CORROSION INHIBITION OF MILD STEEL USING EXTRACTS OF VELVET BEAN (Mucuna pruriens) AND KAVA LEAVES (Piper methysticum)

BY

UFONDU PEARL CHIENYE (B. Eng, FUTO)

20134872178

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CERTIFICATION

This is to certify that this work, **"Corrosion Inhibition of Mild Steel Using Extracts of Velvet Bean (Mucuna pruriens) and Kava Leaves (Piper methysticum)"**, was carried out by **UFONDU, Pearl Chienye** (Reg; 20134872178), in partial fulfilment for the award of a Masters of Science Degree, for Pollution Control in the Department of Environmental Management, School of Environmental Sciences, Federal University of Technology, Owerri.

22/3/19

DR J. D. NJOKU
(Project Supervisor)
DATE

25/03/19

DR. P. N. OKEKE
(Head of Department, Environmental Management)
DATE

25/03/19

PROF E. E. Oguzie
(Dean, School of Environmental Sciences)
DATE

PROF (MRS) N. N. Oti
(Dean, Post graduate School)
DATE

28/8/19

PROF I. A. MADU
(External Examiner)
DATE

DEDICATION

I dedicate this work first to God, for I could not do a thing without Him, and then to my family for being a strong support right through it.

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ABSTRACT

This work investigated two plant leaves extract Velvet Bean and Kava, for inhibition properties and measured their efficiencies with change in time, extract concentration, and media. The metal used was mild steel, and the media HCl and NaCl. It also determined their optimum extract concentration among the tested range. Statistical analysis were also carried out on experimental results. Velvet bean leaf extract was obtained using ethanol in a hot extraction process through reflux. Kava leaf was juiced fresh because of its high moisture content. Extract concentrations - 1000, 2000, 3000, 4000, and 5000mg/L were prepared for both leaves. The different concentrations for both leaves were tested in 1M HCl medium first, for five days respectively. The different concentrations for Velvet bean leaf were also used in NaCl medium for twenty-five days. In both HCl and NaCl media, the optimum concentration for Velvet bean leaf extract was 4000mg/L, after five days (91.77% efficiency) and twenty-five days (65.44% efficiency) respectively. For Kava leaf, the optimum extract concentration in 1M HCl media was 5000mg/L also after five days (94.16% efficiency). The efficiencies of both inhibitors were seen to increase as their concentrations were increased, and reduce as time increased. Velvet bean leaf extract was also seen to be fairly stable in both acid and base media over time. In NaCl solution, its efficiency was 65.44% after twenty-five days immersion, and 93.14%, after a delayed immersion of two weeks in 1M HCl solution. Statistical analysis showed VBL extract obeyed a quadratic model in both media, and KVL a purequadratic model. Their high R^2 values close to unity showed the adequacy of the models respectively and validated the experimental data. Extract concentration and time had a high effect on inhibition efficiency and were statistically significant. It would be of an advantage to quickly apply the use of these two plant leaves extracts in inhibiting corrosion on mild steel in 1M HCl and NaCl media, in actual industrial environments. Research should be done to check the extracts behaviour and corrosion inhibition efficiency at elevated temperatures, and other media. Even though these two plants could grow all year round, and are not yet popular as food in Nigeria, it would be beneficial for more research to be done on synthesising inhibitor components of the plants in the laboratory so as not shorten food supply by other plant use.

Keywords: Corrosion, Corrosion inhibition, Inhibition efficiency, Weight loss, Optimum parameters, Velvet bean and Kava leaves.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Corrosion is the destructive attack on a material by reaction with its environment. (Int. J. Electrochem. Sci., 6; 2011) Corrosion is the atmospheric oxidation of metals. That means that oxygen combines with the metal to form a new layer. Corrosion is a natural process, which converts a refined metal to a more stable form, such as its oxide or hydroxide. Iron and steel for example naturally combine with other chemical elements to return to their lowest energy states. Iron combines with oxygen and water, both of which are present in most natural environments, to form hydrated iron oxides (rust), similar in chemical composition to the original iron ore (ASM International; 2000). In the most common use of the word, this means electrochemical oxidation. Corrosion causes very important material and economical losses due to partial or total replacement of equipment and structures, and plant shutdowns. Corrosion not only has economic implications, but also social, which include the safety and health of people either working in industries or living in nearby towns (Rafael, et. al, 2014).

Corrosion occurs in metals like Iron, Aluminium, Chromium, and Zinc. Corrosion can also occur in materials other than metals, such as ceramics or polymers. In this context, the term degradation is more commonly used. Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances (Oguzie, Wang, 2009). Corrosion can be concentrated locally to form a crack or pit, or it can extend across a wide area more or less uniformly corroding the surface. Corrosion of metals is a problem that has been given great attention especially in the oil and gas industries. Metal surfaces are often made to come into contact with an acid medium because acid solutions are extensively used in industry. The commonly used acids are hydrochloric acid, sulphuric acid, nitric acid, thus metals corrode easily.

Corrosion is a diffusion-controlled process, and occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface, such as passivation and chromate conversion, can increase a material’s corrosion resistance (Piping and Piping Technology, 2012). However some corrosion mechanisms are less visible and less predictable. Recognizing the symptoms and mechanism of a corrosion problem is an important preliminary step on the road to finding a convenient solution. There are basically five methods of corrosion control; changing to a more suitable material, modification to the environment with the use of inhibitors, using protective metallic or organic coatings, modifications to the system or component (such as; providing adequate ventilation and drainage to minimize the accumulation of condensation, avoiding depressed areas where drainage is inadequate, avoiding the use of absorptive materials in contact with metallic surfaces, preparing surfaces adequately prior to the application of any protective coating system), and providing easy access for the purpose of corrosion inspection and maintenance work (Philip, Taylor, et. al, 2010).

The use of corrosion inhibitors constitutes one of the most economical ways to mitigate the corrosion rate, protect metal surfaces against corrosion, and preserve industrial facilities. A particular advantage of corrosion inhibition is that it can be implemented or changed in situ without disrupting a process. Corrosion inhibitors are substances which, when added to a corrosion system decreases or eliminates anodic dissolution (Oguzie, 2007). They are chemicals that react with a metallic surface, or the environment this surface is exposed to, giving the surface a certain level of protection. Inhibitors are widely used in the corrosion protection of metals in several environments (Oguzie, E. E.; Wang, S. G.; et. al; 2009).

Inhibitors often work by adsorbing themselves on the metallic surface, and protecting the metallic surface by forming a film. Inhibitors are normally distributed from a solution or dispersion. Some are included in a protective coating formulation.

Even though a good number of inorganic, organic and polymeric compounds have shown good performances as corrosion inhibitors for different metals and alloys, many of these compounds are toxic and do not fulfil completely the requirements imposed by environmental protection standards. The new generation of environmental regulations requires the replacement of toxic chemicals with "Green chemicals" such as with Alam, et. al's, 2014 eco-friendly coating material research. The final choice of the inhibitor for a particular application is restricted by several factors, including increased environmental awareness and the need to promote environmentally friendly processes. This is the reason why in the last years big efforts have been made by researchers in this area to develop new environmentally friendly corrosion inhibitors. Okafor et al, 2008 research on the inhibitory action of Phyllanthus amarus extracts on the corrosion of mild steel in acidic media; Belkhaouda, et al.'s 2013' research on the inhibition of C-steel corrosion in hydrochloric solution with Chenopodium ambrorsioides extract; and Osita et al.'s 2015 research on corrosion inhibition of mild steel using various plant extracts, are just a few of the researches done geared towards replacing synthetic inhibitors with eco-friendly substitutes.

The use of naturally occurring substances of plant and animal origin, known as green inhibitors, has generated much interest in recent times. These plant/ animal extracts are cheap, abundant, less toxic, readily available and environmentally friendly. Velvet bean – Mucuna pruriens (locally called *Agbala* in Igbo and *Werepe* in Yoruba), and Kava – Piper methysticum (locally called *Awa* in Igbo), like other plants discovered as corrosion inhibitors, have medicinal properties. Again like the others, phytochemical screening of the Velvet bean plant revealed that it contains alkaloids, flavonoids, tannins saponins, cardiac glycosides, anthraquinones and carbohydrates. Recent investigations have shown the corrosion inhibitive effect of extracts from local plants such as Pachylobus edulis, Sida acuta and Ginkgo biloba (Umoren and Ekanem, 2010; Eduok et al, 2012, Cheng et al. 2013), exhibiting good inhibitor efficiencies on the corrosion of different metals.

1.2 PROBLEM STATEMENT

The serious consequences of the corrosion process has become a problem of worldwide significance. In addition to our everyday encounters with this form of degradation, corrosion causes plant shutdowns, waste of valuable resources, loss or contamination of products, reduction in efficiency, costly maintenance, and expensive overdesign (Marcus, et. al, 2008). It can also jeopardise safety, as well as inhibit technological progress. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases (Oguzie, 2007). Corrosion is a challenge that continues to be of great relevance in a wide range of industrial applications and products, therefore the pressing need to stop or reduce it considerably.

Corrosion control of metals and alloys however, is an expensive process and industries spend huge amounts to control this problem. It is estimated that the cost of corrosion in developed countries such as the US and European countries is about 3-5% of their Gross National Product (Bhaskaran *et al*., 2005). There is the need for cheaper ways to address this problem which would still be effective.

Corrosion damage can be prevented by using various methods such as upgrading materials, blending of production fluids, process control and chemical inhibition (Ashassi-Sorkhabi *et al.,* 2005). Among these methods, the use of corrosion inhibitors (Raja and Sethuraman, 2008) has proven the best to prevent destruction or degradation of metal surfaces in corrosive media. It is one of the most economical and practical methods in reducing corrosive attack on metals. Corrosion inhibitors are chemicals either synthetic or natural which, when added in small amounts to an environment, decrease the rate of attack by the environment on metals. A number of synthetic compounds (Bentiss et. al, 2006; Bobina et. al, 2013) are known to be applicable as good corrosion inhibitors for metals. Nevertheless, the popularity and use of synthetic compounds as a corrosion inhibitor is diminishing due to the strict environmental regulations and toxic effects of synthetic compounds on human and animal life. Consequently, there exists the need to develop a new class of corrosion inhibitors with low toxicity, eco-friendliness and good efficiency.

Throughout the ages, plants have been used by human beings for their basic needs such as production of food-stuffs, shelters, clothing, fertilizers, flavours, fragrances, medicines and last but not least, as corrosion inhibitors. The use of natural products as corrosion inhibitors can be traced back to the 1930's when plant extracts of Chelidonium majus (Celandine) and other plants were used for the first time in H_2SO_4 pickling baths (Sanyal, 1981). After then, interest in using natural products as corrosion inhibitors increased substantially and scientists around the world reported several plant extracts (Belkhaouda *et al*., 2013; Oguzie, 2008; Raja and Sethuramam, 2009; Osita *et. al.,* 2015; Oguzie *et al*., 2006; etc.) as promising green anticorrosive agents.

Although, a number of plants and their phytochemical leads have been reported as anticorrosive agents, enormous opportunities exist to find out novel, economical and eco-friendly corrosion inhibitors from this outstanding source of natural products. It is also vital to get plants that are readily available and widely grown in our environment, and will not be difficult to source.

In this study, the corrosion inhibition properties of two plant species namely; Velvet bean – Mucuna pruriens (locally called Agbala in Igbo), and Kava – Piper methysticum (locally called Awa in Igbo), both grown in Nigeria would be investigated. These plants are home-grown and easily sourced. If found to inhibit corrosion effectively, it presents inhibitors of readily available plant species, cheap to obtain. Their mechanisms would also be obtained, offering users useful information on their application. Their corrosion inhibition efficiencies in different media would also be calculated enabling effective comparison for industries or any users on the choice of inhibitors for application at any time.

1.3 AIM AND OBJECTIVES OF THE STUDY

The aim is to determine the corrosion inhibition properties of two plant species, in acidic media (1M HCl acid solution), and in Sodium Chloride (NaCl) media, compare their efficiencies and determine their mechanisms. This aim would be achieved through the following objectives;

1. To determine the effectiveness of Velvet bean and Kava leaves extracts as corrosion inhibitors
2. To determine the effects of extract concentration on corrosion inhibition performance of both leaves.
3. To calculate corrosion-inhibition rates of different concentrations of the two leave extracts respectively, in 1M HCl acid media, and determine optimum extract concentration for both leaves.
4. To compare inhibition efficiency of the two leave extracts respectively, in the different media (acidic and basic).
5. To test the effect of exposure time on corrosion inhibition performance of both extracts.
6. To carry out a factorial design to determine the optimum combination of extract concentration, acid medium concentration, and exposure time, to achieve maximum inhibition efficiency of both leaves.

7. To deduce a model for both leaves respectively in the corrosion inhibition of mild steel in the two media.

1.4 JUSTIFICATION OF THE STUDY

In many industries, mild steel is the material of choice in the fabrication of reaction vessels, storage tanks etc. which is easily subjected to corrosion in the presence of acids (Chidiebere, Ogukwe, et.al. 2012). The exploration of natural products as corrosion inhibitors is becoming the subject of extensive investigation due principally to the low cost and eco-friendliness of these products, and is fast replacing the synthetic, expensive and hazardous organic inhibitors. This study aims at finding and comparing environmentally safe and inexpensive inhibitors among plants found in Nigeria for the corrosion of mild steel in acidic media. This study gives info on more ‘green’ corrosion inhibitors that are non-toxic to the environment and still very efficient inhibitors. The plants are locally sourced and so, are cheap and easily accessible. It will aid in the combat against corrosion and all its effects economically, environmentally and otherwise.

This study offers corrosion experts in the oil and gas industries and other processing industries, environmentally-friendly options of inhibiting corrosion of mild steel (popularly used) in acid media. They could test and adopt the use of any of the two leaf extracts on a larger scale. The test to determine optimum parameters for maximum inhibition efficiency easily gives users an idea on how best the extracts can be applied to obtain desired results. The comparison of both leaf extracts offers users vital information necessary in making choices. Lastly this study determines the pathway and model which the reactions with the plant extracts follow. This information would be relevant to Industrial Chemists, Chemical, Petroleum, and Environmental Engineers, and users in the industries. They would make informed decisions with the understanding of the mechanism of these reactions and could better adapt these plant extracts for corrosion inhibition in industries.

1.5 SCOPE OF THE STUDY

This work would investigate and compare the corrosion inhibitive properties of two plant species in particular – Velvet bean leaves (Mucuna pruriens), and Kava leaves (Piper methysticum). The optimum extract concentration (from among 1000mg/L, 2000mg/L, 3000mg/L, 4000mg/L, and 5000mg/L) of both plant leaf-extracts would be determined in an acidic medium of 1.0M Hydrochloric acid, and base medium Sodium Chloride solution at different time intervals (24, 48, 72, 96, and 120 hours respectively for acid medium; 5, 10, 15, 20, 25 days for base medium). Information on optimum conditions (extract concentration, and exposure time) for maximum inhibition efficiency for both plant leaf-extracts would be derived using MATLAB software.

1.6 LIMITATION OF STUDY

The Velvet bean plant when it matures and bears its fruit, has fibres and seed in its fruit. When one touches these seeds or fibre or has physical contact with it, it can cause severe itching for some hours. The leaves do not have the same effect, at all; but great care has to be taken in harvesting the leaves of the plant, if the plant has matured to its fruit bearing stage to avoid this scenario. It is easier to harvest the leaves when the fruits have not emerged.

This study would test quite a number of parameters to determine the effective use of these two leaf extracts. This exercise though rewarding, would take hours on end and could be very exhausting. Again, constant power supply which may not be easily available, would be needed especially as tests may run till late in the day, to ensure accurate results and readings are obtained.

There are a large variety of plants in the universe. There are also quite a number of species in this part of the world, home-grown like the two in this study, that haven't been investigated. Others not yet tested may have corrosion inhibitive properties. Of the nearly 300,000 plant species that exist on the earth, only a few (less than 1%) of these plants have been completely studied relative to their anticorrosive activity. This study is on just two of the many plants in existence. There is need for more research to be carried out to discover more plants

Again, the study would be focused on corrosion inhibition in acidic and base media whereas, there are other media in which corrosion takes place such as in, fresh water, other acid media(sulphuric acid, cement, etc.) which would not be covered here. Findings from this study may not be easily applied to corrosion in these other media. A lot of work still has to be done on corrosion inhibition using 'green' inhibitors in different media.

CHAPTER TWO

LITERATURE REVIEW

2.1 CORROSION OF METALS

Corrosion is a natural process. Just like water flows to the lowest level, all natural processes tend toward the lowest possible energy states. The term ‘corrosion’ can be defined as the interaction (electrochemical reaction) of a metal with the surrounding environment, causing a slow, steady, and irreversible deterioration in the metal, in both physical and chemical properties (Rafael, et. al., 2014).

Corrosion causes very important material and economical losses due to partial or total replacement of equipment and structures, and plant-repairing or shutdowns. Corrosion not only has economic implications, but also social, which include the safety and health of people either working in industries or living in nearby towns.

The factors that cause corrosion can be identified as; physical, chemical, electrochemical, and microbiological. Physical corrosion is caused by impact, stress or exhaustion of the material. Chemical corrosion is caused by oxygen, sulphur, fluorine, chlorine or other gases, which act directly on the metal under environmental conditions that facilitate this phenomenon. Electrochemical corrosion is a spontaneous process that denotes the existence of anodic and cathodic zones, and an electrolyte. Microbiological corrosion is the deterioration of a metal that occurs directly or indirectly as a result of the activity of microorganisms such as bacteria and algae. Biological activity may cause corrosion in a variety of media such as natural water, sea water, petroleum products and oil emulsions.

According to the environment to which materials are exposed, there are various forms of corrosion: uniform or general, bit, erosion, stress, cavitation, galvanic and hydrogen embrittlement-blistering.

2.2 EFFECTS OF CORROSION ON THE ENVIRONMENT

The word corrode is derived from the Latin *corrodere*, which means “to gnaw to pieces.” The general definition of corrode is to eat into or wear away gradually, as if by gnawing. For purposes here, corrosion can be defined as a chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties. The environment consists of the entire surrounding in contact with the material. The primary factors to describe the environment are the following: physical state—gas, liquid, or solid; chemical composition— constituents and concentrations; and temperature. Other factors can be important in specific cases. Examples of these factors are the relative velocity of a solution (because of flow or agitation) and mechanical loads on the material, including residual stress within the material.

Steel corrosion is a costly problem – in fact the annual direct cost of metallic corrosion worldwide is $2.2 Trillion USD (Gerhardus et.al, 2001). However, the cost of corrosion is not just financial. Beyond the huge direct outlay of funds to repair and/or replace corroded and/or decaying structures are the indirect costs (natural resources, potential hazards, and lost opportunity). When a project is constructed with a building material not able to survive its environment for the length of the design life, natural resources are needlessly consumed to continually repair and maintain the structure. Wasting natural resources is a direct contradiction to the growing focus and desire for sustainable development to benefit future generations. In addition to the waste of natural resources, building structures that cannot sustain their environment can lead to hazardous situations. Accidents caused by corroded structures can lead to huge safety concerns, loss of life, resources, and more.

The corrosion behavior of the material depends on the environment to which it is subjected, and the corrosivity of an environment depends on the material exposed to that environment. It is useful to identify both natural combinations and unnatural combinations in corrosion. (Elenwo E and Elenwo O. 2015). Natural or desirable combinations of material and environment include the interaction between the metal and the environment that do not usually result in detrimental or costly corrosion problems such as with nickel in caustic environments, lead in water, and aluminum in atmospheric exposures. Unnatural combinations, on the other hand, are those that result in severe corrosion damage to the metal because of exposure to an undesirable environment. (André and Jivaldo, 2013).

2.3 METHODS OF CORROSION CONTROL

The corrosion of metals is an unavoidable but controllable process. Acid solutions are widely used in acid pickling and industrial cleaning. Hydrochloric acid and sulphuric acid are widely used for this purpose and most acid media cause metal corrosion (Bentiss et al., 2006; Khaled and Hackerman, 2003; Quraishi and Sardar, 2003). One of the methods used to reduce corrosion in petroleum refining processes, is the application of corrosion inhibitors, which are specific for each process phase, medium and corrosion type (González, *et. al.*, 1997). In order to control some of the corrosion problems, several preventive measures are taken:

2.3.1 CATHODIC PROTECTION

This is an effective method to control corrosion on structures either buried or immersed in an electrolyte; according to the operation mode, anodes are classified as impressed current and sacrificial.

2.3.2 PROTECTION WITH ANTICORROSIVE COATING

This is mainly used to form a physical barrier between the corrosive environments and the metal to protect the structure. It is used mainly with metallic elements that are exposed to the atmosphere.

2.3.3 CORROSION INHIBITORS

These are substances that are added in small concentrations (parts per million, ppm) to a corrosive environment which decrease the corrosion rate effectively. This method has its main application in the interiors of pipelines, vessels and equipment. The corrosion measurement is the quantitative method by which we know the effectiveness of the control that is being carried out, and provides feedback that make it possible to optimize the corrosion prevention methods.

Corrosion inhibitors are either organic or inorganic chemicals, or more commonly, formulations of both. Due to the fact that equipment constructed with materials resistant to corrosion is very expensive, it is common to use corrosion inhibitors as a practical, economical and simple alternative. The corrosion inhibitor formulations generally are made up of one or more active ingredients and suitable vehicles (other additives and solvents) that encourage compatibility with the environment and make possible the active transport to the area to be protected (metal surface) (Marcus, et. al, 2012).

Sometimes, two components or active ingredients in a formulation may have a higher efficiency when they are mixed than that obtained from the sum of the efficiencies that are obtained when they are used individually at the same concentration. This effect is known as synergy or synergistic effect and is widely used in the formulation of CIs.

2.4 CORROSION INHIBITION MECHANISM

The action mechanisms of corrosion inhibitors are (Umoren, Ekanem, 2010); by adsorption - forming a film that is adsorbed onto the metal surface; by inducing the formation of corrosion products such as iron sulphide, and by changing media characteristics, producing precipitates that can be protective; and eliminating or inactivating an aggressive constituent.

An inhibitor may be effective in one system, while in another it is not, therefore, it is convenient to consider factors such as: the chemical structure of the inhibitor component; chemical composition of the corrosive medium; nature of the metal surface; operating conditions (temperature, pressure, pH, etc.); thermal stability of the inhibitor, solubility of the inhibitor in the system.

2.5 ENVIRONMENTALLY FRIENDLY CORROSION INHIBITORS (EFCIs)

In recent years, owing to the growing interest and attention of the world towards the protection of the environment and the hazardous effects of using chemicals on the ecological balance, the traditional approach on CIs has gradually changed. In the development of corrosion inhibitors, their toxicity and impact on environmental pollution of both the active and other components of the formulation, are evaluated. The European Economic Community assigned the Paris Commission (PARCOM) the task of providing guidance for environmental pollution control, protection of the ecosystems and the evaluation of the toxicity of raw materials and industrial waste products. The PARCOM has developed a standardized test that covers three aspects: toxicity, biodegradation (the persistence in the environment of the formulation components, and bioaccumulation (the level of product build up in the body).

There are a few studies where corrosion inhibitors are evaluated according to these factors, and designed as low toxicity CIs or EFCIs. Most of the inhibitors that receive this rating are based on products that are derived from natural sources that are considered as compatible, biodegradable or environmentally friendly. (Umoren, *et. al*., 2009).

2.6. PLANT PRODUCTS AS CORROSION INHIBITORS IN ACID MEDIA

In the last years, many research groups have published several papers about the evaluations of plant extracts as CIs. Peter et al 2010 carried out a research on how well Azadirachta indica protected mild steel structures from corrosion in acidic solutions – specifically H_2SO_4 solution. They tested the extracts from the leaves, roots and seeds. The measurement methods were weight loss (which measured the relative decrease in mass) and gasometric techniques (which measured the rate of evolution of gas resulting from the cathodic reaction of the corrosion process). Also, various concentrations of the plant extract were tested across various time durations and temperatures. The results of the experiments show that the leaves, roots and seeds are all good candidates for corrosion inhibition. The best however, were the seeds, followed by the roots and lastly, the leaves. The efficiency of corrosion inhibition increased with increase in extract concentration and with temperature. Their conclusions posit that acid extract of the PE can be considered as a source of relatively cheap, ecofriendly and effective acid corrosion inhibitor. Also, after observing the trend of inhibition efficiency with temperature and from the obtained values of activation energy and heat of adsorption, the corrosion inhibition was attributed to chemical adsorption.

Osita et al 2015 compared the various corrosion rates for Elizabeth leaf (Chromolena odaratum), Okazi leaf (Gnetum africanum) and Utazi leaf (Gongronema latifolium) on mild steel coupons in acidic media (HCl and H_2SO_4). The experiment also included coupons with no plant extract as a control. The research showed that the plant extracts could be used as natural corrosion inhibition agents. The plant extracts were seen to be effective corrosion inhibitors when the right concentration was utilised. The results showed that the plant with the highest inhibition efficiency was Elizabeth leaf (Chromolena odaratum) in both the HCl and the H_2SO_4 solutions. Okazi leaf (Gnetum africanum) was next in corrosion inhibition efficiency and finally, Utazi leaf (Gongronema latifolium). As expected, the longer the coupons were exposed to the acidic media, the faster the rate of corrosion, irrespective of whether there was an inhibitor present. For Okazi leaf (Gnetum africana), increase in concentration resulted in increase in inhibition efficiency up till 15mL concentration in HCl and 10mL concentration in H_2SO_4 and subsequently plateaued. For Utazi leaf (Gongronema latifolium), increase in concentration resulted in increase in inhibition efficiency up till 15mL concentration in HCl and 20mL concentration in H_2SO_4 and subsequently plateaued. For Elizabeth leaf (Chromolena odaratum), increase in concentration resulted in increase in inhibition efficiency up till 15mL concentration in HCl and 20mL concentration in H_2SO_4 and subsequently plateaued.

Recently, another research by Obot and Obi-Egbedi, 2010, described the inhibitive action of ethanolic extracts from leaves of Chlomolaena Odorata L. (LECO) as an eco-friendly corrosion inhibitor against acid corrosion of aluminum in 2M HCl, using hydrogen evolution and thermometric techniques; and more recently, against corrosion of mild steel in H_2SO_4 solutions (Lame, *et. al*., 2013) In this last paper, the obtained results showed that LECO functioned as a CI and its efficacy increased with the extract concentration, but decreased with temperature. At a concentration as low as 5 %v/v of the extract, the inhibitory efficiency reached about 95% at 303 K, and 89% at 333 K.

In another interesting work, results showed the excellent inhibitory properties of Coconut coir dust extract (CCDE) with aluminium in 1 M HCl, using weight loss and hydrogen evolution techniques at 30 and 60°C by monitoring the volume of evolved hydrogen gas at fixed time intervals. The representative plots in the absence and presence of different concentrations of the CCDE, showed a remarkable increase in the volume of evolved H_2 gas in the blank acid solution at both studied temperatures and a considerable reduction in the volume of evolved hydrogen gas with the introduction of the CCDE to the medium, suggesting that the CCDE components were adsorbed onto the metal surface, and blocked the electrochemical reaction efficiently by decreasing the available surface area (Belkhaouda, *et. al*., 2013).

Several other investigations on plant extracts as CIs have been done, such as on, Phyllanthus amarus (Obi-Egbedi *et. al*., 2012), Pachylobus edulis (Obot, Obi-Egbedi, 2010), Raphia hookeri (Obot, et. al., 2012), and Spondias mombin L. (Rani, Basu, 2012) etc.

In the category of natural isolated products, amino acids and their derivatives are some of the most studied pure compounds as EFCI. These natural compounds and derivatives have been used as good CIs for mild steel (Oezcan, 2008; Morad, 2005; Olivares, *et. al*., 2006; Fu, *et. al*., 2010; Cui, *et. al*., 2015; Silva, *et.al*., 2006), carbon steel (Amin, *et. al*., 2010; Gece, Bilgic, 2010; Moretti, *et al*., 2002), stainless steel (Zhang, *et. al*., 2005), iron (Radovanovic, *et. al*., 2013), nickel (Zhang, *et. al*., 2008), copper (Barouni, *et. al*., 2008; Ashassi-Sorkhabi, *et. al*., 2005; Ghasemi, Tizpar, 2006; Kiani, *et. al*., 2008; Bobina, *et. al*., 2013), aluminium (Rajendran, *et. al*.,2004), and alloys (Fallavena, *et. al*., 2006), and (Scendo, 2008) in different aggressive solutions. Very recently, the inhibitory properties of l-histidine on the corrosion of carbon steel in weak acid media containing acetic acid/sodium acetate have been tested. The inhibition efficiencies obtained by weight loss measurements are in good agreement with values given by the Tafel method and electrochemical impedance spectroscopy. The adsorption of l-histidine obeys the Langmuir isotherm; the negative values of the Gibbs energy indicate the nature of the interactions between the inhibitor molecules and metal surface. Further, the inhibition effect was studied by using scanning electron microscopy and energy dispersive X-ray analysis (Hoseinzadeh, *et. al*., 2013).

2.7 PLANT PRODUCTS AS CORROSION INHIBITORS IN OTHER MEDIA

There is more application of plant corrosion inhibitors. An example is on the corrosion of mild steel used as reinforcements in concrete for structures. Various research works have been performed recently on the use of plant extracts either as corrosion inhibitor or as additives in electroplating (Loto, C.A, Loto R.T, 2013; Davis, G. D, Fraunhofer, J. A, 2003; Ebenso, *et. al* 2008). The research interest has been necessitated by the fact that the present corrosion inhibitors in the market for the protection of steel reinforcement in concrete exposed to chloride attack or other corrosive environments, are toxic to the environment and thus compromise safety and sustainability drives. Studies such as mentioned above include the use of Bambusa arundinaceais for reinforced concrete (Abdulrahman, A. S; Mohammad, I, 2011); extracts of kola plant and tobacco for mild steel reinforced concrete); Vernonia amygdalina for mild steel in 0.4M HNO_3 ((Nwabanne, J.T; Okafor, V.N; 2011) and extracts of green tea for mild steel in dilute sulphuric acid. It is noteworthy that results of these studies show that extracts of plant materials are at the top of the list of non–chromates that have been used as corrosion inhibitors to replace environmentally hazardous chromates.

A study on the effect of Vernonia amygdalina (bitter leaf extract) as an organic corrosion inhibitor on the corrosion of mild steel embedded in concrete by electrochemical and gravimetric methods (Loto, et.al, 2013) showed that Vernonia amygdalina extract gave good corrosion inhibition performance of the embedded steel rebar in concrete at 25%, 50% and 75% concentrations in NaCl test medium. The highest inhibition efficiency of 90.08 % was achieved at 25% concentration, the lowest inhibitor concentration used. Varied concentration of Vernonia amygdalina and the test exposure time where seen to significantly affect both the corrosion potential of embedded steel rebar in concrete and the pH of the medium.

2.8 PLANT PRODUCT AS CORROSION INHIBITOR IN BASE MEDIA

A work by Lebe, *et. al*., (2016), reports the inhibitive effect of Pentaclethra macrophylla (Bentham) root extracts for mild steel in Potassium hydroxide (0.5M

KOH) at room temperature, 30±1°C. Weight loss measurements were performed thereafter. From the weight loss values, corrosion rates were computed as well as the inhibition efficiency (I %). The result of the EDS micrograph confirmed the presence of the heteroatom of oxygen and phosphate which authenticates the root extract to be a good and efficient inhibitor.

The phytochemical analysis of the leaves and seed extracts of Bentham showed the following components; tannins, saponins, flavonoids, alkaloids and phenols (Dongmo, *et. al.*, 2007; Oyeleke, *et. al.*, 2014). The presence of these active phyto constituents in the extracts may have had great influence on their corrosion inhibition property according to Lebe, *et. al*., (2016). The assessment of the effectiveness of the corrosion inhibitor was done using chemical and electrochemical methods.

Inspection of the figures drawn from table of results revealed that the corrosion rate reduced upon the introduction of Bentham root extracts into the corrosive medium. The extent of reduction in corrosion rate was seen to increase with increase in the concentration of the Bentham root extracts except for the fifth concentration (0.5g/L) which showed slightly higher corrosion rate. Inhibition efficiency increased with increasing inhibitor concentration, and the maximum IE% of 84.02% was obtained at 0.3g/L concentration of the root extracts (Lebe, *et. al*., 2016). Corroborative results between weight loss and other corrosion monitoring techniques have been reported by some researchers (Umoren, *et. al*., 2012; Ebenso, Oguzie, 2005).

Figures further revealed that the inhibition efficiency increased with increase in the concentration of Pentaclethra macrophylla Bentham root extracts but decreased slightly as the temperature was raised. The decrease in the inhibition efficiency of Pentaclethra macrophylla Bentham root extracts as the temperature increased may be attributed to the desorption of the adsorbed components of the extracts on the mild steel surface according to Lebe, *et. al*., (2016). It could be inferred that the extracts acted as a mixed-type inhibitor and the inhibition was due to simple geometric blocking mechanism (Eduok, *et. al.,* 2012).

2.9 BACKGROUND AND TRADITIONAL APPLICATION OF KAVA PLANT

Kava (*Piper methysticum*: Latin "pepper" + Latinized Greek "intoxicating") is an attractive shrub that can grow to more than three meters. The stems are green, jointed with knobby or swollen nodes. The leaves are heart-shaped, about 5-8 inches long with 1 inch leaf stalks. The leaves are palmate veined, that is 11-13 prominent veins originate from the base of the leaf. Male and female flowers are borne in separate clusters on different plants (dioeciously) (Lebot, *et. al.*, 1997). The average fresh weight of Kava's root system is 1 kg at 10 months old. This plant grows well at low elevations where there is constant moisture and partial sun. Traditionally, plants are harvested around four years of age, as older plants have higher concentrations of kava lactones. After reaching about 2 m height, plants grow a wider stalk and additional stalks, but not much taller. The roots can reach a depth of 60 cm (Johnston, *et. al.*, 2006).

Kava root was used mainly as a narcotic drink that induced relaxation and sleep in Hawaii, were more than a dozen varieties of Kava were known. There, the leaves, bark and roots are used as medicine for general debility, weary muscles, chills, colds, headaches, lung and other respiratory diseases, displacement of womb, congestion of urinary tract, rheumatism, and asthma (Balick, *et. al.*, 2002). A systematic review of its evidence by Cochrane concluded it was likely to be more effective than placebo at treating short-term social anxiety (Teschke, *et. al.*, 2011). In Nigeria, Enugu State, Nkanu East Local Government Area, Kava leaf, called *Awa* in Ibo, is used to prepare their local delicacy – *ofe-egusi*. Apart from in Nigeria, Kava is consumed throughout the Pacific Ocean cultures of Polynesia, including Hawaii, Vanuatu, Melanesia and some parts of Micronesia. Its active ingredients are called kava lactones. Due to kava's importance in religious rituals and the seemingly (from the Western point of view) unhygienic preparation method, its consumption was discouraged or even banned by Christian missionaries. (Lebot, *et. al., 1997*) On some islands (most notably the Cook Islands and Niue) their efforts were successful. On other islands, the missionaries either failed to completely eradicate kava (e.g. Hawaii) or actually incorporated it into Christian practices (most notably in Samoa and Tonga). Kava remains legal and regulated as food or dietary supplement in most countries. Several Pacific island-states have created specific legislation aimed at regulating the quality of their kava exports or preventing the exports or consumption of non-noble kava varieties or the parts of the plant that are unsuitable for consumption (leaves, stems). (World Trade Review, 2005)

A total of 18 different kavalactones (or kavapyrones) have been identified to date, at least 15 of which are active (Singh, 2002). However, six of them, including kavain, dihydrokavain, methysticin, dihydromethysticin, yangonin, and desmethoxyyangonin, have been determined to be responsible for about 96% of the plant's pharmacological activity. (Singh, 2002) Some minor constituents, including three chalcones, flavokavain A, flavokavain B, and flavokavain C, have also been identified, (Singh, 2002) as well as a toxic alkaloid (not present in the consumable parts of the plant (Ligresti, *et. al*., 2012).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 MATERIALS FOR EXPERIMENTAL ANALYSIS

3.1.1 REAGENTS

All reagents were of analytical grade, and used as sourced without further purification. Distilled water was used for all solutions preparations. Ethanol was used in preparing leaves extract. 1.0M HCL acid solution, and NaCl solution were employed as the corrosive media. The concentration of the plant extracts used were; 1000mg/L, 2000mg/L, 3000mg/L, 4000mg/L, and 5000mg/L, of Velvet bean and Kava leaves respectively. Mild steel was the metal used.

3.1.2 APPARATUS

The following apparatus were used to carry out the experimental analysis: 500ml conical flask beakers, 2000ml round bottom flask, 1000ml volumetric flask, 50ml measuring cylinder, 100ml measuring cylinder, reflux condenser, water bath, Whatman 14'' filter paper, retort stands, wire gauze, and electronic digital weighing balance.

3.2 PREPARATION OF MATERIALS

3.2.1 METAL SPECIMEN

The percentage composition of mild steel used was 0.01%C, 0.34%Mn, 0.08%P, and 99.51%Fe. Each sheet which was 0.1cm in thickness, was mechanically press-cut into coupons of 3x3cm dimensions. Holes were drilled in the coupons to enable the insertion of a hanger for ease of access of the coupons during removal. These coupons were cleaned with different grades of emery paper, degreased in absolute ethanol, dried in acetone, weighed and stored in moisture free desiccators prior to use.

3.2.2 LEAF EXTRACTS

The plants used as inhibitors were Velvet bean (Mucuna pruriens) and Kava (Piper methysticum). The leaves were obtained from a local market in Enugu State (Gariki market), and were verified at the Department of Crop Science Technology, FUTO.

Velvet bean leaves were thoroughly washed in clean water and sun dried for eight (8) hours. The dried leaves were then ground into powder using an electronic grinder, and stored in an air-tight container prior to use, at room temperature. Exactly 40g of the ground plant powder was added to 200ml of ethanol contained in a 500ml round bottom flask. The resulting solution was heated under reflux for three (3) hours, allowed to cool at room temperature, and then filtered using a Whatman 14'' filter paper. The volume of filtrate obtained was measured, stored in an air tight container and kept away from the sun. The residue obtained was dried then weighed. Thereafter, the residue was used in the determination of the amount of dissolved plant material in the ethanol.

Kava leaves were also thoroughly washed. And because of its high moisture content, it was juiced fresh. The juice was weighed and so was the residue. Preparations of different concentrations were done by volume percentages.

3.3 EXPERIMENTAL SET-UP

After cutting and preparing the steel specimens and leaf extracts, the prepared specimens were all weighed on an electronic mass balance and readings for the initial weight of the specimens were recorded. Weighed samples were suspended under total immersion conditions in 250ml of test solutions at room temperature. The solutions had one blank, or control and the others had the corrosive media with different concentrations of extracts (1000mg/L, 2000mg/L, 3000mg/L, 4000mg/L, and 5000mg/L) of both leaves respectively. All tests were made in aerated and unstirred test solutions.

For the test to determine optimum leaf-extract concentration, eighteen (18) mild steel specimen were used. Fifteen (15) coupons were dipped in corrosive solution with Velvet bean leaf extract of different extract concentrations of 1000mg/L, 2000mg/L, 3000mg/L, 4000mg/L, and 5000mg/L, three (3) coupons for each of the concentrations, and three (3) coupons for the blank solution. These were immersed in 1M HCl acid for 120 hours (5 days), and a similar setup immersed in NaCl medium for twenty-five (25) days.

Twelve (12) coupons were dipped in corrosive media with Kava leaf extracts of different concentrations introduced as mentioned above, in 1M HCl acid for 120 hours (5 days). The control system had two (2) coupons, and every other concentration, two (2) coupons each. Average weight loss measurements were calculated to ensure authenticity of results. Afterwards, corrosion rates calculated and optimum extract concentration determined for both leaves.

Another test to determine the stability of Velvet bean leaf extract as a corrosion inhibitor over a period of time was done. The test involved a blank corrosive environment (1M HCl) without leaf extract, and another corrosive solution that had 4000mg/L of leaf extract. Coupons were reweighed after two weeks (14 days) immersion.

A lot of research has been done on the Velvet bean seed including the work done by Akalezi et al. 2016, who found it that the seed inhibited corrosion effectively especially at higher concentrations of seed extracts. Meanwhile there has been little or no research on the Velvet bean leaf, and Kava leaves too. This tests would investigate these two plant-leaves corrosion inhibition efficiencies, properties and mechanisms.

3.4 GRAVIMETRIC MEASUREMENTS

3.4.1 WEIGHT LOSS MEASUREMENTS

The initially weighed specimens were now reweighed and the weight losses were calculated accordingly.

WL = WI – WF [4] ……………. (2)

Where: WL is weight loss; WI is initial weight; WF is final weight

3.4.2 CORROSION RATE MEASUREMENT

$$\mathbf{C.R} = \frac{\mathbf{Weight\ loss}}{\mathbf{Area \times Time}} \quad \text{…………… (3)}$$

$$\mathbf{Area\ (cm^2) = 2lw + 4lt - \pi r2} \quad \text{………. (4)}$$

Where: l is length; w is width; t is thickness; r is radius; Time (in hours)

3.4.3 INHIBITIVE EFFICIENCY OF INHIBITORS

The percentage inhibitive efficiency, EI was calculated from the following relationship:

$$\mathbf{EI} = \left[\frac{\mathbf{CR_{free} - CR_{inhb}}}{\mathbf{CR_{free}}}\right] \times 100 \quad \text{…………….. (5)}$$

Where: EI is inhibition efficiency; CR_{free} is corrosion rate without inhibitor; CR_{inhb} is corrosion rate with inhibitor.

3.5 STATISTICAL METHODOLOGY

The experimental results were used in response surface study using inhibitor efficiency as response and inhibitor concentration (x_1) and time (x_2) as factors. MATLAB software was used in the analysis. Four statistical models were fit to the data: Linear model, Interaction model, Pure-quadratic model and quadratic model. The best statistical model was chosen based on the value of the adjusted-R^2, beside the R^2. Noting that the closer those values were to unity (1), the more accurate the model was. Other statistical models that were used included; the mean square of errors (MSE), The F-statistics and its p-value. Also noting that the R^2 gave a measure of the variability in the data which the model explained while the MSE, a measure of the error. The closer those values were to zero, the more accurate the model was. Also, that the F-statistics was a measure of model adequacy and its p-value of ≤ 0.05 showed the model was adequate at 95% confidence interval and again, that models with higher F-statistics value and lower p-value were better. The t-statistics and its p-value were next used to determine the significant variables in the model, Analysis of variance (ANOVA) used to determine any significance of the main effects, while surface plots were used to further study interaction of factors.

Linear Model: $y = a_0 + a_1 x_1 + a_2 x_2$

Interaction Model: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_1 x_2$

Pure-quadratic Model: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_1^2 + a_4 x_2^2$

Quadratic Model: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_1 x_2 + a_4 x_1^2 + a_5 x_2^2$

Where; y is the response (inhibitor efficiency), x_1 (inhibitor concentration) and x_2 (time), while a_0 to a_5 are model coefficients.

CHAPTER FOUR

RESULTS AND DISCUSSION

4. 1 EFFECT OF CONCENTRATION ON WEIGHT LOSS

Gravimetric analysis were carried out in 1M HCl and NaCl media in the absence and presence of Velvet Bean Leaf extract and Kava leaf extract respectively. Weight loss measurements were done which provided a direct answer as to how the corrosive environment affected the test samples.

Figure 4.1a and 4.1b; and Figure 4.1c show the variation of weight loss with difference in concentration of the Leave extracts. A visible drop in weight loss is noticed upon addition of leaf extracts for both leaves. This easily indicates that both leaves have corrosion inhibition properties. Weight loss reduces as concentration of extract increases for both leaves.

Figure 4.1a shows the inhibitive properties of Velvet bean leaf in 1M HCl medium. It shows a decrease in weight loss from as high as 0.14g without any extract to as low as 0.01g with 4000mg/L concentration of extract on the first day. The trend continues on all the five (5) days. Fig 4.1b shows the inhibitive properties of Velvet Bean leaf extract in NaCl medium. It still shows a drop in weight loss as concentration of extract increased on all twenty-five (25) days of the experiment. From both figures, weight loss was seen to drop as Concentration of the extract increased until 4000mg/L concentration was reached after which it plateaued a bit. From the figure, an optimum concentration was observed at 4000mg/L among concentrations that ranged from 1000mg/L to 5000mg/L.

Figure 4.1c shows the inhibitive properties of Kava leaf extract. There is a steady decrease in weight loss as Concentration of the Kava leaf extract increased. From 1000mg/L to 5000mg/L, the weight loss kept dropping. The optimum at 5000mg/L.

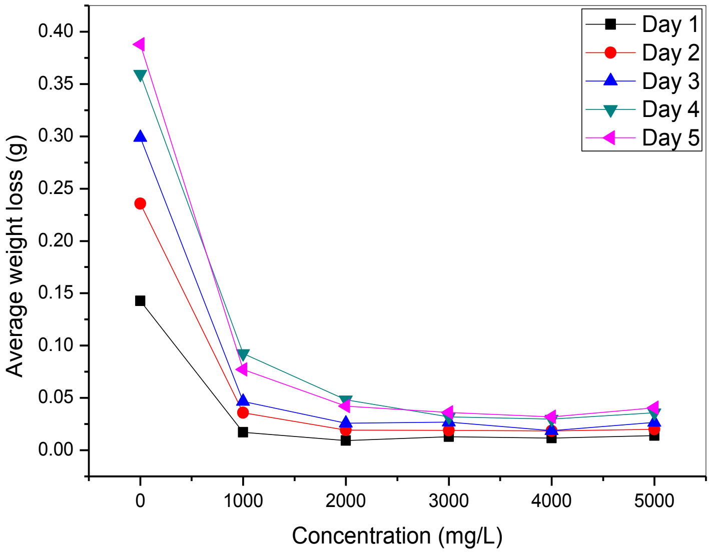


Fig 4.1a: Variation in Weight loss with VB leaf extract concentration at different time intervals in HCl medium

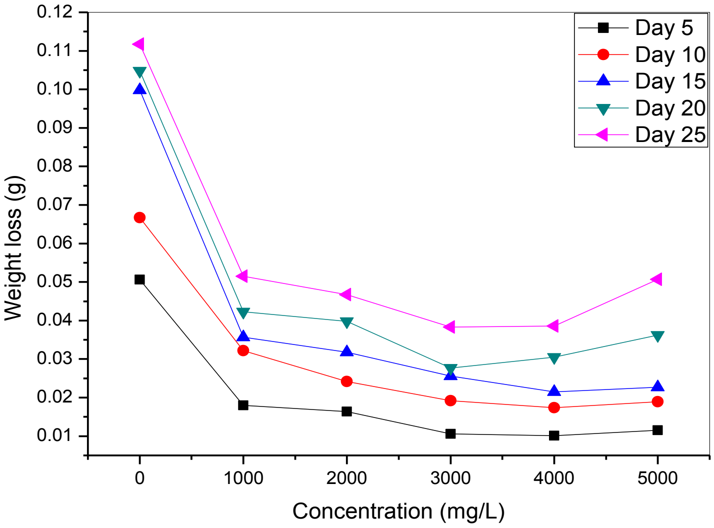


Fig 4.1b: Variation in Weight loss with VB leaf extract concentration at different time intervals in NaCl media

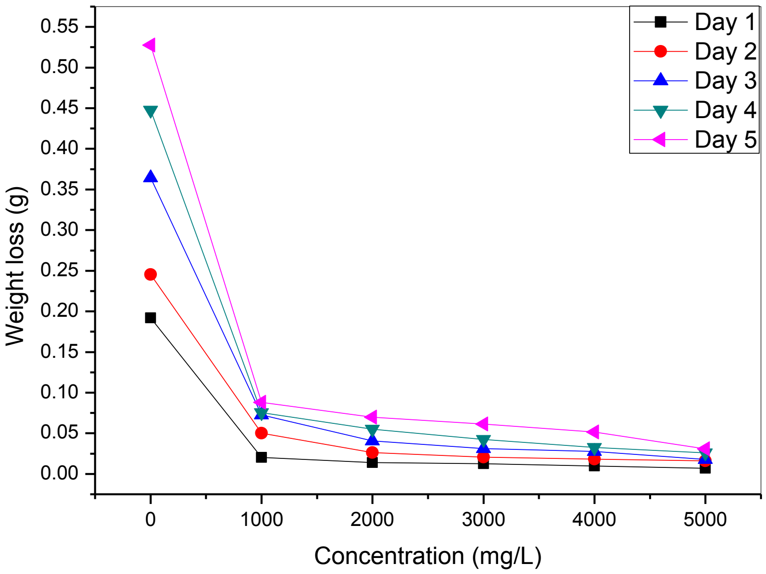


Fig 4.1c: Variation in Weight loss with difference in Concentration of KV leaf extract at different time intervals; in 1M HCl

4.2 EFFECT OF TIME ON WEIGHT LOSS

Fig 4.2a and 4.2b show weight loss increase as time increases. With Velvet bean leaf extract in both 1M HCl medium, and NaCl medium, this trend was noticed. The weight loss is greater with less and less concentration of extract, and is greatest in the blank system without extract.

Fig 4.2c shows an increase in weight loss as time increases in the absence and presence of Kava leaf extract.

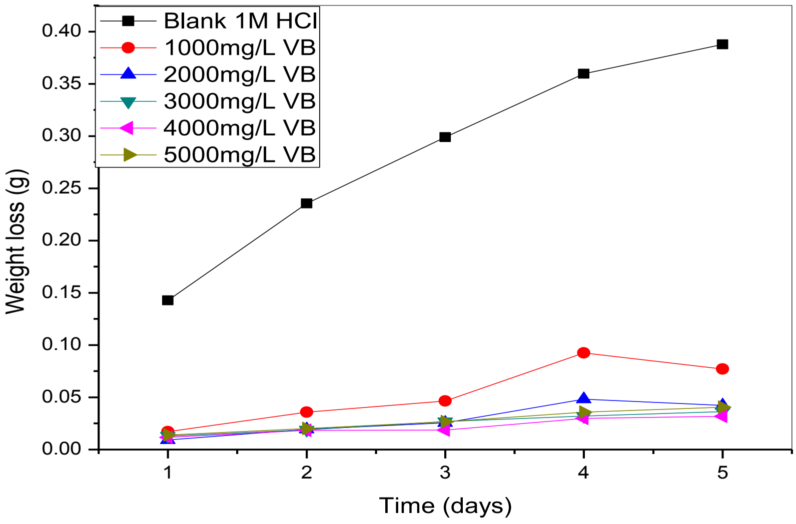


FIG 4.2a: Variation in Weight loss with Time at different concentrations of VB leaf extract in HCl

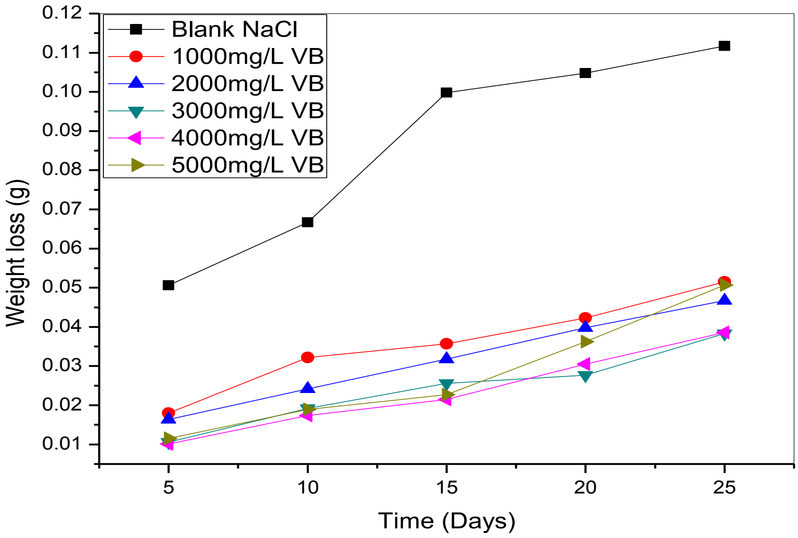


Fig 4.2b: Variation in Weight loss with Time at different concentrations of VB leaf extract in NaCl media.

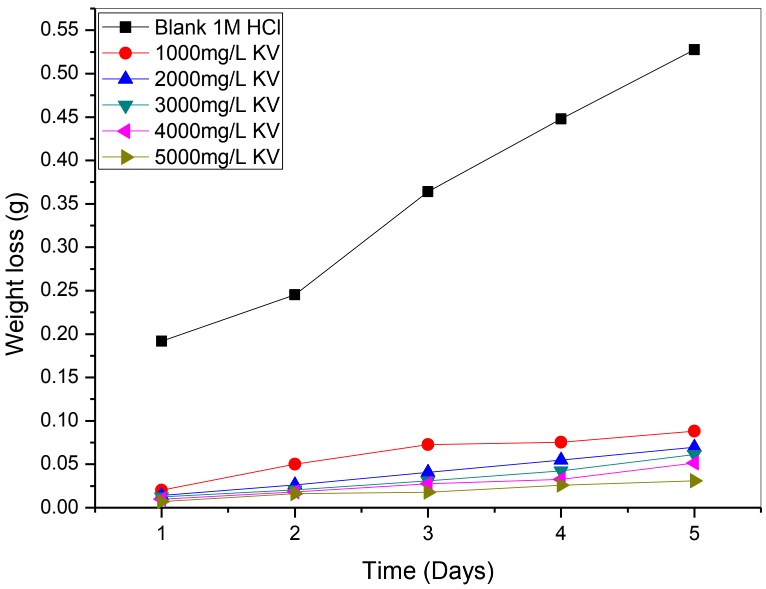


Fig 4.2c: Variation in Weight loss with Time at different KV leaf extract concentration in 1M HCl

4.3 EFFECT ON INHIBITION EFFICIENCY

Fig 4.3a and 4.3b show inhibition efficiency increases with concentration of Velvet bean leaf extract. Fig 4.3c and 4.3d show inhibition efficiency reduces with time in the presence of Velvet bean leaf extract. This is the case in 1M HCl medium and NaCl medium respectively.

Fig 4.3e and 4.3f show the same trend in the presence of Kava leaf extract. It increases with concentration of Kava leaf extract and reduces with time. This is in 1M HCl medium.

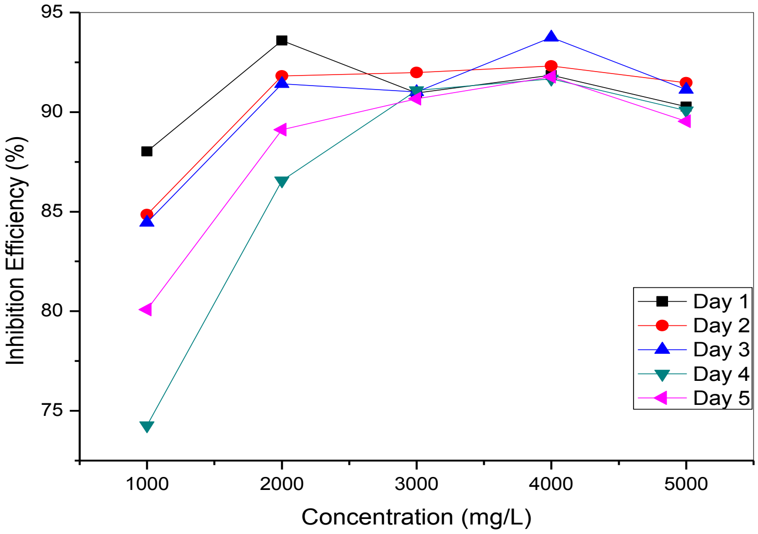


Fig 4.3a: Variation in Inhibition efficiency with VB leaf extract Concentration at different time intervals in 1M HC

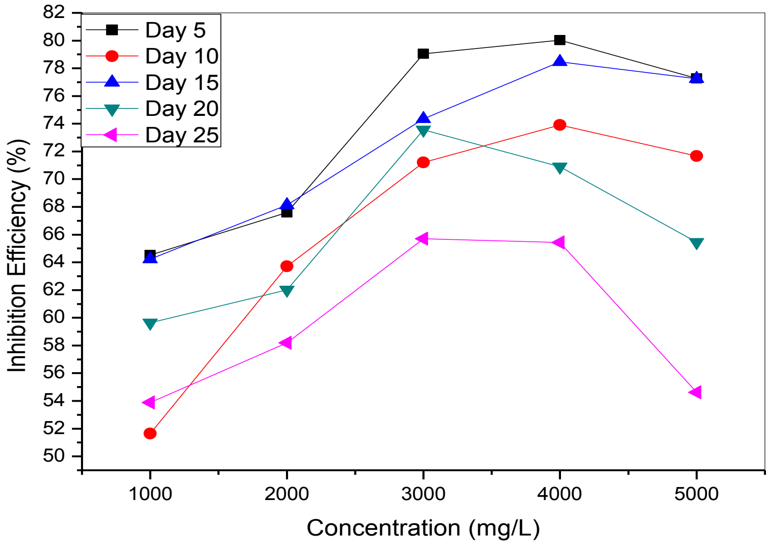


Fig 4.3b: Variation in Inhibition efficiency with VB leaf extract Concentration at different time intervals in NaCl media.

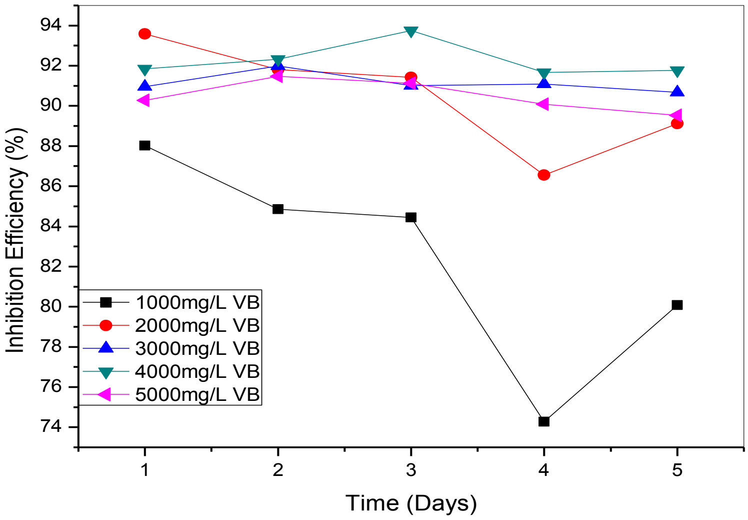


Fig 4.3c: Variation in Inhibition Efficiency with Time at different VB leaf extract concentrations in 1M HCl

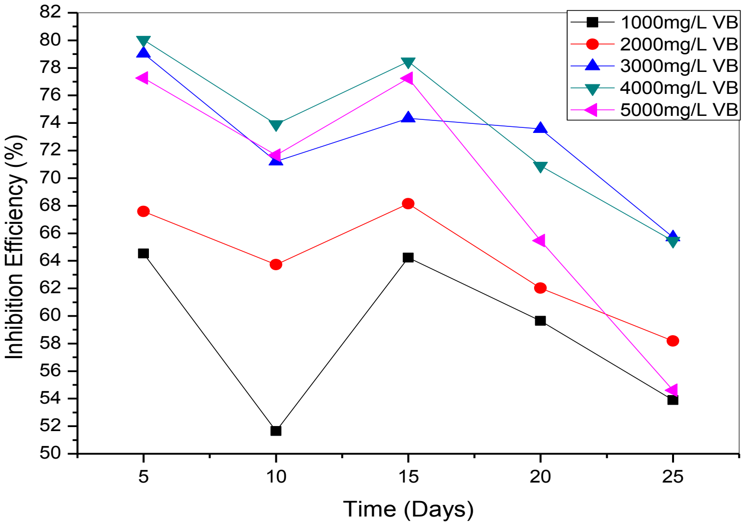


Fig 4.3d: Variation in Inhibition Efficiency with Time at different VB leaf extract concentrations in NaCl media

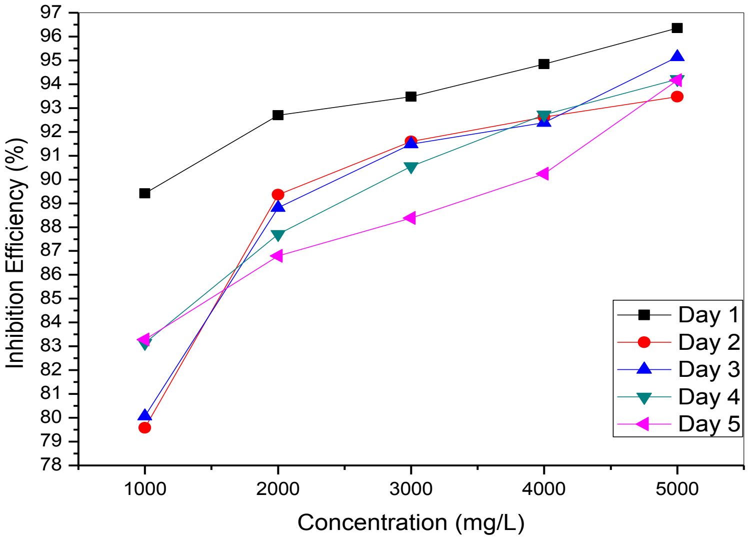


Fig 4.3e: Variation in Inhibition efficiency with KV leaf extract Concentration at different time intervals, in 1M HCl

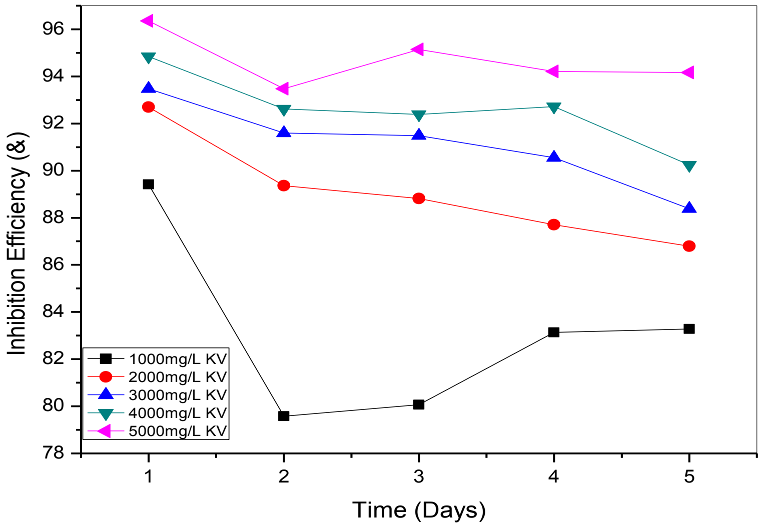


Fig 4.3f: Variation in Inhibition efficiency with Time, at different concentrations of KV leaf extract, in 1M HCl

4.4 ANALYSIS OF VELVET BEAN LEAF EXTRACT AS INHIBITOR IN HCl

Table 4.4a, shows statistical parameters for the four models fit to the data. The quadratic model has the best fit based on the adjusted-R^2 and also the lowest error and p-value. It is therefore the model of choice for the study and explains more than eighty percent of the variability observed in the experimental data.

Table 4.4b, shows the model coefficients and other statistical parameters. Based on the p-value of the t-statistics, all variables are significant at 95% or at least 90% confidence except time-squared. The model is adequate.

The Analysis of variance (Table 4.4c) shows that both factors (main effects) are significant, since they both have p-values less than 0.05, though inhibitor concentration (x_1) is more significant (contributes more to the inhibitor efficiency), since its p-value is lower.

The surface plot (Fig 4.4) shows a close linear relationship of inhibitor efficiency with time and a quadratic relationship with concentration. Thus the optimum inhibitor concentration is a global optimum and cannot be improved on. The contour lines are not parallel lines, thus indicating that the two factors (inhibitor concentration and time) interact with one another instead of acting independently.

The optimum inhibitor efficiency predicted is 94.06% and occurs at an inhibitor concentration of 3200mg/L and time of 24hours (Table 4.4d).

Table 4.4a: Statistical Parameters for Choosing the Best Model (Underlined) for Corrosion Inhibition Efficiency of VBL Extract in HCl Medium

Model	R-squared	Adjusted R-squared	Mean Sq. Error	F- stat	P-val
Linear	0.4404	0.3895	11.8889	8.6556	0.0017
Interaction	0.5187	0.4500	10.7109	7.5449	0.0013
Purequadratic	0.7280	0.6736	6.3567	13.3810	1.8367e-5
Quadratic	0.8063	0.7554	4.7637	15.8228	3.3457e-6

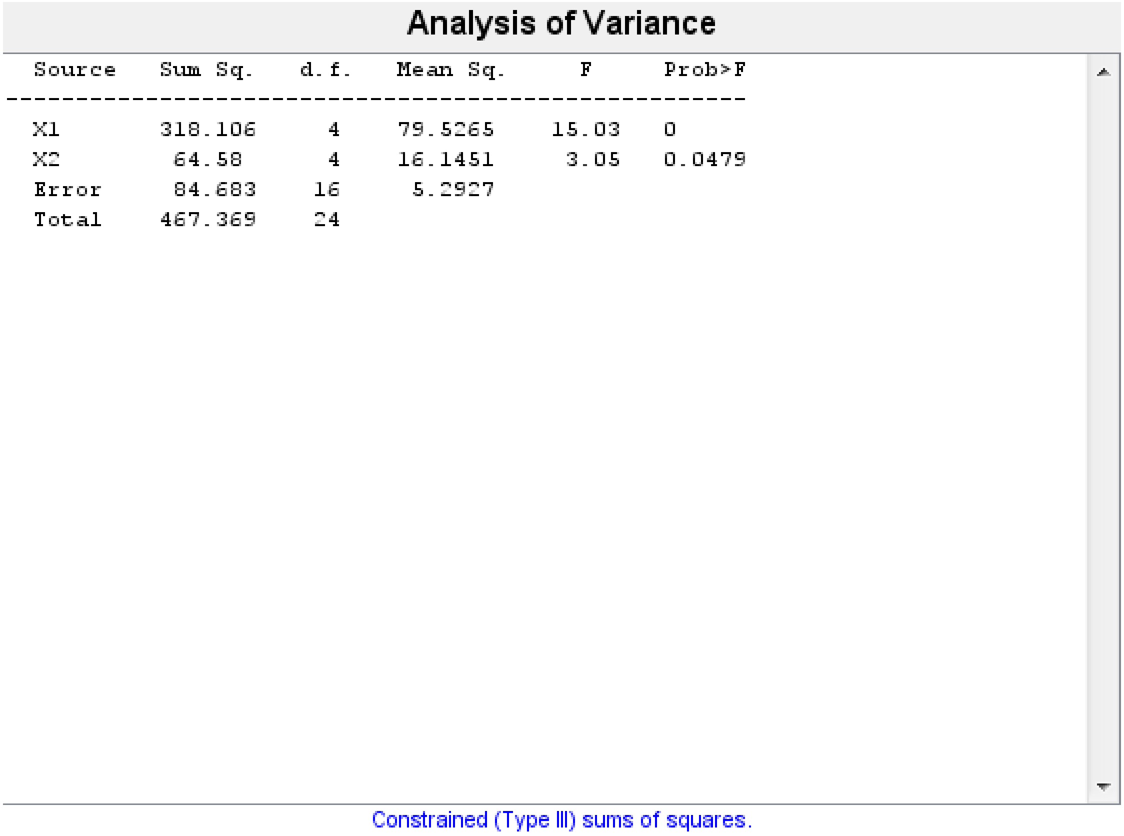
Table 4.4b: Model Coefficients and Parameters for Model with Best Fit for Corrosion Inhibition Efficiency of VBL Extract in HCl Medium

Variables	Coefficients	Std. Error	T-stat	P-val	F-stat
Constant	82.6292	3.5260	23.4341	1.7548e-15	Sse = 90.5073
Inhibitor Conc	0.0083	0.0017	4.8171	1.1977e-4	Dfe = 19
Time	-0.1214	0.0719	-1.6892	0.1075	Dfr = 5
Inh. Conc. * Time	2.5217e-5	9.094e-6	2.7729	0.0121	Ssr = 376.8619
Inh. Conc^2	-1.3854e-6	2.6087e-7	-5.3109	3.9889e-5	F = 15.8228
Time^2	5.2331e-5	4.5289e-4	0.1155	0.9092	p-val = 3.3457e-6

Table 4.4d: Optimum values for factors and Predicted Optimum Response for Corrosion Inhibition Efficiency of VBL Extract in HCl Medium

Optimum Inhibitor Conc. (mg/l)	Optimum Time (hours)	Predicted Optimum Inhibition Efficiency (%)	Remarks
3200	24	94.06	Higher Inhibitor Efficiency is possible at lower values of time.

Table 4.4c: Analysis of Variance (x1=Inhibitor Conc., x2= Time)



Analysis of Variance

```
 Source     Sum Sq.    d.f.    Mean Sq.      F      Prob>F
---------------------------------------------------------
 X1         318.106      4     79.5265     15.03    0
 X2          64.58       4     16.1451      3.05    0.0479
 Error       84.683     16      5.2927
 Total      467.369     24
```

Constrained (Type III) sums of squares.

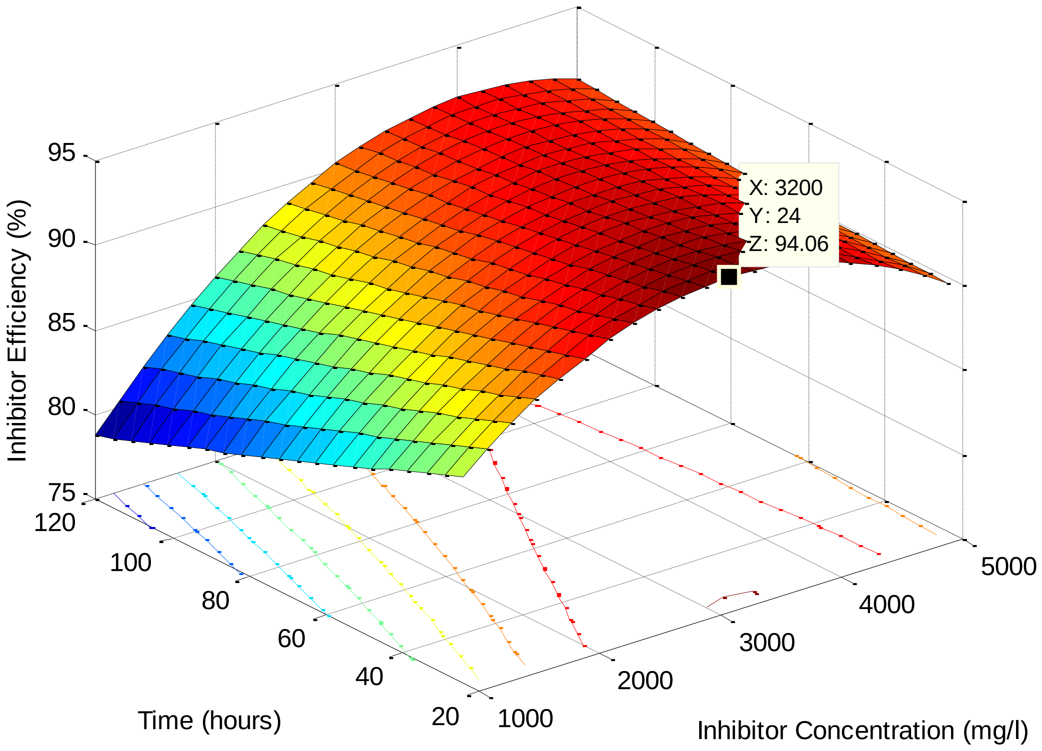


Fig 4.4: Interaction of Inhibitor Concentration and Time on Inhibitor Efficiency of VBL Extracts on Mild Steel, in 1M HCl Medium

4.5 ANALYSIS OF VELVET BEAN LEAF EXTRACT AS INHIBITOR IN NaCl MEDIUM

Table 4.5a shows statistical parameters for the four models fit to the data. The quadratic model has the best fit based on the adjusted-R^2 and also the lowest error and p-value. It is therefore the model of choice for the study and explains nearly eighty percent of the variability observed in the experimental data.

Table 4.5b shows the model coefficients and other statistical parameters. Based on the p-value of the t-statistics, all variables are significant at 95% or at least 90% confidence except time and time-squared. The model is adequate.

The Analysis of variance shows that both factors (main effects) are significant, since they both have p-values less than 0.05, though inhibitor concentration (x_1) is still more significant. (Table 4.5c).

The surface plot (Fig 4.5) shows a weak quadratic relationship of inhibitor efficiency with time and a strong quadratic relationship with concentration. The optimum inhibitor concentration is a global optimum and cannot be improved on. The optimum inhibitor efficiency predicted is 78.84% and occurs at an inhibitor concentration of 4257mg/l and time of 120hours (shown in Table 4.5d).

Table 4.5a: Statistical Parameters for Choosing the Best Model (Underlined) for Corrosion Inhibition Efficiency of VBL Extract in NaCl Medium

Model	R-squared	Adjusted R-squared	Mean Sq. Error	F- stat	P-val
Linear	0.5486	0.5076	32.7180	13.3704	1.5842e-4
Interaction	0.5974	0.5399	30.5741	10.3862	2.1371e-4
Purequadratic	0.7419	0.6903	20.5784	14.3735	1.1038e-5
Quadratic	0.7907	0.7356	17.5699	14.3526	6.8312e-6

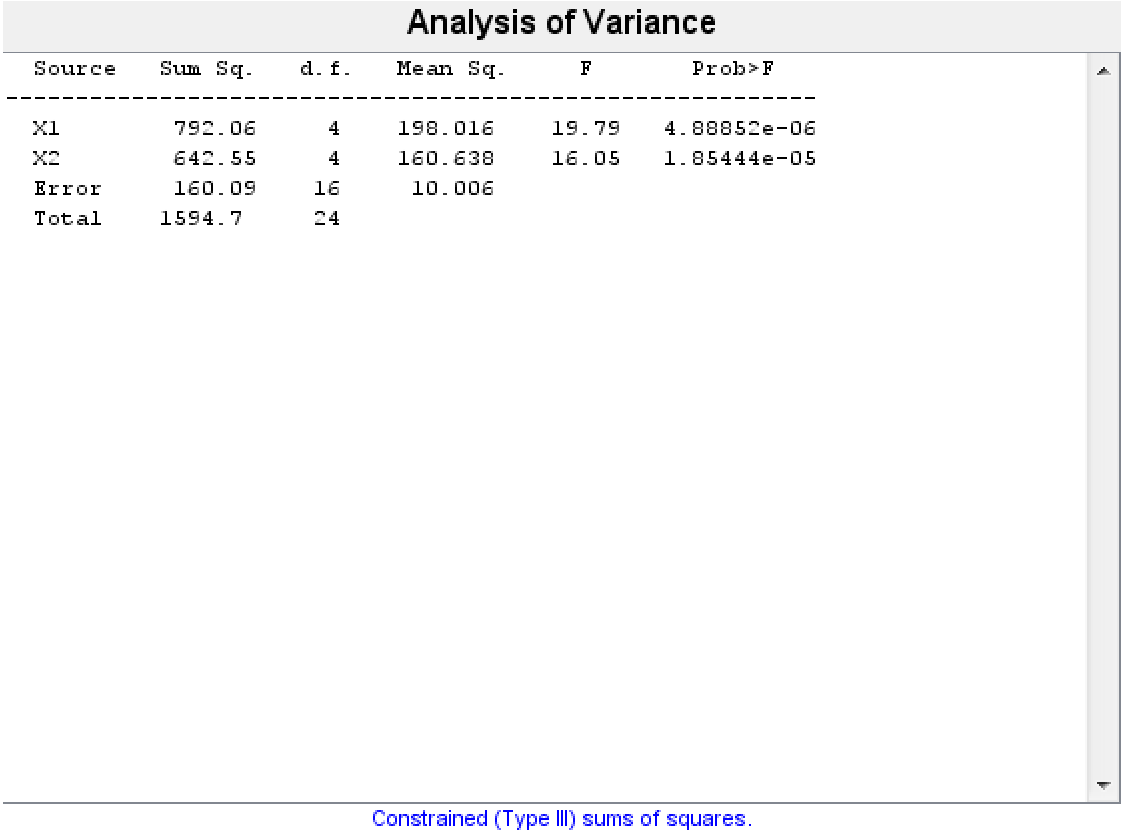
Table 4.5b: Model Coefficients and Parameters for Model with Best Fit for Corrosion Inhibition Efficiency of VBL Extract in NaCl Medium

Variables	Coefficients	Std. Error	T-stat	P-val	F-stat
Constant	39.8751	6.7718	5.8884	1.1389e-5	Sse = 333.8290
Inhibitor Conc	0.0174	0.0033	5.2418	4.6463e-5	Dfe = 19
Time	0.0384	0.0276	1.3904	0.1805	Dfr = 5
Inh. Conc. * Time	-7.3475e-6	3.4930e-6	-2.1035	0.0490	Ssr = 1.2609e3
Inh. Conc^2	-1.9401e-6	5.01e-7	-3.8726	0.0010	F = 14.3526
Time^2	-5.5516e-5	3.4792e-5	-1.5957	0.1271	p-val = 6.8312e-6

Table 4.5d: Optimum values for factors and Predicted Optimum Response for Corrosion Inhibition Efficiency of VBL Extract in NaCl Medium

Optimum Inhibitor Conc. (mg/l)	Optimum Time (hours)	Predicted Optimum Inhibition Efficiency (%)	Remarks
4257	120	78.8435	Higher Inhibitor Efficiency is possible at lower time values.

Table 4.5c: Analysis of Variance (x1=Inhibitor Conc., x2= Time



Analysis of Variance

```
Source     Sum Sq.    d.f.    Mean Sq.      F         Prob>F
----------------------------------------------------------------
X1          792.06      4     198.016     19.79    4.88852e-06
X2          642.55      4     160.638     16.05    1.85444e-05
Error       160.09     16      10.006
Total      1594.7      24
```

Constrained (Type III) sums of squares.

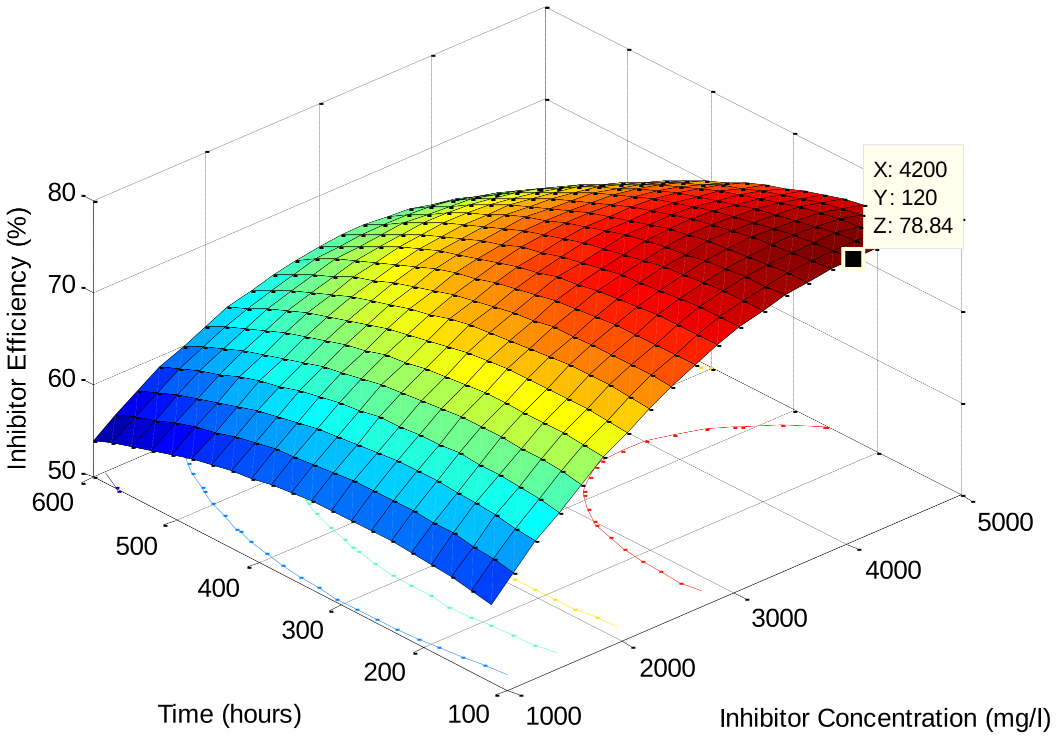


Fig 4.5: Interaction of Inhibitor Concentration and Time on Inhibitor Efficiency of VBL Extracts on Mild Steel, in 1M NaCl Medium

4.6 ANALYSIS OF KAVA LEAF EXTRACT AS INHIBITOR IN HCl

Table 4.6a, shows statistical parameters for the four models fit to the data. The pure-quadratic model has the best fit based on the adjusted-R^2 and also the lowest error and p-value. It is therefore the model of choice for the study and explains more than eighty-six percent of the variability observed in the experimental data.

Table 4.6b, shows the model coefficients and other statistical parameters. Based on the p-value of the t-statistics, all variables are significant at 95% or at least 90% confidence interval. The model is adequate based on p-value of the f-statistics which is less than 0.05.

The Analysis of variance (Table 4.6c) shows that both factors (main effects) are significant, since they both have p-values less than 0.05, though inhibitor concentration (x_1) is still more significant, since its p-value is lower.

With this leaf extract, the surface plot (Fig 4.6), shows a weak quadratic relationship of inhibitor efficiency with time and a strong quadratic relationship with concentration. The optimum inhibitor concentration is at the boundary and thus a local optimum and can be improved on.

The optimum inhibitor efficiency predicted is 96.79% and occurs at an inhibitor concentration of 5000mg/L and time of 24hours (Table 4.6d). The optimum is a little higher than that of velvet beans extract.

Table 4.6a: Statistical Parameters for Choosing the Best Model (Underlined) for Corrosion Inhibition Efficiency of KVL Extract in HCl Medium

Model	R-squared	Adjusted R-squared	Mean Sq. Error	F- stat	P-val
Linear	0.7923	0.7734	4.7335	41.9500	3.1102e-8
Interaction	0.7965	0.7674	4.8587	27.3908	1.8806e-7
Purequadratic	0.8645	0.8374	3.3951	31.9116	2.0063e-8
Quadratic	0.8687	0.8342	3.4630	25.1504	9.1848e-8

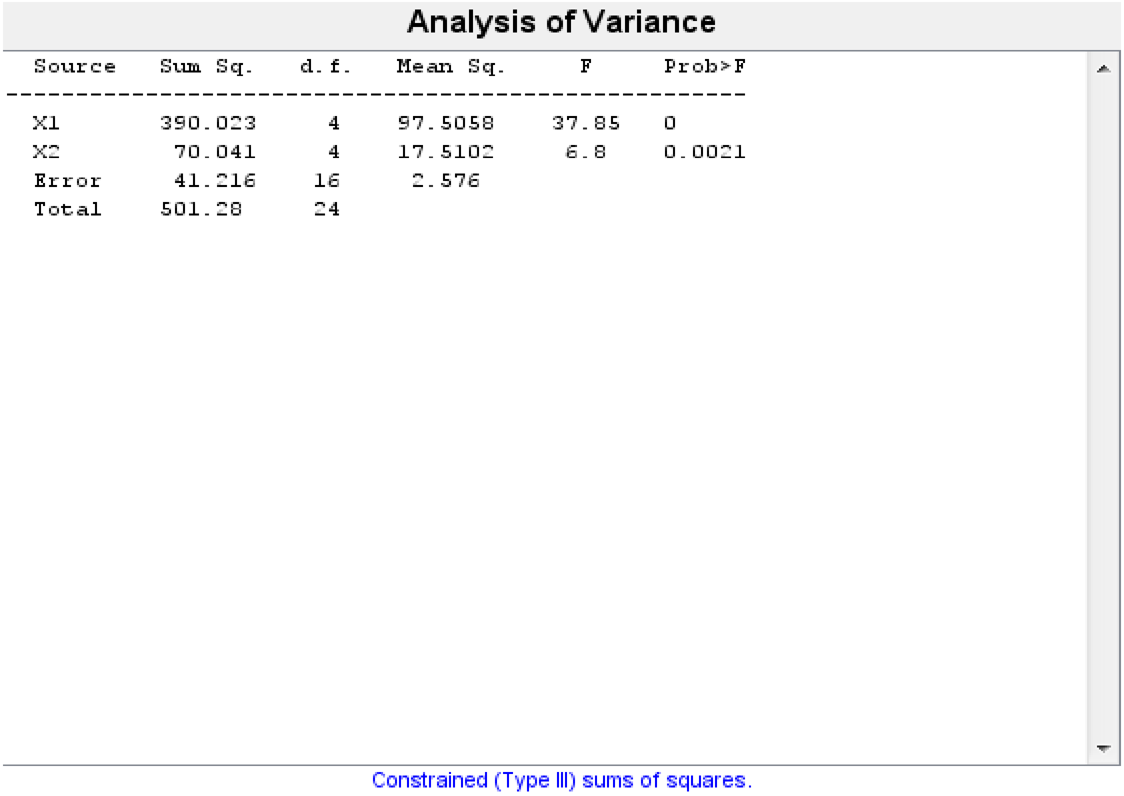
Table 4.6b: Model Coefficients and Parameters for Model with Best Fit for Corrosion Inhibition Efficiency of KVL Extract in HCl Medium

Variables	Coefficients	Std. Error	T-stat	P-val	F-stat
Constant	83.5804	2.4721	33.8096	4.0142e-19	Sse = 67.9027
Inhibitor Conc	0.0062	0.0013	4.6199	1.6549e-4	Dfe = 20
Time	-0.1402	0.0561	-2.4990	0.0213	Dfr = 4
Inh. Conc^2	-5.9329e-7	2.2023e-7	-2.6939	0.0140	Ssr = 433.3768
Time^2	7.066e-4	3.8235e-4	1.8481	0.0794	F = 31.9116 p-val = 2.0063e-8

Table 4.6d: Optimum values for factors and Predicted Optimum Response for Corrosion Inhibition Efficiency of KVL Extract in HCl Medium

Optimum Inhibitor Conc. (mg/l)	Optimum Time (hours)	Predicted Optimum Inhibition Efficiency (%)	Remarks
5000	24	96.79	Improved Inhibitor efficiency can be obtained for higher inhibitor concentration and lower time

Table 4.6c: Analysis of Variance (x1=Inhibitor Conc., x2= Time)



Analysis of Variance

```
  Source     Sum Sq.    d.f.     Mean Sq.      F      Prob>F
----------------------------------------------------------------
  X1         390.023      4     97.5058     37.85    0
  X2          70.041      4     17.5102      6.8     0.0021
  Error       41.216     16      2.576
  Total      501.28      24
```

Constrained (Type III) sums of squares.

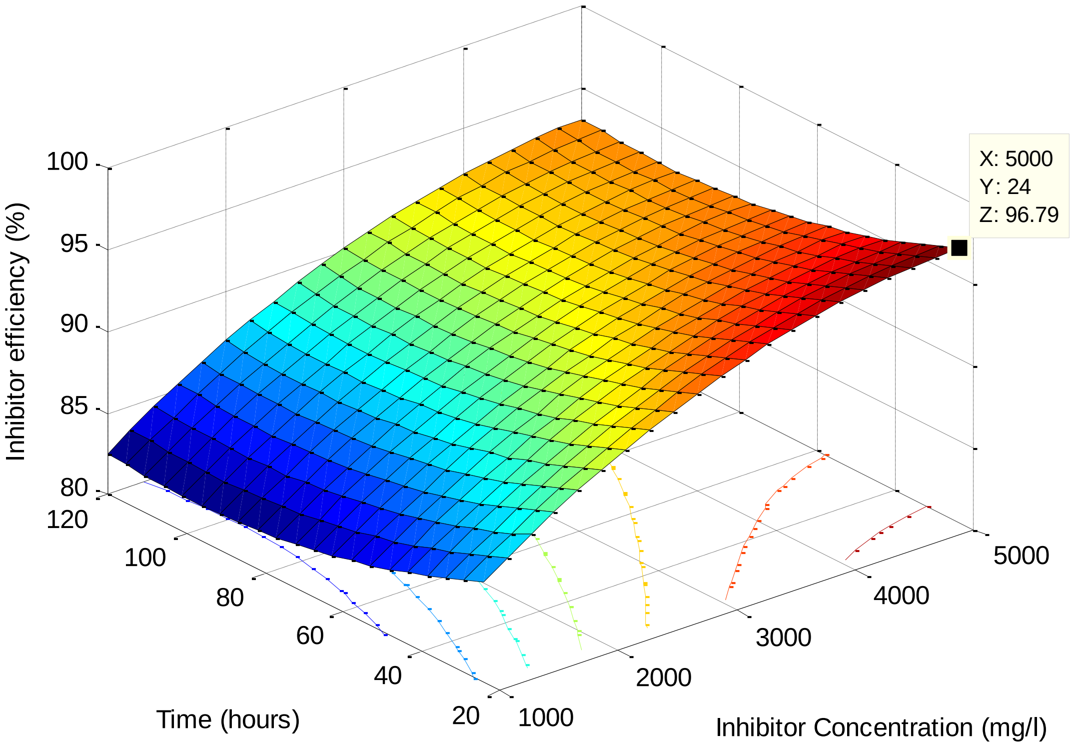


Fig 4.6: Interaction of Inhibitor Concentration and Time on Inhibitor Efficiency of KVL Extracts on Mild Steel, in 1M HCl Medium

4.7 STABILITY OF INHIBITOR

Fig 4.3d and Table 4.7 show that the Velvet bean leaf extract continued to inhibit corrosion even after 25 (twenty-five) days in NaCl medium. Inhibition efficiency was still as high as 65.44% at concentration of 4000mg/L. Table 16 shows results of an analysis using optimum concentration of 4000mg/L of Velvet bean leaf extract on specimen immersed in 1M HCl, for 14 (fourteen) days without interruption. Inhibition efficiency was as high as 93.14%.

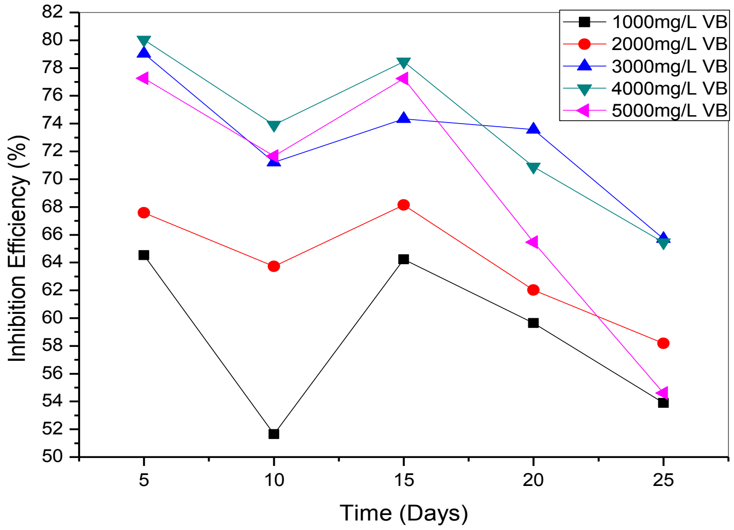


FIG 4.3d Variation in Inhibition Efficiency with Time at different VB leaf extract concentration in NaCl media

Table 4.7: Weight loss of mild steel in 1M HCl in optimum concentration of 4000mg/L Velvet Bean leaf Extract after 14 days immersion.

SAMPLE	INITIAL WEIGHT (g)	FINAL WEIGHT (g)	WEIGHT LOSS (g)	AVERAGE WEIGHT LOSS (g)	SURFACE COVERAGE	INHIBITION EFFICIENCY (%)
Blank HCl						
A	3.3568	1.4876	1.8692	1.8007		
B	2.6716	0.9394	1.7322			
4000						
A	2.9370	2.8200	0.1170	0.1235	0.9314	93.14
B	3.3013	3.1714	0.1299			

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 SUMMARY OF RESEARCH FINDINGS

Velvet Bean and Kava leaves, both locally sourced, have good corrosion inhibition properties on mild steel in acid and base media. The efficiencies of both inhibitors increased as their concentrations increased, and reduced as time increased.

Optimum extract concentration for Velvet bean leaf was 4000mg/L, among concentrations from 1000mg/L to 5000mg/L, giving 91.77% inhibition efficiency in 1M HCl acid medium and 65.44% in NaCl base medium, after 120 hours (5 days) and twenty-five days interval respectively. Also among concentrations from 1000mg/L to 5000mg/L, optimum extract concentration for Kava leaf was 5000mg/L in 1M HCl acid medium after 120 hours (5 days) interval, with an inhibition efficiency of 94.16%.

Velvet bean leaf extract was seen to be a stable corrosion inhibitor for mild steel in both acid and base media and statistical analysis showed the quadratic model was the best fit for VBL extract as an inhibitor in both media. On the other hand, analysis of KVL extract, showed that the purequadratic model was the best fit.

In the statistical analysis of VBL, extract concentration and time significantly affected inhibition efficiency. At an optimum 24hr time interval, optimum extract concentration was found to be 3200mg/L, and could not be improved on. Similarly, extract concentration and time also significantly affected inhibition efficiency for KVL extracts. However, at an optimum time of 24hrs, optimum extract concentration was found to be 5000mg/L and showed signs that it could be improved on.

5.2 CONCLUSIONS

The research has shown that Velvet Bean leaf and Kava leaves have good corrosion inhibition properties on mild steel in both acid and base media. The fact that they are an environmentally friendly option is a huge advantage. In the place of the synthetic corrosion inhibitors that adversely affect the environment, once again, two more environmentally friendly inhibitors have been added to the body of knowledge. Again both leaves are locally sourced and readily available in Nigeria.

Results from the experiments showed that efficiencies of both inhibitors increased as their concentrations were increased, and reduced as time increased. Similarly, the statistical analysis showed that extract concentration and time significantly affected inhibition efficiency of both leaves.

Velvet bean leaf extract was also stable in both acid and base media. In NaCl solution it still was inhibiting corrosion at twenty-five (25) days immersion. Its efficiency was 65.44%. In a delayed immersion of two weeks in 1M HCl solution, it still inhibited corrosion at an efficiency as high as 93.14%. This is of industrial importance as it means that it can be easily applied to use in industries. Cost from plant shutdown and maintenance could be low as the extract could be applied in the system for as long as once in two (2) weeks.

The analysis showed that the quadratic model was the best fit for VBL extract as an inhibitor in both acid and base media, and that the model accounted for at least 80% of the variability in the data. For KVL extract, the purequadratic model was the best fit and accounted for at least 80% of the variability of data.

5.2 RECOMMENDATIONS

The use of these two plant leaves extracts in inhibiting corrosion on mild steel in 1M HCl and NaCl media, in actual industrial environments is recommended. It is crucial for these environmentally friendly and also readily available green inhibitors to gradually replace the synthetic ones. This way the adverse effects on the environment would be greatly reduced.

The stability of Velvet bean leaf over extended time intervals discovered in this research is very relevant in industrial application and it is recommended that this property is tapped into. It would be useful to carry out more research on green corrosion inhibitors such as the Velvet bean and Kava plant leaves, and their application in media different from those covered in this research, as well as at elevated temperatures.

Even though these two plants could grow all year round, and are not yet popular as food in Nigeria, it would be beneficial for more research to be done on synthesising inhibitor components of the plants in the laboratory so as not shorten food supply by other plant use.

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APPENDICES

Appendix 1a

Weight loss of mild steel in 1M HCl in different concentrations of Velvet Bean Leaf Extract after 24 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8392	4.7008	0.1384			
B	5.1635	5.0222	0.1413	0.1427		
C	4.8645	4.7161	0.1484			
1000 A	4.8717	4.8543	0.0174			
B	4.7927	4.7760	0.0167	0.0171	0.8802	88.02
C	4.9189	4.9017	0.0172			
2000 A	4.7994	4.7934	0.0091			
B	4.8282	4.8208	0.0094	0.0091	0.9359	93.59
C	4.7427	4.7355	0.0089			
3000 A	4.9812	4.9681	0.0131			
B	4.8931	4.8806	0.0127	0.0129	0.9096	90.96
C	5.0882	5.0753	0.0129			
4000 A	4.8973	4.8850	0.0119			
B	5.1916	4.8806	0.0116	0.0116	0.9185	91.85
C	4.8459	5.0773	0.0114			
5000 A	4.9398	4.9261	0.0137			
B	4.9731	4.9592	0.0139	0.01387	0.9028	90.28
C	4.7714	4.7574	0.0140			

Appendix 1b

Weight loss of mild steel in 1M HCl with different concentrations of Velvet Bean Leaf Extract after 48 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8392	4.5951	0.2441			
B	5.1635	4.9279	0.2356	0.2356		
C	4.8645	4.6375	0.2270			
1000 A	4.8717	4.8402	0.0315			
B	4.7927	4.7563	0.0364	0.0357	0.8485	84.85
C	4.9189	4.8797	0.0392			
2000 A	4.7994	4.7803	0.0191			
B	4.8282	4.8087	0.0195	0.0193	0.9181	91.81
C	4.7427	4.7235	0.0192			
3000 A	4.9812	4.9623	0.0189			
B	4.8931	4.8742	0.0189	0.0189	0.9129	91.99
C	5.0882	5.0694	0.0188			
4000 A	4.8973	4.8791	0.0182			
B	5.1916	5.1733	0.0183	0.0184	0.9232	92.32
C	4.8459	4.8281	0.0178			
5000 A	4.9398	4.9199	0.0199			
B	4.9731	4.9528	0.0203	0.0201	0.9147	91.47
C	4.7714	4.7513	0.0201			

Appendix 1c

Weight loss of mild steel in 1M HCl in different concentrations of Velvet Bean leaf Extract after 72 hours immersion

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8392	4.5391	0.3001			
B	5.1635	4.8669	0.2966	0.2990		
C	4.8645	4.5641	0.3004			
1000 A	4.8717	4.8274	0.0443			
B	4.7927	4.7444	0.0483	0.0465	0.8445	84.45
C	4.9189	4.8720	0.0469			
2000 A	4.7994	4.7736	0.0258			
B	4.8282	4.8025	0.0257	0.0257	0.9142	91.42
C	4.7427	4.7172	0.0255			
3000 A	4.9812	4.9541	0.0271			
B	4.8931	4.8666	0.0265	0.0269	0.9101	91.01
C	5.0882	5.0612	0.0270			
4000 A	4.8973	4.8788	0.0185			
B	5.1916	5.1724	0.0192	0.0187	0.9375	93.75
C	4.8459	4.8275	0.0184			
5000 A	4.9398	4.9141	0.0257			
B	4.9731	4.9460	0.0271	0.0265	0.9113	91.13
C	4.7714	4.7446	0.0268			

Appendix 1d

Weight loss of mild steel in 1M HCl in different concentrations of Velvet Bean leaf Extract after 96 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8392	4.4777	0.3615			
B	5.1635	4.8049	0.3586	0.3595		
C	4.8645	4.5061	0.3584			
1000 A	4.8717	4.7800	0.0917			
B	4.7927	4.6999	0.0928	0.0925	0.7427	74.27
C	4.9189	4.8259	0.0930			
2000 A	4.7994	4.7531	0.0463			
B	4.8282	4.7769	0.0513	0.0483	0.8656	86.56
C	4.7427	4.6954	0.0473			
3000 A	4.9812	4.9489	0.0323			
B	4.8931	4.8612	0.0319	0.0320	0.9109	91.09
C	5.0882	5.0563	0.0319			
4000 A	4.8973	4.8685	0.0288			
B	5.1916	5.1607	0.0309	0.0299	0.9167	91.67
C	4.8459	4.8158	0.0301			
5000 A	4.9398	4.9037	0.0361			
B	4.9731	4.9379	0.0352	0.0357	0.9008	90.08
C	4.7714	4.7357	0.0357			

Appendix 1e

Weight loss of mild steel in 1M HCl in different concentrations of Velvet Bean leaf Extract after 120 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8392	4.4421	0.3971			
B	5.1635	4.7779	0.3856	0.3878		
C	4.8645	4.4838	0.3807			
1000 A	4.8717	4.7983	0.0734			
B	4.7927	4.7142	0.0785	0.0772	0.8008	80.08
C	4.9189	4.8392	0.0797			
2000 A	4.7994	4.7567	0.0427			
B	4.8282	4.7851	0.0431	0.0422	0.8912	89.12
C	4.7427	4.7019	0.0408			
3000 A	4.9812	4.9442	0.0370			
B	4.8931	4.8579	0.0352	0.0362	0.9067	90.67
C	5.0882	5.0517	0.0365			
4000 A	4.8973	4.8651	0.0322			
B	5.1916	5.1601	0.0316	0.0319	0.9177	91.77
C	4.8459	4.8141	0.0318			
5000 A	4.9398	4.9009	0.0389			
B	4.9731	4.9318	0.0413	0.0406	0.8953	89.53
C	4.7714	4.7297	0.0417			

Appendix 2a

Weight loss of mild steel in NaCl medium in different concentrations of Velvet Bean leaf Extract after 120 hours (5 days) immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8576	4.8070	0.0506			
B	5.1046	5.0541	0.0505	0.0506		
1000 A	4.8386	4.8203	0.0183			
B	5.0316	5.0140	0.0176	0.0180	0.6453	64.53
2000 A	4.8215	4.8052	0.0163			
B	4.9321	4.9157	0.0164	0.0164	0.6759	67.59
3000 A	4.9030	4.8924	0.0106			
B	4.9126	4.9021	0.0105	0.0106	0.7905	79.05
4000 A	4.7356	4.7255	0.0101			
B	4.9448	4.9347	0.0101	0.0101	0.8004	80.04
5000 A	4.8862	4.8748	0.0114			
B	4.7407	4.7292	0.0115	0.0115	0.7727	77.27

Appendix 2b

Weight loss of mild steel in NaCl medium in different concentrations of Velvet Bean leaf Extract after 240 hours (10 days) immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8576	4.7915	0.0661			
B	5.1046	5.0374	0.0672	0.0667		
1000 A	4.8386	4.8062	0.0324			
B	5.0316	4.9996	0.0320	0.0322	0.5165	51.65
2000 A	4.8215	4.8845	0.0242			
B	4.9321	4.9080	0.0241	0.0242	0.6372	63.72
3000 A	4.9030	4.8839	0.0191			
B	4.9126	4.8874	0.0192	0.0192	0.7121	71.21
4000 A	4.7356	4.7183	0.0173			
B	4.9448	4.9273	0.0175	0.0174	0.7391	73.91
5000 A	4.8862	4.8673	0.0189			
B	4.7407	4.7218	0.0189	0.0189	0.7166	71.66

Appendix 2c

Weight loss of mild steel in NaCl medium in different concentrations of Velvet Bean leaf Extract after 360 hours (15 days) immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8576	4.7574	0.1002			
B	5.1046	5.0052	0.0994	0.0998		
1000 A	4.8386	4.8031	0.0355			
B	5.0316	4.9958	0.0358	0.0357	0.6423	64.23
2000 A	4.8215	4.7896	0.0319			
B	4.9321	4.9004	0.0317	0.0318	0.6814	68.14
3000 A	4.9030	4.8789	0.0251			
B	4.9126	4.8866	0.0260	0.0256	0.7435	74.35
4000 A	4.7356	4.7140	0.0216			
B	4.9448	4.9234	0.0214	0.0215	0.7846	78.46
5000 A	4.8862	4.8636	0.0226			
B	4.7407	4.7180	0.0227	0.0227	0.7725	77.25

Appendix 2d

Weight loss of mild steel in NaCl medium in different concentrations of Velvet Bean leaf Extract after 480 hours (20 days) immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8576	4.7527	0.1049			
B	5.1046	4.9999	0.1047	0.1048		
1000 A	4.8386	4.7964	0.0422			
B	5.0316	4.9892	0.0424	0.0423	0.5964	59.64
2000 A	4.8215	4.7819	0.0396			
B	4.9321	4.8921	0.0400	0.0398	0.6202	62.02
3000 A	4.9030	4.8748	0.0282			
B	4.9126	4.8855	0.0271	0.0277	0.7357	73.57
4000 A	4.7356	4.7050	0.0306			
B	4.9448	4.9144	0.0304	0.0305	0.7090	70.90
5000 A	4.8862	4.8490	0.0372			
B	4.7407	4.7058	0.0352	0.0362	0.6546	65.46

Appendix 2e

Weight loss of mild steel in NaCl medium in different concentrations of Velvet Bean leaf Extract after 600 hours (25 days) immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	4.8576	4.7439	0.1137			
B	5.1046	5.0071	0.1097	0.1117		
1000 A	4.8386	4.7871	0.0515			
B	5.0316	4.9802	0.0514	0.0515	0.5389	53.89
2000 A	4.8215	4.7747	0.0468			
B	4.9321	4.8856	0.0465	0.0467	0.5819	58.19
3000 A	4.9030	4.8646	0.0384			
B	4.9126	4.8744	0.0382	0.0383	0.6571	65.71
4000 A	4.7356	4.6971	0.0385			
B	4.9448	4.9062	0.0386	0.0386	0.6544	65.44
5000 A	4.8862	4.8354	0.0508			
B	4.7407	4.6902	0.0505	0.0507	0.5461	54.61

Appendix 3a

Weight loss of mild steel in 1M HCl in different concentrations of Kava leaf Extract after 24 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	5.0744	4.8815	0.1929			
B	4.9827	4.7920	0.1907	0.1918		
1000 A	4.9580	4.9379	0.0201			
B	5.0601	5.0396	0.0205	0.0203	0.8942	89.42
2000 A	4.8480	4.8339	0.0141			
B	4.8789	4.8650	0.0139	0.0140	0.9270	92.70
3000 A	4.6997	4.6869	0.0128			
B	4.8601	4.8480	0.0121	0.0125	0.9348	93.48
4000 A	4.8979	4.8880	0.0099			
B	4.9423	4.9325	0.0098	0.0099	0.9484	94.84
5000 A	4.8578	4.8509	0.0069			
B	4.8875	4.8804	0.0071	0.007	0.9635	96.35

Appendix 3b

Weight loss of mild steel in 1M HCl in different concentrations of Kava leaf Extract after 48 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	5.0744	4.8291	0.2453			
B	4.9827	4.7372	0.2453	0.2453		
1000 A	4.9580	4.9087	0.0493			
B	5.0601	5.0090	0.0510	0.0501	0.7958	79.58
2000 A	4.8480	4.8209	0.0271			
B	4.8789	4.8538	0.0251	0.0261	0.8936	89.36
3000 A	4.6997	4.6786	0.0211			
B	4.8601	4.8401	0.0201	0.0206	0.9160	91.60
4000 A	4.8979	4.8798	0.0181			
B	4.9423	4.9243	0.0180	0.0181	0.9262	92.62
5000 A	4.8578	4.8422	0.0156			
B	4.8875	4.8711	0.0164	0.0160	0.9348	93.48

Appendix 3c

Weight loss of mild steel in 1M HCl in different concentrations of Kava leaf Extract after 72 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	5.0744	4.7158	0.3586			
B	4.9827	4.6130	0.3697	0.3642		
1000 A	4.9580	4.8854	0.0726	0.0726	0.8007	80.07
B	5.0601	4.9876	0.0725			
2000 A	4.8480	4.8072	0.0408	0.0407	0.8882	88.82
B	4.8789	4.8384	0.0405			
3000 A	4.6997	4.6688	0.0309			
B	4.8601	4.8291	0.0310	0.0310	0.9149	91.49
4000 A	4.8979	4.8701	0.0278			
B	4.9423	4.9147	0.0276	0.0277	0.9239	92.39
5000 A	4.8578	4.8403	0.0175			
B	4.8875	4.8697	0.0178	0.0177	0.9514	95.14

Appendix 3d

Weight loss of mild steel in 1M HCl in different concentrations of Kava leaf Extract after 96 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	5.0744	4.6272	0.4472			
B	4.9827	4.5346	0.4481	0.4477		
1000 A	4.9580	4.8824	0.0756			
B	5.0601	4.9847	0.0754	0.0755	0.8314	83.14
2000 A	4.8480	4.7931	0.0549			
B	4.8789	4.8238	0.0551	0.0550	0.8771	87.71
3000 A	4.6997	4.6571	0.0426			
B	4.8601	4.8182	0.0419	0.0423	0.9055	90.55
4000 A	4.8979	4.8652	0.0327			
B	4.9423	4.9099	0.0324	0.0326	0.9272	92.72
5000 A	4.8578	4.8321	0.0257			
B	4.8875	4.8614	0.0261	0.0259	0.9421	94.21

Appendix 3e

Weight loss of mild steel in 1M HCl in different concentrations of Kava leaf Extract after 120 hours immersion.

Sample	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Average Weight Loss (g)	Surface Coverage	Inhibitor Efficiency (%)
Blank A	5.0744	4.5501	0.5243			
B	4.9827	4.4520	0.5307	0.5275		
1000 A	4.9580	4.8704	0.0876			
B	5.0601	4.9714	0.0887	0.0882	0.8328	83.28
2000 A	4.8480	4.7788	0.0692			
B	4.8789	4.8087	0.0702	0.0697	0.8679	86.79
3000 A	4.6997	4.6389	0.0608			
B	4.8601	4.7983	0.0618	0.0613	0.8838	88.38
4000 A	4.8979	4.8465	0.0514			
B	4.9423	4.8908	0.0515	0.0515	0.9024	90.24
5000 A	4.8578	4.8270	0.0308			
B	4.8875	4.8568	0.0307	0.0308	0.9416	94.16

Appendix 4a

Experimental data for velvet bean extract in HCl solution

s/no	Inhibitor conc. (mg/l)	Time (hours)	Inhibitor efficiency (%)
1	1000	24	88.02
2	2000	24	93.59
3	3000	24	90.96
4	4000	24	91.85
5	5000	24	90.28
6	1000	48	84.85
7	2000	48	91.81
8	3000	48	91.99
9	4000	48	92.32
10	5000	48	91.47
11	1000	72	84.45
12	2000	72	91.42
13	3000	72	91.01
14	4000	72	93.75
15	5000	72	91.13
16	1000	96	74.27
17	2000	96	86.56
18	3000	96	91.09
19	4000	96	91.67
20	5000	96	90.08
21	1000	120	80.08
22	2000	120	89.12
23	3000	120	90.67
24	4000	120	91.77
25	5000	120	89.53

Appendix 4b

Experimental data for velvet bean extract in NaCl solution

s/no	Inhibitor conc. (mg/l)	Time (hours)	Inhibitor efficiency (%)
1	1000	120	64.53
2	2000	120	67.59
3	3000	120	79.05
4	4000	120	80.04
5	5000	120	77.27
6	1000	240	51.65
7	2000	240	63.72
8	3000	240	71.21
9	4000	240	73.91
10	5000	240	71.66
11	1000	360	64.23
12	2000	360	68.14
13	3000	360	74.35
14	4000	360	78.46
15	5000	360	77.25
16	1000	480	59.64
17	2000	480	62.02
18	3000	480	73.57
19	4000	480	70.90
20	5000	480	65.46
21	1000	600	53.89
22	2000	600	58.19
23	3000	600	65.71
24	4000	600	65.44
25	5000	600	54.61

Appendix 4c

Table 14: Experimental data for kara leaf extract in HCl solution

s/no	Inhibitor conc. (mg/l)	Time (hours)	Inhibitor efficiency (%)
1	1000	24	89.42
2	2000	24	92.70
3	3000	24	93.48
4	4000	24	94.84
5	5000	24	96.35
6	1000	48	79.58
7	2000	48	89.36
8	3000	48	91.60
9	4000	48	92.62
10	5000	48	93.48
11	1000	72	80.07
12	2000	72	88.82
13	3000	72	91.49
14	4000	72	92.39
15	5000	72	95.14
16	1000	96	83.14
17	2000	96	87.71
18	3000	96	90.55
19	4000	96	92.72
20	5000	96	94.21
21	1000	120	83.28
22	2000	120	86.79
23	3000	120	88.38
24	4000	120	90.24
25	5000	120	94.16