NATURAL PRODUCTS OF GUM ARABIC AND FRANKINENCES AS GREEN INHIBITORS FOR MILD STEEL CORROSION IN ACIDIC MEDIUM

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ABSTRACT

In terms of environmental impacts and cost considerations, plants source were used as a vital alternative approach to organic inhibitors in combating the risk of corrosion. In this work, the properties of corrosion inhibition in gum arabic and frankinences and their components were experimentally examined on mild steel in HCl solution using weight loss methods. and potentiodynamic polarizationte technique. Characterization physical technique, namely electron microscopy scanning (SEM) was employed. Two natural product species of same family viz., gum arabic and frankinences, were investigated in terms of their corrosion inhibition efficiencies for mildd steel in 1 M HCl. Inhibition effect of different concentrations of gum arabic and frankinences viz., 2.5, 5, 7.5 and 10 g/L were tested using weight loss method and electrochemical potentiodynamic polarization measurements. Weight loss measurements were conducted for 4 h at 25, 60 and 85°C. The electrochemical potentiodynamic polarization measurements were carried out at 25°C. Overall, the results showed that both the inhibitors inhibited the corrosion of mild steel in acidic media via adsorption process on mild steel. The inhibition efficiencies increased with the increase in concentrations of the extracts and varied at different temperatures and immersion time. The obtained inhibition efficiencies of products were ranging from 46.84 to 81.76% for gum arabic and was between 53.15 and 84.51% in frankincense. The obtained inhibition efficiencies of products from polarization measurements were from 39.5 to 81% for gum arabic and 40.81 to 28.28% for frankincense respectively. Thus, these results showed that the higher the concentration (7.5 g/L and 10 g/L) of the inhibitor the higher the inhibition efficiency. The SEM image clearly showed a smooth and rough surface due to the presence of inhibition on the surface of the mild steel by the natural products. Therefore, potentiodynamic polarization studies were able to shows the inhibition in the presence of both gum arabic and frankincense.

ABSTRAK

Dalam hal dampak lingkungan dan pertimbangan biaya, sumber tanaman digunakan sebagai pendekatan alternatif yang vital untuk inhibitor organik dalam memerangi risiko korosi. Dalam karya ini, sifat-sifat penghambatan korosi pada permen karet arab dan frankinences dan komponennya diuji secara eksperimental pada baja ringan dalam larutan HCl menggunakan metode penurunan berat badan. dan teknik polarisasi potensiodinamik. Teknik fisik karakterisasi, yaitu pemindaian mikroskop elektron (SEM) digunakan. Dua spesies produk alami yaitu famili yang sama, yaitu getah arab dan frankinensi, diselidiki dalam hal efisiensi penghambatan korosi mereka untuk baja ringan dalam 1 M HCl. Efek penghambatan dari berbagai konsentrasi gum arab dan frankinences yaitu, 2,5, 5, 7,5 dan 10 g / L diuji menggunakan metode penurunan berat badan dan pengukuran polarisasi potensiodinamik elektrokimia. Pengukuran penurunan berat badan dilakukan selama 4 jam pada 25, 60 dan 85 ° C. Pengukuran polarisasi potensiodinamik elektrokimia dilakukan pada suhu 25 ° C. Secara keseluruhan, hasil menunjukkan bahwa kedua inhibitor menghambat korosi baja ringan dalam media asam melalui proses adsorpsi pada baja ringan. Efisiensi penghambatan meningkat dengan meningkatnya konsentrasi ekstrak dan bervariasi pada suhu dan waktu pencelupan yang berbeda. Efisiensi penghambatan yang diperoleh dari produk berkisar antara 46,84 hingga 81,76% untuk getah arab dan antara 53,15 dan 84,51% dalam kemenyan. Efisiensi penghambatan yang diperoleh dari produk dari pengukuran polarisasi adalah dari 39,5 menjadi 81% untuk gom arab dan 40,81 hingga 28,28% untuk masing-masing kemenyan. Dengan demikian, hasil ini menunjukkan bahwa semakin tinggi konsentrasi (7,5 g / L dan 10 g / L) dari inhibitor semakin tinggi efisiensi penghambatan. Gambar SEM jelas menunjukkan permukaan yang halus dan kasar karena adanya penghambatan pada permukaan baja ringan oleh produk alami. Oleh karena itu, studi polarisasi potensiodinamik mampu menunjukkan penghambatan dengan adanya kedua getah arab dan kemenyan.

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LIST OF ABBREVIATIONS

GI	-	Green inhibitor
GA	-	Gum Arabic
FR	-	Frankincense
HCl	-	Hydrochloric acid
IE	-	Inhibition efficiency
IE%	-	Percentage inhibition efficiency
CE	-	Counter electron
RE	-	Reference electrode
WE	-	Working electrode
SCE	-	Saturated calomel electrode
SEM	-	Scanning electron microscope

LIST OF SYMBOLS

mpy	-	Mils per year
T	-	Temperature
M	-	Molar, mole/litter
C	-	Concentration
b_a	-	Anodic Tafel slope
b_c	-	Cathodic Tafel slope
E_{corr}	-	Corrosion Potential
i_{corr}	-	Corrosion current density

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Long time ago corrosion was a very big problem, and many scientists tried to find a solution to this problem. Over time many scientists invented a lot of solutions some them failed but some of them were temporary solutions. In fifth century BC the Herodotus used tin for protecting corrosion of iron. In 18th century the Europeans thought of painting the ships which were made of iron to protect them from corrosion and this was the primitive way to fight corrosion. In 1824, they used zinc to protect iron from corrosion. Then Faraday made two laws to calculate the corrosion rates used until now *(Acharya, S. and Upadhyay, 2004)*. Corrosion is damage as a result of its interaction electro-chemical and chemical with the atmosphere or the surrounding medium. It occurs gradually in materials to destroy all material. Commonly it happens in metals *(Acharya, S. and Upadhyay, 2004)*. It also happens when the material is in contact with atmospheric air or in chemical surrounding at any temperature. It is a big problem since the beginning of life because of evolving industries use materials this day more than the pas *(Ebenso, E.E., Isabirye, D.A. and Eddy, N.O, 2010)*. The main reason for corrosion is the origin of these metals. Same metals do not exist in nature.

The broad utilisation of mild steel as a core material in construction industries, chemical and allied industries, general engineering and other related areas of applications *(Noor and Al-Moubaraki, 2008; Verma, 2016)* owned to its outstanding characteristics and relatively low cost *(Azzaoui, 2017)* is threatened by a major setback, corrosion. Metal corrosion leads to a waste in resources and highly reduced equipment's lifespan especially in acidic solutions *(Al-Fakih, 2015; Verma, 2017; Verma, 2016)*. This has necessitated extensive research efforts between the academia and industries aimed at curbing corrosion or reducing it considerably

(Verma, 2017). Corrosion inhibitors, as the most viable approach, has dominated research space in this field. They act to form layers on the metals (or metal oxides) surface by adsorption on the metallic surfaces using heteroatoms such as N, O, S; polar functional groups such as -OH, -NH_2, -NO_2, -CN; pi-electrons and aromatic rings etc. as adsorption centres *(Kumar, 2016; Lukovits, 2001; Verma, 2016)*. These action leads to a structural change by introducing a new layer which consequently ensures a reduction in the rate of the electrochemical partial reaction *(Popova, 2003)*. This is to prevent further oxygen access to the cathode while also preventing diffusion of hydrogen from it. In general, they are added to the acid solution during acidification and act to prevent dissolution of the metal *(Al-Fakih, 2015; Lukovits, 2001; Verma, 2016)*.

In attempt to curb corrosion, inorganic substances such as chromates, phosphates, dichromats, nitrates, sulphide of alkaline metals, have been extensively used but some of these inorganic substances, as well as their derivates, constitute pollutants to the environments *(Ferreira, 2004)*. Given the rising concern for green ecosystems and strict regulations for environmental sustainability, non-toxic and green corrosion inhibitors are being investigated. Among all the non-toxic and explored alternatives to corrosion inhibitions, organic products are found to be efficient in preventing corrosion and cost-effective *(Ferreira, 2004; Kuma, 2016; Verma, 2017)*. Satisfactory anticorrosion properties have been found in organic products containing N, S and O heteroatoms *(Kumar, 2016)*. More recent studies have focused on organic and highly eco-friendly products with very low negative environmental effects such as Multicomponent reactions (MCRs) *(Verma, 2016)* and mainly, plant extracts. Plant extracts are readily available, cheap, eco-friendly, and renewable. They have been reported to be highly effective as inhibitors of iron and steel corrosion in acid solutions *(Rani and Basu, 2012; Verma, 2017)*.

On this premise, this work utilises selected two natural products namely, Gum Arabic and Frankincense, to investigate their ability to be used as green inhibitors on mild steel in acidic medium.

Gum Arabic (Acacia Senegal, GA), one of the oldest and most common natural gums, can be obtained from various species of Acacia trees *(Bentrah H, Rahali Y, Chala A, 2014)*. Owing to the cost effectiveness, non-toxicity and biocompatibility, GA is widely used in the food and paint industries as a stabiliser, emulsifier and viscosity control.

Olibanum or Boswellia Serrata Gum (BSG), frankincense originates from Africa, India and the Middle East. It is a resin from genus Boswellia trees, found in India and Arabia.

Techniques studied for corrosion inhibition using gum arabic and frankincense in only weight loss method.

1.2 Problem Statement

Gum arabic and frankincense have been studied on corrosion inhibitors using weight loss mostly, and some have used electrochemical potentiodynamic method *(Abdeen 2019, Shen 2019, Umoren 2006, Abu-Dalo 2012, Umoren 2008, Umoren 2009 and Ahmmed S Ibrehem 2016).*

As for the steel corrosion measurement, several methods are used such as weight-loss measurements. The advantage of this method its simplicity since it requires no specialized equipment other than an accurate balance. This experiment is normally performed according to a standard method *(eg, ASTM G1-90, 1996)*. However, the disadvantages of the weight-loss methods compared to other techniques is time consuming (usually >1 week) in addition to possible errors that can occur due to the scaling and liquid absorption. On the other hand, electrochemical potentiodynamic method are much faster (typically 1–2 days) than weight-loss methods and can give more qualitative indications of the corrosion rate over short time. The ability to test more conditions in less time makes these methods ideal for screening the relative corrosiveness of novel amines compared to other methods.

Inhibition of steel corrosion in acidic solutions using natural products as corrosion inhibitors is the most practical method. Therefore, this research focuses on an experimental study on frankincense and gum under effective experimental conditions and different from the previous one to act as solid corrosion inhibitors in solutions.

1.3 Aim and Objectives

This research aims to determine the inhibitive potential of natural products studied for applications to mild steel in acid medium. The objectives of the study are:

i. To evaluate the inhibition efficiency of gum arabic and frankincense as corrosion inhibitors for mild steel in acidic medium (1M HCl) at several temperature measures using weight loss in different concentrations measurements of 2.5, 5, 7.5 and 10 g/L.

ii. To evaluate various corrosion parameters through galvanostatic polarization technique at room temperature measured at different concentrations (2.5, 5, 7.5 and 10 g/L).

iii. characterization the surface of mild steel in the presence of gum arabic and frankincense using scanning electron microscopy (SEM).

1.4 Research Scopes and Limitations

In this study, gum arabic and the Frankincense were purchased from Oman examined as green inhibitors of corrosion of mild steel obtained from Sultan Qaboos university in Oman, in 1 M HCl using the method of weight loss and measurements of electrochemical techniques. The weight loss method was measured for different concentrations of each extract, 2.5, 5, 7.5, and 10 g/L under different conditions for weight loss by conducting experiments at 25, 60 and 85°C for 4 hours.

Electrochemical measurements were performed at room temperature 25°C using the same concentrations used in the weight loss measurement method. The method of measuring the weight loss of all-natural products in different conditions and concentrations showed mixed results, where inhibitor efficiency (IE) was calculated as 46% and compared. In addition, weight loss results were used to determine surface coverage. Furthermore, from the electrochemical results, the type of inhibitory behaviour was determined by either anodic, cathodic or mixed-type inhibitors as well as their IE%. Surface was characterization for effect of corrosion using SEM.

1.5 Research Significance

The problem of corrosion and the attendant economic losses, especially in the sectors of the oil and gas industry has been addressed by high-cost industrial methods. With the importance of using the diversity of mild steel, this will lead to further corrosion, and therefore a large increase of losses. Therefore, the need for further studies aimed at preventing or reducing steel corrosion to provide great opportunities in addressing this problem, in particular, by using natural products rather than artificial compounds. This research exposes the inhibition potential of gum arabic and frankincense, on mild steel corrosion in acidic medium. This research focuses on the use of plant extracts of the same family as green inhibitors for corrosion of carbon steel. Therefore, the results of this research will be very useful for all steel environmental conditions, especially in the oil and gas industry. Thus, with both environmental benefits and economic returns, they will get their metal equipment protected from corrosion and prevent it from occurring for as long as possible.

REFERENCES

Abu-Dalo, M., Othman, A., & Al-Rawashdeh, N. (2012). Exudate gum from acacia trees as green corrosion inhibitor for mild steel in acidic media. *Int. J. Electrochem. Sci*, *7*(1), 9303-9324.

Abdeen, D. H., Atieh, M. A., Merzougui, B., & Khalfaoui, W. (2019). Corrosion Evaluation of 316L Stainless Steel in CNT-Water Nanofluid: Effect of CNTs Loading. *Materials*, *12*(10), 1634.

Ahmed, M. I., Islam, M. A., & Ali, M. N. (2017). *Determination Of Corrosion Rate of Mild Steel in Different Medium Measuring Current Density*. Paper presented at the International Conference on Mechanical Engineering and Renewable Energy, Chittagong, Bangladesh.

Ahmmed S Ibrehem , Awatif Al-Shab, Moza salim Al-Ansari , Sara Al-Yafai, Fatma Baomar (2016). Protection of carbon steel against corrosion using Frankincense, Oman.

Ajeigbe, S., Basar, N., Maarof, H., Al-Fakih, A., Hassan, M., & Aziz, M. (2017). Evaluation of Alpinia galanga and its active principle, 1'-acetochavicol acetate as eco-friendly corrosion inhibitors on mild steel in acidic medium. *Journal of Materials and Environmental Sciences*, *8*(6), 2040-2049.

Al-Fakih, A., Aziz, M., & Sirat, H. (2015). Turmeric and ginger as green inhibitors of mild steel corrosion in acidic medium. *Journal of Materials and Environmental Science, 6*(5), 1480-1487.

Al-Yasiry, A. R. M., & Kiczorowska, B. (2016). Frankincense-therapeutic properties. *Advances in Hygiene & Experimental Medicine/Postepy Higieny i Medycyny Doswiadczalnej, 70*.

Anupama, K.K., and Abraham, J. (2012). Electroanalytical Studies On The Corrosion Inhibition Behavior Of Guava (Psidium Guajava) Leaves Extract On Mild Steel In Hydrochloric Acid. *Research on Chemical Intermediates.* Volume 39(9): pp. 4067-4080.

Azzaoui, K., Mejdoubi, E., Jodeh, S., Lamhamdi, A., Rodriguez-Castellón, E., Algarra, M., . . . Lgaz, H. (2017). Eco friendly green inhibitor Gum Arabic

(GA) for the corrosion control of mild steel in hydrochloric acid medium. *Corrosion science, 129*, 70-81.

Banu, A. M., & Ahamed, K. R. (2017). Natural products as corrosion inhibitor-a review.

Bardal, E. (2007). *Corrosion and protection*: Springer Science & Business Media.

Basik, M., Mobin, M., & Aslam, J. (2017). An Eco-Friendly Corrosion Inhibitor for Mild Steel in 1 M HCl Medium.

Bentrah, H., Rahali, Y., & Chala, A. (2014). Gum Arabic as an eco-friendly inhibitor for API 5L X42 pipeline steel in HCl medium. *Corrosion science, 82*, 426-431.

Brycki, B. E., Kowalczyk, I. H., Szulc, A., Kaczerewska, O., & Pakiet, M. (2017). Organic Corrosion Inhibitors. In *Corrosion Inhibitors, Principles and Recent Applications*: IntechOpen.

Cui, S., Wu, Y., & Ding, H. (2013). The range of dietary fibre ingredients and a comparison of their technical functionality.

Dariva, C. G., & Galio, A. F. (2014). Corrosion inhibitors–principles, mechanisms and applications. In *Developments in corrosion protection*: IntechOpen.

Darling, D., & Rakshpal, R. (1998). *Green chemistry applied to corrosion and scale inhibitors.* Paper presented at the Corrosion.

Ebenso, E.E., Eddy, N.O. and Odiongenyi, A.O. (2008). Corrosion inhibitive properties and adsorption behaviour of ethanol extract of Piper guinensis as a green corrosion inhibitor for mild steel in H2SO4. African Journal of Pure and Applied Chemistry (2)11: 107–115

Ernst, E. (2008). Frankincense: systematic review. *Bmj, 337*, a2813.

Featherstone, S. (2015). *A Complete Course in Canning and Related Processes: Volume 3 Processing Procedures for Canned Food Products*: Woodhead Publishing.

Ferreira, E., Giacomelli, C., Giacomelli, F., & Spinelli, A. (2004). Evaluation of the inhibitor effect of L-ascorbic acid on the corrosion of mild steel. *Materials Chemistry and Physics, 83*(1), 129-134.

Frank, M. B., Yang, Q., Osban, J., Azzarello, J. T., Saban, M. R., Saban, R., . . . Lin, H.-K. (2009). Frankincense oil derived from Boswellia carteri induces tumor cell specific cytotoxicity. *BMC Complementary and Alternative Medicine, 9*(1), 6.

Ghali, E., Sastri, V. S., & Elboujdaini, M. (2007). *Corrosion prevention and protection: practical solutions*: John Wiley & Sons.

HarvestRain. (2017). Acacia Gum at a glance. Accessed [Online] on March 28 2019 via http://www.harvestraincommodities.com/gum-arabic-acacia-gum--frankincense-resin.html.

Hepper, F. N. (1969). Arabian and African frankincense trees. *The Journal of Egyptian Archaeology, 55*(1), 66-72.

Ibrehem, A. S., Al-Shab, A., Al-Ansari, M. s., Al-Yafai, S., & Baomar, F. (2016). Protection of carbon steel against corrosion using Frankincense. *Wulfenia Journal, 23*(1), 379-393.

K. Bilkova, N. Hackerman and M. Bartos, J. Science and Engineering Corrosion, NACE International 60 (10) (2004) 965.

Kesavan, D., Gopiraman, M., & Sulochana, N. (2012). Green inhibitors for corrosion of metals: a review. *Chem. Sci. Rev. Lett, 1*(1), 1-8.

Kumar, S., Vashisht, H., Olasunkanmi, L. O., Bahadur, I., Verma, H., Singh, G., Ebenso, E. E. (2016). Experimental and theoretical studies on inhibition of mild steel corrosion by some synthesized polyurethane tri-block co-polymers. *Scientific reports, 6*, 30937.

Lansing, T. a. (1982). Review of Corrosion Causes and Corrosion Control in a Technical Facility. *DSN Engineering Section*, 42-69.

Li, W. and Li, D.Y. (2006) Influence of Surface Morphology on Corrosion and Electronic Behavior. ActaMaterialia 54, pg: 445–452.

Lukovits, I., Kalman, E., & Zucchi, F. (2001). Corrosion inhibitors—correlation between electronic structure and efficiency. *Corrosion, 57*(1), 3-8.

Mobin, M., Basik, M., & Aslam, J. (2018). Boswellia serrata gum as highly efficient and sustainable corrosion inhibitor for low carbon steel in 1 M HCl solution: experimental and DFT studies. *Journal of Molecular Liquids, 263*, 174-186.

Mohd, N., & Ishak, A. S. (2015). Thermodynamic study of corrosion inhibition of mild steel in corrosive medium by Piper nigrum extract. *Indian Journal of Science and Technology, 8*(17), 1.

Noor, E. A., & Al-Moubaraki, A. H. (2008). Corrosion behavior of mild steel in hydrochloric acid solutions. *Int. J. Electrochem. Sci, 3*(1), 806-818.

NPTEL. Properties and Applications of Materials Accessed [Online] on 6th April 2019 via https://nptel.ac.in/courses/113106032/113106016%113106020-

%113106020Properties%113106020and%113106020Applications%113106020of%113106020Materials.pdf.

Okafor, P.C., Osabor, V.I. and Ebenso, E.E. (2007). Eco-friendly corrosion inhibitor: Inhibitive action of ethanol extracts of Garcinia kola for the corrosion of mild steel in H2SO4 solutions. Pigment and Resin Technology 35(5): 299 - 305.

Ololade, O. (2018). Processing and Modification of Gum Arabic in Specific Applications. In *Gum Arabic* (pp. 127-142): Elsevier.

Popova, A., Sokolova, E., Raicheva, S., & Christov, M. (2003). AC and DC study of the temperature effect on mild steel corrosion in acid media in the presence of benzimidazole derivatives. *Corrosion science, 45*(1), 33-58.

Raja, P. B., Ismail, M., Ghoreishiamiri, S., Mirza, J., Ismail, M. C., Kakooei, S., & Rahim, A. A. (2016). Reviews on corrosion inhibitors: a short view. *Chemical Engineering Communications, 203*(9), 1145-1156.

Rani, B., & Basu, B. B. J. (2012). Green inhibitors for corrosion protection of metals and alloys: an overview. *International Journal of corrosion, 2012*.

Roberge, P. R. (2008). *Corrosion engineering: principles and practice* (Vol. 2): McGraw-Hill New York.

Shodganga. (2017). Introduction to Corrosion and its Prevention. Accessed [Online] on 4th April 2019 via http://shodhganga.inflibnet.ac.in/bitstream/10603/79572/10610/10610_chapter%10201.pdf.

Shen, C., Alvarez, V., Koenig, J. D., & Luo, J. L. (2019). Gum Arabic as corrosion inhibitor in the oil industry: experimental and theoretical studies. *Corrosion Engineering, Science and Technology*, *54*(5), 444-454.

Siemoneit, U., Koeberle, A., Rossi, A., Dehm, F., Verhoff, M., Reckel, S., Bernhard, F. (2011). Inhibition of microsomal prostaglandin E2 synthase- 1 as a molecular basis for the anti inflammatory actions of boswellic acids from frankincense. *British journal of pharmacology*, *162*(1), 147-162.

Skarke, C., Kuczka, K., Tausch, L., Werz, O., Rossmanith, T., Barrett, J. S., Schwarz, J. A. (2012). Increased Bioavailability of 11- Keto- β- Boswellic Acid Following Single Oral Dose Frankincense Extract Administration After a Standardized Meal in Healthy Male Volunteers: Modeling and Simulation Considerations for Evaluating Drug Exposures. *The Journal of Clinical Pharmacology*, *52*(10), 1592-1600.

Sastri V.S. (2011) Introduction and Forms of Corrosion, Green Corrosion Inhibitors: Theory and Practice, John Wiley & Sons, Inc., First Edition.

Sulieman, A. M. E.-H. (2018). Gum Arabic as Thickener and Stabilizing Agents in Dairy Products. In *Gum Arabic* (pp. 151-165): Elsevier.

Tang, Y., Zhang, F., Hu, S., Cao, Z., Wu, Z. and Jing, W. Novel benzimidazole derivatives as corrosion inhibitors of mild steel in the acidic media. Part I: Gravimetric, electrochemical, SEM and XPS studies. Corrosion Science. 2013. 74: 271-282.

Tomić, M. V., Pavlović, M. G., Jotanović, M., & Fuchs-Godec, R. (2010). Protection of copper

using corrosion inhibitor-literature review. *Quality of life, 1*(1).

Toussaint, A. (2015). Use of Organic and Inorganic Corrosion Inhibitors in High Performance Coatings. Accessed [Online] on the 5th April 2019 via https://www.halox.com/news/files/Toussaint-ECS.pdf.

Tucker, A. O. (1986). Frankincense and myrrh. *Economic botany*, *40*(4), 425-433.

Umoren, S. A., Obot, I. B., Ebenso, E. E., Okafor, P. C., Ogbobe, O., & Oguzie, E. E. (2006). Gum arabic as a potential corrosion inhibitor for aluminium in alkaline medium and its adsorption characteristics. *Anti-corrosion methods and materials*, *53*(5), 277-282.

Umoren, S. (2008). Inhibition of aluminium and mild steel corrosion in acidic medium using Gum Arabic. *Cellulose, 15*(5), 751.

Umoren, S. A. (2009). Synergistic influence of gum arabic and iodide ion on the corrosion inhibition of aluminium in alkaline medium. *Portugaliae Electrochimica Acta*, *27*(5), 565-577.

Uwah, I.E., Ugi, B.U., Okafor, P.C. and Ikeuba, A.I. (2013). Comparative study of the corrosion inhibition and adsorption characteristics of ethanol extracts of Andrographis paniculata(King bitters) and Vernonia amygdalina (Bitter leaf) on Mild steel in HCl solution. International Journal of Applied Chemistry 9 (1): 73 – 88

Verma, C., Ebenso, E. E., & Quraishi, M. (2017). Ionic liquids as green and sustainable corrosion inhibitors for metals and alloys: an overview. *Journal of Molecular Liquids, 233*, 403-414.

Verma, C., Olasunkanmi, L. O., Ebenso, E. E., Quraishi, M. A., & Obot, I. B. (2016). Adsorption behavior of glucosamine-based, pyrimidine-fused heterocycles as

green corrosion inhibitors for mild steel: experimental and theoretical studies. *The Journal of Physical Chemistry C, 120*(21), 11598-11611.

Williams, P. A., & Phillips, G. (2009). Gum arabic. In *Handbook of hydrocolloids* (pp. 252-273): Elsevier.