NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

EFFECTS OF PLANT EXTRACTS ON CORROSION RATES OF MILD STEEL IN ACIDIC MEDIUM

M.Sc. THESIS

20205812 Bawa BAMAIYI

Supervisor

Prof. Dr. Mahmut Ahsen SAVAŞ

Nicosia

December, 2022

NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF MECHANICAL ENGINEERING

EFFECTS OF PLANT EXTRACTS ON THE CORROSION RATE OF MILD STEEL IN ACIDIC MEDIUM

M.Sc. THESIS

Bawa BAMAIYI

Nicosia
December, 2022

BAWA
BAMAIYI

EFFECTS OF PLANT EXTRACTS ON THE CORROSION
RATE OF MILD STEEL IN ACIDIC MEDIUM

MASTER THESIS

2022

NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF MECHANICAL ENGINEERING

EFFECTS OF PLANT EXTRACTS ON CORROSION RATES OF MILD STEEL IN ACIDIC MEDIUM

M.Sc. THESIS

20205812 Bawa BAMAIYI

Supervisor
Prof. Dr. Mahmut Ahsen SAVAŞ

Nicosia
December, 2022

Approval

We certify that we have read the thesis submitted by Bawa BAMAIYI titled **"Effects of plant extracts on the corrosion rate of mild steel in acidic medium"** and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Mechanical Engineering.

Examining Committee	Name-Surname	Signature
Head of the Committee:	Assist. Prof. Dr. Metin Bilin	
Committee Member*:	Assist. Prof. Dr. Elbrus Bashir İmanov	
Supervisor:	Prof. Dr. Mahmut A. Savaş	

Approved by the Head of the Department

20/02/2023

Assoc. Prof. Dr. Hüseyin ÇAMUR
Head of the Mechanical Engineering Department

Approved by the Institute of Graduate Studies

20/03/2023

Prof. Dr.Kemal Hüsnü Can BAŞER
Head of the Institute of Graduate Studies

NEAR EAST UNIVERSITY INSTITUTE OF GRADUATE STUDIES 1988

Declaration

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Bawa BAMAIYI
20/03/2022

Acknowledgments

I am grateful to God Almighty for His mercy upon my life and my wife whose support I enjoyed during the course of my studies and to the entire family who stood by my side.
My profound gratitude to my thesis supervisor Prof. Dr. Mahmut A. Savaş who is always available for me to guide me,I can’t thank him enough. To Engineer Mamaki Usman Peni, Dr Ademola Samuel and the laboratory technologist Mr. Mailafiya, I am most grateful.

To all staff of Mechanical Engineering Department, Near East University, those who taught me directly or indirectly. I say thank you all for what God has used you to add to my life during the period of my study. May God reward you richly

Bawa BAMAIYI

Abstract

Effects of Plant Extracts on the Corrosion Rate of Mild Steel in Acidic Medium

Bawa BAMAIYI

M.Sc., Department of Mechanical Engineering
Supervisor's Name: Prof. Dr. Mahmut A. SAVAŞ

……………/December/2022 80 pages

The majority of industrial corrosion inhibitors are costly and harmful. Natural corrosion inhibitors, on the other hand, are inexpensive, non-toxic, and renewable. Natural or green corrosion inhibitors are plant extracts that slow the rate of corrosion reactions. In this thesis, weight-loss strategies were used to test the efficacy of extracts of locust bean, banana sap, and lemon leaves as corrosion inhibitors on mild steel in dilute hydrochloric (HCl) acid. The effectiveness of 2.5 milliliters of ethanol on locus bean (*Parkia biglobosa*), banana sap (*Musa paradisiaca*), and lemon leaves (*Citrus limonum*) as mild steel corrosion inhibitors in 0.5M diluted HCl acid was tested using weight loss procedures. For the initial corrosion tests, extract concentrations of 0.5 ml, 1.0 ml, 1.5 ml, 2.0 ml, and 2.5 ml were used for one and three hours, respectively. The results for the lowest corrosion rate and their effectiveness were obtained when extracts of *Parkia biglobosa, Musa paradisiaca,* and *Citrus limonum* were used for an hour at 38 °C, 45 °C, and 55 °C, respectively. The results were used to conclude that in an acidic environment, extracts of lemon leaves, banana sap, and locust beans can be used as corrosion inhibitors. Compared to lemon leaves and locust beans, banana sap appears to be less effective as a potential corrosion inhibitor.

Keywords: *mechanical engineering, plant extracts, corrosion, metal, steel, acidic medium*

Özet

Bitki Ekstraktlarının Yumuşak Çeliğin Asidik Ortamda Korozyon Oranına Etkileri

Bawa BAMAIYI

Yüksek Lisans, Makine Mühendisliği Bölümü
Danışmanın Adı: Prof. Dr. Mahmut A. SAVAŞ

20/Aralık/2022 80 sayfa

Geleneksel korozyon önleyici kimyasallar pahalı ve çevreye zararlı olabilmektedir. Farklı bir seçenek olarak doğal, biyolojik korozyon önleyiciler araştırılmaktadır. Örneğin, bitkilerden elde edilen bazı solisyonlar korozyon önlemede etkili olabilmekte; çevreye ve insan sağlığına zararsız vermemektedir. Bu çalışmada Nijerya'da çok yaygın harnup (locus bean), muz dalı (banana sap) ve limon yapraklarından etanol içerisinde elde edilen solisyonların seyreltik (0.5 M) HCL asit içerisinde bekletilen imalat çeliğinin (mild steel) paslanmasını önleyici/yavaşlatıcı etkileri ağırlık kaybı (weight loss) yöntemleri ile incelenmiştir. Korozyon ilerleme hızı ve korozyon önleme etkinliği hesaplamaları sonucu her üç solisyonun da imalat çeliğinin paslanmasını yavaşlattığı görülmüştür. Limon yaprakları ile harnup tanelerinden elde edilen solisyonların muz dalından elde edilen solisyondan daha etkili oldukları anlaşılmıştır.

Anahtar Kelimeler: *makine mühendisliği, bitki özleri, korozyon, metal, çelik, asidik ortam*

Table of Contents

Approval i
Declaration ii
Acknowledgments iii
Abstract iv
Özet v
Table of Contents vi
List of Tables viii
List of Abbreviations x

CHAPTER I

Introduction 11
- Statement of the Problem 12
- Aim of the Study 12
- Research's objectives 13
- Significance of the Study 13
- Justification 13
- Study's Purpose 13
- Limitations of the Study 14

CHAPTER II

Literature Review 15
- Corrosion's Definition 15
- Corrosion Causes 16
- Corrosion Mechanism 16
  - Mild Steel Corrosion in HCl Solution Mechanism 17
- Inhibitors of Conventional Corrosion 18
  - Making Plant Extract 20
  - Plant extract phytochemicals 20
- Effectiveness of Plant Extract 22
  - Weight loss measurement (WLM) 23
- Mechanism of plant extract inhibition 24
- Prevention of corrosion 25
- Corrosion inhibition in acidic solutions 27
- General principles of corrosion inhibition 30
  - Corrosion inhibitor classification 30

- Corrosion inhibition in a solution nearly neutral 31
- Adsorption isotherms 31
  - Inhibitors' physical and chemical adsorption 33
  - Adsorption kinetics 34
- Kinetic Parameters 35
- Experimental Inhibitors 36
  - Sodium benzoate (C_6H_5COONa) 36
  - Banana plant 36
  - Locust bean tree 36
  - Lemon leaves (Citrus limonum) 37
- Factors influencing corrosion 37

CHAPTER III

MATERIALS AND METHODS 40

- Materials 40
- Inhibitors 40
- Methods 42
  - Acid Solution 42
  - Preparation of the Samples 42
  - Procedures for the Experiment 43

CHAPTER IV

Findings and Discussion **Error! Bookmark not defined.**

- Results 47
- Analysis of Results 56
- Discussion of the findings 57

CHAPTER V

Discussion 58

CHAPTER VI

Conclusion and Recommendations 61

- Conclusions 61
- Recommendations 61

REFERENCES 62

List of Tables

Page

Table 1. The Locust beans' corrosion rate (r0) in the absence of an inhibitor after one hour and three hours 47

Table 2. Corrosion rate in the absent of inhibitor (r0) after 1hr and 3hrs for banana sap 47

Table 3. Corrosion rate for lemon leaves after one hour and three hours in the absence of an inhibitor (r0) 47

Table 4. Locust beans' corrosion rate after an hour at various concentrations and temperatures in the presence of an inhibitor 48

Table 5. After 1 hour, the rate of corrosion in the presence of an inhibitor in banana sap at various concentrations and temperatures 48

Table 6. After 1 hour, the rate of corrosion in the presence of an inhibitor in lemon leaves of various concentrations and temperatures 49

Table 7. After three hours, the rate of corrosion for locust beans in the presence of an inhibitor at various concentrations and temperatures 49

Table 8. After three hours, the rate of corrosion for banana sap in the presence of an inhibitor at various concentrations and temperatures 49

Table 9. After three hours, the rate of corrosion for lemon leaves in the presence of an inhibitor at various concentrations and temperatures 50

Table 10. Efficacy of the inhibitor for locust beans after 1 hour at various doses and temperatures 50

Table 11. After one hour, banana sap inhibitor effectiveness at various temperatures and concentrations 51

Table 12. The efficiency of the inhibitor for Lemon Leaves at various temperatures and concentrations after an hour 51

Table 13. Inhibitor efficiency at different concentrations and temperatures after 3hrs for Locust Beans 51

Table 14. Inhibitor efficiency at different temperatures and concentrations after 3hrs for banana sap 51

Table 15. Inhibitor efficiency at different temperatures and concentrations after 3hrs for lemon leaves 52

List of Figure

Page

Figure 1. Metals and alloys' corrosion-causing factors (Raja et al., 2016) ....**Error! Bookmark not defined.**

Figure 2. Table of alloys steel. Source: Steven Brandley Feb 25, 2021

Figure 3. Crack on the component cause by corrosion. Source: Paul Dvorak May 17, 2018.. 39

Figure 4. Examination of mild steel chemically........ 40

Figure 5. Banana sap........ 40

Figure 6. Locust bean........ 41

Figure 7. Lemon leaves........ 41

Figure 8. Preparation for an investigation corrosion test (a. mild steel b. inhibitors)........ 44

Figure 9. A graph of corrosion rate for plants extracts with concentration of inhibitor at 1 hour 53

Figure 10. A graph of corrosion rate for plants extracts with concentration of inhibitor at 3 hours........ 54

Figure 11. Inhibitor efficiency for plants extracts at different temperatures after 1 hour........ 55

Figure 12. Inhibitor efficiency for plants extracts at different temperatures after 3 hours 56

List of Abbreviations

W_1	Weight loss values without the inhibitor
W_2	Weight loss values with the inhibitor
CRp	presence of the inhibitor
CRa	Absence of the Inhibitor
K	Adsorptional equilibrium constant
f	Adsorption energy
R	gas constant
Ea	Activation energy
P	Pressure in N/m
H	Adsorption heat
A	Exposed surface area
ρ	Density of mild steel
T	Time of exposure in hours

CHAPTER I

Introduction

Mild steel is useful in engineering for a number of things, such as making some vehicle parts, structural shapes, and sheets for use in structures, buildings, etc. (Umeozokwere Anthony et al., 2016). Due to its beneficial qualities, such as ductility and toughness, high machinability, and weldability, it is helpful in the engineering sectors. The reason why mild steel was produced. To strengthen buildings, it is mostly employed in the construction industry. Pig iron is used to make steel, which has a maximum carbon concentration of 2.1% and additional components like manganese at 1.65%. A crucial characteristic associated with how quickly a material reacts in a given environment is the ability to protect metals and their alloys against corrosion. It is easier to obtain, less expensive to produce, and frequently did not involve resistance to corrosion as a main factor (Habeeb et al., 2018). Among the biggest issues arising from the expanding use of mild steel in industry and construction businesses is the regulation of corrosion rate when exposed to various corrosive conditions. A metal becomes oxidized as a result of corrosion, a natural process that lowers metal’s binding energy and causes bulk metal to lose one or more electrons (Amadi, 2000). Due to chemical attack or reactivity with their surroundings, metals and alloys attempt to revert to their more stable thermodynamic forms during corrosion, a natural, spontaneous process. The damaging attack on a material caused by a reaction with its environment is another definition of corrosion. Events that are both natural and man-made can cause corrosion (Goyal et al., 2018). On a global level, corrosion's harmful impacts have become a serious problem. In addition to the regular occurrences of this type of degradation, corrosion causes factory closures, resource waste, product loss or contamination, efficiency decrease, expensive maintenance, and expensive machine design. It also compromises safety and slows the development of technology (Chuka et al., 2014). The fact that corrosion issues include a variety of disciplines in the complexity of the subject is further increased by their diverse in nature and the responsibilities they entail. For corrosion to be controlled, it is essential to understand how corrosion works, use materials and designs that are resistant to corrosion, and employ protective systems, tools, and procedures. Large corporations, industries, and governmental bodies have established committees and groups to address corrosion-related issues, but frequently, the producers and their customers share responsibility. This kind of circumstance can quickly result in neglect, which can be very costly in terms of both resources and people (Helen et al., 2014). Earlier studies, attested to the enormous cost of corrosion damages, which can account for 3–5% of the GNP of industrialized nations (Helen et al., 2014). One of the findings of the 1971 U.K. government-sponsored inquiry presided over by Hoar was that a sizable portion of corrosion failures were preventable and that corrosion avoidance could be effectively addressed through increased education. According to recent studies, vegetable tannins are efficient metal and alloy inhibitors in acidic environments, and their inhibitory processes depend on the harsh environment and pH level (Chuka et al., 2014). The usefulness of these tannins in preventing corrosion on iron and steel substrates, however, has only been thoroughly investigated when using fast testing, electrochemical techniques, weight loss assessments, and molecular modelling (Yazdanfar et al., 2010).

This study uses a weight loss approach to minimize the rate of mild steel corrosion in an acidic environment. Plant extracts of locust beans (*Parkia biglobosa*), banana sap trees (*Musa paradisiaca*), and lemon leaves (*Citrus limonum*) will be employed as inhibitors.

Statement of the Problem

Since it threatens economics, safety, and the preservation of materials in many technical applications, corrosion is a major issue that needs to be handled (Popoola, 2019). Insufficient corrosion prevention, according to the literature, led to greater expenses for corrosion-related maintenance, repair, and rehabilitation, as well as replacement of damaged buildings (Brycki et al., 2017). Moreover, the rust restoration process is risky and could cause personnel harm or even death (Shehata et al., 2017). These elements drive scientists to view corrosion as a significant issue that needs to be addressed right away on a global scale. In order to provide corrosion inhibition using plant extracts, this research is conducted.

Aim of the Study

The purpose of this study is to evaluate the effects of locust bean (*Parkia Biglobosa*), banana sap tree (*Musa paradisiaca*), and lemon leaf (*Citrus limonum*) corrosion inhibition on mild steel in a 1M hydrochloric acid solution.

Research's objectives

This thesis' main objective is to look at how mild steel reacts to the corrosion-inhibiting properties of lemon leaves (*Citrus limonum*), banana sap trees, and locust beans (*Parkia biglobosa*) in 0.5 M hydrochloric (HCL) acid solutions. The project will center on:

- Research on the effectiveness of plant extracts in preventing rusting.
- The process by which plant extracts for mild steel are inhibited in HCl acid solution.
- An investigation of how much HCl the mild steel rod used after one and three hours.

Significance of the Study

Finding novel, possible plant extracts that could be employed as corrosion inhibitors for mild steel and other industrial applications is the significance of this study endeavor.

Justification

In West African nations, including Nigeria, locust beans (*Parkia biglobosa*), banana sap trees (*Musa paradisiaca*), and lemon leaves (*Citrus limonum*) are frequently found in large quantity. They were chosen for this study project for a variety of reasons, including their availability and—most importantly—their non-toxic character, which fit the prerequisites for using their extracts as inhibitors. The list of inexpensive, nontoxic, and ecologically acceptable plant extracts that could be utilized as corrosion inhibitors for low carbon steel in HCl acid solution will grow as a result of research into their corrosion inhibition efficacy and mechanisms of inhibition.

Study’s Purpose

In this study, weight loss techniques are used to calculate the rate of mild steel corrosion. The temperature ranged from 380°C to 450°C and 550°C, while the immersion period ranged from 1 hour to 3 hours.

Limitations of the Study

The experiment was only performed up to 550C since previous studies have shown that extracts desorb at higher temperatures, decreasing their effectiveness. Also, because there was no discernible increase in inhibitor efficiency at these levels, the highest inhibitor concentrations and exposure times employed in this study were limited to 2.5 ml and 3 hours, respectively.

CHPATER II

Literature Review

Corrosion's Definition

During corrosion, metals and alloys naturally try to revert to their more stable thermodynamic states due to chemical assaults or interaction with their surroundings (Shehata et al., 2017). Both natural and man-made events can contribute to corrosion (Goyal et al., 2018),

In the event of corrosion brought on by chemical attack or reactivity with the environment, metals, and alloys will naturally attempt to return to their more stable thermodynamic states (Shehata et al., 2017). Corrosion can result from both organic and artificial causes (Goyal et al., 2018).

The degradation of desired metal properties as a result of contact with particular environmental conditions is referred to as the natural and unavoidable process of metal corrosion (Umoren et al., 2019). It has long been understood that corrosion poses a risk to both the environment and public health. Metals and alloys in general showed a great tendency to corrode due to the presence of acid.

Metals are prone to corrode in acidic solutions because the acid may enter the metal's surface and break it down into its ions (Mahross et al., 2016). This leads to the production of stable corrosion products in a variety of industrial processes (Alaoui Mouayd et al., 2014; Mahross et al., 2016). For instance, acid descaling, acid pickling, and the removal of mill scale from metal surfaces were all used in industrial acid cleaning (Goyal et al., 2018; Verma et al., 2018). Corrosion in the oil and gas sector may be related to the nature of crude oil, which promotes corrosion due to hazardous components such sulfur (Laredo et al., 2004; Meriem-Benziane et al., 2017).

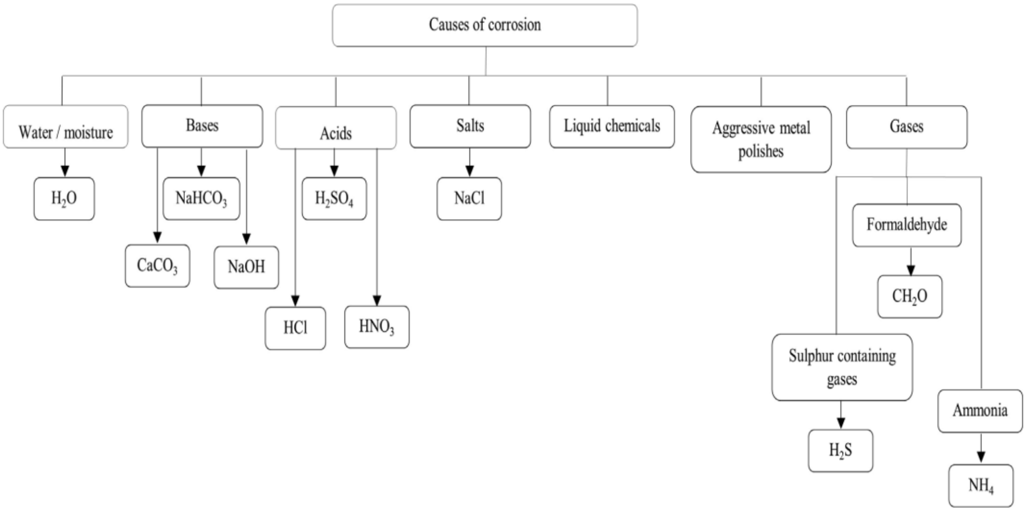
Corrosion can cause catastrophic failure in some structures, such as the rapid corrosion of metallic components (Mourya et al., 2014), which can be expensive to repair. Maintenance is necessary due to the time lost during process system downtime (Shehata et al., 2017). Moreover, the rust restoration procedure carries a high danger of injury or even death to workers (Shehata et al., 2017). These factors influence scientists to see corrosion as a serious problem that need immediate global attention. Most metals are reactive and chemically unstable, and under certain circumstances, they can react. This process is referred to as corrosion. The process of corrosion is extremely varied and sophisticated process that occurs in a number of challenging circumstances. Corrosion specialists claim that in order for corrosion to take place, the following conditions must be true:

- Anode and cathode
- A setting with a cathodic reactant that can oxidize the metal to a chemically mixed state, such as one with oxygen, water, acids, etc.
- A way for electric charges to be transferred in the environment.

Corrosion Causes

Figure 1.

Metals and alloys' corrosion-causing factors (Raja et al., 2016)



Corrosion Mechanism

The following corrosion mechanisms were noted by Fontana, (1986):

- Chemical Attacks: This happens when gaseous media directly attack the metallic surface with chemicals. The oxidation of iron at room temperature or even higher temperatures is a common example, as shown by the following process (Fontana, 1986).

$O_2 + 2Fe = 2FeO$ It is possible to ionically represent the reaction, which is an oxidation-reduction process.

Fe is therefore equal to Fe plus 2 and 2e…………………………(2.2)

$2O + 2e = O^{-2}$ ……………………………………………….(2.3)

- Wet corrosion, also known as electrochemical oxidation, is the process when water and oxygen react with a metal in the manner shown below.

$4Fe = 4Fe + 6H_2O + 3O_2\ (OH)_3$ …………………………………(2.4)

Mild steel corrosion in HCl Solution mechanism

Local cathodes and anodes occur at various locations when mild steel comes in contact with HCl solution. Iron oxidizes at the local anode in accordance with the ionic reaction listed below:

$Fe = Fe^{+2} + 2e$ ……………………………………………………(2.5)

Hydrogen is reduced at the local cathode in accordance with the following reaction:

$2H^{+} + 2e = H_2$ ……………………………………………………(2.6)

$Fe + 2H^{+} = Fe^{+2} + H_2$ is the total reaction.………………………..(2.7)

In every situation, the number of electrons obtained at the cathode equals the number of electrons lost at the anode. The weight loss of the metal at the anode and the volume of hydrogen evolved at the cathode are used as the foundation for Equations 2.5 and 2.6 to calculate the corrosion rate. These measures are frequently referred to as gravimetric and gasometric, respectively. In this study, the effects of plant extracts on corrosion inhibition were assessed using the gravimetric method.

Inhibitors of conventional corrosion

Traditional inorganic corrosion inhibitors (TICIs) and synthetic organic corrosion inhibitors (SOCIs) are two popular traditional inhibitors that have been employed (SOCIs). Because of their inexpensive cost, simple production process, high efficacy at low doses, and easy application, these inhibitors are the most cost-effective (Verma et al., 2018).

Therefore, despite the fact that SOCIs are preferred in acidic environments, TICIs are preferred in close to neutral environments (Goni et al., 2019). In addition to having polar functional groups in the molecule that contain heteroatoms like sulphur (S), oxygen (O), or nitrogen (N) atoms, a good organic inhibitor will also have a hydrophobic moiety that repels corrosive aqueous species from the metal surface (Yadav et al., 2016). Since they get electrons from p-orbitals, SOCIs with electronegative functional groups and p-electrons in conjugated double or triple bonds, in particular, exhibit high inhibitive properties (Yadav et al., 2016).

Pyridines (Abd El-Maksoud & Fouda, 2005; Ansari et al., 2015), fatty amides (Olivares-Xometl et al., 2008), amides/imidazolines (Rahuma & Kannan, 2014; W. P. Singh & Bockris, 1996), and 1,3-azoles (Antonijević et al., 2009; Daley & Hodges, 2010; Kendig & Buchheit, 2003) are a few examples of SOCIs. TICIs are readily available on the market as arsenates, phosphates, chromates, and dichromates (Goni et al., 2019). TICIs are less expensive than SOCIs and have a longer endurance to high temperatures, but they are unable to perform in acid solutions with a concentration of more than 17% HCl (Tamalmani & Husin, 2020). Additionally, typical CIs like phosphates and sulfites have been shown to be harmful to the environment (Dargahi et al., 2015). The proliferation of algae in aquatic ecosystems could result from an excessive phosphate intake, which would cause eutrophication (Kim et al., 2013). The biotic communities, on the other hand, are adversely affected by harmful sulphites (Miri & Chouikhi, 2005). Due to their slow rate of degradation or loss of potency in the environment, hazardous substances are well known to be bad for both ecological and human health. As a result, it is more likely that hazardous compounds will accumulate and have long-term effects like cancer on both people and the environment (Kendig & Buchheit, 2003; Raja et al., 2016).

As public awareness of the negative effects these chemicals have on human health and the environment has grown, stricter regulations and limitations on their usage have been developed in Europe and the US (Alaneme, Olusegun, & Adelowo, 2016; Alaneme, Olusegun, & Alo, 2016; Izadi et al., 2019). Commercial CIs are no longer frequently used to reduce corrosion because of their environmental toxicity (Arthur et al., 2013), particularly for aquatic life (Ansari et al., 2015). In spite of the strong anticorrosion potential of TICIs and SOCIs, toxicity (Daley & Hodges, 2010), which causes environmental contamination during synthesis and application (Pais & Rao, 2019; Raja & Sethuraman, 2008), as well as time-consuming synthetic procedures and pricey synthesis reagent prices (Umoren & Solomon, 2014), have been identified as significant limitations. As a result, researchers' interest in developing GCIs has increased (Verma et al., 2018).

Several studies that examine the development of GCIs have been conducted utilizing published articles found in the Web of Science (WoS) over the period 2010–2020. An overview of the publications acquired from WOS indicates that about 1408 records have been published on the subject of the GCIs, comprising 1288 papers, 71 proceeding articles, 8 book chapters, 17 early access, 51 reviews, 3 corrections, and 1 meeting abstract. GCIs are divided into two types: organic GCIs and inorganic GCIs (El Ibrahimi et al., 2020). Due to their high efficacy, inorganic GCIs are frequently used in aqueous systems, whereas the organic class of these inhibitors is composed of safe synthetic compounds (Bethencourt et al., 1998; Tamalmani & Husin, 2020).

Wei et al. pointed out the advantage of organic GCIs over inorganic GCIs. They claim that the capacity of OGCIs to uniformly passive metal surfaces may give the finest defence against hostile media. By forming brittle passive layers on the metal surface, inorganic inhibitors make the metal more vulnerable to pitting and crevice corrosion, two types of localized corrosion attacks (Wei et al., 2020).

Making Plant Extract

Following the selection of plant materials, the drying procedure is often followed by the grinding and sifting procedures to turn the extract into powder form. All plant parts must go through the initial drying phase, with the exception of the fruit's juice extraction. Drying in the traditional manner typically takes a long time and is done at room temperature. Bark, for instance, can be dried in the sun or the shade and takes 20e30 days on average (Marsoul et al., 2020; Shrestha et al., 2019). Many techniques can be used to separate and extract the necessary extract from plants after drying. Examples of extraction methods that adhere to the extraction principle include pressing, distillation, solvent extraction, and sublimation (Zhang et al., 2018). It can be summed up by saying that extraction processes entail heating, chilling, and isolating active compounds while the solvent is still present (Miralrio & Vázquez, 2020).

Solvent extraction is the method used most often to extract plants. Plant tissue must first be permeated by the solvent in order to solubilize the compounds before extracting phytochemicals using a solvent (Capello et al., 2007; Chauhan et al., 2021). Depending on the concentration of the desired extract or phytochemicals, a variety of solvents may be used as the extraction medium.

Researchers discovered that the ethanol extract of Rhizophora apiculate contained more tannins, flavonoids, and phenolics than the acetone extract (Tan & Kassim, 2011).

Plant extract phytochemicals

It is believed that phyto-constituents produce a lot of chemical molecules naturally, such as organic compounds (Lebrini et al., 2011) or bioactive chemicals (Krishnaveni & Ravichandran, 2014; Lebrini et al., 2011), which have been used as corrosion inhibitors in many industrial systems (Shehata et al., 2017). Many researches have been done on different plant sections that can be taken off to stop rusting. According to Umoren et al., (2016), *Sida acuta* has a variety of phytochemicals based on the plant component, including tannins and organic acids, among others, in the stem extract. Plant extracts have been explored as GCIs because different parts of plants contain varying amounts and types of phytochemicals. Also, differing concentrations of phytochemicals in the extract, such as condensed tannins and anthocyanins, depend on a number of factors, including plant age and the impact of climate (Zam et al., 1970). For instance, it was discovered that the plant's growth phase affects the dispersion as well as concentration of functional components in Aloe vera gel extract (Ray et al., 2013). Due to its chemical structure resembling that of common organic compounds with proven performance, plant extract can operate as a corrosion inhibitor. Phytochemicals can be divided into six basic kinds and their subclasses based on their chemical compositions and properties. These phytochemicals are thought to be the cause of corrosion inhibition. As a result, identifying the chemical components of plant extracts is crucial for estimating the performance of the extracts as corrosion inhibitors. Chemical analysis of plant extracts can be used to find and characterize phytochemicals such fatty acids, heavy metals, and volatile and non-volatile organic compounds (VOCs) (Muhamad et al., 2017). Several technologies, such as gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS), and Fourier-transform infrared spectroscopy (FTIR), are frequently employed to identify phytochemical substances (GC-MS). Due to the difficulty of the investigation and the uneven distribution of antioxidant properties in the substance, liquid chromatography-mass spectrometry (LC-MS) has emerged as the best alternative for the separation, identification, and quantification of extract components in plants. (Dugo et al., 2001). For instance, Liu et al., (2019) confirmed the primary phenolic components in ginger extract using LC-MS (Liu et al., 2019). The LC-MS chromatograms and mass spectroscopy were used to confirm the presence of the important phenolics 6-gingerol, 8-gingerol, cyclocurcumin, 1-hydroxy-1, 5-bis (4-hydroxy-3-methoxyphenyl), 1-hydroxy-1, 5-bis (4-hydroxy-3, 5-dimethyloxyphenyl), pentan-3-one, and arginine. Further redox reactions should be inhibited, and corrosion attack on metal surfaces should be avoided, because metals need to receive electrons to reach their octet state and become more stable when there are active phenolic components (Chung et al., 2019). The LC-MS results confirmed that ginger extract had the properties needed to prevent corrosion, including the phenolic components, in light of this (phytochemical compounds).

These conclusions are accurate as well. Fourier-transform infrared spectroscopy was employed by Alibakhshi et al. (2019) to examine the chemical composition of Iranian licorice leaves (FTIR). The presence of the OeH stretching mode, the C]O stretching, the CH stretching vibration, the CeO stretching, the C stretching, and the CeH stretching was shown by the FTIR spectrum. This indicates that the hydroxyl, carboxylic, and carbonyl functional groups found in Persian liquorice leaf extracts may contribute to the inhibition of corrosion by forming bonds with iron atoms on the mild steel surface. In early research, the phytochemicals in plant extract were identified using gas chromatography-mass spectrometry (GC-MS). Since it can separate more than 50 different components from a single sample, GC-MS is one of the best methods for identifying bioactive chemicals such long-chain hydrocarbons, alcohols, acids esters, alkaloids, steroids, amino acids, and nitro compounds (Muthulakshmi et al., 2012). For instance, alkanol and carboxylic acid can both be identified using GC-MS spectra because they both include p-electrons and heteroatoms like S and O that can serve as adsorption centers (Arthur et al., 2013; Eddy et al., 2009).

Effectiveness of plant extract

Corrosion Inhibition Gravimetric analysis, electrochemical analysis, and surface analysis are a few of the common approaches taken to investigate the inhibitory effects of plant extracts on corrosion. The most common method for evaluating the efficacy of GCIs derived from plant extracts is weight loss measurement (WLM), and an inhibitory mechanism can be hypothesized. In the meantime, potentiodynamic polarization (PDP) analysis, electrochemical impedance spectroscopy (EIS) [(Gromboni et al., 2021; Marsoul et al., 2020), and electrochemical noise measurement are new electrochemical process measurements (Shao et al., 2021).

The results from these quicker measurements are comparable to those from the conventional gravimetric method (Adam et al., 2015). The mechanism of inhibition can be better understood by looking at the kinetics of corrosion when an electrochemically produced inhibitor is present. Open-circuit potential (EOCP) is first employed to gauge the steady current flowing across the metal's surface (Faiz et al., 2020). The results are equivalent in magnitude despite the two methodologies' theoretical differences, demonstrating that they are acceptable and can be used to support corrosion inhibition's efficacy.

Weight loss measurement (WLM)

WLM and the substrate's weight loss are used to determine an inhibitor's efficiency. Before and after the substrate is submerged in the corrosive liquid, its weights are measured. Substrates' corrosion resistance is then evaluated using the following equations:

Inhibition efficiency (IE WLM %) = $(W_1 - W_2)/W_1 \times 100\%$................................ (2.9)

The equation 2.9 can be written as:

(1 - CRp/CRa) x 100%................................ (2.10), where W1 represents weight loss values without the inhibitor and W2 represents weight loss values with the inhibitor, A represents the area of the substrate, t represents immersion time, CRa represents the absence of the inhibitor, and CRp represents the presence of the inhibitor

Benahmed et al. (2020) looked into how Elaeoselinum thapsioides (BEET) butanolic extract's inhibition efficiency of steel in 1 M HCl was affected by temperature, BEET concentration, and changes in the CR. They discovered that while the CR decreased as the concentration of BEET increased, the inhibition efficiency significantly increased. In addition, they assert that "the active surface of steel is protected" despite the proliferation of BEET molecules (Benahmed et al., 2020). Shielding layer" reduces metal's reactivity in acidic conditions by acting as a protective barrier (Yaktini et al., 2018). In addition, they have demonstrated that inhibition efficiency decreases while CR rises with increasing acid solution temperature. At a higher acid solution temperature, the adsorption process slowed down, indicating an acceleration in the desorption of BEET molecules from the carbon steel surface (Benahmed et al., 2020).

Mechanism of plant extract inhibition

The inhibiting process is conducted to verify the accuracy of IE for GCIs based on plant extracts. Mixed-type adsorbent inhibitors are often used to refer to GCIs' physisorption, chemisorption, or combined adsorption processes on metal substrates (Faisal et al., 2018). Mixed inhibitors are the most effective form of protection because they have an impact on both anodic and cathodic reactions (Brycki et al., 2017). The nature and chemical structure of corrosion inhibitors, corrosive media, and inhibitory adsorptions of this kind can be affected by surface charge and the metal substrate (Wei et al., 2020).

Hanini et al. (2019) created the physical adsorption mechanism by utilizing the properties of corrosion inhibitors (Hanini et al., 2019). In the acidic environment, extracts with numerous bonds, heteroatoms, and so on were to pronate easily. Positively charged inhibitor species are produced by protonation of the inhibitor. These species can form electrostatic contact or connecting bridges by being adsorbed utilizing chloride ions onto the positively charged steel surface.

Similar results were obtained by Gerengi and Sahin (2012) when *Schinopsis lorentzii* extract was employed in 1 M HCl (Gerengi & Sahin, 2011). The extract has functional groups with oxygen atoms (OeH, C]C, CeH, and CeO) and aromatic rings that can be protonated.

Physisorption is then applied to adsorb the protonated component molecules (A. Singh et al., 2010).

Also, it's important to think about how the inhibitory mechanism is affected by the corrosive media. When various corrosive mediums are utilized, various adsorption techniques are observed, according to Oguzie, (2008). Hibiscus sabdariffa extract was found to physisorb in 2 M HCl and chemisorb in 1 M H2SO4 by the researchers (Oguzie, 2008). Surface charges and pre-adsorbed ions have an impact on how GCIs and metal surfaces physisorb, either indirectly or directly. Moreover, corrosive in order for physisorption or chemisorption to prevent GCI corrosion, agents need to target the surface of the metal in order to shield the surface of the metal substrate.

It is essential to determine the inhibitory mechanism in order to support the efficacy of GCI inhibition. The inhibitory mechanism can be ascertained using techniques like WLM and potentiodynamic polarization, for instance. This review extensively investigates and discusses the gravimetric data modification and electrochemical research of the aforementioned procedures because they are usually employed to confirm a certain corrosion preventing mechanism.

Prevention of corrosion

An inhibitor of corrosion is a chemical that, when applied to a small amount of water, effectively slows the rate at which a metal exposed to water corrodes. Inhibitors of corrosion fall into two categories: those that hinder corrosion and those that promote oxidation. The former includes molybdates, organic nitrates, inorganic nitrates, and inorganic chromates, while the latter includes nitrogen, sulfur, and phosphorous. Mass loss measurement is the most common method for determining inhibition. However, care must be taken when using the method and interpreting the data. In the study, inhibition is represented by changes in the content of metal ions that have been monitored over time using the solution analysis approach.

Moreover, there are tests that are based on established test protocols; such as ASTM B117 (Mercer, 2013).

There is a qualitative correlation between inhibition efficacy and the percentage of the inhibitor adsorbed on the metal surface, according to studies. Inhibitor adsorption is impacted by the remaining charge on the metal's surface as well as the inhibitor's sort and compound construction. On a metal surface, the two primary methods of inhibitor adsorption are electrostatic adsorption and chemisorption.

The electrostatic interaction of inhibitory dipoles with the metal's electrically charged surface results in electrostatic adsorption. The weak forces that characterize electrostatic adsorption. The metal has inhibitory species that have been adsorbed by electrostatic forces and can be easily desorbed. One of the key components of electrostatic adsorption is the fact that the ions are not in direct contact with the metal. The metal is separated from the ions by a layer of water molecules. The electrostatic adsorption method has a low activation energy and is temperature insensitive.

Chemisorption is the most common interaction in corrosion inhibition schemes between metal surfaces and inhibitor molecules. The species that have adsorbed come into contact with the metal's surface. Electrostatic sorption is faster but has a lower activation energy than chemisorption. The temperature dependency shows that at higher temperatures, inhibition efficiencies are greater. It is specific to certain metals and cannot be fully reversed, unlike electrostatic adsorption. The polar or charged character of the organic molecule or ionic species induces the creation of a physisorbed surface coating, which can then be maintained through chemisorption to establish a donor-type bond. Multiple bonds, especially aromatic rings or triple bonds, as well as electrons that are very loosely bound, such as in neutral organic molecules with lone pair electrons or -electron systems and anions, enhance the transfer of electrons from the adsorbed species.

Chemisorption sites are typically present in the functional groups of the organic inhibitors that are utilized. Lone pair electrons necessary for the formation of coordinate bonds can be found within functional groups that contain elements from groups V and VI of the Periodic Table. With decreasing electronegativity in the order O N S Se, the possibility that these elements will form stronger co-ordinate bonds—and hence, stronger adsorption—increases depending on the characteristics of the functional groups that include them (Mansfield, 1987). The elements' polarizability and electron density have also been used to explain the aforementioned order. This has led to the proposal of a Lewis acid-base surface bond, in which the metal serves as the electron acceptor and the inhibitor as the electron donor. In order to research corrosion inhibition processes, inhibitors have been arbitrarily categorized as either "hard" or "soft" based on the hard and soft acid base concept. Hardness and softness are both correlated with high and low polarizability. Hard bases react with hard acids more quickly than soft bases do, according to the hard and soft acid base (HSAB) principle.

Neutral metal atoms typically react with soft acids, such as inhibitors containing sulfur. Hard bases, such as nitrogen- or oxygen-containing inhibitors, are believed to interact with metal surfaces less strongly (Mansfield, 1987). Since an inhibitor's mode of action may change depending on the experimental circumstances, it is frequently impossible to pinpoint a single general mechanism of action for it. As a result, an inhibitor's primary mode of action in acidic solutions may be influenced by a variety of variables, including concentration, pH, the kind of acid anion, the presence of other species in the solution, the quantity of secondary inhibitor synthesis, and the makeup of the metal.

Corrosion inhibition in acidic solutions

In acidic liquids, adsorption is the first step toward inhibition. This is because the inhibitor has free access to the electrochemical processes of cathodic and/or anodic corrosion because the metal surface that needs to stop corroding typically lacks oxide. The inhibitor may alter the composition of the electrical double layer that forms at the metal-solution interface, affect the rate of electrochemical reactions, create a physical barrier to the diffusion of ions or molecules to or from the metal surface, directly obstruct anodic and/or cathodic reaction sites, and interact with corrosion reaction intermediates after adhering to the metal surface.

The adsorbed inhibitor does not completely cover the metal surface, but it does occupy electrochemically active regions, which lessens the intensity of either the anodic or cathodic reactions. The degree to which the electrochemically active spots are blocked by the adsorption inhibitor will determine how quickly corrosion occurs. Our electrochemical study on mild steel with 1-6 g L-1 condensed mangrove tannins in 0.5 M HCl (Adam et al., 2015) shows that the cathodic polarization curves shifted to lower current density values with a greater increase in the negative Ecorr values as the concentration increased, demonstrating that mangrove tannins are cathodic inhibitors. Inclusion of mangrove tannins had no effect on the cathodic Tafel slopes.

This shows that concentration has no effect on the mechanism behind the hydrogen evolution reaction. With 3 and 6 g L-1 of mangrove tannins, respectively, over 80% inhibitory efficacy was seen. According to Martinez and Stern (Martinez & Štern, 2001) and Martinez (Martinez, 2003), the inhibitive property of mangrove tannins in 0.5 M HCl may be related to the chemisorption of flavonoid monomers onto the surface because there isn't a surface deposit. Chemistry modeling suggests that the iron d-orbitals with partial fullness and the flavonoid molecule may adsorb by exchanging donor group (- OH) electrons or aromatic -electrons. The flavonoid molecule's acidic-basic interaction with iron metal is shown by the recently discovered HOMO-LUMO energy gap. At various pH levels, the inhibitory properties of chestnut, quebracho, and mimosa tannins were examined. At pH 0 and 0.5, all tannins achieved inhibitory effectiveness of more than 80 percent, with a consistent trend toward decreasing effectiveness as pH rises. In terms of inhibitive efficacy, mangrove tannins outperform the other tannins at pH 4.0.

Martinez & Štern (1999) studied the corrosion resistance of low-carbon steel in an acidic solution containing mimosa tannins. Mimosa tannins in sulphuric acid solutions were discovered to inhibit both cathodic and anodic processes at pHs ranging from 1 to 3, making them mixed-type inhibitors. The slopes of both the cathodic and anodic Tafels are fixed. Increased concentrations of Cl-1 and SO4-2 ions dramatically reduce the inhibitory action, and their competitive adsorption is proportional to concentration. The weight reduction measurements recorded were consistent with the results. According to the Frumkin isotherm and as shown by thermodynamic studies, mimosa tannins spontaneously adsorb in a process that is exothermic at pH = 1 (Martinez & Stern, 2002). The most likely mode of suppression is chemisorbed tannin molecules blocking the metal's surface, as there is no significant variation in activation energy when tannins are present.

The ferric-tannate monochelate is, however, only minimally adsorbed on steel surfaces in sulphuric acid solutions at steady state potential, according to Martinez and Stern (Martinez & Štern, 2001). This is because there are no specifically adsorbed anions in these situations. According to this, inhibition is most likely brought on by the exothermic spontaneous development of a ferric-tannate multilayer on the metal surface at pH = 3. pH = 3 causes the conversion of *Mimosa* tannins into ferric-tannate monochelate. Molecular modeling demonstrates that mimosa tannins are chemically vertically adsorbed to low-carbon steel. A net attractive attraction forms between the molecules of the adsorbate as a result, and the dipole moments become almost parallel to the electrode surface.

The Bocris-Swinkels replacement adsorption isotherms applied to the results of gravimetric tests show that one tannin molecule replaces four water molecules throughout the adsorption process (Martinez & Stern, 2002). Chestnut tannins are absorbed in 2M HCl as neutral molecules as a result of electrostatic forces acting between the molecular dipoles and the charged iron surface, according to the results of molecular modelling and gravimetric measurements (Martinez & Štagljar, 2003). The inhibitor-metal adsorption bond may also have a dominant electrostatic and an unfavourable electrostatic character as a result of the interaction of the positive ends of the molecular dipoles with the metal surface, which is negatively charged in HCl solution as a result of the contact adsorption of chloride ions.

The way the molecules of the inhibitor are oriented The Temkin isotherm offers the greatest fit, and the higher activation energy in inhibited systems shows that the inhibitor molecules preferentially bind to the metal surface.

General principles of corrosion inhibition

According to Fontana, (1986), a corrosion inhibitor is a substance that, when added to corroding medium in a small quantity, significantly reduces the corrosion action (Fontana, 1986). Fontana asserts that inhibitors work in one of the following ways to minimize or prevent corrosion:

- Pollution reduction and decrease in atmospheric humidity
- Making the environment less hostile by removing components that encourage corrosion.
- Dissolved oxygen removal from aqueous corrosion

Corrosion inhibitor classification

Fontana divided corrosion inhibitors into the following categories: organic inhibitors, passivating inhibitors, precipitating inhibitors, volatile corrosion inhibitors, and cathodic/anodic inhibitors (Fontana, 1986). Passivating inhibitors, according to him, are substances that cause a significant anodic shift in the corrosion potential, thereby requiring the identification of metallic inhibitors:

i. Oxidizing anions like chromates, nitrates, and so on that, in the absence of oxygen, can passivate steel.

ii. Ions that don't oxidize, like phosphates, tungstates, and molybdates, and passive steel only works if oxygen is present.

The corrosion of low-carbon steel in acid solutions is influenced by the following factors: steel's composition, inhibitor concentration and type, temperature, acid concentration and type, and the interaction of the inhibitor with the metal in solution. The author went on to explain that, while inhibitor efficiency increases with inhibitor concentration, corrosion inhibition decreases with temperature and acid concentration (Njoku, 2002).

Corrosion inhibition in a solution nearly neutral

In nearly neutral aqueous solutions, it is also feasible to stop the corrosion of metals and alloys. Low-solubility surface products such oxides, hydroxides, and salts are formed during the corrosion processes, as well as oxygen reduction. As a result, the hostile solutions will prevent the oxide-coated surface from oxidizing, which will either strengthen or retain the protective characteristics of the oxide or the surface layers. Inhibition usually starts with the displacement of pre-absorbed water molecules by the adsorption of inhibitor molecules. It is conceivable that a variety of inhibitory mechanisms exist as a result of the inhibitor sticking to the oxide-coated metal surface.

Thin surface layers with poor electronic conductivity can develop when inhibitors restrict oxygen passage. The oxygen reduction reaction is impeded by these additives, which are called cathodic inhibitors. Additives that produce thin passivizing films typically inhibit the anodic m.al dissolving reaction; As a consequence of this, these inhibitors are known as anodic inhibitors (A. Rahim & Kassim, 2012).

Adsorption isotherms

Understanding the mechanism of the inhibitor and how it functions in relation to the target molecule is crucial when creating organic inhibitor systems. It is widely acknowledged that corrosion is prevented by organic molecules adhering to the metal/solution surface (Cisse et al., 2011). The chemical makeup of molecules, the chemical makeup of solutions, the type of the metal surface, temperature, and the electrochemical potential at the metal/solution interface all affect how much adsorption occurs. The adsorption isotherm can be determined if data on the degree of surface coverage by the inhibitor is available. The nature of this isotherm provides valuable information about the behavior of the substance that is absorbed as well as their interactions with the electrode surface (Musa et al., 2012).

The thermodynamics model can be used to explain the adsorption process, according to (Tang et al., 2019), while the kinetic model can be used to explain how an inhibitor prevents corrosion (Tang et al., 2019). The adsorption isotherm has been the subject of numerous proposals for equations. The following adsorption isotherms frequently provide the most accurate descriptions of the experimental data:

1. Langmuir Adsorption Isotherms, which are mathematically represented as:

   Kc = (2.11) where c is the substance's concentration in the solution, expressed as moles per liter, K is the adsorptional equilibrium constant, and is the surface coverage (see equation 20).

2. Isotherms of Frumkin Adsorption, which can be expressed as:

   Kc = / (1 –) exp (-f)... (2.12) where f is the adsorption energy [98].

3. The Temkin Adsorption Isotherms, which can be expressed as:

   Kc = exp (a) – I/I – exp (-1(1-))... (2.13)

   where a is an attraction constant, the constant of adsorptional equilibrium, and K is obtained from the free energy of adsorption.

   K = exp (- /RT)... (2.14) where R is the gas constant that can be determined from the degree of surface coverage (Tang et al., 2019).

Inhibitors' physical and chemical adsorption

Adsorption basically means that absorbate molecules are drawn to an adsorbent surface. An adsorbent material's unsaturated surface forces lead to the preferred concentration of molecules close to a surface. The forces that are both attracting and repelling are balanced during adsorption. Adsorption is almost always an exothermic reaction. Adsorption processes can be classified as either physical (Vander Waals adsorption) or chemical (activated adsorption) depending on the kind of forces that are interacting with the adsorbent and adsorbate.

Physical adsorption preserves the adsorbate and adsorbent's individuality. Through the sharing, transfer, or breakdown of electrons, the adsorbate is divided into individual bonded atoms or radicals in chemisorption. Physical adsorption can be quick (multi-molecular), monomolecular (unimolecular), or two, three, or more layers thick. When it occurs, physical adsorption begins as a monolayer. If the pores are close to the size of the molecules, they can become multi-layered, allowing for further adsorption until the adsorbate fills the pores to the brim. Chemisorption, on the other hand, requires the formation of chemical bonds between the adsorbent and adsorbate and can be gradual and reversible.

Physical adsorption occurs when the right temperature and pressure are present, whereas chemisorption only occurs when a chemical bond is established between the surface and the substance. Chemisorption is always completed by the creation of a monolayer, whereas physical adsorption can involve the formation of monolayers. At the same temperature and pressure as the adsorption, a physically adsorbed molecule can be removed unchanged, but chemisorbed layers cannot. Physical adsorption may occasionally occur on top of a chemisorbed monolayer.

Chemisorption can sometimes happen quickly, but most of the time it needs energy to activate [99]. Instantaneous physical adsorption takes place.

Adsorption kinetics

Similar to how any kinetic process can be represented, the rate at which a molecule adsorbs Rads onto a surface may also be expressed. In the case when it is stated in terms of the molecule's partial pressure above the surface in the gas phase, for example:

Rads = K’Px... (2.15) where x is the kinetic order, K’ is the rate constant, and P is the partial pressure. If the rate constant is then expressed in an Arrhenius form, we get a kinetic equation of the form:

A exp (-Ea / RT) = Rads. Px = (2.16), where Ea is the activation energy needed for adsorption and A is the pre-exponential (frequency) factor.

The rate of adsorption is influenced by the following factors:

1. the rate at which molecules arrive at the surface.
2. The proportion of incident molecules that are subjected to adsorption, or the rate of adsorption (per unit area of surface) as a function of the incident molecular flux, F, and the sticking probability,

S. Rads = S.F (molecules $m^{-2}s^{-1}$)...(2.17)

The Hertzx-Knudsen equation Flux,

F = P / (2 mkT)1/2 (molecules $m^{-2}s^{-1}$)................................ (2.18)

where P is the pressure in N/m^2, m = mass, kg; The sticking probability, which must fall within the range 0 < S< 1, is clearly a property of the adsorbate/substrate system under consideration; It may depend on a number of things, the most important of which are the number of species that have already been adsorbed (zero) and whether or not there is an activation barrier to adsorption. Therefore, in most cases,

S = f(). exp (-Ea / RT)... (2.19) where, once more, Ea is the activation energy for adsorption and f () is a function of the species' existing surface coverage that is yet to be determined.

Joining the conditions for S and F yields the accompanying articulation for the pace of adsorption [99]:

According to Chetouani et al. (2004), a thermodynamic model could adequately explain corrosion inhibition when the adsorption heat, adsorption free energy, and adsorption entropy are known [100]. R = (f().P)/2 kT exp(-Ea)/RT

The adsorption heat, H, can be calculated by plotting the linear regression between ln(k) and 1/T, according to the Van't Hoff equation (2.21). The standard adsorptional free energy, Go, can be calculated by using the equation:

(2.22) If the Langmuir adsorption isotherm is used, then: Kc = (C/55.5) exp (-Gads/RT)

(C/55.5) exp (-Gads/RT) = / (1-0).. (2.23)

The thermodynamic basic equation can be used to calculate the standard adsorptional entropy:

Go=Ho-Tso.. (2.24)

Kinetic parameters

Another useful tool for explaining the mechanism of corrosion inhibition is the kinetic model. The straight-line function of 1/T of steel in an acidic medium is used to represent the logarithm of the rate of corrosion (r) here, which looks like this:

(2.25) where Ea is the apparent activation energy, R is the universal gas constant, T is the absolute temperature, and A is the pre-exponential factor (Tang et al., 2019). Ln(r) = Ea / RT + ln (A)

Experimental inhibitors

Sodium benzoate (C_6H_5COONa)

The corrosion inhibitor sodium benzoate has been used for a very long time. The fact that it shields non-metals in addition to steel from corrosion is its strength. Since sodium benzoate is not an oxidizing agent, it is unlikely that it will contribute directly to the cathodic process and make corrosion worse at concentrations too low to completely stop it. Compounds that are soluble in it do not form. It is unlikely to cause local corrosion, in contrast to inorganic inhibitors like silicates, carbonates, and phosphates (A. A. Rahim et al., 2008).

Benzoates, according to Kuznetsov (2004), prevent passivation by introducing various substituents into the benzene ring and are effective adsorption type inhibitors (Mabrour et al., 2004). Non-oxidizing inhibitors like sodium polyphosphates, sodium silicates, sodium tetra borate (borax), and sodium benzoate are used to protect iron and steel in waters that are neutral or slightly alkaline (Bentiss et al., 1999).

Banana plant

The banana is a fruit that can be eaten. It is produced by a variety of large herbaceous flowering plants that belong to the genus *Musa parandisica.* The firmness, color, and size of the fruit vary.

Indomalaya, Australia, and the majority of West African nations are home to tropical Musa species. In Nigeria, it is a well-known food plant. It provides a significant amount of starch. It has shield-shaped leaves that can reach up to a meter in length and can reach a height of two meters.

Locust bean tree

The Locust Bean Tree, also known as the *Parkia biglobosa*, is a perennial tree that can grow to 30 meters in exceptional conditions. Its height ranges from 7 to 20 meters. Large, wide crown with low-lying branches on a staunt hole; Amber gum keeps bark, which is dark grey brown and thickly flied, out of wounds.

Five to ten years after the tree first bears fruit,

Lemon leaves (Citrus limonum)

a. Description/Taste: Lemon leaves grow alternately along the branches of lemon trees. They vary in precocity, beginning to ripen just before the first rain. Oval, oblong, and finely toothed, the leaves end at a point on the non-stem end. The surface of lemon leaves is matte on the underside and glossy on the top. Lemon leaves are aromatic and only slightly sweet when young, when they are actually red and turn deep green as they mature.

b. Seasons and Accessibility: Lemon leaves are available throughout the year.

c. Current Information: The authentic lemon is also known as Limon, *Limonagria real*, Limon Frances, or Limone. It belongs to the Rosacea genus. It is difficult to harvest the lemon leaves because its branches have a built-in defence mechanism. Although the commercial market for lemon leaves is still relatively small and clearly inferior to that of the lemon tree's primary commodity fruit, their use is widespread throughout many cultures worldwide.

d. Lemon leaves are used for more than just decoration. They can be used for their aromas, blanched and infused into teas, wrapped in meat or seafood, and roosted and steamed—their only non-decorative culinary use—are all options. Grilling the lemon leaves is an option. The lemon's leaves and branches can also be used to make an aromatic fire for grilling outside.

Factors influencing corrosion

A number of factors influence the underlying cause of metal corrosion. The elements listed below: during corrosion by mechanical methods. These attacks on corrosion are the result of a mechanical component working together.

Flow versus Erosion Corrosion caused in this manner: Most metals need to build and keep up a protective scale in order to be resistant to corrosion. Corrosion may quicken in places where scale has been removed. High-velocity flow or turbulence can remove the protective scale, exposing the newly formed metal surface to corrosive attack. It is known as flow-accelerated corrosion or erosion when scale erosion and underlying metal corrosion occur together.

Fretting is a type of corrosion: The relative motion of the surfaces in contact accelerates this corrosion. When a sudden change in pressure causes fluid vapour bubbles to form and burst, this is known as cavitation, which is a type of corrosion. Impingement of water drops is another name for cavitation. When the absolute pressure is decreased, the liquid can reach its vapour pressure, which can cause the bubbles to burst. When the void walls collide, a powerful shockwave is created, putting pressure of up to 1.5 GNln-2 on nearby tiny metal surfaces. The metal deforms in a plastic way as a result of the pressure. Cavitation damage occurs when a bubble collapses within the fluid repeatedly wears down the metal.

Deterioration Fatigue: This is caused by metals' cycles of stress and corrosive conditions. Mechanism for Rusting in Iron (Mild Steel): On polished mild steel, a thin protective oxide film forms when exposed to clean, dry air at standard temperatures. In the presence of electrolytes, the oxide layer does not provide any protection, and it frequently degrades in the air, water, and soil.

The anodic reaction is Fe Fe^{2+} + 2e-.

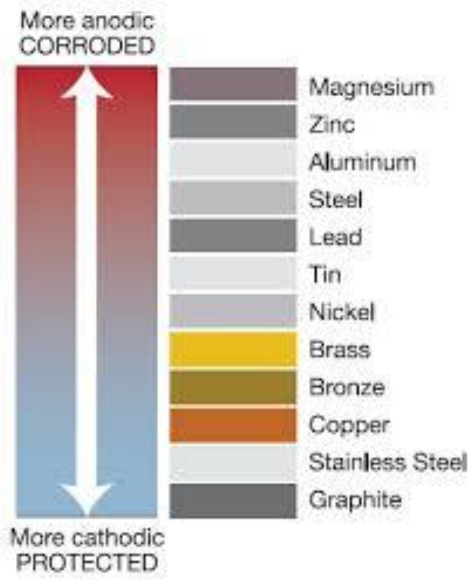
$2H^+$ + 2e- is the cathodic reaction in de-aerated solutions.

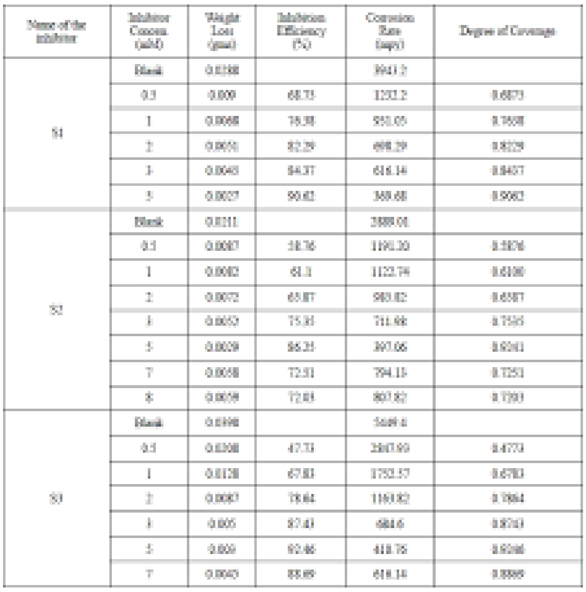
Acidic solutions experience this fast, but alkaline and neutral solutions experience it slowly. In the majority of situations, this is the most typical cathodic reaction type. To create ferrous hydroxide, OI-l- ions combine with Fe^{2+} ions.

A simple type of rust is created when this is oxidized and turns into ferric hydroxide ($Fe(OH_3)$). Reddish-brown rust, a well-known rust color, the final outcome is Fe_2O_3. When the supply of oxygen is low, H_2O, which can take many different forms, is utilised (Scheie, 1992). It's possible to make Fe_3O_4. Fe^{2+} + OH Rust's basic form, Fe (OH_3), is created when Fe $(OH)_2$ reacts with water to make ferric hydroxide. With a reddish brown tint, the final result is the well-known rust. Fe_2O_3. Other kinds of water can be used in place of oxygen in situations where there is a limited supply. Fe_3O_4 might form (Scheie, 1992).

Figure 2.

Table of alloys steel. Source: Steven Brandley Feb 25, 2021 https://materials.sandvik

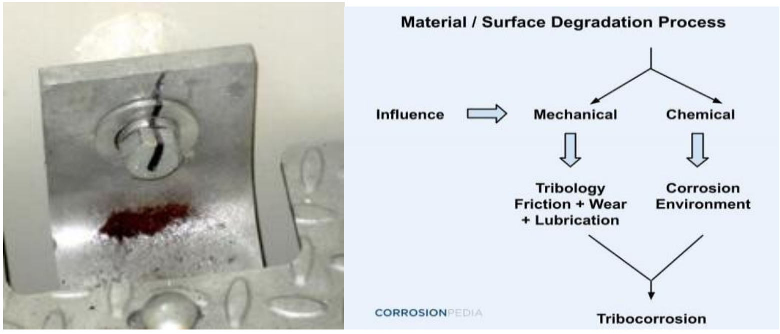




Name of the inhibitor	Inhibitor Concen. (mM)	Weight Loss (gms)	Inhibition Efficiency (%)	Corrosion Rate (mpy)	Degree of Coverage
S1	Blank	0.0188		3943.2	
	0.5	0.009	68.73	1232.2	0.6873
	1	0.0068	78.38	931.05	0.7838
	2	0.0051	82.29	698.29	0.8229
	3	0.0045	84.37	616.14	0.8437
	5	0.0027	90.62	369.68	0.9062
S2	Blank	0.0211		2888.01	
	0.5	0.0087	58.76	1191.20	0.5876
	1	0.0082	61.1	1122.74	0.6100
	2	0.0072	65.87	985.82	0.6587
	3	0.0052	75.35	711.98	0.7535
	5	0.0029	86.25	397.06	0.8261
	7	0.0058	72.51	794.15	0.7251
	8	0.0059	72.03	807.82	0.7203
S3	Blank	0.0398		5449.4	
	0.5	0.0208	47.73	2847.93	0.4773
	1	0.0128	67.83	1752.57	0.6783
	2	0.0087	78.64	1163.82	0.7864
	3	0.005	87.43	684.6	0.8743
	5	0.003	92.46	410.76	0.9246
	7	0.0045	88.69	616.14	0.8869

Figure 3.

Crack on the component cause by corrosion. Source: Paul Dvorak May 17, 2018



CHAPTER III

Materials and Methods

Materials

Inhibitors of the locust bean tree (*Pakia biglobosa*), banana sap, lemon leaves, hydrochloric acid (HCl), desiccators, a funnel, a burette, a retort stand, a water bath, abrasive papers ranging in grades from 240 to 600, and a weighing scale were all used in this study.

3.1.1 A mild steel X-ray fluorescence (XRF) method was used to conduct a chemical analysis on a market-purchased mild steel rod for this study. The findings regarding mild steel's fundamental composition are presented in Table 3.1.

Figure 4.

Examination of mild steel chemically

Fe	C	Si	S	P	Cr	V	Ni	Al	Mn
0.25	0.16	0.4	0.04	0.04	8	0.15	0.032	0.02	0.7

Inhibitors

Four (4) inhibitors were utilized throughout this research project. The inhibitors that came from plants were banana sap, lemon leaves, and the locust bean tree (*Pakiabi globosa*), with HCl being the fourth.

Figure 5.

Banana sap

Figure 6.

Locust bean

Figure 7.

Lemon leaves

In the phytochemical screening process, extracts of lemon, banana, and *Pakiabi globosa* sap were all used. Dry powders from the locust bean tree were used for the extraction and screening. Using a Soxlet extractor, the tannin, which is the primary component that prevents corrosion, was obtained (Yawas et al., 2005). The extracts' most important component is tannin.

Methods

Acid Solution

This study utilized a 0.5 M HCI acid solution. The amount of acid remained constant throughout the investigation. This concentration was chosen to allow for a fair number of reactions to take place within the allotted time frame due to the small size of the cuboids. The following concentrations of the inhibitors were altered to examine the effects of varying inhibitor amounts on the rate of corrosion and inhibitor efficiency: for each inhibitor, 0.5, 0.1, 1.5, 2.0, and 2.5) milliliters in distilled water.

Preparation of the Samples

Mild steel was cut into tiny cubiods, or specimens, measuring 2.0 cm by 1.5 cm by 1.0 cm. Abrasive papers of grades 220 to 600 were used to smoothen the cuboids in order to expose the sample surfaces. After being abraded, the sample was cleaned, degreased, dried, measured with a weighing scale, and kept in a desiccator to keep it out of the outside world.

Figure 8

Procedures for the Experiment

The acid solution was prepared prior to the start of the experiment by diluting concentrated HCl in distilled water to a concentration of 0.5 M HCl. In order to produce the solution that contained 0.1g/cm3 of the dried extracts, ethanol was added to distilled water in order to accelerate the process of dissolution. These stocks of solutions were used to prepare the inhibitor dosages of 0.5, 0.1, 1.5, 2.0, and 2.5 milliliters of filtered water.

A beaker houses the diluted HCl solution as part of the experimental setup. At first, the experiment was conducted without an inhibitor at 38°C. The beaker containing the HCl acid solution contained two steel weighted samples suspended in the air. The beaker was placed on a temperature-controlled water bath. The first sample was taken after an hour and the second after three because the corrosion rate was checked three times an hour. After being removed from the solution, each sample was cleaned, dried, reweighed, and recorded. At 45 °C and 55 °C, the same procedure was carried out unhindered.

The concentrations of the inhibitor that were used were as follows: 1.5, 2.0, and 2.5) milliliters in distilled water. This inhibitor received the same treatment as the others. The experiment was conducted at 38 °C, 45 °C, and 55 °C in the presence of inhibitors to examine the effect of temperature changes on the rate of corrosion and the extract's capacity to function as an inhibitor. Parameters were established on the basis of the reported weight loss.

Figure 9.

Preparation for an investigation corrosion test (a. mild steel b. inhibitors)

Weighting the corroding sample before and after exposure, dividing by the total exposed area and exposure duration, and employing the appropriate conversion constants to obtain the rate in the required units are the steps used to estimate a corrosion rate from mass loss. 3.3.1 Calculating Corrosion Rate The procedure can be represented in millimeters per year using the equation (3.1) that follows.

$C_R = \frac{k\ x\ \Delta w}{A\ x\ T\ x\ \rho}$ -------------------------------- (3.1)

Each trial's corrosion has been calculated using the formulae above:

$C_R = Penetration\ corossion\ rate\ in\ (mm/\text{yr})$

$\Delta w = Weight\ loss\ in\ gram$

$A = Exposed\ Surface\ area\ of\ Cuboid = ?$

$\rho = Density\ of\ mild\ Steel\ (g/cm^3) = 7.86gcm^{-3} = 0.00786\text{gmm}^{-3}$

$T = Time\ of\ exposure\ in\ hours = ?$

$k = Constant\ for\ unit\ conversion = 87.6$

A = Surface area of the cuboid in its entirety $= 2(1 \times b + b \times 1 + b \times h)$

$= 2(1.5 + 1.5 \times 1) = 2(4) = 8cm^2 = 800\text{mm}^2$

Corrosion rate at 45^0C for Lemon Leaves:

$\Delta w = Weight\ loss\ in\ gram = 0.048\text{g} = 0.000048\text{milligrams}$

$\rho = Density\ of\ mild\ Steel\ (g/cm^3) = 7.86gcm^{-3}$

$T = Time\ of\ exposure\ in\ hours = 1\text{hr}$

$k = Constant\ for\ unit\ conversion = 87.6$

A = Total surface area of the cuboid $= 800\text{mm}^2$

$C_R = \frac{k\ x\ \Delta w}{A\ x\ T\ x\ \rho} = \frac{87.6\ x\ 0.000048}{8\ x\ 1\ x\ 7.86} = \frac{0.0042048}{62.88} = 6.69 \times 10^{-5}\text{mm/yr at } 45^0\text{C}$

Corrosion rate at 55^0C for Lemon Leaves:

$\Delta w = Weight\ loss\ in\ gram = 0.036\text{g} = 0.000036\text{milligrams}$

$\rho = Density\ of\ mild\ Steel\ (g/cm^3) = 7.86gcm^{-3}$

$T = Time\ of\ exposure\ in\ hours = 1\text{hr}$

$k = Constant\ for\ unit\ conversion = 87.6$

$A = Exposed\ Surface\ area\ of\ Coupon$= $8cm^2$ = 800mm^2

$C_R = \frac{k\ x\ \Delta w}{A\ x\ T\ x\ \rho} = \frac{87.6\ x\ 0.000036}{8\ x\ 1\ x\ 7.86} = \frac{0.0031536}{62.88}$ = 5.02 x 10^{-5}mm/yr at 55^{0}C

The corrosion rate was calculated for the inhibitors at different concentration and temperatures using MS Excel and their results were presented in Chapter Four.

3.3.2 Inhibitor Efficiency

The values of inhibitor efficiencies and surface coverage were determined for each of the two inhibitors according to Quraishi & Jamal (2002) as inflows:

$$I_E = \frac{(r_0 - r)\ x\ 100\%}{r_0} \qquad \text{--(3.2)}$$

Where; r_0 = corrosion rate in the absence of an inhibitor

r = corrosion rate in the presence of an inhibitor.

The surface coverage θ, is calculated from the formula:

$$\theta\ = \frac{(r_0 - r)}{r_0}$$

Calculation for Lemon Leaves at 0.5ml concentration of inhibitor with a temperature of 38^{0}C

$$I_E = \frac{(r_0 - r)\ x\ 100\%}{r_0}$$

r_0 = corrosion rate in the absence of an inhibitor = 3.76 x10^{-5} mm/yr
r = corrosion rate when an inhibitor is present = 3.06 x 10^{-5} mm/yr

$$I_E = \frac{(3.76\ x10^{-5}\ - 3.06\ x10^{-5}\ )\ x\ 100\%}{3.76x10^{-5}} = \frac{0.7x10^{-5}\ x\ 100\%}{3.76x10^{-5}} = \frac{70\%}{3.76} = 18.6\%$$

Calculation for Lemon Leaves at 1.0ml concentration of inhibitor with a temperature of 38^{0}C

$$I_E = \frac{(r_0 - r)\ x\ 100\%}{r_0}$$

r_0 = corrosion rate in the absence of an inhibitor = 3.76x10^{-5}mm/yr
r = corrosion rate when an inhibitor is present = 3.06 x 10^{-5}mm/yr

$$I_E = \frac{(3.76\ x10^{-5}\ - 2.36\ x10^{-5}\ )\ x\ 100\%}{3.76\ x10^{-5}} = \frac{1.39\ x10^{-5}\ x\ 100\%}{3.76x10^{-5}} = \frac{139\%}{3.76} = 37.0\%$$

MS Excel was used to calculate the inhibitor efficiency for the corrosion rate at various concentrations and temperatures, and the results were presented in Chapter Four.

CHAPTER IV

Findings and Discussion

Results

The corrosion rate of the steel specimen was calculated using Equation 3.1 at various temperatures and exposure times in both the absence and presence of the inhibitor. The values of the inhibitor's inhibitor efficiency were obtained using equation 3.2. The numerous graphs presented here were plotted using the outcomes of the various equations:

Table 1.

The Locust beans' corrosion rate (r0) in the absence of an inhibitor after one hour and three hours

Time (Hr)	Cr at 38 ^{0}C	Cr at 45 ^{0}C	Cr at 55 ^{0}C
1	1.62 x10^{-5}	6.08 x10^{-5}	8.75 x10^{-5}
3	5.76 x10^{-5}	7.48 x10^{-5}	3.88 x10^{-5}

Table 2.

Corrosion rate in the absent of inhibitor (r0) after 1hr and 3hrs for banana sap

Time (Hr)	Cr at 38^{0}C	Cr at 45^{0}C	Cr at 55^{0}C
1	11.25 x10^{-5}	4.16 x10^{-5}	1.37 x10^{-5}
3	5.41 x10^{-5}	3.81 x10^{-5}	5.97 x10^{-5}

Table 3.

Corrosion rate for lemon leaves after one hour and three hours in the absence of an inhibitor (r0)

Time (Hr)	Cr at 38^{0}C	Cr at 45^{0}C	Cr at 55^{0}C

1	3.76 x 10^{-5}	6.69 x 10^{-5}	5.02 x 10^{-5}
3	1.30 x 10^{-5}	1.11 x 10^{-5}	1.25 x 10^{-5}

Table 4.

Locust beans' corrosion rate after an hour at various concentrations and temperatures in the presence of an inhibitor

Concentration of Inhibitor (ml)	Cr at 38^0C	Cr at 45^0C	Cr at 55^0C
0	1.62 x10^{-5}	6.08 x10^{-5}	8.75 x10^{-5}
0.5	1.35 x10^{-5}	6.00 x10^{-5}	5.83 x10^{-5}
1.0	1.20 x10^{-5}	5.35 x10^{-5}	5.41 x10^{-5}
1.5	1.16 x10^{-5}	3.89 x10^{-5}	4.79 x10^{-5}
2.0	0.95 x10^{-5}	0.45 x10^{-5}	4.58 x10^{-5}
2.5	0.85 x10^{-5}	0.37 x10^{-5}	4.37 x10^{-5}

Table 5.

After 1 hour, the rate of corrosion in the presence of an inhibitor in banana sap at various concentrations and temperatures

Concentration of Inhibitor (ml)	Cr at 38^0C	Cr at 45^0C	Cr at 55^0C
0	11.25 x10^{-5}	4.16 x10^{-5}	1.37 x10^{-5}
0.5	8.75 x10^{-5}	3.75 x10^{-5}	1.27 x10^{-5}
1.0	8.33 x10^{-5}	3.54 x10^{-5}	1.18 x10^{-5}
1.5	8.33 x10^{-5}	3.12 x10^{-5}	1.02 x10^{-5}
2.0	6.25 x10^{-5}	2.70 x10^{-5}	0.91 x10^{-5}
2.5	4.16 x10^{-5}	2.29 x10^{-5}	0.83 x10^{-5}

Table 6.

After 1 hour, the rate of corrosion in the presence of an inhibitor in lemon leaves of various concentrations and temperatures

Concentration of Inhibitor (ml)	Cr at 38^0C	Cr at 45^0C	Cr at 55^0C
0	3.76×10^{-5}	6.69×10^{-5}	5.02×10^{-5}
0.5	3.06×10^{-5}	4.74×10^{-5}	3.90×10^{-5}
1.0	2.36×10^{-5}	3.06×10^{-5}	3.48×10^{-5}
1.5	2.23×10^{-5}	2.93×10^{-5}	3.20×10^{-5}
2.0	2.09×10^{-5}	2.39×10^{-5}	4.18×10^{-5}
2.5	1.95×10^{-5}	1.67×10^{-5}	2.79×10^{-5}

Table 7.

After three hours, the rate of corrosion for locust beans in the presence of an inhibitor at various concentrations and temperatures

Concentration of Inhibitor (ml)	Cr at 38^0C	Cr at 45^0C	Cr at 55^0C
0	57.6×10^{-5}	7.48×10^{-5}	3.88×10^{-5}
0.5	54.8×10^{-5}	6.72×10^{-5}	2.43×10^{-5}
1.0	53.4×10^{-5}	4.92×10^{-5}	2.22×10^{-5}
1.5	40.9×10^{-5}	4.88×10^{-5}	2.15×10^{-5}
2.0	38.8×10^{-5}	4.35×10^{-5}	2.01×10^{-5}
2.5	34.0×10^{-5}	3.52×10^{-5}	1.80×10^{-5}

Table 8.

After three hours, the rate of corrosion for banana sap in the presence of an inhibitor at various concentrations and temperatures

Concentration of Inhibitor (ml)	Cr at 38^0C	Cr at 45^0C	Cr at 55^0C

0	5.41 x10^{-5}	3.81 x10^{-5}	5.97 x10^{-5}
0.5	3.12 x10^{-5}	3.54 x10^{-5}	5.55 x10^{-5}
1.0	0.90 x10^{-5}	3.33 x10^{-5}	5.34 x10^{-5}
1.5	0.55 x10^{-5}	3.19 x10^{-5}	5.20 x10^{-5}
2.0	0.48 x10^{-5}	3.05 x10^{-5}	5.13 x10^{-5}
2.5	0.37 x10^{-5}	2.98 x10^{-5}	4.72 x10^{-5}

Table 9.

After three hours, the rate of corrosion for lemon leaves in the presence of an inhibitor at various concentrations and temperatures

Concentration of Inhibitor (ml)	Cr at 38^{0}C	Cr at 45^{0}C	Cr at 55^{0}C
0	1.30 x10^{-5}	1.11 x10^{-5}	1.25 x10^{-5}
0.5	1.25 x10^{-5}	7.89 x10^{-6}	1.21 x10^{-5}
1.0	1.20 x10^{-5}	6.04 x10^{-6}	1.16 x10^{-5}
1.5	1.07 x10^{-5}	5.57 x10^{-6}	1.07 x10^{-5}
2.0	1.02 x10^{-5}	5.11 x10^{-6}	1.02 x10^{-5}
2.5	1.02 x10^{-5}	4.64 x10^{-6}	9.75 x10^{-6}

Table 10.

Efficacy of the inhibitor for locust beans after 1 hour at various doses and temperatures

Concentration of Inhibitor (ml)	Ie (%) at 38^{0}C	Ie (%) at 45^{0}C	Ie (%) at 55^{0}C
0.5	16.7	1.32	33.4
1.0	25.9	12.0	38.2
1.5	28.4	36.0	45.3
2.0	41.4	92.6	47.7
2.5	47.5	93.9	50.1

Table 11.

After one hour, banana sap inhibitor effectiveness at various temperatures and concentrations

Concentration of Inhibitor (ml)	Ie (%) at 38^0C	Ie (%) at 45^0C	Ie (%) at 55^0C
0.5	22.2	9.9	7.3
1.0	25.9	14.9	13.9
1.5	26.0	25.0	25.5
2.0	44.4	35.1	33.6
2.5	63.0	45.0	39.4

Table 12.

The efficiency of the inhibitor for Lemon Leaves at various temperatures and concentrations after an hour

Concentration of Inhibitor (ml)	Ie (%) at 38^0C	Ie (%) at 45^0C	Ie (%) at 55^0C
0.5	18.5	54.2	22.2
1.0	37.0	56.3	30.6
1.5	40.7	64.6	36.1
2.0	44.4	75.0	41.7
2.5	48.2	100.0	44.4

Table 13.

Inhibitor efficiency at different concentrations and temperatures after 3hrs for Locust Beans

Table 14.

Inhibitor efficiency at different temperatures and concentrations after 3hrs for banana sap

Table 15.

Inhibitor efficiency at different temperatures and concentrations after 3hrs for lemon leaves

Concentration of Inhibitor (ml)	Ie (%) at 38^{0}C	Ie (%) at 45^{0}C	Ie (%) at 55^{0}C
0.5	42.3	7.1	7.0
1.0	83.4	12.6	10.6
1.5	89.8	16.3	12.9
2.0	91.1	19.9	14.1
2.5	93.2	21.8	20.9

Concentration of Inhibitor (ml)	Ie (%) at 38^{0}C	Ie (%) at 45^{0}C	Ie (%) at 55^{0}C
0.5	3.6	29.2	3.7
1.0	7.1	45.8	7.4
1.5	17.9	50.0	14.8
2.0	21.4	54.2	18.5
2.5	46.4	58.3	22.2

Figure 8.

A graph of corrosion rate for plants extracts with concentration of inhibitor at 1 hour

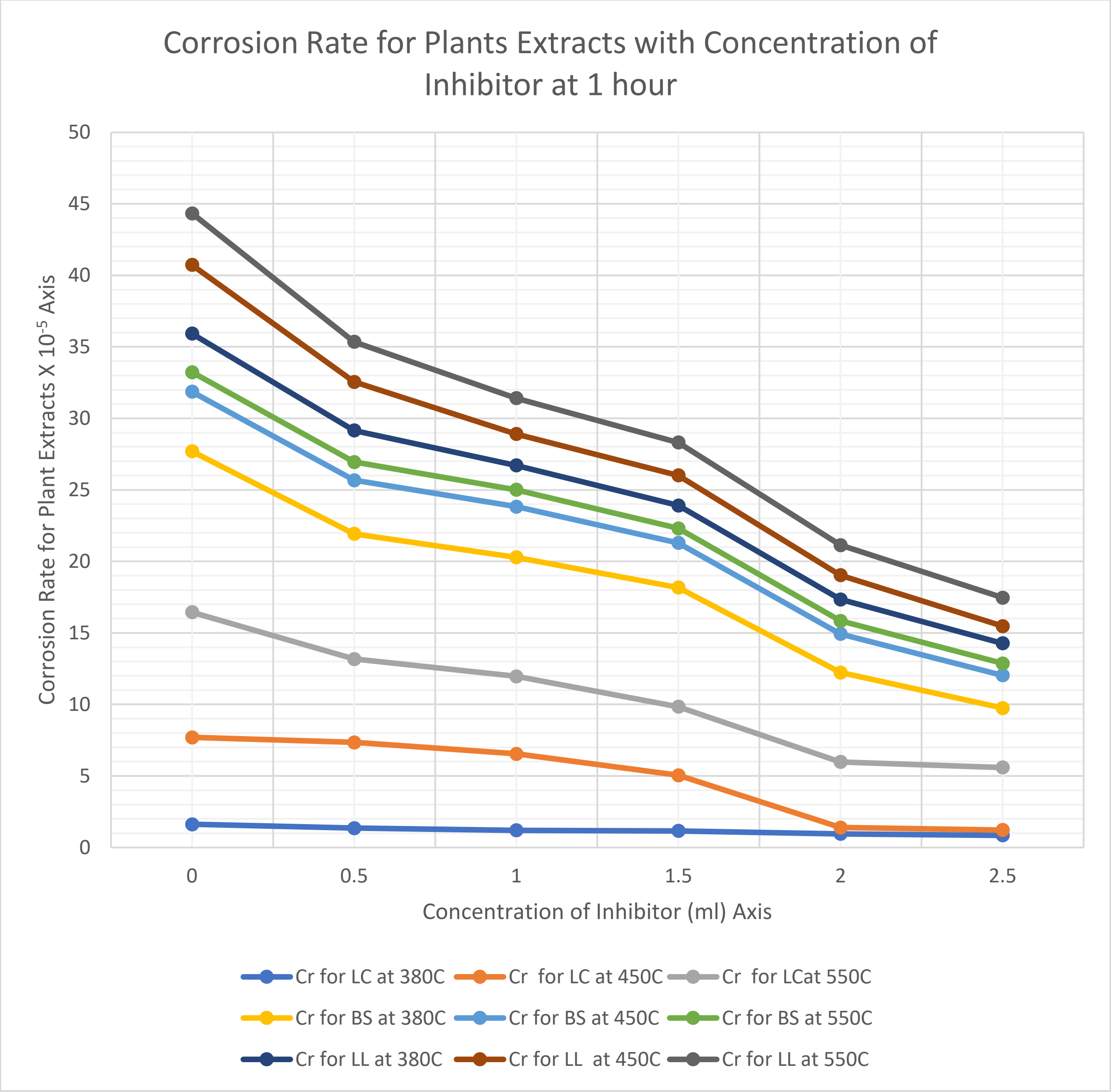


Figure 9.

A graph of corrosion rate for plants extracts with concentration of inhibitor at 3 hours

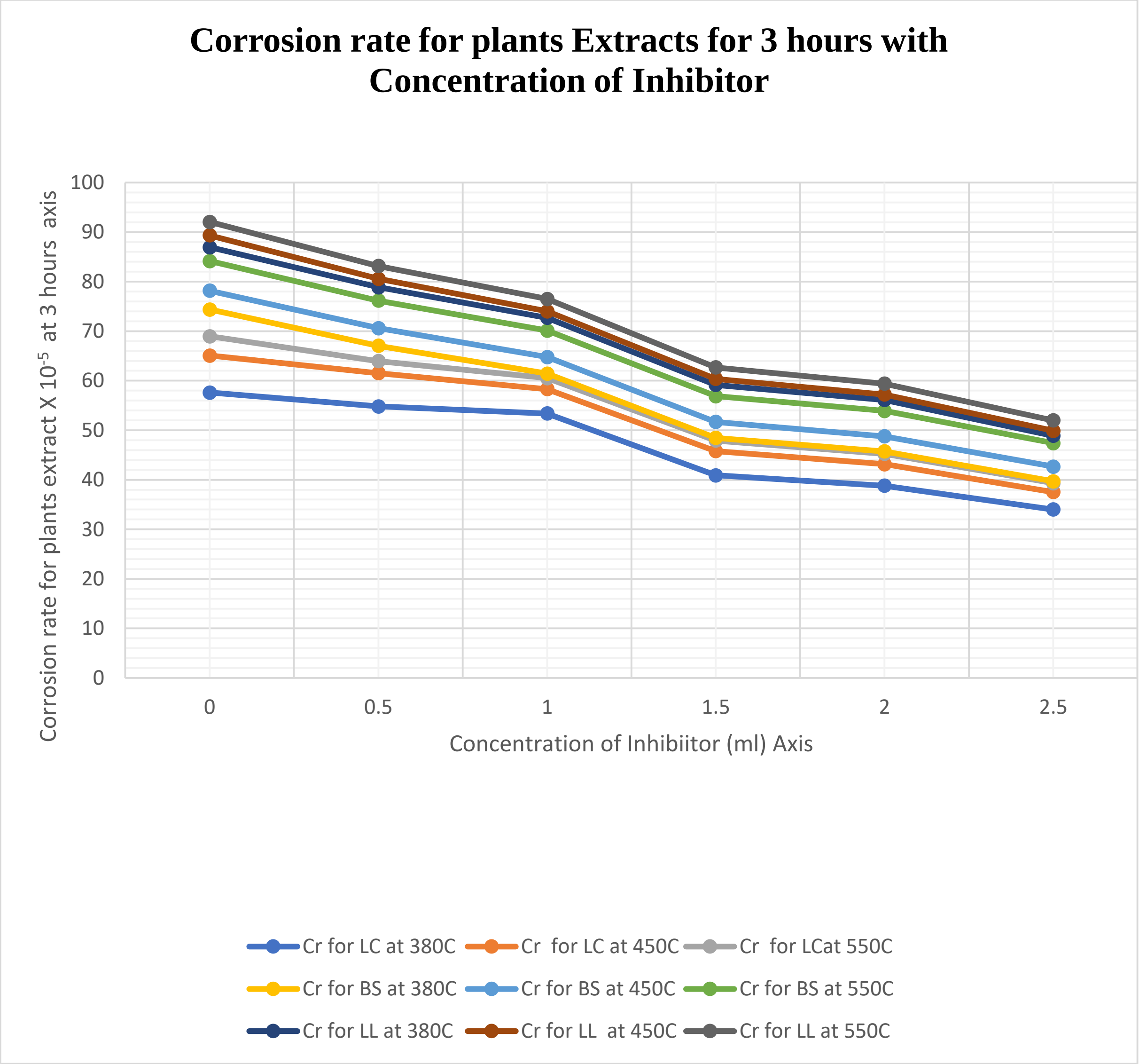


Figure 10.

Inhibitor efficiency for plants extracts at different temperatures after 1 hour

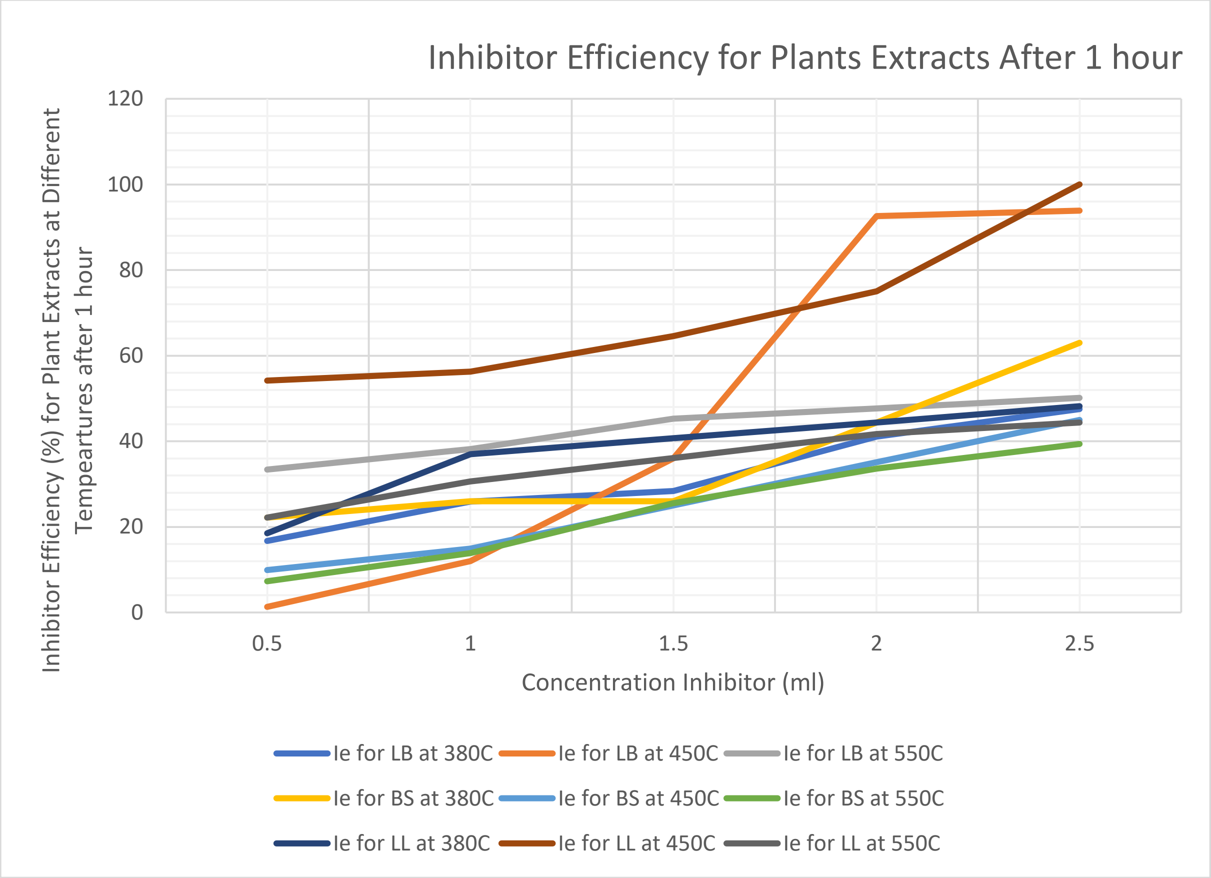
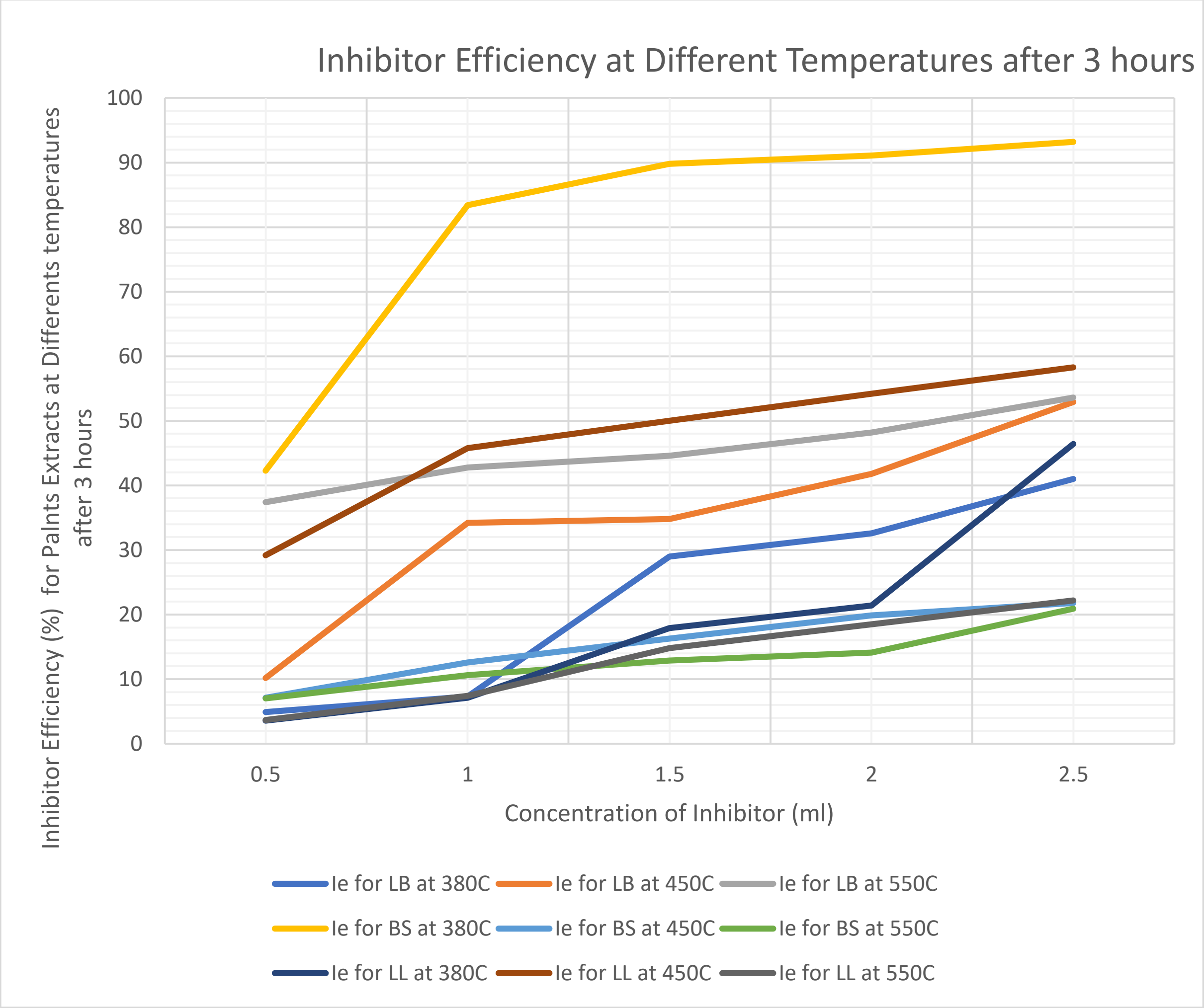


Figure 11.

Inhibitor efficiency for plants extracts at different temperatures after 3 hours



Analysis of Results

The results obtained for corrosion rate from the loss weight experiments was analyzed using analysis of variance (ANOVA) and linear regression was generated using Minitab-16 software.

The regression equation is

Cr = - 6.43 - 1.49 Conc. + 0.256 tempt ……………………………………………….. 4.1

Predictor	Coef.	SE Coef	T	P
Constant	-6.425	1.940	-3.31	0.005
Conc.	-1.4861	0.3327	-4.47	0.000
Tempt	0.25615	0.04072	6.29	0.000

S = 1.20528 R-Sq = 79.9% R-Sq(adj) = 77.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	86.464	43.232	29.76	0.000
Residual Error	15	21.790	1.453		
Total	17	108.255			

Source	DF	Seq SS
Conc	1	28.986
tempt	1	57.478

CHAPTER V

Discussion

Discussion of the Findings

After exposure, the colors of the cuboids—those with and without an inhibitor—change from shiny to dull when viewed visually. The colors were more pronounced when cuboids were exposed to solution without the extract. They demonstrate that while temperature increases the rate of corrosion, it decreases over time. In accordance with Ayeni's 2007 [107] findings, corrosion rate variations were ordered (Cr) 55^{o}C > (Cr) 45^{o}C > (Cr) 38^{o}C. Additionally, it demonstrates that the rate of corrosion decreases with exposure time.

The locust bean plant extract had a maximum corrosion rate of 1.35 x 10^{-5} mm/yr and a corrosion effectiveness of 47.5% after one hour of exposure. The highest corrosion performance was 41% and the corrosion rate increased to 54.8 x 10^{-5} mm/yr after three hours. At 45°C, a corrosion efficiency of 93.9 percent and 6.00 x 10^{-5} mm/yr were measured. The inhibitor's efficiency is 50.1% and the maximum corrosion rate is 5.83 x 10^{-5} mm/year at 55^{o}C. The fact that the rate of corrosion decreased with the concentration of locust bean suggests that a greater number of inhibitor species are available at higher concentrations to obstruct corrosion sites, form films on the surface of the steel, or embed themselves on the steel, all of which reduce the rate of corrosion. The fact that corrosion rates rise with temperature is not surprising. This is in line with the way that temperature affects how quickly chemical reactions happen.

According to Table 4.4.1 and Figureure 4.3, the inhibitor efficiency of the locust beans in an acidic environment after an hour of exposure was measured as having a minimum efficiency of 1.32 percent at 45°C with a concentration of the inhibitor and a maximum efficiency of 93.9 percent with a concentration of the inhibitor of 2.5 ml. With a concentration of 0.5 milliliters of the inhibitor, the minimum efficiency after three hours is 4.9% at 38°C, while the maximum efficiency is 53.6 percent at 55°C, as shown in Table 4.5.1 and Figureure 4.4. This suggests that corrosion rates decreased as inhibitor concentration and exposure time increased. However, the inhibitor's effectiveness increased with temperature, reaching 93.9% in locust beans.

After one hour of exposure at 38°C, the plant extract of banana sap displayed maximum corrosion rates of 8.75 x 10^{-5} mm/yr with a corrosion efficiency of 63.0% and 3.12 x 10^{-5} mm/yr with a corrosion efficiency of 93.2 percent. At 45°C, a corrosion efficiency of 45.0% and 3.75x10^{-5} mm/yr were observed. The inhibitor efficiency is 39.4% and the highest corrosion rate is 1.27x10^{-5} mm/yr at 55°C. According to the relationship between the concentration of banana sap and the rate of corrosion, more inhibitor species are available at higher concentrations to impede corrosion sites, form films on the steel's surface, or absorb themselves on the steel, all of which reduce the rate of corrosion. The fact that corrosion rates rise with temperature is not surprising. This is in line with the way that temperature affects how quickly chemical reactions happen.

According to Table 4.4.2 and Figureure 4.3, the inhibitor effectiveness of banana sap in an acidic environment after one hour of exposure recorded a minimum efficiency of 7.3% at 55^0C and a maximum efficiency of 63.0% at 38°C with the inhibitor concentration. At 55°C and a concentration of 0.5 milliliters of the inhibitor, the lowest efficiency after three hours is 7.0%, while the highest efficiency is 93.2% at 38°C and a concentration of 2.5 milliliters of the inhibitor is shown in Table 4.5.2. It was discovered that as exposure time and inhibitor concentration increased, corrosion rates decreased. However, as the temperature rose, the inhibitors became more effective, leading to a 93.2 percent yield of bananas.

The lemon leaf plant extract had a maximum corrosion rate of 3.06 x 10^{-5} mm/yr and a corrosion efficiency of 48.2 percent after one hour of exposure. The highest corrosion rate and corrosion efficiency after three hours were 1.25 x 10^{-5} mm/yr. At 45°C, we measured corrosion efficiency of 100 percent and 4.74x10^{-5} mm/yr. The inhibitor efficiency is 44.4% and the highest corrosion rate is 4.18x10^{-5} mm/yr at 55°C. Lemon leaf concentration shows a correlation with a decrease in corrosion rate. This suggests that, at higher concentrations, more inhibitor species are available to block corrosion sites, form films on the steel's surface, or absorb themselves on the steel, thereby reducing corrosion rate. The fact that corrosion rates rise with heating is not surprising. This is in line with the way that temperature affects how quickly chemical reactions happen.

According to Table 4.4.3 and Figure 4.3, the Lemon Leaves inhibitor efficiency in the acidic environment was reported to have a minimum efficiency of 18.5% at 38°C and a maximum efficiency of 100% at 45°C after a one-hour exposure at a concentration of 2.5 ml. At 38°C and a concentration of 0.5 milliliters of the inhibitor, the lowest efficiency after three hours is 3.6%, while the highest efficiency is 58.3% at 45°C and a concentration of 2.5 milliliters of the inhibitor is shown in Figure 4.4. This indicates that corrosion rates decreased with increasing inhibitor concentration and exposure time. However, Lemon Leaves had an inhibitor efficiency rating of 58.3% as the temperature rose.

CHAPTER VI

Conclusion and Recommendations

Conclusions

Based on the weight loss measurement results for the examination of the corrosion inhibition properties of plant extracts (locust beans, banana sap, and lemon leaves) in a hydrochloric acid environment, the following conclusions were drawn:

1. In an acidic environment, the extracts of lemon leaves, banana sap, and locust beans may be mild steel corrosion inhibitors. It was discovered that while exposure time and inhibitor concentration increased the corrosion rates, temperature decreased them. The locust bean, banana sap, and lemon leaves were ranked according to how effective the inhibitor was at stopping growth: 93.9 percent, 93.2 percent, and 96.1%, respectively.
2. In the 0.5 M HCl solution, the outcome demonstrates that locust bean extract and lemon leaves are superior inhibitors to banana sap inhibitor.

Recommendations

1. In order to determine the concentration at which the extract will not be effective, it is necessary to investigate the effect that varying the acid concentration has.
2. It is necessary to investigate the effects of plant extracts as corrosion inhibitors in alkaline media for potential applications in basic media.
3. To add to the list of plant extracts that could be used as inhibitors for mild steel and other industrial applications in various results, additional non-toxic and effective plant extracts ought to be investigated.

REFERENCES

Abd El-Maksoud, S. A., & Fouda, A. S. (2005). Some pyridine derivatives as corrosion inhibitors for carbon steel in acidic medium. *Materials Chemistry and Physics*, *93*(1), 84–90. https://doi.org/10.1016/J.MATCHEMPHYS.2005.02.020

Adam, M. R., Rahim, A. A., & Shah, A. M. (2015). Synergy between iodide ions and mangrove tannins as inhibitors of mild steel corrosion. *Annals of Forest Science*, *72*(1), 9–15. https://doi.org/10.1007/S13595-014-0398-9/TABLES/4

Alaneme, K. K., Olusegun, S. J., & Adelowo, O. T. (2016). Corrosion inhibition and adsorption mechanism studies of Hunteria umbellata seed husk extracts on mild steel immersed in acidic solutions. *Alexandria Engineering Journal*, *55*(1), 673–681. https://doi.org/10.1016/J.AEJ.2015.10.009

Alaneme, K. K., Olusegun, S. J., & Alo, A. W. (2016). Corrosion inhibitory properties of elephant grass (Pennisetum purpureum) extract: Effect on mild steel corrosion in 1 M HCl solution. *Alexandria Engineering Journal*, *55*(2), 1069–1076. https://doi.org/10.1016/J.AEJ.2016.03.012

Alaoui Mouayd, A., Koltsov, A., Sutter, E., & Tribollet, B. (2014). Effect of silicon content in steel and oxidation temperature on scale growth and morphology. *Materials Chemistry and Physics*, *143*(3), 996–1004. https://doi.org/10.1016/J.MATCHEMPHYS.2013.10.037

Alibakhshi, E., Ramezanzadeh, M., Haddadi, S. A., Bahlakeh, G., Ramezanzadeh, B., & Mahdavian, M. (2019). Persian Liquorice extract as a highly efficient sustainable corrosion inhibitor for mild steel in sodium chloride solution. *Journal of Cleaner Production*, *210*, 660–672. https://doi.org/10.1016/J.JCLEPRO.2018.11.053

Amadi, S. A. (2000). Corrosion Control. *Journal of School of Engineering*, *1*, 32.

Ansari, K. R., Quraishi, M. A., & Singh, A. (2015). Pyridine derivatives as corrosion inhibitors for N80 steel in 15% HCl: Electrochemical, surface and quantum chemical studies. *Measurement*, *76*, 136–147. https://doi.org/10.1016/J.MEASUREMENT.2015.08.028

Antonijević, M. M., Milić, S. M., & Petrović, M. B. (2009). Films formed on copper surface in chloride media in the presence of azoles. *Corrosion Science*, *51*(6), 1228–1237. https://doi.org/10.1016/J.CORSCI.2009.03.026

Arthur, D. E., Jonathan, A., Ameh, P. O., & Anya, C. (2013). A review on the assessment of polymeric materials used as corrosion inhibitor of metals and alloys. *International Journal of Industrial Chemistry*, *4*(1), 2. https://doi.org/10.1186/2228-5547-4-2

Benahmed, M., Selatnia, I., Djeddi, N., Akkal, S., & Laouer, H. (2020). Adsorption and Corrosion Inhibition Properties of Butanolic Extract of Elaeoselinum thapsioides and Its Synergistic Effect with Reutera lutea (Desf.) Maires (Apiaceae) on A283 carbon Steel in Hydrochloric Acid Solution. *Chemistry Africa*, *3*(1), 251–261. https://doi.org/10.1007/S42250-019-00093-8/TABLES/8

Bentiss, F., Lagrenee, M., Traisnel, M., & Hornez, J. C. (1999). The corrosion inhibition of mild steel in acidic media by a new triazole derivative. *Corrosion Science*, *41*(4), 789–803. https://doi.org/10.1016/S0010-938X(98)00153-X

Bethencourt, M., Botana, F. J., Calvino, J. J., Marcos, M., & Rodríguez-Chacón, M. A. (1998). Lanthanide compounds as environmentally-friendly corrosion inhibitors of aluminium alloys: a review. *Corrosion Science*, *40*(11), 1803–1819. https://doi.org/10.1016/S0010-938X(98)00077-8

Brycki, B. E., Kowalczyk, I. H., Szulc, A., Kaczerewska, O., Pakiet, M., Brycki, B. E., Kowalczyk, I. H., Szulc, A., Kaczerewska, O., & Pakiet, M. (2017). Organic Corrosion Inhibitors. *Corrosion Inhibitors, Principles and Recent Applications*. https://doi.org/10.5772/INTECHOPEN.72943

Capello, C., Fischer, U., & Hungerbühler, K. (2007). What is a green solvent? A comprehensive framework for the environmental assessment of solvents. *Green Chemistry*, *9*(9), 927–934. https://doi.org/10.1039/B617536H

Chauhan, D. S., Quraishi, M. A., & Qurashi, A. (2021). Recent trends in environmentally sustainable Sweet corrosion inhibitors. *Journal of Molecular Liquids*, *326*, 115117. https://doi.org/10.1016/J.MOLLIQ.2020.115117

Chuka, C. E., Odio, B., Chukwuneke, J., & Sinebe, J. E. (2014). Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments. *International Journal of Scientific & Technology Research*.

Chung, I. M., Kim, S. H., Hemapriya, V., Kalaiselvi, K., & Prabakaran, M. (2019). Inhibition behavior of Tragia involucrata L. phenolic compounds against acidic medium corrosion in low carbon steel surface. *Chinese Journal of Chemical Engineering*, *27*(3), 717–725. https://doi.org/10.1016/J.CJCHE.2018.10.008

Cisse, M. B., Zerga, B., El Kalai, F., Touhami, M. E., Sfaira, M., & Taleb, M. (2011). Surface Review and Letters. *Surface Review and Letters.*, *18*(303).

Daley, R. R., & Hodges, S. A. (2010). *Novel, Environmentally Friendly Corrosion Inhibitor for Self-Etching Wash Primers*. Paint and Coatings Industry,.

Dargahi, M., Olsson, A. L. J., Tufenkji, N., & Gaudreault, R. (2015). Green Technology: Tannin-Based Corrosion Inhibitor for Protection of Mild Steel. *Corrosion*, *71*(11), 1321–1329. https://doi.org/10.5006/1777

Dugo, P., Mondello, L., Errante, G., Zappia, G., & Dugo, G. (2001). Identification of Anthocyanins in Berries by Narrow-Bore High-Performance Liquid Chromatography with Electrospray Ionization Detection. *Journal of Agricultural and Food Chemistry*, *49*(8), 3987–3992. https://doi.org/10.1021/JF001495E

Eddy, N. O., Odoemelam, S. A., & Odiongenyi, A. O. (2009). Inhibitive, adsorption and synergistic studies on ethanol extract of Gnetum Africana as green corrosion inhibitor for mild steel in H2SO4. *Http://Mc.Manuscriptcentral.Com/Tgcl*, *2*(2), 111–119. https://doi.org/10.1080/17518250903170868

El Ibrahimi, B., Jmiai, A., Bazzi, L., & El Issami, S. (2020). Amino acids and their derivatives as corrosion inhibitors for metals and alloys. *Arabian Journal of Chemistry*, *13*(1), 740–771. https://doi.org/10.1016/J.ARABJC.2017.07.013

Faisal, M., Saeed, A., Shahzad, D., Abbas, N., Ali Larik, F., Ali Channar, P., Abdul Fattah, T., Muhammad Khan, D., & Aaliya Shehzadi, S. (2018). General properties and comparison of the corrosion inhibition efficiencies of the triazole derivatives for mild steel. *Corrosion Reviews*, *36*(6), 507–545. https://doi.org/10.1515/CORRREV-2018-0006/ASSET/GRAPHIC/J_CORRREV-2018-0006_EQ_20.JPG

Faiz, M., Zahari, A., Awang, K., & Hussin, H. (2020). Corrosion inhibition on mild steel in 1 M HCl solution by Cryptocarya nigra extracts and three of its constituents (alkaloids). *RSC Advances*, *10*(11), 6547–6562. https://doi.org/10.1039/C9RA05654H

Fontana, M. . (1986). *Corrosion Engineering* (3rd ed.). McGraw- Hill Book Company.

Gerengi, H., & Sahin, H. I. (2011). Schinopsis lorentzii Extract As a Green Corrosion Inhibitor for Low Carbon Steel in 1 M HCl Solution. *Industrial and Engineering Chemistry Research*, *51*(2), 780–787. https://doi.org/10.1021/IE201776Q

Goni, L. K. M. O., Mazumder, M. A. J., Goni, L. K. M. O., & Mazumder, M. A. J. (2019). Green Corrosion Inhibitors. *Corrosion Inhibitors*. https://doi.org/10.5772/INTECHOPEN.81376

Goyal, M., Kumar, S., Bahadur, I., Verma, C., & Ebenso, E. E. (2018). Organic corrosion inhibitors for industrial cleaning of ferrous and non-ferrous metals in acidic solutions: A review. *Journal of Molecular Liquids*, *256*, 565–573. https://doi.org/10.1016/J.MOLLIQ.2018.02.045

Gromboni, M. F., Sales, A., Rezende, M. de A. M., Moretti, J. P., Corradini, P. G., & Mascaro, L. H. (2021). Impact of agro-industrial waste on steel corrosion susceptibility in media simulating concrete pore solutions. *Journal of Cleaner Production*, *284*, 124697. https://doi.org/10.1016/J.JCLEPRO.2020.124697

Habeeb, H. J., Luaibi, H. M., Dakhil, R. M., Kadhum, A. A. H., Al-Amiery, A. A., & Gaaz, T. S. (2018). Development of new corrosion inhibitor tested on mild steel supported by electrochemical study. *Results in Physics*, *8*, 1260–1267. https://doi.org/10.1016/J.RINP.2018.02.015

Hanini, K., Merzoug, B., Boudiba, S., Selatnia, I., Laouer, H., & Akkal, S. (2019). Influence of different polyphenol extracts of Taxus baccata on the corrosion process and their effect as additives in electrodeposition. *Sustainable Chemistry and Pharmacy*, *14*, 100189. https://doi.org/10.1016/J.SCP.2019.100189

Helen, L. Y. S., Rahim, A. A., Saad, B., Saleh, M. I., & Bothi Raja, P. (2014). Aquilaria Crassna Leaves Extracts-a Green Corrosion Inhibitor for Mild Steel in 1 M HCl Medium. *Int. J. Electrochem. Sci*, *9*, 830–846. www.electrochemsci.org

Izadi, M., Shahrabi, T., Mohammadi, I., & Ramezanzadeh, B. (2019). Synthesis of impregnated Na+-montmorillonite as an eco-friendly inhibitive carrier and its subsequent protective effect on silane coated mild steel. *Progress in Organic Coatings*, *135*, 135–147. https://doi.org/10.1016/J.PORGCOAT.2019.05.037

Kendig, M. W., & Buchheit, R. G. (2003). Corrosion Inhibition of Aluminum and Aluminum Alloys by Soluble Chromates, Chromate Coatings, and Chromate-Free Coatings. *Corrosion*, *59*(5), 379–400. https://doi.org/10.5006/1.3277570

Kim, E., Yoo, S., Ro, H.-Y., Han, H.-J., Baek, Y.-W., Eom, I.-C., Kim, H.-M., Kim, P., & Choi, K. (2013). Aquatic Toxicity Assessment of Phosphate Compounds. *Environmental Health and Toxicology*, *28*, e2013002. https://doi.org/10.5620/EHT.2013.28.E2013002

Krishnaveni, K., & Ravichandran, J. (2014). Effect of aqueous extract of leaves of Morinda tinctoria on corrosion inhibition of aluminium surface in HCl medium. *Transactions of Nonferrous Metals Society of China*, *8*(24), 2704–2712. https://doi.org/10.1016/S1003-6326(14)63401-4

Laredo, G. C., López, C. R., Álvarez, R. E., & Cano, J. L. (2004). Naphthenic acids, total acid number and sulfur content profile characterization in Isthmus and Maya crude oils. *Fuel*, *83*(11–12), 1689–1695. https://doi.org/10.1016/J.FUEL.2004.02.004

Lebrini, M., Robert, F., & Roos, C. (2011). Alkaloids extract from Palicourea guianensis plant as corrosion inhibitor for C38 steel in 1 M hydrochloric acid medium. *International Journal of Electrochemical Science*.

Liu, Y., Song, Z., Wang, W., Jiang, L., Zhang, Y., Guo, M., Song, F., & Xu, N. (2019). Effect of ginger extract as green inhibitor on chloride-induced corrosion of carbon steel in simulated concrete pore solutions. *Journal of Cleaner Production*, *214*, 298–307. https://doi.org/10.1016/J.JCLEPRO.2018.12.299

Mabrour, J., Akssira, M., Azzi, M., Zertoubi, M., Saib, N., Messaoudi, A., Albizane, A., & Tahiri, S. (2004). Effect of vegetal tannin on anodic copper dissolution in chloride solutions. *Corrosion Science*, *46*(8), 1833–1847. https://doi.org/10.1016/J.CORSCI.2003.10.022

Mahross, M. H., Naggar, A. H., Seaf Elnasr, T. A., & Abdel-Hakim, M. (2016). Effect of rice straw extract as an environmental waste corrosion inhibitor on mild steel in an acidic Media. *Chemistry of Advanced Materials*, *1*(1), 6–16. https://doi.org/10.5829/idosi.aejsr.2016.11.3.22793

Mansfield, F. (1987). *Corrosion mechanisms*. Marcel Dekker Inc.

Marsoul, A., Ijjaali, M., Elhajjaji, F., Taleb, M., Salim, R., & Boukir, A. (2020). Phytochemical screening, total phenolic and flavonoid methanolic extract of pomegranate bark (Punica granatum L): Evaluation of the inhibitory effect in acidic medium 1 M HCl. *Materials Today: Proceedings*, *27*, 3193–3198. https://doi.org/10.1016/J.MATPR.2020.04.202

Martinez, S. (2003). Inhibitory mechanism of mimosa tannin using molecular modeling and substitutional adsorption isotherms. *Materials Chemistry and Physics*, *77*(1), 97–102. https://doi.org/10.1016/S0254-0584(01)00569-7

Martinez, S., & Štagljar, I. (2003). Correlation between the molecular structure and the corrosion inhibition efficiency of chestnut tannin in acidic solutions. *Journal of Molecular Structure: THEOCHEM*, *1–3*(640), 167–174. https://doi.org/10.1016/J.THEOCHEM.2003.08.126

Martinez, S., & Stern, I. (2002). Thermodynamic characterization of metal dissolution and inhibitor adsorption processes in the low carbon steel/mimosa tannin/sulfuric acid system. *Applied Surface Science*, *199*(1–4), 83–89. https://doi.org/10.1016/S0169-4332(02)00546-9

Martinez, S., & Štern, I. (1999). Ferric-Tannate Formation and Anticorrosive Properties of Mimosa Tannin in Acidic Solutions. *Chemical and Biochemical Engeenering Quartely*, *13*(4), 191–199. https://www.bib.irb.hr/19264

Martinez, S., & Štern, I. (2001). Inhibitory mechanism of low-carbon steel corrosion by mimosa tannin in sulphuric acid solutions. *Journal of Applied Electrochemistry*, *31*(9), 973–978. https://doi.org/10.1023/A:1017989510605

Mercer, A. D. (2013). Test methods for corrosion inhibitors: Report prepared for the European Federation of Corrosion Working Party on Inhibitors. *Http://Dx.Doi.Org/10.1179/000705985798272849*, *20*(2), 61–70. https://doi.org/10.1179/000705985798272849

Meriem-Benziane, M., Bou-Saïd, B., & Boudouani, N. (2017). The effect of crude oil in the pipeline corrosion by the naphthenic acid and the sulfur: A numerical approach. *Journal of Petroleum Science and Engineering*, *158*, 672–679. https://doi.org/10.1016/J.PETROL.2017.08.073

Miralrio, A., & Vázquez, A. E. (2020). Plant Extracts as Green Corrosion Inhibitors for Different Metal Surfaces and Corrosive Media: A Review. *Processes 2020, Vol. 8, Page 942*, *8*(8), 942. https://doi.org/10.3390/PR8080942

Miri, R., & Chouikhi, A. (2005). Ecotoxicological marine impacts from seawater desalination plants. *Desalination*, *182*(1–3), 403–410. https://doi.org/10.1016/J.DESAL.2005.02.034

Mourya, P., Banerjee, S., & Singh, M. M. (2014). Corrosion inhibition of mild steel in acidic solution by Tagetes erecta (Marigold flower) extract as a green inhibitor. *Corrosion Science*, *85*, 352–363. https://doi.org/10.1016/J.CORSCI.2014.04.036

Muhamad, I. I., Hassan, N. D., Mamat, S. N. H., Nawi, N. M., Rashid, W. A., & Tan, N. A. (2017). Extraction Technologies and Solvents of Phytocompounds From Plant Materials: Physicochemical Characterization and Identification of Ingredients and Bioactive Compounds From Plant Extract Using Various Instrumentations. *Ingredients Extraction by Physicochemical Methods in Food*, 523–560. https://doi.org/10.1016/B978-0-12-811521-3.00014-4

Musa, A. Y., Jalgham, R. T. T., & Mohamad, A. B. (2012). Molecular dynamic and quantum chemical calculations for phthalazine derivatives as corrosion inhibitors of mild steel in 1M HCl. *Corrosion Science*, *56*, 176–183. https://doi.org/10.1016/J.CORSCI.2011.12.005

Muthulakshmi, A., Jothibai Margret, R., & Mohan, V. R. (2012). GC-MS Analysis of Bioactive Components of Feronia elephantum Correa (Rutaceae). *Journal of Applied Pharmaceutical Science*, *2*(2), 69–74.

Njoku, R. . (2002). *Effects of inhibitors, formaldehyde, acetaldehyde and benzaldehyde on corrosion of low carbon steel in Hydrochloric Acid Pickling solution*. ABU.

Oguzie, E. E. (2008). Evaluation of the inhibitive effect of some plant extracts on the acid corrosion of mild steel. *Corrosion Science*, *50*(11), 2993–2998. https://doi.org/10.1016/J.CORSCI.2008.08.004

Olivares-Xometl, O., Likhanova, N. V., Domínguez-Aguilar, M. A., Arce, E., Dorantes, H., & Arellanes-Lozada, P. (2008). Synthesis and corrosion inhibition of α-amino acids alkylamides for mild steel in acidic environment. *Materials Chemistry and Physics*, *110*(2–3), 344–351. https://doi.org/10.1016/J.MATCHEMPHYS.2008.02.010

Pais, M., & Rao, P. (2019). Biomolecules for Corrosion Mitigation of Zinc: A Short Review. *Journal of Bio- and Tribo-Corrosion*, *5*(4), 1–11. https://doi.org/10.1007/S40735-019-0286-9/TABLES/1

Popoola, L. T. (2019). Organic green corrosion inhibitors (OGCIs): A critical review. *Corrosion Reviews*, *37*(2), 71–102. https://doi.org/10.1515/CORRREV-2018-0058/ASSET/GRAPHIC/J_CORRREV-2018-0058_FIGURE_004.JPG

Quraishi, M. A., & Jamal, D. (2002). Inhibition of mild steel corrosion in the presence of fatty acid triazoles. *Journal of Applied Electrochemistry*, *32*(4), 425–430. https://doi.org/10.1023/A:1016348710085/METRICS

Rahim, A. A., Rocca, E., Steinmetz, J., & Jain Kassim, M. (2008). Inhibitive action of mangrove tannins and phosphoric acid on pre-rusted steel via electrochemical methods. *Corrosion Science*, *50*(6), 1546–1550. https://doi.org/10.1016/J.CORSCI.2008.02.013

Rahim, A., & Kassim, J. (2012). Recent Development of Vegetal Tannins in Corrosion Protection of Iron and Steel. *Recent Patents on Materials Sciencee*, *1*(3), 223–231. https://doi.org/10.2174/1874464810801030223

Rahuma, M. N., & Kannan, B. M. (2014). Corrosion in Oil and Gas Industry: A Perspective on Corrosion Inhibitors. *Journal of Material Sciences & Engineering*, *3*(3), 1000e110. https://doi.org/: 10.4172/2169-0022.1000e110

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. *Https://Doi.Org/10.1080/00986445.2016.1172485*, *203*(9), 1145–1156. https://doi.org/10.1080/00986445.2016.1172485

Raja, P. B., & Sethuraman, M. G. (2008). Natural products as corrosion inhibitor for metals in corrosive media — A review. *Materials Letters*, *62*(1), 113–116. https://doi.org/10.1016/J.MATLET.2007.04.079

Ray, A., Gupta, S. D., & Ghosh, S. (2013). Evaluation of anti-oxidative activity and UV absorption potential of the extracts of Aloe vera L. gel from different growth periods of plants. *Industrial Crops and Products*, *49,* 712–719. https://doi.org/10.1016/J.INDCROP.2013.06.008

Scheie, L. L. (1992). Inhibition of corrosion of mild steel in Hydrochloric Acid pickling solution. *Journal of Corrosion Science and Technology*, *2*, 116–118.

Shao, Q. H., Yin, X. D., Liu, H. X., Zhao, B., Huang, J. Q., & Li, Z. L. (2021). Kidney Injury Following Ibuprofen and Acetaminophen: A Real-World Analysis of Post-Marketing Surveillance Data. *Frontiers in Pharmacology*, *12,* 3807. https://doi.org/10.3389/FPHAR.2021.750108/BIBTEX

Shehata, O. S., Korshed, L. A., Attia, A., Shehata, O. S., Korshed, L. A., & Attia, A. (2017). Green Corrosion Inhibitors, Past, Present, and Future. *Corrosion Inhibitors, Principles and Recent Applications*. https://doi.org/10.5772/INTECHOPEN.72753

Shrestha, P. R., Oli, H. B., Thapa, B., Chaudhary, Y., Gupta, D. K., Das, A. K., Nakarmi, K. B., Singh, S., Karki, N., & Yadav, A. P. (2019). Bark Extract of *Lantana camara* in 1M HCl as Green Corrosion Inhibitor for Mild Steel. *Engineering Journal*, *23*(4), 205–211. https://doi.org/10.4186/ej.2019.23.4.205

Singh, A., Singh, V. K., & Quraishi, M. A. (2010). Aqueous extract of kalmegh (andrographis paniculata) leaves as green inhibitor for mild steel in hydrochloric acid solution. *International Journal of Corrosion*, *2010*. https://doi.org/10.1155/2010/275983

Singh, W. P., & Bockris, J. O. (1996). *Toxicity Issues of Organic Corrosion Inhibitors: Applications of QSAR Model*. OnePetro. /NACECORR/proceedings-abstract/CORR96/All-CORR96/113866

Tamalmani, K., & Husin, H. (2020). Review on Corrosion Inhibitors for Oil and Gas Corrosion Issues. *Applied Sciences 2020, Vol. 10, Page 3389*, *10*(10), 3389. https://doi.org/10.3390/APP10103389

Tan, K. W., & Kassim, M. J. (2011). A correlation study on the phenolic profiles and corrosion inhibition properties of mangrove tannins (Rhizophora apiculata) as affected by extraction solvents. *Corrosion Science*, *53*(2), 569–574. https://doi.org/10.1016/J.CORSCI.2010.09.065

Tang, J., Hu, Y., Wang, H., Zhu, Y., Wang, Y., Nie, Z., Wang, Y., & Normand, B. (2019). Complicated synergistic effects between three corrosion inhibitors for Q235 steel in a CO 2-saturated 3.5 wt% NaCl solution. *Int. J. Electrochem. Sci*, *14*, 2246–2264. https://doi.org/10.20964/2019.03.61

Umeozokwere Anthony, O., Mbabuike Ikenna, U., Oreko Benjamin, U., & Ezemuo, D. . (2016). Corrosion rates and its impact on mild steel in some selected environments. *Journal of Scientific and Engineering Research*, *3*(1), 34–43.

Umoren, S. A., Eduok, U. M., Solomon, M. M., & Udoh, A. P. (2016). Corrosion inhibition by leaves and stem extracts of Sida acuta for mild steel in 1 M H2SO4 solutions investigated by chemical and spectroscopic techniques. *Arabian Journal of Chemistry*, *9*, S209–S224.

https://doi.org/10.1016/J.ARABJC.2011.03.008

Umoren, S. A., & Solomon, M. M. (2014). Recent developments on the use of polymers as corrosion inhibitors-a review. *Open Materials Science Journal*, *8*(1), 39–54. https://doi.org/10.2174/1874088X01408010039

Umoren, S. A., Solomon, M. M., Obot, I. B., & Suleiman, R. K. (2019). A critical review on the recent studies on plant biomaterials as corrosion inhibitors for industrial metals. *Journal of Industrial and Engineering Chemistry*, *76*, 91–115. https://doi.org/10.1016/J.JIEC.2019.03.057

Verma, C., Ebenso, E. E., Bahadur, I., & Quraishi, M. A. (2018). An overview on plant extracts as environmental sustainable and green corrosion inhibitors for metals and alloys in aggressive corrosive media. *Journal of Molecular Liquids*, *266*, 577–590. https://doi.org/10.1016/J.MOLLIQ.2018.06.110

Wei, H., Heidarshenas, B., Zhou, L., Hussain, G., Li, Q., & Ostrikov, K. (Ken). (2020). Green inhibitors for steel corrosion in acidic environment: state of art. *Materials Today Sustainability*, *10*, 100044. https://doi.org/10.1016/J.MTSUST.2020.100044

Yadav, M., Gope, L., Kumari, N., & Yadav, P. (2016). Corrosion inhibition performance of pyranopyrazole derivatives for mild steel in HCl solution: Gravimetric, electrochemical and DFT studies. *Journal of Molecular Liquids*, *216*, 78–86. https://doi.org/10.1016/J.MOLLIQ.2015.12.106

Yaktini, A. E. L., Lachiri, A., Faydy, M. E. L., Benhiba, F., Zarrok, H., Azzouzi, M. E. L., Zertoubi, M., Azzi, M., Lakhrissi, B., & Zarrouk, A. (2018). Practical and theoretical study on the inhibitory influences of new azomethine derivatives containing 8-hydroxyquinoline moiety for the corrosion of carbon steel in 1 M HCl. *Oriental Journal of Chemistry*, *34*(6), 3016–3029. https://doi.org/10.13005/OJC/340643

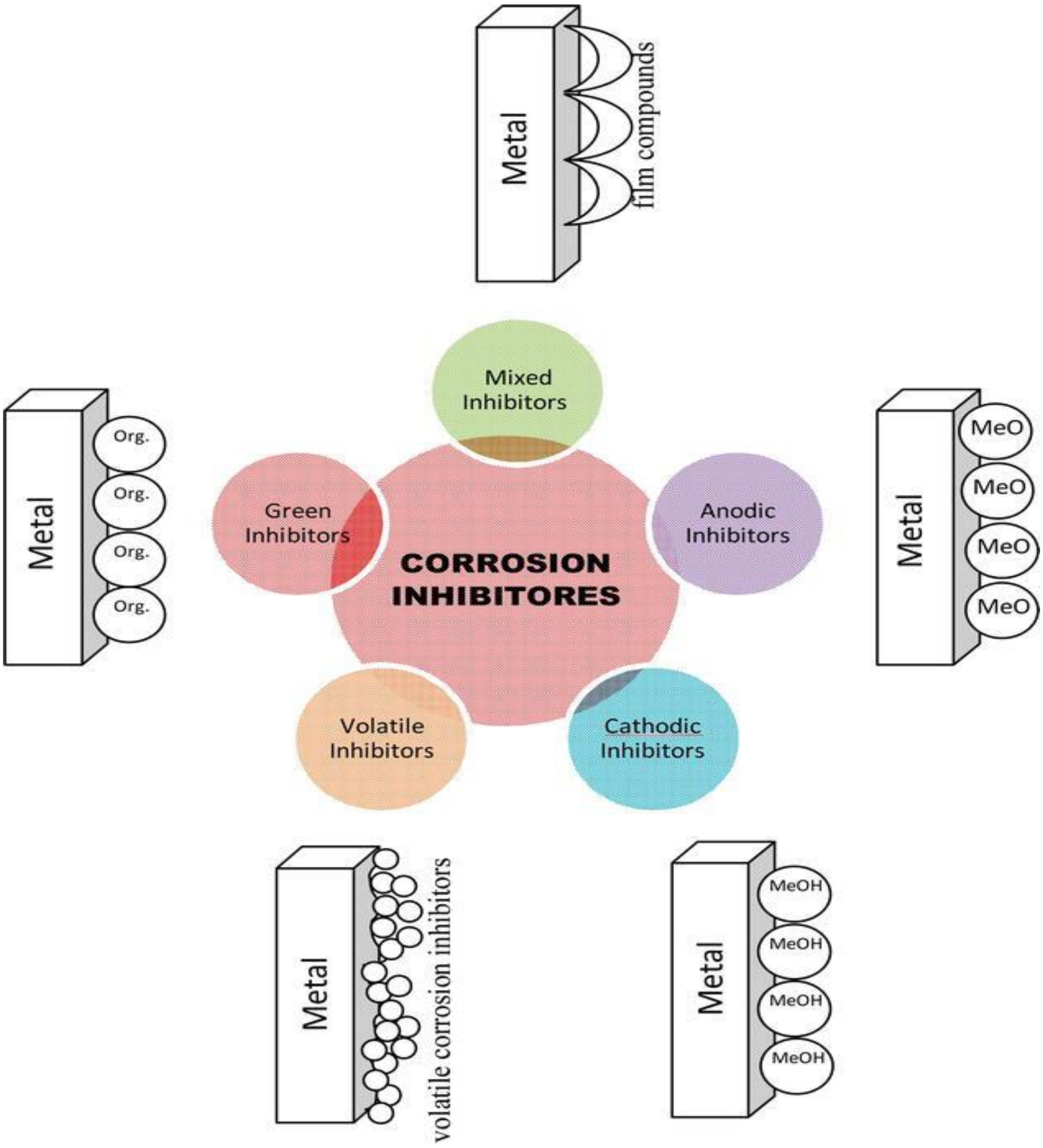
Yawas, D. S., Aku, S. Y., & Oloche, O. B. (2005). Non-toxic plant extracts as corrosion inhibitors of carbon steel in HCl. *Journal of Corrosion Science and Technology NICA*, *3*(1), 128-133.

Yazdanfar, K., Zhang, X., Keech, P. G., Shoesmith, D. W., & Wren, J. C. (2010). Film conversion and breakdown processes on carbon steel in the presence of halides. *Corrosion Science*, *52*(4), 1297–1304. https://doi.org/10.1016/J.CORSCI.2010.01.003

Zam, W., G, B., W, A., & W, K. (1970). Separation and Purification of Proanthocyanidins Extracted from Pomegranate's Peels (Punica Granatum). *International Journal of Pharmaceutical Sciences and Nanotechnology*, *5*(3), 1808–1813. https://doi.org/10.37285/IJPSN.2012.5.3.8

Zhang, Q. W., Lin, L. G., & Ye, W. C. (2018). Techniques for extraction and isolation of natural products: A comprehensive review. *Chinese Medicine (United Kingdom)*, *13*(1), 1–26. https://doi.org/10.1186/S13020-018-0177-X/FIGUREURES/13

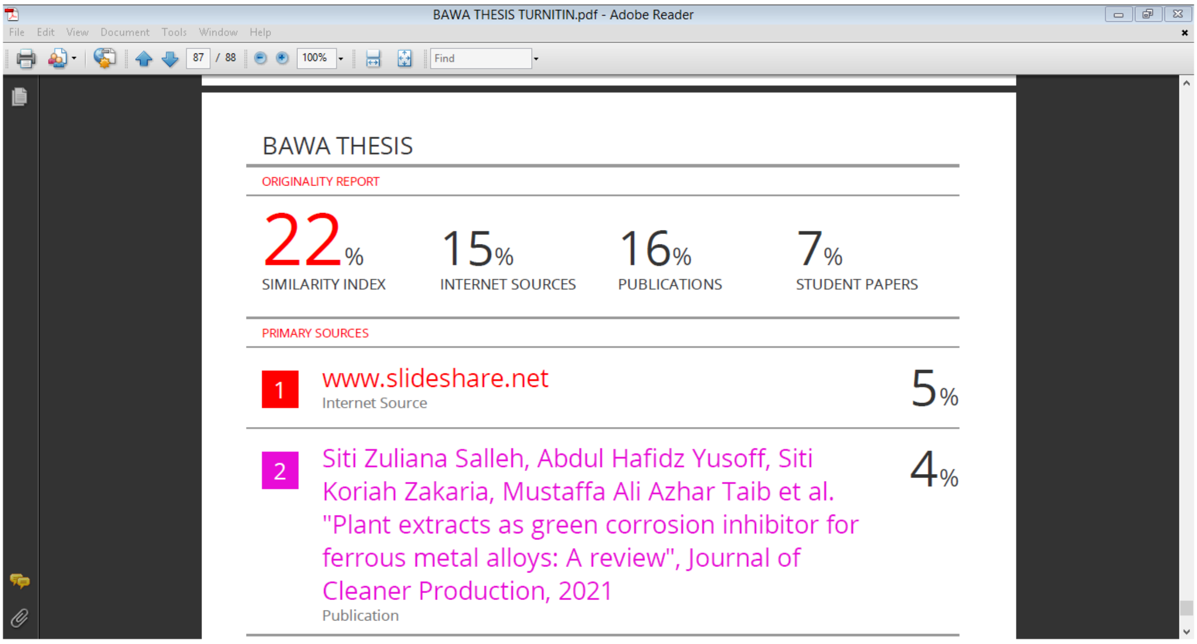
APPENDIX I



Green corrosion inhibitors

APPENDIX II

TURNITIN REPORT



BAWA THESIS

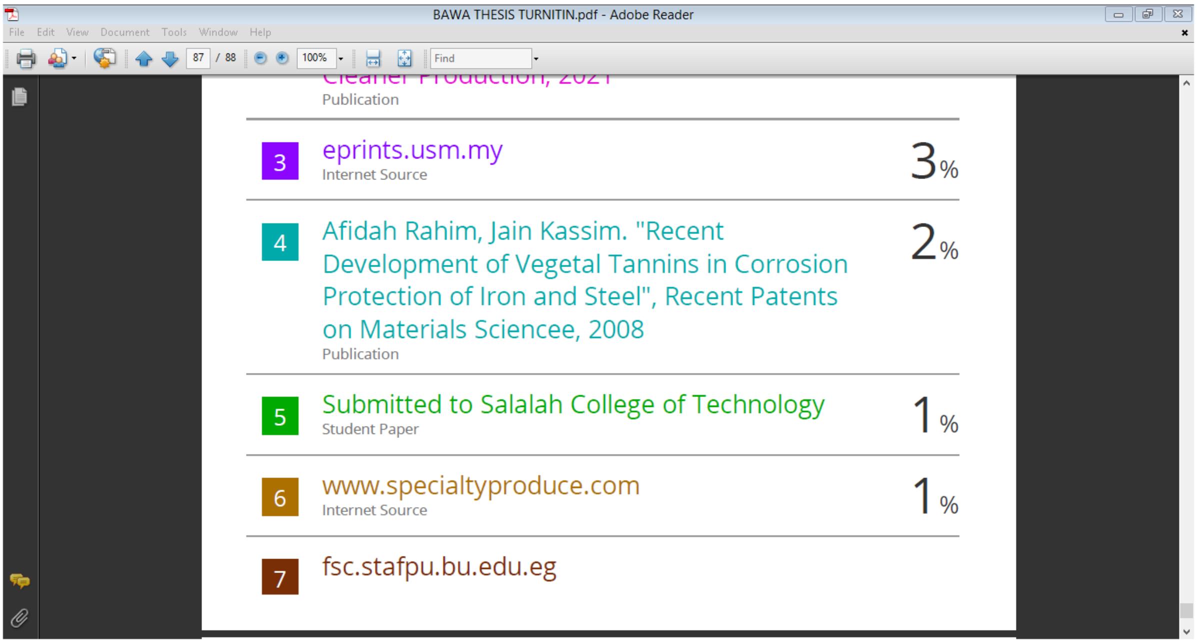
ORIGINALITY REPORT

22%	15%	16%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1 www.slideshare.net
Internet Source
5%

2 Siti Zuliana Salleh, Abdul Hafidz Yusoff, Siti Koriah Zakaria, Mustaffa Ali Azhar Taib et al. "Plant extracts as green corrosion inhibitor for ferrous metal alloys: A review", Journal of Cleaner Production, 2021
Publication
4%



Publication

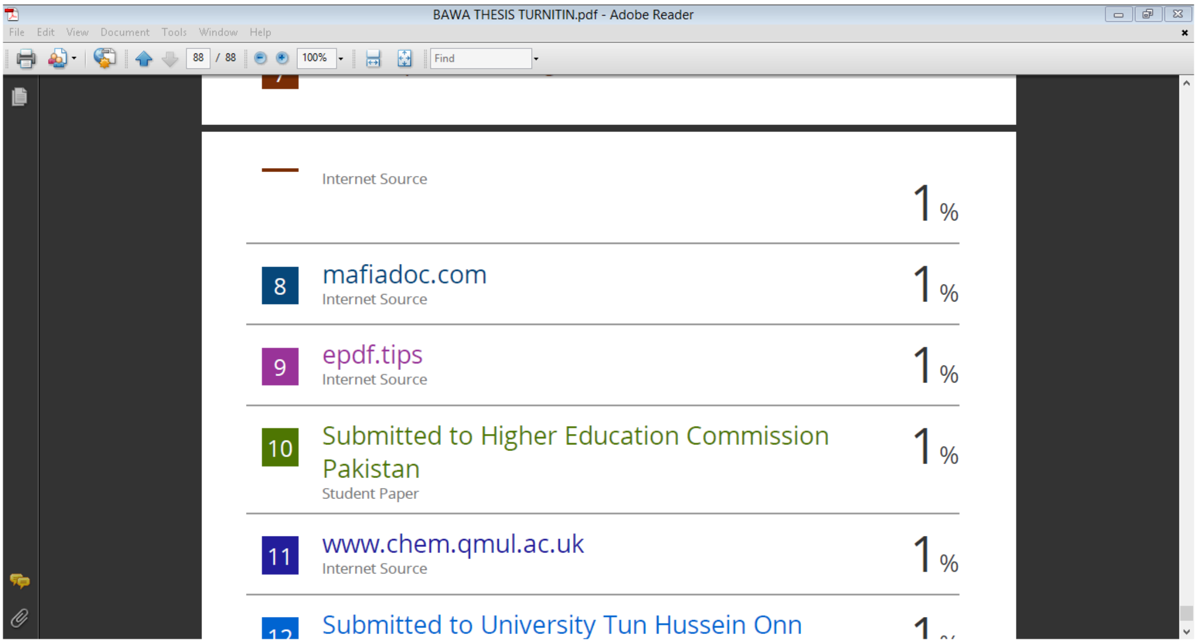
3 eprints.usm.my
Internet Source
3%

4 Afidah Rahim, Jain Kassim. "Recent Development of Vegetal Tannins in Corrosion Protection of Iron and Steel", Recent Patents on Materials Sciencee, 2008
Publication
2%

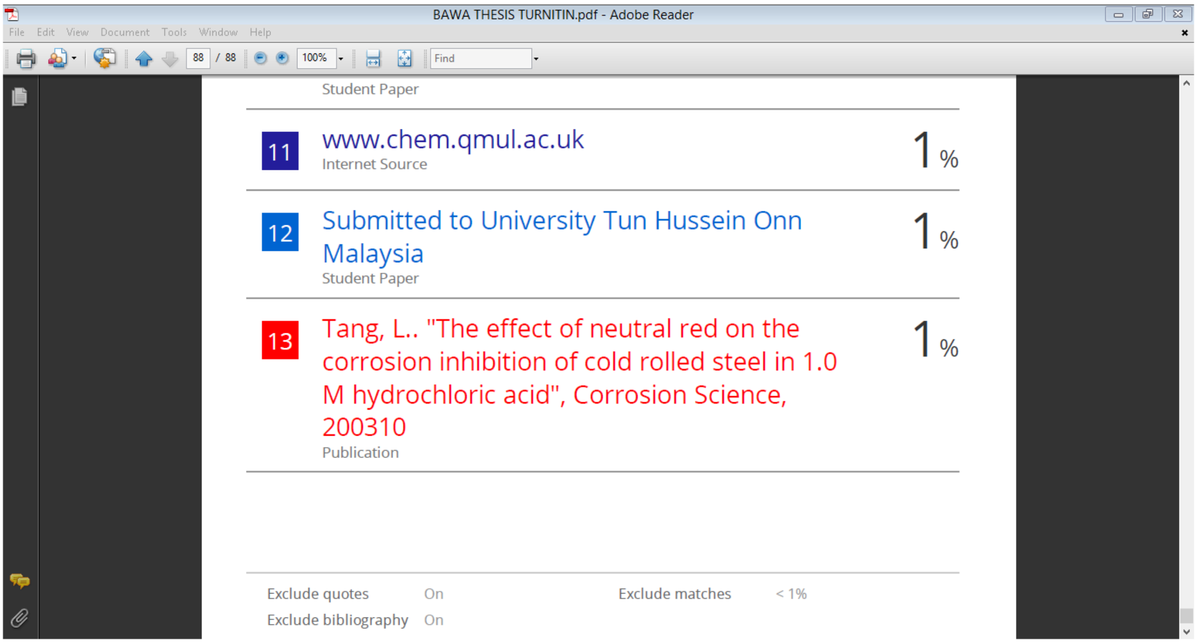
5 Submitted to Salalah College of Technology
Student Paper
1%

6 www.specialtyproduce.com
Internet Source
1%

7 fsc.stafpu.bu.edu.eg



	Internet Source	1 %
8	mafiadoc.com Internet Source	1 %
9	epdf.tips Internet Source	1 %
10	Submitted to Higher Education Commission Pakistan Student Paper	1 %
11	www.chem.qmul.ac.uk Internet Source	1 %
12	Submitted to University Tun Hussein Onn	1



Student Paper

11	www.chem.qmul.ac.uk Internet Source	1 %
12	Submitted to University Tun Hussein Onn Malaysia Student Paper	1 %
13	Tang, L.. "The effect of neutral red on the corrosion inhibition of cold rolled steel in 1.0 M hydrochloric acid", Corrosion Science, 200310 Publication	1 %

Exclude quotes On
Exclude bibliography On
Exclude matches < 1%

APPENDIX III

CURRICULUM VITAE

BAWA BAMAIYI

E-mail: bawabamaiyi@yahoo.com
Mobile Number: 08039162227
Permanent Address: UMCA, Zuru, Kebbi State.
Contact Address: Department of Mechanical Engineering,
Federal Polytechnic, P.M.B 1012, Kaura-Namoda, Zamfara State, Nigeria.

SKILLS

Microsoft Packages – Proficient in MS Packages (MS-Word, MS-Excel, Powerpoint, MS-Access),

PERSONAL DATA

Date of Birth:	03 February, 1963
State of Origin:	Kebbiun State
Local Government Area:	Zuru
Place of Birth:	Zuru
Sex:	Male
Nationality:	Nigerian
Marital Status:	Married

SCHOOLS ATTENDED WITH DATES

Danga Gomo Primary School, Zuru, Kebbi State.	1971 - 1978
Government Teachers College, Zuru, Kebbi State	1978 - 1983
Sokoto State Polytechnic, Birnin Kebbi, Sokoto State.	1983 – 1986
Sokoto State Polytechnic, Birnin Kebbi, Sokoto State.	1989 –1991
Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State	2013 –2015
Shehu Shagari College of Education, Sokoto, Sokoto State	2002 - 2004
Near East University, Nicosia, Cyprus	2021 - 2023

ACADEMIC QUALIFICATIONS WITH DATES

MSc. Mechanical Engineering	(in view)
Post Graduate Diploma in Mechanical Engineering (PGDME)	2015
Post Graduate Diploma in Education (PGDE)	2005
Higher National Diploma in Metallurgical Engineering (HND)	1991
National Diploma in Metallurgical Engineering (ND)	1986
Senior Secondary School Certificate (WAEC O/L)	1983

WORKING EXPERIENCE

- Sultan Abubakar College, Sokoto, Sokoto State. 1987 - 1991
  Post: Introductory Technology Teacher

- Attaihiru Secondary School, Birnin Kebbi State. 1991 - 1992
  Post: Introductory Technology Teacher
- Ministry of Education, Birnin Kebbi, Kebbi State 1992 - 1993
  Post: Technical Officer
- Government Technical College, Zuru, Kebbi State 1993 – 2009
  Post: Head of Department and Metal Work Teacher
- Federal Polytechnic, Kaura Namoda, Zamfara State 2009 – Till Date
  Post: Academic Staff

PROFESSIONAL MEMBERSHIP

Registered Member of Nigeria Institution of Mechanical Engineering (NIMECHE)
Registered Member of National Association of Engnieering Craftsman (NAEC)

HOBBIES

Reading, Researching, Travelling, Badminton and Interacting with People

REFEREES

Engr. Ahmed Muhammad Gusau
Former Deputy Rector,
Federal Polytechnic, Kaura-Namoda, Zamfara State.
08080356985

Mr. Karatu Wele
Deputy Director, Ministry of Education,
Birnin Kebbi, Kebbi State

Engr. Mohammed Mohammed
Head of Department,
Federal Polytechnic,
Kaura-Namoda, Zamfara State.
08038396499