exposure time increased were observed. The inhibition efficiencies of the extract in the various media also showed significant increase in all the media. The Langmuir adsorption isotherms indicated that the adsorption of the molecules of the extract on the metal surface was uniformly distributed over the entire metal surface and also the adsorptive forces were strong enough to cause effective adhesion to prevent further corrosion attack. In conclusion, it was established that *Zingiber officinale* leaf extracts are good inhibitors of corrosion and that the inhibitive potency of the extract increases with increase in the concentrations of the extract and the corrosion media as exposure time increased, with the extract showing better inhibition characteristics in NaOH than H_2SO_4.

Keywords: Corrosion, Engineering Mild Steel, Tetraoxosulphate (VI) acid, Sodium Hydroxide, *Zingiber officinale*.

RESEARCH PAPER

***Corresponding Author:**
Idu K. H
Department of Physics,
Taraba State University, ATC,
660213, Jalingo, Nigeria

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INTRODUCTION

Corrosion is the inherent tendency of metals to revert from a processed metallic state back to their more natural existing form called Ores (Adam *et al.*, 2018). Mild steel being an alloy of carbon and iron have homogenous content ratio of 0.2 -0.5% in the matrix elements (Chaubey *et al*., 2017). As a result of this ratio, their properties such as tensile stress, hardness, ductility and ability to withstand an impressed load are improved (Adam *et al*., 2018). The factors that determine corrosive environment include moisture content air permeability (porosity), salinity (salt analysis), acidity, alkalinity, conductivity and presence of micro-organism (Deyab *et al*., 2017; El-Bribri *et al*., 2013). Although mild steel are greatly used in many engineering construction, it has been on record that mild steel can corrode in both acidic media (Hajar *et al*., 2016; Helen *et al*., 2014). Among the four ways of preventing corrosion of mild steel the most effective is the use of inhibitors (Ibrahim *et al*., 2016; Mouaden *et al*., 2018). For an inhibitor to be an effective protector against metal corrosion, it should be readily adsorbed on the metal surface through either physisorption or chemisorptions process. Green corrosion inhibitors are biodegradable, they do not contain toxic compounds and their leaves has been used as eco-friendly corrosion inhibitors (Obot *et al.*, 2019).

More examples of green inhibitors are; bitter leaf, fluted pumpkin leaves, watermelon, cassava, mango, nchanwu (*Ocimium basilicum*) (Prabakaran *et al.*, 2016; Singh *et al.*, 2018). Ginger is a rhizome of the monocotyledonous perennial plant though called "root" and is used for treating many ailments such as arthritis, colic diarrhea, heat condition, common cold, flu-like symptoms, headache and painful menstrual periods (Al-Otaibi *et al.*, 2012), and also contain essential chemicals such as sesequiterperoids and monoterpenoids, the sesqquepenoid include(-) zingiberene as the main component, lesser β-sesueuiphellandrene, bisabolene and fernesene, while the the monoterpenoids include β-phellandrene, cineol and citral (Obot *et al.*, 2009; Yildirin and Cetin, 2008). In this research work effort was made towards establishing the inhibition potentials of varying concentrations of *Zingiber officinale* leaf extracts on engineering mild steel exposed to acidic and hydrolyzed corrosion environments.

MATERIALS AND METHODS

Well known dimensions of mild steel coupons were suspended through thread to the different concentrations of the corroding media in the beakers and their weights recorded before and after they were immersed into the media. After 1week intervals the final weights were recorded. The weight loss of the coupons was calculated. These data were gathered and CPR analyses were used to make necessary conclusions about the general behavior of the mild steel as earlier targeted.

Materials

The materials which were used for these experiment includes; known composition of plain rod of mild steel which were cut into coupons of desired size dimensions placed at 15mm height by 10mm diameter, the different acidic standard solutions media, (H_2SO_4) of Molarities 1.0 M and 0.5 M H_2SO_4, measuring cylinders, electronic weighing balance (Kerobn 5002), containing vessels (beakers), Distilled water, biceps, polymeric thread, retort stand, chewing stick, measuring cylinders, calibrated syringes, Venire caliper, varied volumes of the measured extract.

Processing of Materials

The ginger roots were excavated washed peeled and cut into pieces. About 97g dried mass of the pieces of ginger was soaked for three days and macerated in 650cm^3 of distilled water, after hard hand pressing with a finely pore sieve the filtrate from the sieve were then collected ginger extract corked into a plastic container for use in the laboratory for the experiment.

Method of Determining the Corrosion Penetration Rates

The relation devised for the determination of corrosion rate in millimeters per year (mm/py) is given as:

$$Cpr = \frac{K\Delta W}{\rho At} \quad \text{……………. (Eqn. 1)}$$

Where,

CPR= corrosion penetration rate in millimeters per year (mm/py),

ρ = density of the mild steel coupons in g/cm^3, is approximately 7.85g/cm^3

A = total exposed area of the specimen, herein becomes the area of a solid cylinder given by

$S_{a=} 2\pi rh + 2\pi r^2 \ where \ h = 15mm$

$r = (\frac{10}{2})$mm, Substituting the values and solving adequately,

the area A becomes, $S_{a=} (2 \times 3.142 \times 5 \times 15) + (2 \times 3.142 \times 25)$

$S_{a=} 471.3 + 157.1$, $S_{a=} 628.4mm^2$, $S_{a=} \frac{628.4}{1000} m^2$

$S_{a=} 0.628m^2$ = 62.8cm^2, t = time of exposure in hours, K is given as 87.8 which is the corrosion rate constant.

Also, the inhibition efficiency of the extract was calculated using the formula:

$$IE\% = \left[\frac{CR_a - CR_p}{CR_a}\right] x100 \quad \text{……………. (Eqn. 2)}$$

Closely associated with inhibition efficiency is the Langmuir adsorption isotherm adapted for this study. A simplistic assumption was made to the effect that the surface coverage of the adsorbed layer (Ɵ) is related to inhibition efficiency as follows:

$$\theta = \left[\frac{CR_a - CR_p}{CR_a}\right] \quad \text{…………….. (Eqn. 3)}$$

Where, CR_p = Corrosion rate in the presence of inhibitor, CR_a = Corrosion rate in the absence of the inhibitor and θ = coverage of the adsorbate on the metal surface.

RESULTS AND DISCUSSION

Results

Figures 1–12 represent the results obtained. Figure 1–4 are the corrosion penetration rates in the molar concentrations of H_2SO_4 and NaOH, Figures 5–8 are the inhibition efficiencies of the various concentrations of *Zingiber officinale* in H_2SO_4 and NaOH, while Figures 9–12 are the Langmuir adsorption isotherms for the various concentrations of *Zingiber officinale* in H_2SO_4 and NaOH.

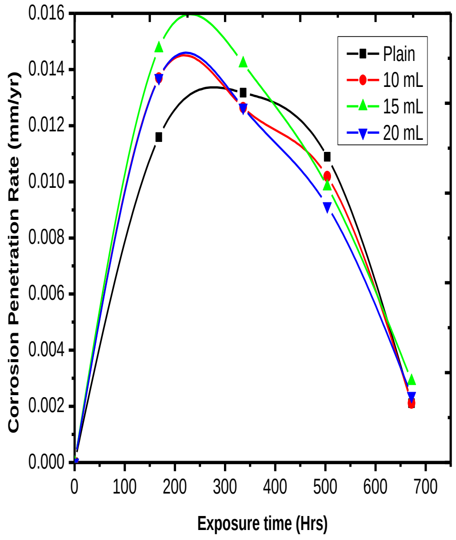

Fig 1: Corrosion penetration rate against Exposure time for 0.5 M H_2SO_4 with varying concentrations of *Zingiber officinale*

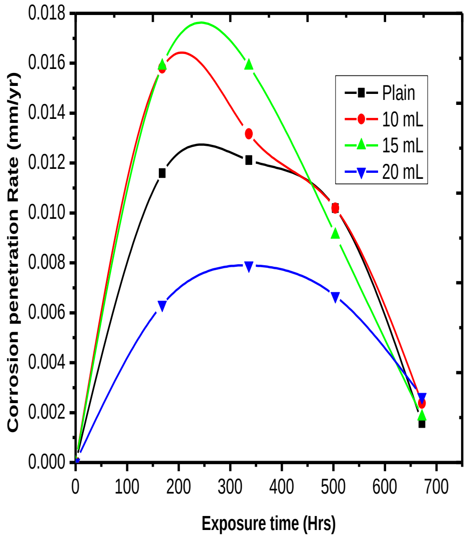

Fig 3: Corrosion penetration rate against Exposure time for 0.5 M NaOH with varying concentrations of *Zingiber officinale*

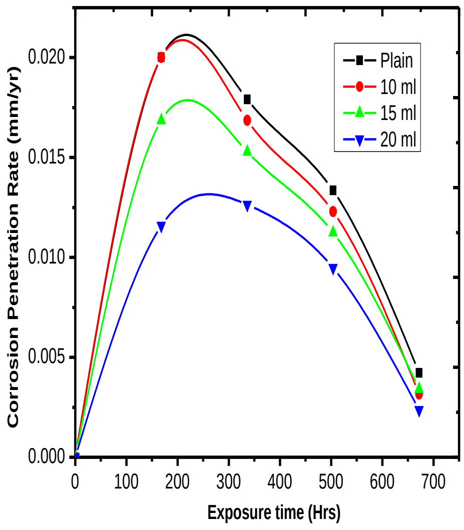

Fig 2: Corrosion penetration rate against exposure time for 1.0M H_2SO_4 with varying concentrations of *Zingiber officinale*

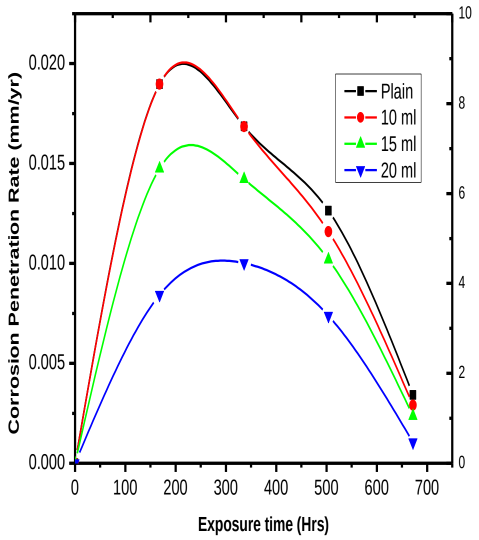

Fig 4: Corrosion penetration rate against Exposure time for 1.0M NaOH with varying concentrations of *Zingiber officinale*

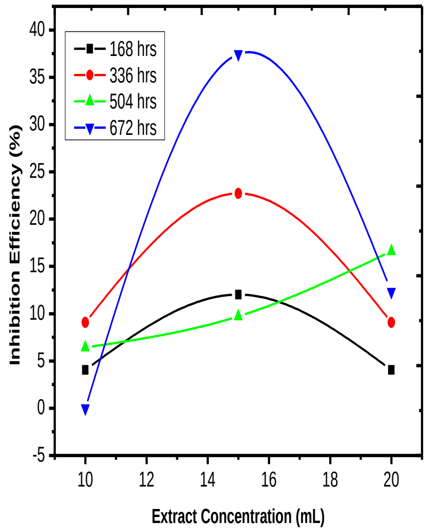

Fig 5: Inhibition efficiency against concentrations of *Zingiber officinale* in 0.5 M H_2SO_4

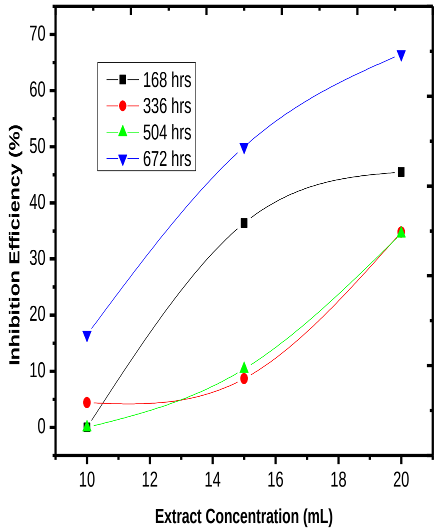

Fig 7: Inhibition efficiency against concentrations of *Zingiber officinale* in 0.5 M NaOH

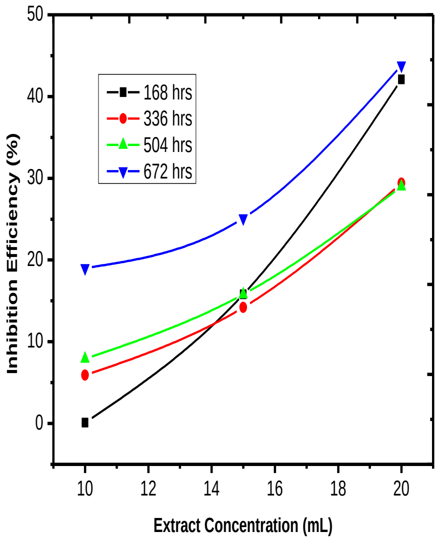

Fig 6: Inhibition efficiency against concentrations of *Zingiber officinale* in 1.0 M H_2SO_4

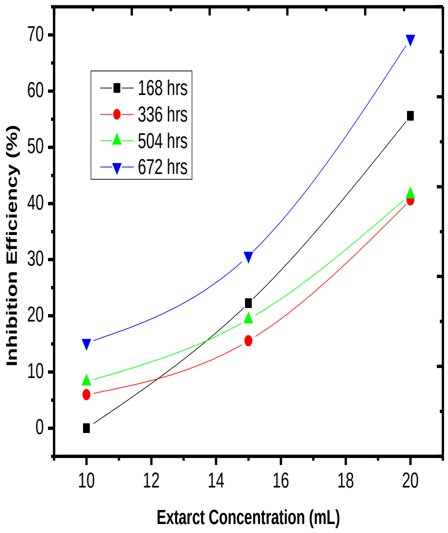

Fig 8: Inhibition efficiency against concentrations of *Zingiber officinale* in 1.0 M NaOH

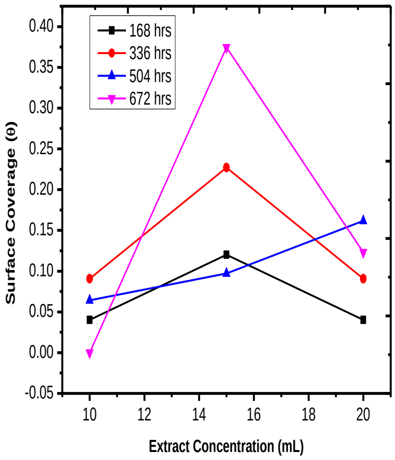

Fig 9: Langmuir adsorption isotherm for *Zingiber officinale* in 0.5 M H_2SO_4

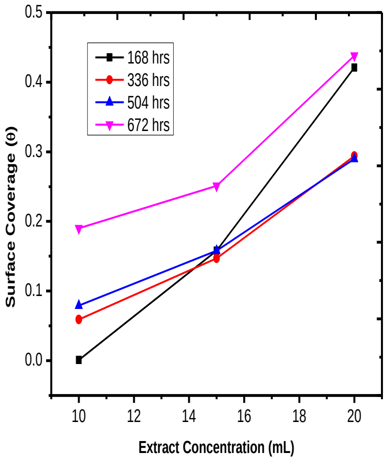

Fig 10: Langmuir adsorption isotherm for *Zingiber officinale* in 1.0 M H_2SO_4

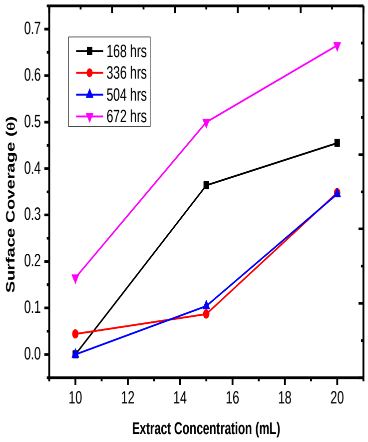

Fig 11: Langmuir adsorption isotherm for *Zingiber officinale* in 0.5 M NaOH

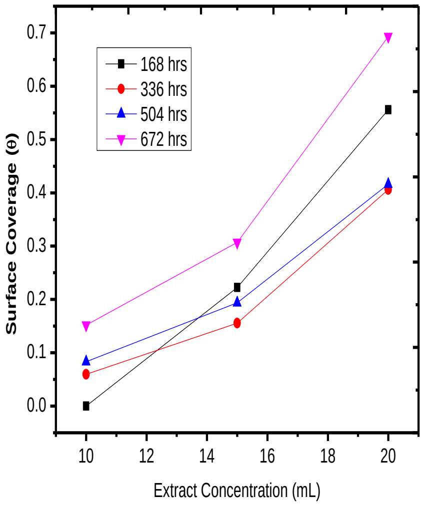

Fig 12: Langmuir adsorption isotherm for *Zingiber officinale* in 1.0 M NaOH

DISCUSSION

Corrosion Penetration Rate

From Figures 1–4, it can be clearly explained that the corrosion rate profile for passivating metals were obtained. Typically, there was an initial steep increase in corrosion rate, reaching a maximum, and then a progressive decline in rate as exposure time increased. This behaviour is supported by previous works (Al-Otaibi *et al*., 2012; Ibrahim *et al*., 2016; Helen *et al*., 2014). The effect of the extract concentration on the corrosion rate behavior is also indicative of the fact that increasing the concentration of the extract in the corrosion media resulted in reduction in the corrosion rate (Okafor *et al*., 2010; Omotosho, 2016). It is also evident from the plots that the corrosion rates in sodium hydroxide were less than those in tetraoxosulphate (VI) at each extract concentration. It should be easy to understand from the foregoing that corrosion species appear to be more present in acids than bases.

Inhibition Efficiency

A cursory look at Figures 5–8 will show that there was a linearly progressive increase in the inhibition potentialities of the extract as the concentration increased. Several works in the past has substantiated this phenomenon (Chukwukere *et al*., 2020; Nwigbo *et al*., 2012; Owate *et al*., 2014; Odiongenyi *et al*., 2008). Curiously however, this linearity was seen to be lost after the 15 mL beaker for 0.5 M H_2SO_4 throughout the duration of the experiment. This is depicted by the humps shown at the 15 mL concentration in Figure 5. It does appear that the 15 mL concentration is the optimum extract concentration in 0.5 M H_2SO_4 beyond which the inhibition efficiency begins to depreciate. Being an electrochemical process, a lot of interplay of factors including, but not limited to reaction kinetics, acid dilution, phytochemical constitution of the extract and thermodynamics may have accounted for this reduction in efficiency. All things being equal, we conclude that the most probable cause of this behaviour is essentially the depleting of the adsorbent species in the extract as a result of the formation of corrosion complexes that chose to remain in solution instead of adhering to the metal surface effectively.

Surface Area Coverage (Langmuir isotherm Concept)

Relating surface area coverage with inhibition efficiency, it is known that inhibition efficiency typically increases with higher surface area coverage. When a corrosion inhibitor covers a greater portion of the metal surface, it forms a more effective protective barrier against corrosion agents, reducing the likelihood of corrosion attack. This increased coverage often leads to better inhibition efficiency by limiting the exposure of the metal to the corrosive environment (Kumar *et al*., 2018; Eddy *et al*., 2011; Ehujiro *et al*., 2014).

Under a stable thermodynamic system, the belief of several authors is that there will be a uniform distribution of the adsorbent molecules on the metal surface (Loto *et al*., 2017; Uwa *et al*., 2010; Finsgar and Jackson, 2014; Okafor *et al*., 2010). The simplest way to understand this is by plotting the Langmuir adsorption isotherms as shown for this case in Figures 9–12.

A critical observation of the plots show that the surface areas of the metal surface covered by the adsorbent molecules from the extract increased as the concentration of the extract also increased, the only exception in this case being the 0.5 M H_2SO_4. As a result of the observed reduction in inhibition efficiency beyond the 15 mL concentration, the surface area coverage was also limited, implying that there were not enough adsorbent molecules of the extract to cover the metal surface effectively since most of the adsorbent species preferred to remain in solution, forming other complexes instead of migrating to the metal surface to adhere.

CONCLUSION

It is now clearly established that *Zingiber officinale* extracts are good inhibitors of corrosion whose inhibitive potency is dependent on the extract concentration, medium latency and exposure time. Comparatively, the inhibition characteristics of *Zingiber officinale* in NaOH was better than in H_2SO_4. This is quite explainable in the sense that acids contain more corrosion propagating species than bases. Following from these findings it is concluded that *Zingiber Officinale* can serve as a veritable green alternative to the hazardous and oftentimes expensive synthetic inhibitors widely used in our oil and gas industries to ameliorate the devastating impacts of corrosion.

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