INVESTIGATION OF CORROSION INHIBITION OFGUAVA, BANANA AND ALMOND PLANT EXTRACT IN 0.5M OF HCl AND H_2SO_4 SOLUTION ON LOW CARBON STEEL

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIAIN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARDOF MASTERS OF SCIENCE DEGREE IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING,

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AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

OCTOBER, 2015

DECLARATION

I declare that the work in this dissertationentitled **"INVESTIGATION OF CORROSION INHIBITION OF GUAVA, BANANA, AND ALMOND PLANTS EXTRACT IN 0.5 M OF HCl AND H_2SO_4 SOLUTION ON LOW CARBON STEEL"**was carried out by me in the Department of Mechanical Engineering under the supervision of Dr. D. S. Yawas and Dr. M. Dauda. The information derived from the literature has been duly acknowledged in the text and a list of references provided. To the best of my knowledge, no part of this dissertation was previously presented for another degree or diploma at this or any other institution.

AdegokeADESANMI_____ _____

Name of Student Signature Date

CERTIFICATION

The dissertation entitled "**INVESTIGATION OFCORROSION INHIBITION GUAVA, BANANA, AND ALMOND PLANTS EXTRACT IN 0.5 M OF HCl AND H_2SO_4 ACID SOLUTION ON OF LOW CARBON STEEL**" by **AdesanmiADEGOKE** meets the regulations governing the award of the degree of Master of Science (M.Sc) in Mechanical Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This research work is dedicated to the glory of God the Most High, my late father Mr. Emmanuel Adesanmi and to all victims of wars and conflicts.

ABSTRACT

Extracts from the leaves of three plants namely; guava (*Psidiumguajava: Fem- Myrtaceae*), banana (*Musa species: Fem-Musaceae*) and almond leaves (*Prunusamygdamus: fem-Rosaceae*) were subjected to physico-chemical, phytochemical screening and corrosion test using gravimetric measurement with a low carbon steel flat bar coupon. The corrosion inhibition mechanism of the three plants extract on the low carbon steel surface in 0.5M HCl and H_2SO_4 acid at different temperatures (30-60^oC) show that the inhibition efficiency (IE) increases with increase in concentration of the inhibitor (250ppm-1000ppm) but decreases with increase in temperature (303K -333K) for all the three inhibitors throughout the test period, indicating a physisorption of extract on the carbon steel surface. As the concentration of the inhibitors increases, higher values of the positive activation energy (Ea) ranging from 45.509 kJ/mol - 56.051 kJ/mol indicating physisorption adsorption and positive enthalpy of activation (42.869 kJ/mol - 53.413 kJ/mol) indicating the endothermic nature of adsorption of the inhibitor on low carbon steel were obtained. The values of free energy of adsorption were found to increase (26.624 kJ/mol -29.859 kJ/mol) with increasedin temperature indicating a comprehensiveadsorption (a combination of physisorption and chemisorption) of the inhibitors on the low carbon steel surface. The adsorption on the low carbon steel surface agrees the Langmuir adsorption isotherm. The inhibition efficiency of the three extracts were above 50% in both media with guava extract having the overall best performance of 77.79% in HCl while banana extract with 77.25% in H_2SO_4 solution respectively.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Corrosion phenomena, control and prevention are unavoidable major scientific issues that must be addressed daily as far as there are increasing needs of metallic materials in all facets of technological development (Loto et al, 2011). Corrosion is the deterioration of materials by chemical interaction with their environment. The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than simple loss of a mass of a metal. Failure of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. (Umoren, 2009).

It has been reported after corrosion cost studies carried out in a number of countries including the United Kingdom, Sweden, Germany, and Finland that the annual cost of corrosion ranged as high as 5% of GNP (Corrosion Control Solutions, 2013). This represents a huge sum of money which should have been channeled into the provision of basic social amenities in these countries. In practice corrosion can never be stopped but can be hindered to a reasonable level.

Due to problems from corrosion that are confronting industries; several methods of corrosion control and prevention have been put in place. These include: cathodic protection, lubrication, anodic protection, alloying, coating, inhibition etc. The choice and application of any of the methods is based on their efficiency, economic factors and the nature of the corrosive environment. (Njoku, 1998).

The use of inhibitors is one of the most practical methods for protection against corrosion in corrosive environments. Inhibitors are chemicals that directly or indirectly coat a film on a metal surface to protect it from its environment. Most inhibitors are

adsorbed by the metal surface from a solution or dispersed, but some are applied directly as coatings. Generally, the dissolution of metal can be suppressed by the action of adsorptive inhibitors which may prevent the adsorption of the aggressive ions, and by the formation of a more resistant film on the metallic surface (El Maghraby, 2010).

Corrosion inhibition is of great practical importance, being extensively employed in curtailing wastage of engineering materials and minimizing corrosion control costs. Inhibitor applications is quite varied often playing an important role in oil extraction and processing industries, heavy industrial manufacturing, water treatment facility, water-containing hydraulic fluids, water treatment chemicals, engine coolants, ferrous metal cleaners, automatic transmission fluids, automotive component manufacture, cutting fluids etc. to minimize localized corrosions and unexpected sudden failures. (Loto, et al. 2012)

Historically, most of the known corrosion inhibitors are synthetic chemicals (Heavy Metal), expensive and very hazardous toenvironment. Therefore, it is desirable to source for environmentally safe inhibitors (Paul, et al. 2012).

In very recent time, however, there has been the need to look at some other environment friendly substances, especially from natural resources that could be used to control/prevent incessant corrosion problems apart from the synthesized inorganic and other organic chemicals, some of which are toxic to the environment. Many scientific researchers have responded to this need and it has generated increased research studies into the use of plant extracts (Loto, et al. 2011). The use of natural products otherwise tagged "green corrosion inhibitors" has been advocated because of the cost, toxic nature and environmentally unfriendliness of some of the inorganic and organic corrosion inhibitors. More so, they are readily available, cheap and a renewable source of materials. Very encouraging results have been obtained in this regard. An attempt at making a contribution to this growing research area has necessitated the

present investigation. Plant parts that have been used include leaves, bark, fruit and the roots. In very many cases, the corrosion inhibitive effect of some of the plants' extracts has been attributed to the presence of tannin in their chemical constituents. Also associated with the presence of tannin in the extracts is the bitter taste in the bark and/ or leaves of the plants. (Loto, et al. 2011).

In this work, corrosion inhibition of guava, banana and almond leave extract in hydrochloric and sulphuric solutions on low carbon steel was investigated.The leaves of these plants, were chosen on ecological basis (they are referred to as green corrosion inhibitor which are environmentally friendly), presence of tannin (have an array of hydroxyl and carboxyl groups through which the molecules can adsorb on corroding metallic surfaces), in their chemical constituents and their abundance.

The choice of low carbon steel as the test specimen was due to its wide usage and good mechanical properties which include: ductility, malleability, formability, high tensile strength, impact strength, weldability etc. It is also comparatively cheap and available in abundance. These properties make low carbon steels to be used in many engineering applications and their subjection to acidic environments is also common feature during processing and in some areas of application. Thus it becomes imperative to investigate the corrosion behavior of low carbon steels in acid solution as well as their response to inhibition in such media (Njoku, 1998).

1.2 Statement of the Problem

According to the Gas and Oil Pipeline Standards (GOST) of Nigeria, the standard lifetime of a pipeline is 33 years but research findings revealed that 18% of pipeline failure is caused by corrosion (Achebe, et al. 2012).

Most of the corrosion inhibitors used in processing industry are synthetic in nature, hence not environmentally friendly.

Human health hazard like lung cancer are known to have arisen as a result of long time exposure to inorganic inhibitors such as chromates, phosphates.

Waste recycling: The proposed plant extracts to be used are agricultural wastes that needed to be recycled.

1.3 The Present Research

In this research, extract from guava, banana and almond leaves, were used to inhibit corrosion of low carbon steel in 0.5M of HCl and H_2SO_4solution. The coupon was brought out of the test media at various intervals and corrosion rate (C.R) was determine through weight loss measurement, while the inhibitor efficiency, film attractive power, activation energy and enthalpy of adsorption of the inhibitors were calculated using the required expression and relationship.

1.4 Aim and Objectives

The aim of this research wasto carry out an investigationof corrosion inhibition of guava, banana and almond plantsextract in 0.5M of HCl and H_2SO_4 on low carbon steel. The specific objectives are:

i. **Formulation of inhibitor from extract ofguava, banana and almond leaves**
ii. **To determinethe Physico-chemical and Phyto-chemical properties of plant extracts**
iii. **To carry out corrosion test on low carbon steel using weight loss technique by varying concentration of inhibitors and temperature.**
iv. **To compare the inhibition properties of extract from guava leaves banana leaves and almond leaves**
v. **To determine the effect of increased in concentration of plants extract and temperature on percentage inhibitive efficiency of plants extract.**

vi. **To determine the order of ranking of the inhibitive properties of plants extract with respect to increase in temperature.**

vii. **To determine the effect of increase in concentration on the activation energy (Ea).**

viii. **To determine the effect of plants extract on the enthalpy and entropy of the system.**

ix. **To determine the best fit adsorption isotherm for the plants extract.**

x. **To determine the adsorption ability of the plants extract on low carbon steel,**

xi. **To evaluate the surface condition of mild steel in contact with hydrochloric and sulphuric acid solution in the absence and presence of both inhibitors using scanning electron microscope (SEM).**

1.5 Significance of the Study

i. **The development of an alternative corrosion inhibitorthat are effective and environmentally friendly substances when compare to chromates which are toxic and carcinogenic in nature are the focus of present researchers (Loto, et al. 2012).**

ii. **Most of the corrosion inhibitors are not just only synthetic and hazardous in nature but very expensive. Therefore, it is desirable to source for cheaper and environmentally safe inhibitors (Paul, et al, 2012).**

iii. **Owing to the increasing ecological awareness as well as the strict environmental regulations limiting the uses of toxic substance as corrosion inhibitor, the attention of researchers are currently focusing on the development of "green" alternatives to mitigating corrosion. (Special Issue on Green approaches to corrosion mitigation, 2011).**

iv. **Due to the availability of these plants and the simplicity in processing them into inhibitors, they are less expensive when compared to inhibitors produced using synthetic chemicals.**

v. **Carbon steel is widely used as a constructional material in most of the major industries particularly in food , petroleum, power production, chemical and electrochemical industries, due to its versatile mechanical properties and low cost. The major problem of carbon steel is its dissolution in acidic medium. Corrosion of iron and steel in acidic aqueous solutions is one of the major areas of concern in many industries where acids are widely used for applications such as industrial acid cleaning, acid pickling, acid descaling, and oil well acidizing. Due to corrosive nature of acid solution, materials for construction are getting corroded easily. (Abd El-hameed, 2011).**

1.6 Justification of Research

This work was no doubt justifiable owing to the increasing ecological awareness as well as the strict environmental regulations, and consequently the need to develop environmentally friendly processes, attention is currently focused on the development of "green" alternatives to mitigating corrosion in which the leaves of guava, banana and almond happen to fall into this category. The guava trees are more predominant in the northern part of Nigeria while banana and almond trees are more abundant in the Southern part of the country. The fruits of the trees are edible but the leaves are of little or no use to the persons who cultivate the trees. Hence, it is most appropriate to utilize the leaves in the production of corrosion inhibitors, which will compete or replaced some organic and inorganic chemical corrosion inhibitors which are hazardous, harmful and toxic to human and the environment (Okafor, et al. 2012).

1.7 Scope of the Study

This Study was limited toinvestigation of inhibition effectiveness ofextract from guava, almond and banana leaves in 0.5M of HCl and H_2SO_4 solution on low carbon steel using weight loss method in the presences of each inhibitor at various concentration and temperatures. The surface morphology of the coupon was examined using scanning electron microscope (SEM).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Corrosion is an increasingly serious and costly problem that can lead to plant and equipment failures, leakages in oil and gas pipelines as well as failure of steel bridges, ships, and buildings. These failures range from being an annoyance to being catastrophic. Failures caused by corrosion could and do lead to a direct failure of a component which could affect the entire system and can not only be very expensive in terms of down-time to repair or replace plant and equipment, but can also costly in loss of productivity, human life and health as well as to the environment (Corrosion Control Solutions, 2013).

Nigeria, a major user of ferrous and non-ferrous metal is also experiencing its own share of corrosion problems. One of the major industrial sectors in Nigeria experiencing this problem is the Oil and Gas industry. Research work on the analysis of oil pipeline failures in oil and gas industries in the Niger delta area of Nigeria was carried out to ascertain the causes of these failures. Information on pipeline conditions was gathered for the period between 1999 and 2010. Observations showed that the major causes of failure include: ageing, corrosion, mechanical failures – welding defects, pressure surge

problems, stress, wall thickness, etc. From the data gotten and results that were obtained, recommendations were given on measures to minimize these failures. According to the Gas and Oil Pipeline Standards (GOST) of Nigeria, the standard lifetime of a pipeline is 33 years but this research findings revealed that 42% of failures were mechanically induced, 18% by corrosion, third party activity contributed 24%, 10% through operational error and 6% by natural hazards(Achebe et al., 2012).

2.2 Corrosion

Corrosion is known to be the fundamental means by which the deterioration of metal takes place by chemical attack or reaction with its environment. It is a constant and continuous problem, often very difficult to eliminate completely, (Rani and Basu, 2012).Most metals corrode on contact with the followings: water, moisture in the air, oils, acids, bases, salts, aggressive metal polishes, and other solid and liquid chemicals. Gaseous substances like acid vapors, ammonia gas, formaldehyde gas, and sulfurcontaining gases. Corrosion specifically refers to any process involving the deterioration or degradation of metal components. The best known case is that of the rusting of steel. Corrosion processes are usually electrochemical in nature, having the essential features of a battery(www.stoprust.com).

For corrosion to take place in steel, iron (Fe) at the surface of a component undergoes a number of simple changes. First,

$$Fe \rightarrow Fe^{n+} + n \text{ electrons} \quad \text{---------- (2.1)}$$

The iron atom looses some electrons and becomes a positively charged ion. This allows it to bond to other groups of atoms that are negatively charged.

Wet steel rusts to give a variant of iron oxide so the other half of the reaction must involve water (H_2O) and oxygen (O_2) in the form

$O_2 + 2H_2O + 4e^- \rightarrow 4OH$ ---------- (2.2)

This makes sense as a negatively charged material that can combine with the iron and electrons, which are produced in the first reaction.(Bill and Gareth, 2003)

$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$ ----------(2.3)

Oxygen dissolves quite readily in water and becauseit'susually excess it, reacts with the iron hydroxide.

$4Fe(OH)_2 + O_2 \rightarrow 2H_2O + 2Fe_2O_3.H_2O$ ----------2.4

(brown rust).

2.2.1 Adsorption

Adsorption is an important step in inhibition by organic-based film forming in corrosion inhibitors. Adsorption results from the polar or charged nature of the organic molecule first establishing a physisorption surface film (through Van der Wall's forces) which may further stablise through chemisorption to form a donor type bond (Pearson, 1968).

Adsorption is the primary step in achieving inhibition in acid solutions. The metal surface to be inhibited is usually oxide free allowing the inhibitor ready access to retard the cathodic and/or the anodic electrochemical processes of corrosion on the metal surface. Anodic inhibitors cause the formation or maintenance of a passive film on the material surface and this film essentially prevents the anodic dissolution of the metal. The effectiveness of anodic inhibitors depends on the metal. But in cathodic inhibitors, the rate of corrosion is controlled by the rate of oxygen reduction i.e cathodic inhibitors reduces the rate of this by forming thick (compared to passive) films on the metal surface which reduce oxygen transport to the surface.

The possible processes giving rise to insoluble products on the metal surface are:

a) **Reaction of solution species with hydroxides to precipitate a solid,**
b) **Reaction of solution species with ferrous ions,**
c) **Reduction of solution species at the active metal surface followed by precipitation, and**
d) **Decomposition of solution species followed by precipitation (Yawas, 2005).**

Often, more than one of these processes will occur particularly with combination of cathodic inhibitors and it can be difficult to separate those processes responsible for the reduction in corrosion rate from those that are irrelevant as regards inhibition but occur, nevertheless (Yawas, 2005).

2.2.2 Adsorption Principle

Adsorption is a process in which molecules leave the solution and are held in the chemical surface of the solid by chemical and physical bonding. The adsorbed material is called the adsorbate while the absorbing face is the absorbent. The bonding is chemical if it is irreversible and physical, if it is reversible (Bikerman, 1958 and Quraishi and Ansari 2003). The number of molecules of fluid phase which will adsorb to a given solid surface at equilibrium depend on:

(1) **PH which increases as adsorption reduces**
(2) **Relative concentration of the solute in the solvent**
(3) **Adsorption forces**
(4) **Degree of ionization**
(5) **The available surface area; and**
(6) **The prevailing temperature (Yawas 2005)**

2.2.3 Adsorption Isotherm

Adsorption isotherms are mathematical models that describe the distribution of the adsorbate species among liquid and adsorbent, based on a set of assumptions that are

mainly related to the heterogeneity/ homogeneity of adsorbents, the type of coverage and possibility of interaction between the adsorbate species (Dada et al, 2012). It can also be defined as the relationship obtained by determining the amount of material adsorbed as a function of absorbent concentration at constant temperature. The adsorption isotherms are based on either monolayer or multilayer coverage of the adsorbate on the solid phase (Yawas, 2005). Adsorption data are usually described by adsorption isotherms, such as Langmuir, Freundlich, Temkin, Dubinin-Raduskevich, Redlich-Peterson and Toth isotherms. The adsorption isotherm in this work is the Langmuir isotherms.

The Langmuir model is based on the assumption that the maximum adsorption occurs when a saturated monolayer of solute molecules is present on the adsorbent surface, the energy of adsorption is constant and there is no migration of adsorbate molecules in the surface plane. The Langmuir isotherm is given by:(Kumar and Kirthika, 2009).

$$q_e = \frac{q_m K_L C_e}{1+K_L C_e} \quad \text{---------- 2.5}$$

Langmuir adsorption parameters were determined by transforming the Langmuir equation into a linear equation

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L C_e} \quad \text{----------2.6}$$

Where:

C_e**= the equilibrium concentration of adsorbate (mg/L^{-1})**

q_e**= the amount of metal adsorbed per gram of the adsorbent at equilibrium (mg/g).**

q_m**= maximum monolayer coverage capacity (mg/g)**

K_L**= Langmuir isotherm constant (L/mg).**

The essential features of the Langmuir isotherm may be expressed in terms of equilibrium parameter R_L, which is a dimensionless constant referred to as separation factor or equilibrium parameter.

$$R_L = \frac{1}{1+(1+K_L C_o)-}$$ ----------2.7

Where

C_o **= initial concentration**

R_L **value indicates the adsorption nature to be either unfavourable if** $R_L > 1$**, linear if** $R_L = 1$**, favourable if 0**$< R_L < 1$ **and irreversible if** $R_L = 0$**.**

2.3 Classification of Corrosion

Corrosion is classified in different ways. The preferred classification of corrosion is given below (Fontana, 1987).

2.3.1 Dry Corrosion

This type of corrosion takes place in the absence of a liquid phase or above the dew point of the environment. Vapours and gases are usually the corrodents. Dry corrosion is often associated with high temperature; a good example is the attack on steel by furnace.

2.3.2 Wet Corrosion

Wet corrosion takes place when a liquid is present. It usually involves an aqueous solution or electrolyte. This is the most common type of corrosion. A good example is corrosion of turbine blade by water.

2.4 Forms of Corrosion

It is convenient to classify corrosion by the forms in which it manifests itself, the basis for this classification being the appearance of the corroded metal. Each form can be identified by mere visual observation. In most cases the naked eye is sufficient, but sometimes magnification is helpful or required.

Some eight forms of corrosion are unique, but all of them are more or less interrelated. The eight forms are: (1)uniform, or general attack, (2)galvanic, or two-metal corrosion,

(3)crevice corrosion, (4)pitting, (5)intergranular corrosion, (6)selective leaching, or parting, (7) erosion corrosion, and (8)stress corrosion. This listing is arbitrary but covers practically all corrosion failures and problems. The forms are not listed in any particular order of importance(Fontana, 1987).

2.4.1 Uniform Corrosion



Plate I: Uniform Corrosion of Metal sheet(Retrieved November, 28, 2014 from https://www.google.com/search?q=image+of+uniform+corrosion&tbm=isch&tbo=u&source)

Uniform corrosion, as the name suggests, occurs over the majority of the surface of a metal at a steady and often predictable rate. Although it is unsightly its predictability facilitates easy control, the most basic method being to make the material thick enough to function for the lifetime of the component. (Bill and Gareth, 2003)

Uniform corrosion can be slowed or stopped by;

(i) Slow down or stop the movement of electrons

(a) Protective coating

(b) Reduce the conductivity of the solution in contact with the metal an extreme

case being to keep it dry. Wash away conductive pollutants regularly.

(c) Cathodic protection

(ii) Slow down or stop oxygen from reaching the surface.

(iii) Prevent the metal from giving up electrons by using a more corrosion resistant metal higher in the electrochemical series. Use a sacrificial coating which gives up its electrons more easily than the metal being protected. Apply cathodic protection. Use inhibitors.

(iv) Select a metal that forms an oxide that is protective and stops the reaction.

(v) Control and consideration of environmental and thermal factors is also essential.

2.4.2 Galvanic or Two Metal Corrosion



Plate II: Galvanic corrosion of a pipe(Retrieved November 28, 2014, fromhttps://www.google.com/search?q=image+of+galvanic+corrosion&tbm=isch&tbo=u&source

This occurs when two different metals are placed in contact with each other and is caused by the greater willingness of one to give up electrons than the other (Bill and

Gareth, 2003).A potential difference usually exists between two dissimilar metals when they are immersed in a corrosive or conductive solution. (Fontana, 1987).

A number of procedures or practices can be used for combating or minimizing galvanic corrosion. Sometimes one is sufficient, but a combination of one or more may be required. These practices are as follows:

- **(i) Select combination of metals as close together as possible in the galvanic series.**
- **(ii) Avoid the unfavourable area effect of a small anode and large cathode.**
- **(iii) Insulate dissimilar metals wherever practicable.**
- **(iv) Apply coatings with caution.**
- **(v) Use inhibitors**
- **(vi) Avoid threaded joints for materials far apart in the series (Fontana, 1987).**

2.4.3 Pitting Corrosion

(a)  **(b)** 

Plate III:Pitting Corrosion of inside and outside of a pipe (Retrieved November 28, 2014 fromhttps://www.google.com/search?q=image+of+pitting+corrosion&tbm=isch&tbo=u &source)

Pitting corrosion is a form of extremely localized attack that results in holes in the metal. These holes may be small or large in diameter, but in most cases they are

relatively small. Pits are sometimes isolated or so close together that they look like a rough surface.

Control can be ensured by:

(i) Selecting a resistant material

(ii) Ensuring a high enough flow velocity of fluids in contact with the material or frequent washing

(iii) Control of the chemistry of fluids and use of inhibitors

(iv) Use of a protective coating

(v) Maintaining the material's own protective film.

2.4.4 Crevice Corrosion



Plate IV: Crevice corrosion on the surface of a flange (Retrieved November, 28, 2014 from https://www.google.com/search?q=image+of+crevices+corrosion&tbm=isch&tbo=u&source)

If two areas of a component in close proximity differ in the amount of reactive constituent available, the reaction in one of the areas is speeded up. An example of this

is crevice corrosion which occurs when oxygen cannot penetrate a crevice and a differential aeration cell is set up. Corrosion occurs rapidly in the area with less oxygen (Bill and Gareth, 2003).

Some methods and procedures for combating or minimizing crevice corrosion are as follows:

- **(i) Use welded butt joints instead of riveted or bolted joints in new equipment.**
- **(ii) Avoiding sharp corners and designing out stagnant areas**
- **(iii) Close crevices in existing lap joints by continuous welding or soldering.**
- **(iv) Inspect equipment and remove deposits frequently.**
- **(v) Remove solids in suspension early in the process or plant flow sheet, if possible.**
- **(vi) Remove wet packing materials during long shutdowns.**
- **(vii) Use "solid" non-absorbent gaskets, wherever possible.**
- **(viii) Selection of resistant materials.**

2.4.5 Intergranular Corrosion



PlateV:Intergranular corrosion of a copper pipe (Retrieved November, 28, 2014, from https://www.google.com/search?q=image+of+intergranular+corrosion&tbm=isch&tbo=u&source)

Intergranular corrosion is the preferential attack of the grain boundaries of the crystals that form the metal. It is caused by the physical and chemical differences between the centres and edges of the grain (Bill and Gareth, 2003).

Intergranular corrosion can be avoided by:

(i) Selection of stabilised materials

(ii) Control of heat treatments and processing to avoid susceptible temperature range.

2.4.6 Selective Leaching



Plate VI: Selective leaching on the surface of a metal (Retrieved November 28, 2014,from https://www.google.com/search?q=image+of+selective+leaching+corrosion&tbm=isch&tbo=u&source)

This type of corrosion occurs when one component or phase in a solid alloy is more susceptible to attacked than another and corrodes preferentially leaving a porous material that crumbles (Bill and Gareth, 2003). Corrosion by selective leaching is best avoided by selection of a resistant material but other means can be effective such as:

(i) Coating the material

(ii) Reducing the aggressiveness of the environment

(iii)Use of cathodic protection

2.4.7 Erosion Corrosion



Plate VII: Erosion corrosion along the elbow of a metal pipe(Retrieved November 28, 2014,fromhttps://www.google.com/search?q=image+of+erosion+corrosion&tbm=isch&tbo=u&source)

Erosion corrosion is the acceleration or increase in rate of deterioration or attack on a metal because of relative movement between a corrosion fluid and the metal surface. The protective layers and corrosion products of the metal are continually removed exposing fresh metal to corrosion (Fontana, 1987).

Prevention or minimization of this type of corrosion can be achieved by:

(i) Materials with better resistance to erosion corrosion

(ii) Reducing the flow rate and turbulence

(iii) Design

(iv) Alteration of the environment

(v) Coating

(vi) Cathodic protection

(vii) Use of replaceable or robust linings in susceptible areas.

2.4.8 Stress Corrosion



Plate VIII: Stress corrosion of a metal pipe (Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+stress+corrosion&tbm=isch&tbo=u&source)

Stress corrosion cracking (SCC) refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium which eventually leads to the catastrophic failure of the component.

Stress-corrosion cracking may be reduced or prevented by application of one or more of the following methods:

(i) Lowering the stress below the threshold value

(ii) Design to minimise thermal and residual stresses.

(iii) Eliminating the critical environment specie

(iv) Developing compressive stresses on the surface material.

(v) Selection of a suitable material not susceptible to the environment.

(vi) Applying cathodic protection.

(vii) Adding inhibitors to the system if feasible.

(viii) Coatings are sometimes used(Bill and Gareth, 2003;Fontana, 1987).

2.5 The Problem of Corrosion.

The destructive tendency of corrosion is not only limited to the oil and gas industries, but industries such as: Construction, food and beverage and automobile industries, machinery, water treatment and chemical plant. Apart from the heavy economic losses incurred as a result of corrosion, some harmful or disastrous effects of corrosion are as follows:

(i) Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localized zones so as to give a crack like structure, very considerable weakening may result from quite a small amount of metal loss.

(ii) Hazards or injuries to people arising from structural failure or breakdown (e.g. bridges, cars, aircraft).

(iii) Loss of time in availability of profile-making industrial equipment.

(iv) Reduced value of goods due to deterioration of appearance.

(v) Contamination of fluids in vessels and pipes (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion).

(vi) Perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For example a leaky domestic radiator can cause expensive damage to carpets and decorations, while corrosive sea water may enter the boilers of a power station if the condenser tubes perforate.

(vii) Loss of technically important surface properties of a metallic component. These could include frictional and bearing properties, ease of fluid flow over a pipe

surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface.

(viii) Mechanical damage to valves, pumps, etc., or blockage of pipes by solid corrosion products.

(ix) Added complexity and expense of equipment which needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

2.6 Corrosion Inhibitors

It is well known in surface chemistry that surface reactions are strongly affected by the presence of foreign molecules. Corrosion processes, being surface reactions, can be controlled by compounds known as inhibitors which adsorb on the reacting metal surface. The term adsorption refers to molecules attached directly to the surface, normally only one molecular layer thick, and not penetrating into the bulk of the metal itself (Eddy, et al. 2010).

Over the years, considerable efforts have been deployed to find suitable corrosion inhibitors of organic origin in various corrosive media. In acid media, nitrogen-base materials and their derivatives, sulphur-containing compounds, aldehydes, thioaldehydes, acetylenic compounds, and various alkaloids, for example, papaverine, strychnine, quinine, and nicotine are used as inhibitors. In neutral media, benzoate, nitrite, chromate, and phosphate act as good inhibitors. Inhibitors decrease or prevent the reaction of the metal with the media. They reduce the corrosion rate by

(i) Adsorption of ions/molecules onto metal surface,

(ii) Increasing or decreasing the anodic and/or cathodic reaction,

(iii) Decreasing the diffusion rate for reactants to the surface of the metal,

(iv) Decreasing the electrical resistance of the metal surface.

(v) Inhibitors that are often easy to apply and have in situate application advantage (Rani and Basu, 2012).

2.6.1 Types of Corrosion Inhibitors

Several factors including cost and amount, easy availability and most important safety to environment and its species need to be considered when choosing an inhibitor.

Basically, there are two types of corrosion inhibitors; these are organic and inorganic corrosion inhibitors. But at the moment, an intensive research is been undertaken by researchers in the area of plants being used as a corrosion inhibitor due to their non-hazardous and non-toxic to human and the environment.Researchers are trying to classified corrosion inhibitor substances gotten from plant extracts (leaves, fruits, seed, bark) as green corrosion inhibitors. Under this heading, plants as a green corrosion inhibitor shall be brieflydiscussed.

2.6.1.1 Organic Inhibitors

Organic inhibitors generally have heteroatoms. Oxygen, Nitrogen, and Sulphur are found to have higher basicity and electron density and thus act as corrosion inhibitor. O, N, and S are the active centers for the process of adsorption on the metal surface. The inhibition efficiency should follow the sequence Oxygen< Nitrogen< Sulphur<Phosphorous. The use of organic compounds containing oxygen, sulphur, and especially nitrogen to reduce corrosion attack on steel has been studied in some detail. The existing data show that most organic inhibitors adsorbed on the metal surface by displacing water molecules and forming a compact barrier. Availability of non-bonded (lone pair) and p-electrons in inhibitor molecules facilitate electron transfer from the inhibitor to the metal. A coordinate covalent bond involving transfer of electrons from

inhibitor to the metal surface may be formed. The strength of the chemisorption bond depends upon the electron density on the donor atom of the functional group and also the Polaris ability of the group (Rani and Basu, 2012).

It should also be known that most of the synthetic organic inhibitors have hazardous effect and there is the need to develop cheap, nontoxic and ecofriendly processes have encouraged researchers to focus on the use of natural products (Rani and Basu, 2012).

2.6.1.2 Inorganic Corrosion Inhibitor

Inorganic substances such as phosphates, chromates, dichromates, silicates, borates, tungstates, molybdates, and arsenates have been found effective as inhibitors of metal corrosion. Pyrrole and derivatives are believed to exhibit good protection against corrosion in acidic media. These inhibitors have also found useful application in the formulation of primers and anticorrosive coatings, but a major disadvantage is their toxicity and as such their use has come under severe criticism (Rani and Basu, 2012).

2.6.1.3Green Corrosion Inhibitor

Environmental concerns worldwide are increasing and are likely to influence the choice of corrosion inhibitors in the future. Some chemicals are excellent inhibitors, but are quite toxic and readily absorbed through the skin. The known hazardous effects of most synthetic organic inhibitors and restrictive environmental regulations have now made researchers to focus on the need to develop cheap, non-toxic and environmental friendly natural products as corrosion inhibitors. Among the numerous organic compounds that have been tested and are applied industrially as corrosion inhibitors, those that are nontoxic are now far more strategic than in the recent past (Rani and Basu, 2012).

Green corrosion inhibitors (extract from plant) which happen to be nontoxic organic compound, displaying substantially improved environmental properties will be the inhibitors most widely used in the future. These natural organic compounds are either

synthesized or extracted from aromatic herbs, spices and medicinal plants. In the past two decades, the research in the field of ‘‘green’’ corrosion inhibitors has been addressed toward the goalof using cheap, effective molecules at low or ‘‘zero’’ environmental impact.Plant extracts are viewed as an incredibly rich source of naturally synthesized chemical compounds that can be extracted by simple procedures with low cost and are biodegradable in nature. The use of these natural products such as extracted compounds from leaves or seeds as corrosion inhibitors have been widely reported by several authors (Rani and Basu, 2012).

2.6.2 Classification of Corrosion Inhibitors

Several substances which have been observed to have corrosion inhibitive properties have often been classified in various ways.

Revie and Uhlig (2008) identified the following general classification of inhibitors:

(i) Passivators;

(ii) Organic inhibitors, including slushing compounds and pickling inhibitors;

(iii)Vapour phase inhibitors.

2.6.2.1 Passivators

Passivators are usually inorganic oxidizing substances (such as chromates, nitrites, and molybdates) that have the unique property of reacting only slowly when in direct contact with iron, but they are reduced more rapidly by cathodic currents. For this reason, they can adsorb first on the metal surface, with each site of adsorption adding to the cathodic area. The higher the concentration of passivator, the more readily it adsorbs, and the smaller the residual anodic areas become; this situation obviously favours increased anodic polarization and ultimately passivation (Revie and Uhlig, 2008).

2.6.2.2 Pickling inhibitors

Most pickling inhibitors function by forming an adsorbed layer on the metal surface, probably no more than a monolayer in thickness, which essentially blocks discharge of H^+ and dissolution of metal ions. Some inhibitors block the cathodic reaction (raise hydrogen over potential) more than the anodic reaction, or vice versa; but adsorption appears to be general over the entire surface rather than at specific anodic or cathodic sites and both reactions tend to be retarded.

2.6.2.3 Vapour Phase inhibitors

Substances of low but significant vapour pressure, the vapour of which has corrosion – inhibiting properties, are called vapour-phase inhibitors

The mechanism of inhibition has not been studied in detail, but it appears to be one of adsorbed film formation on the metal surface that provides protection against water or oxygen, or both (Revie and Uhlig, 2008).

2.7 Plant Extracts from Guava Banana and Almond.

The guava, banana and almond plants are in abundance in the northern and eastern part of Nigeria. The leaves, bark, and root of these three plants are rich in tannins which can be described as any group of naturally occurring phenolic compounds. Tannins are known to possess corrosion inhibitive properties on metals, particularly on mild steel (Loto, 2011). Their basic structure consists of garlic acid residues which are linked to glucose via glycosidic bonds. Thus tannins have an array of hydroxyl and carboxyl groups through which the molecules can adsorb on corroding metallic surfaces. Ferrous materials, especially mild steel, on the other hand are largely used in acidic media in most industries including oil/gas exploration and ancillary activities (Okiet al, 2011).

2.7.1 Facts about the Plants

For some time now, researchers have been working on natural products, derived from local plants, so as to replace synthetic ones. Plant extracts have been found to contain natural products with varying organic compounds (e.g alkaloid, saponin, pigment, tannins, flavonoids etc) (Yawas, 2005).

2.7.1.1 Guava Plant



Plate IX: Leaves and fruit of a guava plant (Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+guava+plant&tbm=isch&tbo=u&source)

Guava is a common shade tree or shrub in door-yard gardens in the tropics. It provides shade while the guava fruits are eaten fresh and made into drinks, ice cream, and preserves. In the richness of the Tropics, guava fruits often grow well beyond the size of tennis balls on well-branched trees or shrubs reaching up to 20 m high. Cultivated varieties average about 10 meters in height and produce lemon-sized fruits. The tree is easily identified by its distinctive thin, smooth, copper-colored bark that flakes off,

showing a greenish layer beneath (Retrieved November 26, 2014) http://www.rain-tree.com/guava.htm).

Guava leaves leaves are opposite, short-petioled, oval or oblong-elliptic, somewhat irregular in outline, 2 - 6 inches long and 1 - 2 inches wide. The dull-green, stiff but leathery leaves have pronounced veins, and are slightly downy on the underside. Crushed leaves are aromatic. The fruit today is considered minor in terms of commercial world trade but is widely grown in the tropics, enriching the diet of hundreds of millions of people in the tropics of the world. It has spread widely throughout the tropics because it thrives in a variety of soils, propagates easily by cuttings, grafting, air layering, seed and bears fruit relatively quickly. The fruits contain numerous seeds that can produce a mature fruit bearing plant within four years.(Retrieved November 26, 2014 fromhttp://toptropicals.com/html/toptropicals/articles/fruit/guava.htm)

2.7.1.2 Banana Plant



Plate X: Leaves and fruits of a banana plant (Retrieved November 28, 2014 from https://www.google.com/search?q=image+of+banana+plant&tbm=isch&tbo=u&source)

The banana (Arab word meaning finger) is the fruit of the banana tree, a plant of the Musa genus, belonging to the family of Musaceae, that technically is an herbaceous plant, but that is more similar to a tree, with stalks that can be high up to 8 m and leaves long up to 3m. The banana tree is in fact an evergreen, perennial plant native to tropical countries.

The stalk of this plant, called pseudostem, is formed by leaves at the base that are large with a central strong and evident venation; leaves have also secondary parallel venations that can easily torn into fringes. At the top of the pseudostem there is a crown-shaped bud of leaves, more than 2 m long and 1 m large, from which, after about two years, develop the white-yellowish flowers of banana. They bloom in June-July and are protected by violet bracts (rolled up leaves). Later develop fruits, the so-called bananas that grow in groups called *"hands"*, turned up in a cluster, called *"bunch"*. The bunch can be 1 meter long and more: it may contain even more than 200 fruits and it can weigh more than 25 kg; the bunch of bananas withers after fructifying, but a new one will later develop from the underground perennial rhizome. The plant of banana can be, especially in nature, nine-ten metres tall, while the cultivated plants usually are not taller than 3 metres.(Retrieved November 26, 2014, from http://www.zipmec.com/en/banana-history-production-trade-guide-fruit.html)

2.7.1.3 Almond Plant



Plate XI: Leaves of an almond plant(Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+indian+almond+plant&tbm=isch&tbo=u&source)

Indian almond (*Terminalia catappa, Fam.* Combretaceae) is a large tropical tree in the Leadwood tree family. It is considered native to tropical Asia and northern Australia, but is today also common most tropical parts of the world. The tree can reach a height of 35 meters (110 ft). It grows upright and forms a symmetrical crown with horizontal branches distinctively arranged in tiers. As the tree ages, the crown will become increasingly flattened and eventually take on a vase shape. Almond tree leaves are quite big, usually 15 to 25 centimetres long and 10 to 15 centimetres broad. They are thick and leathery with an ovoid shape and sport a glossy dark green colour. Before shedding its leaves to survive the dry season, the Indian almond tree will retract the valuable green pigmentation, leaving the leaves pinkish-reddish or yellow-brown. Indian almond leaves contain several different flavonoids, including kaempferol and quercetin. It is also rich in various tannins; astringent, bitter plant polyphenols that either bind and

precipitate or shrink proteins (Retrieved November 26, 2014 from http://www.indianalmondleaves.com/aquariums.php).

2.8 Review of Related Past Work.

2.8.1 The leaves extract of different plants

Scientific researchers on the use of extracts from plant parts such as leaves, bark, fruit and the roots as corrosion inhibitors are on the increase as the years goes by. This is as a result of plants being a biodegrable and eco-friendly.The leaves which happen to be part of the plant have a composition of several chemical constituents ofwhich tannin happen to be one. In many cases, the corrosion inhibitive effect of some of the plants' extracts has been attributed to the presence of tannin in their chemical constituents (Ayeni, 2012). Also associated with the presence of tannin in the extracts is the bitter taste in leaves of the plants. Some of the researches already carried out using leaves are highlighted below.

Anafi and Obi, (2004) investigated the corrosion inhibition of mild steel in simulated media by a Methanolic Extract of Bitter leaf. The solvent extract of bitter leaf was compared with sodium benzoate with mild steel immersed in sea water, 0.3 M H_2SO_4 and HCl media at ambient temperature using weight loss method. They found out that the inhibition ability of bitter leaf against corrosion was best in sea water where it exhibited an inhibitive efficiency of 61.19%. Sodium benzoate however surpassed bitter leaf in its corrosion inhibition ability in all test media used in the investigation. El-Etre (2007) investigated the inhibitive action of the aqueous extract of olive (*OleaeuropaeaL.*) leaves toward the corrosion of C-steel in 2 M HCl solution using weight loss measurements, Tafel polarization, and cyclic voltammetry. They found out that the extract acts as a good corrosion inhibitor for the tested system. The inhibition efficiency increases with increase in extract concentration. The result showed the

adsorption of extract components onto the steel surface by spontaneous process and it follows the Langmuir adsorption isotherm. The inhibition efficiency is greatly reduced as temperature increased.

Also,Singh, et al (2010) studied the inhibition of the corrosion of mild steel in 1M HCl hydrochloric acid solution by the extract of Kalmegh (*Andrographispaniculata*) leaves using weight loss, electrochemical impedance spectroscopy, linear polarization, and potentiodynamic polarization techniques. The result showed that the Inhibition of mild steel increases with increase in concentration of the extract. They also carried out the effect of temperature and immersion time on the corrosion behavior of mild steelwith addition of extract. The result showed the adsorption of the molecules of the extract on the mild steel surface obeyed the Langmuir adsorption isotherm. They concluded by saying that the extract could serve as an effective inhibitor of the corrosion of mild steel in hydrochloric acid media.

Also, Quraishi et al (2010) studied the inhibition of the corrosion of mild steel in1 M HCl and 0.5 M H_2SO_4 acid solutions by the extract of *Murrayakoenigii* leaves using weight loss, electrochemical impedance spectroscopy (EIS), and linear polarization and potentiodynamic polarization techniques. They found that the inhibition of mild steel increases with increase in concentration of the leaves extract. They also studied the effect of temperature and immersion time on the corrosion behavior of mild steel with addition of extract. The adsorption of the extract on the mild steel surface obeys the Langmuir adsorption isotherm. They concluded by saying that the extract could serve as an effective inhibitor of the corrosion of mild steel in hydrochloric and sulphuric acid media.

Furthermore,Vimala et al. (2011) investigated the inhibition efficiency of acid extract of flowers of *Cassia Auriculata* (CAF) plant on the corrosion of mild steel in 1 M HCl by weight loss measurements and electrochemical studies. The results they obtained shows

that the extract could serve as an effective inhibitor for the corrosion of mild steel in HCl media with efficiency up to 74.7%. Inhibition was found to increase with increasing concentration of the plant extract.

Recently of them all is Iloamaeke et al. (2012) studied corrosion inhibition of mild steelin 0.5 M hydrochloric acidsolution with the extract of *pterocarpussoyauxi* leaves using weight loss measurement at $30^{o}C - 60^{o}C$. The findings showed that the inhibition efficiency increase with increase in inhibitor concentration as a result of the phytochemical constituents of the PS extract but decreased with temperature. The inhibition of corrosion of mild steel obeyed Tempkin and Freundlich adsorption isotherms. PS extract showed inhibitive effect on corrosion of mild steel in acidic environment.

2.8.2 The stems and fruits/seeds extracts of different plants

The stem and fruit/seed of plants which happen to have a composition of chemical constituents havebeing explored bysome researchers in order to ascertain their corrosion inhibition capacities and efficiencies on different metals. Among them are;

Zheludkevich et al. (2005) investigated the inhibition action of carmine and fast green dyes on corrosion of mild steel in 0.5M HCl acid solution using mass loss, polarization, and electrochemical impedance (EIS) methods. Their result indicated that fast green showed inhibition efficiency of 98% and carmine 92%. The inhibitors act as mixed type with predominant cathodic effect.

Also, Chauhan and Gunasekaran (2007) studied the inhibition effect of *Zenthoxylumalatum* plant extract on the corrosion of mild steel in 5% and 15% aqueous hydrochloric acid solution by weight loss and electrochemical impedance spectroscopy (EIS). Their result showed that corrosion inhibition efficiency increases with increase in plant extract concentration.

Quraishi et al. (2009) studied corrosion inhibition of mild steel in 0.5M and 1M hydrochloric solution by black pepper extract (*Piper nigrum*fem: *Piperaceae*) by mass loss measurements, potentiodynamicpolarisation, and electrochemical impedance spectroscopy (EIS). They found out that the an extract from the fruit of the green plant gave maximum inhibition efficiency (98%) at 120 ppm at 35^{o}C for mild steel in hydrochloric acid medium. The corrosion inhibition property was attributed to an alkaloid "Piperine".

Moreover, Torres et al. (2011)carried out a study on the effects of aqueous extracts of spent coffee grounds on the corrosion of carbon steel in a 1M HCl. Two methods of extraction were studied: decoction and infusion. The results showed that the inhibition efficiency of C-steel in 1M HCl increased as the extract concentration and temperature increased.

Also, Alaneme and Olusegun (2012) investigated the inhibition potentials of lignin extract of sun flower (*Tithonia Diversifolia*) by evaluating the corrosion behaviour of medium carbon low alloy steel immersed in 1M H_2SO_4acid solution containing varied concentration of the extract. Mass loss, corrosion rate, and adsorption characterization were utilized to evaluate the corrosion inhibition and adsorption properties of the extract. The results revealed that the lignin extract is an efficient inhibitor of corrosion in mild steel immersed in 1M H_2SO_4. The corrosion rates were observed to decrease with increase in concentration of lignin extract.Ameh et al (2012) investigated the inhibitive effect of *Ficusglumosagum* (FG) for the corrosion of mild steel in H_2SO_4 medium using the weight loss, gasometric, thermometric and scanning electron microscopy (SEM) techniques. The results obtained revealed that FG gum is a good adsorption inhibitor. The adsorption of the inhibitor on mild steel is exothermic, spontaneous and supports the Langmuir adsorption model.

2.8.3 The leaves, bark and fruits/seeds extracts of different plant

The entire parts of a plant which consists of leaves, stem, bark, root and fruits/seeds have some trace of chemical constituents in different quantities, most researchers are now exploring all the parts of the plant in order to ascertain their corrosion inhibition capacities and efficiencies on different metal as no parts of the plant should be treated as a waste as long as it has trace of some chemical constituents. Among such researchers are;

Yawas, (2005) made a suitability assessment of neem, mahagony, cashew, locust bean husk, and *acacianolitica* pod extracts as corrosion inhibitors. Neem, sesame, mahogany, soyabean, cotton, and groundnut seed oils were also analyzed. The result shows that inhibition efficiency increases with increase in inhibitor concentration and temperature but decreased in the case of cotton seed and sesame oil. It also showed the ability of the inhibitors to reduce stress corrosion cracking of carbon steel in acidic media.

In the same light,Okafor et al (2008) studied the inhibitive action of leaves, seeds and a combination of leaves and seeds extracts of *Phyllanthusamarus* on mild steel corrosion in 0.5 MHCl and H_2SO_4 solutions using weight loss and gasometric techniques. The results indicated that the extracts functioned as good inhibitors in both environments and inhibition efficiency increases with extracts concentration. The temperature studies revealed an increase in inhibition efficiency with rise in temperature.Satapathy et al (2009) investigated corrosion inhibition effect of *Justiciagendarussa* extract (JGPE) on mild steel in 1 M HCl medium by weight loss and electrochemical techniques. They achieved inhibition efficiency of 93% with 150 ppm JGPE at 25 °C. The polarization studies showed that JGPE acts as mixed-type inhibitor. The Nyquist plots showed that on increasing JGPE concentration increases charge transfer resistance and decreases double layer capacitance.

Obot and Obi-Egbedi, (2010) investigate the inhibitive and adsorption properties of ethanol extract of *Terminaliacatappa*for the corrosion of mild steel in 0.5 M and 1 M H_2SO_4solution using weight loss, hydrogen evolution, and infrared methods of monitoring corrosion. The result showed an increase in inhibition potential of ethanol extract of *T. catappa*which they attributed to the presence of saponin, tannin, phlobatin, anthraquinone, cardiac glycosides, flavanoid, terpene, and alkaloid in the extract.Oguzie et al (2010) investigated the inhibition of low-carbon-steel corrosion in 1 M HCl and 0.5 M H_2SO_4 by extracts of *Dacryodisedulis* (DE) using gravimetric and electrochemical techniques. They found that the extract inhibit the uniform and localized corrosion of carbon steel in the acidic media, affecting both the cathodic and anodic partial reactions.

Shyamala and Kasthuri, (2011) investigated the inhibition effect of plant extracts, *Ocimum sanctum, Aeglemarmelos*, and *Solanumtrilobatum*, on the corrosion of mild steel in 1M HCl medium using weight loss method, electrochemical methods, and hydrogen permeation method. The results obtained using polarization method shows that plant extracts behave as mixed-type inhibitor while the impedance method reveals that charge-transfer process mainly controls the corrosion of mild steel. On comparison, maximum inhibition efficiency was found in *Ocimum sanctum* with 99.6% inhibition efficiency at 6.0% v/v concentration of the extract.

Loto et al. (2011) investigated the corrosion and plants extract inhibitive protection of mild steel specimens immersed in 0.5 M hydrochloric acid with use extracts of kola plant and tobacco in different concentrations as ‘green’ inhibitors at ambient temperature by gravimetric and metallographic methods. The results showed that addition of different concentrations of the plant extracts gave considerable reduction in the weight loss and in the corrosion rate of the test samples.Lebrini et al (2011) investigated the inhibition effect of alkaloids extract from *Oxandraasbeckii* plant (OAPE) on the corrosion of C38 steel in 1 M

hydrochloric acid solution by potentiodynamic polarization and electrochemical impedance spectroscopy (EIS). The results showed that the corrosion inhibition efficiency increases with increasein plant extracts concentration.

After critical examination of the previous works, most of their limitations were in the area of variation of temperature of media. From the resultsvariation of temperatures of media shows that increase in temperatures reduces the effectiveness of the corrosion inhibitors.

CHAPTER THREE

3.0 MATERIALS, EQUIPMENT AND METHODS

3.1 Introduction

This chapter describes details of materials and the experimental procedure required to determine the inhibiting effect of tannins, alkaloids and flavonoid gotten from guava, banana and almond leaves on Mild steel.

3.2 Materials

The materials used for this study included:

i. **Low carbon steel specimens (test coupons).**

ii. **Extracts from guava, banana and almond leaves.**

iii. **Ethanol, Acetone, and Distilled water**

iv. **HCl and H_2SO_4 acid**

3.3 Equipment

The equipment used consists of the following;

(i) Gallenkamph 2 hotbox oven with maximum temperature 200 ^oC maximum. It was used for drying of extract after extraction from leaves

(ii) Desiccator: It was used for drying and keeping the prepared samples of the steel air tied.

(iii) Beakers (250 ml): they contained the acid solution and the inhibitors in to which the medium carbon steel samples were immersed.

(iv) Measuring cylinder (100 ml): it was used to measure the volume of HCl and H_2SO_4.

(v) Volumetric flask (2000 ml): It was used to dilute HCl and H_2SO_4 with distill water.

(vi) Threads (ordinary cotton wool thread): They were used for the suspension of the coupons in the corrosive media.

(vii) Water bathof Grant JB series model with temperature ranging from 0^oC – 90^oC: It was used for the heating of solution.

(viii) Soxhlet extractor (A model of Quickfit England with flask capacity of 1000ml): it was used in the extraction of the juice extract from the plants leaves using ethanol.

(ix) Sortoriusanalytical balance with model number ED 224S for precision weighing up to 220g maximum andresolution of 0.1mg: it was used for weight measurement of both coupon and plants extract.

(x) Microprocessor digitalized machine: it was used for measurement of pH value of extract.

(xi) Phenom Pro XScanning Electronic Microscope (Model: Phenom Pro X. Equipped with magnification range of 80 - 100,000x, ≤ 14nm resolution, up to 32mm (Ø) size and 100mm heightfully integrated EDS, elemental mapping and line scan: it was used for surface examination of coupon.

3.4 Experimental Procedure

3.4.1 Preparation of Coupon

A low carbon steel sheet coupon used for this research work was obtained from Samaru/Sabon-Gari Market in Zaria. The dimension for the steel bar of 20 mm x50 mm x3mmwas cut out of the steel sheet and the specimens were descaled by wire brushing. Thesurface of the specimens wasprepared base on International Standard Organization (ISO) ISO 8504:2000 (E). The specimens were grounded with 120 – 150 mesh abrasive for a smoother surface, cleaned with acetone, dried in the airand kept in a desiccator. Weight loss tests were later carried out on them (Retrieved 2015, from http://www.international-pc.com).

3.4.1.1 Chemical Composition of Steel Specimen

This was carried out at the extraction metallurgy assay laboratories in the University of Johannesburg in South Africa using Spectral method.

This was done to determine the elements present and their percentages in the steel bars. 50mm x 20mm x 3mm pieces of standard flat bars were cut out from a plate.

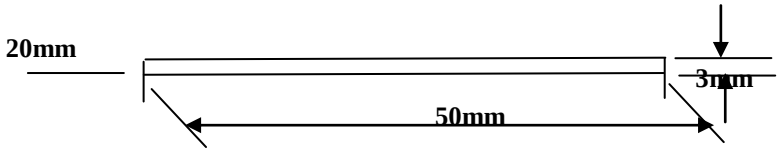


Fig. 3.1: A diagrammatic sketch of the coupon

3.4.1.2 Area and Density of Specimen

For use in this work, flat low carbon steel bar was cut into rectangular coupons. The area of the specimen was obtained from the relation:

$A = 2(xy + yz + xz)$ …… 3.1

Where A = area of specimen

x = breadth of specimen = 20mm

y = length of specimen = 50mm

z = thickness of specimen = 3mm

3.4.2 **Soxhlet** Extraction of Plants Extracts

The leaves of the guava tree (*Psidiumguava)*,banana tree (*Musa species*) and almond(*Prunusamygdalus)* were extracted with the use of a small scale soxhlet extractor which is available in the Department of Pharmacognosy, Ahmadu Bello University Zaria. The soxhlet extractor consists of a main extractor, thimble (round bottom flask), a reflux condenser and an electric heater as shown in plate XII.



Plate XII: The set-up for the extraction of juice extract with soxhlet extrator

The solid material (prepared powder leaves) is placed in a porous bag or "thimble" made of strong filter paper is placed or loaded into the main chamber of the thimble holder of the soxhlet extractor. The soxhlet extractor is placed on a round bottom distillation flask containing the extraction solvent. The solvent is equipped with a condenser. The extracting solvent in the distillation flask is heated and its vapours condense in the condenser. The condensed extractant drips into the thimble containing the powder leaves and extracts it by contact. When the level of the liquid inthimble chamber rises to the top of the siphon tube, the liquid content of the chamber siphon into the distillation flask. The process is continuous and is carried out until a drop of the solvent from the siphon tube does not leave residue when evaporated(ICS, 2008).



Plate XIII: Ethanol solvent boiling at 70^{o}C with extract from the plant.

The solution was evaporated inside a ceramic bowl attemperature 40^{o}C. The dried extract gotten after the evaporation of ethanol is assumed to be 100% concentrated. Each of the juice extracts (the respective distillates) will be stored in a clean bottle and covered properly(Loto et al, 2011).

3.4.3 Chemical Analysis of Plant Extract

Quantitative analysis was used to determine the amount of the chemical components present in the sample, according to the SLTC 2/2 of the Society of Leather Trade Chemist, (2002).

3.4.3.1 Procedure

According to the Society of Leather Trade Chemist (SLTC 2/2) method of analysis, 130ml was collected from the 50 g sample of the different extract samples prepared. The procedure used for determination of the chemical components is as shown below;

3.4.3.2 Determination of Moisture Contents of Samples.

This analysis was done in accordance with society of leather trade chemist (SLTC) official method of analysis No SLT 2/3 (a)

Procedure

5g of each ground sample was dried in a weighing bottle to constant weight at 100 – 130 ^{o}C in an electrical oven for 12 hours after that it was reweighed six timeto obtaina constant weight.

Calculation

Percentage moisture content = $(\frac{weight\ of\ original\ sample - weight\ after\ drying}{weigh\ of\ original\ sample}) x\ 100\%$ **…3.2**

3.4.3.3 Determination of Total Solids

This was in accordance with SLTC official method of analysis SLTC 2/3b

Procedure

30ml of the leached tannin infusion was measured into a weighed evaporation dish over a water bath then evaporated to dryness. The evaporated residue was further dried in the oven set at 90.5 – 100^{o}C for 1 hour after which it was cooled in the desiccators for 30 minute before weighing.

This was repeated at hourly interval until a constant weight was achieved.

Percentage total solid = $\frac{weight\ of\ residue \times A}{B \times C}\ x\ 100$ **……3.3**

Where

A = Volume of leached extracts, 130ml

B = Volume of leached extract used, = 50ml

C = Weight of extract used = 40g

For Residue

Weight of evaporating dish empty = W_1

Weight of evaporating dish + sample = W_2

Weight of solid =($W_2 - W_1$) = W_S

Percentage total solids = $\frac{Ws \times 130}{50 \times 40} \times 100$

3.4.3.4 Determination of Total Soluble

These was determine and calculated in accordance with SLT 2/3 c, the prepared leached extract was filtered and the first 50ml was discarded. Another 50ml was filtered to optically clear filtrate.

The 50ml was measured into a weighed evaporating dish over the water and evaporated to dryness. The residue was further dried in the oven set at 98.5 – 100^{o}C for 1 hour after which it was cooled in the desiccators and then weighed. The test for the sample was repeated at an hour interval until a constant weighed was achieved.

3.4.3.5 Determination of Non-Tannins Content

The determination of substances not absorbable was done in accordance with the official method of analysis SLT (2002).

Procedure:

A quantity of weighed chrome powder containing 6.25g of dry powder was added to the bottle containing 100ml of unfiltered tannin infusion plus (26.25ml) ethanol solvent and it was thoroughly shaken by hand for 15 seconds and then to a mechanical shaker at 50-65 rpm for exactly 10 minutes for proper mixing. The sample was poured into a filter cloth which was supported by a funnel and then was drained and squeezed. To the filtrate, 1 kg of kaolin was added for quicker filtration. 50ml of the clear filtrate was evaporated in an evaporating dish, of a known weight and then later dried in an oven set at 98 – 100^{o}C to constant weight.

3.4.3.6 Determination of Tannin Content

Tannin was determined by deduction after having determined the total soluble and non-tannins

where

$Tc = Tannin\ content$

$Ts = Total\ soluble$

$Tn = Non\ tannin$

Thus:

$$Tc = Ts - Tn$$

i.e $\% Tc = \% Ts - Tn$ **..... 3.4**

3.4.3.7 Determination of Total Salt

A known volume of the filtered solution (50ml) was evaporated on a water bath and was sulphated and then boiled in 40ml distilled water on a water bath for 1 hour, this was then filtered and a known volume (50ml) of the sample was added to 10ml $BaCl_2$ solution and then evaporated on a water bath. It was then dried and cooled in a desiccator for 30 minutes and then weighed. The weight was then recorded and the total salt was calculated.

3.4.3.8 Determination of Total Acid

Procedure

100ml of the filtered tannin solution was diluted with 100ml decarbonized distilled water and then titrated with N/20 sodium hydroxide (NaOH) to pH 6.8 (it has been established that at this pH of 6.8, all acid solution must have been dissociated). The volume of sodium hydroxide (NaOH) used was then recorded and the acid content calculated.

3.4.3.9 Determination of pH Value of Extract.

pH value is a measure of the hydrogen ion activity of an aqueous solution. The pH of the leaves extract was measured using a direct reading microprocessor digitalized machine. The machine measured the pH of the extracts at a temperature of 25.5^0C.

3.4.3.10Determination of Density

The mass-volume relationship was used to determine the density of the leaves extracts. Mass of 3ml of the extracts was measured with the aid of digital balance, and then the density was calculated by dividing the mass by the volume.

3.4.4 Phyto-Chemical Analysis of Plants Extract

The phyto-chemical analysis for the extracts was carried out in the Department of Pharmacognosy, Ahmadu Bello University Zaria. Below is the tabulated procedure for the analysis.

Table 3.1 Phytochemical Tests (Evans, 2002)

1.0 Test for Carbohydrates			
	Test	**Observation**	**Inference**
(a)	**A few drops of molisch reagent was added to little quantity of extract in a test tube and a small quantity of concentrated sulphuric acid was allowed to run down the side of the test tube.**	**A lower purple to violet colour at the interface**	**Indicate the presence of carbohydrate**
2.0 Test for Cardiac Glycosides			

	Test	Observation	Inference
	Extract was dissolved in glacia acetic acid containing traces of ferric chloride. The test tube was held at angle of 45 degree, 1ml of concentrated sulphuric acid was added down the side	**A purple ring colour was formed at interface**	**Indicates the presence of cardiac glycosides**
3.0 Test For Anthraquinones Derivatives			
	Test	**Observation**	**Inference**
	Small portion of the extract was shooked with 10ml of benzene and filtered. 5ml of 10% of ammonia solution was added to the filrate and stirred.	**Pink-red or violet colour is observed**	**Indicates the presence of free Anthraquinones.**
4.0 Test for Saponins			
	Test	**Observation**	**Inference**
	Small quantity of the extract was dissolved in 10ml of distilled water. This was shaken vigorously for 30 seconds and was allowed to stand for 30 minutes. A honey comb formed for more than 5 minutes	**A honey comb is formed**	**Indicates the presence of Saponin.**
5.0 Test for Flavonoids			
	Test	**Observation**	**Inference**
(a)	**Few drops of aqueous NaOH were added to 5ml of extract.**	**A yellow colouration is observed**	**Indicates the presence of flavonoid**
6.0 Test for Tannins			
	Test	**Observation**	**Inference**
(b)	**About 0.5ml of extract was dissolved in 10ml of distilled water, then filtrated.**	**A blue-black precipitate is formed.**	**Indicate the presence of tannin**
7.0 Test for Akaloids			

	Test	Observation	Inference
(a)	Few drops of Mayer's reagent was added to sample of the extract in a test tube.	Cream precipitate is formed	Indicate the presence of alkaloids.
(b)	Few drops of dragendorff's reagent was added to the extract		Indicate the presence of alkaloids.
(c)	Few drops of Wagner's was added to a small amount of extract.		Indicate the presence of alkaloids.

8.0 Test for Steroid and Triterpenes

	Test	Observation	Inference
	Equal volume of acetic anhydride was added to the extract. 1ml of concentrated sulphuric acid was added down side the tube.	Red, pink or purple colour was observed and a blue-green or blue was also observed.	Red, pink and purple Indicates the presence of triterpenes, while the blue or blue-green indicates the presence of steriod

3.4.5 Preparation of Acids Acid Solution (Test media)

3.4.5.1 Preparation of 0.5M HCl acid

The concentrated HCl acid used for this research has a density of 1.18g/cm^3, a percentage purity of 37% and molar mass of 36.5g/mol.

To obtain the molarity of the concentrated HCl acid,the following relation was used (Yawas, 2005):

Molarity = $\frac{Concentration}{Molar\ mass}$ **…….....3.5**

and concentration = standard volume × density × percentage purity

For 1 liter (1000cm^3) of standard HCl acid,

Concentration = 1000 × 1.18 × 37%

Hence, the molarity is given by:

$$\text{Molarity} = \frac{1000 \times 1.18 \times 0.37}{36.5} = 11.96\ \text{M}$$

From the relation $C_1V_1 = C_2V_2$

Where C = concentration, and

V = volume

Since 1000ml of 0.5M HCl acid is required,

Hence,

$$11.96 \times V_1 = 0.5 \times 1000$$

$$V_1 = \frac{0.5 \times 1000}{11.96}$$

$$= 41.81\text{ml}$$

Therefore, 41.81ml of HCl acid was dissolved in 1000ml of distilled water in a standard flask to obtain the desired concentration

3.4.5.2 Preparation of 0.5M H_2SO_4 Acid

Standard concentrated H_2SO_4 acid has a density of 1.84g/cm^3 and percentage purity of 98%. It has a molar mass of 98g/mol.

As in section 3.2.2.1, the molarity of H_2SO_4 acid is:

$$\text{Molarity} = \frac{1000 \times 1.84 \times 0.98}{98} = 18.40\text{M}$$

Similarly, the volume of standard H_2SO_4 acid required for 1000ml of 0.5M H_2SO_4 can be obtained as follows:

$$18.4 \times V_1 = 0.5 \times 1000$$

Hence,

$$V_1 = \frac{0.5 \times 1000}{18.40}$$

=27.17ml

Therefore, 27.17ml of H_2SO_4 acid was dissolved in 1000ml of distilled water in a standard flask to obtain the desired concentration.

3.4.6 Weight Loss Measurements

Gravimetric experiments were conducted with rectangular coupons having dimension of 20 ×50 × 3 mm. The total geometric surface area was 24.2cm^2. Subsequently, each coupon was polished using different grades of silicon carbide impregnated emery paper (120, 400, 800, and 1000 grits), degreased in ethanol, dipped in acetone, removed and allowedto dry in air before use. Test was carried out with 8 coupons each as control immersed in 100ml blank for both sulphuric and hydrochloric acid. The experiments were conducted under total immersion conditions in beakers maintained at 27-31^{o}C.



Plate XIV: Coupons in their immersed form in a 250ml beaker

The quantity of almond extract of 0.025g, 0.05g, 0.075g and 0.1g were dissolved in 100ml0.5M HCl and H_2SO_4acidsolutions to obtain concentration of 250, 500, 750 and 1000ppm. In each experiment, 8 cleaned couponswere weighed (m_1) and immersed completely in the inhibited acids solutions. At ambient temperature of 30^{o}C, thecoupons were retrieved at intervals of 3days progressively for 24 days; this was to allow for

specimen to react in the solution.Finally the samples were washed with runningwater to remove any corroded product(s), dipped in acetone, dried and re-weighed (m_2). The weight loss (W) was taken as the difference between the weight at a given time and the initial weight of the test coupon.

The experiment was repeated using banana and guava extract with the concentration of the inhibitors varied as that of almond extract.

For 0.025g inhibitor concentration in 100ml acid solution, we know that 1g = 1000mg

Therefore, 0.025g = 25mg. Similarly, 1000ml = 1liter therefore 100ml = 0.1 liters.

Concentration (ppm) = mass in milligrams/ volume in liters

$$= \frac{25\ mg}{0.1\ l} = 250\text{ppm}$$

The above calculation was repeated for 0.05g, 0.075g and 0.1g in 100 ml acids solutions to obtain 500,750 and 1000 ppm inhibitor concentrations respectively.

3.4.7 Effect of Temperature

To elucidate the mechanism of inhibition and to determine the kinetic parameters of the corrosion process, weight loss measurementswere performedat 303, 313, 323 and 333K. In this case, the coupons were retrieved from the solution after 4 hours ofimmersion, using the hot water bath. The difference in weight of the coupons was again taken as the weight loss (Yawas, 2005).

The rate of corrosion (CR), inhibition efficiency (IE), degree of surface coverage (Ɵ), film attractive free energy (ΔG_{ads}), activation energy (E_a),equilibrium constant of adsorption (K) and film heat of attraction were determine from the used inhibitors.

3.4.8 Microstructure Examination

The surface condition of the coupons in contact with 0.5 M HCl and 0.5MH_2SO_4 acid solutions in the absence and presence of the inhibitors was analysed with the aid ofa

scanning electron microscope (SEM)at a magnification of 100 μm and 10 μm. The Energy dispersive Spectrum was also obtained alongside with the Element Identification Spectrum. This was done inthe Chemical Analysis Laboratory of Chemical Engineering Department, Ahmadu Bello University, Zaria.

SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the samples surface topography and composition. The electron beam is scanned in a raster scan pattern, and the beam position is combined with the detected signal to produce an image.

3.5 Corrosion Rate

The expression for measurement of corrosion rate (C.R) in millimeters penetration per year (mm/y) was used to measure corrosion rate (C.R) for the specimens, which was expressed in equation 3.1 (Callister, 1997).

$$C.R. = \frac{87.6w}{at\rho} \quad \text{.....(3.7)}$$

Where, w is corrosion weight loss of mild steel (mg), a is the total surface area of the specimen in (cm^2), t is the exposure time in hours (h), ρ is the density of the specimen (g/cm^3)

3.5.1 Inhibitor Efficiency

The percentage inhibitor efficiency (%IE) was calculated using the relation in equation 3.8 (Khaled, 2008).

$$IE = \frac{(C.R)_0 - (C.R)}{(C.R)_0} X\ 100\% \quad \text{---------- 3.8}$$

Where $(C.R)_O$and (C.R) are the corrosion rates in (mm/yr) with and without different concentrations of the juice extracts respectively.

3.5.2 Degree of Surface Coverage

The degree of coverage of the surface (θ) of mild steel by molecules of the inhibitor can be expressed as using equation 3.9 (Khaled, 2008).

$\theta = \frac{CR_O - CR}{CR_O}$ ……..**3.9**

3.5.3 Film Attractive Power

From the degree of surface coverage at a given inhibitor concentration and temperature, the film attractive power was computed using equation 3.10 (Umoren et al, 2010).

$\mathbf{K_{ads}} = \frac{\theta}{C(1-\theta)}$ ----------**3.10**

Were K_{ads} = Film attractive power or equilibrium constant of adsorption, θ degree of surface coverage, C concentration of inhibitor.

3.6 Thermodynamic and Kinetic Model

3.6.1 Activation Energy (E_a).

This is the minimum energy reacting molecules must possess before a chemical reaction can take place.

The values of activation energy for the corrosion of mild steel in the absence and presence of the inhibitors were calculated using Arrhenius equation 3.11 (Kairi and Kassim 2013)

$log\ CR = \frac{-E_a}{2.303RT} + \log A$ ---------- ---------**3.11**

Where E_a*the activation energy of the reaction, R is* the universal gas constant (8.314 J mol^{-1}),$CR$is the corrosion rate at temperature $T$and Universal gas constant R.

3.6.2 Enthalpy ΔH_{ads} and EntropyΔS_{ads} of Adsorption

Enthalpy is thesum of the internal energy of the system plus the product of the pressure of the gas in the system and its volume while entropy is the measure of disorderliness of a system.The thermodynamic parameters for the heat of adsorption and entropy of the

inhibitors on the low carbon steel (ΔH_{ads}) and (ΔS_{ads}) in the presence and absence of inhibitors was calculated using the transition state equation 3.12

$$\log(\frac{CR}{T}) = \log(\frac{R}{Nh}) + \frac{\Delta S_{ads}}{2.303R} - \frac{\Delta H_{ads}}{2.303RT} \text{----------3.12}$$

Where N is the Avogadro's Number (6.02252 x 10^{23} mol^{-1}) and h is the Plank's constant (6.626176 x 10^{34} Js).

Also the equilibrium constant of adsorption (K_{ads}) of guava, banana and almond inhibitors is related to the free energy of adsorption according to equation 3.13 (Zhang and Hua, 2009).

3.6.3 Free energy of Adsorption ΔG_{ads}

This is a measure of the energy which is available to do work outside the system. It is the driving force behind a process and determines the spontaneity of a reaction. The free energy of adsorption ΔG_{ads} at different temperatures was calculated from the equation (Yawas, 2005)

$$\Delta G_{ads} = -RT\ In\ (55.5\ K_{ads}) \text{ ---------- -----3.13}$$

Where

T = Absolute temperature in Kelvin, R= Universal gas constant (8.3145 J/mol K), ΔG_{ads} =Gibbs energy of adsorption (KJ/mole). The constant value 55.5 is the concentration of water in solution in mol/K

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Analysis of Results Obtained

Table 4.1: Elemental composition of Low Carbon Steel

C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Cu %	Al %
0.215	3.350	1.316	0.102	<0.100	0.029	0.015	0.022	0.012	0.130

As %	B %	Ca %	Co %	Mg %	N %	Nb %	Pb %	Sn %	Ti %
<0.0050	0.0041	~0.0072	0.0063	0.014	0.653	0.220	<0.100	<0.0020	0.0042

V %	W %	Zn %	Zr %	Se %	Fe %
<0.0050	<0.010	0.013	<0.0020	<0.020	93.65

4.1.1 The calculate area and density of coupon

A = 2[(20mm × 50mm) + (50mm + 3mm) + (20mm × 3mm)]

$=2420mm^2 \equiv 24.2cm^2$

The total geometric surface area of the specimen is $24.2cm^2$

The density of mild steel is $7.87g/cm^3$

Table 4.2 represents the chemical compounds that are presence and absence in each of the plant extract after the phytochemical analysis was successfully carried-out using the method described in table 4.2 of chapter three.

Table 4.2: Phytochemical analysis of plants extract

Chemical Constituents	Guava Leaves Extracts	Banana Leaves Extract	Almond Leaves Extract
Tannin	+	+	+
Alkaloids	+	-	-
Flavonoids	+	+	+
Saponins	+	+	+
Carbohydrate	+	+	+
Cardiac glycoside	+	+	+
Steroid and triterpenes	+	+	+
Anthraquinones	+	+	+

Key

+…….Presence

_.....Absence

Table 4.3 represents the values gotten from the physico-chemical analysis of the plant extracts using the SLTC 2/2 method of analysis by Society of Leather Trade Chemist in chapter 3

Table 4.3: Physico-chemical analysis of plants extract

	Guava Leaves Extracts	Banana Leaves Extract	Almond Leaves Extract
Moisture Content (%)	2.4	3.1	2.9
Total Solid (%)	51.59	76.39	78.26
Total Soluble (%)	48.41	23.61	21.74
Non-Tannin Content (%)	19.2	15.81	14.13
Tannin Content (%)	29.21	7.8	7.61

Total salt content (ml)	**46.13**	**23.80**	**16.11**
Total acid content (ml)	**43.41**	**12.01**	**20.44**
PH of extract	**4.81**	**5.11**	**5.20**
Density (kg/m^3)	**0.05**	**0.015**	**0.04**
Specific density (kg/m^3)	**0.87**	**0.89**	**0.89**

4.1.2 Graphical Representations of the Results Obtained from Corrosion Test.

Figures 4.1- 4.16 are graphical representation of the relationship between corrosion and time of immersion of coupons in both media in the absence and presence of the plants extract at various concentrations at a constant temperature of 30^{o}C.

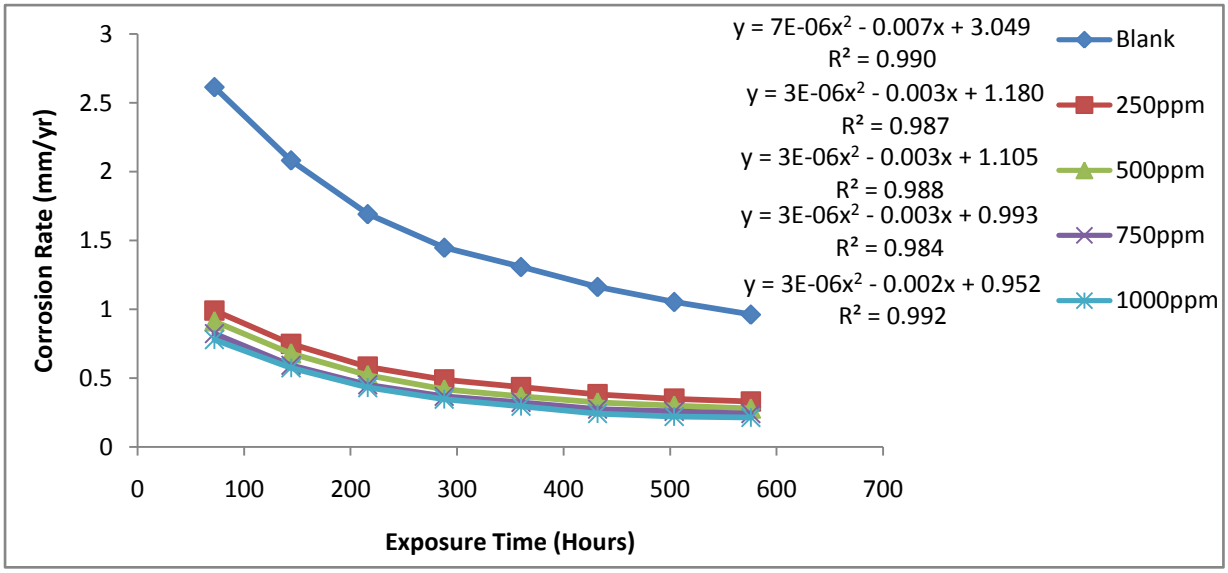


Fig. 4.1: Corrosion rate-time curve of Low Carbon Steel in 0.5M HCl in absence and presence of various concentrations of guava extractat temperature of 30^{o}C

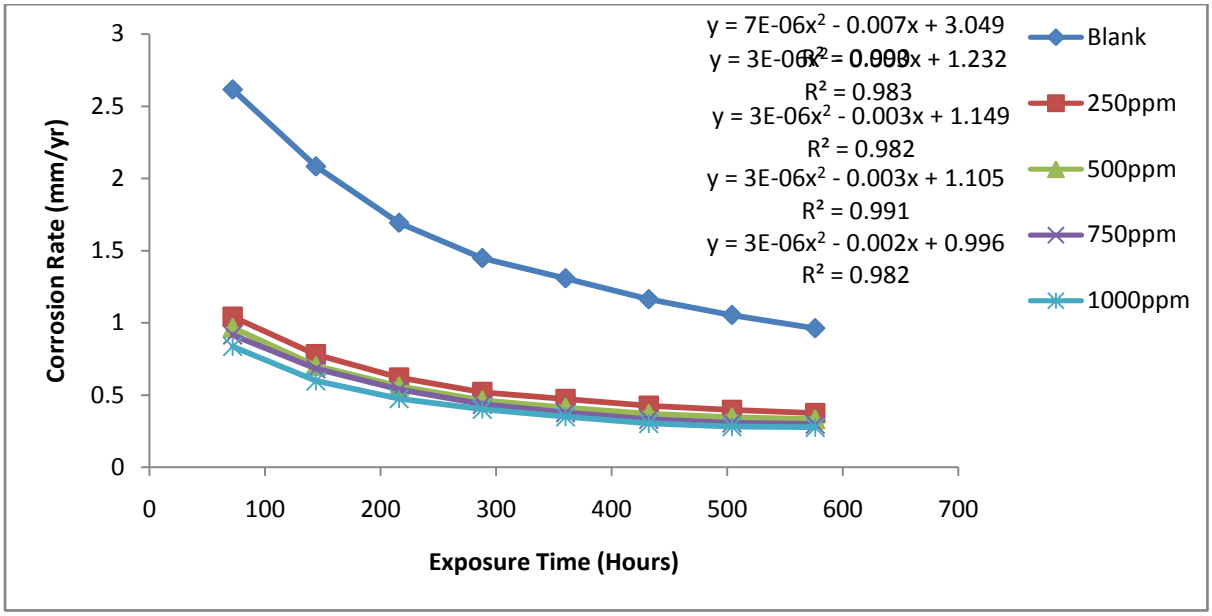


Fig. 4.2: Corrosion rate-time curve of Low Carbon Steel in 0.5M HCl in absence and presence of various concentrations of banana extract at temperature of 30 ℃

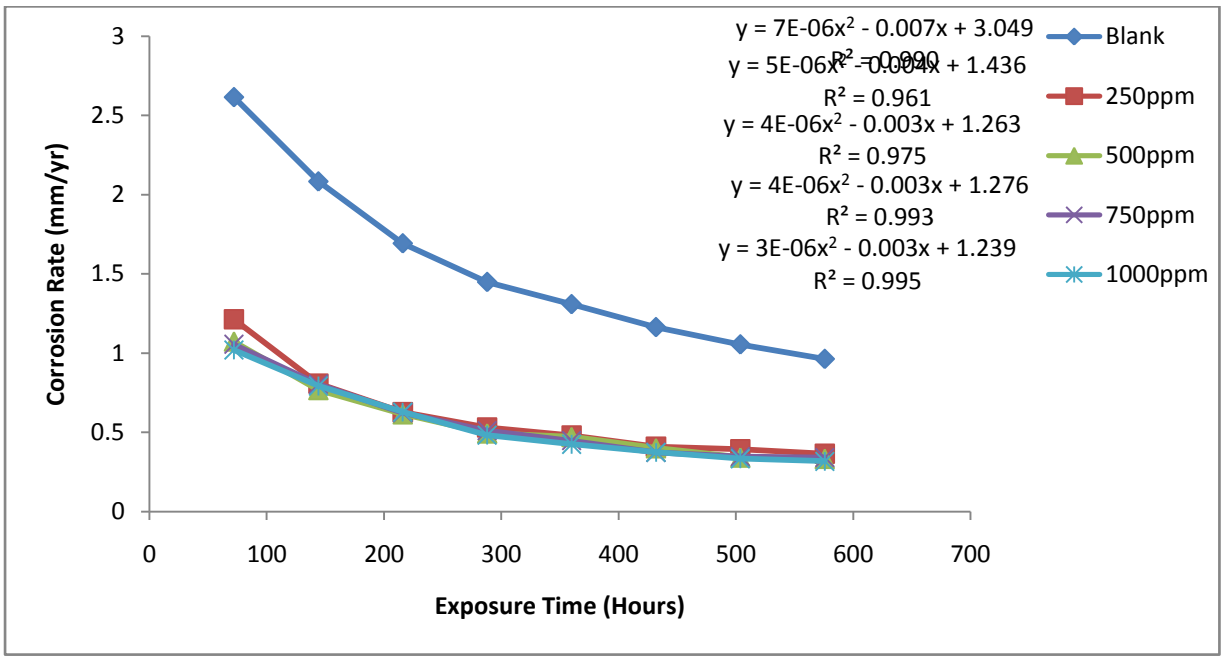


Fig. 4.3: Corrosion rate-time curve of Low Carbon Steelin 0.5M HCl in absence and presence of various concentrations of almond extract at temperature of30 ℃

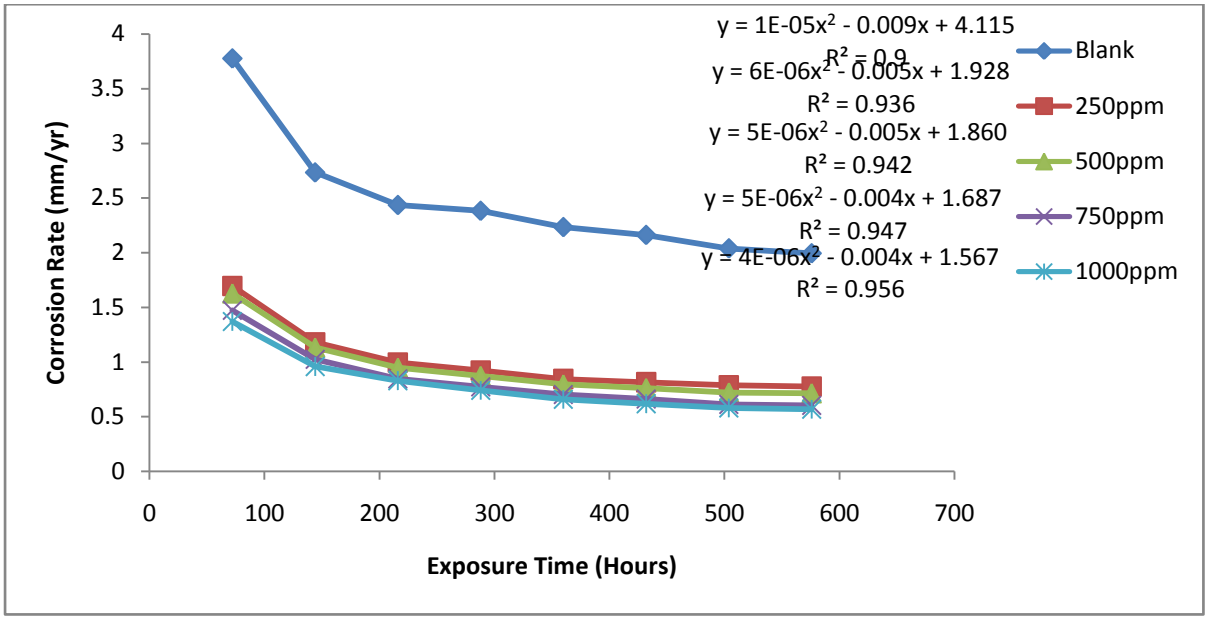


Fig. 4.4: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2S0_4 in absence and presence of various concentrations of guava extract at temperature of30 ℃

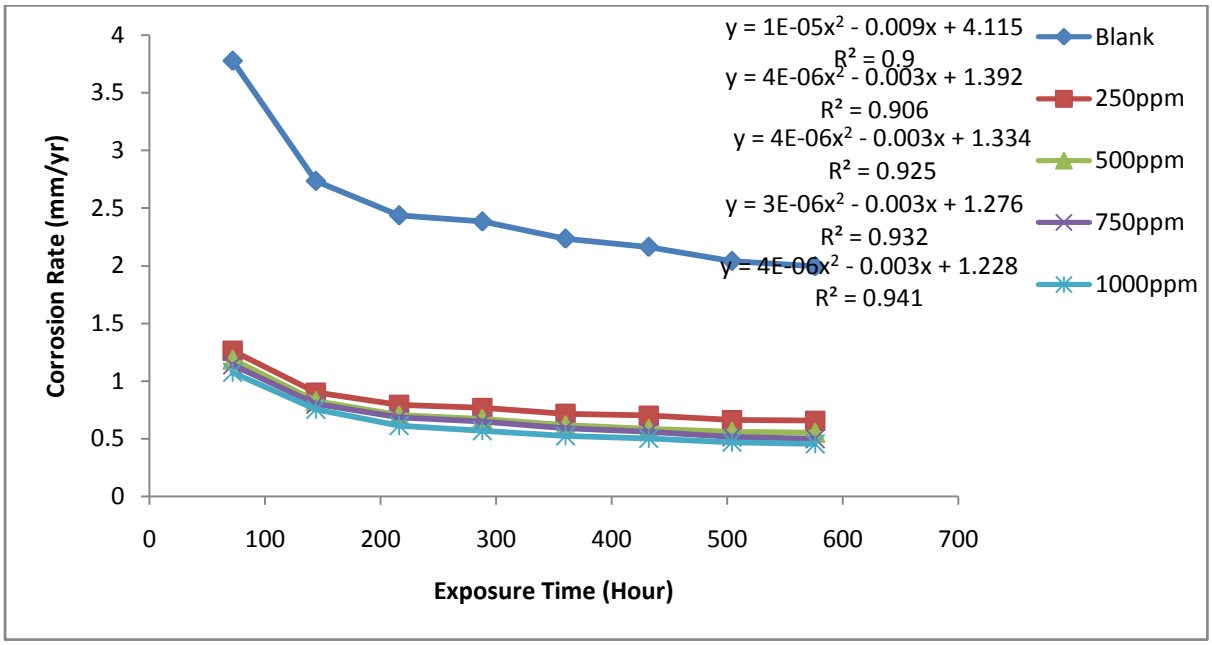


Fig. 4.5: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2S0_4 in absence and presence of various concentrations of bananaextract at temperature of30 ℃

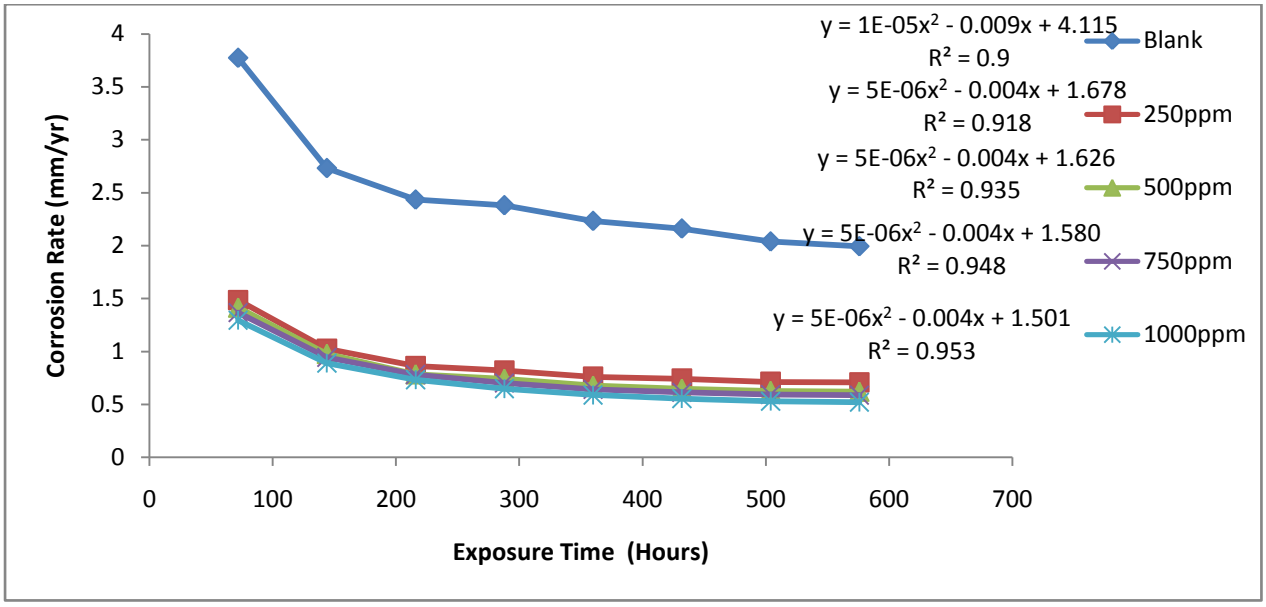


Fig. 4.6: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2S0_4 in absence and presence of various concentrations of almond extract at temperature of30 ℃

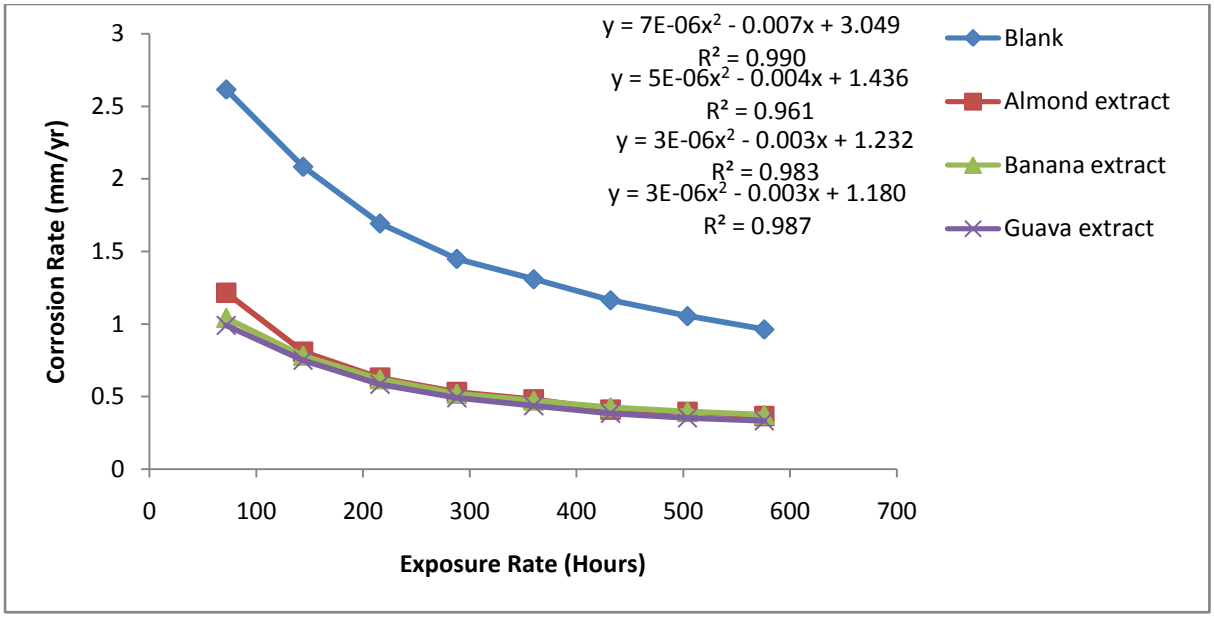


Fig. 4.7: Corrosion rate-time curve of Low Carbon Steel in 0.5M HCl in absence and presence 250ppm concentrations of the three extracts at temperature of 30℃

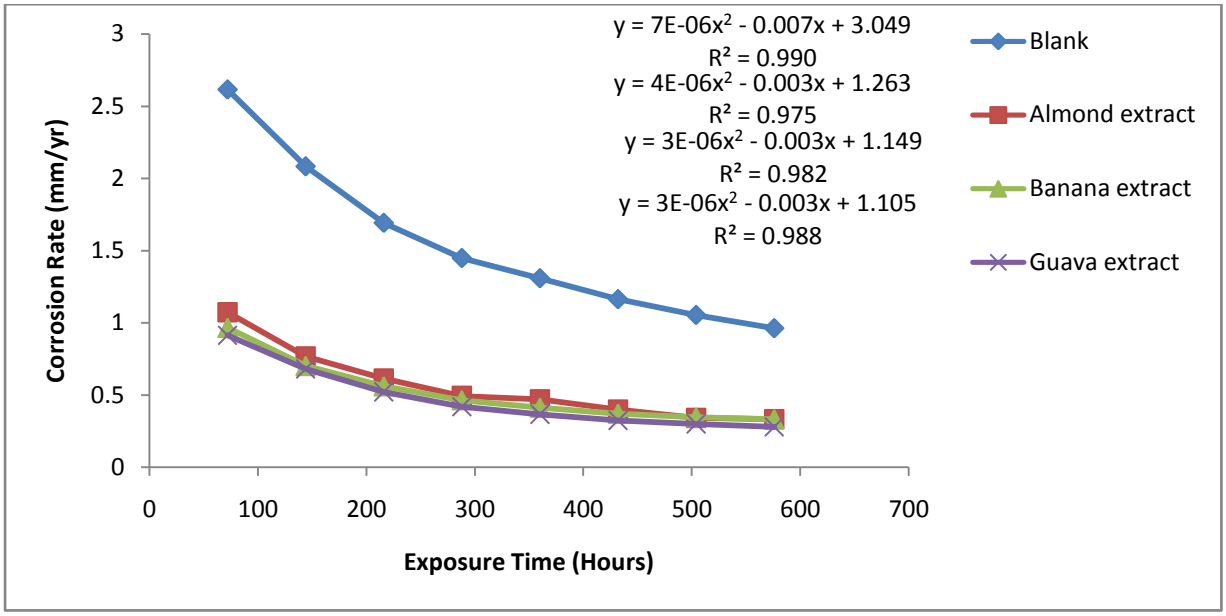


Fig. 4.8: Corrosion rate-time curve of Low Carbon Steelin 0.5M HCl in absence and presence 500ppm concentrations of the three extracts at temperature of 30 ℃

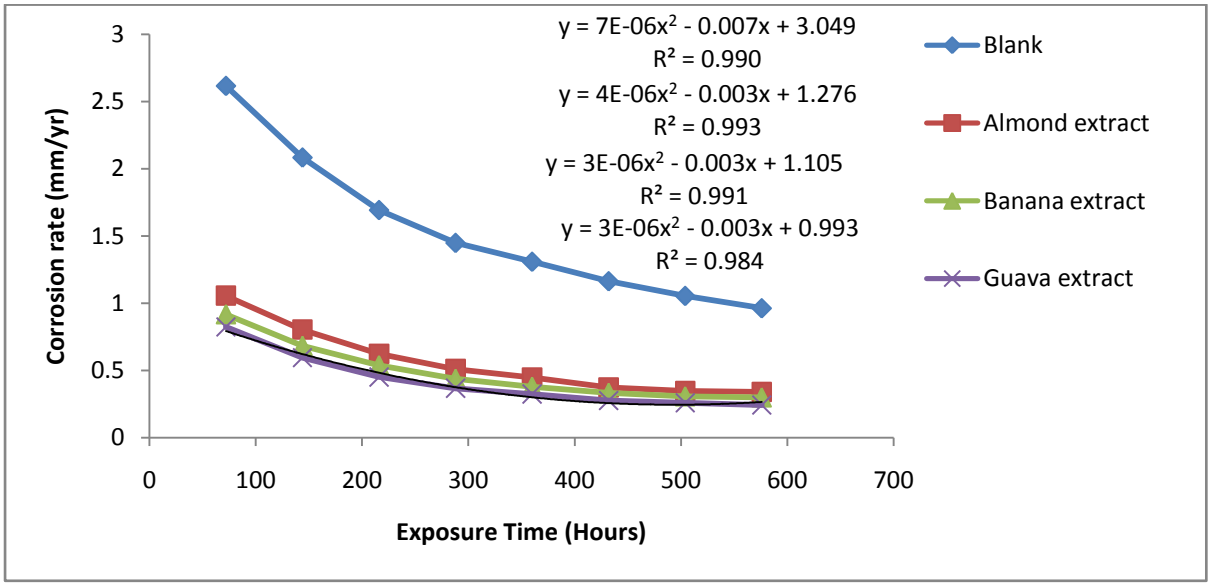


Fig. 4.9: Corrosion rate-time curve of Low Carbon Steel in 0.5M HCl in absence and presence 750ppm concentration of the three extractsat temperature of 30 ℃

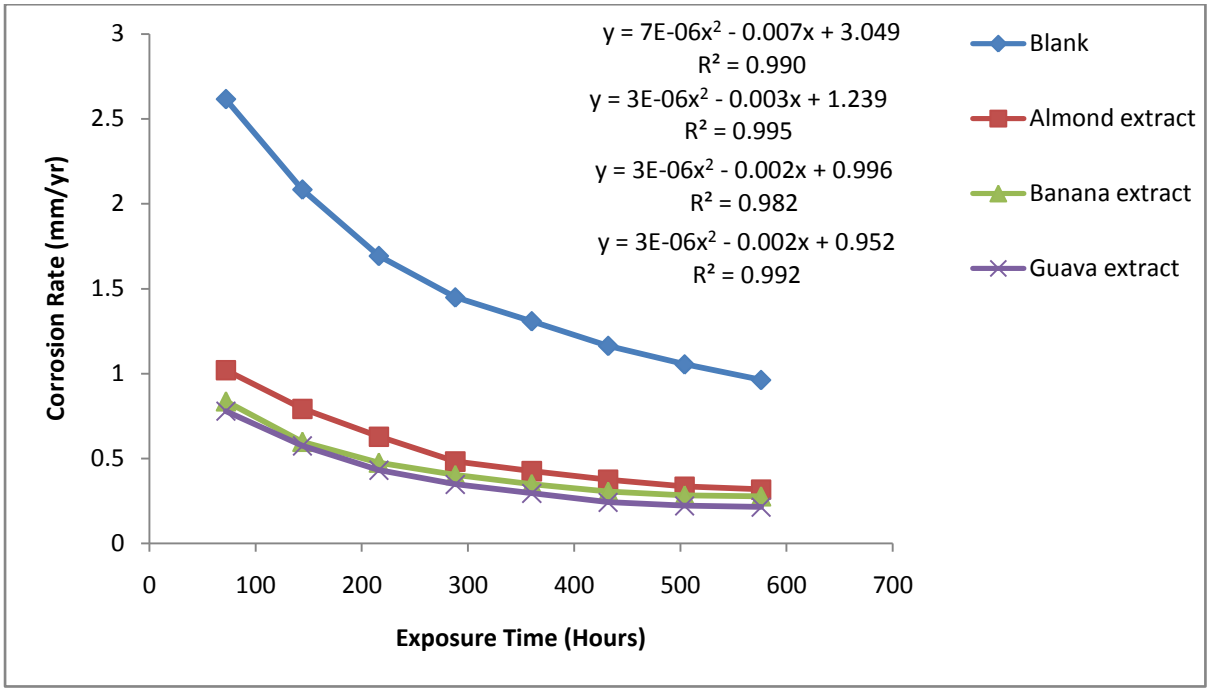


Fig. 4.10: Corrosion rate-time curve of Low Carbon Steelin 0.5M HCl in absence and presence 1000ppm concentrations of the three extracts at temperature of 30℃

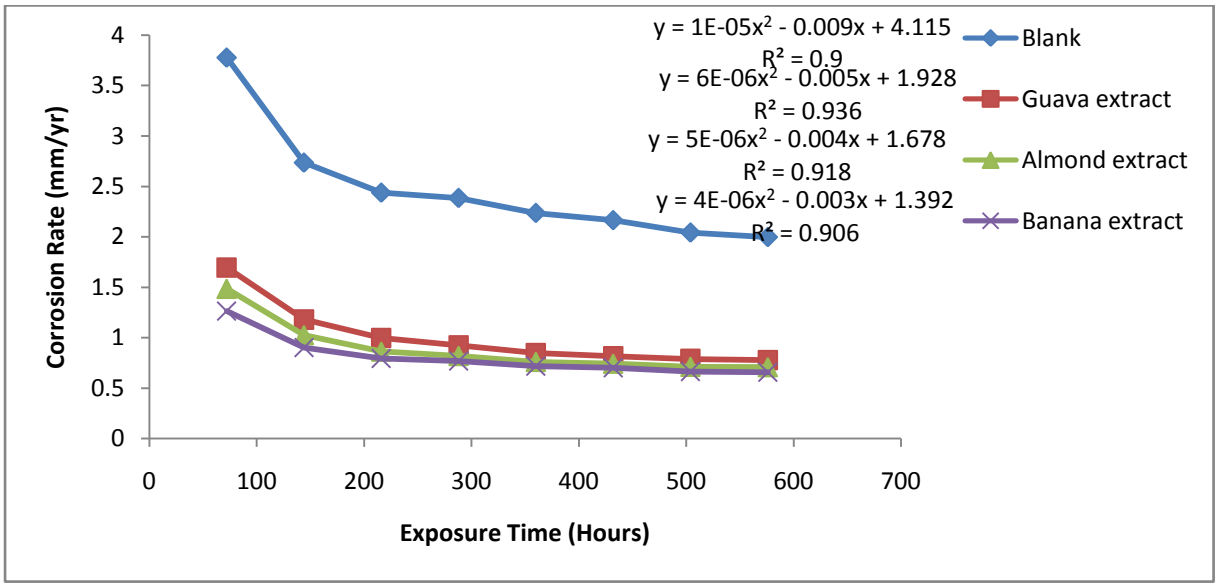


Fig. 4.11: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2SO_4 in absence and presence 250ppm concentrations of the three extract at temperature of 30 ℃

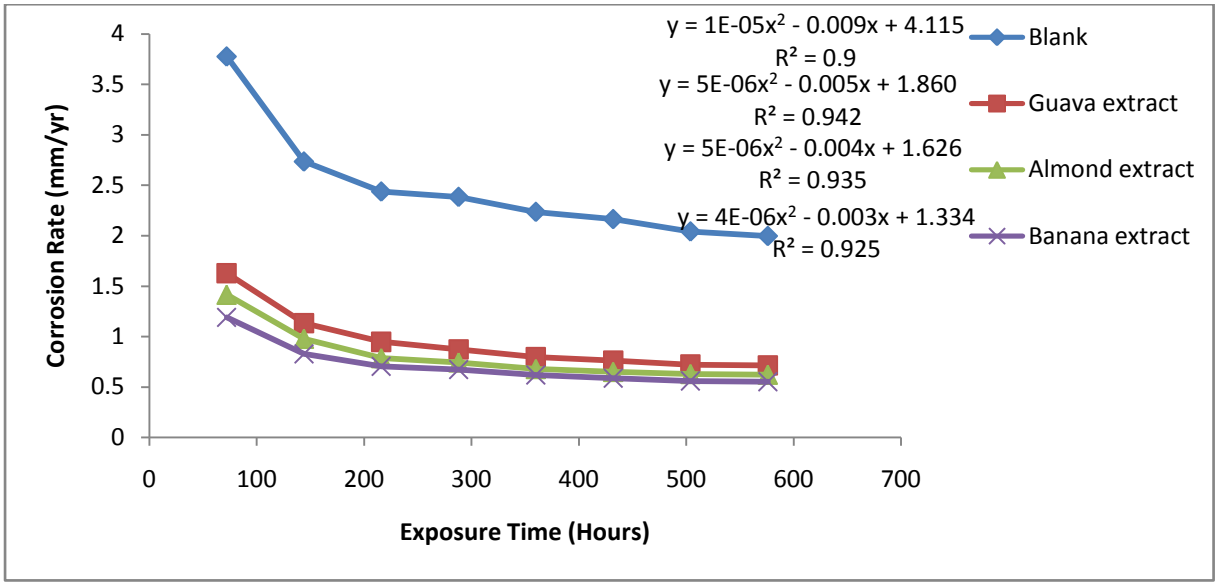


Fig. 4.12: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2SO_4 in absence and presence 500ppm concentration of the three extractsat temperature of 30 ℃

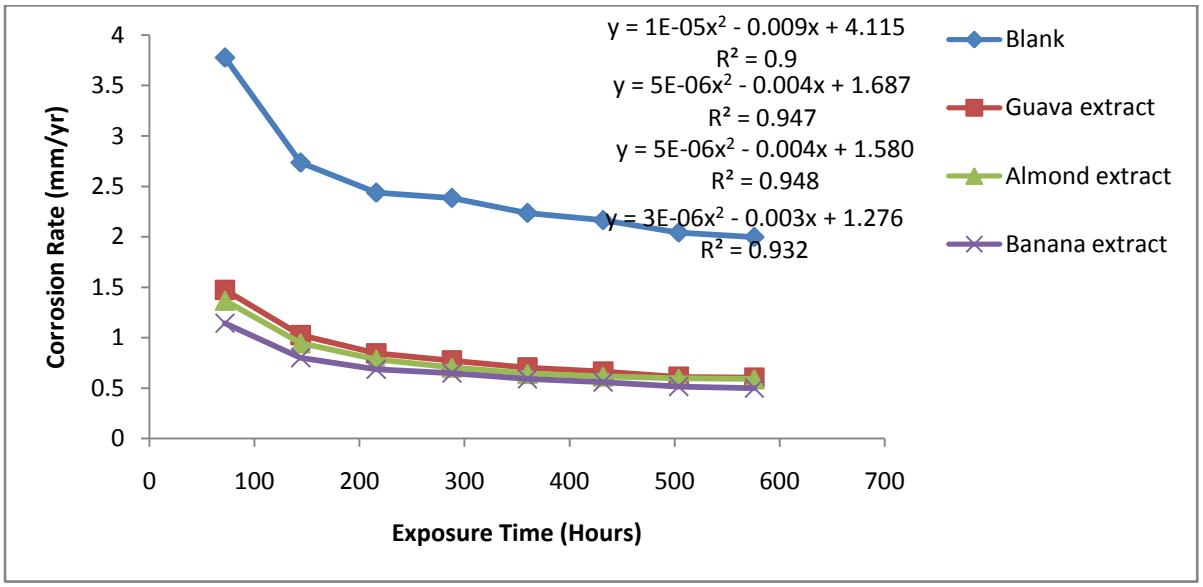


Fig. 4.13: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2SO_4 in absence and presence 750ppm concentration of the three extracts at temperature of 30 ℃

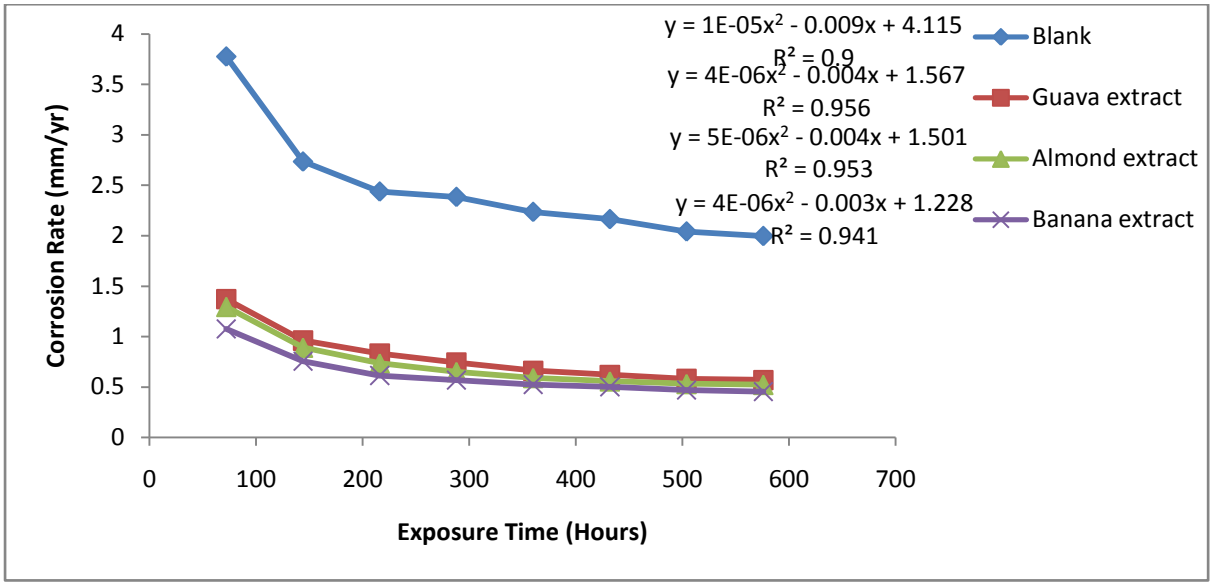


Fig. 4.14: Corrosion rate-time curve of Low Carbon Steelin 0.5M H_2SO_4 in absence and presence 1000ppm concentration of the three extractsat temperature of 30 ℃

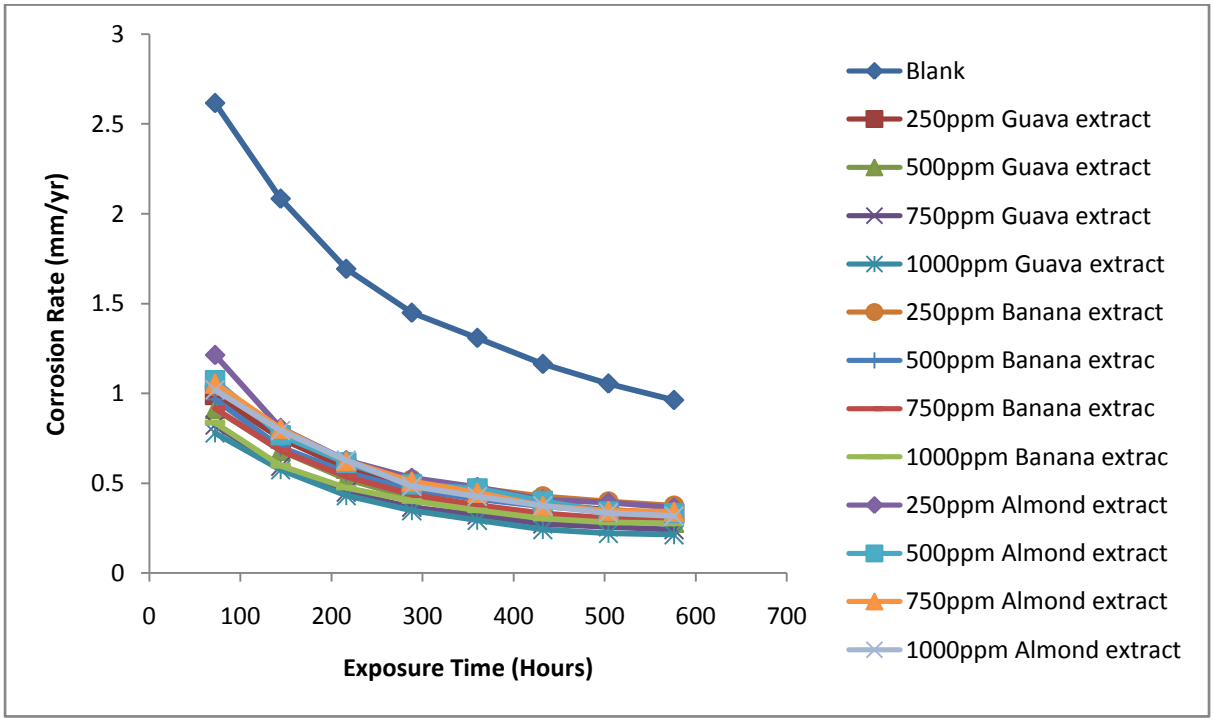


Fig. 4.15: Corrosion rate-time curve of Low Carbon Steelin 0.5M HCl in absence and presence of various concentrations of the three extracts at temperature of 30 ℃.

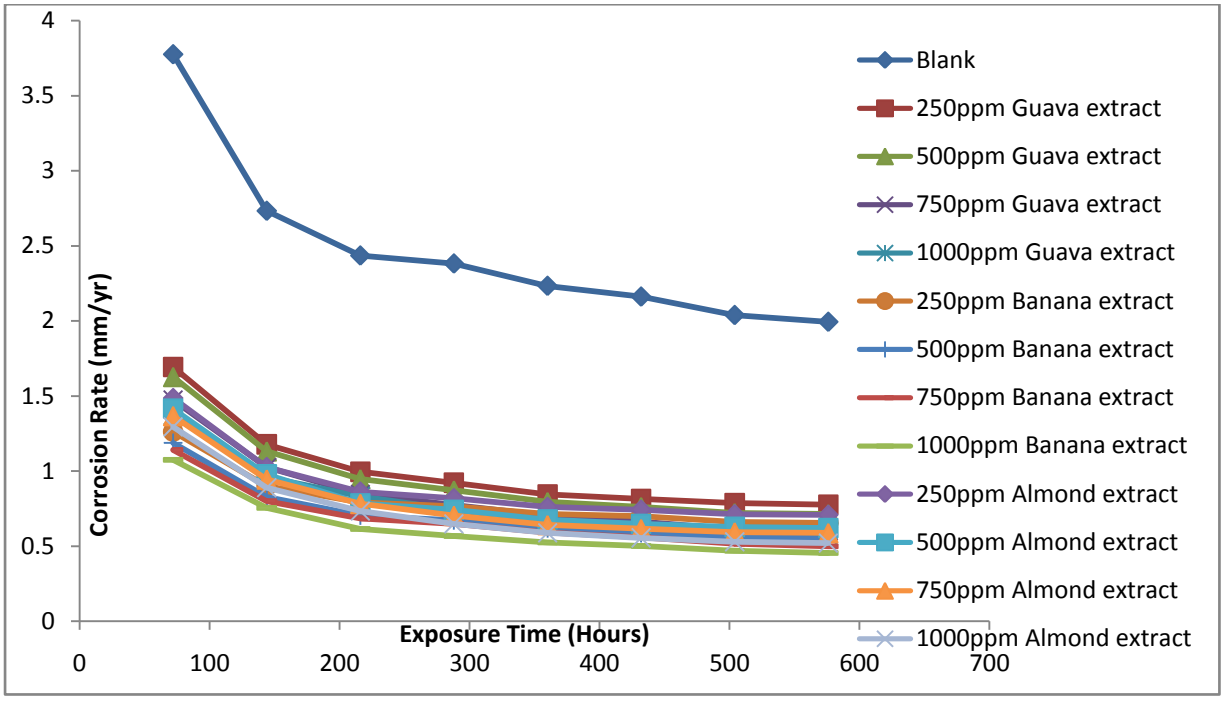


Fig. 4.16: Corrosion rate-time curve of Low Carbon Steel in 0.5M H_2SO_4 in absence and presence of variousconcentrations of the three extracts at temperature of30 ℃

Figures 4.17-4.18 are graphical representation of the relationship between percentage inhibition efficiency and concentration of the plants extract at 1000 ppm at constant temperature of 30°C.

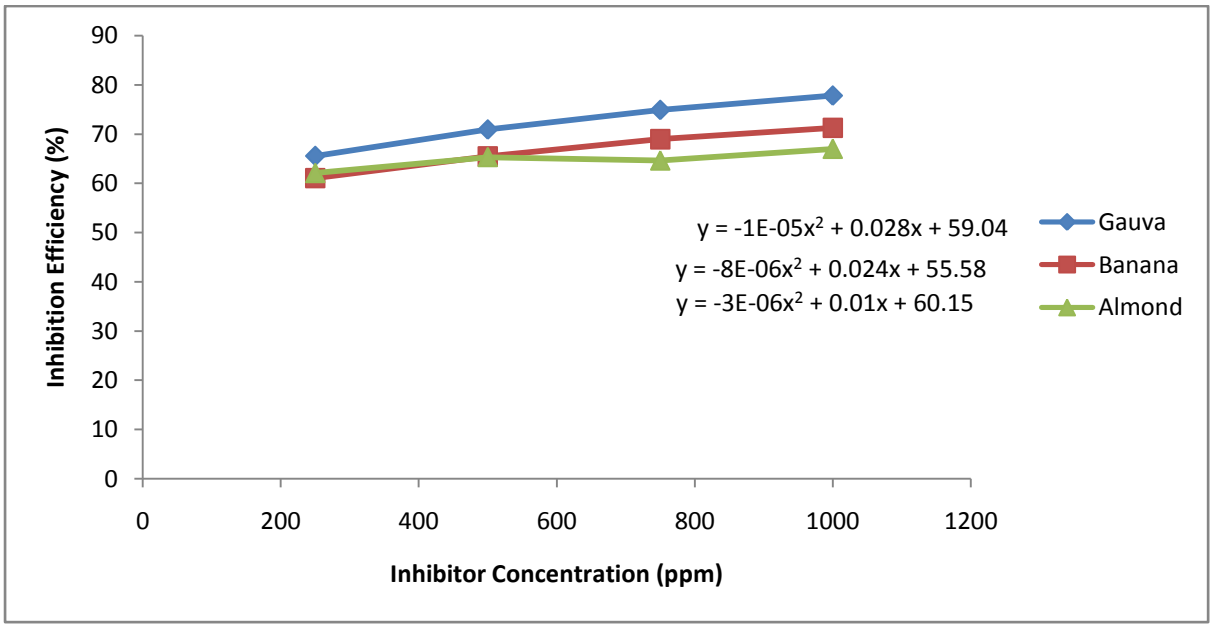


Fig. 4.17: Percentage Inhibition Efficiency (%IE) against inhibitor concentration curve of the extracts in 0.5M HCl at temperature of 30 ℃

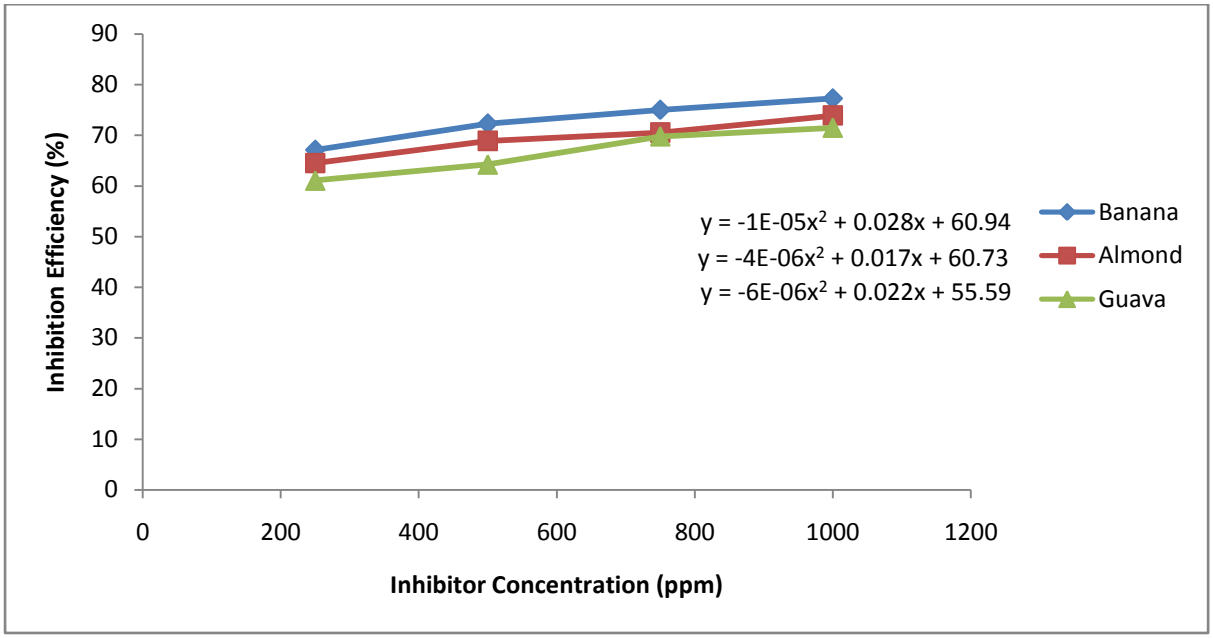


Fig. 4.18: % Inhibition Efficiency against inhibitor concentration curve of the extracts in 0.5M H_2SO_4at temperature of 30 ℃

Figures 4.19 - 4.21 are graphical representation of the relationship between percentage inhibition efficiency and various concentration of the plants extract at different range of temperatures.

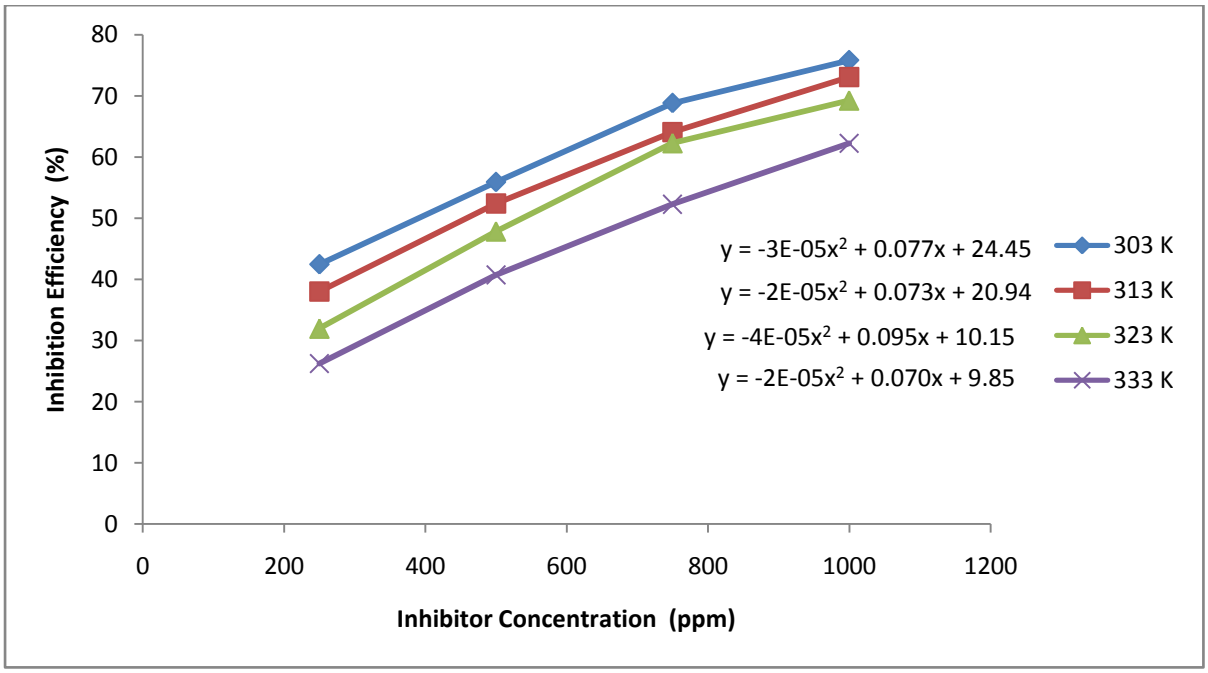


Fig. 4.19: Variation of Percentage inhibition efficiency (%IE) with inhibitor concentration in 0.5M HCl in the presence of guava extractsat different temperatures

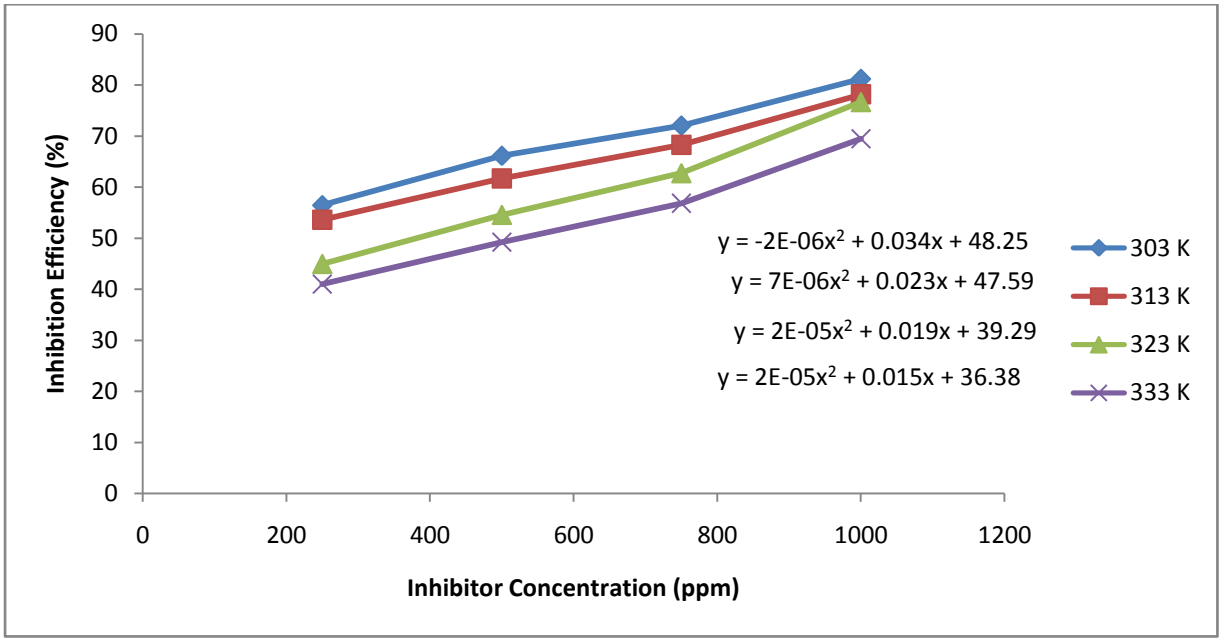


Fig. 4.20:Variation of Percentage inhibition efficiency (%IE)with inhibitor concentration in 0.5M HCl in the presence of banana extractat different temperatures

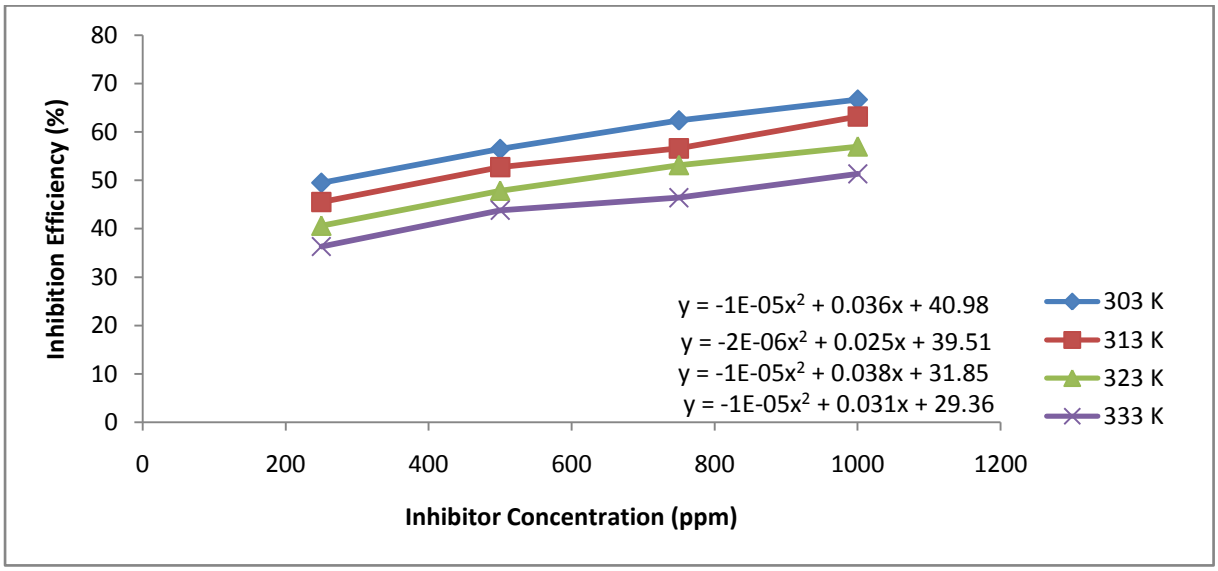


Fig. 4.21: Variation of Percentage inhibition efficiency (%IE) with inhibitor concentration in 0.5M HCl in the presence of almond extractat different temperatures

Figures 4.22 - 4.25 are graphical representation of the relationship between percentage inhibition efficiency and temperature at various concentration of the plants extract.

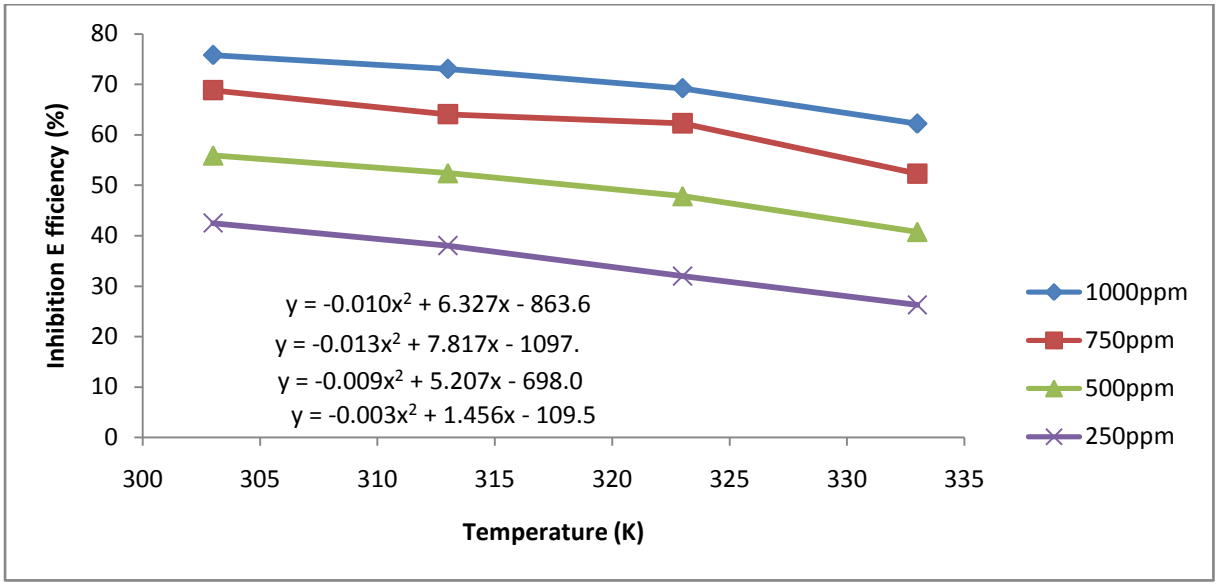


Fig. 4.22: Variation of Percentage inhibition efficiency (%IE) with temperature for 0.5M HCl in the presence of guava extract at various concentrations

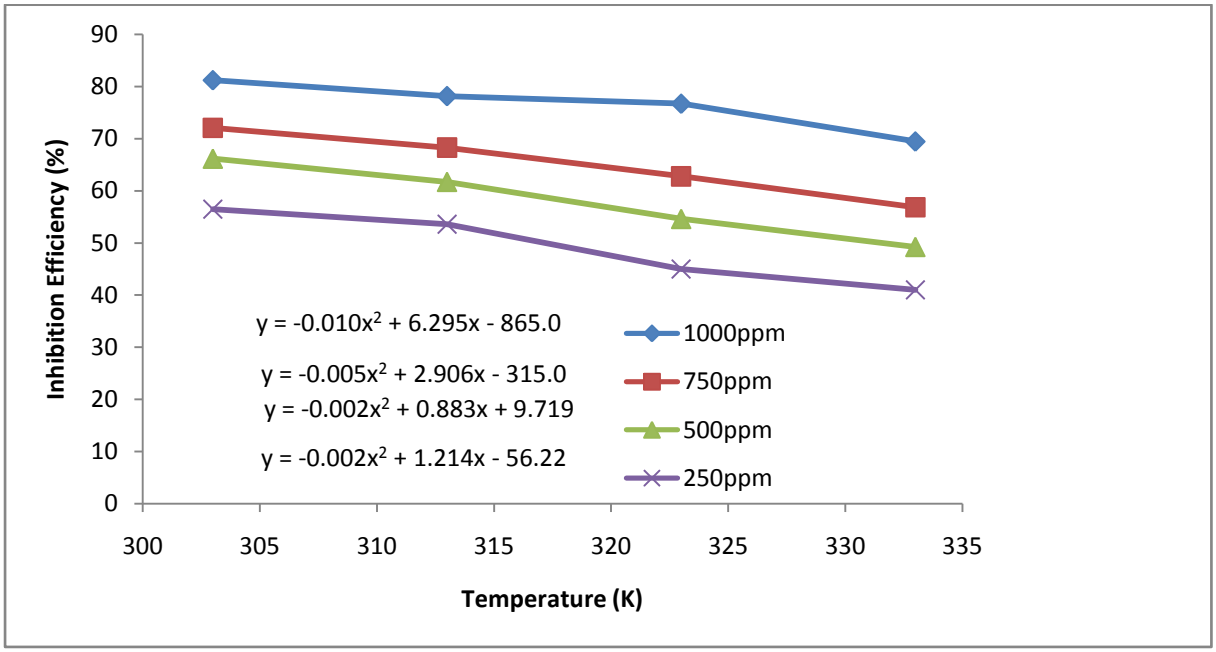


Fig. 4.23: Variation of Percentage inhibition efficiency (%IE) with temperature for 0.5M HCl in the presence of banana extractat various concentrations

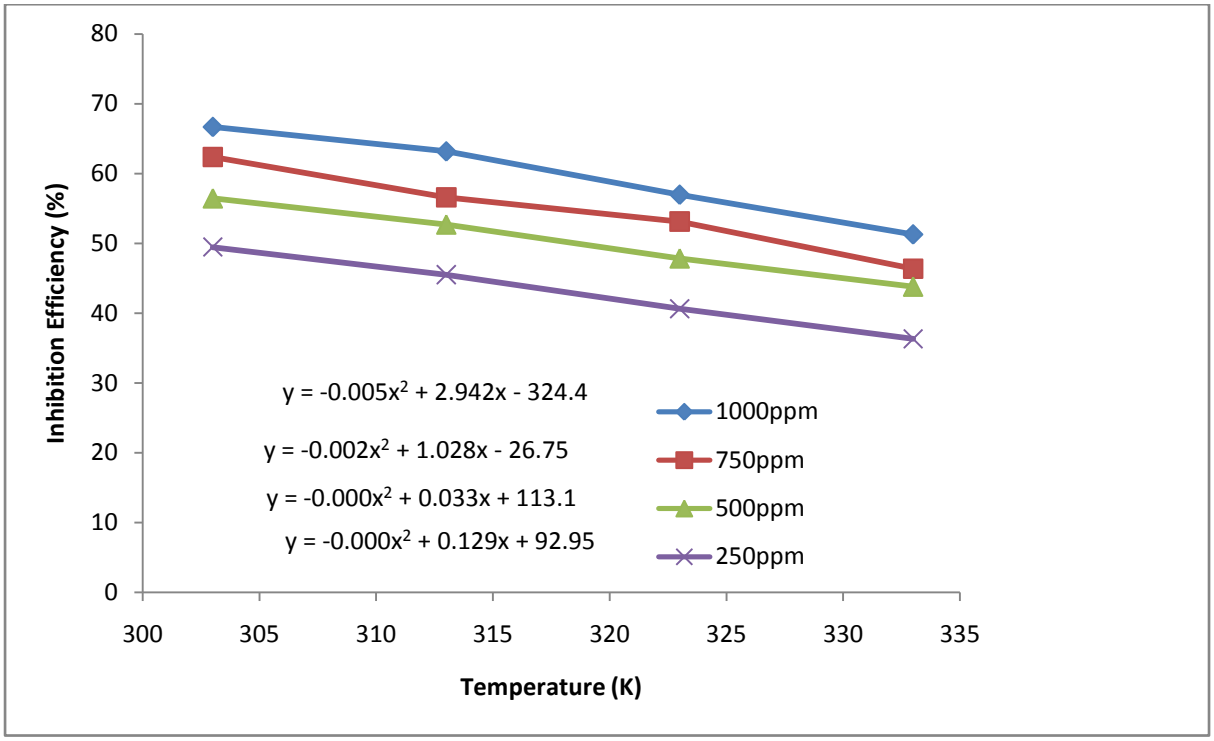


Fig. 4.24: Variation of Percentage inhibition efficiency (%IE) with temperature for 0.5M HCl in the presence of almond extractat various concentrations

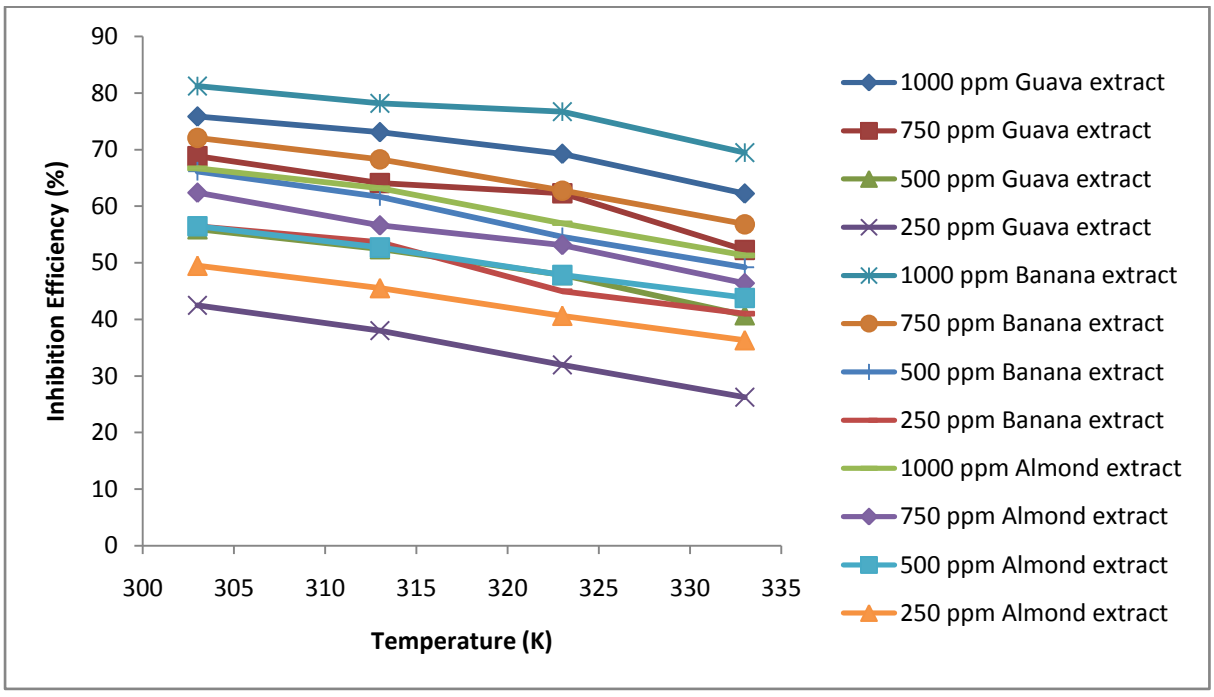


Fig. 4.25: Variation of percentage inhibition efficiency (%IE) with temperature in 0.5M HCl in the presence of the extractsat various concentrations

Figures 4.26 - 4.28 are graphical representation of the relationship between percentage inhibition efficiency and various concentration of the plants extract at different range of temperatures.

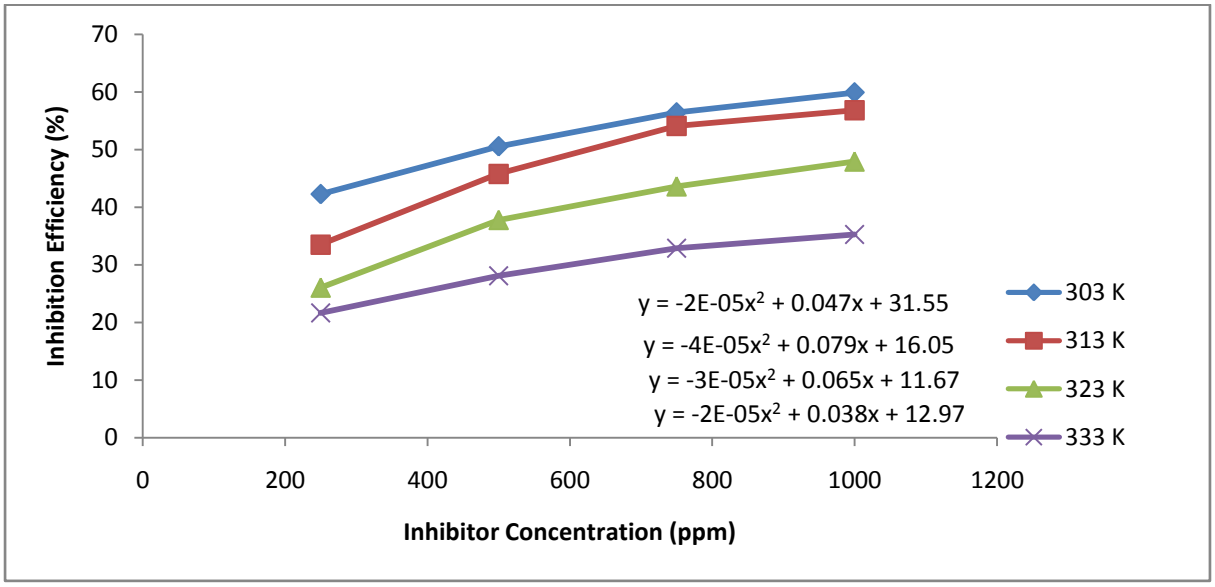


Fig. 4.26: Variation of Percentage inhibition efficiency (%IE) with inhibitor concentration in 0.5M H_2SO_4 in the presence of guava extractat different temperatures

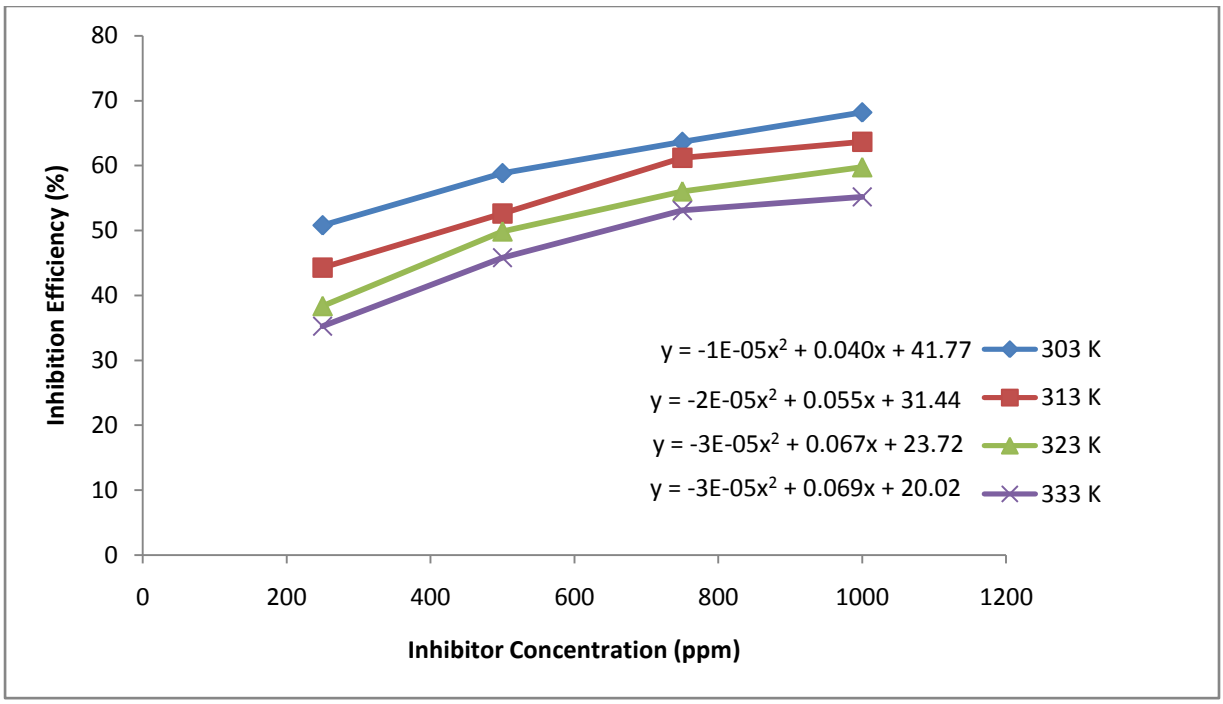


Fig. 4.27: Variation of Percentage inhibition efficiency (%IE) with inhibitor concentration in 0.5M H_2SO_4 in the presence of banana extract at different temperatures

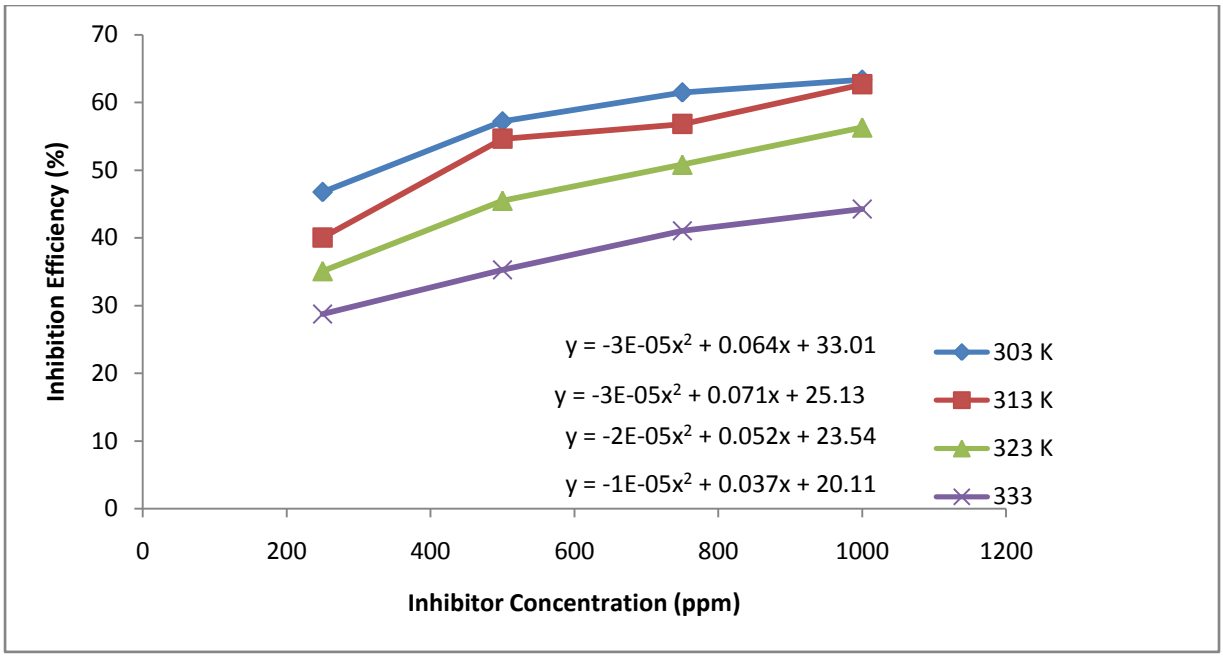


Fig. 4.28: Variation of Percentage inhibition efficiency (%IE) with inhibitor concentration in 0.5M H_2SO_4 in the presence of almond extract at different temperatures

Figures 4.29-4.32 are graphical representation of the relationship between percentage inhibition efficiency and temperature at various concentration of the plants extract

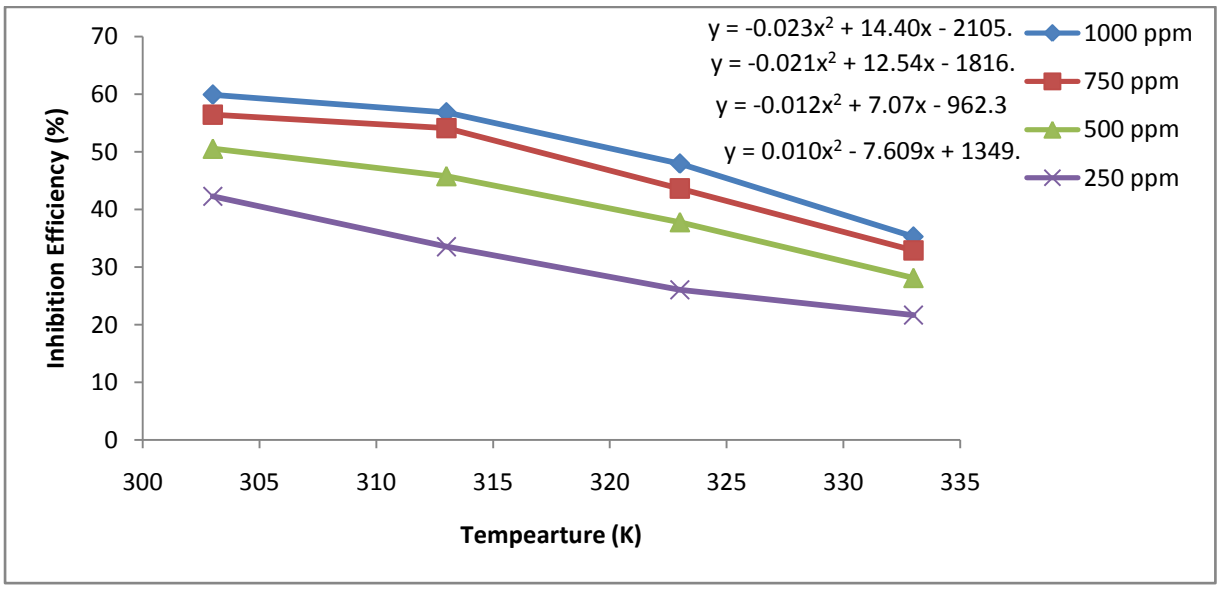


Fig. 4.29:Variation of Percentage inhibition efficiency (%IE) with Temperature in 0.5M H_2SO_4 in the presence of guavaextract at various concentrations

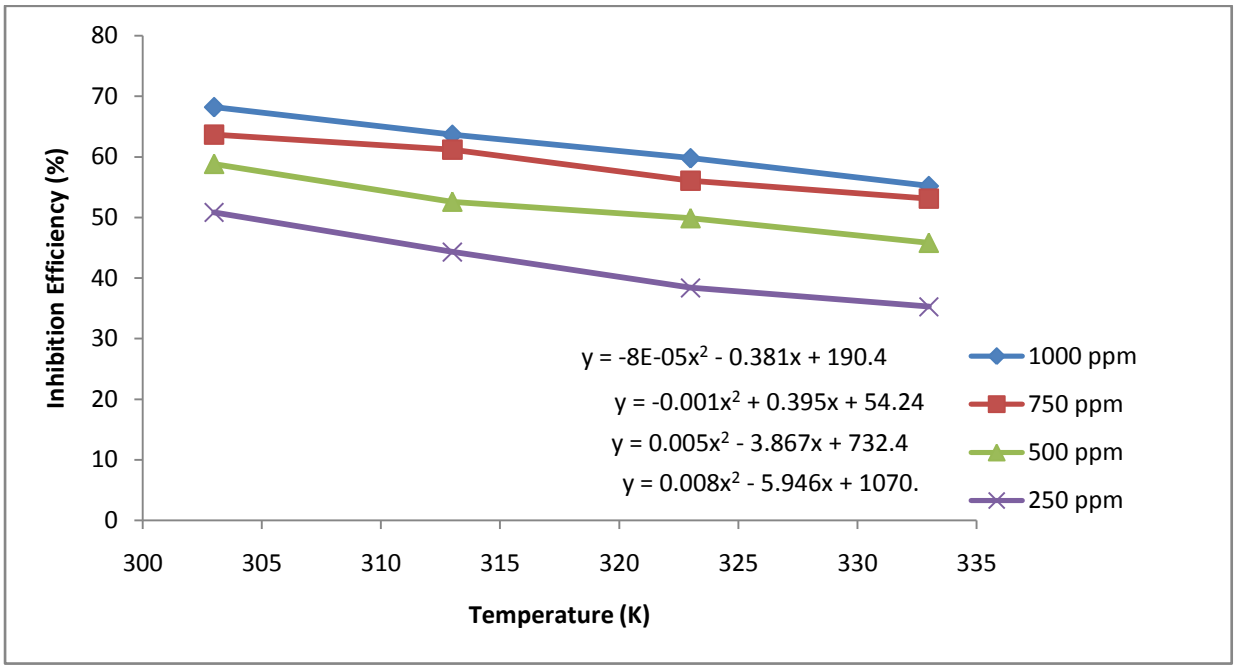


Fig. 4.30: Variation of Percentage inhibition efficiency (%IE) with Temperature in 0.5M H_2SO_4in the presence of bananaextract at various concentrations

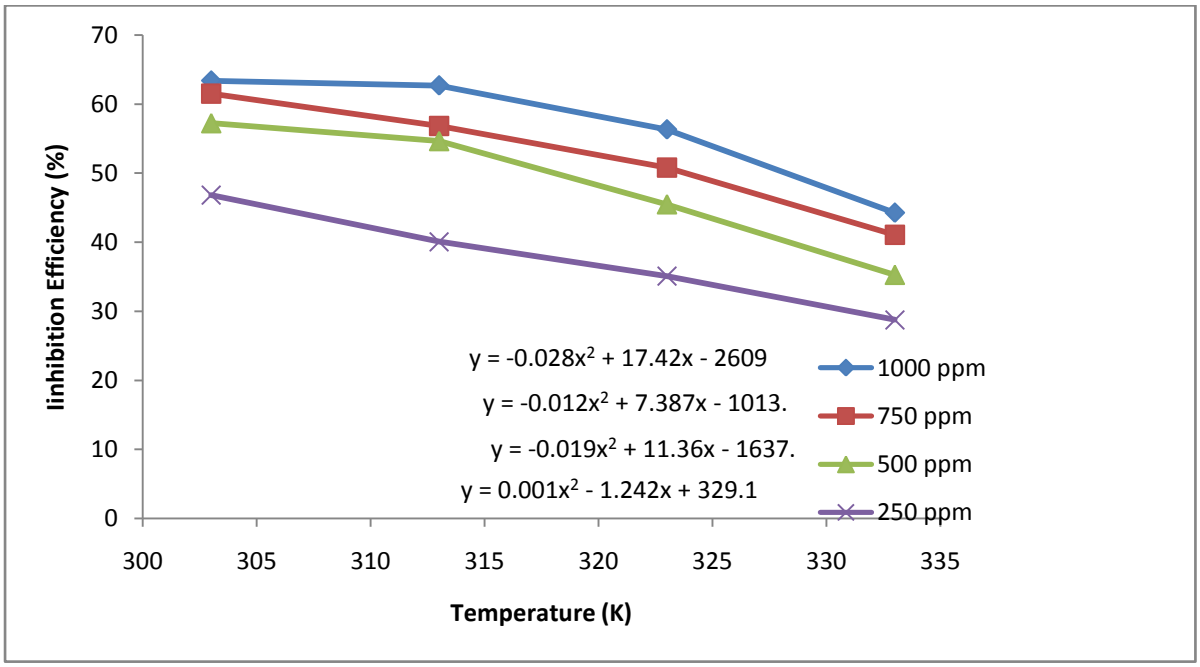


Fig. 4.31: Variation of Percentage inhibition efficiency (%IE) with Temperature in 0.5M H_2SO_4in the presence of almond extract at various concentrations

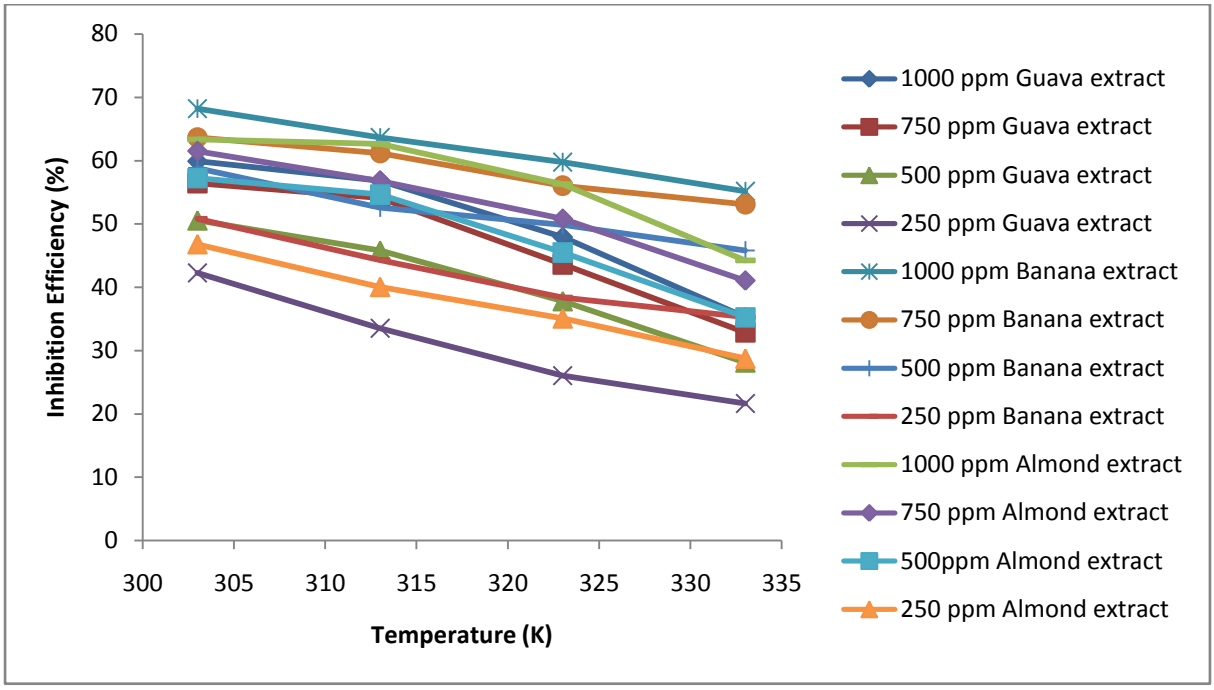


Fig. 4.32: Variation of Percentage inhibition efficiency (%IE) with Temperature in 0.5M H_2SO_4 in the presence of theextracts of various concentrations

Figures 4.33 – 4.38 are Arrhenius plot used in the determination of activation energy (Ea) by the usage of the appropriate equation 3.11 as described in chapter 3.

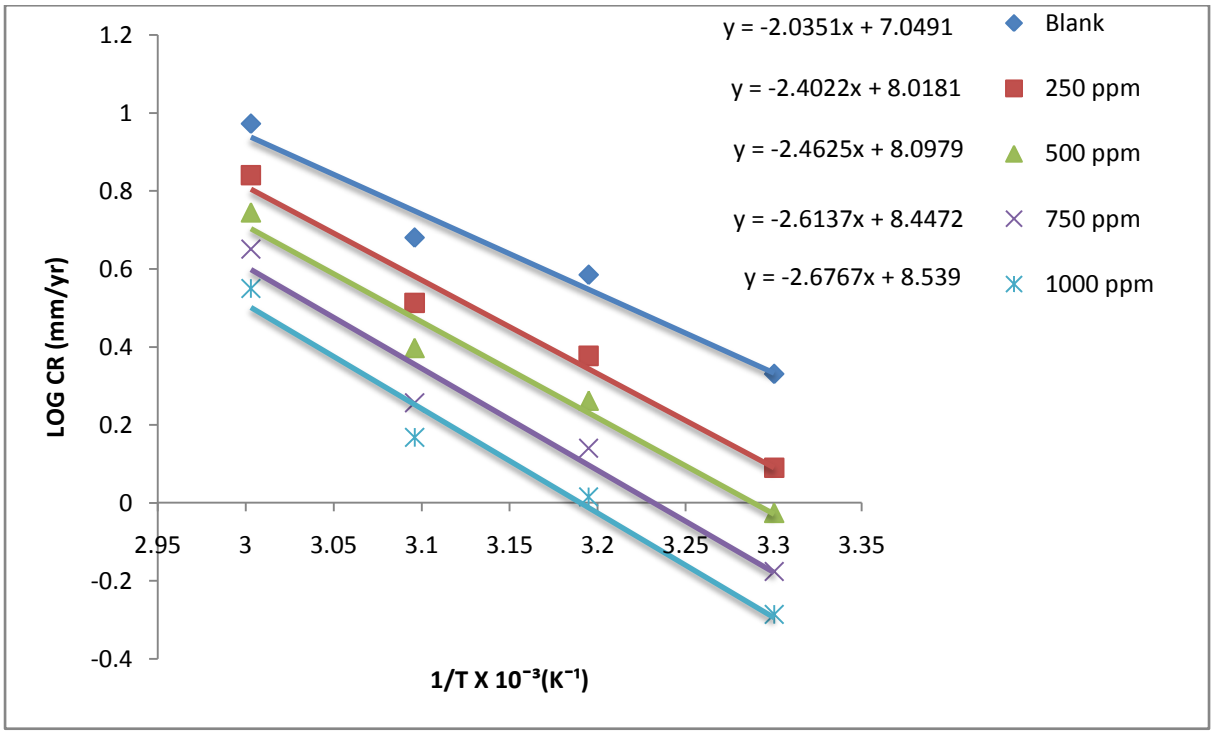


Fig. 4.33: Arrhenius plot for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of guava extract

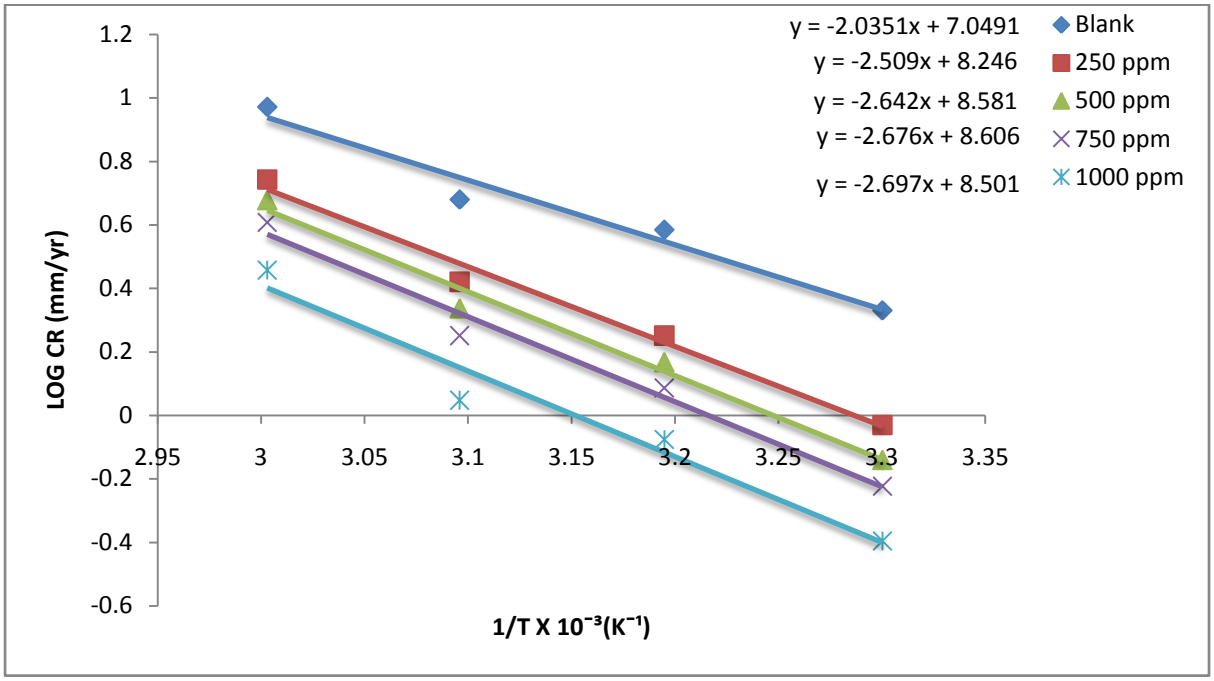


Fig. 4.34: Arrhenius plot for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of bananaextract

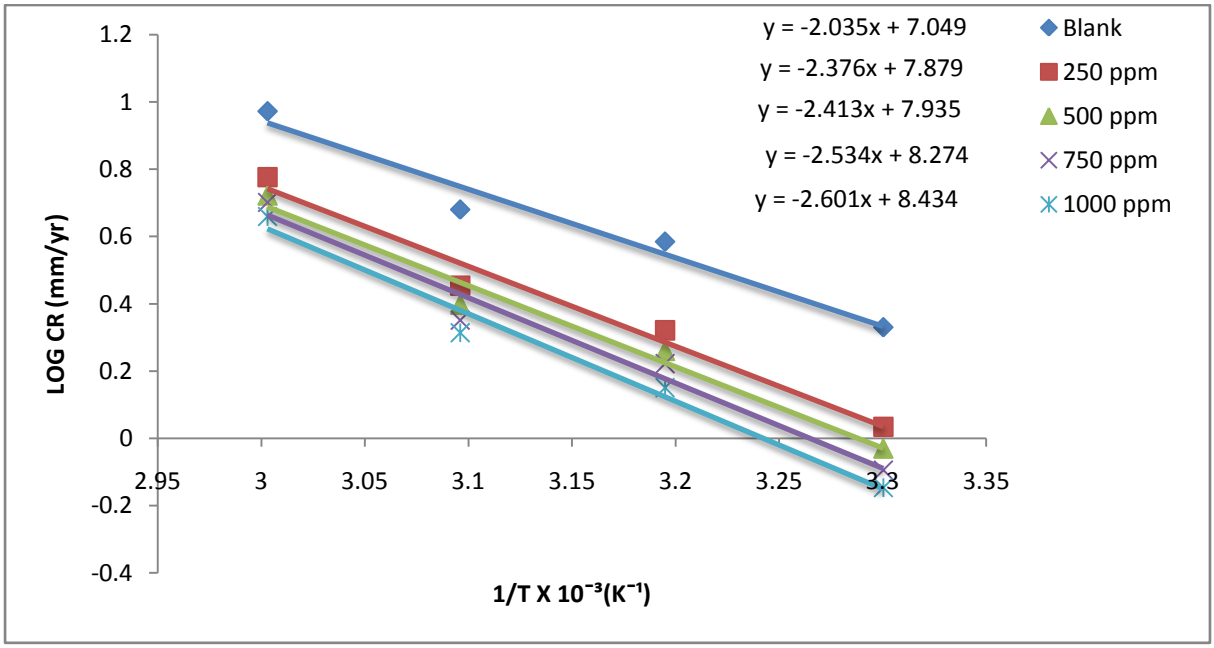


Fig. 4.35: Arrhenius plot for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of almondextract

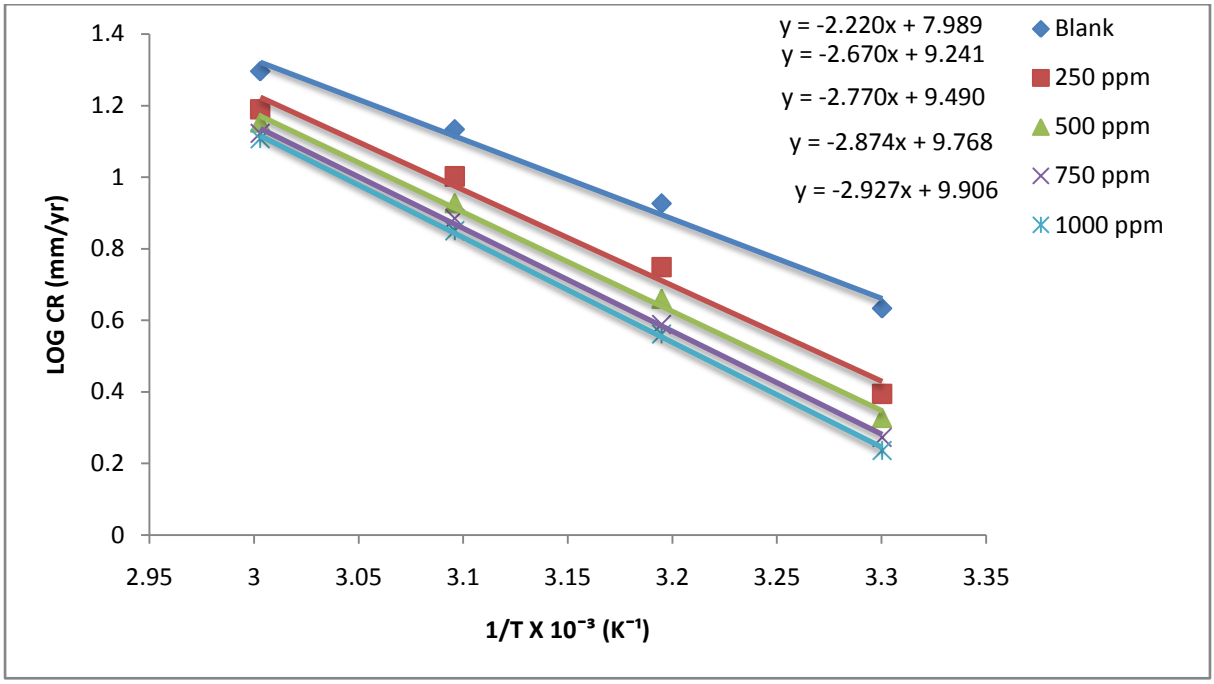


Fig. 4.36: Arrhenius plot for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentrations of guava inhibitor

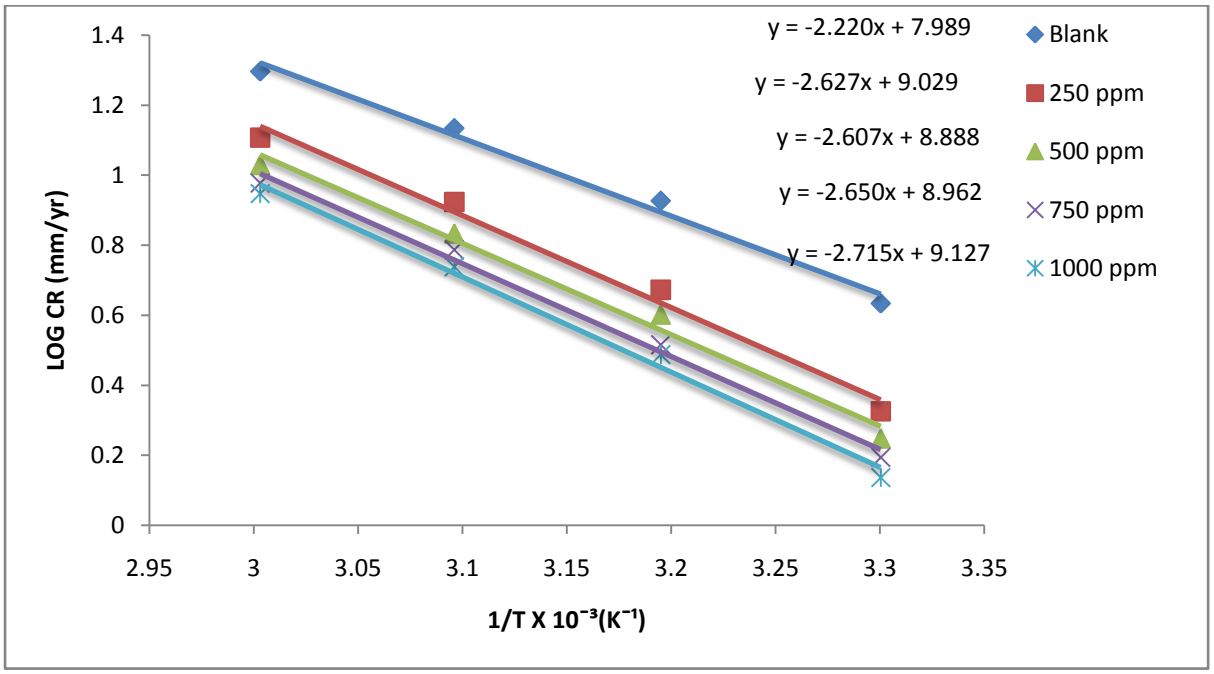


Fig. 4.37: Arrhenius plot for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentrations of bananaextract

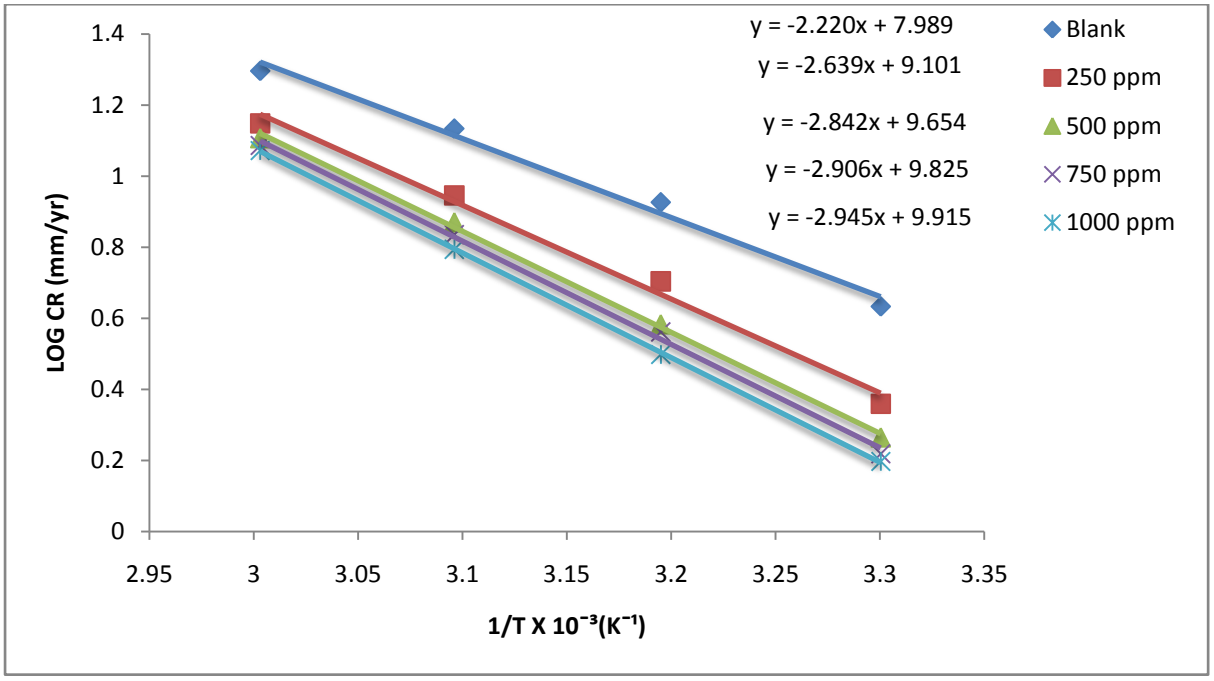


Fig. 4.38: Arrhenius plot for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentrations of almond extract

Figures 4.39- 4.44 are plot used in the determination of the enthalpy and entropy of the system.

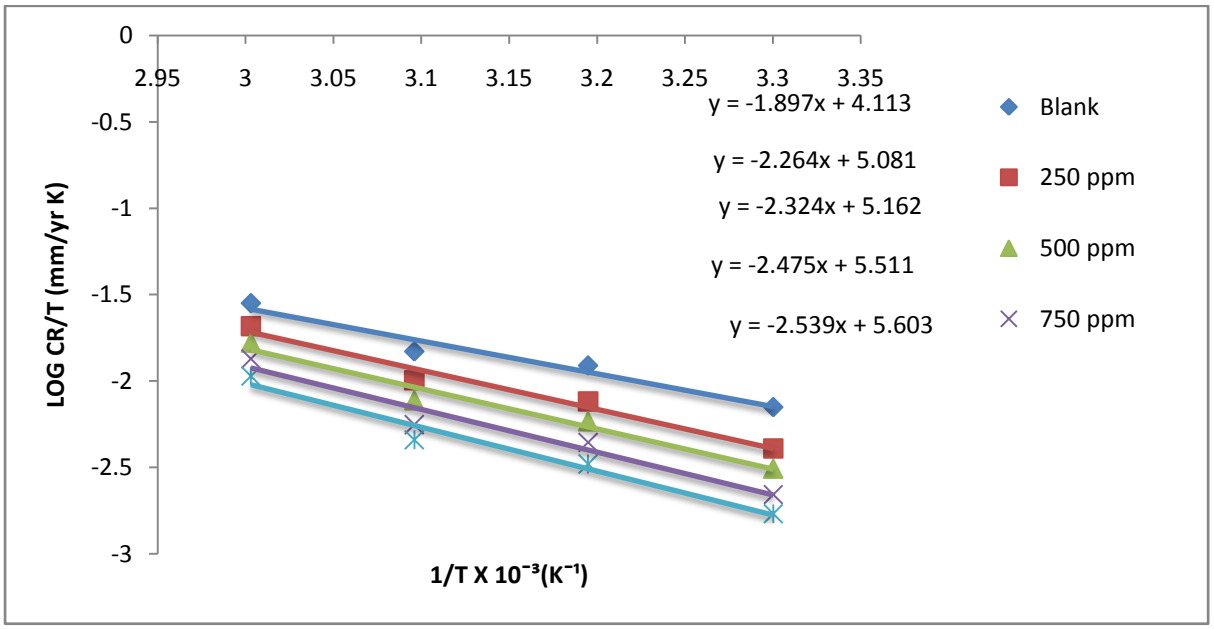


Fig. 4.39: Plots of log (CR/T) versus 1/T for the corrosion for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of guava extract

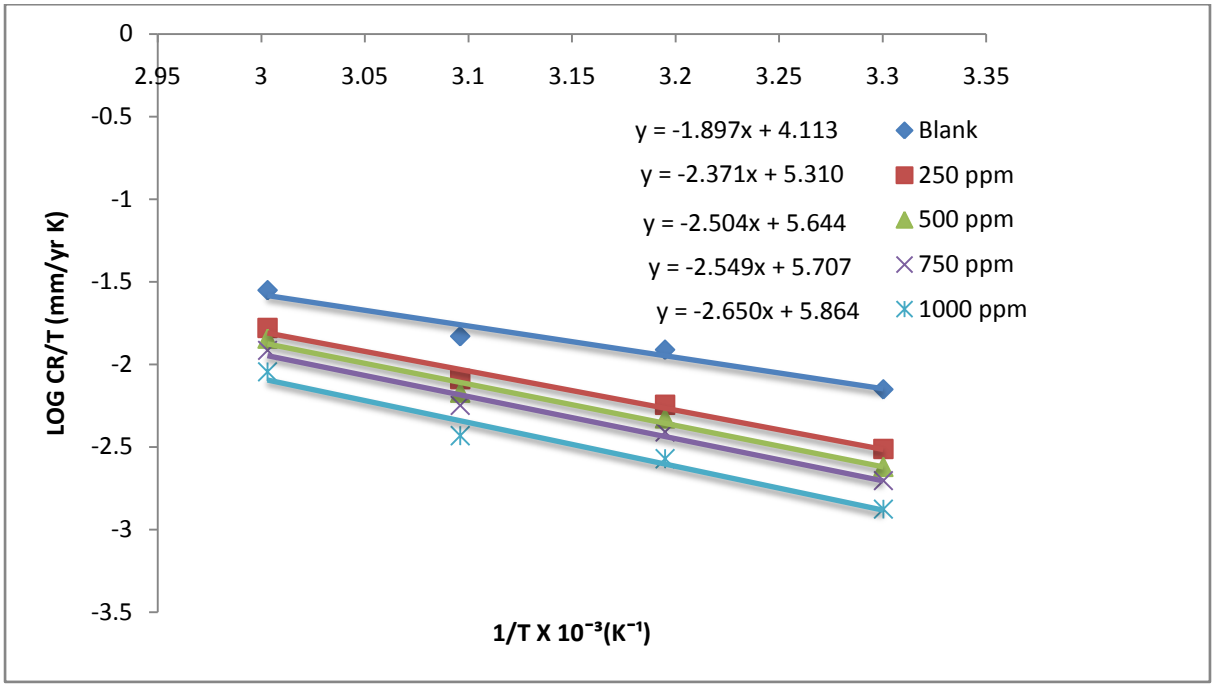


Fig. 4.40: Plots of log (CR/T) versus 1/T for the corrosion for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of bananaextract.

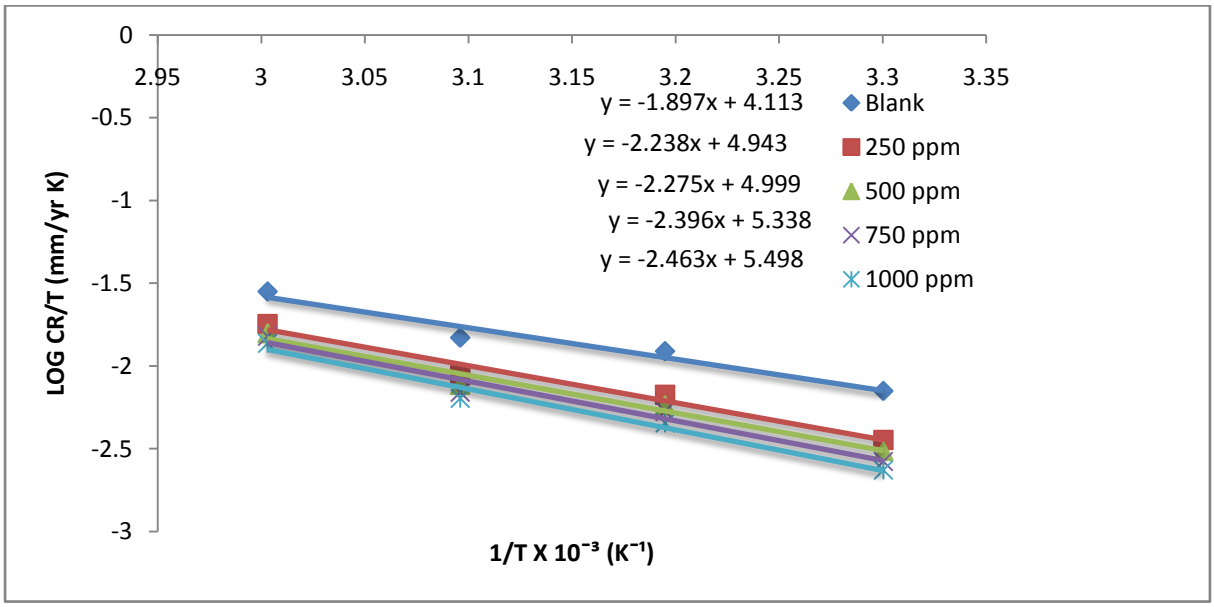


Fig. 4.41: Plots of log (CR/T) versus 1/T for the corrosion for Low Carbon Steel in 0.5M HCl in the absence and presence of various concentrations of almond extract

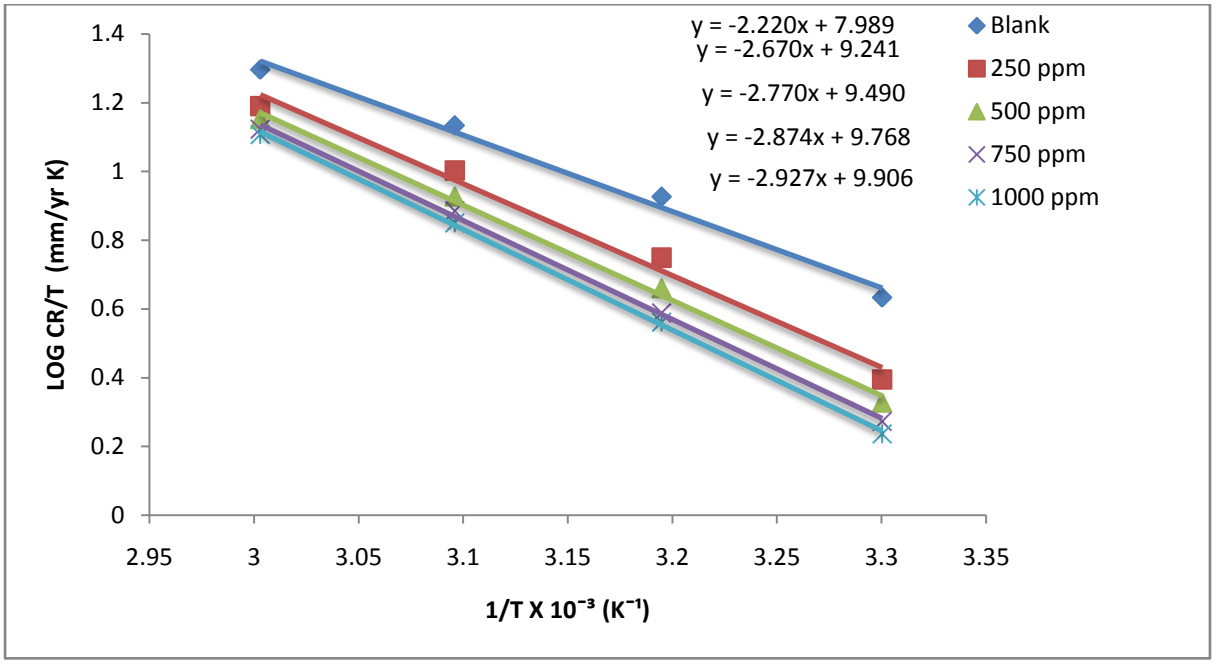


Fig. 4.42: Plots of log (CR/T)versus 1/T for the corrosion for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of guavaextract

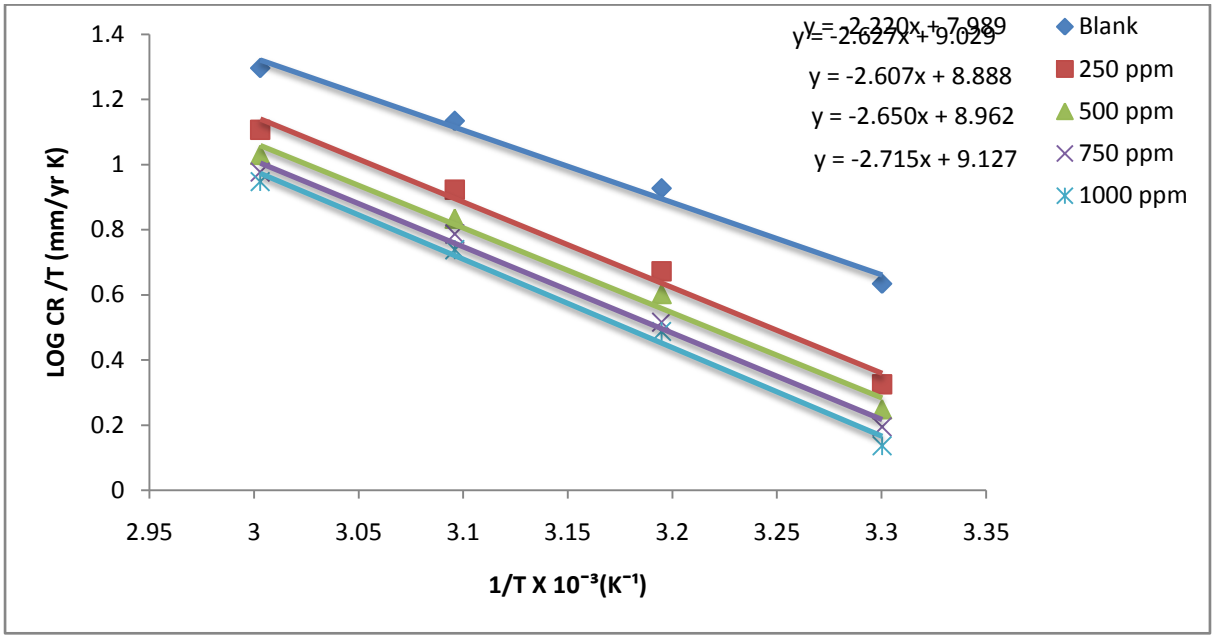


Fig. 4.43: Plots of log (CR/T) versus 1/T for the corrosion for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of bananaextract

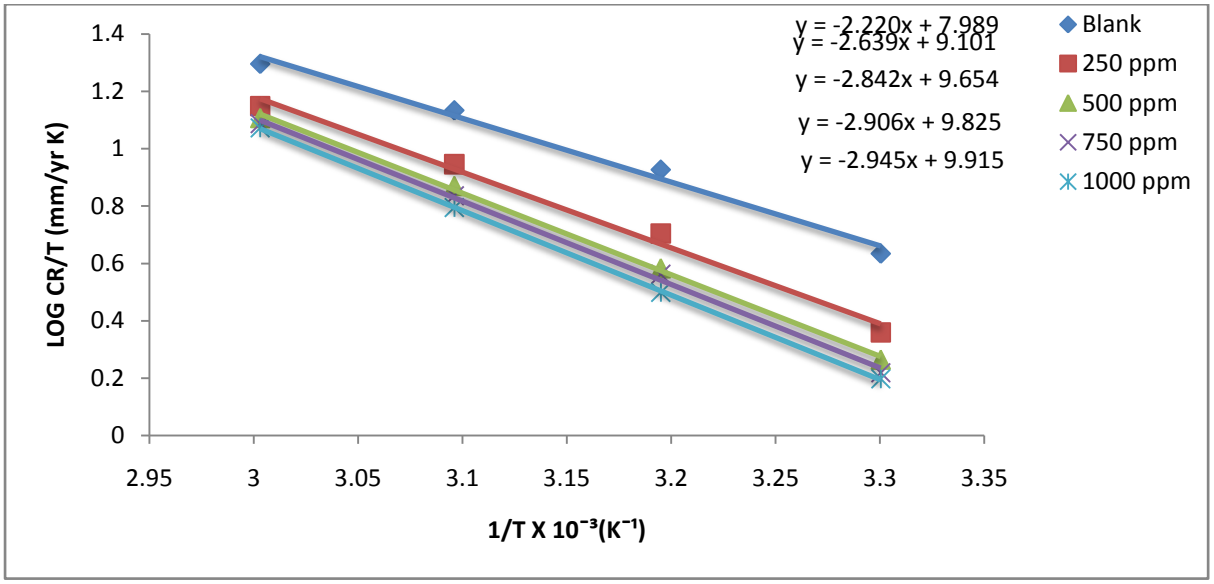


Fig. 4.44: Plots of log (CR/T) versus 1/T for the corrosion for Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of almond extract

Figure 4.45 – 4.50 are plots used in the determination of the constant equilibrium of adsorption K_{ads}which are used to evaluate the free Gibb's energy of the system.

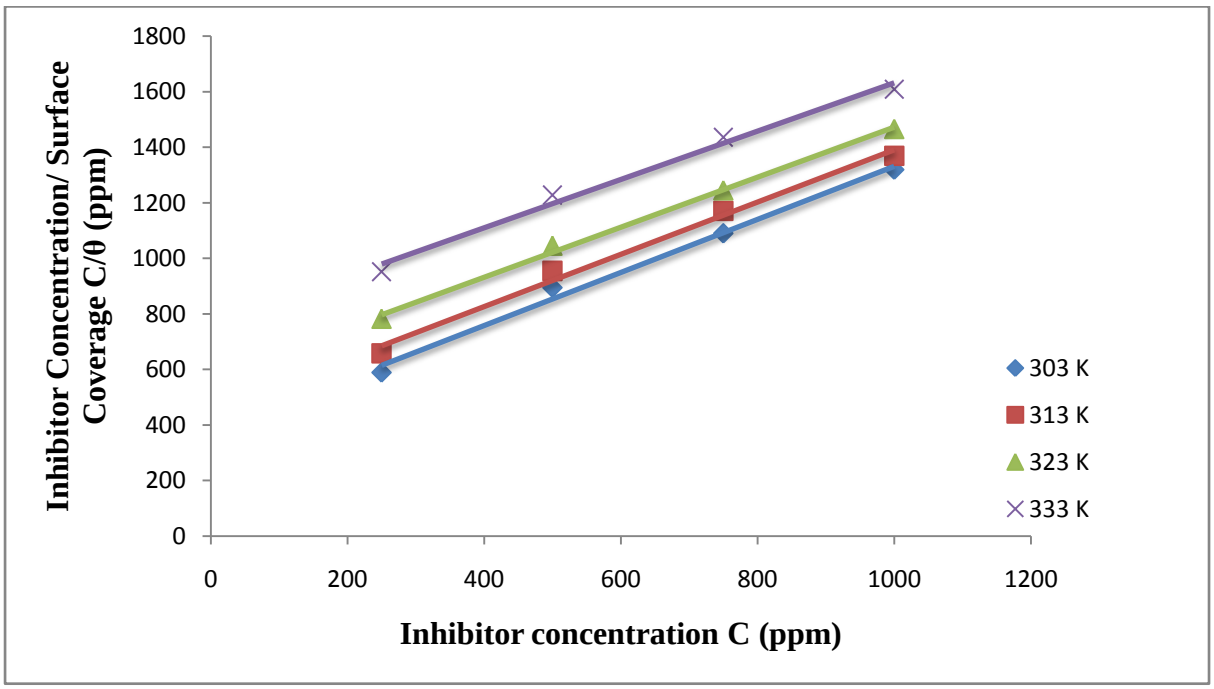


Fig. 4.45: Plots of (C/θ) versus C for the corrosion for Low Carbon Steel in 0.5M HCl of various concentration of guava extract at different temperatures

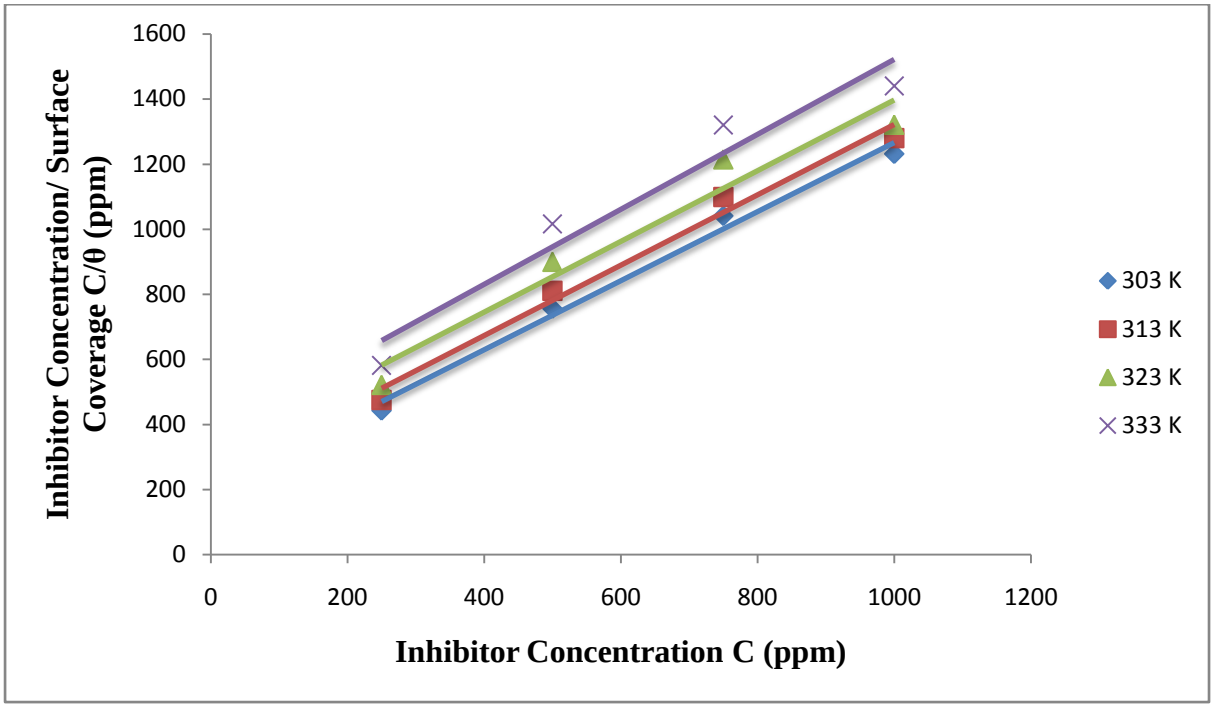


Fig. 4.46: Plots of (C/θ) versus C for the corrosion for Low Carbon Steelin 0.5M HCl ofvarious concentration of banana extractat different temperatures

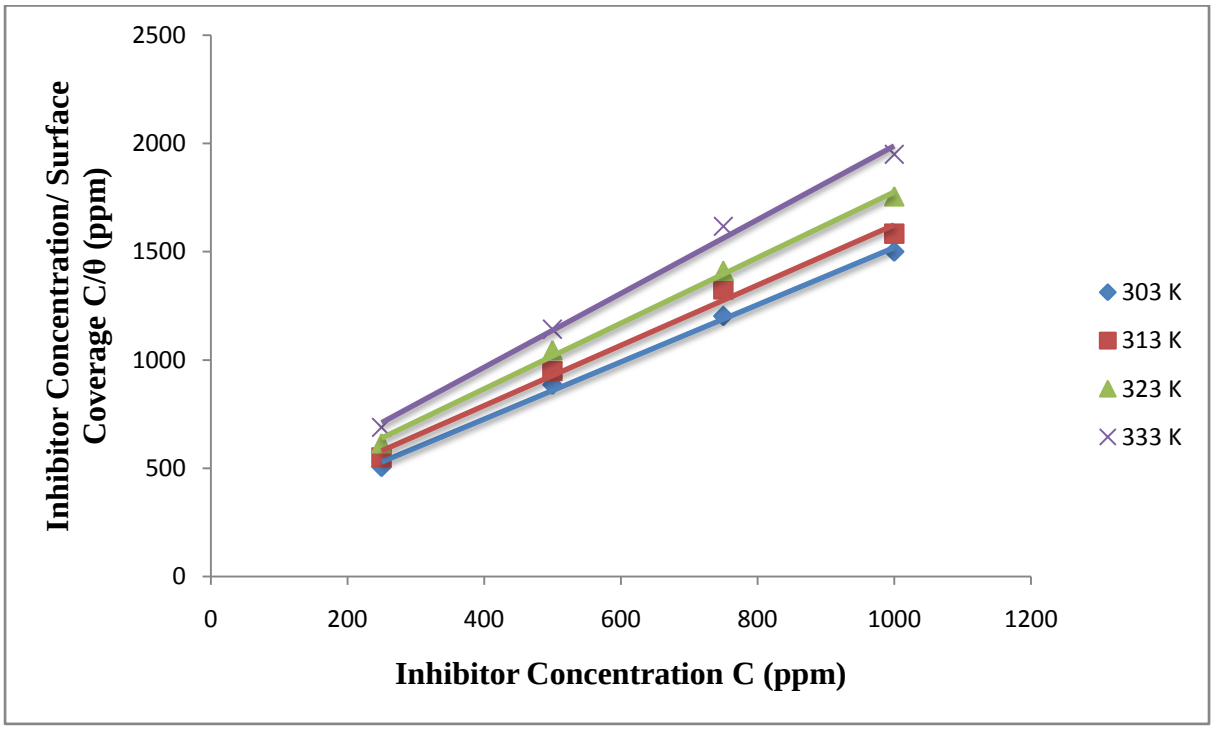


Fig. 4.47: Plots of (C/θ) versus C for the corrosion for Low Carbon Steel in 0.5M HClof various concentration of almond extract at different temperatures.

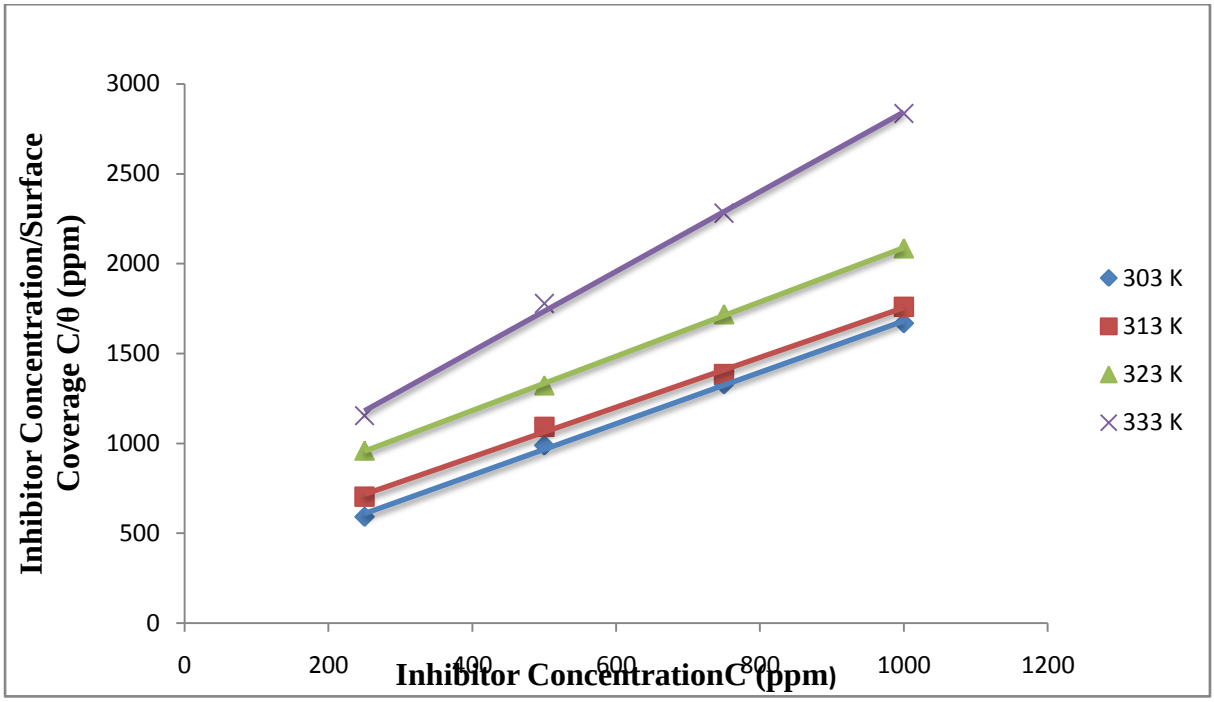


Fig. 4.48: Plots of (C/θ) versus C for the corrosion for Low Carbon Steel in 0.5M H_2SO_4 ofvarious concentration of guava extract at different temperatures.

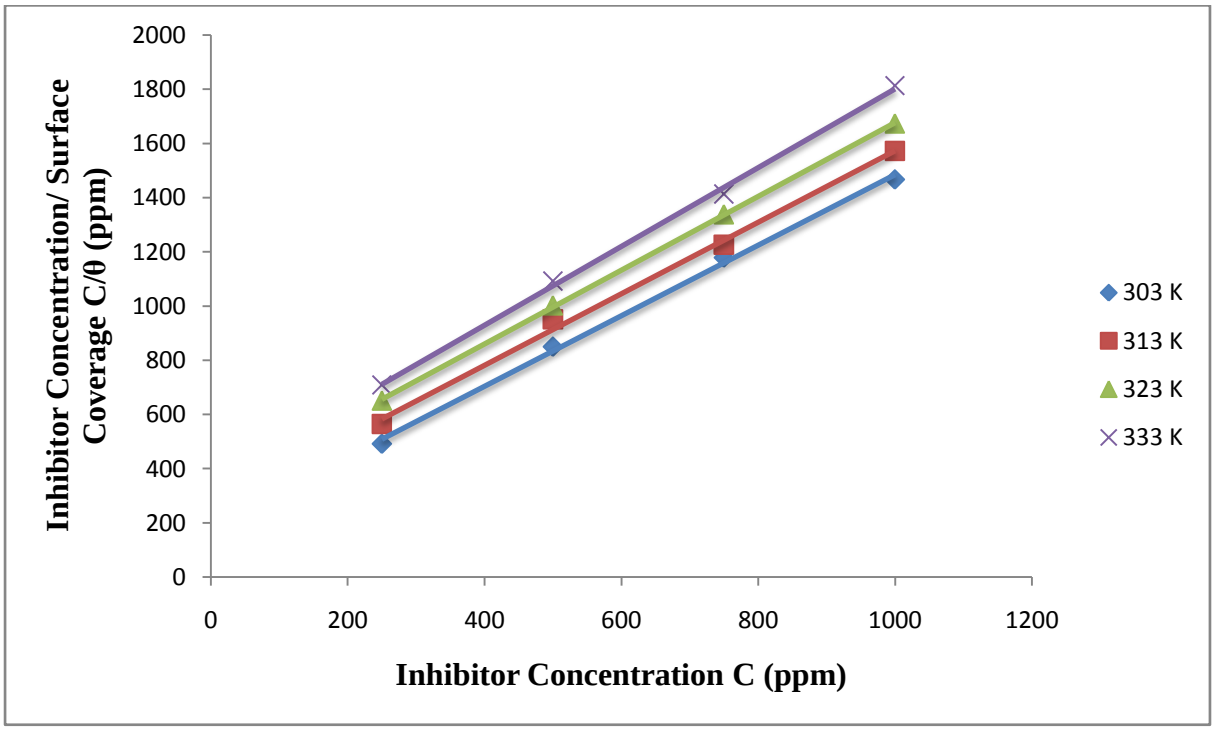


Fig. 4.49: Plots of (C/θ) versus C for the corrosion for Low Carbon Steel in 0.5M H_2SO_4 of various concentration of banana extractat different temperatures

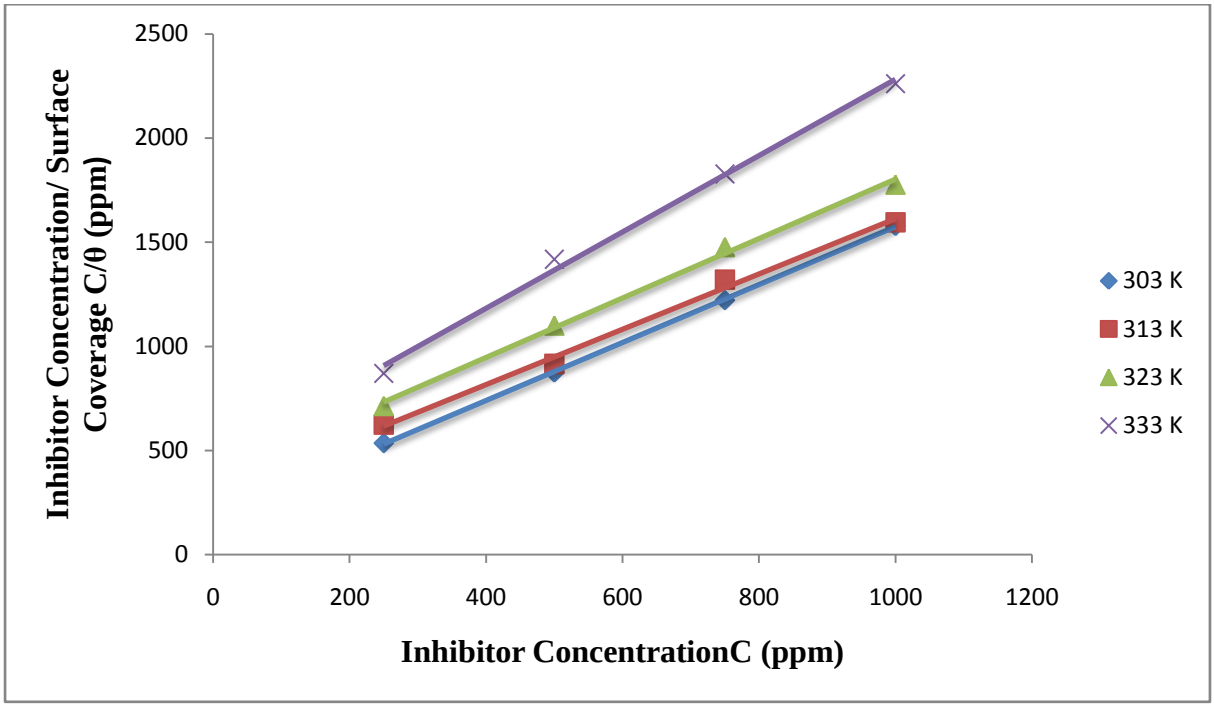
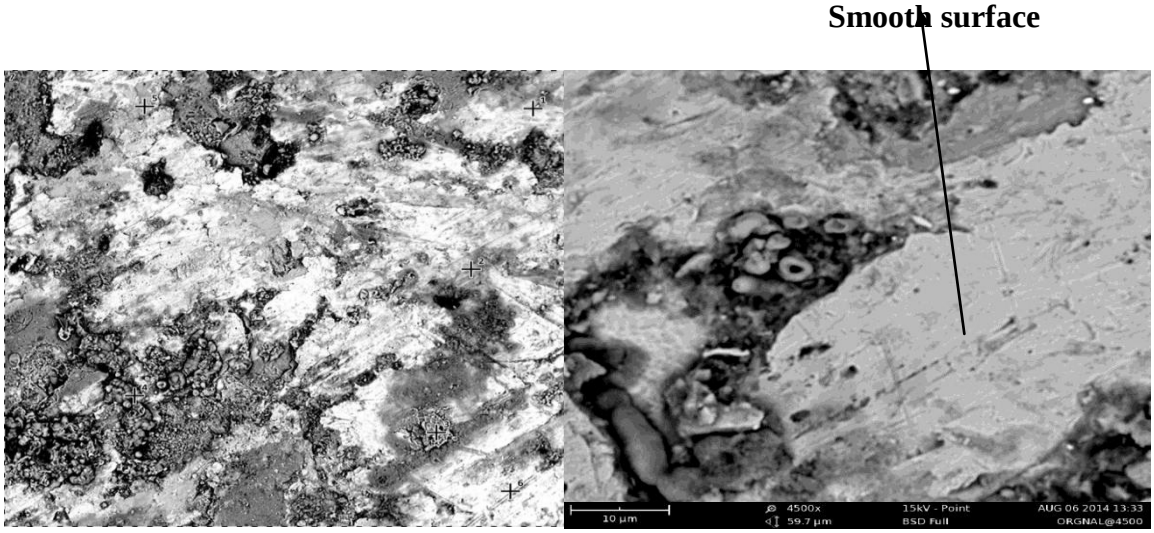
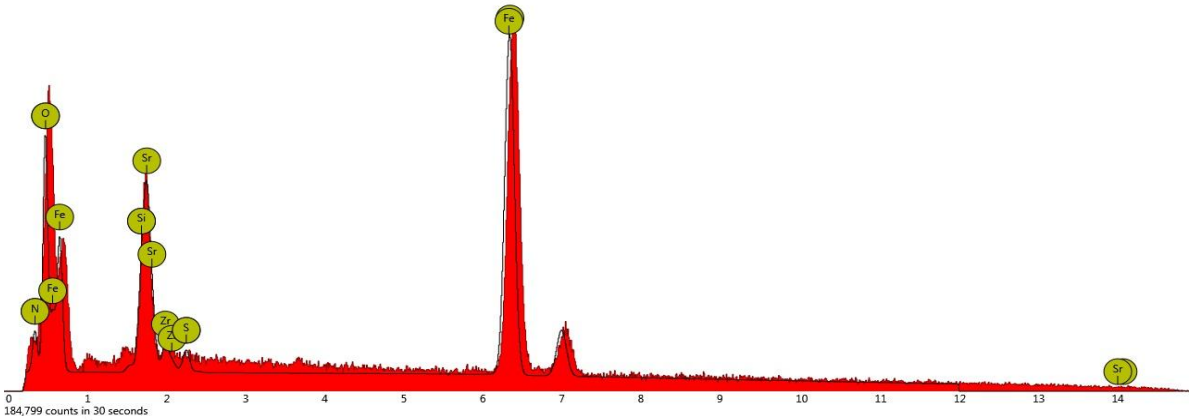


Fig. 4.50: Plots of (C/θ) versus C for the corrosion Low Carbon Steel in 0.5M H_2SO_4 of various concentration of almond extract at different temperatures

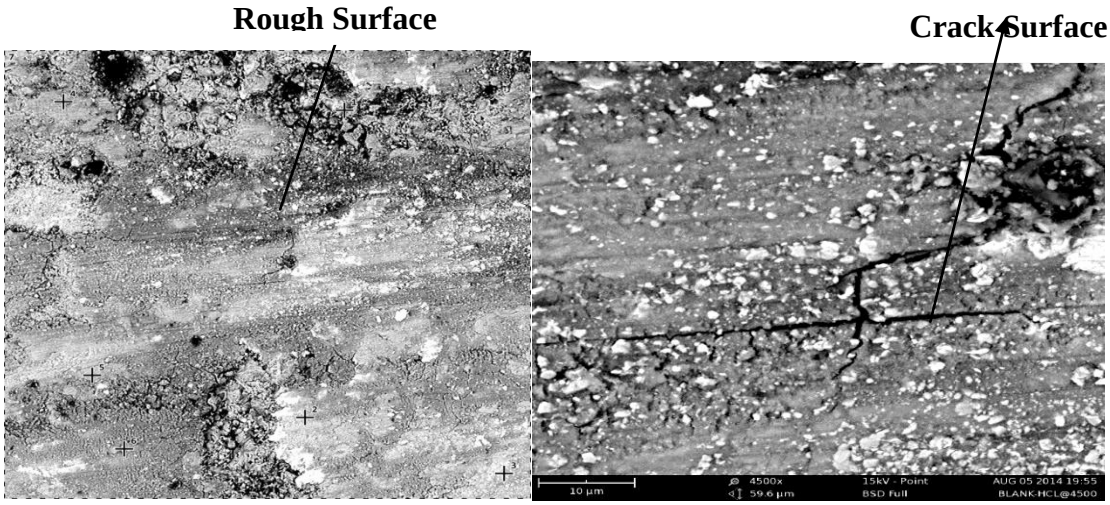
Plate XV - XXIII are Scannedmicrographs surface of the coupons which were taken before and after their immersion into the corrosive media of both HCl and H_2SO_4in the presence and absence of the plants extract for examination of the surfaces after 24 days of immersion. Along with the micrograph are the Energy Dispersive Spectrometer (EDS) and Element Identification (EID)which shows the element presence in on the coupon and their modes of distribution.





	Weight percentage	Certainty
O	38.0 %	98.7 %
Fe	36.5 %	99.2 %
Sr	13.3 %	98.7 %
N	4.4 %	96.2 %
Si	3.3 %	97.4 %
Zr	3.3 %	95.9 %
S	1.1 %	95.0 %

PlateVX: 100µm and 10µm SEM micrograph surface with EDS and EID of a Low Carbon Steel



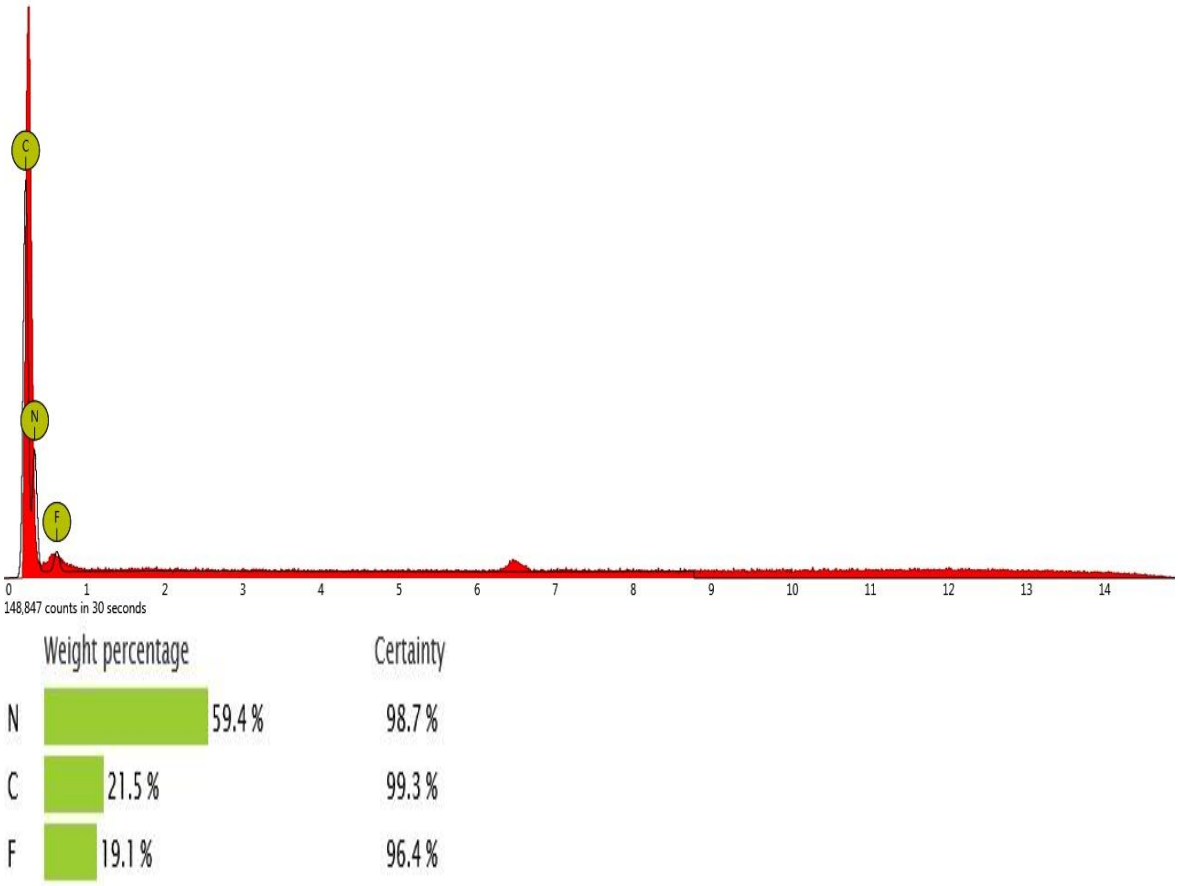
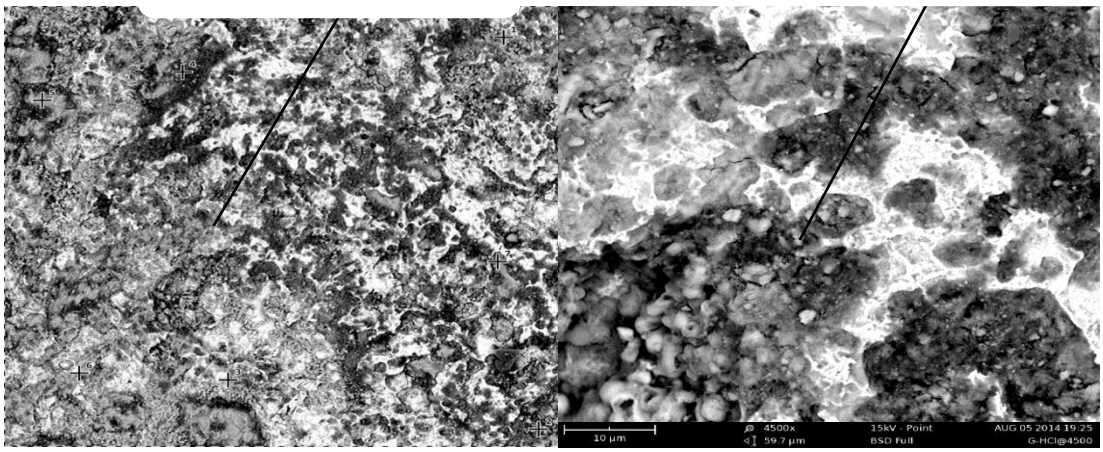


Plate XVI: 100µm and 10µm of SEM micrograph surface with EDS and EID of a Low Carbon Steel in 0.5 M HCl in the absence of extract for 24 days

Thin Protective layer **Fibre-like protective layer**



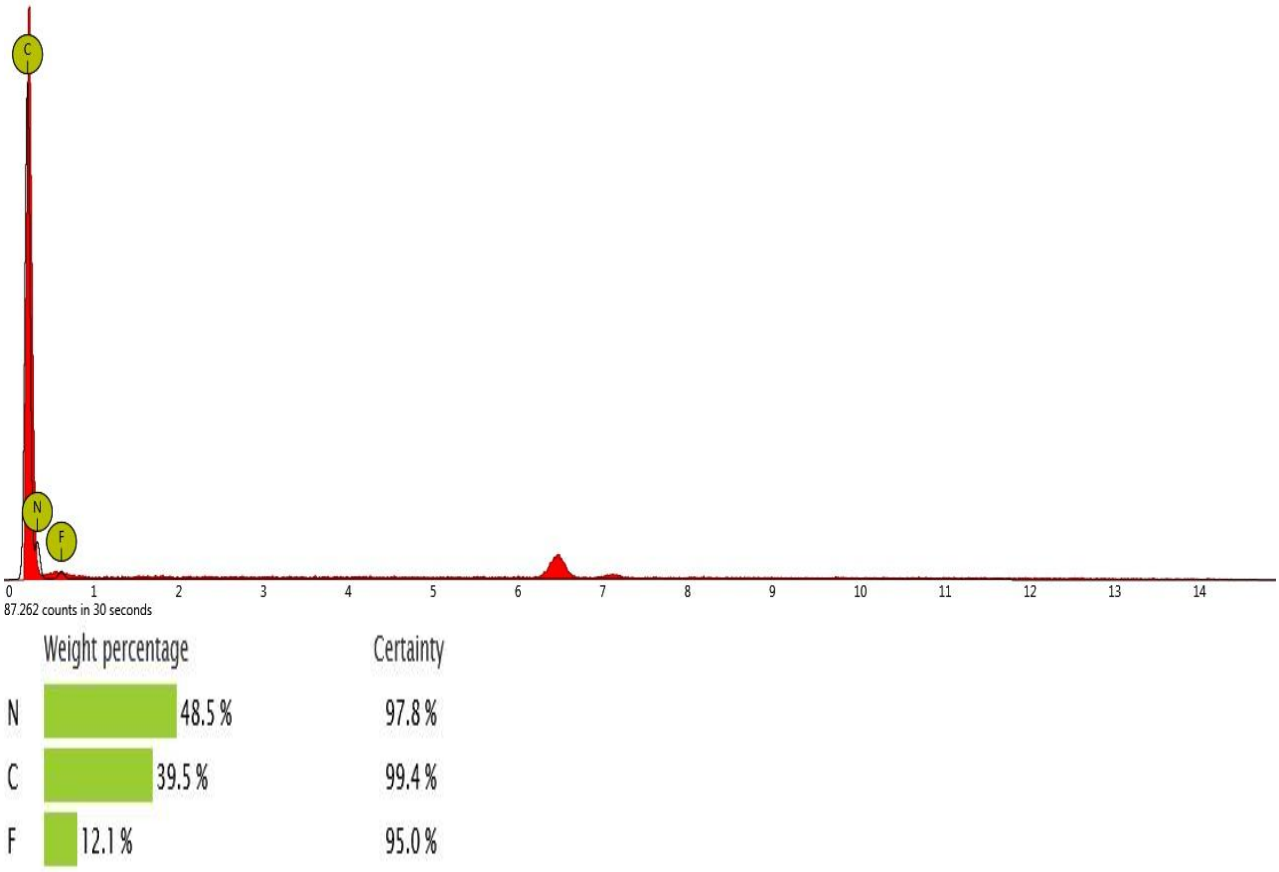
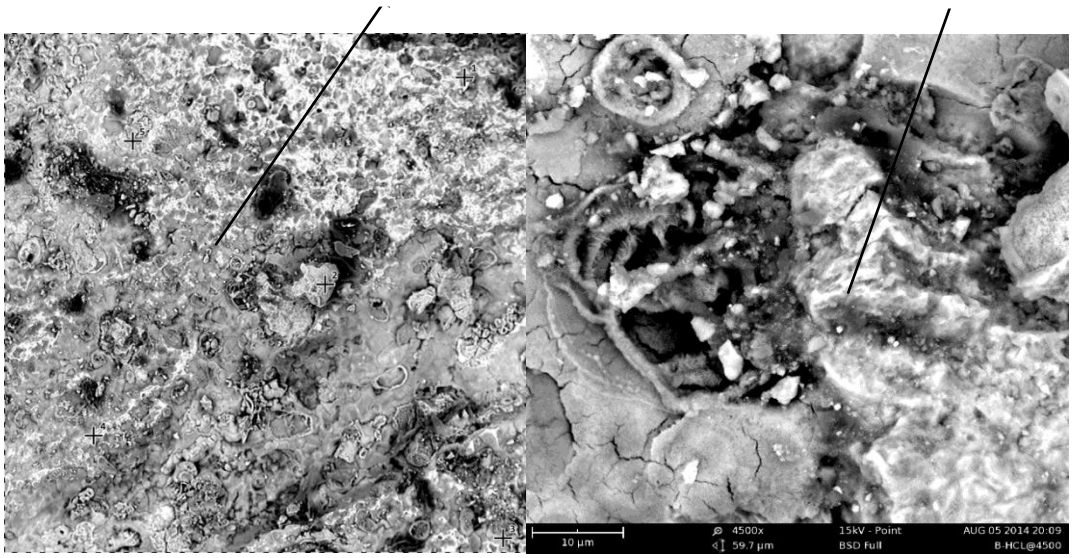


Plate XVII: : 100µm and 10µm of SEM micrograph with EDS and EID of a Low Carbon Steel in 0.5M HCl in the presence of 1000ppm guava extract for 24 days

Thin Protective layer **Fibre-like Protective layer**



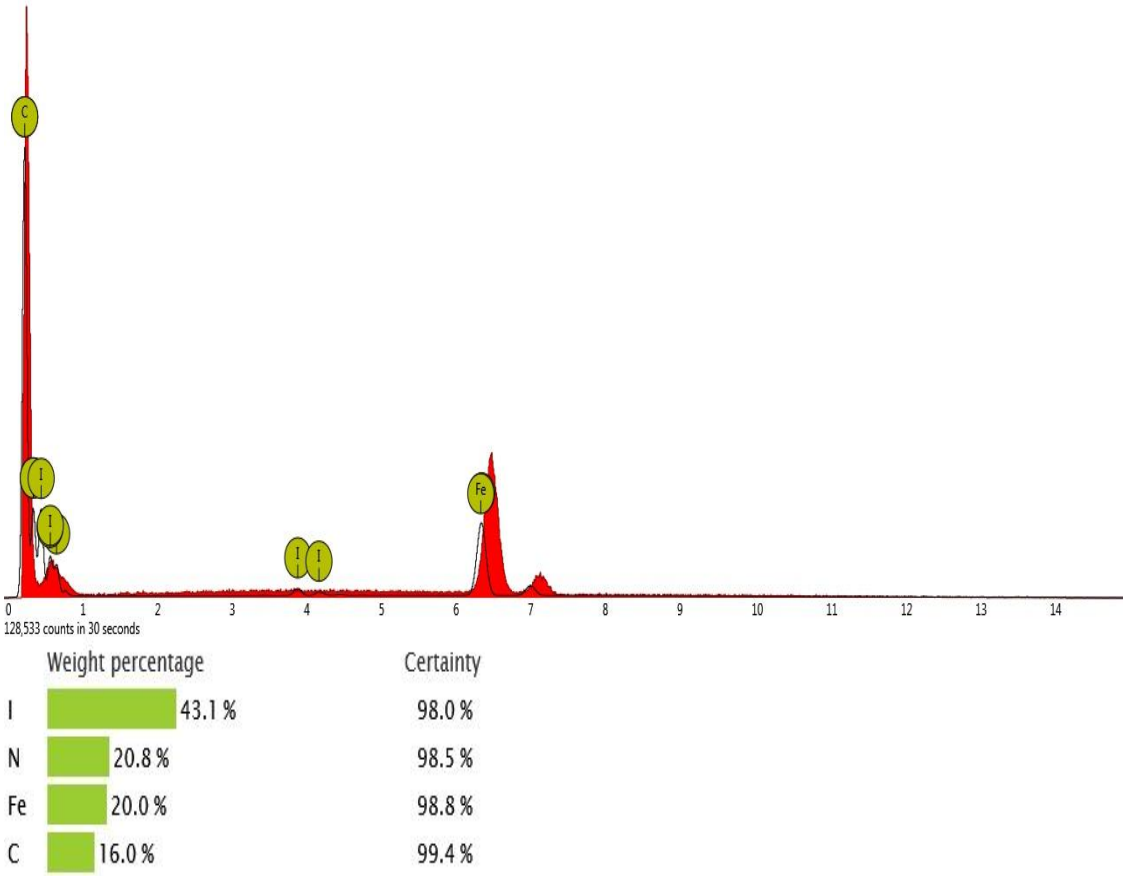
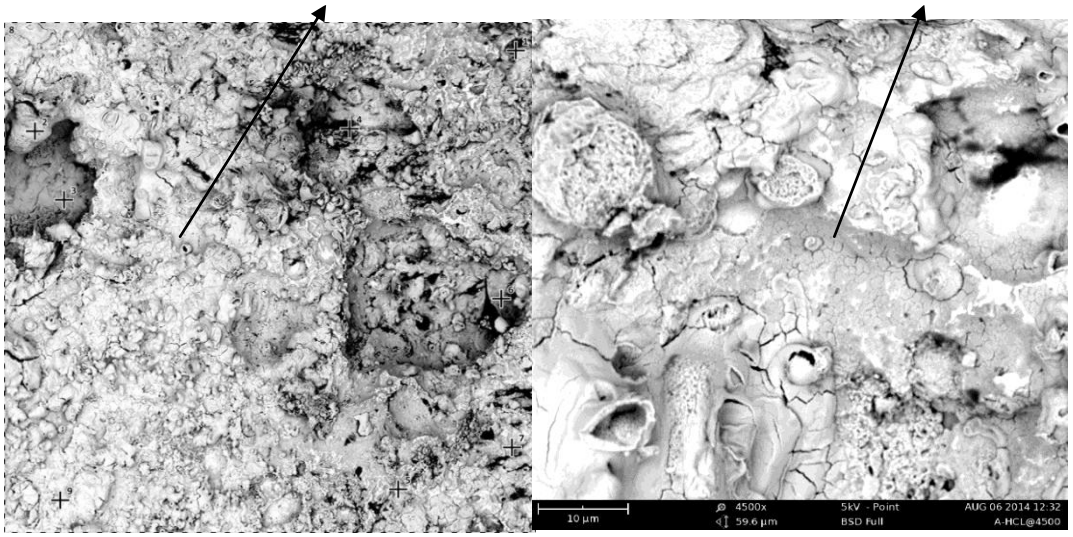
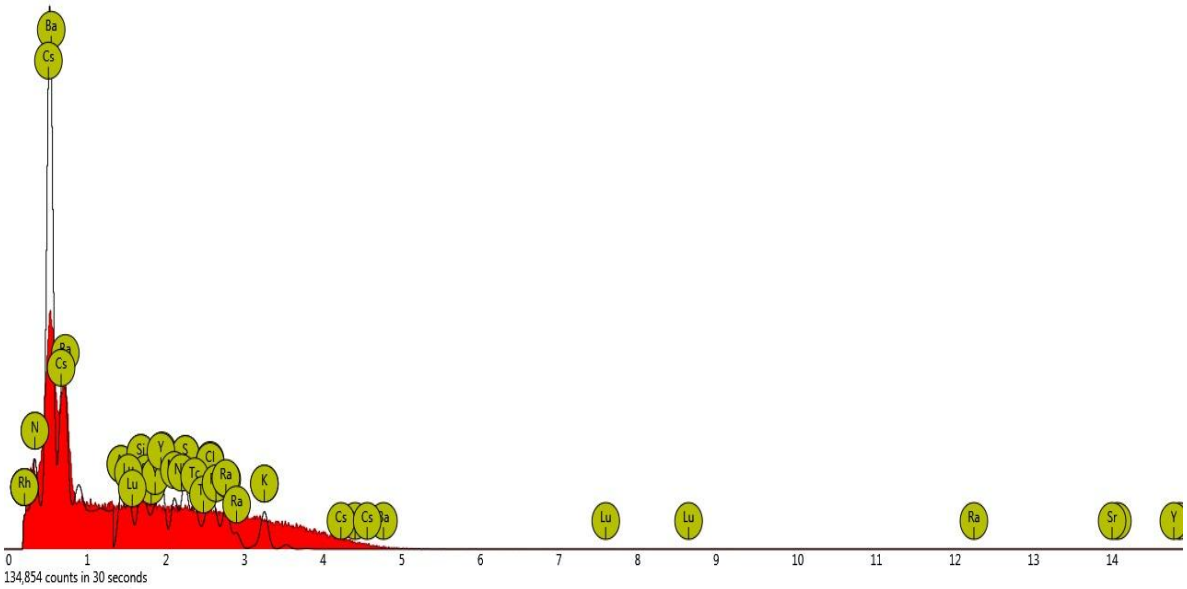


Plate XVIII: : 100µm and 10µm of SEM micrograph with EDS and EID of a Low Carbon Steel in 0.5 M HCl in the presence of 1000ppm banana extractfor 24 days

Thin protective layer **Sheet like protective layer**



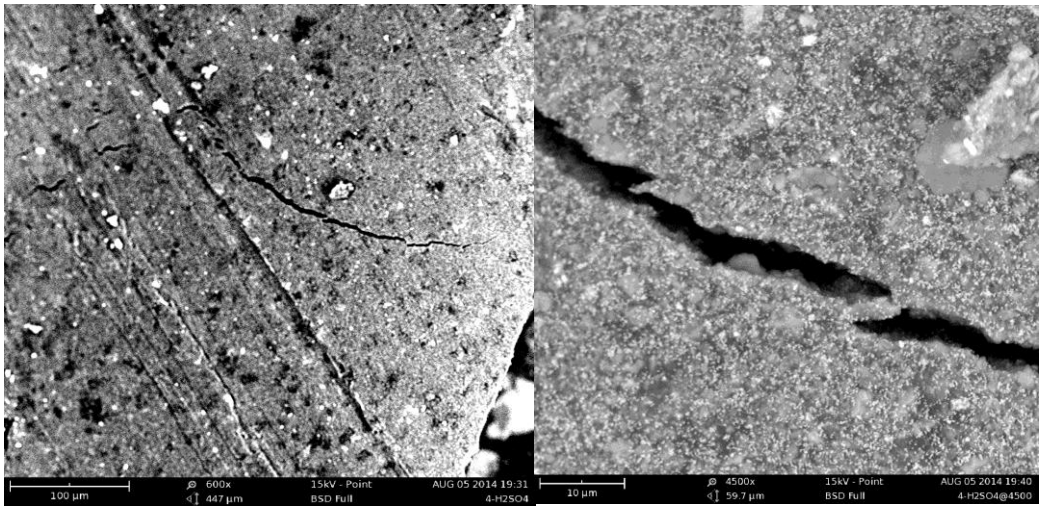


	Weight percentage	Certainty
Ba	25.8 %	98.3 %
Ra	13.8 %	97.7 %
Cs	13.5 %	97.8 %
Nb	6.1 %	98.1 %
K	5.6 %	97.9 %
Tc	5.6 %	97.9 %
Lu	5.0 %	98.0 %
Rh	4.5 %	97.2 %
Cl	3.6 %	98.1 %
Y	3.2 %	97.3 %
S	2.8 %	98.2 %
Sr	2.4 %	97.6 %
P	2.3 %	98.1 %
N	2.2 %	97.0 %
Si	1.9 %	98.2 %
Al	1.8 %	98.1 %

Plate XIX: : 100µm and 10µm ofSEM micrograph surface with EDS and EID of aLow Carbon Steel in 0.5 M HCl in the presence of 1000ppm almond extract for 24 days

Cracks and pits

Large Cavity



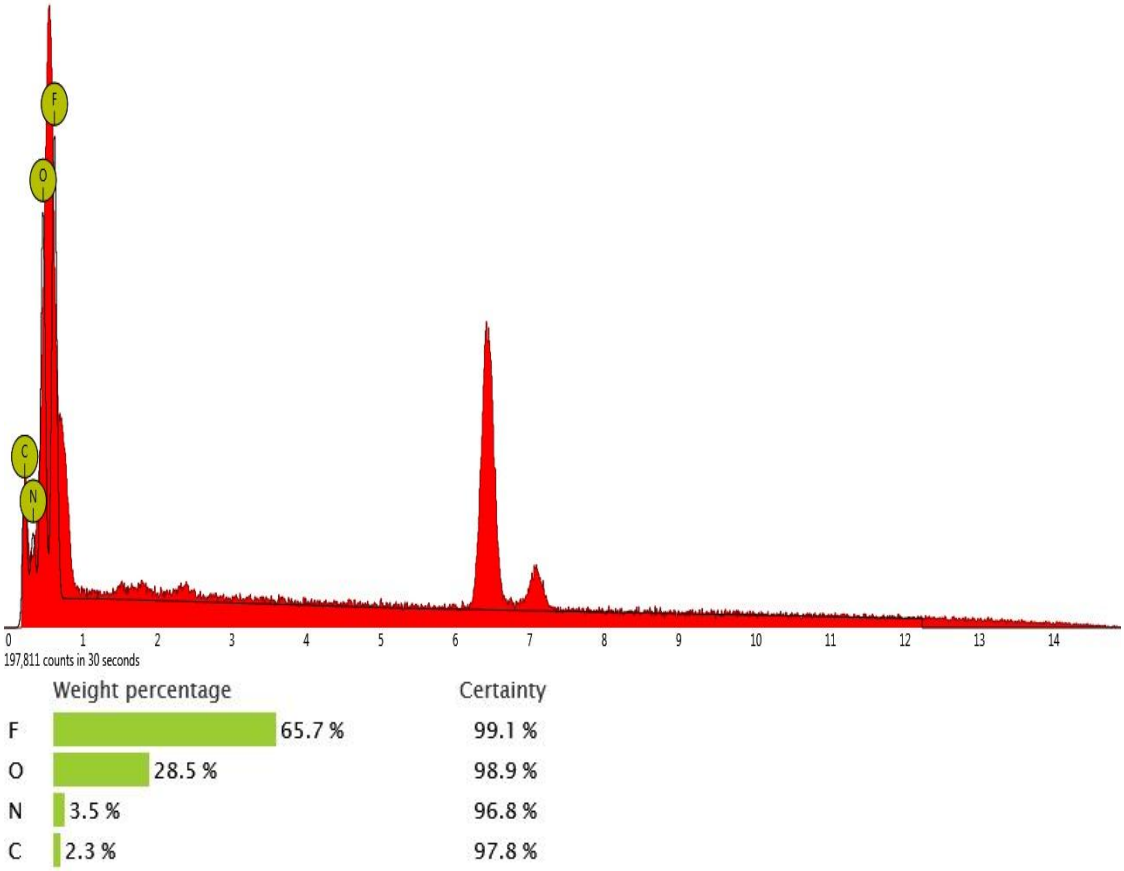
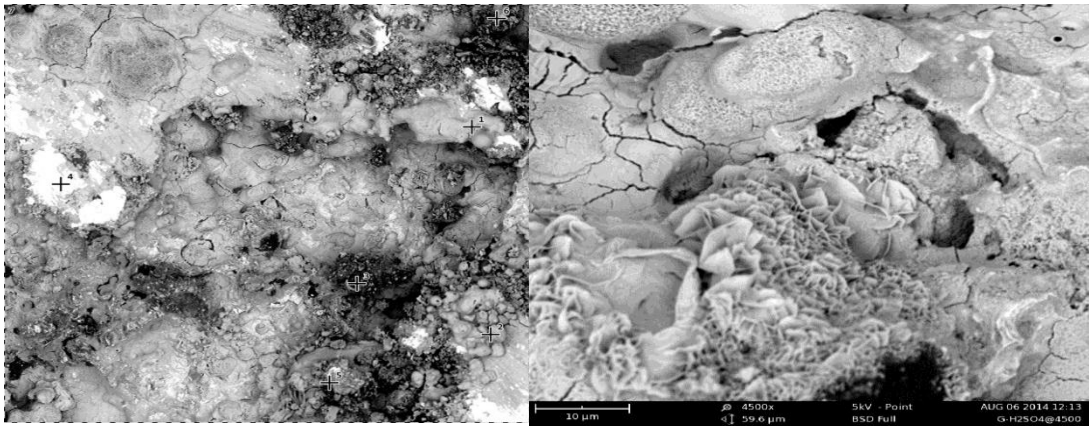
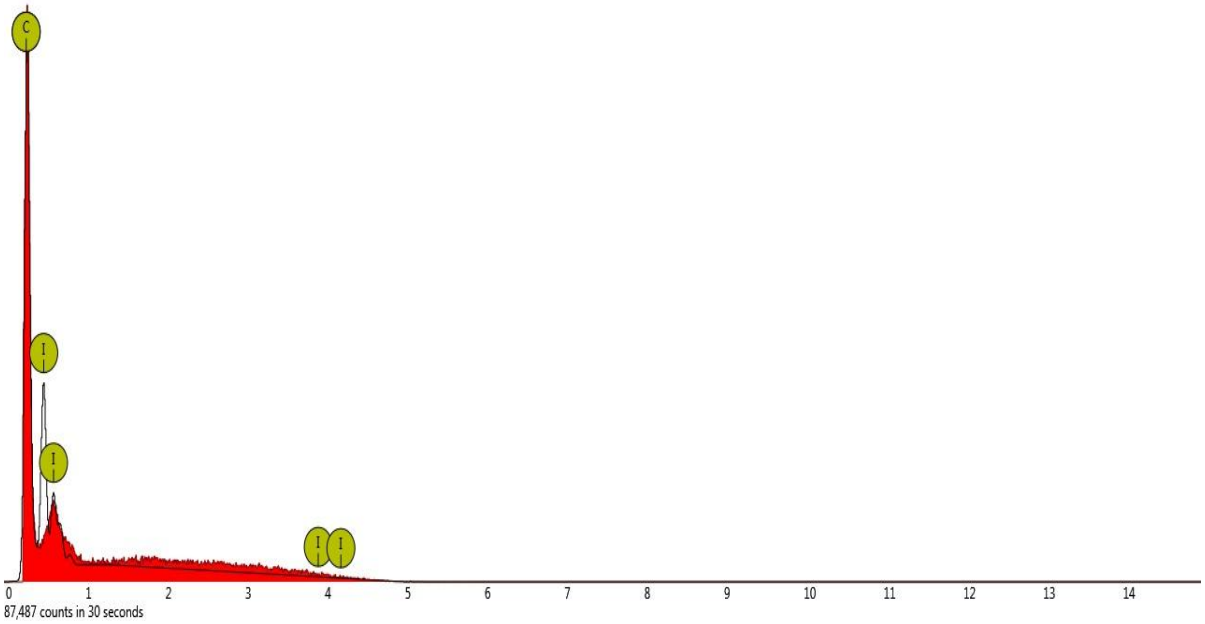


Plate XX: 100µm and 10µm of SEM micrograph surface with EDS and EID of a Low Carbon Steelin 0.5 M H_2SO_4 in the absence of extract

Thin protective layer

Fibre- like protective layer



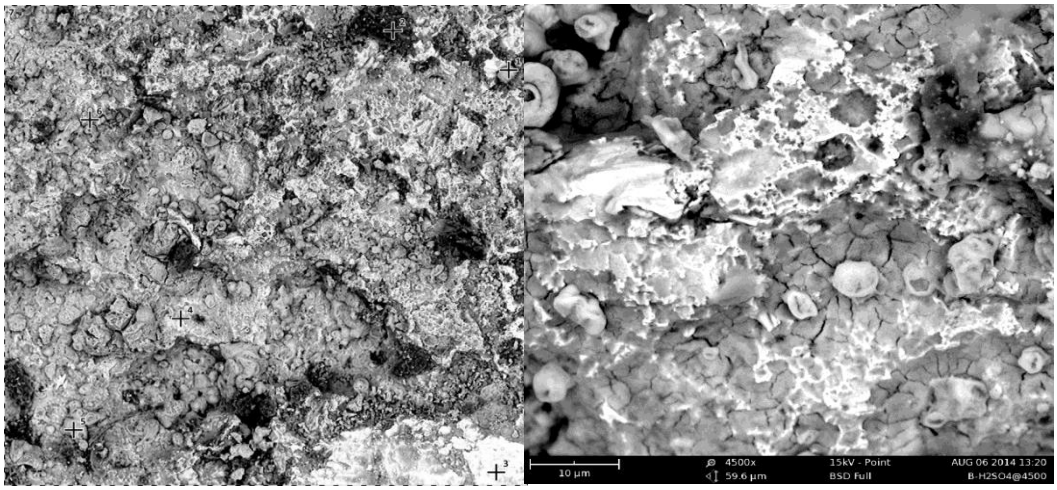


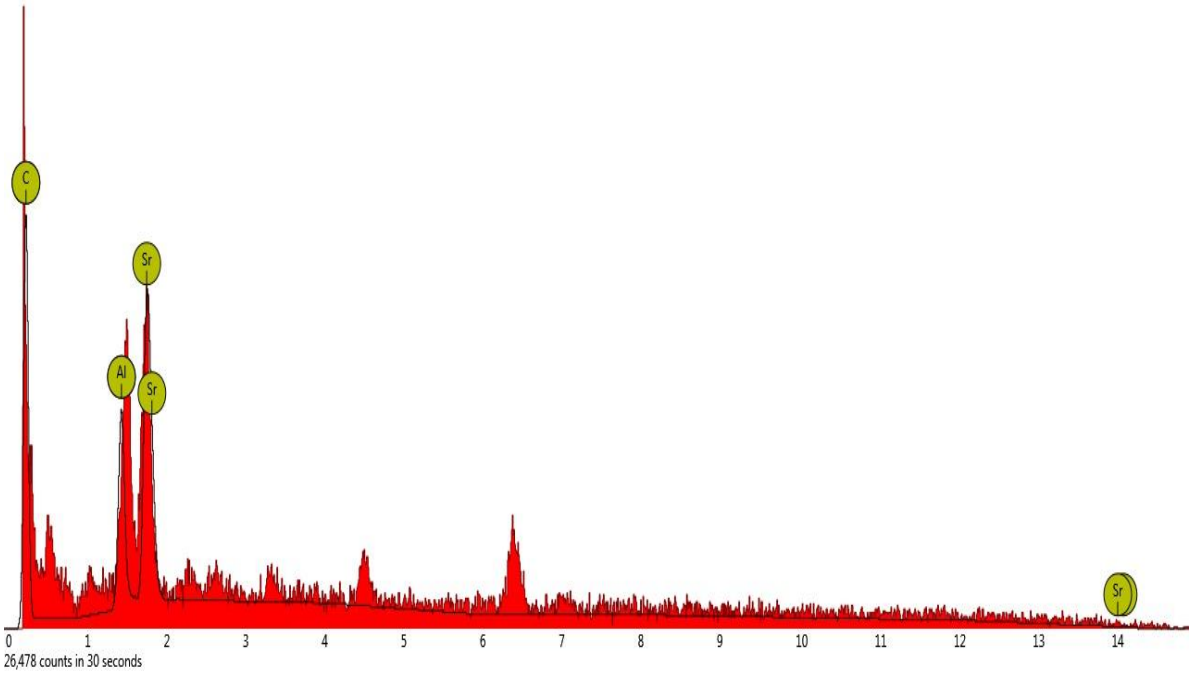
	Weight percentage	Certainty
I	82.2 %	98.1 %
C	17.8 %	99.3 %

Plate XXI: : 100µm and 10µm of SEM micrographsurface with EDS and EID of Low Carbon Steel in 0.5 M H_2SO_4 in the presence of 1000ppm guava extractfor 24 days

Thin film protective layer

Fibre – like protective layer

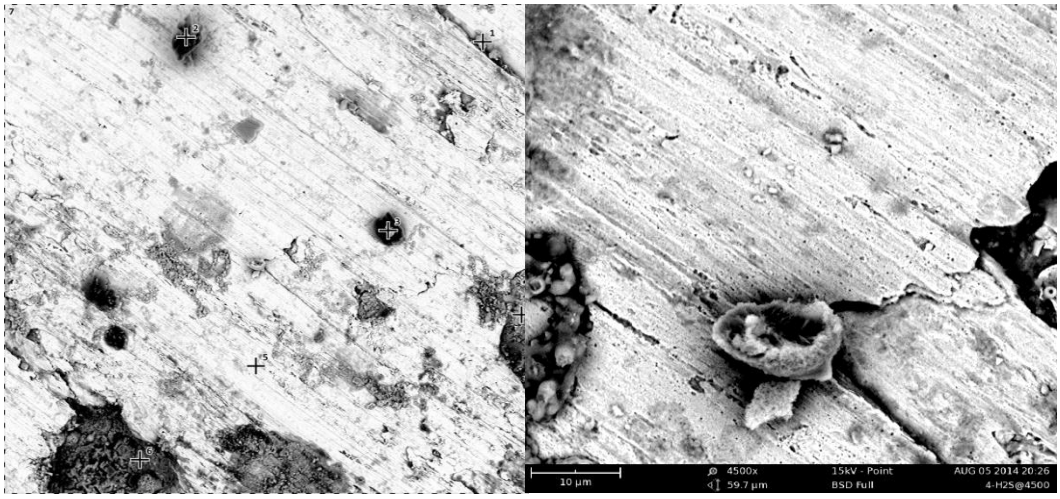


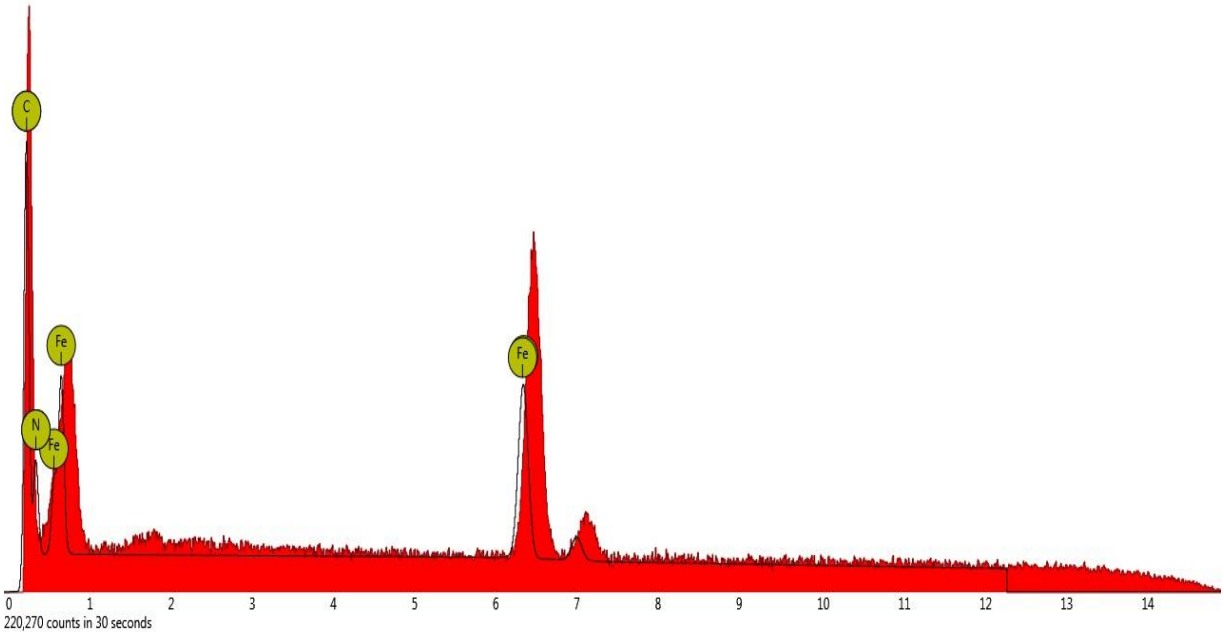


	Weight percentage	Certainty
Sr	43.9 %	97.2 %
C	43.3 %	97.2 %
Al	12.8 %	96.3 %

Plate XXII: (a) : 100µm and 10µm of SEM micrographsurface with EDS and EID a Low Carbon Steel in 0.5 M H_2SO_4 in the presence of 1000ppm banana extract

Smooth surface **Smooth surface** **Rough surface**





	Weight percentage	Certainty
N	43.6 %	98.3 %
C	30.8 %	99.4 %
O	18.3 %	95.4 %
Fe	7.3 %	97.2 %

Plate XXIII: 100µm and 10µmof SEM micrographsurface with EDS and EID of a Low Carbon Steel in 0.5 M H_2SO_4 in the presence of 1000ppm almond extract.

4.2 Discussion of Results

4.2.1 Phytochemical

Table 4.2show the result obtained from the phytochemical analysis that was carried out on the plants extract. The results show that guava and almond extract contentthe following chemical constituents; Alkaloids, Cardiac Glycosides, Saponins, Flavonoids, Tannins, Anthraquinones, Carbohydrates, Steroid and Triterpenes while the banana leaves extract has all the chemical constituents with the exception of Flavonoids. The presenceof the chemical compound like the Tannins, Flavonoids, Alkaloids, Cardiac Glycosides, Sponins in the plant resulted in low corrosion rate in the acid media when compared with the blank media. The presence of functional groups like Oxygen (O), Nitrogen (N) and Sulphur in molecules of the plant extracts serve as the active centres for the adsorption of the inhibitor on the metal surface as a result of their higher basicity and electron density. The availability of non-bonded (lone pair) and p-electrons in the functional groups of the inhibitor molecules facilitates electron transfer from inhibitor to the surface of the metal. The above findings are in agreement with Yawas(2005), Oki et al (2011), Nwabanne and Okafor (2011) and Rani and Basu(2012).

4.2.2 Physico-chemical Analysis

Table 4.3show the result obtained from the physico-chemical analysis that was carried out on the plants extract.The results show that guava, banana and almond extract content some percentage of tannin.These tannins have an array of hydroxyl and carboxyl groups through which the active molecules of the extract are adsorb on metallic surfaces and they serve as a barrier between the metal surface and the corrosive medium thereby resulting to low corrosion rate on the metal surface. The plants extract also content some high level of organic acid as show in table 4.3, the hydrogen atoms of the organic acid react with the hydroxyl group from the corrosive media thereby preventing them from coming in contact with the metallic surface. Theseaction resulted to a lower corrosion rate on the metallic surface in media

containing plant extractwhen compare with the blank media. This is in agreement with the finding of Saratha, et al.(2009) and Oki, et al. (2011).

4.2.3 Weight Loss

Tables 1-26 in appendixshow the corrosion rate (mm/yr) for steel specimen immersed in 0.5M HCl and H_2SO_4 for 24 days at 3 days intervals for each of the eight samples as a function of exposure time at room temperature ranging from 27 - 32℃. The results shows that the corrosion rate decreased as the days increased from 3 days – 24 days for the different concentration of extracts from 250 – 1000ppm. This behavior is attributed to higher adsorption level of active inhibitor molecules from the extract on the metal surface forming a thin film on the metal surface to prevent further attack from the corrosive environment thereby reducing weight loss by specimen, which is in agreement with the findings of Yawas(2005), Nwabanne and Okafor(2011) and Kairi and Kassin(2013).

4.2.4 Effect of Inhibitor Concentration

Figures 4.18-4.19show the graphs of percentage inhibition efficiency againstinhibitor concentration for the corrosion of a low carbon steel in both 0.5M HCl and H_2SO_4 acid solutions at ambient temperature. It is evident that increase in concentration of the inhibitors in the acidic media resulted to adsorption of more active ions from the plant extract on the surface of the specimen and less contact of the specimen with the acidic environment which lead toincrease in percentage inhibition efficiency and the reduction in weight loss of specimen.These suggest that the higher the concentration of guava, almond and bananaextract in HCl and H_2SO_4 acid solution, the higherwill be the inhibition efficiency of low carbon steel in HCl and H_2SO_4 acid media. This is in agreement with theresult obtained by Yawas(2005) and Nwabanne and Okafor(2011).

Figures 4.20-4.22 and 4.27- 4.29 show the graphs of percentage inhibition efficiency against inhibitor concentration for the corrosion of a low carbon steel in both 0.5M HCl

and H_2SO_4 acid solutions at various temperature (313-333K). The results show that inhibitive efficiency for each of the plant extracts at a fixed concentration decreases with increase in temperature. This also suggest that the rate of corrosion of low carbon steel in both HCl and H_2SO_4 solutions increases with temperature and the percentage inhibition efficiency of the inhibitors for the low carbon steel decreases with increasing temperature, a trend that supports the mechanism of physical adsorption. This is a pointed to fact that the protective films of the inhibitors formed on the surface of the specimen of the low carbon steel are less stable at higher temperature.

4.2.5 Effect of Temperature

The figures 4.23-4.26, 4.30 - 4.33 show the graphs of inhibition efficiency against temperature (303, 313, 323 and 333K) for a fixed immersion of 4 hours in 0.5M HCl and H_2SO_4.The results show that the rate of percentage inhibition efficiency of inhibitors (at different concentration) decreaseswith increases temperature, a trend that supports the mechanism of physical adsorption. This could lead to the conclusion that the protective films of the inhibitors formed on the surface of the specimen of the low carbon steel are less stable at higher temperature. Which may be due todesorption of some adsorbed molecules from the surface of the low carbon steel at higher temperature leading to the greater area of steel been exposed to attack from the acidic environment. This is similar to the result obtained by Abd El-Hameed(2011).

4.2.6 Kinetic Parameter of Activation

Figures4.34 – 4.39 show a plot of logarithm of corrosion rate CR against the inverse (reciprocal) of the absolute temperature which gave a linear graphs with slope equal to $-E_a/2.303R$ and the intercept equal to log A. Hence the activation energy (E_a) and the pre-exponential factors A were calculated and tabulated in tables 4.35 – 4.41 at appendix ii. These value were found to range from 46.0 kJ/mol—51.251 kJ/mol, 48.044

kJ/mol—51.648 kJ/mol and 45.509 kJ/mol – 49.806 kJ/mol for guava, banana and almond extract in HCl and 51.129 – 56.051, 50.303 – 51.996 and 50.547 – 55.088 kJ/mol for guava, banana and almond extract in H_2SO_4 solution respectively. The range of values obtained for the different inhibitors used were higher than that of the blank indicating that the corrosion of low carbon steel is retarded by the presence of plant extracts in HCl and H_2SO_4 media. It can also be observed that the activation energy is lower than the threshold value of 80 kJ/mol (Eddy, 2009) required for the mechanism of chemical adsorption. Therefore, the adsorption of the inhibitors on the low carbon steel surface supports the mechanism of physical adsorption (physisorption). Higher values of $E_a$in the presence of inhibitor are a good indication of the extract increasing the energy barrier for the corrosion process. The trend of this result is in agreement with the findings of Eddy(2009).

Figures 4.40 – 4.45 show a plot of log CR/T against reciprocal of absolute temperature from alternative formulation of Arrhenius equation (transition state equation) which gave a straight line in form of a linear graph with slope equal to $-\Delta H_a/2.303R$ and the intercept equal $[\log(R/Nh)+\Delta S_a/2.303R]$. The enthalpy of activation ($-\Delta H_a$) and the entropy of activation (ΔS_a) were calculated and tabulated with the linear regression inhibition as shown table 33 — 38at appendix ii, for the three inhibitor in the two different media (HCl and H_2SO_4).The large positive value of ΔH_a and the negative value of ΔS_a recorded in table indicate that the adsorption of inhibitors on the surface of low carbon steel is endothermic in nature.

It can also be seen from the table that E_a and ΔH_a values vary in the same way with inhibitor concentration. This result helps to verify the known thermodynamic relation between E_a and ΔH_a. The calculated values of E_a - ΔH_ain table 4.35 – 4.40 are close to RT is 2.67 kJ/mol. This result shows the inhibitor acted equally on E_a and ΔH_a.The trend of this result is in agreement with works ofZarrouk et al.(2011)

4.2.7 Thermodynamic Parameters and Adsorption Isotherm

Figure 4.46 – 4.51 show the linear plots for C/θ against concentration C with the reciprocal of the intercept of Langmuir plotted lines from the graph equal to K_{ads} the adsorptive equilibrium constant representing the degree of absorption. The various values of K_{ads} for the three inhibitors are shown in tables 4.4 - 4.46 at appendix ii. The higher values K_{ads} indicate that inhibitors were strongly adsorbed on metal surface. The slope and linear regression coefficient R^2 of these lines were nearly unity, meaning that each inhibitor molecule occupies one active site on the metal surface (strong adsorption of inhibitors), which is a strong indication of adherence of the adsorption assumption data of Langmuir isotherm.

The Gibbs free energy of adsorption (ΔG_{ads}) was calculated from equation and the values were tabulated as shown in tables 39 – 44 at appendix ii. The negative values of ΔG_{ads} shows that, the adsorption of the inhibitors on the low carbon steel surface is a spontaneous process, which is a sign of a strong interaction of the inhibitor molecule on the surface of low carbon specimen which is in agreement with the findings of Zarrouk et al.(2011).Generally, values of ΔG_{ads} around -20 kJ/mol or lower are constant with the electrostatic interaction between the charged molecules and the charged metal (physisorption). Those more negative than -40 kJ/mol involve charge sharing or transfer from the inhibitor molecules to the metal surface to form a coordinate type of bond (Chemisorption) (Zarrouk et al, 2011).The calculated values of ΔG_{ads} are greater than -20 kJ/mol but less than -40 kJ/mol indicating that the adsorption of mechanism of inhibition on low carbon steel in 0.5M HCl and H_2SO_4 solution at the studied temperatures may be combination of both physisorption and chemisorption (Comprehensive adsorption),which is in agreement with the findings of Zarrouk et al,. (2011).

Generally, the more negative the value of ΔG_{ads} the stronger the strength of adsorption, as observed in this study.

4.2.8 Scanning Electron Microscope (SEM) of Coupons with their Energy dispersive spectrometer (EDS) and Element Identification (EID)

Plate 4.1;depict the morphologies of polished low carbon steel with smooth surface. SEM micrographs obtained from low carbon steel surface after 24 days of immersion in 0.5M HCl and H_2SO_4 for the untreated and treated low carbon steel in 1000ppm extract of guava, banana andalmond are shown in plates xv – xix and xx – xxiiirespectively.It can be clearly observed that the low carbon steel surface morphologies of those immersed in the acidic media without inhibitor were badly attack with evident of pits and cracks by the corrosive environment when compare to those immersed in the media containing inhibitors. It can be conclude that the extract of guava, banana and almond leaves which served as inhibitor at a concentration of 1000ppm were able to lower the corrosion rate by the acidic environment as a result of the formation of films layer on the metal surface which is in agreement with the findings of Abd El-Hameed et al. (2011).

The EDS analysis and EID with their quantification of the low carbon steel were taken at few different spots. Both corrosive media of 0.5M HCl and H_2SO_4 with their extract containing nitrogen N, carbon C, and oxygen O , fluorine F, iodine I with the element of others atoms and their weight percentage on the metal surface can be used quantitatively to explain the adsorption of extracts.From plate xvi – xix and xx – xxiii, it is clear that in the presence of the plant extract, the oxygen from the corrosive media were completely suppressed by the inhibitors while the oxygen seen on the EDS and EID of plate 4.9 are oxygen from the plant extract which serve as centre for the adsorption of molecules from the inhibitors on the metal surface by displacing water molecule from the surface of the metal. The results also show that carbon content of the

plant extract reacted with oxygen molecule in the media which brought about the reduction or total suppression of oxygen whileheteroatom of nitrogen in the plant extract serve as a centre for the adsorption of molecules of inhibitor on the metal surface by displacing water molecule from the surface of the metal. It is also observed from figure 4.63 that the O peak is higher in the corrosive media in comparison to the polished and treated low carbon steel specimen. Thus it can be concluded that there is a good protective film adsorbed on the low carbon steel surface which is responsible for the corrosion inhibitive effect. This result is in agreement with the findings of Yawas (2005), Zaabar et al., (2014) and Kairi and Kassim (2012).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusion can be drawn from the result and discussion of this study.

i. **The plants extract was successfully formulated from leaf of guava, almond and banana as corrosion inhibitor.**

ii. **The ethanol extract of guava, banana and almond are good inhibitor for the corrosion of low carbon steel in HCl and H_2SO_4**

iii. **The extract of guava, banana and almond have a high significant effect on the reduction of the corrosion of low carbon steel at room temperature as a result of the formation of films on the substrate thereby displacing water molecules from the metal surface when compare with the blank.**

iv. **The inhibitive efficiencies of the extracts at room temperature were ranked as follow: guava>banana>almond for HCl media and banana>almond>guava for H_2SO_4.**

v. **The efficiency of the inhibitors increase with increased in concentration but decreases with increase in temperature (physisorption).**

vi. **With respect to increase in temperature, the inhibitive properties of the extracts can be ranked as follows: In HCl acid solution they are found to be in this increasing order: almond<guava<banana while for H_2SO_4 acid solution the increasing order is found to be: guava<almond<banana**

vii. **The increase in concentration resulting to higher activation energy suggests physisorption mechanism in both acid media.**

viii. **The positive values of enthalpy of activation and negative entropy of activation indicate an endothermic reaction.**

ix. **The closeness to unity of the R^2 values indicates a strong adherence to Langmuir isotherm.**

x. **The negative value of free gibbs energy and positive enthalpy of adsorption (ΔG and ΔH_{ads}) indicates the spontaneous interaction with high adsorption ability of the extract on low carbon steel at lower temperature which is consistent with the model of langmuir isotherm.**

xi. **The SEM studies reveal that the corrosion of low carbon steel in 0.5M HCl and H_2SO_4acid solution was diminished by the protective surface of the film formed by the addition of leaf extract.**

5.2 Recommendation

i. **Present research work was only to weight loss methods. However, subsequent investigation can be carried out using electrochemical impedance spectroscopy (EIS), Tofel Polarization, polarization resistance and gasometric methods.**

ii. **The inhibiting action of the extracts onnon-ferrous alloys at various temperatures could be investigated**

iii. **Mediums such as crude oil, distillate fuels etc. could be used to characterize the inhibition propensity of these inhibitors.**

5.3 Contributions to Knowledge

REFERENCES

Abd El-hameed, R.S, (2011). "Aminolysis of Polyethylene terephthalate Waste as Corrosion Inhibitor for Carbon Steel in HCL Corrosive medium". *Advances in Applied Science Research*, 2(3), 483-499.

Achebe, C.H,Nenke, U.C, and Anisiji O.E.(2012).“*Analysis of Oil Pipeline Failure in the Oil and Gas.* Retrieved March13, 2013 from,http://www.iaeng.org/publication/IMECS2012/IMECS2012 pp1274-1279

Alaneme, K.K and Olusegun, J. S, (2012). “Corrosion Inhibition Performance of Lignin Extract of Sun Flower (Tithonia Deversifolia) on Medium Carbon Low Alloy Steel Immersed in H_2SO_4 Solution” Leonardo Journal of Science, 20, 59-70.

Ameh, O.P, Magaji, .L and Salihu, .T, (2012). "Corrosion inhibition and adsorption behaviour for mild steel by Ficus glumosa gum in H2S04 solution". *African Journal of Pure and Applied Chemistry*, 6(7), 100 - 106.

Anafi, F.O, and Obi, A. I, (2004). "Corrosion Inhibition of Mild Steel in Simulated Media by a Methanolic Extracts of Bitter Leaves". *Journal of Pure and Applied Science*, 7(2), 203-210.

(2012) " Effect of Aqueous Extracts of Bitter Leaf Powder on the Corrosion Inhibition of Al-Si Alloy in 0.5 M Caustic Soda Solution" Journal of Minerals and Materials Characteriszation and Engineering, 11, 667 - 670

Bananas- history, production, trade (2013). Retrieved November 26, 2014, from http://www.zipmec.com/en/banana-history-production-trade-guide-fruit.html

Bill, N and Gareth,H, (2003, February). NPL. Beginners Guide to Corrosion, pp. 1-10.

Biker, J.J. (1958). Surface Chemistry Theory: Massachusetts Institute of Technology, Cambridge, Massachusetts, 2nd edition. Academic press inc. publishers. New York.

Chauhan,R.L and Gunasekaran,G, (2007). "Corrosion inhibition of mild steel by plant extract in dilute HCL medium".*Corrosion Science*, 49(3), 1143-1161.

Corrosion Control Solutions (n.d.).Retrieved March 12, 2013, from http://www.corr-ex.com/library_corrosion_control_solutions.php.

Dada, A.O, Olalekan, A.P, Olatunya, A.M and Dada, O (2012). "Langmuir, Freundlich, Temkin and Dubinin-Radushkevich Isotherms Studies of Equilibrium Sorption of Zn^{2+} onto Phosphoric Acid Modified Rice Husk".*IOSR Journal of Applied Chemistry*, 3(1),38-45

Eddy, O. N, Odoemelam, A. S, andOdiongeO. A,(2009). "Ethanol extract of musa species peels as a green corrosion inhibitor for mild steel: Kinetics, adsorption and thermodynamicconsiderations,"*Electronic Journal of Environmental, Agricultural and Food Chemistry*, 8(4), 243–255.

El-Etre,Y.A, (2007). "Inhibition of acid corrosion of carbon steel using aqueous extract of olive leaves". *Journal of Colloid and Interface Science*, 314(2) 578-583.

EL Maghraby,.A.A, (2009). "Corrosion Inhibition of Aluminium in Hydrocloric Acid Solution using Potassium Iodate Inhibitor". *The Open Corrosion Journal*, 2, 189-196.

Evans W.C., (2002), Trease and Evans. Pharmacognosy, 15th edition W.B. Saunders, Toronto, Harcourt Pub Ltd., pp 1-40, 516-525.

Fontana, M.G, (1987). Corrosion Engineering (Third Edition ed.). McGraw-Hill International.

Iloamaeke,M.I, Onuegbu, T.U, Ajiwe, E.I.V and Umeobika, C.U (2012). "Corrosion inhibition of mild steel by pterocarpus Soyauxi leaves extract in HCL medium".*International Journal of Plant, Animal and Enviroment*, 2(3), 22-28.

Image of banana plant (n.d.).Retrieved November 28, 2014 from https://www.google.com/search?q=image+of+banana+plant&tbm=isch&tbo=u&source

Image of crevices corrosion (n.d.). Retrieved November, 28, 2014 from https://www.google.com/search?q=image+of+crevices+corrosion&tbm=isch&tbo=u&source

Image of erosion corrosion (n.d.). Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+erosion+corrosion&tbm=isch&tbo=u&source

Image of galvanic corrosion (n.d.). Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+galvanic+corrosion&tbm=isch&tbo=u&source

Image of guava plant (n.d.).Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+guava+plant&tbm=isch&tbo=u&source

Image of indian almond plant (n.d.). Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+indian+almond+plant&tbm=isch&tbo=u&source

Image of Intergranular corrosion (n.d.). Retrieved November, 28, 2014, from https://www.google.com/search?q=image+of+intergranular+corrosion&tbm=isch& tbo=u&source

Image of pitting corrosion (n.d.). Retrieved November 28, 2014 fromhttps://www.google.com/search?q=image+of+pitting+corrosion&tbm=isch&tbo=u &source

Image of selective leaching corrosion (n.d.). Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+selective+leaching+corrosion&tbm=isch&tbo=u&source

Image of stress corrosion (n.d.). Retrieved November 28, 2014, from https://www.google.com/search?q=image+of+stress+corrosion&tbm=isch&tbo=u& source

Image of uniform corrosion (n.d.). Retrieved November, 28, 2014 from https://www.google.com/search?q=image+of+uniform+corrosion&tbm=isch&tbo=u&source

Indian almond leaves (n.d.). Retrieved November 26, 2014, from http://www.indianalmondleaves.com/aquariums.php

(ICS), I. C. f. S. a. H. T. (2008). Extraction Technologies for Medicinal and Aromatic Plants S. P. S. K. Sukhdev Swami Handa, Gennaro Longo and Dev Dutt Rakesh (Ed.)(pp. 23-24).

Kairi, I. N and Kassim J, (2013). "The Effect of Temperature on the corrosion Inhibition of

Mild Steel in 1 M HCl Solution by Curcuma Longa Extract.*International Journal of Electrochemical Science*.(8) 7138 – 7155

Khaled, K.F, (2008). "New Synthesized guanidine derivative as a green corrosion for mild steel in acidic solutions". *International Journal of Plant, Animal and Enviroment*(3), 462-475.

Kumar, S.P and Kirthika, .K (2009). "Equilibrium and Kinetic Study of Adsorption of Nickel

from Aqueous Solution onto Bael Tree Leaf Powder" Journal of Engineering Science

and Technology. 4(4) 351-363

Lebrini,M, Robert .F, Lecanite,A, and Roos,C (2011). "Corrosion inhibition pof C38 steel in 1M hydrochloric acid medium by alkaloids extract from Oxandra asbecki plant". *Corrosion Science*, 53(2) 687-695.

Loto,C.A, Loto,T.R and Popoola,.I.P.A, (2011, August 4). "Corrosion and Plant Extracts Inhibition of Mild Steel in HCL".*International Journal of The Physical Sciences*, 6(15), 3616-3623.

Loto,T.R, Loto,C.A and Popoola,.I.P.A, (2012). "Effect of Aminobenzene Concentration on

the Corrosion inhibition of Mild Steel in Sulphuric acid". *International Journal of Electrochemical Science,* 7, 7016 - 7032

Loto, T.R, Loto, C.A, Popoola, .I.P.A and Ranyaos, .M, (2012) "Pyrimidine Derivatives as Environmentally-Friendly Corrosion Inhibitors: *International Journal of The Physical Sciences*, 6(15), 3616-3623.A Review." 7(19), 2697-2705.

Njoku, E.R, (1998). "Effect of Inhibitors on Corrosion of Mild Steel in HCL Pickling Solution".*M.Sc Thesis Department of Metallurgical Engineering, ABU, Zaria-Nigeria*.

Nwabanne, J.T and Okafor V.N. (2011)." Inhibition of the corrosion of mild steel in acidic

medium by Vernonia Amygdalina: Adsorption and thermodynamics study"

***Journal of Emerging Trends in Engineering and Applied Sciences*, 2(4): 619-625**

Obot,I. B and Obi-Egbedi, N. O, (2010). "An interesting and efficient green corrosion Inhibitor for aluminium from extracts of ChlomolaenaodorataL. in acidic solution," *Journalof Applied Electrochemistry,* 40(11), 1977–1983.

Oguzie,E.E, Enenebeaku,C.K, Akalezi, O.C, Okoro, C.S, Ayuk,A.A and Ejike, .E.N, (2010). "Adsorption and Corrosion-inhibiting effect of Dacryodis edulis extract on low-carbon-steel corrosion in acidic media". *Journal of Colloid and Interface Science,* 349(1), 283-292.

Okafor C.P., Ebenso E.E., El-Etre Y.A. and Quraishi A.M., (2012), "Green Approach to Corrosion Mitigation" International Journal of Corrosion,

Okafor,C.P, Ikpi,E.M, Uwah,I.E, Ebenso,E.E, Ekpe and Umoren, .A.S, (2008). "Inhibitory action of Phyllanthus amarus extracts on the corrosion of mild steel in acidic media". *Corrosion Science*, 50(8), 2310-2317.

Oki, M, Charles, E, Alaka, C, and Oki, K.T, (2011). "Corrosion Inhibition of Mild Steel in Hydrochloric Acid by Tannins from RhizophoraRacemosa" ***Material Sciences and Applications,*** **2, 592-595**

Paul, O.A, Ladan,M and Takuma, S, (2012, April 10). "Corrosion Inhibition and Adsorption Behaviour for Mild Steel by Ficus Glumosa Gum in H2SO4 Solution". *African Journal of Pure and Applied Chemistry*, 6(7), 100-106.

Pearson, R.G (1968). "Hard and Soft Acids and Bases, HSAB, part 1: Fundamental Principles"*Journal of Chemical Education*. 45(9), 581-586

Quraishi, .M.A and Ansari, F. A., (2003). "Corrosion inhibition by fatty acid triazoles for mild steel and oil – well tubular steel in 15% boiling HCl and temal of oil chemists socciety, 77, 265

Quraishi, .M.A, Singh, .A, Singh, K.V, Yadav, .K.D and Singh, .K.A, (2010). "Green approach to corrosion inhibition of mild steel in hydrochloric acid and sulphuric acid solutions by the extract of Murraya Keonigii leaves". *Materia Chemistry and Physics,* 122, 114-122.

Quraishi, M. A, Yadav, D. K, andAhamad,I, (2009). "Green approach to corrosion inhibition by black pepper extract in hydrochloric acid solution," ***Open Corrosion Journal,*** **(2),56–60.**

Rani, B.E.A, Basu,.B.B. J, (2012). "Green Inhibitors for Corrosion Protection of Metals and Alloys: An Overview". *International Journal of Corrosion.*

Revie, W.R and Uhlig, H.H. (2008):*Corrosion and Corrosion control. An introduction to Corrosion Science and Engineering.*Fourth Edition. New York: John Wiley and Sons.

Saratha, R., Priya, S. V. and Thilagavathy, P.,(2009).“Investigation of Citrus aurantiifolia leaves extract as corrosion inhibitor for mild steel in 1 M HCL,” *E-Journal of Chemistry*, 6(3), 785–795,

Satapathy, K.A, Gunasekaran,G, Sahoo, C.S, Amit, .K, and Rodrigues,V.P, (2009). "Corrosion inhibition by Justicia gendarussa plant extract in hydrochloric acid solution". *Corrosion Science*, 51(12) 2848-2856.

Shyamala, .M, and Kasthuri,K.P, (2011). "A Comparative study of the inhibitory effect of the extracts of Ocimum Sanctum, Aegle marmelos and Solanum trilobatum on the corrosion of mild steel in hydrochloric acid medium". *International Journal of Corrosion.*, 11.

Singh,A., Singh,K.V and Qurashi,M.A, (2010). Aqueous extract of Kalmegh (Andorographis paniculata) leaves as Green inhibitor for mild steel in hydrochloric acid solution". *International Journal of Corrosion*, 10.

Special Issue on Green approaches to corrosion mitigation. Int. J. Corros. Available at http://www.hindawi.com/journals/ijc/si/gacm/2011

Society of Leather Trade Chemists, (2002).

Taylor, .L (2005).Database file for Guava (*psidium guajava*). Retrieved November 26, 2014, from http://www.rain-tree.com/guava.htm

Torres, V. V, Amado, R. S and Faia de Sá, C., (2011).“Inhibitory action of aqueous coffee ground extracts on the corrosion of carbon steel in HCl solution,” *Corrosion Science*, 53(7), 2385–2392,

Tropical Guava - *Psidium guajava, P. littorale (family: Myrtaceae)*(2014).Retrieved November 26, 2014 fromhttp://toptropicals.com/html/toptropicals/articles/fruit/guava.htm

Umoren, A.S, (2009). "Polymers as Corrosion Inhibitors for Metals in different Media - A Review". *The Open Corrosion Journal*, 2, 175-188.

Umoren, S.A, Ebenso, E.E, Okafor, P.C and Ogbobe, O, (2003) "Water soluble polymers as corrosion inhibitors of mild steel in acidic medium", "*Pigment Resin Technol*" ,35(6), 346-352.

Vimala,R.J, Rose, .L.A and Raja, .S, (2011). "Cassia auriculata extract as corrosion inhibitor for mild steel in acid medium". *International Journal of ChemTech Research,* 3(4), 1791-1801.

www.stoprust.com. Retrieved June, 5, 2012.

Yawas, D.S., (2005) " Suitability Assessment of some Plant Extracts and Fatty acid vegetable oils as corosion inhibitors".*Ph.D Dessertation in the Department of Mechanical Engineering, ABU, Zaria - Nigeria.*

Zaabar, .A, Aitout, .R, and Makhloufi, .L, (2014). "Inhibition of acid corrosion of mild steel by aqueous nettle extracts", *Pigment & Resin Technology,* 43/3 (2014) 127-138

Zarrouk, A, Hammouti B, Zarrok, H, Al-Deyab, S.S, and Messali, A, (2011). "Temperature effect, Activation Energies and Thermodynamic Adsorption Studies of L-Cysteine Methyl Ester Hydrochloride As Copper Corrosion Inhibitor in Nitric Acid 2M", *International Journal of Electrochemical Science*. (6) 6261 – 6274.

Zhang, Q.B and Hua, .Y.X, (2009). "Corrosion inhibition of mild steel by alkylimidazolium ionic liquids in hydrochloric acid". *Electrochimica Acta*, 54, 1881-1887.

Zheludkevich,M. L, Serra, .R, Montemor, M. F, and Ferreira M. G. S, (2005), "Oxide nanoparticle reservoirs for storage and prolonged release of the corrosion inhibitors," *ElectrochemistryCommunications*, 7(8), 836–840.

APPENDIX A

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QMatrix Analysis Results

Sample Identification

SampleNo: VENDA 'A'

	C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Cu %	Al %
1.	0.195	3.478	1.218	0.066	<0.100	0.028	0.0077	0.017	0.011	0.077
2.	0.234	3.222	1.413	0.137	<0.100	0.030	0.022	0.028	0.013	0.183
⇑										
↑										
Ø	**0.215**	**3.350**	**1.316**	**0.102**	**<0.100**	**0.029**	**0.015**	**0.022**	**0.012**	**0.130**
↓										
⇓										
σ	0.028	0.181	0.138	0.050		0.0014	0.010	0.0078	0.0014	0.075
υ	13.02	5.403	10.49	49.02		4.828	66.67	35.45	11.67	57.69

	As %	B %	Ca %	Co %	Mg %	N %	Nb %	Pb %	Sn %	Ti %
1.	<0.0050	0.0027	>0.0072	0.0054	0.013	0.512	<0.00005	<0.100	<0.0020	0.0034
2.	<0.0050	0.0055	>0.0072	0.0073	0.014	0.795	0.440	<0.100	<0.0020	0.0050
⇑										
↑										
Ø	**<0.0050**	**0.0041**	**–0.0072**	**0.0063**	**0.014**	**0.653**	**0.220**	**<0.100**	**<0.0020**	**0.0042**
↓										
⇓										
σ		0.0020		0.0013	0.0010	0.200	0.311			0.0011
υ		48.78		20.63	7.143	30.63	141.36			26.19

	V %	W %	Zn %	Zr %	Se %	Fe %
1.	<0.0050	<0.010	0.0090	<0.0020	<0.020	94.11
2.	<0.0050	<0.010	0.017	<0.0020	<0.020	93.18
⇑						
↑						
Ø	**<0.0050**	**<0.010**	**0.013**	**<0.0020**	**<0.020**	**93.65**
↓						
⇓						
σ			0.0057			0.658
υ			43.85			0.703

Fe100
Bruker Elemental

Concentrations
1/1

APPENDIX B

Table 1-26 represent the values of the corrosion rate, degree of surface coverage and percentage inhibition efficiency that were deduce from the weight loss experienced by coupons after 72 hours - 578 hours of immersion in HCl and H_2SO_4 solution in the

absence and presence of various concentration of plants extract at temperature of 30°C as described in chapter 3.

Table 1: Corrosion rate for Low Carbon Steel in 0.5M HClin the absence of extract

Exposure Time (hour)	Initial Weight m_1(g)	Final Weight m_2(g)	Weight loss $w = m_1 - m_2$(mg)	Corrosion Rate CR_o(mm/yr)
72	31.4645	31.0551	409.4	2.6153
144	31.6153	30.9632	652.1	2.0829
216	30.797	30.0023	794.7	1.6922
288	31.4372	30.5304	906.8	1.4482
360	30.6286	29.6048	1023.8	1.3081
432	31.7415	30.6491	1092.4	1.1631
506	31.7782	30.6233	1154.9	1.054
578	30.7323	29.5272	1205.1	0.9623

Table 2: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 250ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$ (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.9651	30.8101	155.0	0.9902	0.6214	62.14
144	31.4574	31.2228	234.6	0.7493	0.6402	64.02
216	31.194	30.9204	273.6	0.5826	0.6558	65.58
288	30.9308	30.6238	307.0	0.4903	0.6615	66.15
360	32.2203	31.8798	340.5	0.435	0.6674	66.74
432	31.6098	31.25	359.8	0.3831	0.6706	67.06
506	31.8445	31.4605	384.0	0.3504	0.6675	66.75
578	30.7058	30.2906	415.2	0.3315	0.6555	65.55

Table 3: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 500ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR	Surface Coverage Ø	Inhibition Efficiency %

				(mm/yr)		
72	31.8994	31.7565	142.9	0.9129	0.651	65.1
216	30.8533	30.6081	245.2	0.5221	0.6915	69.15
288	31.0511	30.789	262.1	0.4186	0.711	71.1
360	31.3018	31.0143	287.5	0.3673	0.7192	71.92
432	31.4628	31.1584	304.4	0.3241	0.7213	72.13
506	30.9306	30.601	329.6	0.3008	0.7146	71.46
578	30.929	30.5784	350.6	0.28	0.7091	70.91

Table 4: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 750ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.2388	31.11	128.8	0.8228	0.6854	68.54
144	30.9553	30.7695	185.8	0.5935	0.7151	71.51
216	30.1238	29.9124	211.4	0.4502	0.734	73.4
288	30.6855	30.456	229.5	0.3665	0.7469	74.69
360	31.4495	31.1961	253.4	0.3238	0.7525	75.25
432	31.1056	30.8483	257.3	0.274	0.7645	76.45
506	30.516	30.2336	282.4	0.2577	0.7555	75.55
578	30.652	30.3493	302.7	0.2417	0.7488	74.88

Table 5: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 1000ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.7734	31.6515	121.9	0.7787	0.7023	70.23
144	31.6924	31.5126	179.8	0.5743	0.7243	72.43
216	31.4731	31.2705	202.6	0.4314	0.7451	74.51
288	31.3709	31.1534	217.5	0.3474	0.7602	76.02
360	30.8084	30.5781	230.3	0.2942	0.7751	77.51
432	30.6516	30.4248	226.8	0.2415	0.7924	79.24
506	31.4013	31.1596	241.7	0.2206	0.7907	79.07
578	31.3001	31.0324	267.7	0.2138	0.7779	77.79

Table 6: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 250ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1-m_2$ (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.9341	30.7711	163.0	1.0413	0.6019	60.19
144	30.7741	30.5296	244.5	0.781	0.6251	62.51
216	30.4916	30.2007	290.9	0.6194	0.6339	63.39
288	30.4527	30.1276	325.1	0.5192	0.6415	64.15
360	32.3904	32.0208	369.6	0.4722	0.639	63.9
432	31.3041	30.904	400.1	0.426	0.6337	63.37
506	31.2918	30.8569	434.9	0.3969	0.6234	62.34
578	30.3344	29.8653	469.1	0.3746	0.6107	61.07

Table 7: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 500ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1-m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.5484	30.3972	151.2	0.9659	0.6307	63.07
144	31.3083	31.0887	219.6	0.7014	0.6632	66.32
216	30.9803	30.7171	263.2	0.5605	0.6688	66.88
288	31.0877	30.7972	290.5	0.464	0.6796	67.96
360	30.7243	30.4014	322.9	0.4126	0.6846	68.46
432	31.708	31.3596	348.4	0.3709	0.6811	68.11
506	31.1294	30.7504	379.0	0.3459	0.6718	67.18
578	30.9031	30.4866	416.5	0.3326	0.6544	65.44

Table 8: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 750ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1-m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.9698	30.8263	143.5	0.9167	0.6495	64.95
144	31.4543	31.2406	213.7	0.6826	0.6723	67.23
216	30.6194	30.3668	252.6	0.5379	0.6821	68.21
288	31.1981	30.9243	273.8	0.4373	0.6981	69.81
360	30.947	30.6508	296.2	0.3784	0.7107	71.07
432	30.7339	30.4212	312.7	0.3329	0.7138	71.38
506	31.517	31.1808	336.2	0.3068	0.7089	70.89
578	30.4868	30.1124	374.4	0.299	0.6893	68.93

Table 9: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 1000ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.087	30.956	131.0	0.8369	0.68	68.00
144	31.1296	30.9423	187.3	0.5983	0.7128	71.28
216	30.7414	30.518	223.4	0.4757	0.7189	71.89
288	31.9323	31.6804	251.9	0.4023	0.7222	72.22
360	31.5514	31.2781	273.3	0.3492	0.7331	73.31
432	31.1831	30.8973	285.8	0.3043	0.7384	73.84
506	31.01	30.7006	309.4	0.2824	0.7321	73.21
578	30.725	30.3782	346.8	0.2769	0.7122	71.22

Table 10: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 250ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.7134	31.5234	190.0	1.2138	0.5359	53.59
144	30.419	30.1662	252.8	0.8075	0.6123	61.23
216	30.6381	30.3432	294.9	0.628	0.6289	62.89
288	30.0962	29.7643	331.9	0.5301	0.634	63.4
360	30.4436	30.0685	375.1	0.4792	0.6336	63.36
432	30.9006	30.5168	383.8	0.4086	0.6487	64.87
506	30.8205	30.3904	430.1	0.3925	0.6276	62.76
578	30.0425	29.5855	457.0	0.3649	0.6208	62.08

Table 11: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 500ppmalmond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.5619	31.394	167.9	1.0726	0.5899	58.99
144	30.3805	30.1404	240.1	0.7669	0.6318	63.18
216	31.8568	31.5684	288.4	0.6141	0.6371	63.71
288	30.1136	29.8045	309.1	0.4937	0.6591	65.91
360	32.3314	31.9628	368.6	0.4709	0.64	64
432	31.6823	31.3063	376.0	0.4003	0.6558	65.58
506	31.2217	30.8474	374.3	0.3416	0.6759	67.59
578	29.2638	28.8459	417.9	0.3337	0.6532	65.32

Table 12: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 750ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.1413	30.9762	165.1	1.0547	0.5967	59.67
144	31.5121	31.2606	251.5	0.8033	0.6143	61.43
216	30.5989	30.3063	292.6	0.6231	0.6318	63.18
288	31.1116	30.7921	319.5	0.5103	0.6477	64.77
360	30.8109	30.4613	349.6	0.4467	0.6585	65.85
432	31.7294	31.3789	350.5	0.3732	0.6792	67.92
506	31.6569	31.277	379.9	0.3467	0.6711	67.11
578	31.0681	30.6417	426.4	0.3405	0.6462	64.62

Table 13: Corrosion rate for Low Carbon Steel in 0.5M HCl in the presence of 1000ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.8478	31.6882	159.6	1.0196	0.6102	61.02
144	31.4082	31.1601	248.1	0.7925	0.6195	61.95
216	31.3234	31.0283	295.1	0.6284	0.6287	62.87
288	31.0441	30.742	302.1	0.4825	0.6669	66.69
360	31.4058	31.0726	333.2	0.4257	0.6746	67.46
432	31.4555	31.1038	351.7	0.3745	0.6781	67.81
506	30.9509	30.5842	366.7	0.3345	0.6825	68.25
578	31.0084	30.6106	397.8	0.3177	0.6699	66.99

Table 14:Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4 in the absence of inhibitor

Exposure Time (hour)	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR_o (mm/yr)
72	30.8276	30.2366	591.0	3.7755
144	31.0446	30.1888	855.8	2.7335
216	32.2168	31.0729	1143.9	2.4358
288	30.2046	28.7127	1491.9	2.3827
360	30.9942	29.2456	1748.6	2.2341
432	30.2356	28.2046	2031.0	2.1624
506	32.2194	29.9843	2235.1	2.0398
578	30.136	27.638	2498.0	1.9947

Table 15: Corrosion rate for Low Carbon Steel in 0.5 M H_2SO_4 in the presence of 250ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.4888	31.2237	265.1	1.6935	0.5514	55.14
144	31.155	30.7861	368.9	1.1783	0.5689	56.89
216	30.6364	30.169	467.4	0.9953	0.5914	59.14
288	30.7041	30.1266	577.5	0.9223	0.6129	61.29
360	30.8917	30.2303	661.4	0.845	0.6218	62.18
432	31.0708	30.3052	765.6	0.8151	0.623	62.3
506	31.456	30.5928	863.2	0.7878	0.6138	61.38
578	30.607	29.6343	972.7	0.7767	0.6106	61.06

Table 16: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4 in the presence of 500ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.321	31.0662	254.8	1.6277	0.5689	56.89
144	31.7785	31.4241	354.4	1.132	0.5859	58.59
216	30.5992	30.1545	444.7	0.947	0.6112	61.12
288	31.0891	30.5431	546.0	0.872	0.634	63.4
360	31.0692	30.4473	621.9	0.7946	0.6443	64.43
432	31.1854	30.4707	714.7	0.761	0.6481	64.81
506	31.1014	30.3115	789.9	0.7209	0.6466	64.66
578	30.5645	29.6709	893.6	0.7136	0.6423	64.23

Table 17: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4in the presence of 750ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.5148	30.2843	230.5	1.4725	0.61	61
144	30.903	30.5824	320.6	1.024	0.6254	62.54
216	30.5017	30.1049	396.8	0.845	0.6531	65.31
288	30.2234	29.7397	483.7	0.7725	0.6758	67.58
360	30.6898	30.1402	549.6	0.7022	0.6857	68.57
432	30.8102	30.1883	621.9	0.6621	0.6938	69.38
506	32.009	31.34	669.0	0.6105	0.7007	70.07

578	30.0477	29.2927	755.0	0.6029	0.6978	69.78

Table 18: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4 in the presence of 1000ppm guava extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(g)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	32.0313	31.8168	214.5	1.3703	0.6371	63.71
144	32.155	31.8545	300.5	0.9598	0.6489	64.89
216	31.1862	30.7961	390.1	0.8307	0.659	65.9
288	31.382	30.9176	464.4	0.7417	0.6887	68.87
360	31.3254	30.8088	516.6	0.66	0.7046	70.46
432	31.3181	30.7363	581.8	0.6195	0.7135	71.35
506	31.2512	30.6159	635.3	0.5798	0.7158	71.58
578	30.2008	29.4883	712.5	0.569	0.7148	71.48

Table 19: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4in the presence of 250ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.8341	31.6366	197.5	1.2617	0.6658	66.58
144	30.5613	30.2796	281.7	0.8999	0.6708	67.08
216	31.5087	31.1367	372.0	0.7921	0.6748	67.48
288	30.0145	29.5348	479.7	0.7661	0.6785	67.85
360	30.6023	30.0426	559.7	0.7151	0.6799	67.99
432	31.4247	30.7672	657.5	0.7	0.6763	67.63
506	31.0454	30.3206	724.8	0.6615	0.6757	67.57
578	30.0116	29.1901	821.5	0.656	0.6711	67.11

Table 20: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4 in the presence of 500ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.995	30.8091	185.9	1.1876	0.6855	68.55
144	30.702	30.4429	259.1	0.8276	0.6972	69.72
216	31.5215	31.191	330.5	0.7038	0.7111	71.11
288	30.1519	29.731	420.9	0.6722	0.7179	71.79
360	31.2858	30.802	483.8	0.6181	0.7233	72.33
432	31.8838	31.3327	551.1	0.5868	0.7287	72.87
506	31.1858	30.5718	614.0	0.5603	0.7253	72.53

578	29.608	28.916	692.0	0.5526	0.723	72.3

Table 21: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4in the presence of 750ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.9886	30.8101	178.5	1.1403	0.698	69.8
144	31.5563	31.3058	250.5	0.8001	0.7073	70.73
216	30.1704	29.8492	321.2	0.684	0.7192	71.92
288	31.0098	30.6045	405.3	0.6473	0.7283	72.83
360	32.5638	32.1025	461.3	0.5894	0.7362	73.62
432	31.6707	31.1462	524.5	0.5584	0.7418	74.18
506	30.6993	30.1348	564.5	0.5152	0.7474	74.74
578	31.9425	31.3182	624.3	0.4985	0.7501	75.01

Table 22: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4in the presence of 1000ppm banana extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	30.8971	30.7289	168.2	1.0745	0.7154	71.54
144	31.3772	31.1408	236.4	0.7551	0.7238	72.37
216	31.4024	31.1142	288.2	0.6137	0.7481	74.81
288	31.1118	30.7566	355.2	0.5673	0.7619	76.19
360	30.9063	30.4963	410.0	0.5238	0.7655	76.55
432	31.3184	30.8482	470.2	0.5006	0.7685	76.85
506	30.7705	30.2566	513.9	0.469	0.7701	77.01
578	31.1602	30.5918	568.4	0.4539	0.7724	77.25

Table 23: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4 in the presence of 250ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss $w = m_1 - m_2$(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.385	31.1525	232.5	1.4853	0.6066	60.66
144	30.8636	30.5424	321.2	1.026	0.6247	62.46
216	29.955	29.55	405.0	0.8624	0.646	64.6
288	31.1667	30.654	512.7	0.8188	0.6563	65.63
360	31.3314	30.7363	595.1	0.7603	0.6597	65.97
432	30.7259	30.0284	697.5	0.7426	0.6566	65.66
506	32.3309	31.5508	780.1	0.7119	0.651	65.1

578	30.6013	29.7145	886.8	0.7081	0.645	64.5

Table 24: Corrosion rate for Low Carbon Steel in 0.5M H_2SO_4in the presence of 500ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.9675	31.7461	221.4	1.4146	0.6254	62.54
144	32.3309	32.0249	306.0	0.9774	0.6424	64.24
216	30.637	30.2684	368.6	0.7849	0.6778	67.78
288	31.5419	31.077	464.9	0.7425	0.6884	68.84
360	31.2502	30.72	530.2	0.6774	0.6968	69.68
432	31.1044	30.4951	609.3	0.6487	0.7	70
506	31.2132	30.525	688.2	0.6281	0.6921	69.21
578	31.496	30.7184	777.6	0.6209	0.6887	68.87

Table 25: Corrosion rate for Low Carbon Steel in 0.5 M H_2SO_4in the presence of 750ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.9263	31.7124	213.9	1.3664	0.6381	63.81
144	32.1025	31.8067	295.8	0.9448	0.6544	65.44
216	30.4672	30.1	367.2	0.7819	0.679	67.9
288	31.5966	31.1565	440.1	0.7029	0.705	70.5
360	30.9091	30.4074	501.7	0.641	0.7131	71.31
432	31.6874	31.11	577.4	0.6148	0.7157	71.57
506	31.1006	30.4505	650.1	0.5933	0.7091	70.91
578	31.8046	31.0683	736.3	0.588	0.7052	70.52

Table 26: Corrosion rate for Low Carbon Steel in 0.5 M H_2SO_4in the presence of 1000ppm almond extract

Exposure Time (hour)	Initial Weight m_1 (g)	Final weightm_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage Ø	Inhibition Efficiency %
72	31.3578	31.1553	202.5	1.2936	0.6574	65.74
144	31.3382	31.0597	278.5	0.8896	0.6746	67.46
216	30.8091	30.4647	344.4	0.7334	0.6989	69.89
288	30.51	30.1038	406.2	0.6487	0.7277	72.77
360	31.7405	31.2795	461.0	0.589	0.7364	73.64
432	30.4078	29.886	521.8	0.5556	0.7431	74.31
506	31.5794	30.9992	580.2	0.5295	0.7404	74.04

578	30.557	29.9046	652.4	0.521	0.7388	73.88

Tables 27-33 represent the values of the corrosion rate, degree of surface coverage and percentage inhibition efficiency that were deduce from the weight loss experienced by coupons after 4 hours of immersion in HCl and H_2SO_4 solution in the absence and presence of various concentration of plants extract at different temperature of 30, 40, 50, and 60^oC as required in chapter 3.

Table 27: Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of guava extract in 0.5M HCl at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp (k)	Inhibitor Concentration ppm	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss w = m_1-m_2 (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage θ	Inhibition Efficiency (%)
303	Blank	28.8425	28.8239	18.6	2.1388	0	0
	250	33.0789	33.0682	10.7	1.2304	0.4247	42.47
	500	27.4646	27.4564	8.2	0.9429	0.5591	55.91
	750	30.5538	30.548	5.8	0.6669	0.6882	68.82
	1000	28.5697	28.5652	4.5	0.5174	0.7581	75.81
313	Blank	30.6995	30.6661	33.4	3.8406	0	0
	250	29.1197	29.099	20.7	2.3803	0.3802	38.02
	500	29.4428	29.4269	15.9	1.8283	0.524	52.4
	750	31.2494	31.2374	12	1.3799	0.6407	64.07
	1000	30.8099	30.8009	9	1.0349	0.7305	73.05
323	Blank	30.4434	30.4018	41.6	4.7835	0	0
	250	30.4777	30.4494	28.3	3.2542	0.3197	31.97
	500	29.3476	29.3259	21.7	2.4952	0.4784	47.84
	750	30.0897	30.074	15.7	1.8053	0.6226	62.26
	1000	30.5548	30.542	12.8	1.4719	0.6923	69.23
333	Blank	30.9522	30.8707	81.5	9.3716	0	0
	250	30.4289	30.3688	60.1	6.9108	0.2626	26.26
	500	27.9505	27.9022	48.3	5.554	0.4074	40.74
	750	29.5597	29.5208	38.9	4.473	0.5227	52.27
	1000	30.9025	30.8717	30.8	3.5416	0.6221	62.21

Table 28: Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of banana extract in 0.5M HCl at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp (k)	Inhibitor Concentration ppm	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss $w = m_1-m_2$ (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage θ	Inhibition Efficiency (%)
303	Blank	28.8425	28.8239	18.6	2.1388	0	0
	250	28.8087	28.8006	8.1	0.9314	0.5645	56.45
	500	28.7487	28.7424	6.3	0.7244	0.6613	66.13
	750	28.5962	28.591	5.2	0.5979	0.7204	72.04
	1000	27.885	27.8815	3.5	0.4025	0.8118	81.18
313	Blank	30.6995	30.6661	33.4	3.8406	0	0
	250	33.7612	33.7457	15.5	1.7823	0.5359	53.59
	500	30.1603	30.1475	12.8	1.4719	0.6168	61.68
	750	30.5759	30.5653	10.6	1.2189	0.6826	68.26
	1000	30.6858	30.6785	7.3	0.8394	0.7814	78.14
323	Blank	30.4434	30.4018	41.6	4.7835	0	0
	250	30.2908	30.2679	22.9	2.6332	0.4495	44.95
	500	33.7437	33.7248	18.9	2.1733	0.5457	54.57
	750	30.2965	30.281	15.5	1.7823	0.6274	62.74
	1000	31.2303	31.2206	9.7	1.1154	0.7668	76.68
333	Blank	30.9522	30.8707	81.5	9.3716	0	0
	250	33.0753	33.0272	48.1	5.5309	0.4098	40.98
	500	30.408	30.3666	41.4	4.7605	0.492	49.2
	750	29.8409	29.8057	35.2	4.0476	0.5681	56.81
	1000	30.6801	30.6552	24.9	2.8632	0.6945	69.45

Table 29: Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of almond extract in 0.5M HCl at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp (k)	Inhibitor Concentration ppm	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss $w = m_1-m_2$ (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage θ	Inhibition Efficiency (%)
303	Blank	28.8425	28.8239	18.6	2.1388	0	0
	250	30.5087	30.4993	9.4	1.0809	0.4946	49.46
	500	30.9775	30.9694	8.1	0.9314	0.5645	56.45
	750	27.823	27.816	7	0.8049	0.6237	62.37
	1000	30.0554	30.0492	6.2	0.7129	0.6667	66.67
313	Blank	30.6995	30.6661	33.4	3.8406	0	0
	250	33.0304	33.0122	18.2	2.0928	0.4551	45.51
	500	33.1194	33.1036	15.8	1.8168	0.527	52.7
	750	29.8725	29.858	14.5	1.6673	0.5659	56.59
	1000	30.829	30.8167	12.3	1.4143	0.6317	63.17
323	Blank	30.4434	30.4018	41.6	4.7835	0	0
	250	30.5883	30.5636	24.7	2.8402	0.4063	40.63
	500	28.6673	28.6456	21.7	2.4952	0.4784	47.84
	750	29.35	29.3305	19.5	2.2423	0.5313	53.13
	1000	30.1439	30.126	17.9	2.0583	0.5697	56.97
333	Blank	30.9522	30.8707	81.5	4.7835	0	0
	250	30.0475	29.9956	51.9	5.9679	0.3632	36.32
	500	30.7441	30.6983	45.8	5.2665	0.438	43.8
	750	29.1752	29.1315	43.7	5.025	0.4638	46.38
	1000	30.6889	30.6492	39.7	2.0583	0.5129	51.29

Table 30:Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of guava extract in 0.5M H_2SO_4 at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp (k)	Inhibitor Concentration ppm	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss $w = m_1-m_2$ (mg)	Corrosion Rate CR (mm/yr)	Surface Coverage θ	Inhibition Efficiency (%)
303	Blank	27.6066	27.5692	37.4	4.3006	0	0
	250	33.3365	33.3149	21.6	2.4838	0.4225	42.25
	500	27.6532	27.6347	18.5	2.1273	0.5054	50.54
	750	27.8181	27.8018	16.3	1.8743	0.5642	56.42
	1000	28.5571	28.5421	15	1.7248	0.5989	59.89
313	Blank	30.5734	30.5	73.4	8.4401	0	0
	250	30.9095	30.8607	48.8	5.6114	0.3352	33.52
	500	33.7076	33.6678	39.8	4.5765	0.4578	45.78
	750	28.7712	28.7375	33.7	3.8751	0.5409	54.09
	1000	30.2619	30.2302	31.7	3.6451	0.5681	56.81
323	Blank	30.4882	30.3699	118.3	13.6031	0	0
	250	33.419	33.3315	87.5	10.0615	0.2604	26.04
	500	32.8529	32.7793	73.6	8.4631	0.3779	37.79
	750	30.5851	30.5184	66.7	7.6697	0.4362	43.62
	1000	30.0261	29.9645	61.6	7.0833	0.4793	47.93
333	Blank	31.2897	31.1179	171.8	19.755	0	0
	250	30.3343	30.1997	134.6	15.4774	0.2165	21.65
	500	30.7621	30.6386	123.5	14.2011	0.2811	28.11
	750	30.4715	30.3562	115.3	13.2582	0.3289	32.89
	1000	29.9815	29.8703	111.2	12.7867	0.3527	35.27

Table 31: Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of banana extract in 0.5M H_2SO_4 at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp	Inhibitor	Initial	Final	Weight	Corrosion	Surface	Inhibition

(k)	Concentration ppm	Weight m_1 (g)	Weight m_2 (g)	Loss w = m_1-m_2 (mg)	Rate CR (mm/yr)	Coverage θ	Efficiency (%)
303	Blank	27.6066	27.5692	37.4	4.3006	0	0
	250	30.4876	30.4692	18.4	2.1158	0.5080	50.80
	500	27.8588	27.8434	15.4	1.7708	0.5882	58.82
	750	26.8906	26.877	13.6	1.5638	0.6364	63.64
	1000	28.6302	28.6183	11.9	1.3684	0.6818	68.18
313	Blank	30.5734	30.5	73.4	8.4402	0	0
	250	30.8771	30.8362	40.9	4.7030	0.4428	44.28
	500	29.1526	29.1178	34.8	4.0016	0.5259	52.59
	750	28.2933	28.2648	28.5	3.2772	0.6117	61.17
	1000	30.8436	30.8169	26.7	3.0702	0.6362	63.62
323	Blank	30.4882	30.3699	118.3	13.6031	0	0
	250	30.1039	30.031	72.9	8.3827	0.3838	38.38
	500	30.6465	30.5872	59.3	6.8188	0.4987	49.87
	750	30.7482	30.6962	52	5.9794	0.5604	56.04
	1000	30.1928	30.1452	47.6	5.4734	0.5976	59.76
333	Blank	31.2897	31.1179	171.8	19.755	0	0
	250	30.028	29.9168	111.2	12.7867	0.3527	35.27
	500	29.7337	29.6406	93.1	10.7054	0.4581	45.81
	750	30.4156	30.335	80.6	9.2681	0.5309	53.09
	1000	30.5283	30.4513	77	8.8541	0.5518	55.18

Table 32: Degree of surface coverage (θ) and percentage inhibition efficiency (% IE) of almond extract in 0.5M H_2SO_4 at 303-333 K, obtained from weight loss measurement after 4hrs.

Temp (k)	Inhibitor Concentration ppm	Initial Weight m_1 (g)	Final Weight m_2 (g)	Weight Loss w = m_1-m_2(mg)	Corrosion Rate CR (mm/yr)	Surface Coverage θ	Inhibition Efficiency (%)
303	Blank	27.6066	27.5692	37.4	4.3006	0	0
	250	29.8189	29.799	19.9	2.2883	0.4679	46.79

	500	29.6508	29.6348	16	1.8398	0.57219	57.22
	750	28.9693	28.9549	14.4	1.6558	0.61497	61.50
	1000	29.8913	29.8776	13.7	1.5753	0.63369	63.37
313	Blank	30.5734	30.5	73.4	8.4401	0	0
	250	33.3179	33.2739	44	5.0595	0.4006	40.06
	500	29.5064	29.4731	33.3	3.8291	0.5463	54.63
	750	29.3538	29.3221	31.7	3.6451	0.5681	56.81
	1000	30.9838	30.9564	27.4	3.1507	0.6267	62.67
323	Blank	30.4882	30.3699	118.3	13.6031	0	0
	250	30.5948	30.518	76.8	8.8311	0.3508	35.080
	500	30.6863	30.6218	64.5	7.4168	0.4548	45.48
	750	30.139	30.0808	58.2	6.6923	0.5080	50.80
	1000	30.1319	30.0802	51.7	5.9449	0.5630	56.30
333	Blank	31.2897	31.1179	171.8	19.755	0	0
	250	30.5805	30.4581	122.4	14.0746	0.2875	28.75
	500	31.2897	31.1785	111.2	12.7867	0.3527	35.27
	750	29.8689	29.7676	101.3	11.6483	0.4104	41.04
	1000	30.5638	30.468	95.8	11.0159	0.4424	44.24

Table 33 – 38 represent the evaluated values of pre-exponential factor andactivation energy (Ea) gotten from the graphs of figure 4.33-4.38 whileenthalpy (ΔH_a) and entropy (ΔS_a) were evaluated from the graph of figure 4.39-4.44 after applying the appropriate equations in chapter three.

Table 33: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M HCl in the absence and presence of various concentration of guava extract.

Concentration (ppm)	Pre-exponential factor (mg/cm^2 h)	Linear regression coefficient (R^2)	E_a (KJ/mol)	ΔH_a (KJ/mol)	ΔS_a (J/mol K)	$E_a - \Delta H_a$ (KJ/mol)	Linear regression coefficient (R^2)
Blank	1.12×10^{10}	0.9655	38.966	36.33	-118.83	2.636	0.9606
250	1.04×10^{11}	0.9758	46.0	43.355	-100.3	2.645	0.9729
500	1.25×10^{11}	0.9718	47.15	44.513	-98.76	2.637	0.9686
750	2.80×10^{11}	0.9591	50.045	47.405	-92.08	2.64	0.9547
1000	3.46×10^{11}	0.9717	51.251	48.613	-90.30	2.638	0.9688

Table 34: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M HCl in the absence and presence of various concentration of banana extract

Concentration (ppm)	Pre-exponential factor (mg/cm^2 h)	Linear regression coefficient (R^2)	E_a (KJ/mol)	ΔH_a (KJ/mol)	ΔS_a (J mol/ K)	$E_a - \Delta H_a$ (KJ/mol)	Linear regression coefficient (R^2)
Blank	1.12×10^{10}	0.9655	38.966	36.33	-118.83	2.636	0.9606
250	1.76×10^{11}	0.9849	48.044	45.406	-95.93	2.634	0.9832
500	3.81×10^{11}	0.9833	50.451	47.96	-89.53	2.491	0.9815
750	4.04×10^{11}	0.9800	51.243	48.82	-88.31	2.636	0.9821
1000	3.17×10^{11}	0.9588	51.648	50.75	-85.32	2.645	0.9673

Table 35: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M HCl in the absence and presence of various concentration of almond extract

Concentration (ppm)	Pre-exponential factor (mg/cm^2 h)	Linear regression coefficient (R^2)	E_a (KJ/mol)	ΔH_a (KJ/mol)	ΔS_a (J/mol K)	$E_a - \Delta H_a$ (KJ/mol)	Linear regression coefficient (R^2)
Blank	1.12×10^{10}	0.9655	38.966	36.33	-118.834	2.636	0.9606
250	7.6×10^{10}	0.9756	45.509	42.869	-102.956	2.640	0.9727
500	8.62×10^{10}	0.9770	46.21	43.569	-101.882	2.641	0.9743
750	1.88×10^{11}	0.9711	48.521	45.884	-95.391	2.637	0.9679
1000	2.71×10^{11}	0.9805	49.806	47.165	-92.329	2.641	0.9784

Table 36: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of guava extract

Concentration	Pre-	Linear	E_a	ΔH_a	ΔS_a	$E_a - \Delta H_a$	Linear

(ppm)	exponential factor (mg/cm^2 h)	regression coefficient (R^2)	(KJ/mol)	(KJ/mol)	(J/mol K)	(KJ/mol)	regression coefficient (R^2)
Blank	9.76×10^{10}	0.9888	42.520	39.880	-100.66	2.640	0.9871
250	1.75×10^{12}	0.9872	51.129	48.488	-76.67	2.641	0.9856
500	3.09×10^{12}	0.9964	53.049	50.409	-71.91	2.640	0.9959
750	5.86×10^{12}	0.9987	55.038	52.398	-66.60	2.640	0.9985
1000	8.06×10^{12}	0.9994	56.051	53.413	-63.95	2.639	0.9993

Table 37: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of banana extract

Concentration (ppm)	Pre-exponential factor (mg/cm^2 h)	Linear regression coefficient (R^2)	E_a (KJ/mol)	ΔH_a (KJ/mol)	ΔS_a (J/mol K)	$E_a - \Delta H_a$ (KJ/mol)	Linear regression coefficient (R^2)
Blank	9.76×10^{10}	0.9888	42.522	39.880	-100.86	2.642	0.9871
250	1.07×10^{12}	0.9874	50.303	46.686	-84.16	3.617	0.9863
500	7.74×10^{11}	0.9872	50.503	47.290	-83.61	3.21	0.9856
750	9.17×10^{11}	0.9929	50.742	48.102	-82.22	2.64	0.992
1000	1.34×10^{12}	0.9915	51.996	49.359	-79.05	2.637	0.9905

Table 38: Corrosion Kinetic (Activation) parameters for the corrosion of Low Carbon Steel in 0.5M H_2SO_4 in the absence and presence of various concentration of almond extract

Concentration (ppm)	Pre-exponential factor (mg/cm^2 h)	Linear regression coefficient (R^2)	E_a (KJ/mol)	ΔH_a (KJ/mol)	ΔS_a (J/mol K)	$E_a - \Delta H_a$ (KJ/mol)	Linear regression coefficient (R^2)
Blank	9.76×10^{10}	0.9888	42.520	39.880	-100.86	2.640	0.9871
250	1.26×10^{12}	0.9908	50.547	47.906	-79.56	2.641	0.9896
500	4.52×10^{12}	0.9986	52.149	50.644	-68.95	1.505	0.9984
750	6.69×10^{12}	0.9979	54.299	52.113	-66.85	2.186	0.9960
1000	8.23×10^{12}	0.9999	55.088	53.130	-63.95	1.958	0.999

Tables 39-44 represent the values of linear regression coefficient (R^2), equilibrium of constant adsorption $K_{ads}$and free Gibb's energy (ΔG_{ads}) which were evaluated from figure 4.39-4.44 using the appropriate equations in chapter 3.

Table 39: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of guava extract on Low Carbon Steel in 0.5M HCl at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9913	1047.23	-27.641
313	0.9906	1063.60	-28.593
323	0.9968	1110.99	-29.623
333	0.9887	1150.09	-30.637

Table 40: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of banana extract on Low Carbon Steel in 0.5M HCl at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9888	942.774	-27.376
313	0.9835	925.583	-28.232
323	0.9497	920.895	-29.120
333	0.9433	868.433	-29.859

Table 41: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of almond extract on Low Carbon Steel in 0.5M HCl at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9967	757.46	-26.825
313	0.9910	718.96	-27.574
323	0.9973	660.28	-28.226
333	0.9945	586.89	-28.774

Table 42: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of guava extract on Low Carbon Steel in 0.5M H_2SO_4 at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9984	699.59	-26.624
313	0.9974	721.87	-27.584
323	0.9997	662.30	-28.235
333	0.9982	451.00	-28.045

Table 43: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of banana extract on Low Carbon Steel in 0.5M H_2SO_4 at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9977	768.70	-26.862
313	0.9962	758.32	-27.713
323	0.9999	735.02	-28.514
333	0.9984	688.37	-29.216

Table 44: Values of thermodynamic parameters (from Langmuir adsorption isotherm) for the adsorption of almond extract on Low Carbon Steel in 0.5M H_2SO_4 at different temperatures.

T (K)	Linear regression coefficient (R^2)	K_{ads} (mol^{-1})	ΔG_{ads} (KJ/mol)
303	0.9999	718.70	-26.692
313	0.9945	753.13	-27.695
323	0.9967	700.72	-28.386
333	0.9956	545.43	-28.571