Characterization of the Inhibitive Potentials of the Extract of Calyx of White Sorrel (Oxalis Acetosella) on Mild Steel in H₂SO₄ and NaOH Media

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Abstract: The study of calyx of Oxalis acetosella (White sorrel) plant in tetraoxosulphate (vi) acid and sodium hydroxide media was undertaken using the Weight Loss Technique of corrosion measurement. Square mild steel rods were obtained from a local store and cut into seventy two (72) cuboidal test coupons each of dimensions (10 mm x 5 mm x 5 mm). The coupons were then subjected to standard metallurgical procedures for corrosion experimentation. Extraction of the active ingredients in the calyx of the White sorrel was done using the Reflux Technique. The required concentrations of the inhibitor (5 ml, 10 ml, 15 ml and 20 ml) were separately added to each of the beakers containing the corrosion media (0.5 M H₂SO₄, 1.0 M H₂SO₄, 0.5 M NaOH and 1.0 M NaOH). The test coupons were then tied with nylon strings and suspended inside each of the beakers at 4 coupons per beaker. The setup was allowed to stand on a laboratory table for 672 hours with one sample removed from each beaker every 168 hours and subjected to standard post-immersion procedures for corrosion characterization. Subsequently, the corrosion rates and inhibition efficiencies were calculated using known formulae. Plots of corrosion rates, inhibition efficiencies and Langmuir adsorption isotherms were made and analyzed. The results obtained showed that the corrosion rates followed the normal trends for passivating metals, which is characterized by an initial steep rise followed by a progressive decrease as exposure time increased. Comparatively, the corrosion rate was observed to decrease as the inhibitor concentration increased in both H₂SO₄ and NaOH, but the inhibitive effects were more pronounced in the acid medium than the base. The effectiveness of the adsorption layer in preventing further corrosion is amply supported by Langmuir relationship that tries to examine layer thickness and uniformity on the nature and concentration of the corrosion media. A conclusion is drawn to the effect that the calyx of Oxalis acetosella can serve as an alternative green inhibitor to the synthetic ones in use today.

1. Introduction

Corrosion has been severally defined in contemporary times as the unintentional degradation of materials, particularly metals due to interaction with their environments (Callister, 2007; Fontana, 1987; Tebbji *et al.,* 2007; Ahmad, 2006). It is electrochemical in nature and starts preferentially from the surface (Askeland, 1985; Sastri *et al.,* 2007; Hammouti *et al.,* 1995). There are several types of

corrosion processes encountered in practice which includes but not limited to general corrosion, pitting corrosion, crevice corrosion, microbial corrosion and stress-corrosion-cracking (Schweitzer, 2010).

The scourge of corrosion in the industry is globally recognized as one of the most serious problems in modern societies and has much serious economic, health, safety, technological, and cultural consequences (Mejeh *et al.,* 2020). For instance, it is estimated that the annual cost of corrosion in the developed countries of the world like the United States is $276 billion, which is about 3.1% of the GDP (Gerhardus *et al.,* 2002), in China, $310 billion (Hou *et al.,* 2017) and in India, $26.1 billion (Bhaskaran *et al.,* 2016) to mention but a few.

Therefore, over the years, efforts have been intensified in finding efficient and cost effective ways to mitigate this humongous corrosion cost. In this connection, the use of corrosion inhibitors is considered a major pathway to the solution used in the oil and gas production and processing industries as a defense against corrosion (Waidi *et al.,* 2020; Ouadi *et al.,* 2002). But the environmental impact, toxicity and relatively high cost of synthetic inhibitors has remained a major challenge such that in recent times, the applications of the new green inhibitors of predominantly plant origin have continued to gain interest in the technological world (Omotosho, 2016; Zarrok *et al.,* 2012). In the field of material science and corrosion control, scientists are persistent in seeking better and more efficient ways of combating the corrosion of metals (Idenyi *et al.*, 2015a; Idenyi *et al.,* 2015b; Idu *et al.,* 2015; Hmamou *et al.,* 2012; Abboud*et al.,* 2009).

Oxalis acetosella, belonging to the *oxalidaceae* family of *eudicots* class in the *angiosperm*s phylum of the *plantae* kingdom is a low-growing herbaceous plant with a creeping, rhizomatous growth habit. The leaves are trifoliate, meaning they are divided into three leaflets, resembling the shape of a clover leaf. Each leaflet is typically heart-shaped and measures about 1 to 2.5 cm in width. The leaf color is typically green, but it can turn reddish or purple in certain conditions. The stems are slender, often reddish or purplish in color, and they arise from the rhizomes. The plant spreads via these creeping stems. The flowers of *Oxalis acetosella* are typically white to pale pink with five petals. They are solitary and arise on slender stalks. The flowers may have faint pink or purple veins running through them. After flowering, the plant produces small, capsule-like fruits that contain tiny seeds. *Oxalis acetosella* is commonly found in temperate forests, woodlands, and shaded areas. It prefers moist, well-drained soil and is often seen in cool, damp environments. It has a circumboreal distribution, meaning it can be found in various parts of the Northern Hemisphere, including Europe, North America, and Asia. *Oxalis acetosella* has a sour taste due to the presence of oxalic acid, which gives it a tart flavor. In some regions, its leaves are edible and have been used as a source of vitamin C. However, it should be consumed in moderation because oxalic acid can be harmful in large quantities. This plant serves as a food source for various herbivores and insects in its natural habitat. The presence of *Oxalis acetosella* can indicate the health of woodland ecosystems, as it is often found in undisturbed, well-preserved forest environments (Nesom, 2009; Beaulieu, 2021; Serviss *et al.,* 2021).

Oxalis acetosella is known to contain phytochemicals such as ascorbic acid, tocopherols, carotenoids, chlorophyll, flavonoids, phenolic acids and total phenolics (Sircelj *et al.,* 2010; Packham, 1978; Miralrio and Vazquez, 2020). Rodenkirchen (1998) reported in Sircelj *et a*l (2010) that the oxalate content for *Oxalis acetosella* is 110 – 140 mg/g dry weight. Siener *et al* (2006) also reported in Sircelj *et al* (2010) that this oxalate value compared favourably with those found in rhubarb and spinach, the two best known high oxalate-containing garden-grown plants. The medical benefits of *Oxalis acetosella* has been extensively investigated. For instance, Dashwood (1997), Dillard and German (2000), Podsedek (2007), and Meyer *et al* (1998) all stated in Sircelj *et al* (2010) that phenolics as well as carotenoids, tocopherols, chlorophyll and ascorbic acid play key role in prevention of various

diseases associated with oxidative stress, such as cardiovascular diseases, cancer, artherosclerosis, inflammation, neurodegenerative diseases, diabetes and other chronic diseases. Selvi *et al* (2021) investigated the inhibition efficiency of *Oxalis acetosella* in HCL, however, little or no literature exists on the potentialities of *Oxalis acetosella* as a green corrosion inhibitor, particularly in tetraoxosulphate (vi) acid and sodium hydroxide media. Therefore, this work essentially focuses attention on the analysis of the corrosion inhibition performance of calyx of *Oxalis acetosella* in tetraoxosulphate (vi) acid and sodium hydroxide media as a way to broaden the frontiers of knowledge in the area of the utilization of the abundant tropical plants for corrosion prevention and control.

2. Methodology

2.1 Materials

The materials used for this study includes: mild steel, plastic containers, white sorrel calyx, tetraoxosulphate (vi) acid (H_2SO_4), sodium hydroxide (NaOH), distilled water, acetone, emery cloth or sandpaper, cello tape, nylon thread and sieve.

The equipment and tools used include: electronic weighing balance (Tapson's Scientific Instruments Co. Model=TAPT 3000 G), beakers, measuring cylinder, hacksaw and blades, vernier caliper and measuring tape.

2.2 Material preparation of mild steel and leaf extracts

Fresh white sorrel's calyx was obtained from the farm behind Taraba State Polytechnic, Jalingo, Nigeria. The calyx of White sorrel were carefully sorted to remove any impurities, washed and dried separately under the shade to reduce their moisture content, after which they were grounded into fine powder. The fine powdered calyx were sieved with a sieve (150 μm mesh size). The sieved samples were stored in different containers and labeled until needed for corrosion studies.

Photo 1: The leaves, dried and powder of White sorrel calyx.

Extraction of the active ingredients in the calyx of the White sorrel was done using the Reflux Technique. Here, 30 g of the powdered calyx of White sorrel was measured using an electronic balance into four round bottom flasks and each 30 g was soaked in 600 ml of boiling 1.0 M H_2SO_4, 0.5 M H_2SO_4, 1.0 M NaOH and 0.5 M NaOH for 1 hour 30 minute on a Bunsen burner. The content of each flask was filtered using a filter paper. The filtrates were used as stock solution. Square mild steel square rods were obtained from a local store. The mild steel rods were cut into seventy two test

specimens each of dimensions (10 mm x 5 mm x 5 mm). 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. The washed specimen were air dried (Ehujuo *et al.,* 2014; Eddy *et al.,* 2011) to remove any moisture that might be present on the test specimens. The required concentrations of the inhibitors (5 ml, 10 ml, 15 ml and 20 ml) were respectively added to each of the beakers containing the corrosion media (0.5 M H_2SO_4, 1.0 M H_2SO_4, 0.5 M NaOH and 1.0 M HaOH). The test coupons were then tied with nylon strings and suspended inside each of the containers at 4 coupons per container. The setup was allowed to stand on a table in the Faculty of Engineering Laboratory of Taraba State University, Jalingo, Nigeria for 672 hours with one sample removed from each container every 168 hours, washed in a distilled water, rinsed in ethanol, and air-dried before re-weighing.

2.3 Weight Loss Measurement

The weight loss measurement was calculated as the difference in weight before and after immersion for the periods of 168 hours, 336 hours, 504 hours and 672 hours respectively and the result was used to calculate the corrosion rate according to the following equation:

$$CR = \frac{87.6W}{\rho A t} \qquad \text{Eqn.1}$$

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

The inhibition efficiencies (IE %) of the *Oxalis triangularis* in each of the corrosion media was calculated using the equation:

$$IE\% = \left(\frac{CR_a - CR_p}{CR_a}\right) \times 100 \qquad \text{Eqn.2}$$

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 (Θ) is related to inhibition efficiency as follows:

$$\theta = \left[\frac{CR_a - CR_p}{CR_a}\right] \qquad \text{Eqn.3.}$$

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.

3. Results and Discussion

Figures 1 – 4 represent the corrosion rate against exposure time for Oxalis acetosella in the corrosion media, Figures 5 – 8 show the inhibition efficiency versus concentration for the extracts in the various media and Figures 9 – 12 are the Langmuir plots for the extracts in the various corrosion media.
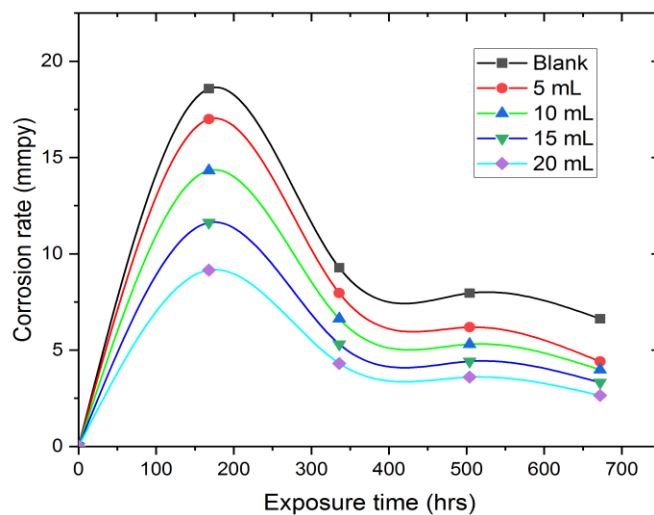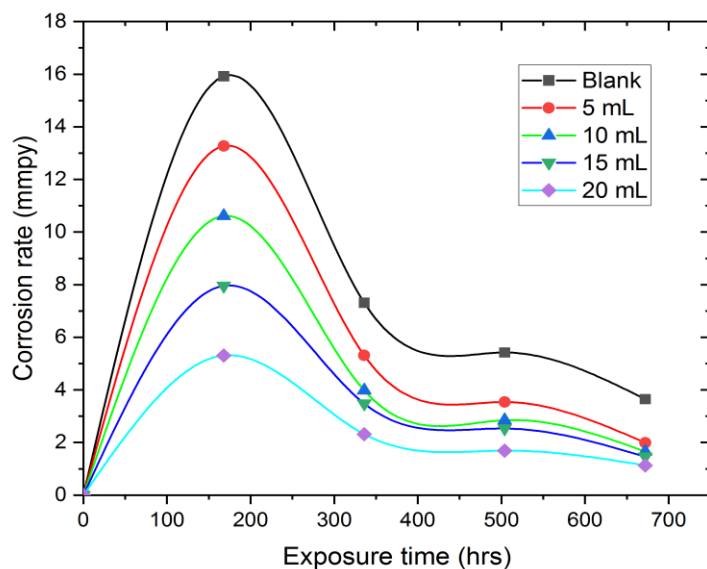
Figure 1. Variation of corrosion rate with exposure time for mild steel in 0.5 M H_2SO_4
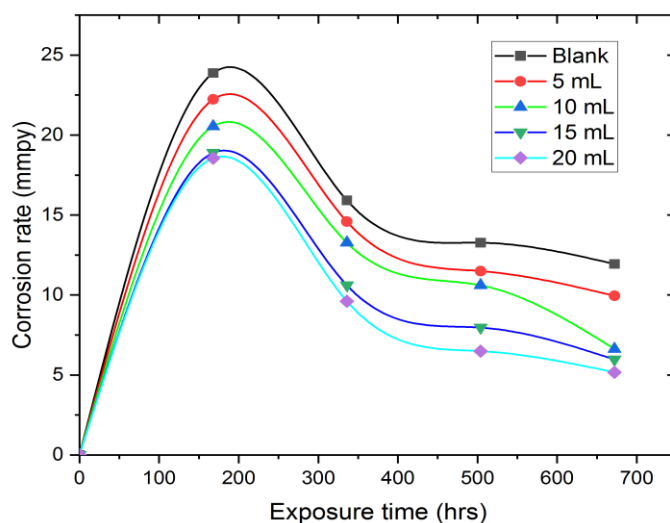
**Figure 2.** Variation of corrosion rate with exposure time for mild steel in 1.0 M H_2SO_4
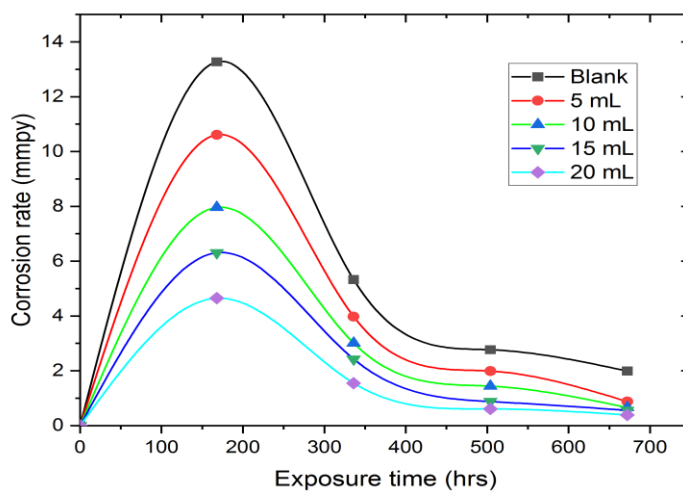
**Figure 3.** Variation of corrosion rate with exposure time for mild steel in 0.5 M NaOH

Figure 4. Variation of corrosion rate with exposure time for mild steel in 1.0 M NaOH

Corrosion Rate Analysis

A critical look at Figures 1 – 4 clearly shows that the corrosion rate profiles depict the behavior that is common with passivating metals like steel. There was an initial steep rise in corrosion rate up until the 168 hours period, which was followed by a progressive decrease as the exposure time increased to the 673 hours period. The inference drawn from this is that there was a formation of a film of corrosion product that covered the metal surface over time, thereby preventing a direct contact between the metal and the corrosion media. According to some studies, film formation is an indication of the functional groups possessed by green inhibitor, which is the basic characteristics of corrosion inhibitors (Nwigbo et al., 2012; Owate et al., 2014; Okewale and Olaitan, 2017), and the presence of these functional groups slow the corrosion rate, thereby protecting the mild steel from corrosion attack. This trend was somewhat however distorted in all the media where at the 336 hours period there were spikes in the corrosion rate depicted by the sudden rise in the plot again peaking at the 504 hours period before declining again to the 672 hour period. These anomalies are attributed to several factors including the decline in the potency of the extract due to deterioration, caving off of the adsorbed layer due to weakening of the adsorbent force (Dillard and German, 2000; Gopiramin et al., 2012; David, 2021; Kalaiselvi et al., 2010; Devesh et al., 2018; Nahle et al., 2010) and possible agitation of the system setup by interlopers in the surrounding environment where the experiment was mounted (Idenyi et al., 2015a,b; Okafor et al., 2010; Mejeh et al., 2020; Kamal and Sethuraman, 2012), which in this case is the general purpose laboratory in Taraba State University, Jalingo, Nigeria. In general, however, it is established that extracts of the calyx of *Oxalis acetosella* inhibited corrosion in both H_2SO_4 and NaOH respectively. The natural extract can be used in pickling acids as well as alkaline media. The inhibition process is due by the various molecules forming the extracts at various contents, leading to a barrier against the arrival of aggressive ions as H^+ and OH^- responsible on the degradation of metallic materials (Nick et al., 2011; Lazrak et al., 2021; Fadhil et al., 2020; Barouni et al., 2014; Elmsellem et al., 2014; Saidi et al., 2016).
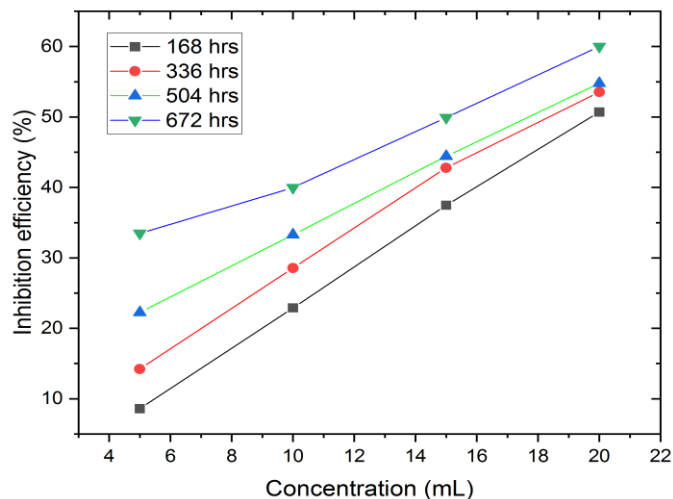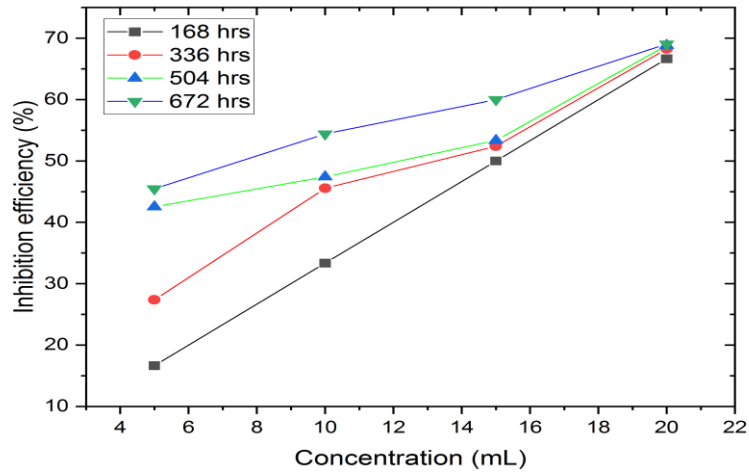
**Figure 5.** Variation of Inhibition efficiency with concentration for mild steel in 0.5 M H_2SO_4.
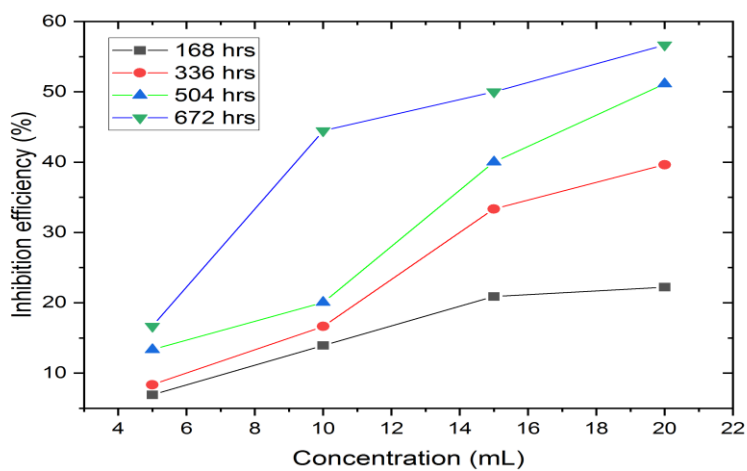
Figure 6. Variation of Inhibition efficiency with concentration for mild steel in 1.0 M H_2SO_4
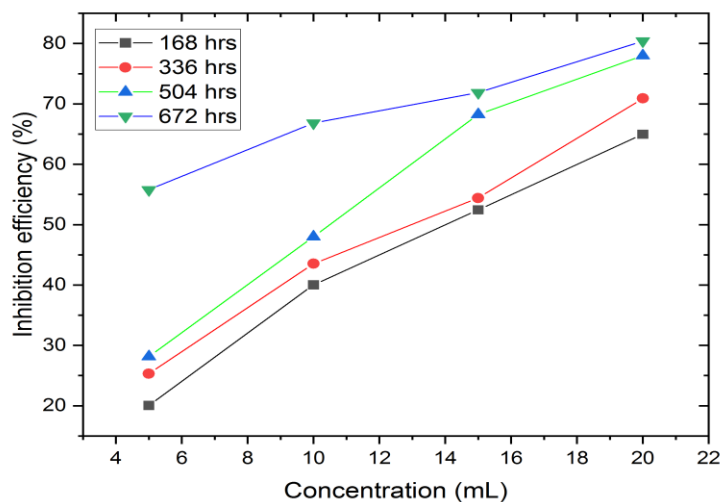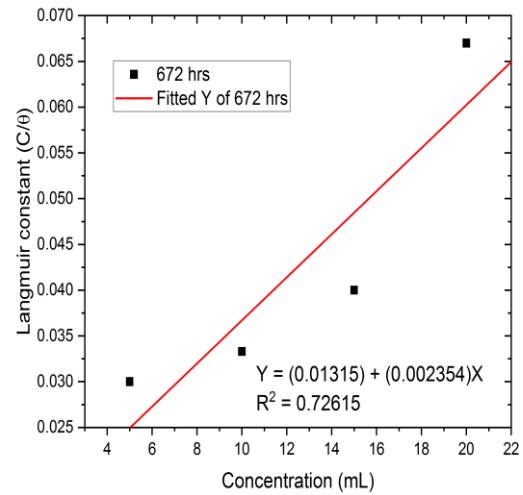

Figure 7. Variation of Inhibition efficiency with concentration for mild steel 0.5 M NaOH.

Figure 8. Variation of Inhibition efficiency with concentration for mild steel 1.0 M NaOH.
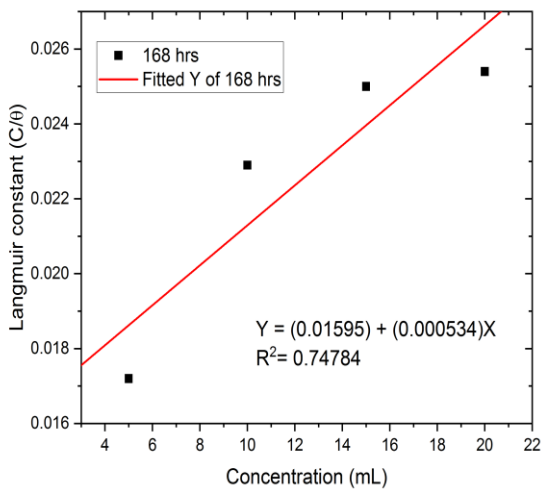
Figure 9a. Langmuir adsorption isotherms for white sorrel calyx at 168 hours in 0.5 M H_2SO_4.

Figure 9b. Langmuir adsorption isotherms for white sorrel calyx at 672 hours in 0.5 M H_2SO_4
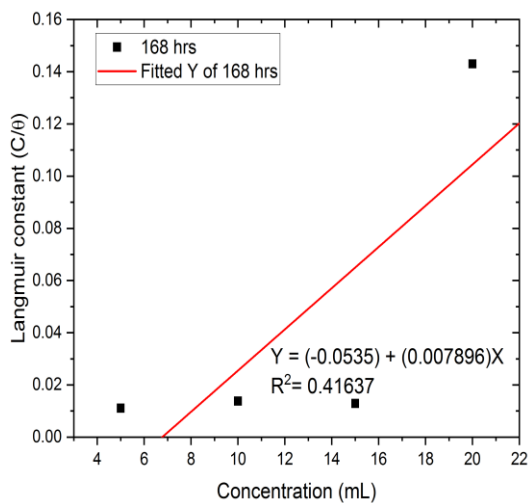
Figure 10a. Langmuir adsorption isotherms for white sorrel calyx at 168 hours in 1.0 M H_2SO_4

Figure 10b. Langmuir adsorption isotherms for white sorrel calyx at 672 hours in 1'0 M H_2SO_4

Figure 11. Langmuir adsorption isotherms for white sorrel calyx at 168 hours in 0.5 M NaOH

Figure 11b. Langmuir adsorption isotherms for white calyx at 672 hours in 0.5M NaOH

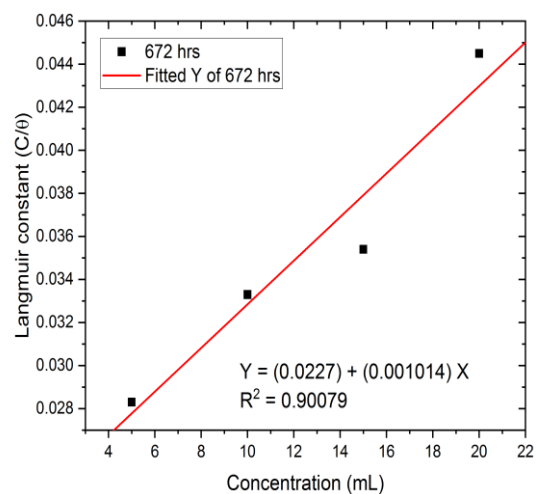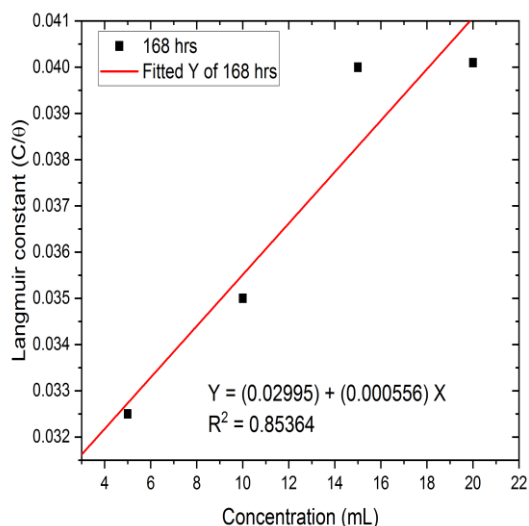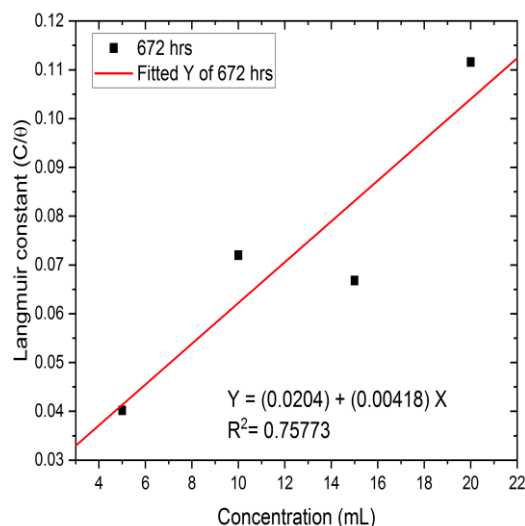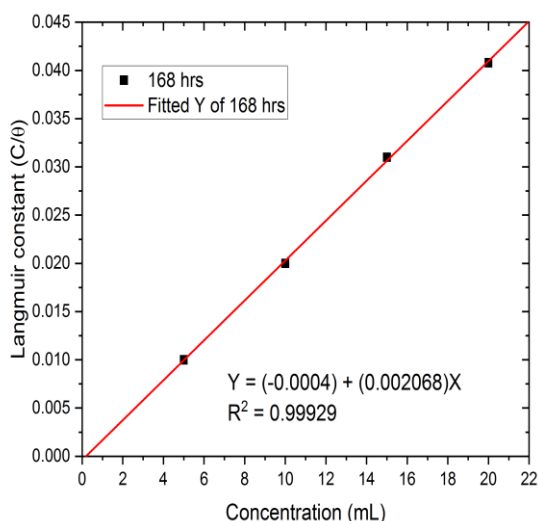**Figure 12a**. Langmuir adsorption isotherms for white sorrel calyx at 168 hours in 1.0 M NaOH
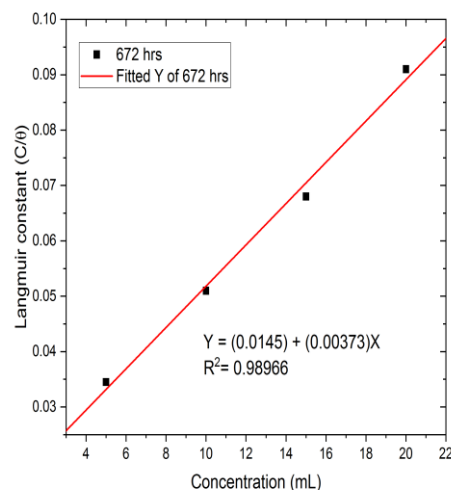
Figure 12b. Langmuir adsorption isotherms for white calyx at 672 hours in 1.0M NaOH

Inhibition Efficiency

Corrosion inhibition efficiency is a measure of how well a corrosion inhibitor substance protects a metal or material from corroding in a given corrosion environment. It is generally a somewhat complex phenomenon in the sense that several factors (and not only exposure time) influence it. Initially, when the inhibitor is applied, and as exposure time increases, it can provide a strong protection against corrosion attack by helping to adsorb on the metal surface thereby creating an enabling corrosion protection film (Loto *et al.,* 2013; Fouda *et al.,* 2017). However, this adsorbed film layer may begin to cave as exposure time increases due to the desorption of the thin film from the metal surface as a result of thermodynamic kinetics and other associated variables like chemical degradation of the inhibitor material, unintended system agitation and such like factors (Odiongenyi *et al.,* 2009; Sanni *et al.,* 2019).

In the present study, the inhibition efficiency of the mild steel immersed in 0.5 M and 1.0 M (H_2SO_4) was observed to increase with increase in concentration of the *Oxalis acetosella* extract due to the increase in the number of adsorbed molecules on the mild steel surface, thereby blocking the active sites from acid attack. These observations have equally been reported in previous studies (Loto *et al.,* 2013; Fouda *et al.,* 2017). However, increase in exposure time decreases the inhibition efficiency slightly, irrespective of inhibitor concentration. The decline in inhibition efficiency with time could be attributed to desorption of the white sorrel extract from the mild steel surface as has been observed by Odiongenyi *et al* (2009) and Sanni *et al* (2019)

Langmuir Adsorption Isotherm

Langmuir plots are typically associated with adsorption phenomena, where they illustrate the relationship between the amount of substance adsorbed onto a surface and the concentration of that substance in the surrounding environment (Nwabanne & Okafor, 2012). In the context of corrosion, Langmuir plots can be used to study the relationship between the extent of corrosion and the concentration of a corrosive species (such as an electrolyte or a corrosive gas) in the environment surrounding the metal surface (Umoren *et al.,* 2006). A Langmuir plot used in the context of corrosion would involve plotting the reciprocal of the Langmuir constant (K^{-1}), C/θ on the y-axis and the concentration of the corrosive species, C on the x-axis. Plotting the reciprocal of the Langmuir (K^{-1}) against concentration can offer valuable insights into the adsorption process. A linear relationship, like in these cases shown indicates that the adsorption followed the Langmuir model, showcasing a consistent equilibrium between adsorbed molecules and available surface sites (Oguzie *et al.,* 2004; Eddy *et al.,* 2008; Bouyanzer *et al.,* 2016; Da-Rocha *et al.,* 2010; Eddy, 2010). Two other important considerations are the slope and the intercept of the plot. A positive slope of the line indicates that there is maximum adsorption at equilibrium for the given adsorbate-adsorbent system (Allaoui *et al.,* 2017; Aribo *et al.,* 2017; Eddy & Ebenso, 2010), which in this case is the mild steel surface and the medium containing the extract of *Oxalis acetosella*. An intercept generally offers insights into the factors affecting adsorption. If it occurs on the y-axis, it suggests that at zero concentration, the reciprocal of the Langmuir constant (K^{-1}) approaches infinity such that at very low concentrations, the adsorption process becomes highly favourable or approaches an infinite binding capacity between the adsorbent and the adsorbate; while on the x-axis, it suggests a high affinity of the adsorbent for the adsorbate, indicating strong binding or interaction between the two (Ekanem *et al.,* 2010; Ezemonye *et al.,* 2006; Fouda *et al.,* 2017; Kumpawat *et al.,* 2010; Odiongenyi *et al.,* 2009; Oguzie. 2008; Patela *et al.,* 2010). The examination of literature shows that the natural extract contains polyphenols, flavonoids, anthocyanins, and tannins (Peredo Pozos *et al.,* 2020; Sirag *et al.,* 2014). The presence of these kind of molecules contributes to the inhibition process via the synergistic intermolecular effect of the various molecules (Lrhoul *et al.,* 2023; El Mounsi *et al.,* 2015; El Ouariachi *et al.,* 2015).

Conclusion

Based on the foregoing discussion, we conclude that the extract of *oxalis acetosella* calyx can be a veritable green inhibitors in both acidic and basic environments and can be used as a substitute for the present day synthetic inhibitors used in our oil and gas industries but which are known to be hazardous to health and the environment, including the fact that they are generally expensive as well. It is suggested that further works should focus on the development of an efficient and cost-effective extraction process for harnessing the potentialities of this inhibitor for industrial use.

References

Abboud Y., Abourriche A., Tanane O., *et al.* (2009), Corrosion inhibition of carbon steel in acidic media by Bifurcaria bifurcata extract, *Chem. Eng. Comm.* 196 N°7, 788-800.

Ahmad, Z. (2006). *Principles of corrosion engineering and corrosion control.* Butterworth-Heinemann.

Akpanyung K. V., & Loto, R. T. (2019). Pitting corrosion evaluation: a review. *J. Phys.: Conf. Ser.* 1378 022088, 1-15.

Allaoui, M., Rahim, O., & Sekhri, L. (2017). Electrochemical study on corrosion inhibition of iron in acidic medium by Moringa Oleifera extract. *Oriental Journal of Chemistry, 33*, 637-646.

Aribo, S., Olusegun, S. J., Ibhadiyi, L. J., Oyetunji, A., & Folorunso, D. O. (2017). Green inhibitors for corrosion protection in acidizing oilfield environment. *Journal of the Association of Arab Universities for Basic and Applied Sciences, 24*, 34-38.

Barouni K., Kassale A., Albourine A., Jbara O., Hammouti B., Bazzi L. (2014), Aminoacids as corrosion inhibitors for copper in nitric acid medium: Experimental and theoretical study, *J. Mater. Environ. Sci.* 5 (2), 456-463

Bhaskaran, R., Bhalla, L., & Sarin, V. (2016). Cost of corrosion protection in Indian oil and petroleum products transmission pipelines: A case study. *IJABER, 14*(7), 5169-5180.

Bouyanzer, A., Hammouti, B., Majidi, L., Haloui, B., 2010. Testing natural fenugreek as an ecofriendly inhibitor for steel corrosion in 1M HCl. *Portug. Electrochim. Acta 28,* 165-172.

Da-Rocha, J. C., Gomes, J. A. P. & D'Elia, E. (2010). Corrosion inhibition of carbon steel in hydrochloric acid solution by fruit peel aqueous extracts. *Corrosion Science, 52,* 2341-2348.

Dashwood, R. H. (1997). The importance of using pure chemicals in (anti) mutagenicity studies: Chlorophyllin as a case in point. *Mutal Res., 381*(2), 283-286.

David, B. (2021). *How to grow and care for purple shamrock (false shamrock).* Dotdash Meredith.

Davis, G. D., Anthony von Fraunhofer, J., Krebs, L. A. & Dacres, C. M. (2001). The use of tobacco extracts as corrosion inhibitors. *Corrosion 2001* Paper 1558.

Devesh P. K., Akshay P., Sorathiya, L. & Himanshukumar R. P. (2018).Corrosion monitoring and detection techniques in petrochemical refineries, *Journal of Electrical and Electronics Engineering 10*(13), 85-93.

Dillard, C. J., & German, J. B. (2000). Phytochemicals: Nutraceuticals and human health. *J. of Sci. of Food and Agric., 80,* 1744-1756.

Eddy, N. O. (2010). Adsorption and inhibitive properties of ethanol extract of Garcinia kola and Cola nitida for the corrosion of mild steel in H_2SO_4. *Pigm. Resin Technol. 39,* 348-354.

Eddy, N. O. & Ebenso, E. E. (2010). Corrosion inhibition and adsorption properties of ethanol extract of Gongronema latifolium on mild steel in H_2SO_4. *Pigm. Resin Technol. 39,* 77-83.

Ekanem, U. F., Umoren, S.A., Udousoro, I. I. & Udoh, A. P. (2010). Inhibition of mild steel corrosion in HCl using pineapple leaves (Ananas comosus L.) extract. *J. Material Science. 45,* 5558-5566.

El Mounsi I., Elmsellem H., Aouniti A., *et al.* (2015), Hexane extract of Nigella sativa L as eco-friendly corrosion inhibitor for steel in 1 M HCl medium, *Der Pharma Chemica,* 7N°10, 350-356

Elmsellem H., Youssouf M. H., Aouniti A., *et al.* (2014), Adsorption and inhibition effect of curcumin on mild steel corrosion in hydrochloric acid, *Russian J. Appl. Chem.,* 87 (6), 744-753

Ezemonye, L. I. N., Ogeleka, D. F. & Okeimen F. E (2006). Toxicity of neatex (industrial detergent) and Norust Cr 486(corrosion inhibitor) to earthworms (Aporrectodea Ionga) in naturally spiked soil. *African Journal of Biotechnology, 5*(11), 1113-1117.

Fernandes, J. S., & Montenor, F. (2015). Corrosion. *Materials for Construction and Civil Engineering, 10*(2), 679-716.

Fadhil A.A., Khadom A.A., Ahmed S.K., Liu H., Fu C., Mahood H.B. (2020) Portulaca grandiflora as new green corrosion inhibitor for mild steel protection in hydrochloric acid: quantitative, electrochemical, surface and spectroscopic investigations, *Surfaces and Interfaces* 20, 100595

Fouda, A. S., El-Ewady, G., & Ali, A. H. (2017). Modazar as promising corrosion inhibitor of carbon steel in hydrochloric acid solution. *Green Chemistry Letters and Reviews, 10*(2), 88-100

Gopiramin, M., selvakumaran, N., Kesevan, D.and Karvarbenbu, R. (2012). Adsorption and corrosion inhibition behavior of N-(phenylcarbamothioyl) Benzamide on mild steel in acidic medium. *Progress in Organic Coatings, 73*(43), 104-111.

Hammouti B., Aouniti A., Taleb M., Brighli M., Kertit S. (1995). L-Methionine methyl ester hydrochlorid as corrosion inhibitor of iron in 1M HCl, *Corrosion,* 51 N°6, 411-416

Hmamou B.D., Salghi R., Zarrouk A., Messali M., Zarrok H., Errami M., Hammouti B., Bazzi Lh., Chakir A. (2012) Inhibition of steel corrosion in hydrochloric acid solution by chamomile extract, Der Pharma Chim.4 N°4, 1496-1505

Hou, B., Li, X., Ma, X., Du, C., Zhang, D., Zheng, M., Xu, W., Lu, D., & Ma, F. (2016). The cost of corrosion in China. *Npj Materials Degradation, 1*(4), 1-10.

Idenyi N. E., Nwofe P. A., Agbo P. E. & Idu H. K. (2015a) Effects of psidium guavaja (guava) and moringa oleifera leaves extract on the corrosion susceptibility of mild steel in an acidic medium, *Australian Journal of Basic and Applied Sciences, 9,* 245-250.

Idenyi N. E., Nwofe P. A. & Idu H. K. (2015b) Influence of moringa oleifera and psidium guavaja leaves extract on the corrosion susceptibility of mild steel in an alkaline medium, *Journal of Applied Science Research, 11,* 158-163.

Idu H. K., Idenyi N. E. & Nwofe P. A. (2015) Investigations on the inhibitory properties of moringa oleifera and psidium guajava leaves extract on the corrosion susceptibility of mild steel, *Middle-east Journal of Scientific Research, 23*, 2862-2867.

Kalaiselvi, P., Chellammal, S., Palanichamy, S. & Subramanian, G. (2010). Artemisia pallens as corrosion inhibitor for mild steel in HCl medium. *Material Chemistry Physics, 120*, 643-648.

Kamal, C. & Sethuraman, M. G. (2012). Spirulina platensis – a novel green inhibitor for acid corrosion of mild steel. *Arab. J. Chem. 5,* 155-161.

Kumar, R., Singh, R., Kumar, S. (2018). Erosion and hot corrosion phenomena in thermal power plant and their preventive methods: a study. *Asian Journal of Mechanical Engineering*, *7*(1), 38-45.

Kumpawat, N., Chaturvedi, A. & Upadhyay, R. K. (2010). A comparative study of corrosion inhibition efficiency of stem and leaves extract of ocimum sanctum (Holy basil) for mild steel in HCl solution. *Protect. Metals Physics Chemistry Surface. 46,* 267-270.

Lazrak, J., Arrousse, N., Ech-chihbi, E. et al. (2021) Valorization of Cinnamon Essential Oil as Eco-Friendly Corrosion Inhibitor for Mild Steel in 1.0 M Hydrochloric Acid Solution. *Surf. Engin. Appl.Electrochem.* 57, 360–373. https://doi.org/10.3103/S1068375521030108

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. 15th September, 2020.

Lrhoul H., Sekkal H. & Hammouti B. (2023) Natural Plants as Corrosion Inhibitors: Thermodynamic's restrictions, *Mor. J. Chem.,* 14(3), 689-698, https://doi.org/10.48317/IMIST.PRSM/morjchem-v11i3.40144

Mejeh, K. I., Isaac, O. E., Oparadike, F. E. & Luke A. A. (2020). Study of corrosion inhibitive behaviour of moringa oleifera leaf extract on mild steel. *Journal of New Views in Engineering and Technology (JNET)*, *2*(2), 21-28.

Meyer, A. S., Heinonen, M., & Frankel, E. N. (1998). Antioxidants interactions of catechin, cyaniding, caffeic acid, quercetin and ellagic acid on human LDL oxidation. *Food Chem., 61*(1-2), 71-75.

Miralrio, A., & Vazquez, A. E. (2020). Plant extracts as green corrosion inhibitors for different metal surfaces and corrosion media: A review. *Processes, 8,* 1-27. doi:10.3390/pr8080942.

Nahle, Y., Abu-Abdoun, I., Abdel-Rahman, I., Al-Khayat, M., (2010). UAE neem extract as a corrosion inhibitor for carbon steel in HCl solution. *International Journal Corrosion.* doi:10.1155/2010/460154.

Nesom, G. L. (2009). Taxonomic notes on aciculate oxalis (oxalidaceae) in the United States. *Phytologia, 9*(3), 1-7.

Nik W.B.W., Zulkifli F., Rosliza R., Rahman M.M. (2011) Lawsonia Inermis as green inhibitor for corrosion protection of aluminium alloy, *International Journal of Modern Engineering and Research Technology,* 1, 723-728

Nnanna, L. A., & Owate, I. O. (2014). An Interesting and Efficient Green Corrosion Inhibitorf for aluminum from extracts of moringa oleifera in acidic solution. *Scientia Africana, 13*, 52-63.

Nwigbo, S. C., Okafor, V. N., & Okewale, A. O. (2012). Comparative Study of elaeis guiniensis exudates (Palm wine) as a corrosion inhibitor for mild steel in acidic and basic solutions. *Research Journal of Applied Science Engineering and Technology, 4*(9), 1035-1039.

Odiongenyi, A. O., Odoemelam, S.A., & Eddy, N.O. (2009). Corrosion inhibition and adsorption properties of ethanol extract of vernonia amygdalina for the corrosion of mild steel in H_2SO_4, *Portugaliae Electrochimica Acta, 27*(1), 33-45.

Oguzie, E.E., (2008). Evaluation of the inhibitive effect of some plant extracts on the acid corrosion of mild steel. *Corrosion Science, 51,* 1868-1875.

Okafor, P.C., Ebenso, E.E., Ekpe, U.J. (2010). Azadirachta indica extracts as corrosion inhibitor for mild steel in acid medium. *International Journal of Electrochemical Science*. 5, 973–998.

Okafor, P.C., Ikpi, M.E., Uwah, I.E., *et al.* (2008). Inhibitory action of Phyllanthus amarus extract on the corrosion of mild steel in acid media. *Corrosion Science*, *50,* 2310–2317.

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.

Omotosho, O. A. (2016). Inhibition Evaluation of Chemical and Plant Extracts on the Corrosion of Metallic Alloys in Acidic Environment. *Ph.D. dissertation, Covenant University, Nigeria.*

Ouafi A., Hammouti B., Oudda H., Kertit S., Touzani R., Ramdani A. (2002), New pyrazole derivatives as effective Inhibitors for the corrosion of mild steel in HCl medium, *Anti-Corros. Meth. Mater.* 49 N°3, 199-204.

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.

Packham, J. P. (1978). Oxalis acetosella L. *J. of Ecology, 66*(2), 669-693.

Patela, N., Rawat, A., Jauhari, S., Mehta, G., 2010. Inhibitive action of Bridelia retusa leaves extract on corrosion of mild steel in acidic media. *Eur. J. Chem. 1,* 129-133.

Peredo Pozos, G.I.; Ruiz-López, M.A.; Zamora Nátera, *et al.* (2020) Antioxidant Capacity and Antigenotoxic Effect of Hibiscus sabdariffa L. Extracts Obtained with Ultrasound-Assisted Extraction Process. *Appl. Sci.*, 10, 560. https://doi.org/10.3390/app10020560

Podosedek, A. (2007). Natural antioxidants and antioxidant capacity of brassica vegetables: A review. *LWT – Food Sci. and Tech., 40*(1), 1-11.

Prawoto, Y., & Ibrahim K. M. (2009). Effect of ph and chloride concentration on the corrosion of duplex stainless steel. *Arabian Journal for Science and Engineering*, *34*(2), 19-32.

Raja P.B., Rahim, A.A., Osman, H., Awang, K., 2010. Inhibitory effect of Kopsia singapurensis extract on the corrosion behavior of mild steel in acid media. *Acta Phys. Chim. Sin. 26,* 2171-2176

Raja, P.B., Sethuraman, M.G., 2009. Strychnos nux-vomica an ecofriendly corrosion inhibitor for mild steel in 1M sulfuric acid medium. *Mater. Corros. 60*, 22-28.

Rodenkirchen H. (1998) Evidence for a nutritional disorder of oxalis acetosella L. on acid forest soils; I. control situations and effect of dolomitic liming and acid irrigation. *Plant and Soil, 199,* 141-152

Saidi N., Elmsellem H., Ramdani M., *et al.* (2016) A Moroccan Opuntia Ficus Indica methanolic flowers extract as an eco-friendly antioxidant and anti-corrosion for mild steel in 1 M HCl, *J. Mater. Environ. Sci* 7 (11), 4105-4115

Sanni, O., Popoola, A. P. I., & Fayomi, O. S. I. (2019). Electrochemical Analysis of Austenitic Stainless Steel (Type 904) Corrosion Using Egg Shell Powder in Sulphuric Acid Solution, *Energy Procedia, 157,* 619-625.

Saratha, R., Vasudha, V.G., 2010. Emblica officinalis (Indian Gooseberry) leaves extract as corrosion inhibitor for mild steel in 1 N HCl medium. *Eur. J. Chem. 7,* 677-684.

Sastri, V. S., Ghali, E., & Elboujdaini, M. (2007). *Corrosion Prevention and Protection: Practical solutions.* John Wiley & Sons.

Schweitzer, P. A. (2010). *Fundamentals of Corrosion: Mechanisms, causes and preventive methods.* CRC Press.

Selvi, P., Valarselvan, S., Syed-Abuthahir, S. S. (2021). Corrosion inhibition effect of an aqueous extract of oxalis acetosella plant leaves on mild steel immersed in 1M hydrochloric acid. *IJBPAS, 10*(11), 1478-1496.

Serviss, B. E., Hardage, J. W., & Peck, J. H. (2021). Oxalis triangularis (Oxalidaceae) naturalized in the Arkansas flora. *Phytoneuron, 2021*(54), 1-5.

Siener, R., Honow, R., Seidler, A., Voss, S., & Hesse, A. (2006). Oxalate contents of species of the polygonaceae, amaranthaceae and chenopodiaceae families. *Food Chem., 98*(2), 220-224.

Singh, A., Ahamad, I., Singh, V.K., Quraishi, M.A., 2010b. Inhibition effect of environmentally benign Karanj (Pongamia pinnata) seed extract on corrosion of mild Steel in hydrochloric acid solution. *J. Solid State Electrochem.* doi:10.1007/s10008 010-1172-z.

Singh, A., Singh, V.K., Quraishi, M.A., 2010a. Aqueous extract of Kalmegh (Andrographis paniculata) leaves as green inhibitor for mild steel in hydrochloric acid solution. *Int. J. Corros*. doi:10.1155/ 2010/275983.

Sirag, N.; Elhadi, M.M.; Algaili, M.A.; Hozeifa, M.H.; Mohamed, O. Determination of total phenolic content and antioxidant activity of Roselle (Hibiscus sabdariffa L.) Calyx ethanolic extract. *Stand. Res. J. Pharm. Pharmacol.* 2014, 2, 34–39.

Sircelj, H., Mikuli-Petkovsek, M., & Batic, F. (2010). Antioxidants in spring leaves of oxalis acetosella L. *Food Chem., 123*(2), 351-357.

Tan, Y. J. (2011). Experimental methods designed for measuring corrosion in highly resistive and inhomogeneous media. *Corrosion Science*. 53, 1145-1155.

Tebbji K., Bouabdellah I., Aouniti A., *et al.* (2007), N-benzyl-N,N-bis[(3,5-dimethyl-1H-pyrazol-1-yl)methyl]amine as corrosion inhibitor of steel in 1 M HCl, *Mater. Let.* 61N°3, 799-804.

Uwah, I.E., Okafor, P.C., Ebiekpe, V.E., (2013). Inhibitive action of ethanol extracts from Nauclea latifolia on the corrosion of mild steel in H_2SO_4 solutions and their adsorption characteristics. *Arab. J. Chem. 6,* 285-293.

Valek, L. and Martinezis. (2007). copper corrosion inhibition by Azadirachta indica calyx Extract in 0.5M sulphuric acid. *Material letters,* 61(1), 148-151

Waidi, Y. B., Nkoi, B. Amadi, R. K. C. and Luke, A. A. (2020). Determination of the Effect of Newbouldia Leavis Leaf Extract on the Corrosion of Mild Steel in Sulphuric Acid. *Journal of Newviews in Engineering and Technology (JNET)*, 2(1), 9-16.

Zarrok H., Zarrouk A., Salghi R., Oudda H., *et al.* (2012) Gravimetric and quantum chemical studies of 1-[4-acetyl-2-(4-chlorophenyl)quinoxalin-1(4H)-yl]acetone as corrosion inhibitor for carbon steel in hydrochloric acid solution,, *J. Chem. Pharmac. Res.,* 4 N°12, 5056-5066

Zhang, W., & Frankel S. (2007). Transitions between pitting and intergranular corrosion in AA2024. *Electrochimica Acta. 48*(9), 1193-1210. doi: 10.1016/S0013-4686(02)00828-9

Znini, M., Majidi, L., Bouyanzer, A., *et al.* (2012). Essential oil of Salvia aucheri mesatlantica as a green inhibitor for the corrosion of steel in 0.5M H_2SO_4. *Arab. J. Chem. 5,* 467-474.

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