(CALAMANSI) CITROFORTUNELLA MICROCARPA RIND EXTRACT AS PLANT DERIVED GREEN CORROSION INHIBITOR FOR MILD STEEL IN 1.0M HCl

Gian Carlo E. Arguelles, Mark Ceazar D. Torres, Brian James U. Wu, Jerry G. Olay*, Renato C. Ong

Department of Chemical Engineering, College of Engineering, Adamson University, 900 San Marcelino, Ermita, Manila 1000, Philippines

*jerry.oly@adamson.edu.ph

Abstract. The inhibitive action of extracts from Citrofortunella microcarpa (Calamansi) peels on mild steel in 1.0M HCl solution has been studied using the weight-loss method, electrochemical method, and SEM-EDX analysis. The measurements showed that calamansi peels have good inhibition properties. Weight loss results suggest that inhibitive efficiency increases as the concentration increases. It was also found that the adsorption stabilizes at 72 hours and degrades at longer immersion times. SEM studies of the immersed mild steel showed the decreasing extent of corrosion attack on mild steel at an increasing ratio of inhibitor, while EDX analysis shows the reduction of the formation of corrosion products, suggesting the formation of inhibitor film on the mild steel surface. The Calamansi peel extract inhibitor obeys the Langmuir adsorption isotherm model and the mode of adsorption was found to be physical and spontaneous. The results of the electrolysis technique have shown the favoring of inhibition in cathodic reactions.

Keywords: Corrosion inhibitor, Inhibitive efficiency, Weight loss method, SEM, Adsorption Isotherm.

Introduction

Corrosion is the material degradation by chemical reaction with their environment. This, in turn, can lead to damage to steel structures, causing economic damages, and threatening our safety and the environment (M'hiri et al., 2016). The use of corrosion inhibitors is a practical method to protect steel from corrosion, especially when exposed to acidic solutions during different processes in the industry (Patni, Agarwal, & Shah, 2013). Acids are also used in processing industries as inhibitors and for the elimination of deposited scales from metallic surfaces (Hassan, Khadom, & Kurshed, 2016). From the perspective of materials of construction and corrosion, Hydrochloric acid is one of the most challenging common acids to handle. It is very corrosive to many alloys and metals used in industry (Hmimou et al., 2012).

Numerous ways have been established for inhibiting corrosion. Utilization of inhibitors for the regulation of corrosion of alloys and metals in contact with aggressive surroundings is among one of the acceptable methods used to reduce and prevent corrosion. However, efficient inorganic inhibitors such as phosphates, chromates and nitrites; and organic inhibitors such as polyamines, long-chain carboxylates, imidazole, and derivative compounds; are not only costly to produce but are also toxic and non-biodegradable. Due to this environmental and economic concern, much interest is being poured into organic, eco-friendly corrosion inhibitor research. Sources such as food by-products, plant parts, and extracts are being considered, as they are easily available, inexpensive, and are less harmful to the environment. Inhibitors from plant sources contain compounds such as proteins, tannin, alkaloids, etc. which work as potential inhibitors for many metals in acidic medium (Agarwal, 2014; Hassan, Khadom, & Kurshed, 2016).
The present work aims to show corrosion inhibitive property of calamansi peel extract using weight loss, electrochemical studies, and SEM-EDX analysis in 1M HCl for mild steel. *Citrofortunella microcarpa* is among the most widely cultivated fruit crop in the Philippines. Citrus fruits such as calamansi, are utilized mainly for its pulp and juice, the rest of the fruit, including the rind, are considered waste products. If its potential use is as a corrosion inhibitor is explored, not only can it possibly replace toxic, synthetic and organic inhibitors, but it also helps in the reduction of environmental pollution.

**Materials and Methodology**

**Preparation of the Mild steel specimen**

(0.16% C; 0.14% Si; 0.33% Mn; 0.005% S; 0.017% P; 0.0013; balance Fe) specimens of dimension 3.00x2.54x0.25 cm were used for weight loss and electrochemical studies. Before all measurements, the specimens were polished using different grades of emery paper from 220 to 1200, washed with distilled water and degreased with acetone and later dried.

**Preparation of plant extract**

The *Citrofortunella microcarpa* fruit peels were gathered then washed with running water, and then shade dried. The dried fruit peels were powdered and 10g of the powder was soaked in 250mL of HCl then boiled for 4 hours. The prepared solution was left overnight then filtered using a Buchner funnel to remove impurities. The filtrate was then made to 250mL by adding 1M of HCl.

**Preparation of Electrolyte**

AR Grade HCl was mixed with distilled water until 1M HCl was acquired; 250mL 1M HCl solution was prepared. These solutions; 1M HCl, 5:100, 10:100 and 15:100 were ratios in the volume of the *Citrofortunella microcarpa* fruit peel solution to 1M HCl.

**Weight loss method**

Weighted steel specimens of dimension 3.00x2.54x0.25 cm were completely immersed in 100 mL of electrolyte (1M HCl) with and without different concentrations of FL and LP extracts at room temperature. To prepare different concentrations, different amounts of FL and LP extracts were added to 1M HCl accordingly in v/v ratio. Specimens were immersed for 2, 4, 8, 16, 32, 64, 96 and 120 hours. Specimens were then retrieved, washed with water, dipped into acetone, air-dried and reweighed. From the weight loss data, the corrosion rates (R) were calculated from Eq. (1):

\[
W = W_0 - W_f
\]

Where \(W\) the weight loss in grams, \(W_0\) is the weight before immersion, and \(W_f\) is the weight after immersion. The corrosion rate in Milis per year (mpy) is defined by:

\[
R(\text{mpy}) = \frac{KW}{DAT}
\]
Where R is the corrosion rate in Mils penetration per year (mpy) it is equal to a thousandth of an inch. It is used to gauge corrosion rates. K is a constant equal to 3.45x10⁶ for mpy, W is the weight loss in grams, D is the density for steel in gm/cm³, A is the surface area, and T is the immersion period in hours. The inhibition efficiency (η) was computed using:

$$\eta(\%) = \frac{R_0 - R_i}{R_0} \times 100\%$$

Where $R_0$ is the corrosion rate in the absence of the inhibitor and $R_i$ is the corrosion rate with the presence of the inhibitor from the fruit peel extract (Kumar & Yadav, 2018).

**Electrochemical measurements**

Electrochemical techniques were used. Utilizing an electrolytic cell-based set-up, similar to electroplating setup was used to measure weight loss due to electrochemical deposition. The power supply used is Sanwa AC DC Converter Charger Model SCC-3A with a maximum output of 12 Volts and 3 Amperes. Each set-up contained 50 ml of electrolyte (1M HCl). Mild steel with a surface area of 10.8 cm² was used as the electrode. The electrode was polished using emery paper, washed with acetone, rinsed with distilled water and then dried. Open circuit potential was established and then recorded in 5 to 15-minute intervals, each with increasing inhibitor concentration.

**Surface Analysis**

The surface morphology of mild steel specimens was examined by SEM-EDX analysis. For these studies, a mild steel specimen was immersed in the absence and presence of the inhibitor. Scanning electron microscope images obtained from the JEOL 5300 Scanning Electron Microscope, equipped with secondary and backscatter electron detectors, and an X-ray detector for energy dispersive spectroscopy measurements. Samples were analyzed under 500x and 1000x magnification. Surface micrographs were compared to determine the extent of corrosion damage (Kumar & Yadav, 2018). EDX analysis was used to determine the formation of corrosion products, and the extent of the mitigation of the formation of these products in the presence of the inhibitor.

**Results and Discussions**

**Weight loss experiment**

The variation of the corrosion rate (in mpy) of mild steel with an immersion time of 24 hrs in 1M HCl solutions in the absence and presence of varying ratios of the inhibitor are shown in Table 1. A decrease in the corrosion rate was observed from samples immersed at all varying concentrations of inhibitor, and pure extract solution.

**Table 1:** Inhibition efficiency for different concentration extracts for the corrosion of mild steel in 1M HCl obtained from weight loss measurement

| Concentration (solvent:extract) | % Volume/V olume | Initial Weight (g) | Weight Loss (mg) | Corrosion Rate (mpy) | Inhibition Efficiency (%) |
|-------------------------------|-----------------|-------------------|-----------------|---------------------|--------------------------|
| 1M HCl                        | 1M HCl          | 7.2977            | 0.0297          | 50.271              | -                        |
| 5:100                         | 4.76            | 7.9773            | 0.0091          | 15.398              | 69.37                    |
| 10:100                        | 9.09            | 7.6433            | 0.0067          | 11.342              | 77.43                    |
| 15:100                        | 13.04           | 7.5039            | 0.0049          | 8.263               | 83.56                    |
| Extract solution              | 100             | 7.6772            | 0.0029          | 4.861               | 90.33                    |
In Figure 1, variations of corrosion rate at different concentrations, and different immersion times are shown. Corrosion rates were observed to be lowest at 72 hours, indicating the stabilization of the adsorption. However, a notable corrosion rate increase can be observed for succeeding immersion times of 96, and 120 hours. This shows that peak adsorption of the inhibitor was achieved for an immersion time of 72 hours. The increase in corrosion rate during extended periods of immersion, show the deterioration of the adsorbed layer on the mild steel surface.

**Electrochemical measurements**

| Concentration in 50ml 1M HCl | 5 minutes | 10 minutes | 15 minutes |
|-----------------------------|-----------|------------|------------|
| 5g (positive)               | 0.0026g   | 0.0073g    | 0.108g     |
| 5g (negative)               | 0.3852g   | 0.6684g    | 1.1220g    |
| 10g (positive)              | 0.0018g   | 0.0030g    | 0.0059g    |
| 10g (negative)              | 0.3026g   | 0.6866g    | 0.9171g    |
| 15g (positive)              | 0.0050g   | 0.0142g    | 0.0176g    |
| 15g (negative)              | 0.2344g   | 0.4558g    | 0.6601g    |

**Table 2:** Weight loss of mild steel using electrolytic cell set up

Table 2 shows data obtained from the cathodic and anodic reaction of mild steel subjected to direct electric current by an external power supply. It can be that both electrodes lost weight at all three-time points. It was also observed that the anode lost significantly more weight than the cathode. The weight loss in the cathode is lowest in 10g concentration at a value of 0.0018, 0.0039, and 0.0059 for a run time of 5, 10, and 15 minutes respectively, which implies that the inhibition favors the cathodic reaction at 10g, although anodic reaction have significantly more weight loss, it was observed that the increase of inhibitor concentration resulted to a decrease in weight loss, implying the inhibitive effect of the solution favoring the cathodic reaction.
Adsorption Isotherm

At constant temperature, the testing of adsorption isotherm was obtained from the degree of surface coverage (Θ) and the concentration of the inhibitor in the acid solution. In this case, the adsorption of the inhibitor molecule replaces every single gaseous free (oxide-free) site on the surface of the metal. The inhibitor replaces the adhered water molecule forming a film.

\[
\text{Inhibitor} + x\text{H}_2\text{O} \quad \leftrightarrow \quad \text{Inhibitor}_{\text{adsorbed}} + x\text{H}_2\text{O}
\]

where \( x \) is the number of water molecules displaced by a single inhibitor molecule on a space. At the reaction's equilibrium, the rate of adsorption is equal to the rate of desorption, and at this point, adsorption isotherm plots can be gathered through the given surface coverage as a function of concentration. The equation for the Θ is defined as \( \Theta = \%\text{IE}/100 \). The surface coverage data were obtained using the inhibition efficiencies from the weight loss experiments. Then, a suitable adsorption isotherm (Figure 2-3) was obtained using the data.

The Freundlich adsorption isotherm was applied to investigate its mechanism by the following equation:

\[
\Theta = KC^{1/n}
\]

where \( \Theta \) is the amount of solute per weight of solid, \( C \) is the concentration of inhibitor, \( K \) is a specific constant, and \( 1/n \) is the adsorption strength. The linearized equation will be:

\[
\log\Theta = \log K + \frac{1}{n}\log C
\]

The data points for the Freundlich isotherm are obtained from the weight loss data and are presented in Table 3.

| \( \log C \) | \( 24 \text{ Hrs} \) | \( 48 \text{ Hrs} \) | \( 72 \text{ Hrs} \) | \( 96 \text{ Hrs} \) | \( 120 \text{ Hrs} \) |
|--------------|----------------|----------------|----------------|----------------|----------------|
| 0.69897      | -0.1588        | -0.1412        | -0.1358        | -0.1456        | -0.15021       |
| 1            | -0.1116        | -0.1164        | -0.1089        | -0.1243        | -0.13579       |
| 1.176091     | -0.0780        | -0.0757        | -0.0684        | -0.0747        | -0.08076       |
| 2            | -0.0442        | -0.0408        | -0.0382        | -0.0458        | -0.05198       |

**Table 3**: Data for plotting Freundlich Adsorption Isotherm

From the plot in Figure 2, a non-linear relationship among the parameter can be observed, meaning that the adsorption of the inhibitor does not obey the Freundlich Isotherm.
The Langmuir adsorption isotherm was also applied to investigate its mechanism by the following equation:

$$\frac{C}{\theta} = \frac{1}{K} + C ; \quad K = \frac{1}{C_{H_2O^*} \frac{\Delta G_{ads}}{RT}}$$

The adsorption parameters for the Langmuir adsorption isotherm are estimated and given in Table 4. Figure 3 shows that the adsorption process follows the Langmuir adsorption isotherm as the correlation coefficient ($R^2$) obtained 0.9997 is close to unity.

**Table 4:** Adsorption Parameters of inhibitor extracts in 1M HCl obtained from Langmuir adsorption isotherm

| Slope   | $K$(mL/L) | $R^2$     | $\Delta G_{ads}$ |
|---------|-----------|-----------|-----------------|
| 1.0856  | 0.1853    | 0.9997    | -5.767          |
From the intercept of the line on the vertical axis, the specific constant K is calculated. The value of the standard free energy of adsorption is determined using the equation:

$$\Delta G_{ads} = -2.303RT \log(55.5K)$$

The spontaneity of the adsorbed layer and the spontaneity of the adsorption process itself are attributed to the negative value of $\Delta G_{ads}$. The mode of adsorption was found to be physisorption since it is generally attributed to $\Delta G_{ads}$ near -20kJ/mol, which indicates electrostatic interactions between the charged metal surface and the inhibitor.

**SEM-EDX analysis**

![SEM-EDX images](image)

**Figure 4**: SEM images of (1) dry mild steel (2) mild steel immersed in 1M HCl (3) mild steel immersed in 5:100 (4) mild steel immersed in 10:100 (5) mild steel immersed in 15:100 (6) mild steel immersed in extract solution at x1000 magnification.

Figure 4 shows the SEM micrographs of mild steel specimens immersed in different concentrations of inhibitor solution under 1000x magnification. In comparison, it can be observed that samples immersed in the presence of the organic inhibitor have surfaces that are less corroded compared to the surface of dry mild steel. The extent of apparent surface damage is observed to decrease as inhibitor concentration increases. SEM study shows that the inhibitor acts as a good corrosion inhibitor by the adsorption on the mild steel surface.
Figure 5: EDX Spectrum for dry mild steel, mild steel immersed in 1M HCl, and mild steel immersed in inhibitor solution
The EDX analytical technique was used for the elemental analysis and the determination of the specimen composition. From Figure 5, an oxygen peak was observed to appear for the specimen immersed in pure 1M HCl, this indicates the formation of corrosion products. The specimen immersed in the inhibitor solution was observed to have a lower oxygen peak indicating the inhibition from the formation of iron oxides through strong adsorption of the inhibitor on the mild steel surface.

**Conclusion**

SEM studies showed the decreasing extent of corrosion attack on mild steel at an increasing ratio of inhibitor, suggesting the formation of inhibitor film on the mild steel surface. EDX spectra analyses show a significant decrease in the oxygen peak, in inhibited solution, indicating the inhibition of formation of corrosion products such as metal oxides.

Weight loss results suggest that inhibitive efficiency increases with the increment of inhibitor ratio. The maximum inhibition efficiency value of 91.57% attained at pure calamansi inhibitor. Immersion time studies show that the inhibition efficiency peaks and stabilizes at the 72-hour mark and notably decreases in inhibition efficiency afterward. Corrosion rates were also observed to increase past the 72-hour mark, indicating the weakening of the adsorptive film on the mild steel surface at extended periods of immersion.

The adsorption of *Citrofortunella microcarpa* inhibitor solution to mild steel at 1M HCl obeys the Langmuir Adsorption Isotherm, attributed to spontaneous physical adsorption onto the metal surface, this is concluded based that $\Delta G_{ad}$ of -20kJ/mol and less negative is associated to physical adsorption.

Electrochemical results show the favoring of inhibition of cathodic reactions, and that the increase in inhibitor ratio would result in a decrease in weight loss. All results suggest that *Citrofortunella microcarpa* rind extract solution acts as a good corrosion inhibitor for mild steel in 1M HCl.

**Recommendation**

Corrosion inhibitor concentration and time of immersion could still be increased for improved analysis. In this study, *Citrofortunella microcarpa* rind is used as an additive to HCl which is then used as a dissolution medium, it is recommended to explore the possibility of identifying, and isolating the inhibitive components in the rind to synthesize a primary coating, before subjecting the sample to immersion in acidic medium. The application of potentiodynamic polarization techniques is recommended, to determine the type of inhibitor, and for a more in-depth analysis of corrosion parameters. It is also recommended to employ other testing methods to support weight loss and surface analysis data, as well as adsorption isotherm modeling.
References

A. S, Kareem A. Ganiyu, A. (2015). The Corrosion Inhibition of Mild Steel in Sulphuric Acid Solution by Adsorption of African Perquetina Leaves Extract. International Journal of Innovative Research in Science, Engineering and Technology, 04(03), 1809–1821.

Abdel-Gaber, A. M., Abd-El-Nabey, B. A., Khamis, E., & Abd-El-Khalek, D. E. (2011). A natural extract as scale and corrosion inhibitor for steel surface in a brine solution. Desalination, 278(1–3), 337–342.

Agarwal, K. (2014). Fenugreek leaves and lemon peel as a green corrosion inhibitor for mild steel in 1M HCl medium. Journal of Materials Science & Surface Engineering, 1(2), 44–48.

Al-otaibi, M. S., Al-Mayouf, A. M., Khan, M., & Mousa, A. A. (2014). Corrosion inhibitory action of some plant extracts on the corrosion of mild steel in acidic media. Arabian Journal of Chemistry, 7(3), 340–346.

Ansari, K. R., Quraishi, M. A., Prashant, & Ebenso, E. E. (2013). Electrochemical and thermodynamic investigation of diclofenac sodium drug as a potential corrosion inhibitor for mild steel in hydrochloric acid. International Journal of Electrochemical Science, 8(12), 12860–12873.

Arockiasamy, P., Sheela, X. Q. R., Thenmozhi, G., Franco, M., Sahayaraj, J. W., & Santhi, R. J. (2014). Evaluation of Corrosion Inhibition of Mild Steel in 1M Hydrochloric Acid Solution by Mollugo cerviana. International Journal of Corrosion, 2014.

Ayawei, N., Ebelegi, A. N., & Wankasi, D. (2017). Modeling and Interpretation of Adsorption Isotherms. Journal of Chemistry, 2017.

Blustein, G., Romagnoli, R., Jaén, J. A., Di Sarli, A. R., & del Amo, B. (2006). Zinc basic benzoate as eco-friendly steel corrosion inhibitor pigment for anticorrosive epoxy-coatings. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 290(1–3), 7–18.

Buchweishaija, J. (2009). Phytochemicals As Green Corrosion Inhibitors in Various Corrosive Media: a Review. Tanaz. J. Sci, 35, 77–92.

Chemical, I., Method, S., & Hazards, R. (2005). ALERT, (February).

Cheong, M. W., Chong, Z. S., Liu, S. Q., Zhou, W., Curran, P., & Yu, B. (2012a). Characterization of calamansi (Citrus microcarpa). Part I: Volatiles, aromatic profiles and phenolic acids in the peel. Food Chemistry.

Cheong, M. W., Chong, Z. S., Liu, S. Q., Zhou, W., Curran, P., & Yu, B. (2012b). Characterization of calamansi (Citrus microcarpa). Part I: Volatiles, aromatic profiles and phenolic acids in the peel. Food Chemistry, 134(2), 686–695.

Cheong, M. W., Zhu, D., Sng, J., Liu, S. Q., Zhou, W., Curran, P., & Yu, B. (2012a). Characterization of calamansi (Citrus microcarpa). Part II: Volatiles, physicochemical properties and non-volatiles in the juice. Food Chemistry.

Cheong, M. W., Zhu, D., Sng, J., Liu, S. Q., Zhou, W., Curran, P., & Yu, B. (2012b). Characterization of calamansi (Citrus microcarpa). Part II: Volatiles, physicochemical properties and non-volatiles in the juice. Food Chemistry, 134(2), 696–703.

Conley, S. (2013). Corrosion Mechanisms Processes: Understanding the Basic Elements That Cause Rust is the First Step in Preventing Rust. The Tube and Pipe Journal. Retrieved from www.tubepipejournal.net.
da Rocha, J. C., da Cunha Ponciano Gomes, J. A., & D’Elia, E. (2010). Corrosion inhibition of carbon steel in hydrochloric acid solution by fruit peel aqueous extracts. Corrosion Science, 52(7), 2341–2348.

de Assunção Araújo Pereira, S. S., Pégas, M. M., Fernández, T. L., Magalhães, M., Schöntag, T. G., Lago, D. C., … D’Elia, E. (2012). Inhibitory Action of Ilex paraguariensis Extracts on the Corrosion of Carbon Steel in HCl Solution. Corrosion Science, 65, 360–366.

G., C., & F., A. (2014). Corrosion Inhibitors – Principles, Mechanisms, and Applications. Developments in Corrosion Protection.

Gunasekaran, G., & Chauhan, L. R. (2004). Eco-friendly inhibitor for corrosion inhibition of mild steel in phosphoric acid medium. Electrochimica Acta, 49(25), 4387–4395.

Hassan, K. H., Khadom, A. A., & Kurshed, N. H. (2016). Citrus aurantium leaves extracts as a sustainable corrosion inhibitor of mild steel in sulfuric acid. South African Journal of Chemical Engineering, 22, 1–5.

Hmimou, J., Rochdi, A., Touri, R., Ebn Touhami, M., Rifi, E., Hallaouti, a. El, … Chebab, D. (2012). Study of corrosion inhibition of mild steel in acidic medium by 2-propargyl- 5-p-chlorophenyltetrazole : Part I. Journal of Materials and Environmental Science, 3(3), 543–550.

Ituen, E., James, A., Akaranta, O., & Sun, S. (2016). Eco-friendly corrosion inhibitor from Pennisetum purpureum biomass and synergistic intensifiers for mild steel. Chinese Journal of Chemical Engineering.

Kairi, N. I., & Kassim, J. (2013). The effect of temperature on the corrosion inhibition of mild steel in 1 M HCL solution by Curcuma longa extract. International Journal of Electrochemical Science, 8(5), 7138–7155.

Kassim, M., Abdul Rahim, A., & Azman Ismail, M. (2001). Anti-Corrosive Performance of Wash Primer Based on Mangrove Tan= =N, -“I=–N. ISh Symposium of Malaysian Chemical Engineers SOMChE, 2001, 4–5.

Khan, G., Newaz, K. M. S., Basirun, W. J., Ali, H. B. M., Faraj, F. L., & Khan, G. M. (2015). Application of natural product extracts as green corrosion inhibitors for metals and alloys in acid pickling processes- A review. International Journal of Electrochemical Science, 10(8), 6120–6134.

Kumar, H., & Yadav, V. (2018). Aloe vera L. as a green corrosion inhibitor for mild steel in 5.0 M hydrochloric acid solution. Asian Journal of Chemistry, 30(3), 474–478.

Lecante, A., Robert, F., Blandinieres, P. A., & Roos, C. (2011). Anti-corrosive properties of S. tinctoria and G. ourengou alkaloid extract on low carbon steel. Current Applied Physics, 11(3), 714–724.

M’hiri, N., Veys-Renaux, D., Rocca, E., Ioannou, I., Boudhrioua, N. M., & Ghoul, M. (2016a). Corrosion inhibition of carbon steel in acidic medium by orange peel extract and its main antioxidant compounds. Corrosion Science, 102, 55–62.

M’hiri, N., Veys-Renaux, D., Rocca, E., Ioannou, I., Boudhrioua, N. M., & Ghoul, M. (2016b). Corrosion inhibition of carbon steel in acidic medium by orange peel extract and its main antioxidant compounds. Corrosion Science, 102, 55–62.

Maksoud, S. a A. El. (2008). The Effect of Organic Compounds on the Electrochemical Behaviour of Steel in Acidic Media. A review. Intl. Journal of Electrochemical Science, 3, 528–555.
Negm, N. A., Kandile, N. G., Badr, E. A., & Mohammed, M. A. (2012). Gravimetric and electrochemical evaluation of environmentally friendly nonionic corrosion inhibitors for carbon steel in 1M HCl. Corrosion Science, 65, 94–103.

Nimmo, B., & Hinds, G. (2003). Beginners Guide to Corrosion. NPL, February, (February), 1–10.

Noor, E. A., & Al-Moubaraki, A. H. (2008). Corrosion behavior of mild steel in hydrochloric acid solutions. International Journal of Electrochemical Science, 3(7), 806–818.

Okafor, P. C., Ebenso, E. E., Ibok, U. J., Ekpe, U. J., & Ikpi, M. I. (2003). Inhibition of 4-acetamidoaniline on corrosion of mild steel in HCl solution. Transactions of the SAEST, 38, 91.

Patni, N., Agarwal, S., & Shah, P. (2013). Greener Approach towards Corrosion Inhibition. Chinese Journal of Engineering, 2013, 1–10.

Peres, R. S., Cassel, E., & Azambuja, D. S. (2012). Black Wattle Tannin As Steel Corrosion Inhibitor. ISRN Corrosion, 2012, 1–9.

Pereyra, A. M., Herrera, L. K., Echeverria, F. E., Castaño, J. G., & Giudice, C. A. (2006).