

**EFFECTS OF AFRICAN BASIL(*Ocimumgratissimum*) AND BUSH
MINT(*Hyptissuaveolens*) LEAVES EXTRACTS IN INHIBITING
CORROSION OF MEDIUM CARBON STEEL IN 0.5M OF HCl, H₂SO₄
AND NaCl MEDIA**

BY

FATAI AMBALI

M.SC/ENG/16067/2011-2012

**DEPARTMENT OF MECHANICAL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY, ZARIA.
NIGERIA**

SEPTEMBER, 2015

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AND NaCl MEDIA**

BY

Fatai AMBALI, B.Eng. (BUK, Kano)

(M.SC/ENG/16067/2011-2012)

**A DISSERTATION SUBMITTED TO THE SCHOOL OF
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DEPARTMENT OF MECHANICAL ENGINEERING,

FACULTY OF ENGINEERING,

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

SEPTEMBER, 2015

DECLARATION

I declare that the work in this dissertation entitled “Effects of African Basil (*Ocimum gratissimum*) and Bush Mint (*Hyptissuaveolens*) Leaves Extracts in inhibiting corrosion of Medium Carbon Steel in 0.5M of HCl, H₂SO₄ and NaCl Media” was carried out by me in the Department of Mechanical Engineering under the supervision of Dr. D. S. Yawas and Prof.A. I. Obi. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented or intended to be presented for another degree or diploma at this or any other institution.

AMBALI, Fatai

SignatureDate

CERTIFICATION

This dissertation entitled “EFFECTS OF AFRICAN BASIL (*Ocimum gratissimum*) AND BUSH MINT (*Hyptissuaveolens*) LEAVES EXTRACTS AS CORROSION INHIBITORS OF MEDIUM CARBON STEEL IN 0.5M OF HCL, H₂SO₄ AND NACL MEDIA” by Fatai AMBALI meets the regulations governing the award of the degree of Master of Science in Mechanical Engineering of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Dr. D. S. Yawas.....

Chairman, supervisory committeeSignature

Date

Prof.A.I.Obi.....

Member, supervisory committeeSignature

Date

Dr. M. Dauda.....

Head of Department

Signature

Date

Prof. KabirBala.....

Dean, School of Postgraduate StudiesSignatureDate

DEDICATION

This research work is dedicated to the glory of the Most High God who is the custodian of all grace.

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ABSTRACT

In this study, extracts from *Ocimumgratissimum*(O.G) and *Hyptissuaveolens*(H.S) leaves were subjected to the following analyses: physicochemical and phytochemical analyses. The medium carbon steel samples were subjected to corrosion inhibition test using gravimetric method, mechanical tests (hardness, tensile, and impact) and surface morphology evaluation using scanning electron microscopy (SEM). The corrosion inhibition effects of the leaves extracts on medium carbon steel surface in 0.5M of HCl, H₂SO₄ and NaCl solutions were investigated at different temperatures (30, 40, 50 and 60°C). The results obtained show that the inhibition efficiency (IE) increased (with at least 1.8% in HCl, 1.6% in H₂SO₄ and 2.6% in NaCl)with increase in the inhibitors concentration (0-8% v/v) but decreases with increase in temperature from 30-60°C for both inhibitors. The results showed that O.G has highest IE of 82.9% in HCl, 73.4% in H₂SO₄ and 82.7% in NaCl. Also H.S has IE of 81.5% in HCl, 69.7% in H₂SO₄ and 88% in NaCl. As the concentration of the inhibitors increases, higher values of the positive activation energy (E_a) (from 32.80-53.1kJ/mol, 22.5-33.2kJ/mol and 20.3-37.7 kJ/mol in HCl, H₂SO₄ and NaCl respectively) and positive enthalpy of adsorption (ΔH)were obtained, indicating the physical adsorption and

endothermic nature of the inhibitors on carbon steel. Also the negative values of free energy of adsorption (ΔG_{ads}) (between 18kJ/mol-24kJ/mol) indicating a physisorption of the inhibitors and the adsorption of both O.G and H.S leaves extracts on the steel surface in the three media was found to obey the Langmuir adsorption isotherm. The results obtained from the mechanical properties of the steel showed higher values (97.5HRB, 637.5N/mm² and 52.2J) for the inhibited samples than uninhibited ones (96.5HRB, 559.3N/mm² and 46.0J). Finally the results obtained from SEM confirmed the high performance of the inhibitor by minimizing the pits and severe damage on the carbon steel samples.

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LIST OF ABBREVIATIONS AND SYMBOLS

Al –Aluminium

As - Arsenic

C -Carbon

Ca - Calcium

Co- Cobalt

Cr - Chromium

Cu - Copper

Fe - Iron

H₂O - Water

K - Kelvin

Mn–Manganese

Mo - Molybdenum

Ni - Nickel

OH⁻ -Hydroxyl ion

O - Oxygen

P –Phosphorus

S –Sulphur

Sb- Antimony

Si - Silicon

Sn - Tin

Te - Tellurium

V - Vanadium

Vs - Versus

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The deterioration of facilities by corrosion is a major problem in Construction Company, oil and gas, ship building and other engineering firms (Burubai and Dagogo, 2007). Corrosion of metals/alloys, which can be defined as the deterioration or disintegration of materials due to their reaction with the environment, has continued to receive attention in the technological world (Umoren, 2009). Like other natural hazards such as earthquakes or severe weather disturbances, corrosion can cause dangerous and expensive damage to everything from pipelines, bridges, and public buildings to vehicles, water and wastewater systems, and even home appliances. In addition to causing severe damage and threats to public safety, corrosion disrupts operations and requires extensive repair and replacement of failed assets (Gunter, 2009).

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, 2005). Carbon steel is a major material utilized in most structural members such as beams, plates, bars and pipes used both onshore and offshore. Considering the severity of the damage caused by corrosion in various engineering fields, there is need to retard the corrosion rate, if not to prevent it completely (Burubai and Dagogo, 2007).

There are several methods for prevention of corrosion which basically comprise those protective measures providing separation of metal surfaces from corrosive environments or those which cater for adjustment or altering the environment. These various methods of corrosion prevention

include cathodic protection, anodic protection, protective coatings, selection of materials, proper design, alloying, and the use of inhibitors (Burubai and Dagogo, 2007).

Corrosion inhibitors are of great practical importance, as they are extensively employed in reducing metallic waste in production, minimizing the risk of material failure and the consequent sudden shut-down in industrial processes that leads to added costs (Roberge, 1999). Inhibitors tend to ameliorate the destructive behaviour of an aggressive environment. Corrosion inhibitors are widely used in industry to prevent or reduce corrosion rate of metals in alkaline, acidic media and industrial processes such as acid pickling and cleaning of refinery equipment, oil well acidizing and acid descaling (Loto, 2005). The action of inhibitors is always associated with changes in the state of the surface being protected due to adsorption or formation of poorly soluble compounds with metal cations. The adsorption of the inhibitors onto the metal/alloy surfaces retards the cathodic or anodic electrochemical processes that accompany corrosion of the metal/alloy (Kuznetsov, 2004).

The use of chemical inhibitors has been very effective in addressing corrosion, but its use has been limited because of the environmental threats. These inhibitors may cause temporary or permanent damage to organs, namely; kidney or liver, or disturbing a biochemical process and enzyme system at some sites in the body. These known hazardous effects of most synthetic corrosion inhibitors are the motivation for the use of some natural products such as plants as corrosion inhibitors (Ambrish *et al.*, 2012).

The use of naturally occurring plant extracts as inhibitors is particularly interesting and economical because they are readily available, renewable sources of materials, non-toxic, ecological friendly and poses little or no threat to the environment. Moreover, they can be extracted by simple procedures with low cost (Avwiri and Igho, 2003). Plant parts that have been

used include leaves, barks, fruits and the roots. In very many cases, the corrosion inhibitive effect of some plants extracts has been attributed to the presence of tannin in their chemical constituents (Loto, 2003).

The present research work focused on the use of African basil(*Ocimum gratissimum*) and bush mint (*Hyptis suaveolens*) leaves extracts as corrosion inhibitors of medium carbon steel in 0.5Molar Concentration of Sulphuric Acid (H_2SO_4), Hydrochloric Acid (HCl) and Sodium Chloride (NaCl) solutions. Both leaves were chosen because they are non toxic plants, which contain condensed tannin in their chemical constituents and available in the Northern and Southern parts of Nigeria.

Carbon steel was chosen because it is one of the major construction materials which is extensively used in chemical and allied industries for the handling of acid, alkali and salt solutions. Besides, carbon steel has been widely used as construction and fabrication materials for pipe works in the oil and gas production such as down hole tubular, flow lines, vessels, ancillary equipment and transmission pipe lines. This is primarily due to their availability, low cost, ease of fabrication and high strength.

The choice of Sulphuric and Hydrochloric Acids is connected to their predominant use in acid pickling, industrial cleaning, oil well acidizing, acid descaling etc.

1.2 Statement of Problem

In recent years, the deterioration of infrastructural installation such as buildings, roads, bridges, tunnels, train tracks, water distribution systems, energy distribution systems for electricity, gas and oil, communication systems and devices have become very obvious due to corrosion. Public safety is more and more at risk and some cases, lives have been lost from failure to adequately address these corrosion issues.

Corrosion in all types of metals is inevitable in operation. The case of petrochemicals and oil industries is worse as the economic losses and ecological damage caused by corrosion is high due to the very large number of metal equipment and structures that come into contact with highly aggressive media.

Oil spills are common events in Nigeria and occur due to a number of causes including: corrosion of pipelines, sabotage, oil production operation and non functional production equipment. Oil spill is a factor which causes massive aquatic deaths and denies farmers their right to plant crops and even simple access to cleaner and healthier water. The oil spills have caused land, air and water pollution, severely affecting surrounding villages by decreasing fish stocks, contaminating water supplies and arable land (Nduka *et al.*, 2008). According to the Nigeria National Oil Spill Detection and Response Agency (NOSDRA) approximately 2,400 oil spills has been reported between 2006 and 2010 that resulted from corrosion, sabotage, bunkering and poor infrastructure.

An example of the reported case is the spill and fire that occurred in Jesse, Delta State that claimed up to 1,600 lives of Nigerians. Its cause was connected to sudden failure of the pipeline resulting from different forms of corrosion attacks (Soyinka, 1998).

Since corrosion cannot be totally eradicated in any system, it is now important to develop means of retarding its effects which lead to the introduction of inhibitors. Therefore, this research work will help to reduce failure due to corrosion and increase the service life of infrastructural installation and safety of human life.



Plate I: Oil spillage in Niger Delta Region, Southern Nigeria (shell report, 2006).

1.3 The Present Research

In this research, juice extracts from *Ocimum gratissimum* and *Hyptis suaveolens* were used as corrosion inhibitors for medium carbon steel. The leaves extracts were introduced from 0-8% v/v with the interval of 2% into 0.5 Molar Concentration of Sulphuric Acid, hydrochloric Acid and Sodium Chloride solution.

The medium carbon steel rods were machined down to cylindrical shapes of standard dimensions for impact and tensile samples. The specimens were fully immersed in the test media containing the leaves extracts and the acid solutions, and each sample was taken out of the test solutions at various intervals, washed and reweighed to determine the weight loss, corrosion rate, inhibition efficiency, the degree of surface coverage, tensile, hardness and impact strength of the steel.

1.4 Aim and Objectives

The aim of this research was to investigate the effect of African basil(*Ocimum gratissimum*) and bush mint (*Hyptis suaveolens*) leaves extracts in inhibiting corrosion of medium carbon steel in 0.5M of hydrochloric acid, sulphuric acid and sodium chloride solutions. The specific objectives are as follows:

- I. To extract juice from *Ocimum gratissimum* and *Hyptis suaveolens* leaves and to Prepare experimenting media.
- II. To carry out phytochemical and physicochemical analyses of the leaves extracts.
- III. To carry out corrosion test on medium carbon steel using weight loss method.
- IV. To analyse the efficiencies of the inhibitors on the samples at different concentrations and temperatures.
- V. To analyse the kinetic and thermodynamics parameters of the inhibitors.
- VI. To investigate the effect of corrosion on the mechanical properties (hardness, tensile, and impact test) of medium carbon steel specimens after corrosion test.
- VII. To carry out microstructure analysis of the specimen using Scanning Electron Microscopy (SEM).

1.5 Significance of the Study

Iron and its alloys are widely used in many applications, which have resulted in research in to corrosion resistance in various aggressive environments. Among the methods of preventing corrosion problem, corrosion inhibitors are of great practical importance, as they are extensively employed in reducing metallic waste in production, minimizing the risk of material failure and the consequent sudden shut-down in industrial processes that leads to added costs (Roberge, 1999).

Most of the corrosion inhibitors are synthetic chemicals that are toxic, expensive and very hazardous to environment. Therefore, it is desirable to source for environmentally safe inhibitors (Paul *et.*, 2012).

The investigation of this work is to develop inhibitors with low toxicities, biodegradable and good efficiency. It is also to promote low cost indigenous technology and to minimize corrosion problems using available and cheap corrosion inhibitors.

In a nut shell, The use of naturally occurring plant extracts have been chosen because they are readily available, renewable sources of materials, non-toxic, ecological friendly, poses little or no threat to the environment and very easy to process.

1.6 Scope of the Study

The present study encompassed the following:

- I. The extracts from *Ocimum gratissimum* and *Hyptis suaveolens* leaves were used as corrosion inhibitors.
- II. Carry out weight loss analysis on the medium carbon steel after corrosion test in the presence and absence of each inhibitor at both room and elevated temperature.
- III. Preparation of specimens from medium carbon steel of known compositions and immersed into aqueous solutions of hydrochloric acid, sulphuric acid and sodium chloride containing the extracts from each inhibitor.
- IV. Scanning electron microscopy (SEM) examination of the metal surface in contact with hydrochloric acid and sulphuric acid with and without the inhibitors.
- V. Carry out hardness, tensile and impact test on the specimens before and after the corrosion test in the presence and absence of each inhibitor.

1.7 Definitions of Terms

- I. Inhibitor: it is a substance which when added to corrosive media decreases or prevents the corrosion rate of the metal.
- II. Adsorption: is the adhesion of atoms, ions or molecules from a gas, liquids or dissolved solid to a surface. This process creates a film of the adsorbate (Inhibitor) on the surface of the adsorbent (carbon steel).
- III. Tannin: is an astringent, bitter plant polyphenolic compound that bonds to and precipitates proteins and various other organic compounds like amino acids and alkaloids.
- IV. Ameliorate: to make something become better or improve.
- V. Onshore: happening or existing on the land.
- VI. Offshore: happening or existing in the sea.

CHAPTER TWO

2.0

LITERATURE REVIEW

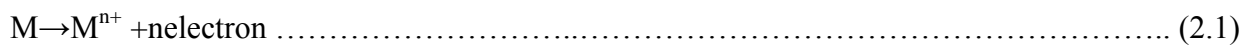
2.1 Corrosion

Corrosion can be defined as the deterioration of material by reaction with its environment. The corrosion occurs because of the natural tendency for most metals to return to their natural state; e.g., iron in the presence of moist air will revert to its natural state, iron oxide. Most metals corrode on contact with water (and moisture in the air), acids, bases, salts, oils, aggressive metal polishes, and other solid and liquid chemicals. The best known case is the rusting of steel (Rani and Basu, 2012).

Corrosion is usually characterized by two conjugate reactions, viz- anodic and cathodic reactions the anodic reaction involves the dissolution of the metal accompanied by the release of electrons from the metal.

For electrochemical reactions to occur there must be a cathode, anode and electrolyte whose site may shift as the corrosion reaction occurs. The cathode is the negative pole where chemical reduction occurs while the anode is the positive pole where oxidation occurs leading to the conversion of the metal at this pole to its hydrated ions thus corroding (Ogusie *et al.*, 2010).

At the anode, the metal is oxidized as



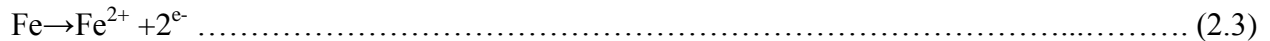
Where M is the metal and n is number of electron

At the cathode site, oxygen reduces as

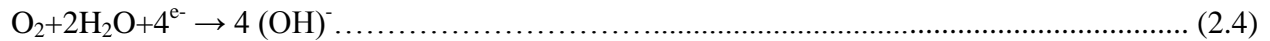


For steel, corrosion occurs in stages. At the onset attack occurs at anodic areas on the surface where ferrous ions go into solution, electrons are released from the anode and move through the metallic structure to adjacent cathodic sites where they combine with oxygen and water.

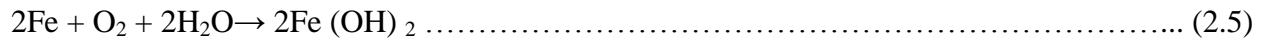
At the anode,



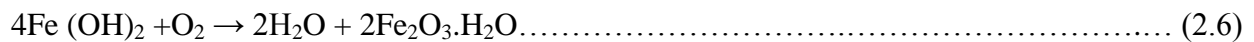
At the cathode,



Combining equations (2.3) and (2.4) gives



The hydroxyl ions (OH⁻) react with the ferrous ions from the anode to produce ferrous hydroxide, which is further oxidized in air to produce hydrated ferric oxide (red rust). This type of corrosion occurs when there is no water or moisture to aid the corrosion.



Iron hydroxide + Oxygen → Water + hydrated iron oxide

Corrosion leads to loss of strength, hardness, toughness and other desirable mechanical properties which the metal possesses (Yawas, 2005).

2.2. Forms of Corrosion

Corrosion occurs in several and widely differing forms. Classification is based on one of three factors:

- Nature of the corrodent: corrosion can be classified as ‘wet’ or ‘dry’.

Dry corrosion: This type of corrosion occurs when there is no water or moisture to aid the corrosion, and the metal oxidizes with the atmosphere alone. It occurs when oxygen in the air reacts with metal without the presence of a liquid. 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 gases.

Wet corrosion:Wet corrosion takes place when a liquid is present. It usually involves an aqueous solution or electrolyte. This type of corrosion is the common type. This is because most of the harm caused by corrosion around us can be traced to the fact that there is presence of liquid. A good example is corrosion of turbine blade by water.

- Mechanism of corrosion: this involves either direct chemical or electrochemical reactions.

Direct chemical attack, or pure chemical corrosion, is an attack resulting from a direct exposure of a bare surface to caustic liquid or gaseous agents.

An electrochemical attack may be likened chemically to the electrolytic reaction that takes place in electroplating, anodizing, or in a dry cell battery. The reaction in this corrosive attack requires a medium, usually water, which is capable of conducting current of electricity. When a metal comes in contact with a corrosive agent and is also connected by a liquid or gaseous path through which electrons may flow, corrosion begins as the metal decays by oxidation.

- Appearance of the corroded metal: corrosion is either uniform and the metal corrodes at the same rate over the entire surface, or it is localized, in which case only small areas are affected.

Classification by appearance, which is particularly useful in failure analysis, is based on identifying forms of corrosion by visual observation with either the naked eyes or magnification.

The morphology of attack is the basis for classification as well as the type of environment to which the material is exposed (Callister, 2003). Eight major forms of wet corrosion can be identified based on appearance of the corroded metal. These are discussed as follows:

2.2.1 Uniform Corrosion

Uniform corrosion is a generalized corrosive attack that occurs over a large area on the surface of

a material. It is the most common form of corrosion encountered with the majority of metals, a classic example being the rusting of carbon steel. It is only dependent upon the material's composition and the environment. It is recognized as a general dulling of the surface and, if allowed to continue, the surface becomes rough and possibly frosted in appearance. The result is a thinning of the material until failure occurs. Uniform corrosion rates are fairly predictable, following an exponential relationship as follows (Benjamin *et al.*, 2006).

$$p = At^{-B} \dots\dots\dots (2.7)$$

Where p is corrosion rate (mm/yr), t is exposure time (hrs), A, B is constants, dependent upon material and environment.

The decrease in corrosion rate with time is a direct result of an oxide scale layer forming on the metal's surface, which then deters further corrosion from occurring. There are extreme cases however, where the corrosivity of the environment is severe and prevents an oxide layer from forming. In this case, the corrosion rate will be constant with time (Benjamin *et al.*, 2006).

Uniform corrosion can be prevented or reduced by:

- I. Using organic or metallic coatings wherever feasible.
- II. The use inhibitors.
- III. Cathodic protection.
- IV. Chemical resistant protective coating (Benjamin *et al.*, 2006).

2.2.2 Galvanic Corrosion

Galvanic corrosion is an electrochemical action of two dissimilar metals in the presence of an electrolyte and an electron conductive path. It occurs when dissimilar metals are in contact. It is recognizable by the presence of a buildup of corrosion at the joint between the dissimilar metals. Systems meeting these requirements essentially form an electrochemical cell which will conduct

electricity. The induced electrical current can then attract electrons away from one of the metals, which thus acts as the anode in the electrochemical cell. This usually results in acceleration of the rate of corrosion of the anode. The opposing metal, the cathode, will consequently receive a boost in its resistance to corrosion, since it can supply any imminent corrosion reactions with electrons from an external source. Galvanic corrosion is usually observed to be greatest near the surface where the two metals are in contact (Benjamin *et al.*, 2006).

Galvanic corrosion can be prevented by:

- I. The use of one material to fabricate electrically isolated systems or components where practical.
- II. Selecting combinations of metals as close together as possible in the galvanic series.
- III. Avoiding the unfavorable area effect of a small anode and large cathode.
- IV. Insulating dissimilar metals wherever practical [for example, by using a gasket].
- V. Applying coatings with caution.
- VI. Adding inhibitors, if possible, to decrease the aggressiveness of the environment.
- VII. Avoiding threaded joints for materials far apart in the series.

2.2.3 Crevice Corrosion

Crevice or contact corrosion is the corrosion produced at the region of contact of metals with metals or metals with non metals. It occurs as a result of water or other liquid entrapment in localized areas dependent upon component/system design. These designs include primarily sharp angles, fasteners, joints, washers and gaskets. Crevice corrosion can also occur under debris build up on surfaces, sometimes referred to as “poultice corrosion.” Poultice corrosion can be quite severe; due to an increasing acidity in the crevice area. Crevice corrosion may begin through the

action of an oxygen concentration cell and continue to form pitting (Benjamin *et al.*, 2006).

Crevice Corrosion can be prevented by:

- I. Designing new components and systems to minimize areas where crevice corrosion may occur.
- II. Employing welded joints rather than fastened joints.
- III. Selecting resistant materials to crevice corrosion in the intended environment.
- IV. Avoiding the use of hydrophilic materials in fastening systems and gaskets.
- V. The proper use of sealants to prevent the ingress of water.
- VI. Frequent inspection of equipment and removal of surface deposits.
- VII. The use of protective coatings and cathodic protection.

2.2.4 Pitting Corrosion

Pitting corrosion, also simply known as pitting, is an extremely localized form of corrosion that occurs when a corrosive medium attacks a metal at specific points causing small holes or pits to form. This usually happens when a protective coating or oxide film is perforated, due to mechanical damage or chemical degradation. Pitting can be one of the most dangerous forms of corrosion because it is difficult to anticipate and prevent, relatively difficult to detect, occurs very rapidly, and penetrates a metal without causing it to lose a significant amount of weight (Benjamin *et al.*, 2006).

Pitting Corrosion can be prevented or reduced by:

- I. Proper selection of materials.
- II. The use of inhibitors.
- III. Application of protective coating and cathodic protection.

2.2.5 Intergranular Corrosion

Intergranular corrosion is a form of relatively rapid and localized corrosion associated with a defective microstructure known as carbide precipitation. It is the preferential attack at, or adjacent to the grain boundaries of a metal. Almost all engineering metals are composed of individual crystals, or grains that meet at areas of relative impurity and misalignment. Intergranular corrosion occurs when the grain boundaries or areas directly adjacent to them are anodic to the surrounding grain materials. This can happen because of differences in impurity levels or strain energy of the misalignment of atoms in the grain boundaries (Benjamin *et al.*, 2006).

Methods to limit intergranular corrosion include:

- I. Keep impurity levels to a minimum.
- II. Proper selection of heat treatments to reduce precipitation at grain boundaries.
- III. Specifically for stainless steels, reduce the carbon content, and add stabilizing elements (Ti, Nb, Ta) which preferentially form more stable carbides than chromium carbide.
- IV. Proper material selection, design, fabrication and weld procedures.
- V. Modification of the environment

2.2.6 Selective Leaching (dealloying corrosion)

Dealloying, also called selective leaching, is a corrosion process in which one element of an alloy is removed preferentially, leaving an altered residual structure. Many alloys consist of mixtures of elements (for instance, brass is produced from zinc and copper), where one element can be anodic with respect to the other element(s) and can selectively corrode by galvanic action. This phenomenon is commonly detectable as a colour change or drastic change in mechanical

strength. For examples, brasses will turn from yellow to red and cast irons will turn from silvery gray to dark gray (Benjamin *et al.*, 2006).

Dealloying is a dangerous form of corrosion because it reduces a strong, ductile metal to one that is weak, brittle and subsequently susceptible to failure. Since there is little change in the metal's dimensions dealloying may go undetected, and failure can occur suddenly (Benjamin *et al.*, 2006).

Methods to limit Selective Leaching include:

- I. Modification of environment.
- II. Cathodic protection can also be used for prevention.
- III. Proper selection of a resistant material such as red brass, this only contains 15% Zn.
- IV. Application of protective coating and cathodic protection.
- V. The use of inhibitors

2.2.7 Erosion Corrosion

Erosion corrosion is a form of attack resulting from the interaction of an electrolytic solution in motion relative to a metal surface. The protective layers and corrosion products of the metal are continually removed exposing fresh metal to corrosion. Mechanical erosion is caused by hard particles impacting the surface, causing craters in the metal. Erosion corrosion is evident in pipelines, cooling systems, valves, boiler systems, propellers, impellers, as well as numerous other components. Specialized types of erosion corrosion occur as a result of impingement and cavitation. Impingement refers to a directional change of the solution whereby a greater force is exhibited on a surface such as the outside curve of an elbow joint. Cavitation is the phenomenon of collapsing vapor bubbles which can cause surface damage if they repeatedly hit one particular location on a metal (Benjamin *et al.*, 2006).

Methods to limit Erosion corrosion include:

- I. Avoid turbulent flow.
- II. Add deflector plates where flow impinges on a wall.
- III. Add plates to protect welded areas from the fluid stream.
- IV. Put piping of concentrate additions vertically into the center of a vessel.
- V. Application of protective coating and cathodic protection.
- VI. Proper selection of a material with better resistance to erosion corrosion.

2.2.8 Stress-Corrosion Cracking (SCC)

Stress corrosion is an environmentally induced cracking phenomenon that sometimes occurs when a metal is subjected to a tensile stress and a corrosive environment simultaneously. It is a process that takes place within the material, where the cracks propagate through the internal structure, usually leaving the surface unharmed. Most cracks tend to propagate in a direction that is perpendicular to the direction of applied stress. Stress may be internally or externally applied (Benjamin *et al.*, 2006).

The stresses involved in SCC can be due either to normal service loads or residual stresses resulting from manufacturing and assembly processes. Examples of manufacturing processes which could lead to residual stresses include casting, welding, cold forming and heat treatment.

There are several methods that may be used to minimize the risk of SCC. Some of these methods include:

- I. Selection of a material that is resistant to SCC.
- II. Employ proper design features for the anticipated forms of corrosion.
- III. Proper design to minimize thermal and residual stresses.
- IV. Environment modifications (pH, oxygen content).

- V. Use surface treatments (shot peening, laser treatments) which increase the surface resistance to SCC.
- VI. Application of protective coating and cathodic protection.
- VII. The use of inhibitors.

2.3. Corrosion Inhibitors

Inhibitors are substances that react with the surface of a material decreasing the materials corrosion rate, or interact with the operating environment to reduce its corrosivity. Inhibitors may be introduced into the environment in which the material is operating as solutions or dispersions to form a protective film. For instance, they can be injected into a completely aqueous recirculation system (e.g. automobile radiators) to reduce the corrosion rate in that system. They may also be used as additives in coating products, such as surface treatments, primers, sealants, hard coatings, and corrosion preventive compounds (CPCs). Furthermore, some inhibitors can be added to water that is used to wash a vehicle, system or component (Benjamin *et al.*, 2006).

Corrosion inhibitors interact with the metal, slowing the corrosion process by:

- I. Shifting the corrosion potential of the metal's surface toward either the cathodic or anodic end.
- II. Adsorption of ions or molecules onto metal surface.
- III. Increasing the electrical resistance of the metal by passivating the surface.

2.3.1 Classification of Corrosion Inhibitors

Inhibitors are usually grouped into five different categories:

- I. Passivators
- II. Cathodic Inhibitors

- III. Organic Inhibitors
- IV. Precipitation Inhibitors
- V. Vapour phase Inhibitors.
- VI. Anodic Inhibitors

2.3.1.1 Passivators

Passivators are a specific type of anodic inhibitor and the most common type of inhibitors mainly because they are very effective in reducing the rate of corrosion. They protect the material by aiding in the formation of a thin, inert film on the surface of a metal, there by moving its corrosion potential toward the noble region, which effectively passivates the metal. Passivators can be either oxidizing (such as nitrites, nitrates and chromates), which do not require oxygen to be present, or no oxidizing (such as phosphates and molybdates), which do require oxygen to be present in the environment. The primary disadvantage of passivators is that they can actually accelerate localized corrosion on the material being protected if the concentration of inhibitors falls below a critical concentration (Benjamin *et al.*, 2006).

2.3.1.2 Cathodic Inhibitors

Cathodic inhibitors specifically target the cathodic region of the metal or electrochemical cell and provide protection by inhibiting the rate of the cathodic reaction. This is generally accomplished by building a barrier layer to obstruct the corrosive agents from accessing the metal surface or by preventing the reagents in the cathodic process from forming their normal products (e.g. hydrogen gas). For example, certain inhibitors can precipitate on selected cathodic areas of the metal to form a barrier, effectively isolating the metal from the environment. Also, other inhibitors can preemptively occupy or react with hydrogen or oxygen, for example, and keep them from forming hydrogen gas or, in the case of oxygen, keep it from oxidizing the

metal. Calcium bicarbonate, zinc compounds, and polyphosphates are examples of cathodic inhibitors (Benjamin *et al.*, 2006).

2.3.1.3 Organic Inhibitors

Unlike cathodic inhibitors, organic inhibitors tend to be active over the entire metal by adsorbing to the surface to form a thin, water-displacing film. The strength of the adsorptive bond between the metal and the film is a key factor in determining the level of protection the inhibitor will provide. This bonding strength is primarily dependent on the relative ionic charge between the metallic surface and the organic inhibitor. Anionic inhibitors (inhibitors with a negative ionic charge), such as sulphurnates, are used for positively charged metal. Cationic inhibitors (inhibitors with a positive ionic charge), such as amines, are used for a negatively charged metal (Benjamin *et al.*, 2006).

2.3.1.4 Precipitation Inhibitors

Precipitation inhibitors are chemicals that can induce the formation of precipitates on a metal. The precipitates tend to cover the entire surface of the metal and act as somewhat of a barrier to the corrosive environment. Examples of precipitation inhibitors are silicates (e.g. sodium silicate) and phosphates (Benjamin *et al.*, 2006).

2.3.1.5 Vapour Phase Inhibitors

Vapour phase inhibitors (volatile corrosion inhibitors) are inhibitors that have high vapour pressures which rapidly spread in to the surrounding atmosphere and are then adsorbed in metallic surfaces, protecting them from atmospheric corrosion (Benjamin *et al.*, 2006).

2.3.1.6 Anodic Inhibitors

The inhibitors that cause the formation or maintenance of passive film on the iron surface are called anodic inhibitors. The films forms are essentially prevent the anodic dissolution of the

metal. These are primarily inhibitors of oxidizing action. The action of oxidant on the anodic process can lead to establishment of passivity (chemical formation of protective films on the anode) and therefore halt corrosion.

Thus oxidants are considered as dangerous inhibitors; in as much as at low concentrations (particularly in the presence of activating anions) they accelerate corrosion (Yawas, 2005).

2.3.2 Inhibitor Compounds

Inhibitors may be inorganic or organic materials. Inorganic inhibitors are usually crystalline salts including sodium chromates, phosphates and molybdates. The negative ions of these materials are responsible for reducing corrosion. Organic inhibitors include sodium sulphurnates, phosphonates, mercaptobenzotriazole (MBT), and aliphatic or aromatic compounds containing positively charged amine groups. Inhibitors may be produced into liquids, solids including hard and soft materials, or vapours to be used in numerous applications. Their greatest use comes in systems involved with liquid heating or cooling systems. Inhibitors are introduced into the liquid media and the concentration and/or the corrosion rate of the system monitored to maintain an optimal concentration level. The selection of inhibitors will depend upon the metal requiring protection, as well as the operating environment (Benjamin *et al.*, 2006).

2.4 Mechanical Properties of Metals

Many materials, when in service, are subjected to forces or loads; examples include the aluminium alloy from which an air plane wing is constructed and the steel in an automobile axle. In such situations it is necessary to know the characteristics of the material and to design the member from which it is made such that any resulting deformation will not be excessive and fracture will not occur. The mechanical behaviour of a material reflects the relationship between its response and deformation to an applied load or force. Important mechanical properties are

strength, hardness, ductility and stiffness. The mechanical properties of materials are ascertained by performing carefully design laboratory experiments that simulate as nearly as possible the service conditions. Factors to be considered include the nature of the applied load and its duration, as well as the environmental conditions. It is possible for the load to be tensile, compressive, or shear, and its magnitude may be constant with time, or it may fluctuate continuously. Application time may be only a fraction of a second, or it may extend over a period of many years. Service temperature may be an important factor.

2.5 Plants Descriptions

2.5.1 *Ocimum gratissimum* leaf

Ocimum gratissimum (O.G) is an herbaceous plant belongs to the Labiatae family. This herb is called tree basil, shrubby basil and African basil in English. The plant is indigenous to tropical and warm temperature region such as India and Nigeria (Nadkarni, 1999). In Nigeria, the plant is called “effirin” by the Yoruba speaking tribe. It is called “Ahuji” by the Igbos, while in the Northern part of Nigeria; the Hausas call it “Daidoya” (Efraim *et al.*, 2003). O.G is mainly used as food spice and traditional herbs which has been recommended for the treatment of various diseases such as diabetes, diarrhoea, prevention of convulsions and seizures.

The plant is woody at the base, grow around 1-3 metres in height, the stems are dark brown in colour bearing leaves from top to bottom, the leaves are narrow and oval in shape growing between 5-13cm in length and 3-9cm width and are green in colour with pale yellow flowers.

The plant gives out a sweet scent of camphor.

2.5.2 *Hyptis suaveolens* leaf

Hyptis suaveolens (H.S) is an upright and branched herbaceous plant belongs to the Lamiaceae family. This herb is called bush tea, bush mint and pignut in English. The plant is most common

tropical region, but sometimes also growing in sub tropical and semi arid environments (Bostock and Holland, 2007). It is commonly used as a refreshing healthy drink and as a treatment for diarrhoea.

The plant is usually growing around 1-1.5 meters in height, the stems are hairy and square in cross section, and the leaves are oppositely arranged 2-10cm long with shallowly toothed margins and emit a strong mint odour if crushed. Flowers are pink or purple, arrange in clusters of 1-5 in the upper leaf axils.



Plate II: *Ocimum gratissimum*(Fred, 2009)



Plate III: *Hyptis suaveolens* ((Bostock and Holland, 2007).

2.6 Review of Past Works

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, 0.3M H₂SO₄ and 0.3M 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.

Yawas (2005) made a suitability assessment of neem, mahogany, cashew, locust bean husk and acacianolitical pod extracts as corrosion inhibitors. Neem, sesame, mahogany, soya bean, cotton and groundnut seed oils were also analyzed. The results he got from his analyses showed that inhibition efficiencies increased with increase in inhibitor concentrations and temperature but decreased in the case of cotton seed and sesame oil. It is also showed the ability of the inhibitors to reduce stress corrosion cracking of carbon steel in acidic media.

El-Etre (2007) investigated the inhibitive action of the aqueous extract of olive (*Olea europaeal.*) 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 increasing extract concentration. Their 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 the temperature is increased.

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 0.5M HCl and H₂SO₄ solutions using weight loss and gasometric techniques. Their results indicated that the extracts functioned as a good inhibitor in both environments and inhibition efficiency increased with extracts concentration. The temperature studied revealed an increase in inhibition efficiency with rise in temperature.

Quraishi *et al.*, (2009) studied the corrosion inhibition of mild steel in 0.5M and 1M hydrochloric acid solution by Black pepper extract (*Piper nigrum*fem*Piperaceae*) using weight loss measurements, potentiodynamic polarization, linear polarization resistance and electrochemical impedance spectroscopy (EIS). Their results revealed that Black pepper extract was a good corrosion inhibitor for mild steel in hydrochloric acid medium and maximum inhibition efficiency (98%) was found at 120 ppm at 35 °C. Potentiodynamic polarization curves showed that black pepper extract was a mixed-type inhibitor. EIS showed that the charge transfer controlled the corrosion process in inhibited solutions. The results obtained show that the Black pepper extract which mainly contains alkaloid ‘Piperine’ served as an excellent green inhibitor for corrosion of mild steel in acid solutions.

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. Their 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.

Oguzie *et al.*, (2010) investigated the inhibition of low-carbon-steel corrosion in 1 M HCl and 0.5 M H₂SO₄ by extracts of *Dacryodisedulis* (DE) using gravimetric and electrochemical techniques. They found out that the extract inhibit the uniform and localized corrosion of carbon steel in the acidic media, affecting both the cathodic and anodic partial reactions.

Quraishi *et al.*, (2010) studied the inhibition of the corrosion of mild steel in 1 M HCl and 0.5 M H₂SO₄ acid solutions by the extract of *Murrayakoenigii* leaves using weight loss, electrochemical impedance spectroscopy (EIS), and linear polarization and potentiodynamic polarization techniques. They found out 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.

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 extract 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 steel with addition of extract. Their result also 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.

Kuburi (2011) investigated the effect of flow velocity and exposure time on the corrosion rate of low carbon steel in crude oil. The study was performed using neem oil and locus bean extracts as inhibitors. Results obtained showed a decrease in corrosion rate with time in uninhibited and inhibited systems but corrosion rate increased with increase in Reynolds number.

Loto *et al.*, (2011) investigated Corrosion and plants extracts inhibitive protection of mild steel specimens immersed in 0.5 M hydrochloric acid at ambient temperature by gravimetric and metallographic methods. Extracts of kola plant and tobacco in different concentrations were used as 'green' inhibitors. Addition of different concentrations of the plants extracts gave considerable reduction in the weight loss and in the corrosion rate of the test samples.

Sanusi and Hussein (2011) investigated on the corrosion effect of mild steel in orange juice using a weight loss technique. Corrosion aggressive substance was discovered to have significant impact on the degradation of equipment and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions. Their results revealed that the corrosiveness of sweet orange juice on mild steel was mainly a function of its acidity.

Shyamala and Kasthuri, (2011) investigated the inhibitory 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 they 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.

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.

Ameh *et al.*, (2012) investigated the inhibitive effect of *Ficusglumosagum* (FG) for the corrosion of mild steel in H₂SO₄ medium using the weight loss, gasometric, thermometric and scanning electron microscopy (SEM) techniques. The results they 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.

Ayeni *et al.*, (2012) investigated the effect of bitter leaf (*Vernoniaamygdalina*) extract as an inhibitor for aluminum silicon alloy in 0.5 M solution of caustic soda using weight loss method. From their result, it was found that the adsorption of *Vernoniaamygdalina* reduced the corrosion rate of this group of alloy in the alkaline medium.

Iloamaeke *et al.*, (2012) Studied Corrosion inhibition of mild steel in 0.5 M hydrochloric acid solution by the extract of *pterocarpussoyauxi* leaves using weight loss measurement at 30°C and 60°C. Their findings showed that the inhibition efficiency increase with an 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.

Nwigbo *et al.*, (2012) focused on the behaviour of palm wine as corrosion inhibitor for mild steel in (0.1 and 0.5 M) H₂SO₄ and NaOH solutions at 303 and 333 K temperatures and inhibitor concentrations using weight loss measurement. Their results showed that weight loss decreased as concentration of both solutions studied increased. The inhibitor performed better under the basic solution compared to the acidic solution. The kinetics results showed that activation energy increased as temperature and inhibitors concentration increased. Palm wine inhibitor adsorbed on the surface of mild steel through physical adsorption.

Paul *et al.*, (2012) evaluated the inhibitive effect of *Ficusglumosagum* (FG) for the corrosion of mild steel in H₂SO₄ 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 and showed that inhibition efficiency increased with increasing temperature.

Nnanna *et al.*, (2013) investigated the adsorption of *Gnetumafricana* leaves extract and corrosion inhibition of carbon steel in 1M hydrochloric acid solutions using gravimetric technique. Inhibition efficiency increased with extract concentration and time of exposure. The effect of temperature on the corrosion behavior of mild steel in 1.0 M HCl with addition of plant extracts was studied at the temperature range of 303–333±1K. Inhibition efficiency of 92.42% was obtained.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This section outlines the various materials and equipment used for this research work, as well as the experimental procedures.

3.1 Materials

The materials used were:

1. Medium carbon steel rods with chemical compositions shown in Table 3.1 analyzed at Dana Steel Rolling Mills, Katsina by spectrometry method. This was done to determine the elements present and their percentage in the steel.
2. Fresh leaves of O.G and H.Swere obtained from Samaru, Zaria, Nigeria.
3. 9 litres each of 0.5 molar concentrations of HCl, H₂SO₄ and NaCl solutions.
4. Distilled water, acetone and 1ml of phenolphthalein.
5. 0.5M potassium hydroxide, 50ml of a mixture of 95% ethanol and ether.

Table 3.1: Elemental Composition of Medium Carbon Steel (Dana Steel Rolling Mills, Katsina).

Elements	C%	Si %	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%
Compositions, wt (%)	0.348	0.221	0.745	0.032	0.035	0.033	0.017	0.128	0.316

Co%	Al%	V%	Sn%	As%	Ca%	Sb%	Te%	Fe%
0.013	0.001	0.001	0.027	0.014	0.001	0.017	0.003	98

3.2 Equipment

The equipment used were:

1. 250ml and 500ml Beakers
2. Desiccator
3. GR-200EC Satorious digital mass balance with max 210g, min10mg made from A & D instrument ltd, Japan.
4. 1000ml Measuring cylinder
5. Threads
6. Cold pressing apparatus is used for the extraction of juice from the leaves
7. Water bath
8. Center lathe machine
9. Vernier caliper
10. Volumetric flask
11. pH testing machine
12. Phenom Prox Scanning Electron Microscope with 80-130,000X electron optical magnification, $\leq 14\text{nm}$ resolution, up to 32mm (\O) size and 100mm height, made in Phenom World, Netherland.
13. Hounsfield Tensometer with capacity of 20kN, made in Tensometer Limited, England
14. Hounsfield Balance Impact Machine with capacity of 65.079J, made in Tensometer Limited, England.
15. 8187.5LKV (B) Indentec universal hardness testing machine with minor load =10kgF, major load = 100kgF, made in U.K.
16. 320 and 600 grits emery paper, Bottle, Thermometer, Pestle and mortar

3.3 Experimental Procedures

3.3.1 Preparation of Solutions.

3.3.1.1 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 36% and a molar mass of 36.5g/mol .

To obtain the volume of the acid required to prepare a dilute solution, the following relation was used (Ojokuku, 2001).

$$V_o = \frac{CV}{C_o} \quad \text{where } C_o = \frac{10P\rho}{M}$$

$$\text{Therefore, } V_o = \frac{MCV}{10P\rho} \dots\dots\dots \mathbf{3.1}$$

V_o is the volume of the concentrated acid, M is the molar mass, $C = 0.5$ molar is the concentration of dilute solution, $V = 1\text{dm}^3$ is the volume of dilute solution, P is percentage purity, ρ is the density and 10 is constant.

$$V_o = \frac{36.5 \times 1 \times 0.5}{10 \times 36 \times 1.18} = 0.04296\text{dm}^3 = 42.96 \text{ cm}^3$$

Therefore, 42.96 cm^3 of the concentrated acid was added to distil water in a 1dm^3 volumetric flask to prepared 0.5 molar HCl solutions.

3.3.1.2 Preparation of 0.5M H₂SO₄ Acid

The concentrated H₂SO₄ acid used for this research has a density of 1.84g/cm^3 , a percentage purity of 98% and a molar mass of 98g/mol .

Using equation 3.1 above

$$V_o = \frac{98 \times 1 \times 0.5}{10 \times 98 \times 1.84} = 0.02717\text{dm}^3 = 27.17 \text{ cm}^3$$

Therefore, 27.17 cm^3 of the concentrated acid was added to distil water in a 1dm^3 volumetric flask to prepared 0.5 molar H₂SO₄ solutions.

3.3.1.3 Preparation of 0.5M NaCl Solution

The sodium chloride used for this work has Molar mass (M_w) of 58.44g/mol. To obtain the mass of sodium chloride required to prepare 0.5M NaCl solution, the following relation was used (Ojokuku, 2001).

$$W = \frac{CM_wV}{1000} \dots\dots\dots 3.2$$
$$= \frac{0.5 \times 58.44 \times 1000}{1000} = 29.22\text{g}$$

Where W is weight of NaCl, C is concentration (mol/dm^3) and V is the volume

Therefore, 29.22g of NaCl was dissolved in 1dm^3 of distill water in a standard flask to obtained the desired concentration.

3.3.2 Preparation of Specimen

The medium carbon steel rods were machined to the dimensions shown in Figure 3.1 and 3.2 for tensile and impact test samples respectively using centre lathe. Two hundred and forty six samples were made for impact, one hundred and thirty eight were made for tensile and ten samples for hardness. The surfaces of all the specimens were smoothed by emery paper (320 and 600 grits), thoroughly cleaned with dry cloth to remove the cutting fluid, dust and dirt. Weight measurements were taken using the electronic weighing balance to determine the original weight before immersion in the corrosive media. The chemical composition of the steel was carried out using spectrometry method. A pin to pin spark was impressed on the sample using a solid technique optical emission spectrograph with 0.0001% sensitivity and the reading was taken from a direct computerized spectrometer.

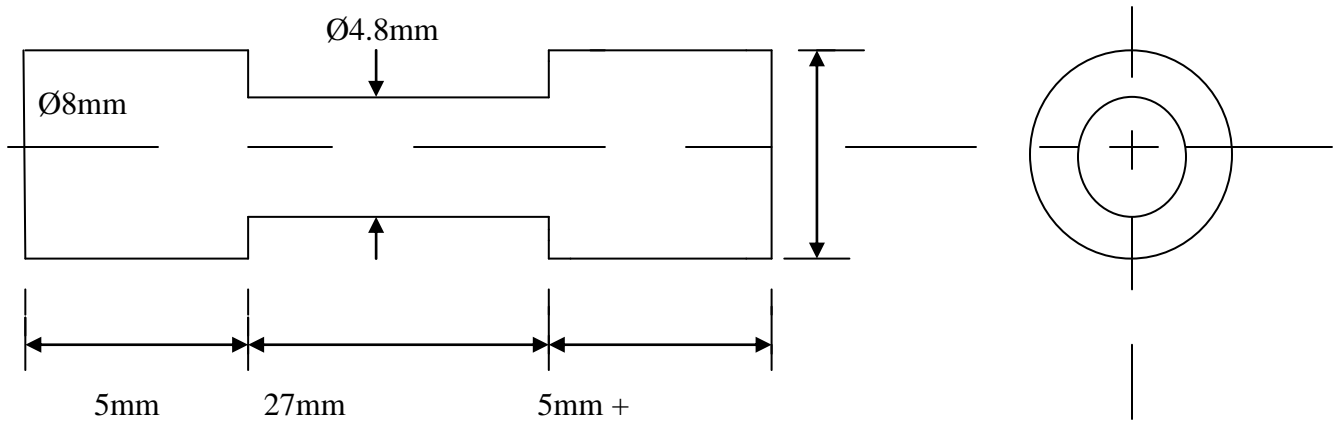


Figure 3.1: Tensile test specimen

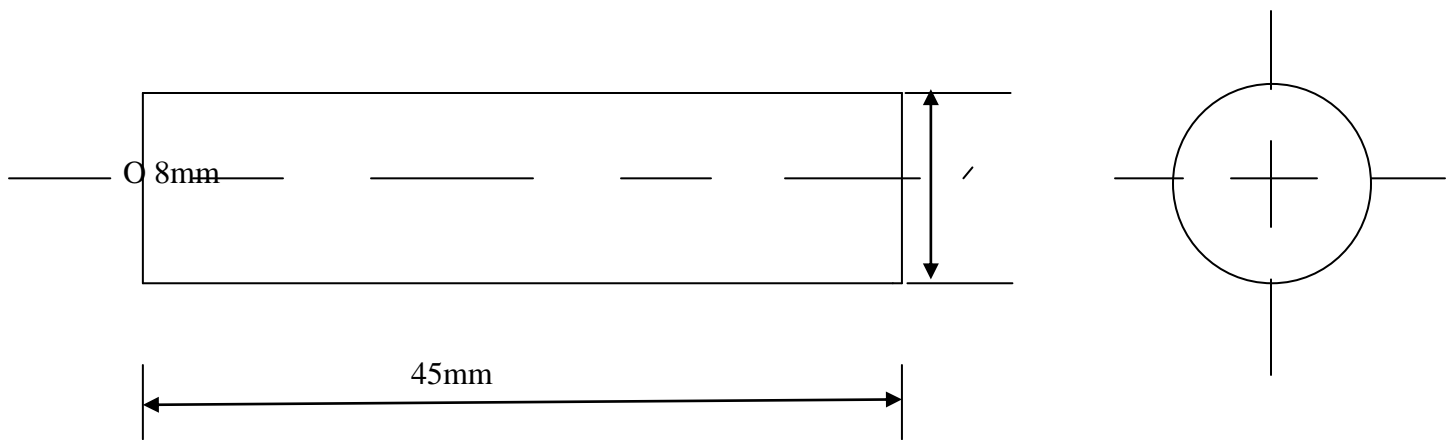


Figure 3.2: Impact test specimen

3.3.3 Preparation of Extracts

The process for preparing the leaves extracts is called cold pressing. This was done by grinding the leaves into even paste using pestle and mortar, and then compressed them to squeeze out the juice using cold pressing apparatus. The extracts were filtered at the end of the extraction period, stored in a clean bottle and covered properly. 1kg of *Ocimum gratissimum* leaf produced 620ml of the extract and 1kg of *Hyptis suaveolens* leaf produced 560ml of the extract using this process. The cold pressing set up is shown in plate IV. This was carried out in National Research institute for chemical technology (NARICT)



Plate IV: Cold Pressing Set up (National Research Institute for Chemical Technology)

3.3.4 Preparation of Test Media and Extracts

Solution of *Ocimum gratissimum* extract in 0.5M HCl, 0.5M H₂SO₄ and 0.5M NaCl were prepared in to different beakers. The percentages of *Ocimum gratissimum* in the prepared corrosive media were as follow: (v/v %) of 0%, 2%, 4%, 6%, and 8% respectively.

The same procedures were also used for *Hyptis suaveolens* extract.

3.3.5 Weight Loss Measurements

Five of the weigh test specimens for each tensile and impact test were fully immersed in each of the test media contained in a beaker for 25 days. Each specimen was taken out of the test media every 5 days, washed with distilled water to remove any corrodent products, dipped in acetone, dried and re-weighed. The weight loss was determined by finding the difference between initial and final weight of the specimen after 5 days of immersion. The equation for weight loss is expressed in equation 3.3(Umoren, 2009).

$$W = W_o - W_f \dots\dots\dots 3.3$$

Where *W* is weight loss after 5 days, *W_o* is initial weight and *W_f* is the final weight.

Besides, the specimens were then subjected to tensile and impact tests (i.e mechanical test) using the Hounsfield Extensometer (Tensile Testing Machine) and Hounsfield Impact Testing Machine respectively. The results were noted. Also the following mechanical properties were determined (tensile strength, impact strength and hardness) using the formulae below (Yawas, 2005):

Total Surface Area (A) for Tensile Tests Sample is given by

$$A = 2(2\pi r_1(r_1 + L)) + 2\pi r_2(r_2 + h) \dots\dots\dots 3.4$$

$$= 2(2\pi \times 4(4 + 5)) + 2\pi \times 2.4(2.4 + 27) = 896.13\text{mm}^2$$

$$= 8.9613\text{cm}^2$$

$$A_o = \pi D_o/4 \dots\dots\dots 3.5$$

$$\text{Ultimate Tensile Strength } (\sigma_u) = Pu/A_o \dots\dots\dots 3.6$$

Where A is area of specimen, r₁ radius of end parts of specimen, L is length of end parts, r₂ radius of middle part, h is length of middle part, A_o is the cross sectional area of tensile sample, D_o is diameter of gauge length, Pu is load and σ_u is tensile strength.

Total Surface Area (A1) for Impact Tests Sample is given by

$$A1 = 2\pi r(r + l) \dots\dots\dots 3.7$$

$$= 2\pi \times 4(4 + 45) = 1232.056\text{mm}^2$$

$$= 12.3206\text{cm}^2$$

Where A1 is the area, r is the radius of impact samples, l is length

3.3.6 Effect of Temperature

To elucidate the mechanism of inhibition and to determine the kinetic parameters of the corrosion process, weight loss measurements were performed at 303, 313, 323 and 333K. In this case the rods were retrieved from the solution after 6 hours of immersion, according to (Zhang

and Hua, 2009) using water bath. The difference in weight of the rods was again taken as the weight loss.

The rate of corrosion (CR), inhibition efficiency (IE), degree of surface coverage (Θ), film attractive free energy, activation energy (Ea), equilibrium constant of adsorption (K) and film heat of attraction were determined from the used inhibitors.

3.3.7 Microstructure Examination

In order to evaluate the surface condition of the metal in contact with HCl, H₂SO₄ and NaCl solutions in the absence and presence of both inhibitors, surface analysis were carried out using scanning electron microscopy analysis (SEM). This was done at the 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.

3.3.8 Corrosion Rates

Corrosion rate is defined as the amount of corrosion loss in thickness per year. The corrosion rates of the medium carbon steel in 0.5M of HCl, H₂SO₄ and NaCl solutions in the absence and presence of *Ocimum gratissimum* and *Hyptis suaveolens* leaves extracts were determined at room temperature. The equation for corrosion rate is expressed in equation 3.4 (Ayeni *et al.*, 2007). $C.R = 87.6W / \rho A t$

3.8. Where *C.R* is the corrosion rate in millimeter per year, *W* is the weight loss in mg; ρ is the density of the steel ($\rho = 7.86 \text{g/cm}^3$); *A* is the total surface area in cm^2 , *t* is the exposure time (hrs).

3.3.9 Inhibitor Efficiency(IE)

Inhibitor efficiency (IE) is defined as a level of performance of inhibitor that causes a decrease in corrosion rate. The Inhibitor efficiency (IE) was determined using the relationship in equation 3.5(Kuznetsov, 2004).

$$IE\% = \frac{(C.R)_o - (C.R)}{(C.R)_o} \dots\dots\dots 3.9$$

Where $(C.R)$ and $(C.R)_o$ are the corrosion rate in the presence and absence of inhibitor respectively.

The degree of surface coverage (θ) at each concentration of inhibitor was calculated using the following equation (Khaled, 2008).

$$\theta = \frac{(C.R)_o - (C.R)}{(C.R)_o} \dots\dots\dots 3.10$$

3.4 Thermodynamic and Kinetic Considerations

3.4.1 Activation Energy (E_a)

Activation energy (E_a) is defined as the minimum energy reacting molecules must possess before a chemical reaction can take place.

The apparent activation energy (E_a) for carbon steel corrosion in 0.5M HCl, 0.5M H₂SO₄ and 0.5M NaCl solutions in the absence and presence of inhibitor were evaluated from Arrhenius equation (Salih, 2007).

$$\text{Log}CR = \text{Log}A -$$

$$\frac{E_a}{2.303RT} \dots\dots\dots 3.11$$

Where E_a is the

activation energy of the reaction, A is the Arrhenius pre exponential factor, R is the gas constant, CR is the corrosion rate, and T is the absolute temperature.

3.4.2 Free Energy of Adsorption (ΔG_{ads})

Free Energy of Adsorption (ΔG_{ads}) 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 equations (Yawas, 2005).

$$(\Delta G_{ads}) = -RT \ln(55.5K_{ads}) \dots\dots\dots 3.12$$

Where

$$K_{ads} = \theta / C (1 - \theta) \dots\dots\dots 3.13$$

θ is the degree of surface coverage on the metal surface, C is the concentration of inhibitors (in %) and K_{ads} is the equilibrium constant.

3.4.3 Enthalpy(ΔH), and Entropy(Δs)of Adsorption)

Enthalpy is defined as a measure of the total energy of a thermodynamic system and entropy is the degree of disorderliness. The enthalpy (heat) (ΔH) and the entropy (Δs)of adsorption of the inhibitors were calculated from transition state equation (Umoren *et al.*, 2008).

$$C.R = RT / N_h \exp\left(\frac{\Delta S}{R}\right) \exp\left(-\frac{\Delta H}{RT}\right) \dots\dots\dots 3.14$$

Where C.R is corrosion rate, h is plank constant ($6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg/s}$), N is the Avogadro's number ($6.02214129 \times 10^{23}$) and R is the gas constant ($0.00831447 \text{ KJ/mol}$). The values of ΔH and Δs were obtained from the slope and intercept of $\text{Log } CR/T \text{ VS } 1/T$ respectively, with the slope equal $(-\Delta H/2.303R)$ and intercept equal $(\text{Log } \frac{R}{Nh} + \Delta s/2.303R)$.

3.5 Physicochemical Analysis of the Leaves Extracts

Quantitative analysis was used for the determination of the chemical composition of the extracts, according to the methods of the Society of Leather Trade Chemists (SLTC), (2002). This was carried out at Nigeria Institute of Leather and Science Technology (NILEST), Samaru, Zaria.

3.5.1 Determination of pH of the Extracts

pH value is a measure of the hydrogen ion activity of an aqueous solution. The pH of the leaves extracts was measured using a direct reading microprocessor digitalized machine. The machine measured the pH of the extracts at a temperature of 25.5°C . The machine used is shown in Plate V



Plate V: pH testing Machine (Nigeria Institute of Leather and Science Technology)

3.5.2 Determination of Boiling Point of the Extracts

The boiling point of the extracts was measured by putting 300ml of the extracts in a boiling tube, which was placed over a Bunsen burner. A thermometer was placed in it to measure the temperature change and the boiling point (Society of Leather Trade Chemists, 2002).

3.5.3 Determination of Density of the Extracts

The mass volume relationship was used to determine the density of the leaves extracts. Mass of 3ml of the extracts was measured into beaker and weigh with digital balance. The density was calculated by dividing the mass by the volume (Society of Leather Trade Chemists, 2002).

3.5.4 Determination of Acid Value (AV) of the Extracts

Acid value is the quantity of base expressed in milligram of potassium hydroxide that is required to titrate all acidic constituents present in a sample.

4g of the extracts was taken in a conical flask and 50ml of a mixture of 95% ethanol and ether were added. 1ml of phenolphthalein was added and the mixture was then titrate with 0.1M potassium hydroxide until a pink colour, which persists for 15s, was obtained. The volume of the potassium hydroxide required was measured and recorded as 'a'. The acid value (AV) was calculated using the equation below (British Herbal Medical Association, 1996);

$$AV = \frac{a \times 0.00561 \times 1000}{\text{weight of extract}} \dots \dots \dots 3.15$$

3.5.5 Determination of Moisture Contents of the Extracts

Moisture content was determined through the method of roasting in accordance with the official method of analysis No SLT 2/3 (a)

$$M_C = \frac{Fw - Dw}{Fw} \dots\dots\dots 3.16$$

Where M_C is the moisture content, Fw is the fresh weight of the leave and Dw is the dry weight. 10g of leaves were first weigh using weighing balance. Then they were dry in an oven to a constant weight at 100°C to 105°C.

3.5.6 Determination of Total Soluble of the Extracts

This was determine and calculated in accordance with SLT 2/3 c, the prepared leached extract was filtered of which the first 50ml was discarded. Another 50ml was filtered to an 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°C-100°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 weight was achieved.

3.5.7 Determination of Non-Tannins Content of the Extracts

The determination of substances not absorbable was done in accordance with the official method of analysis (Society of Leather Trade Chemists, 2002).

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 50-65rpm 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. 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°C-100°C to constant weight.

3.5.8 Determination of Tannins Content of the Extracts

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

Thus;

Tannin content= total soluble-non tannin

% of Tannin= % total soluble-% non-tannin (Society of Leather Trade Chemists, 2002).

3.6 Phytochemical Analysis of the Leaves Extracts

Phyto-chemical screening is the application of simple chemical tests to detect the presence of accumulated natural products such as carbohydrate, cardiac glycosides, flavonoids, tannins etc in the plant extract. These are referred to as secondary metabolites and they are responsible for the therapeutic properties of the plants (Yawas, 2005). This test was carried out in the Department of Pharmacognosy, Ahmadu Bello University (ABU) Zaria, Nigeria. Below are the tabulated procedures for the analysis.

Table 3.2 Phyto-chemical Tests Procedures (Department of Pharmacognosy, Ahmadu Bello University)

1.0 Test for Carbohydrates Using Molisch's Test			
	Test	Observation	Inference

	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 Using Keller-Killiani Test

	Test	Observation	Inference
	Extract was mixed with 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 Anthraquinone Glycosides Using Borntrager's Test

	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 filtrate and stirred.	No pink- red or violet colour was observed	Indicates the absence of Anthraquinone glycosides.

4.0 Test for Saponins Using Frothing Test

	Test	Observation	Inference
	Small quantity of the extract was added to 10ml of distilled water in a test tube. This was shaken vigorously for 30 seconds and was allowed to stand for 10 minutes.	No frothing was observed	Indicates the absence of Saponins.

5.0 Test for Flavonoids Using Sodium Hydroxide Test			
	Test	Observation	Inference
	Few drops of aqueous NaOH were added to 5ml of extract.	A yellow colour was observed	Indicates the presence of flavonoid
6.0 Test for Tannins Using Ferric Chloride Test			
	Test	Observation	Inference
	About 0.5ml of extract was stirred with 10ml of distilled water, then filtrate. Few drops of ferric chloride reagent added to the filtrate	A blue-black precipitate is formed.	Indicates the presence of tannins.
7.0 Test for Alkaloids			
	Test	Observation	Inference
	2 drops of dilute hydrochloric acid was added to the extract in a test tube, then followed by dragendorff's reagent	A red precipitate was formed	Indicate the presence of alkaloids.
8.0 Test for Steroid and Triterpenes Using Liebermann-Burchards Test			
	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 colour was observed and no blue-green or blue was observed.	Red colour indicates the presence of triterpenes and the absence of blue or blue-green indicates the absence of steroid

3.7 Mechanical Testing

Many materials, when in service are subjected to forces or loads depending on the environmental conditions. Hence it can cause deformation of the materials which in turn lead to failure. Therefore, it is necessary to study the mechanical properties such as hardness, tensile and impact strength of the materials.

3.7.1 Tensile Test

Tensile strength indicates the ability of a material to withstand forces that pull it apart as well as the capability of the material to stretch prior to failure. The Hounsfield tensometer was used for the Tensile Test. A graph sheet was inserted into the drum and the test specimen was inserted into the chucks and gripped firmly by the crosshead. While one operator rotates the wheel, a tensile force was being applied to the specimen until fracture; the other operator gently taps the head of the pin on a rotating drum bearing the graph so that the stress strain curve is plotted. The ultimate tensile strengths were determined using equation 3.6.

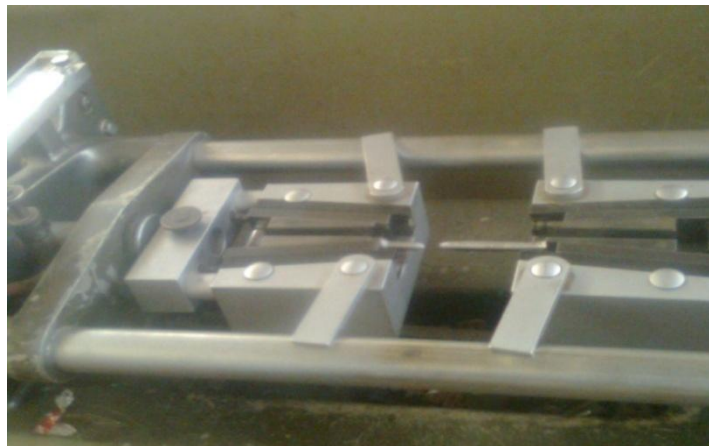


Plate VI: Hounsfield Tensometer (Mechanical Engineering Department, ABU, Zaria).

3.7.2 Impact Test

The Hounsfield impact testing machine was used to determine the impact strength of the specimens before and after corrosion. This was done to determine the toughness of the specimen. The toughness of a material is the amount of energy a material can absorb before fracture. This machine consists of the tups between which the test sample is inserted, the hammer which was thrown to release the tups and fracture the test specimen and a dial which indicates the impact load in foot pounds. The specimens for impact test were prepared to dimensions of 8mm diameter and length of 45mm, notched at 45° with a depth of 1.5mm at the centre. They were then placed between the two jaws of the machine and then the hammer was released and allowed to impact on the specimen. Readings were taken on the scale in foot pounds.

(Note: 1 foot pound = 1.35581795 Joules).

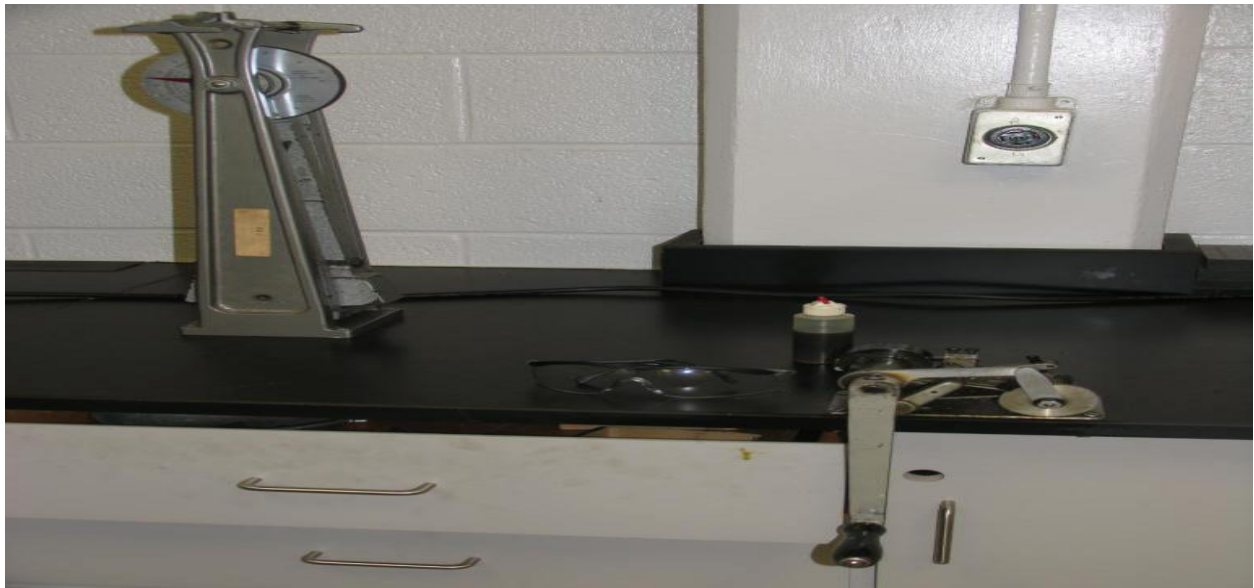


Plate VII: Hounsfield Impact Testing Machine (Mechanical Engineering Department, ABU, Zaria).

3.7.3 Hardness Test

The hardness values of the samples were determined according to the ASTM E140 using the Rockwell hardness tester with a 1/16inc steel ball indenter, minor load of 10KgF, and a major load

of 100kgF. Before the test, the mating surface of the indenter, plunger rod and the test samples were thoroughly cleaned by removing the dirt, scratches. The test was carried out by the indenter moving down into position on the specimen surface, a minor load is applied and a zero reference position is established. A major load is applied for some period then released leaving the minor load; the difference in depth from the zero reference position as a result of the application of the major load gives the Rockwell hardness value. This was repeated three times in order to find the average value.



Plate VIII: Indentec Universal Hardness Testing Machine (Metallurgical and Materials Engineering Department, ABU, Zaria).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Analysis of Results

4.1.1 Graphical Representations of the Results Obtained from Corrosion Test.

Figures 4.1-4.51 showed the results obtained from corrosion test using *Ocimum gratissimum* and *Hyptis suaveolens* leaves extracts in 0.5 molar concentrations of HCl, H₂SO₄ and NaCl media.

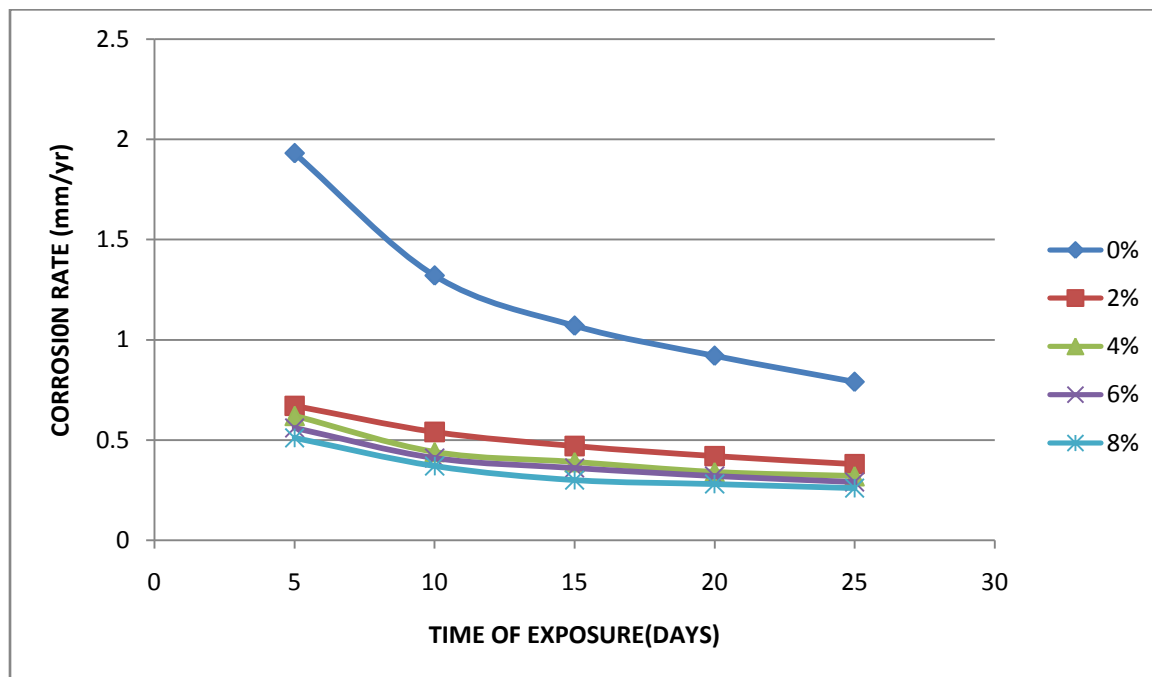


Fig.4.1: Variation of corrosion rate with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Ocimum gratissimum*.

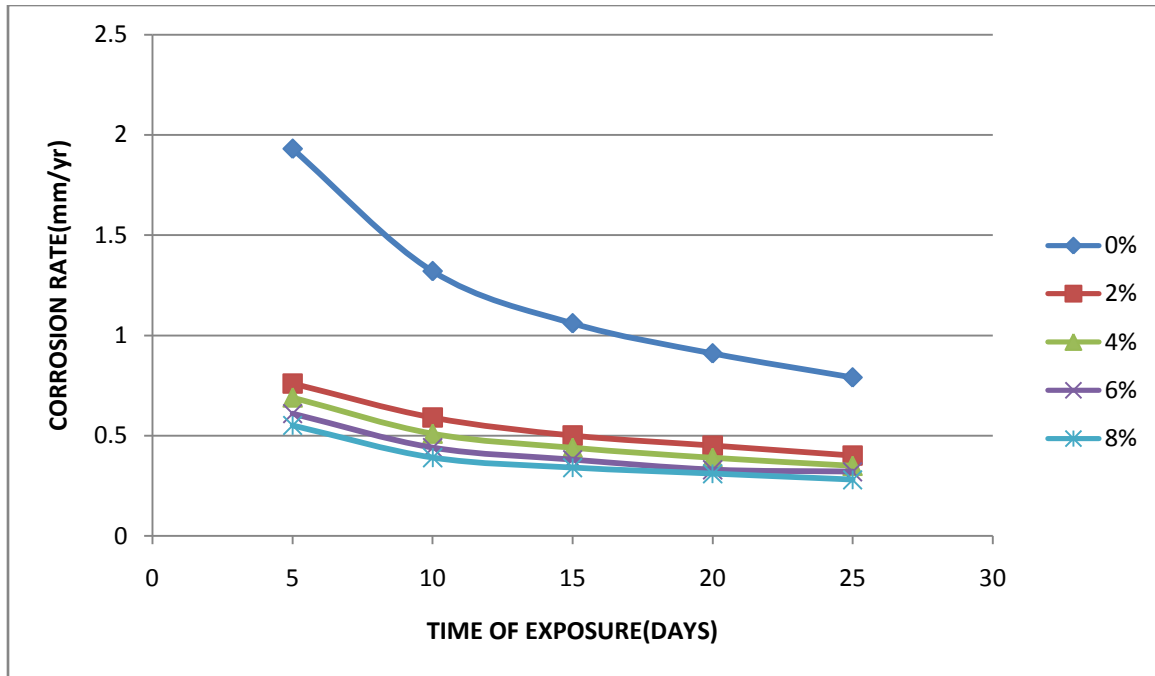


Fig.4.2: Variation of corrosion rate with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Hyptis suaveolens*.

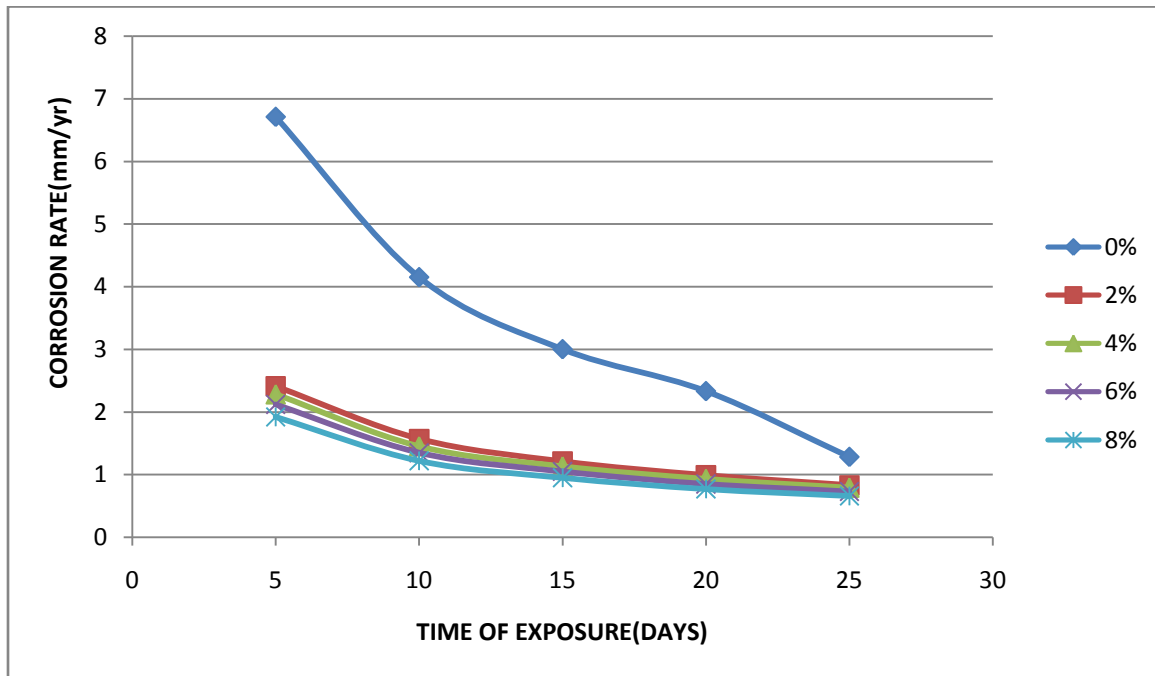


Fig.4.3: Variation of corrosion rate with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Ocimum gratissimum*.

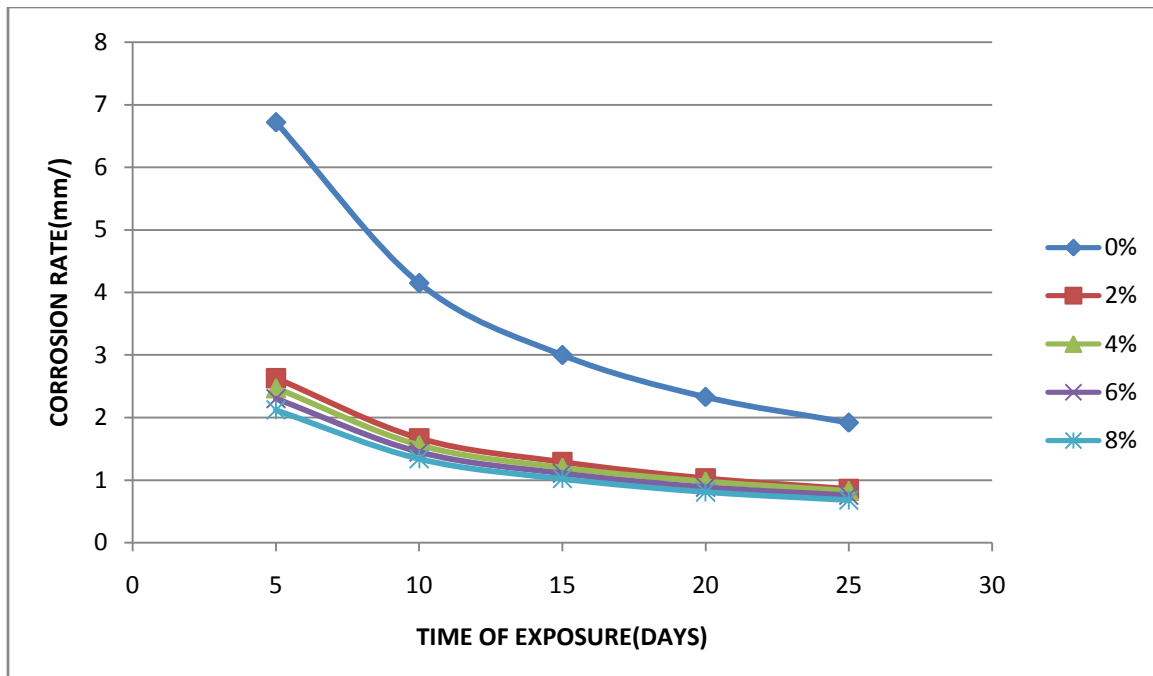


Fig.4.4: Variation of corrosion rate with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Hyptis suaveolens*.

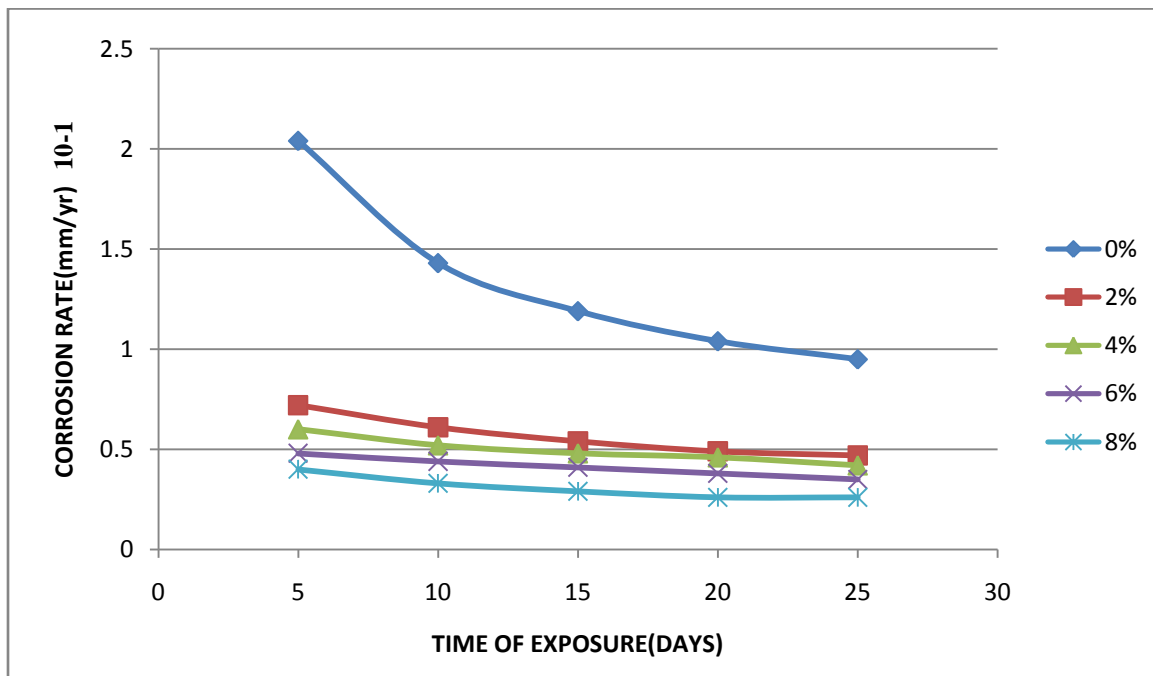


Fig.4.5: Variation of corrosion rate with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Ocimum gratissimum*.

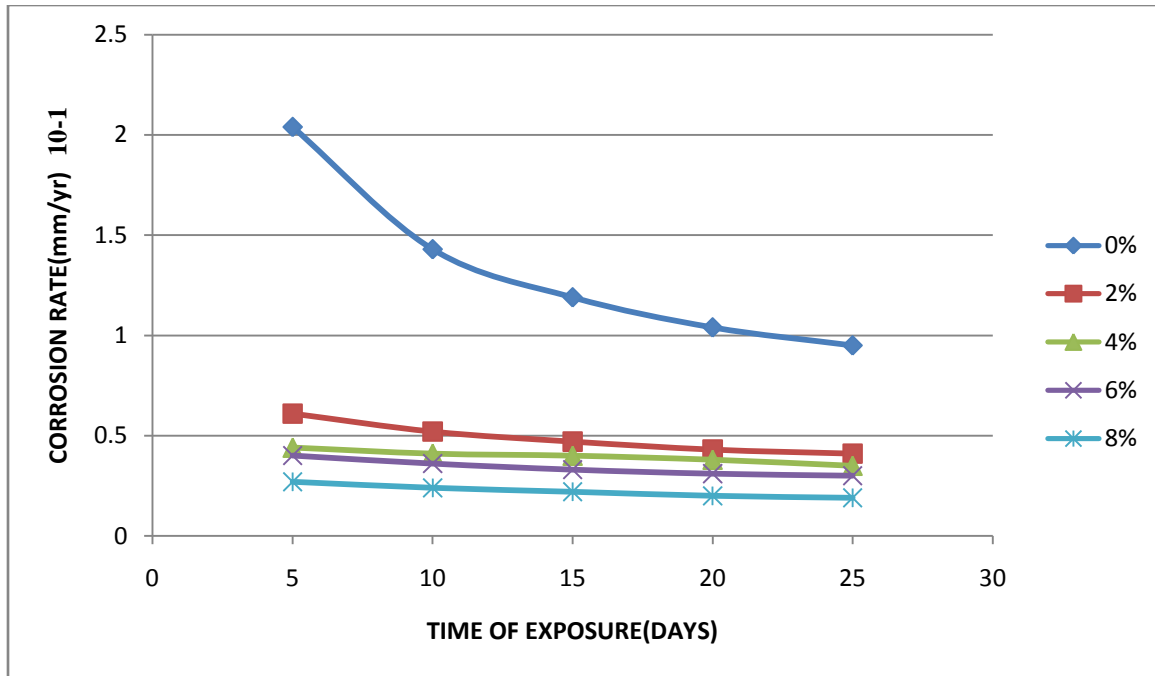


Fig.4.6: Variation of corrosion rate with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Hyptis suaveolens*.

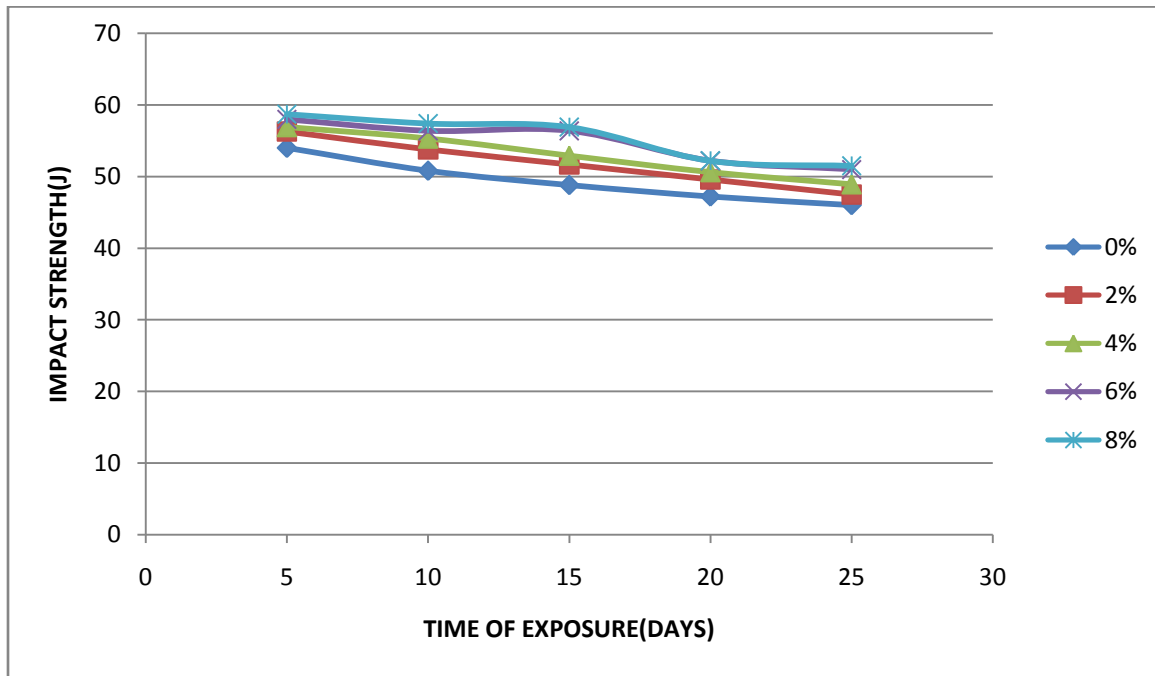


Fig. 4.7: Variation of Impact strength with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Ocimum gratissimum*.

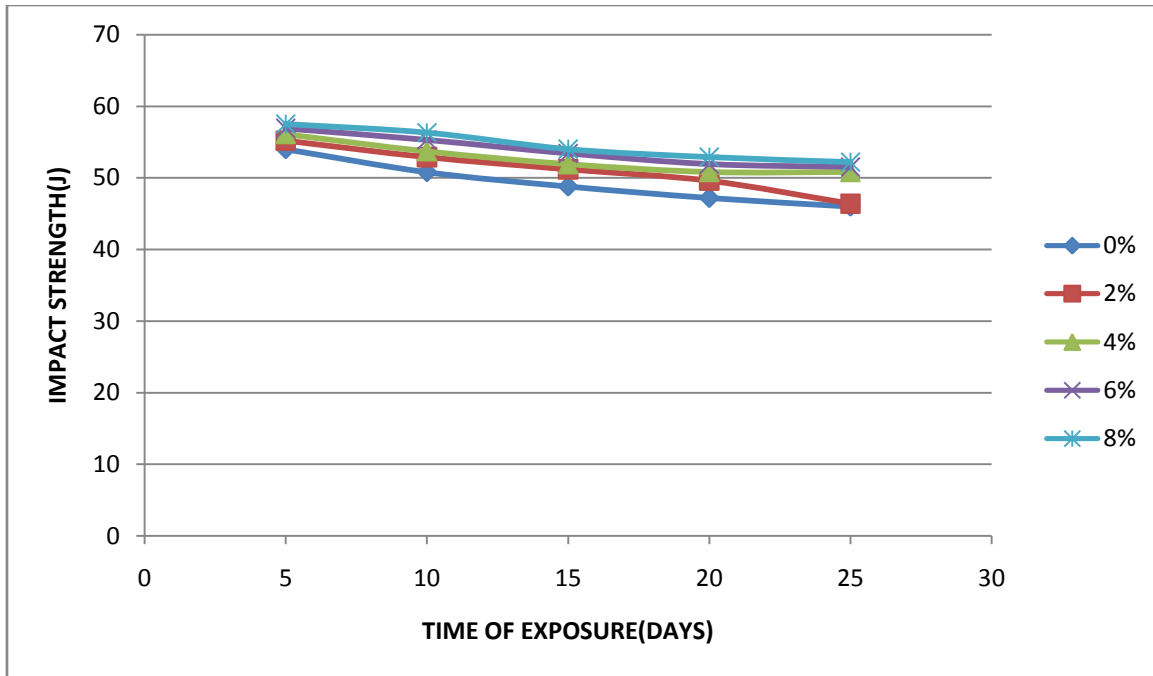


Fig. 4.8: Variation of impact strength with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Hyptis suaveolens*.

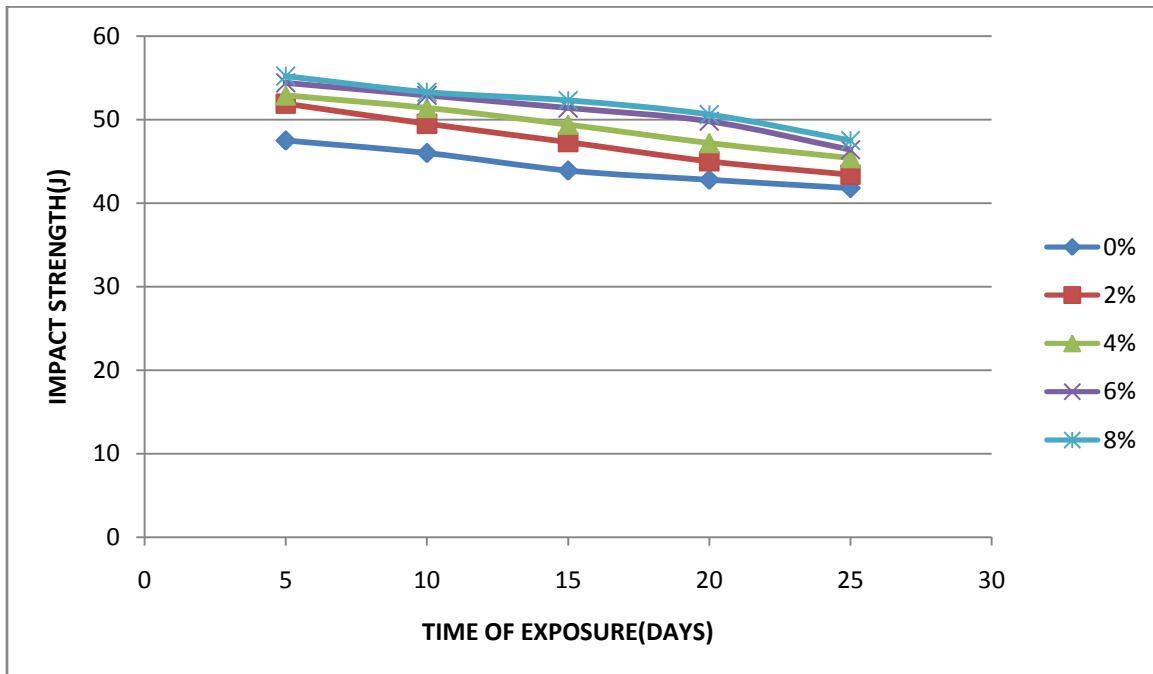


Fig. 4.9: Variation of impact strength with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Ocimum gratissimum*.

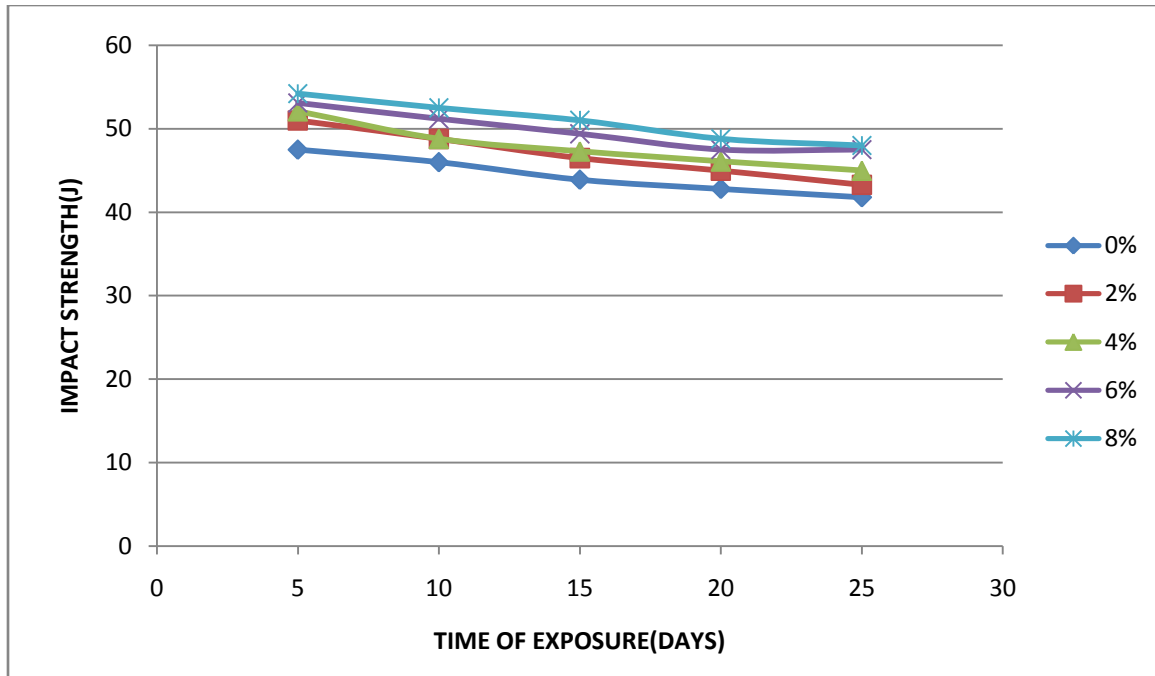


Fig. 4.10: Variation of impact strength with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Hyptis suaveolens*.

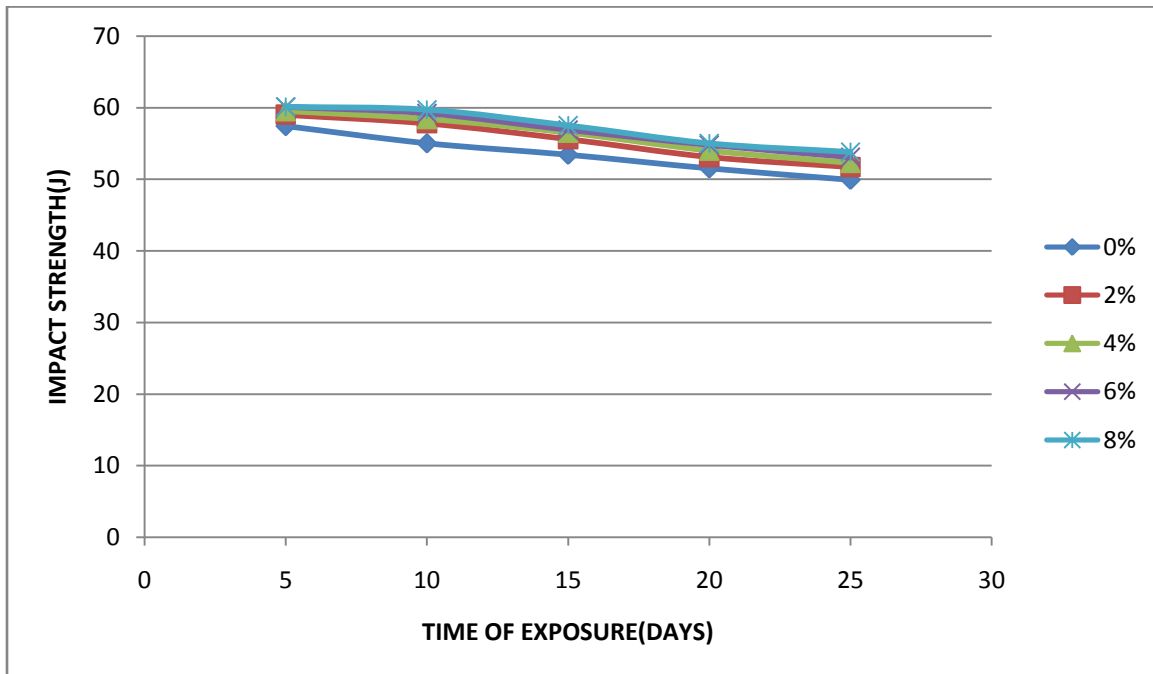


Fig. 4.11: Variation of impact strength with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Ocimum gratissimum*.

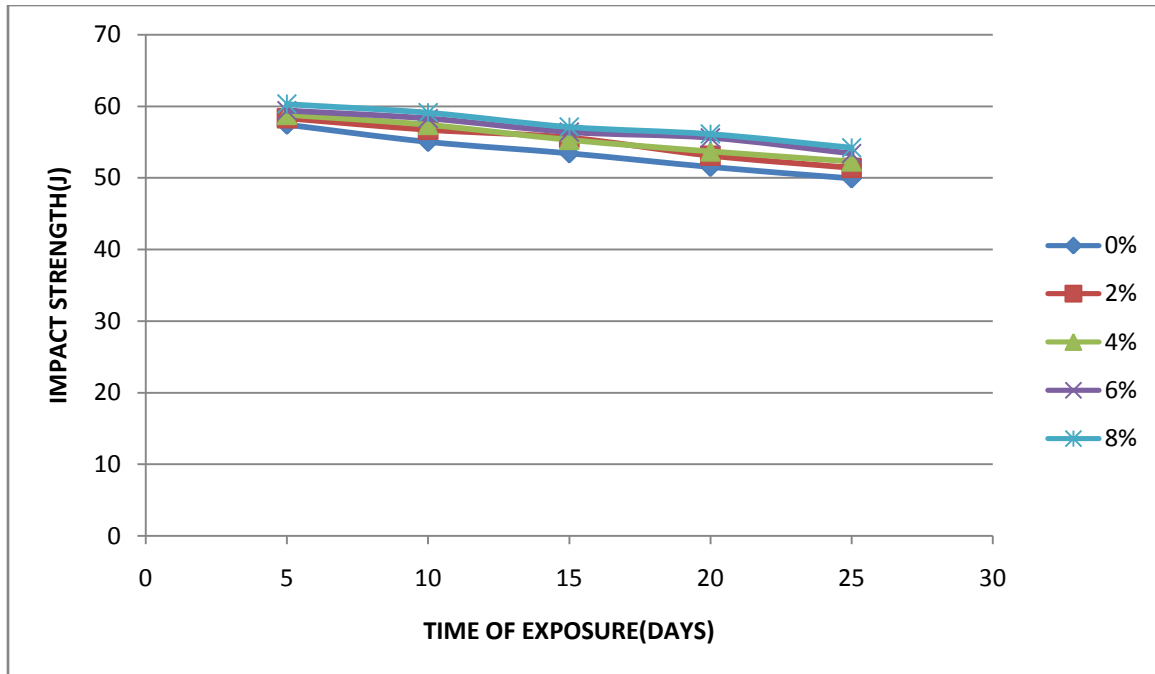


Fig. 4.12: Variation of impact strength with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Hyptis suaveolens*.

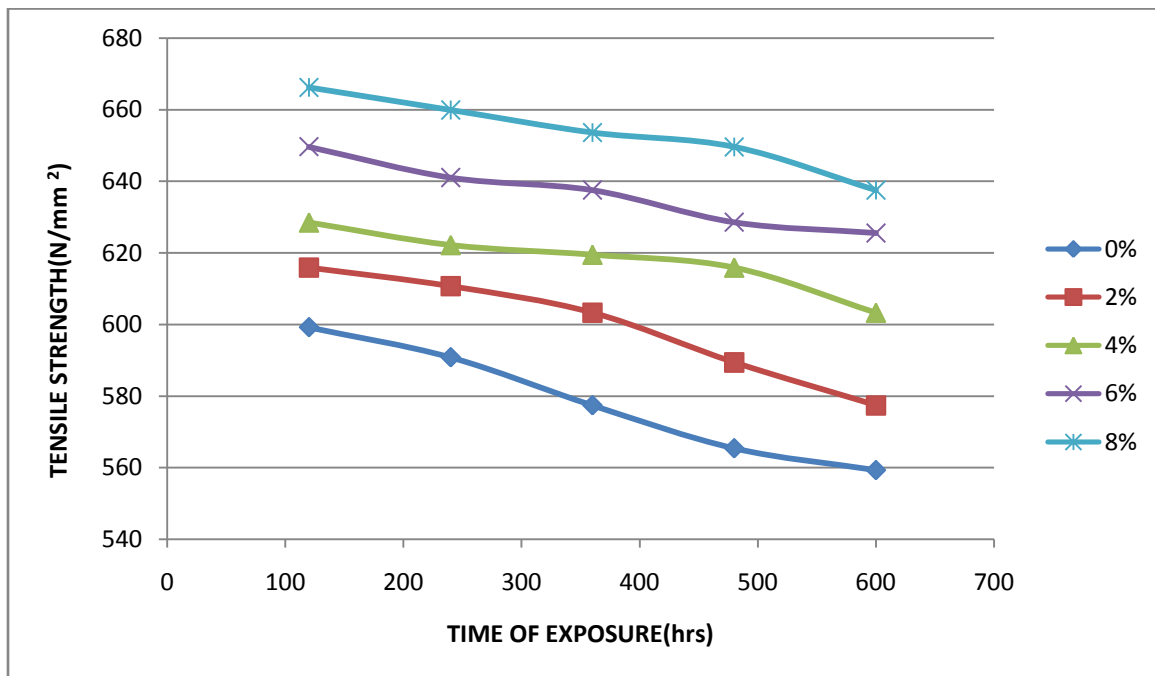


Fig. 4.13: Variation of tensile strength with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Ocimum gratissimum*.

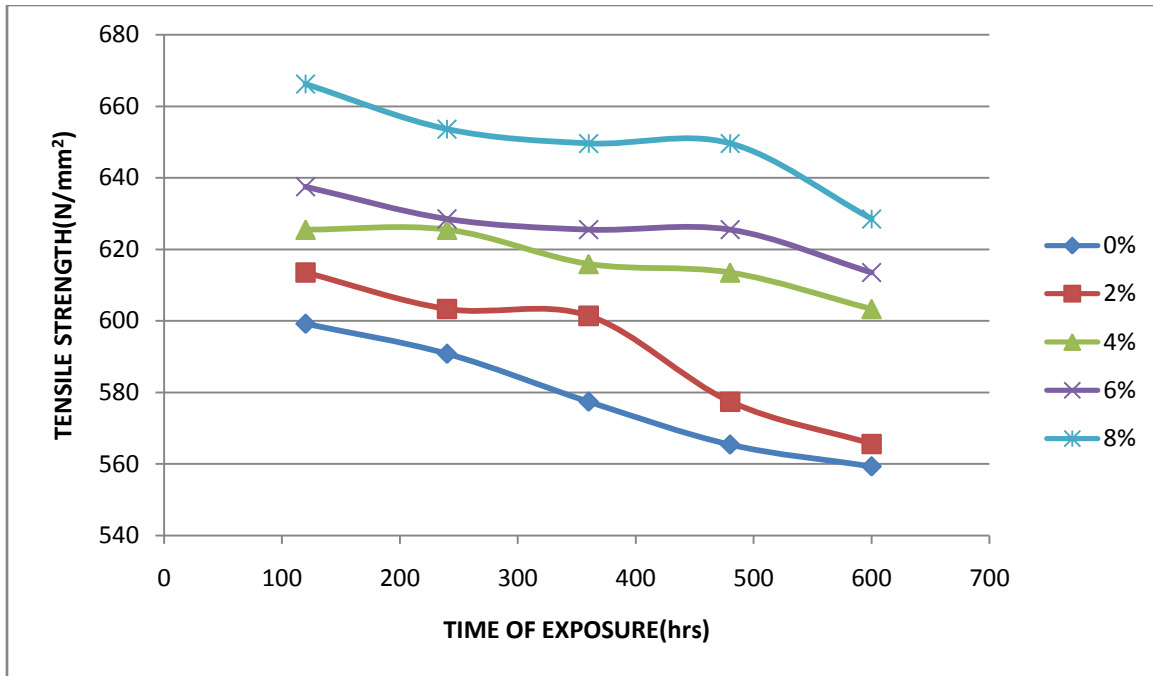


Fig. 4.14: Variation of tensile strength with time curve of medium carbon steel in 0.5M HCl in absence and presence of different concentrations of *Hyptis suaveolens*.

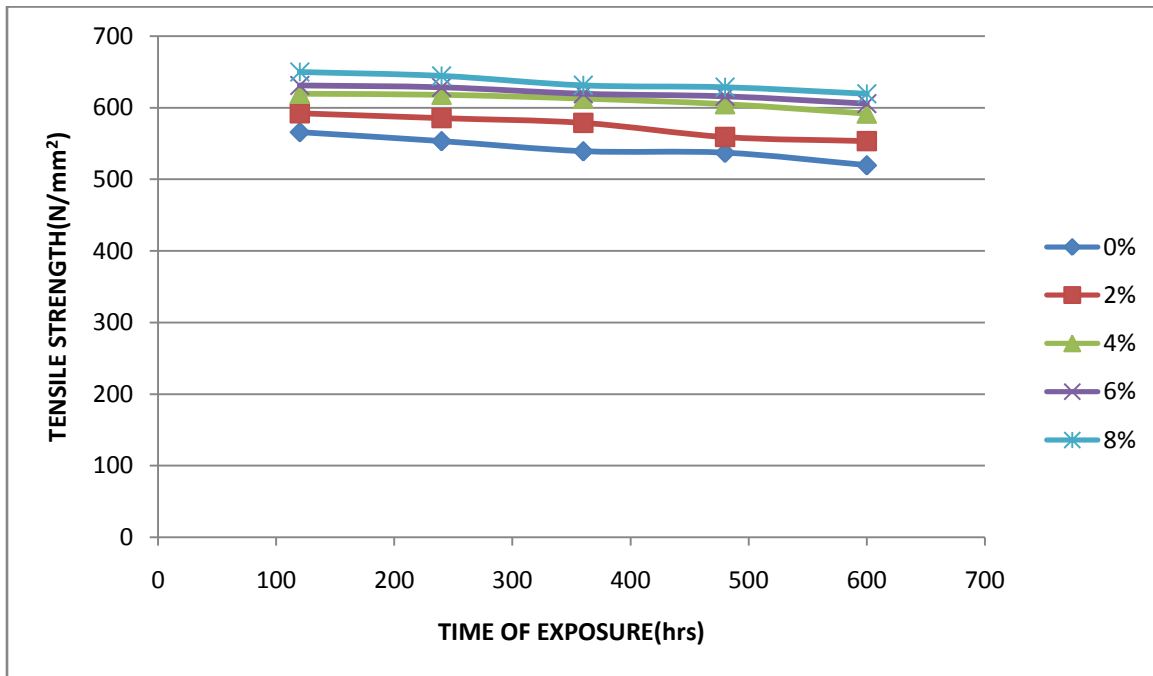


Fig. 4.15: Variation of tensile strength with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Ocimum gratissimum*.

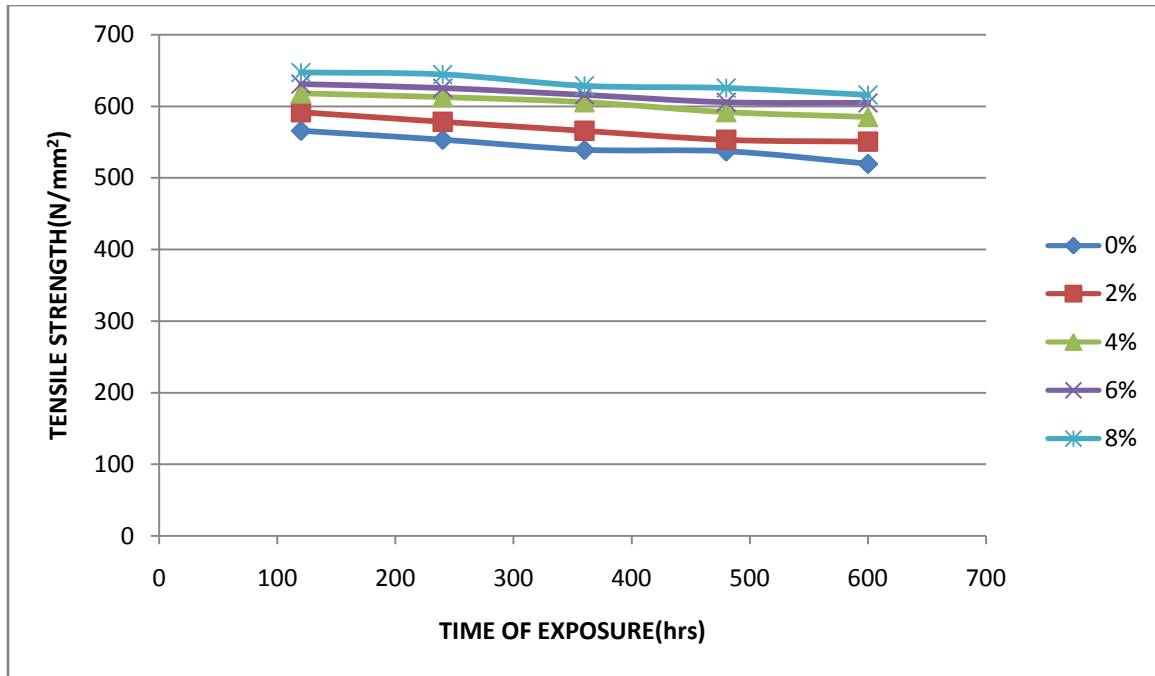


Fig. 4.16: Variation of tensile strength with time curve of medium carbon steel in 0.5M H₂SO₄ in absence and presence of different concentrations of *Hyptis suaveolens*.

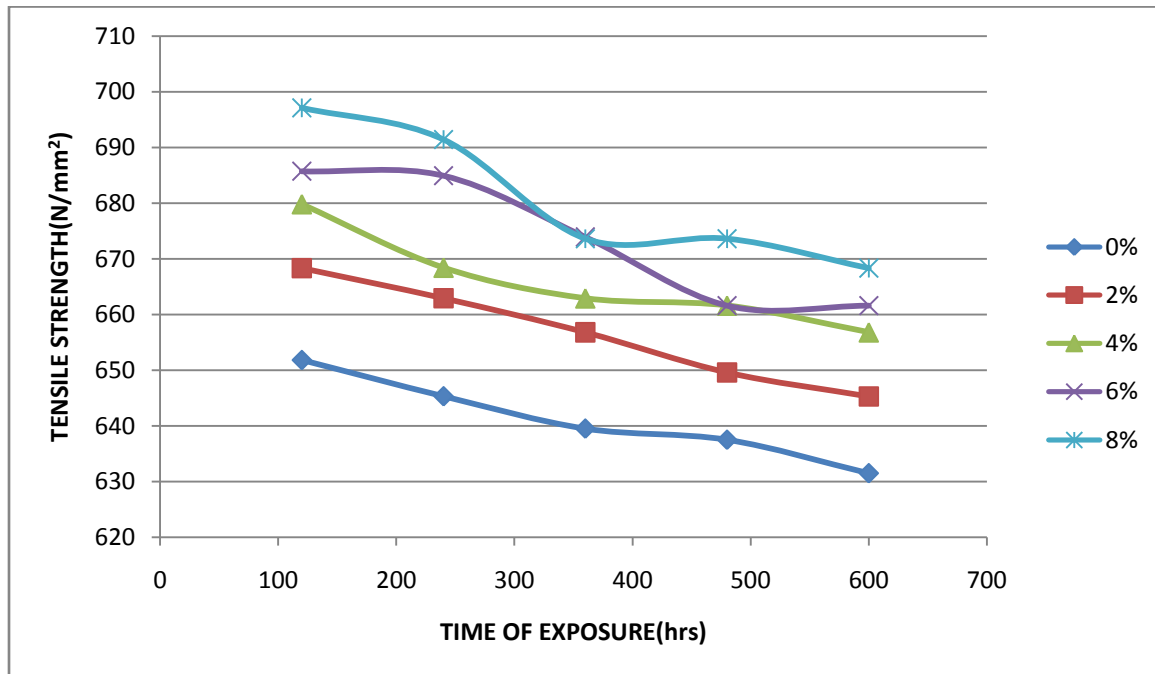


Fig. 4.17: Variation of tensile strength with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Ocimum gratissimum*.

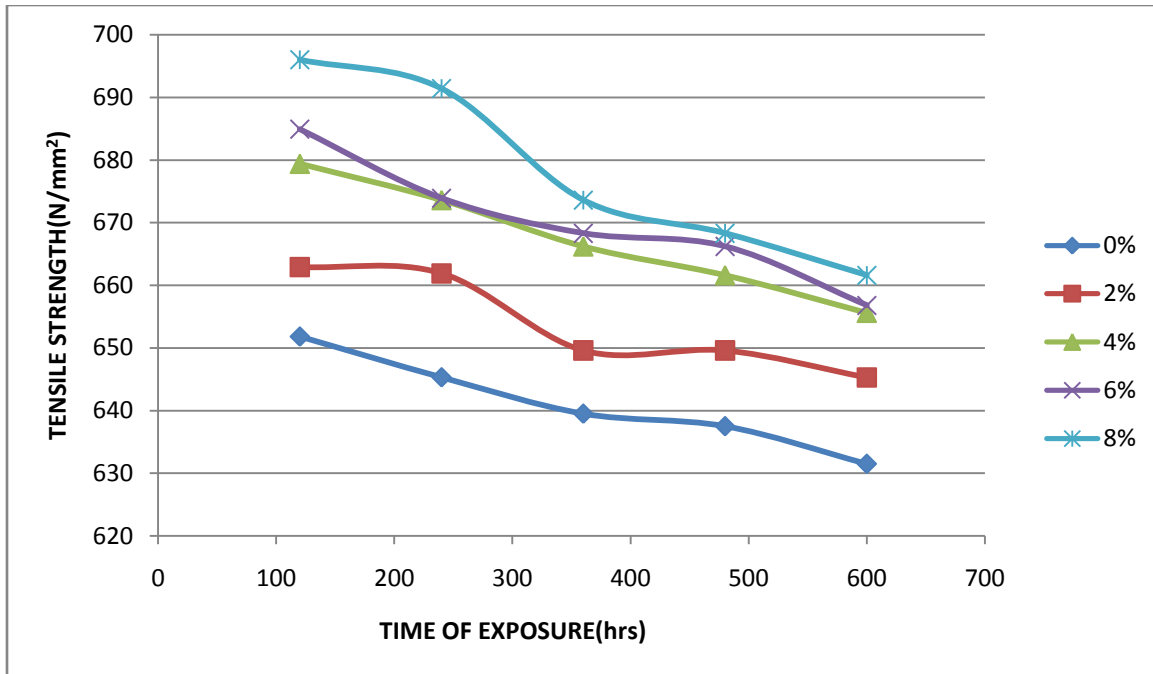


Fig. 4.18: Variation of tensile strength with time curve of medium carbon steel in 0.5M NaCl in absence and presence of different concentrations of *Hyptis suaveolens*.

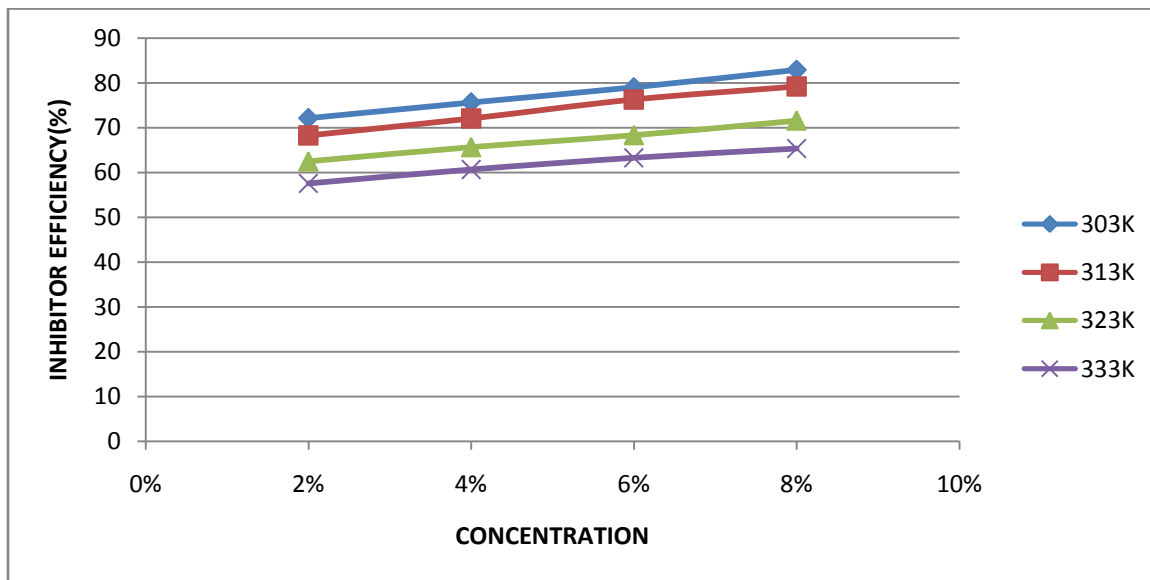


Fig. 4.19: Variation of %IE with inhibitor concentration in 0.5M HCl containing *Ocimum gratissimum* at different temperature.

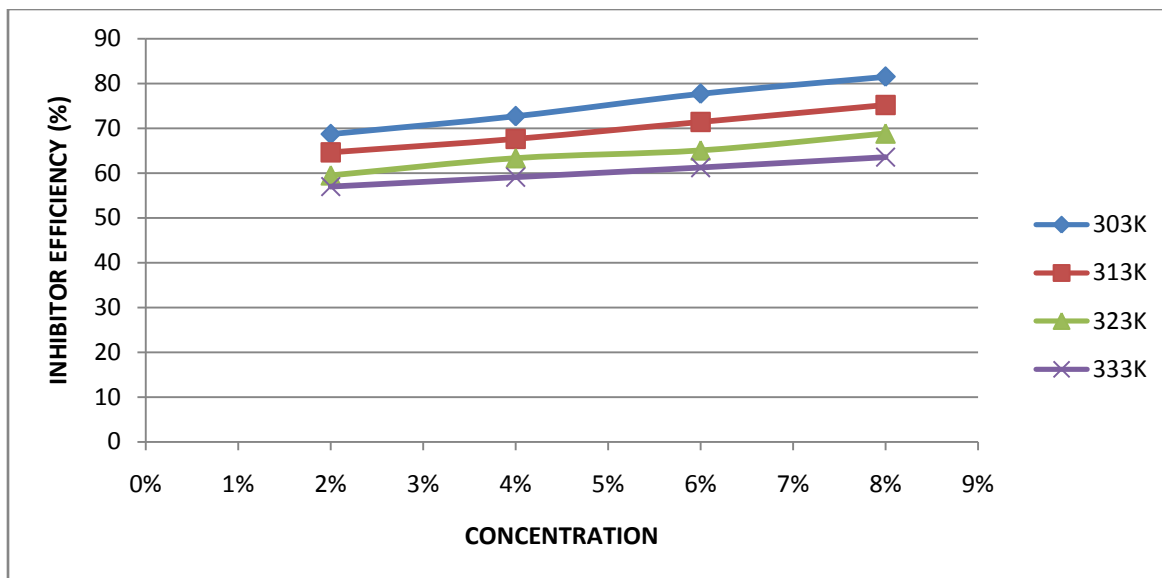


Fig. 4.20: Variation of %IE with inhibitor concentration in 0.5M HCl containing *Hyptis suaveolens* at different temperature.

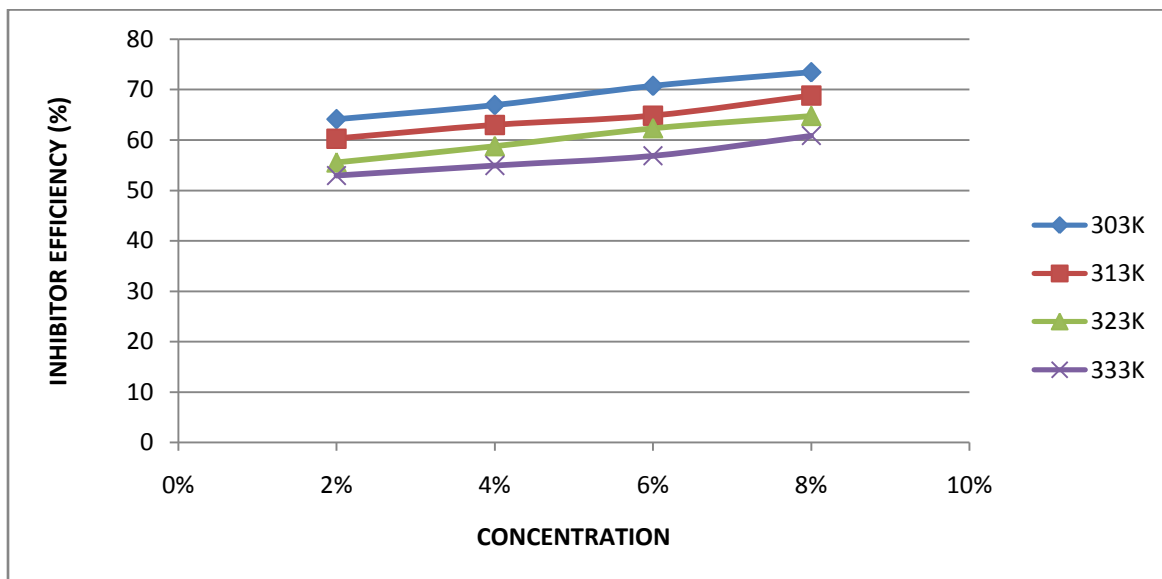


Fig. 4.21: Variation of %IE with inhibitor concentration in 0.5M H₂SO₄ containing *Ocimum gratissimum* at different temperature.

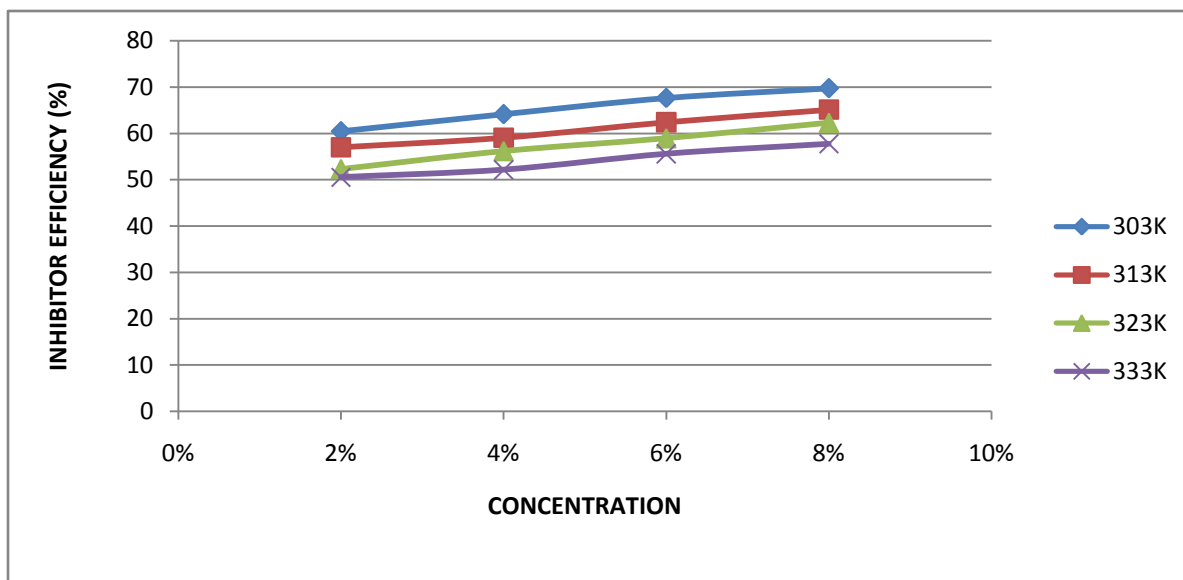


Fig. 4.22: Variation of %IE with inhibitor concentration in 0.5M H₂SO₄ containing *Hyptis suaveolens* at different temperature.

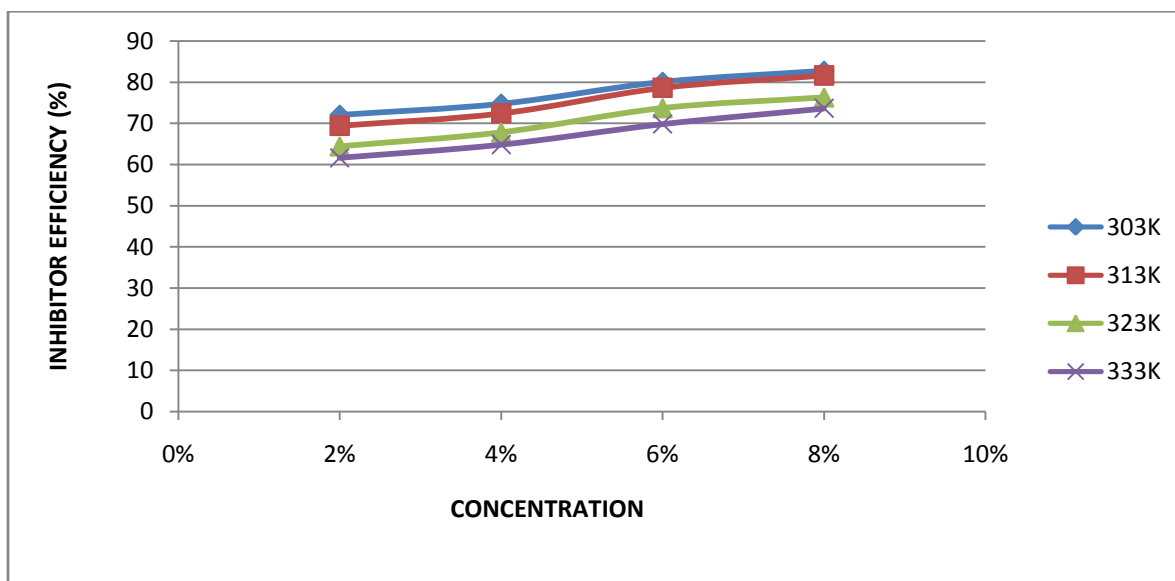


Fig. 4.23: Variation of %IE with inhibitor concentration in 0.5M NaCl containing *Ocimum gratissimum* at different temperature.

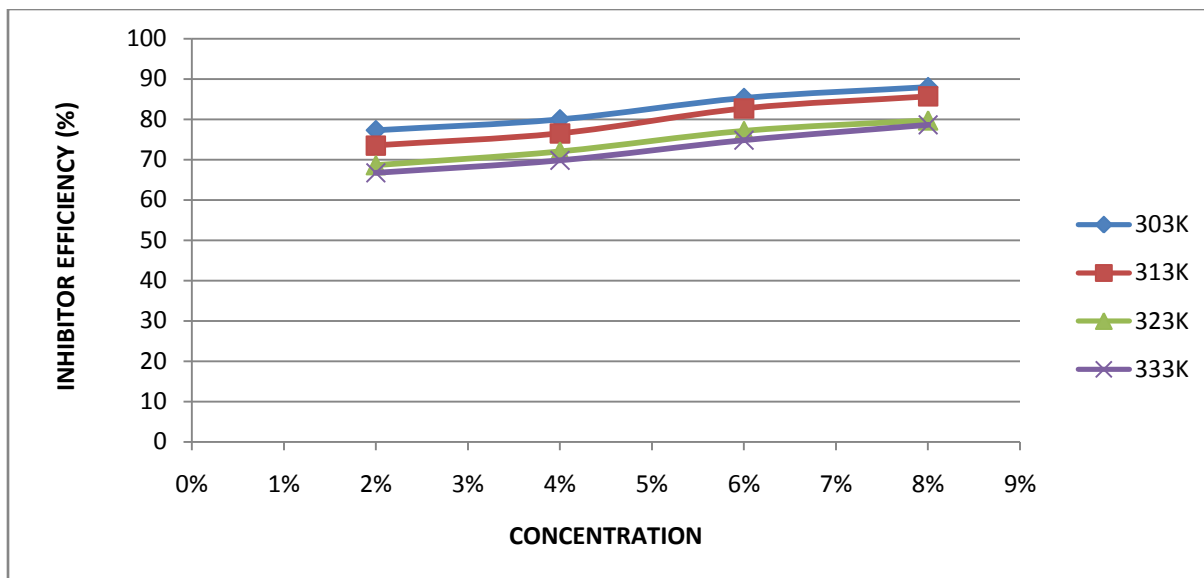


Fig. 4.24: Variation of %IE with inhibitor concentration in 0.5M NaCl containing *Hyptis suaveolens* at different temperature.

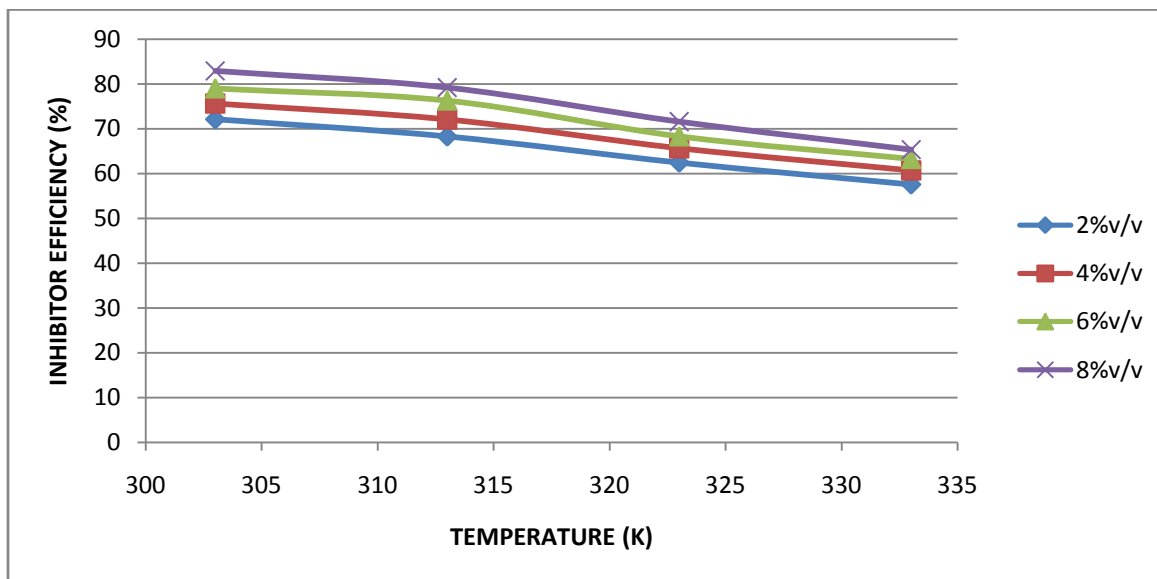


Fig. 4.25: Variation of %IE with temperature in 0.5M HCl containing *Ocimum gratissimum*.

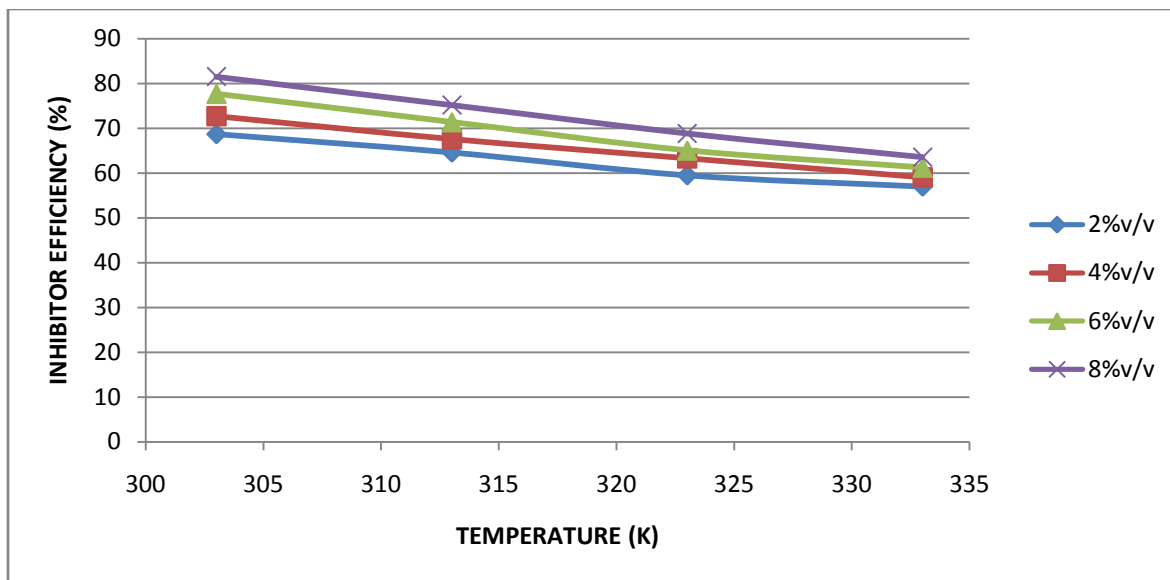


Fig. 4.26: Variation of %IE with temperature in 0.5M HCl containing *Hyptis suaveolens*.

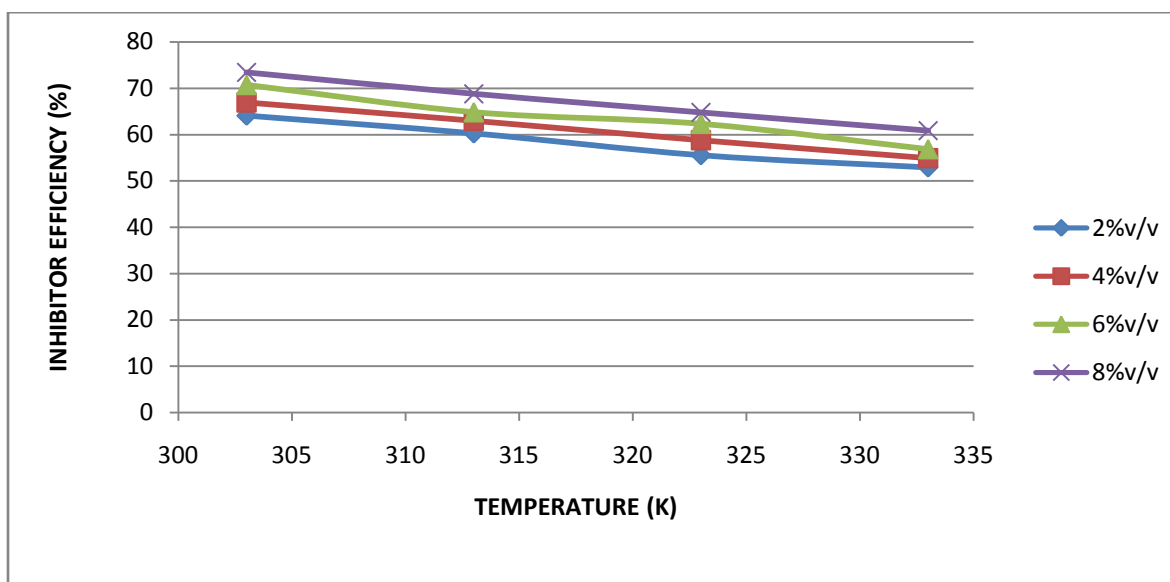


Fig. 4.27: Variation of %IE with temperature in 0.5M H₂SO₄ containing *Ocimum gratissimum*.

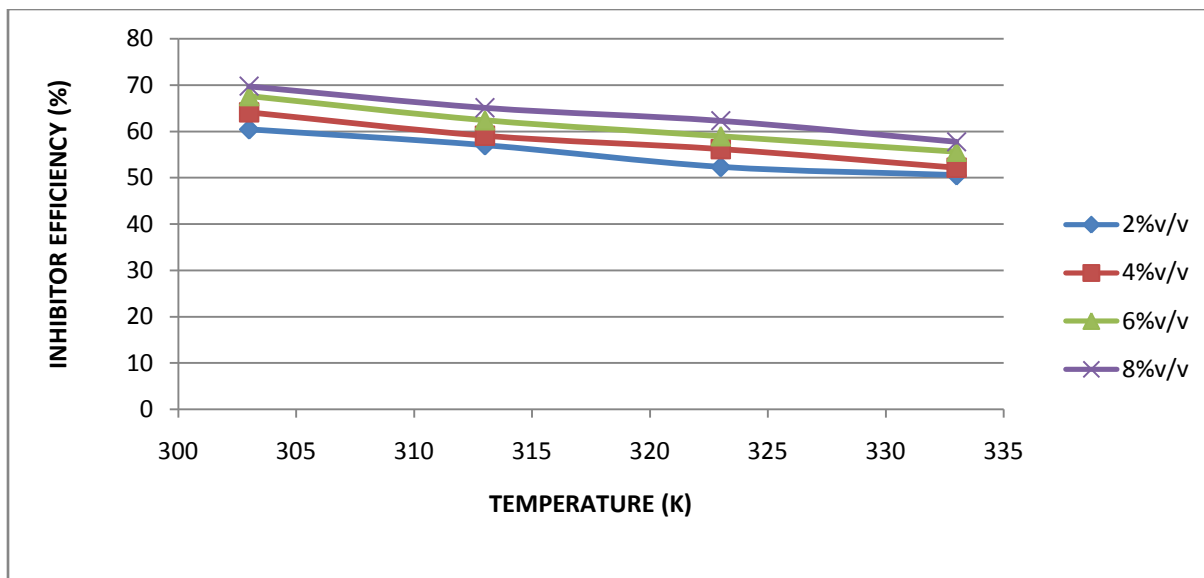


Fig. 4.28: Variation of %IE with temperature in 0.5M H₂SO₄ containing *Hyptis suaveolens*.

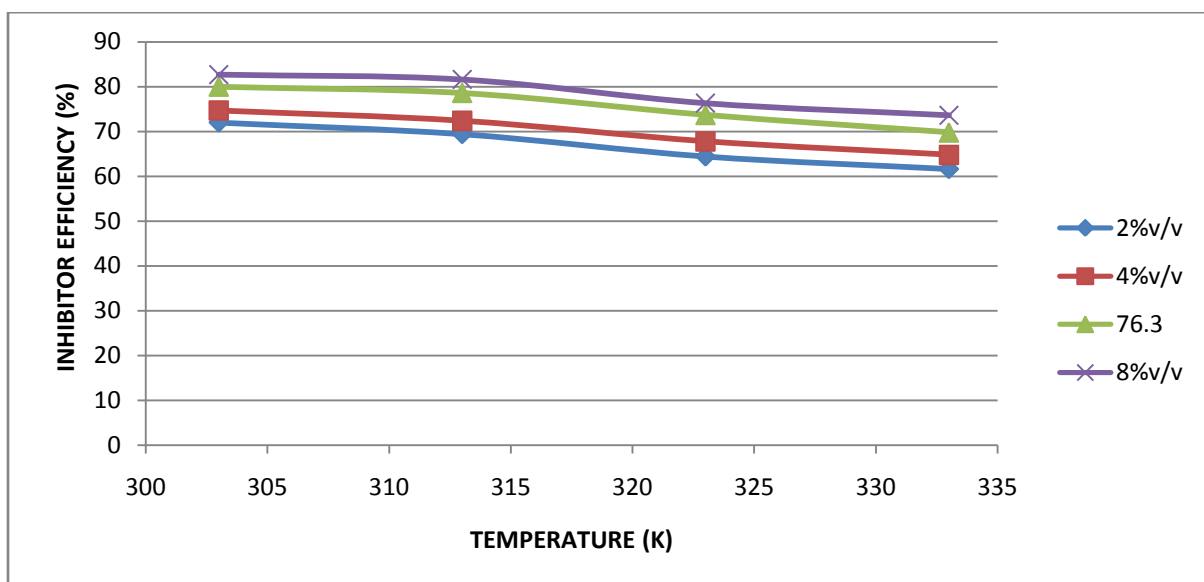


Fig. 4.29: Variation of %IE with temperature in 0.5M NaCl containing *Ocimum gratissimum*.

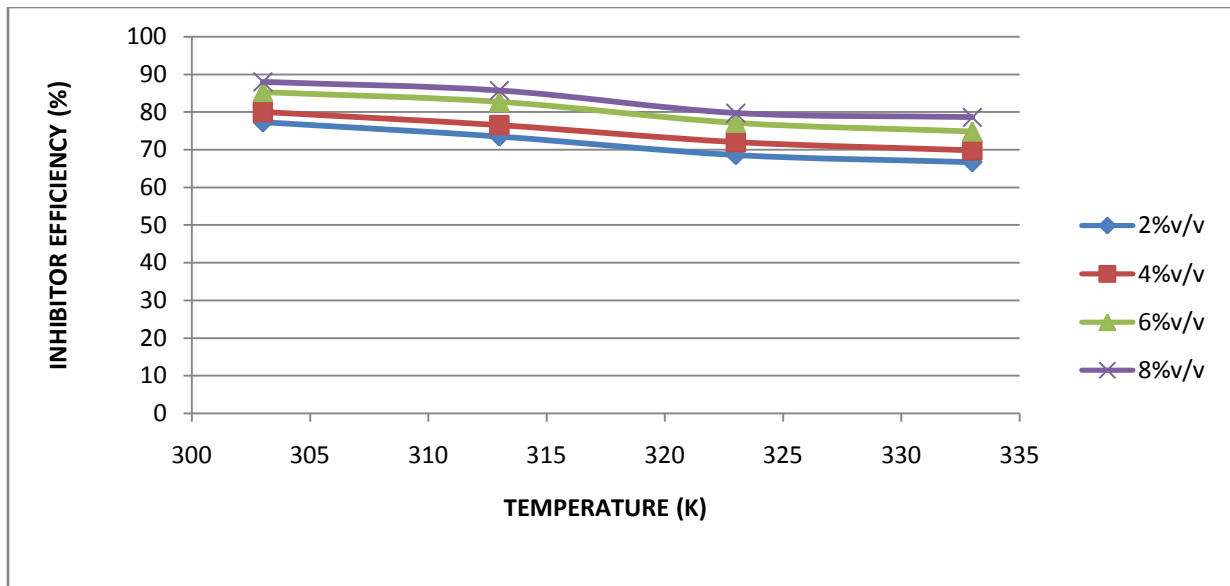


Fig. 4.30: Variation of %IE with temperature in 0.5M NaCl containing *Hyptis suaveolens*

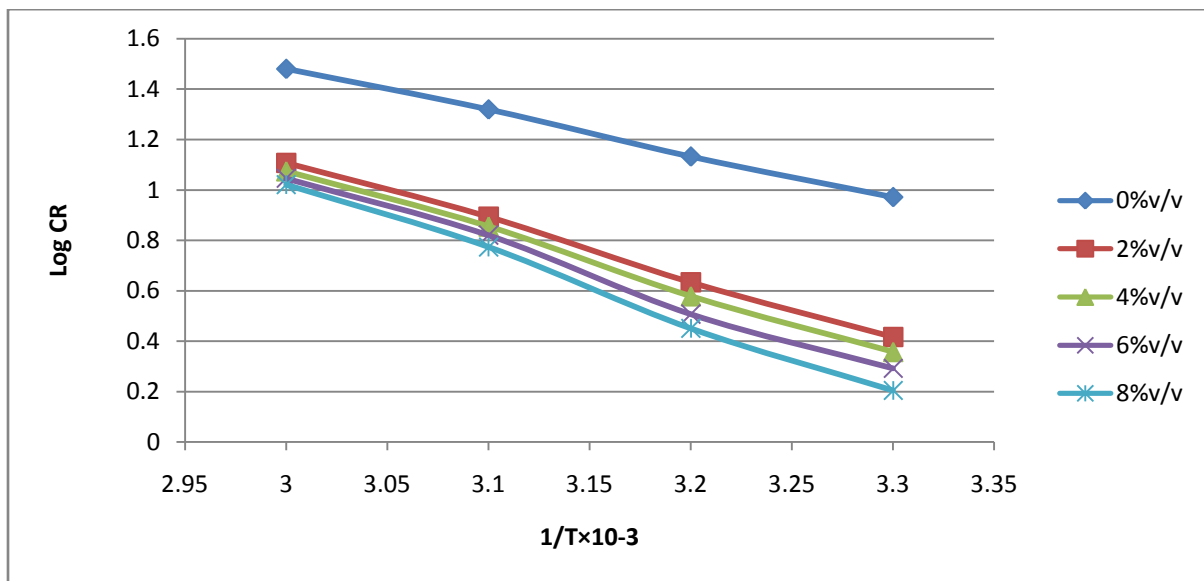


Fig. 4.31: Arrhenius plot for medium carbon steel in 0.5M HCl in the absence and presence of *Ocimum gratissimum*.

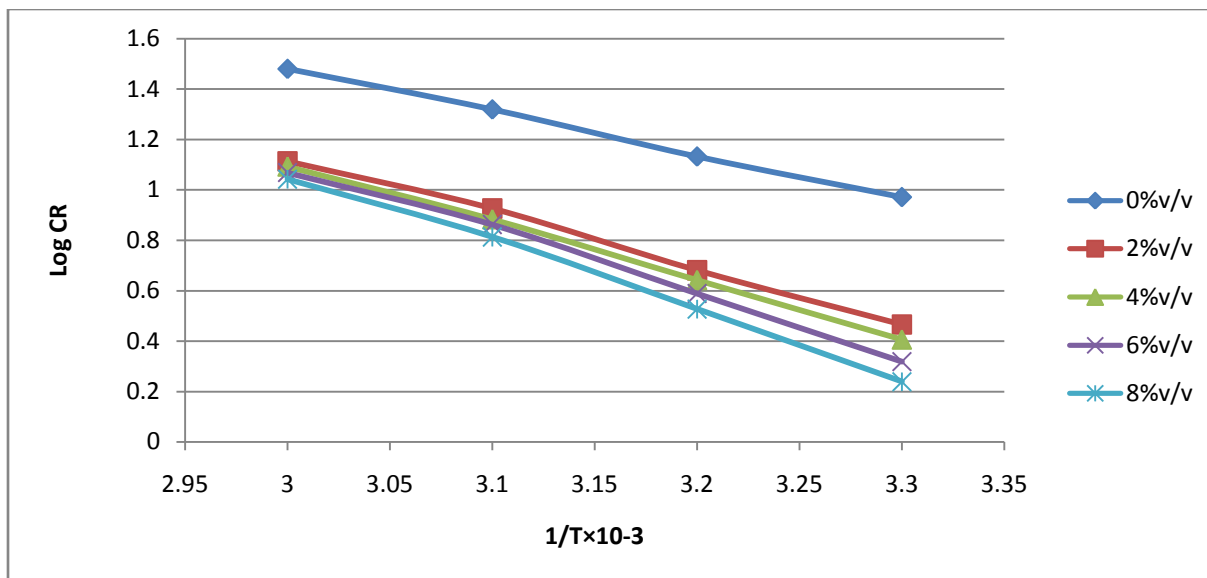


Fig. 4.32: Arrhenius plot for medium carbon steel in 0.5M HCl in the absence and presence of *Hyptis suaveolens*.

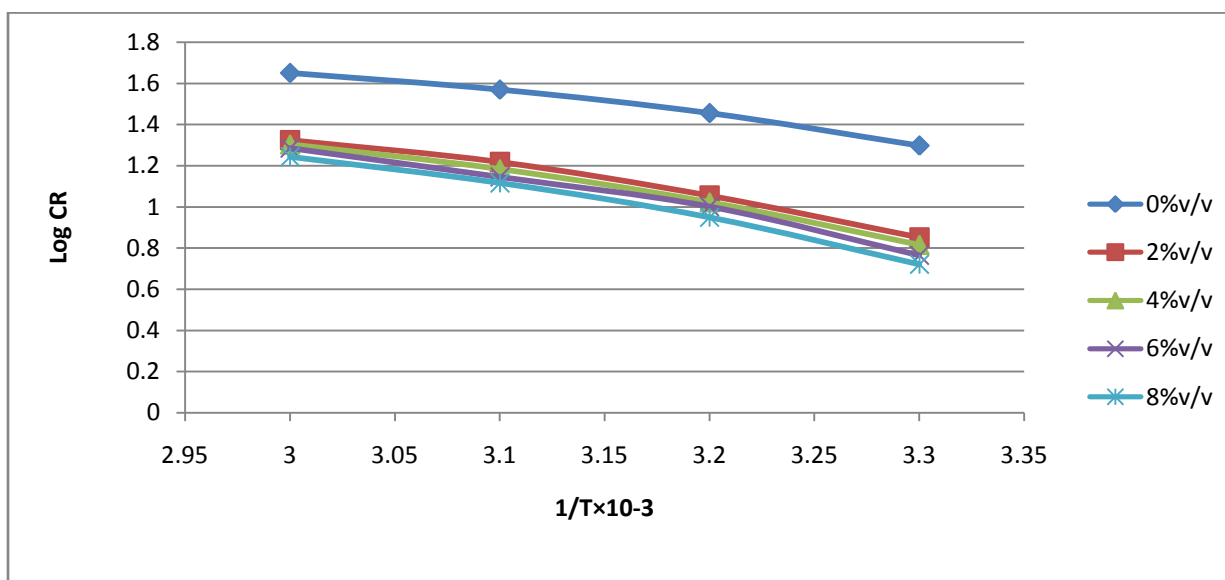


Fig. 4.33: Arrhenius plot for medium carbon steel in 0.5M H₂SO₄ in the absence and presence of *Ocimum gratissimum*.

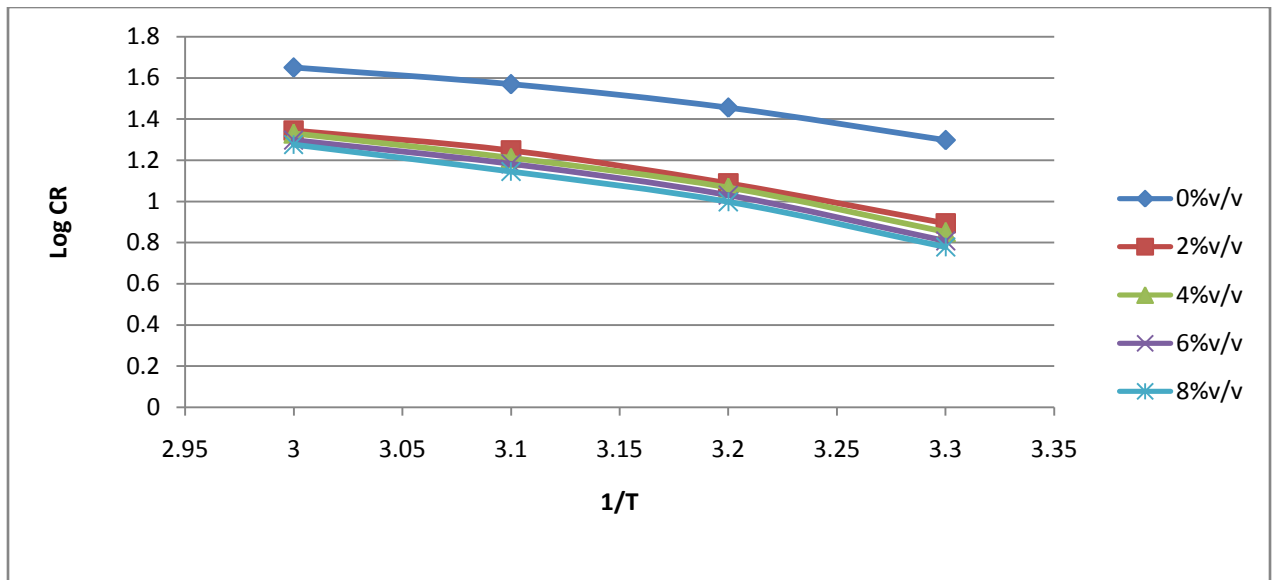


Fig. 4.34: Arrhenius plot for medium carbon steel in 0.5M H₂SO₄ in the absence and presence of *Hyptis suaveolens*.

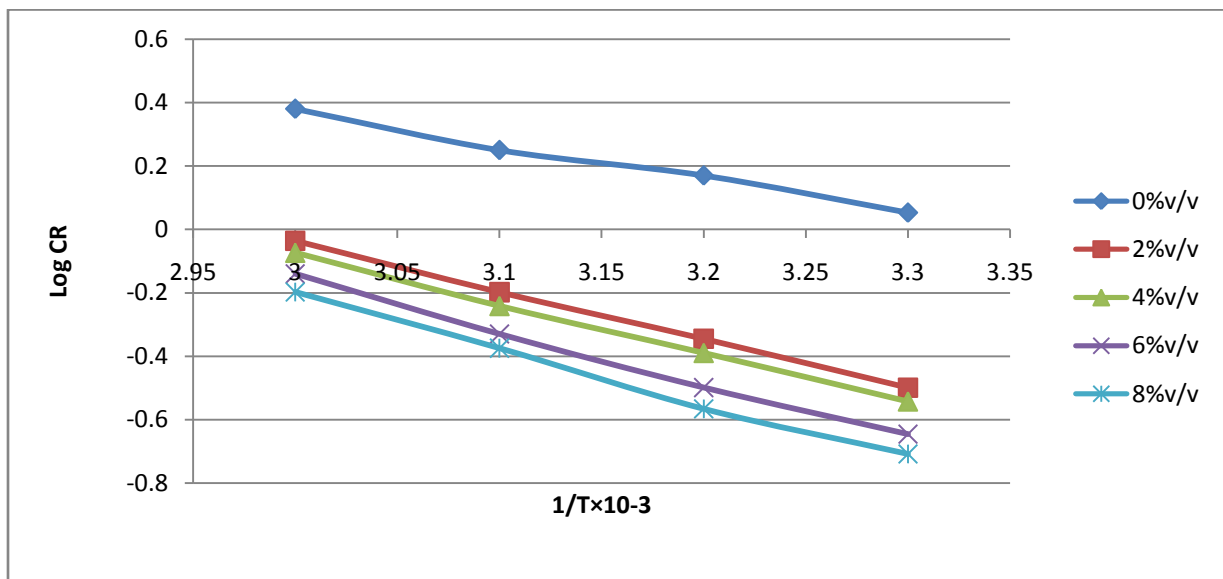


Fig. 4.35: Arrhenius plot for medium carbon steel in 0.5M NaCl in the absence and presence of *Ocimum gratissimum*.

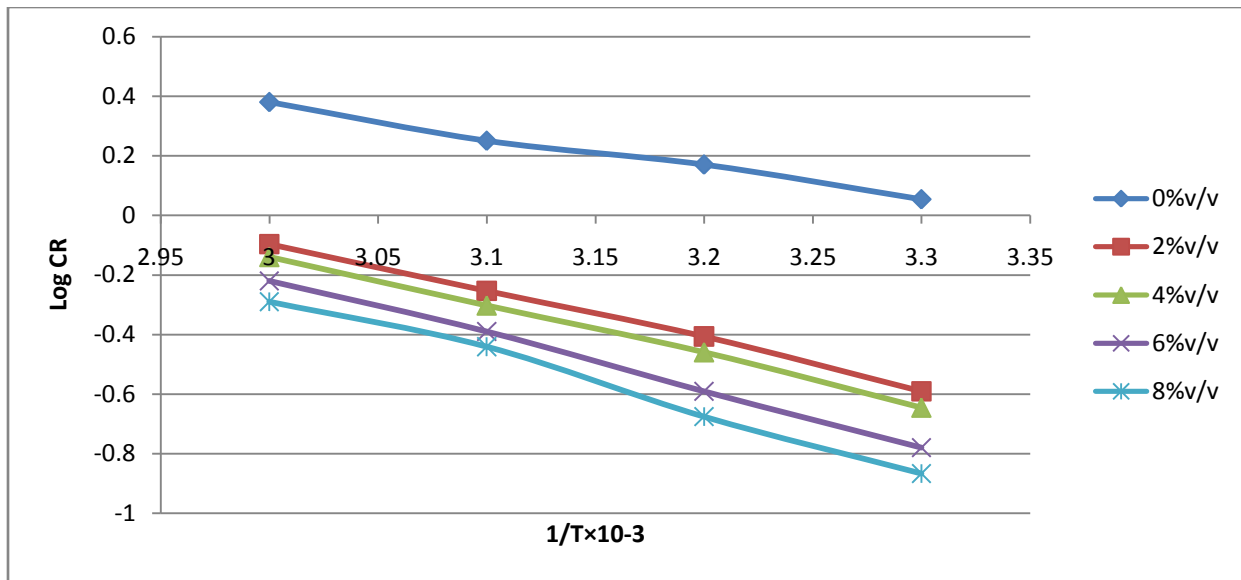


Fig. 4.36: Arrhenius plot for medium carbon steel in 0.5M NaCl in the absence and presence of *Hyptis suaveolens*.

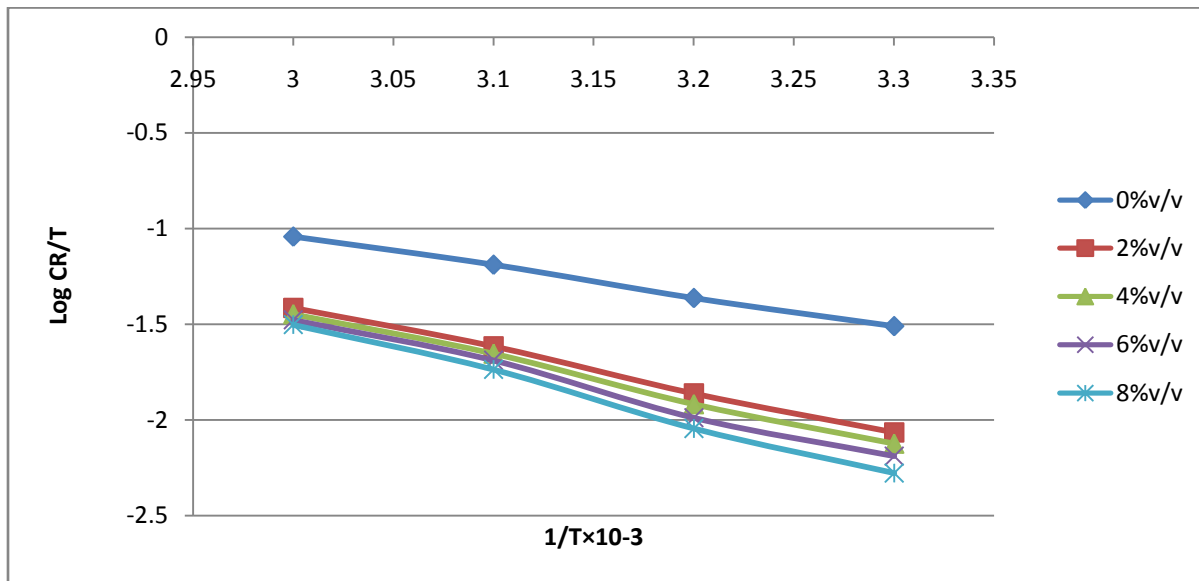


Fig. 4.37: Log CR/T vs. 1/T for medium carbon steel in 0.5M HCl in the absence and presence of *Ocimum gratissimum*.

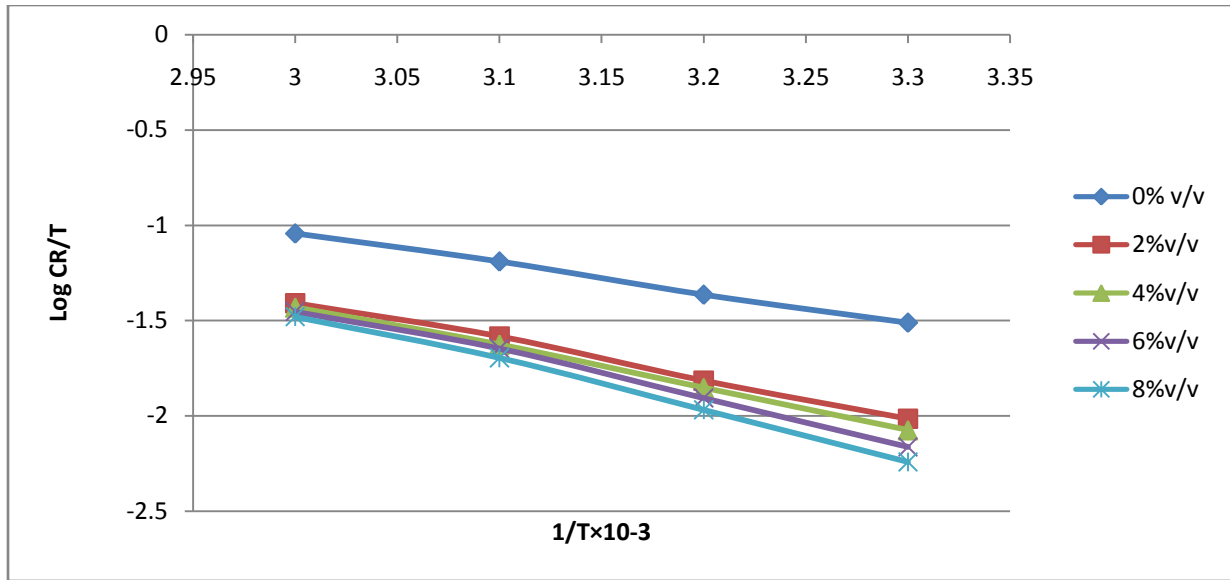


Fig.4.38: Log CR/T vs. 1/T for medium carbon steel in 0.5M HCl in the absence and presence of *Hyptis suaveolens*.

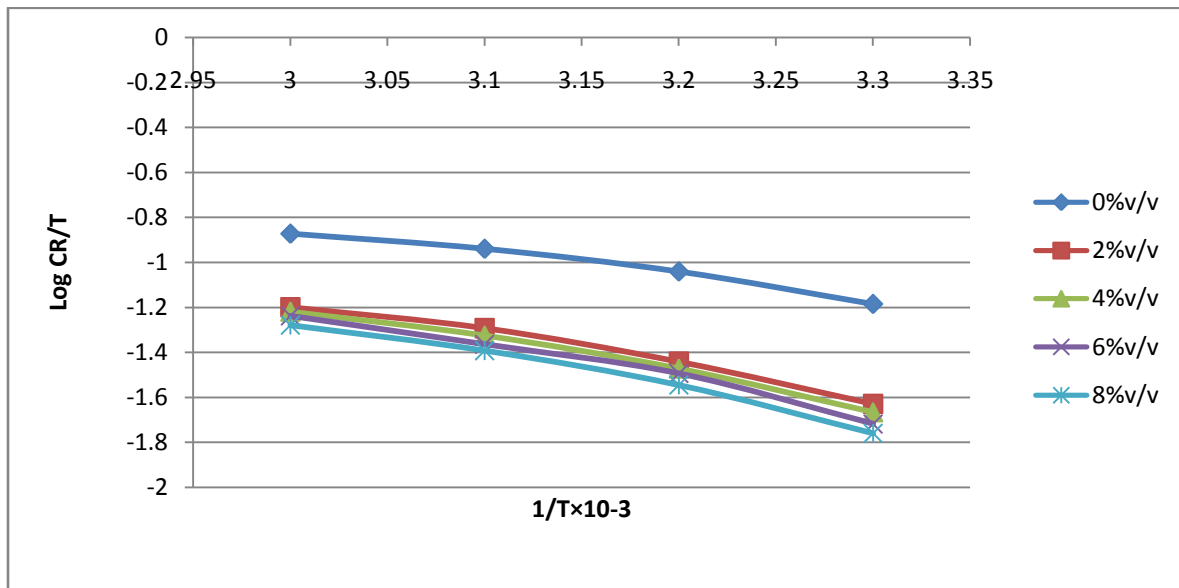


Fig.4.39: Log CR/T vs. 1/T for medium carbon steel in 0.5M H₂SO₄ in the absence and presence of *Ocimum gratissimum*.

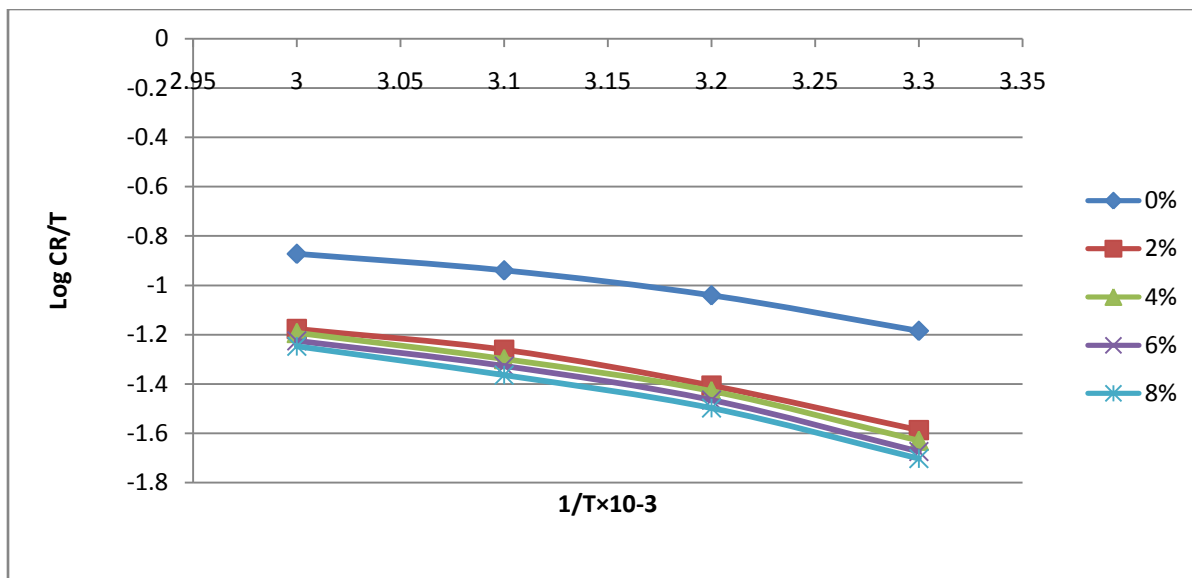


Fig.4.40: Log CR/T vs. 1/T for medium carbon steel in 0.5M H₂SO₄ in the absence and presence of *Hyptis suaveolens*.

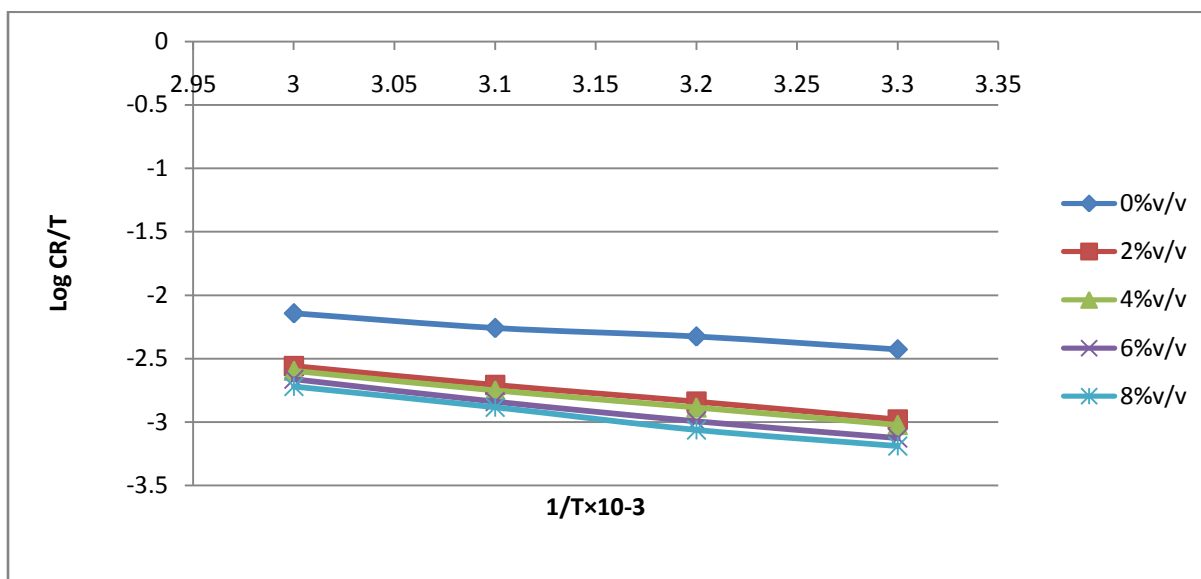


Fig.4.41: Log CR/T vs. 1/T for medium carbon steel in 0.5M NaCl in the absence and presence of *Ocimum gratissimum*.

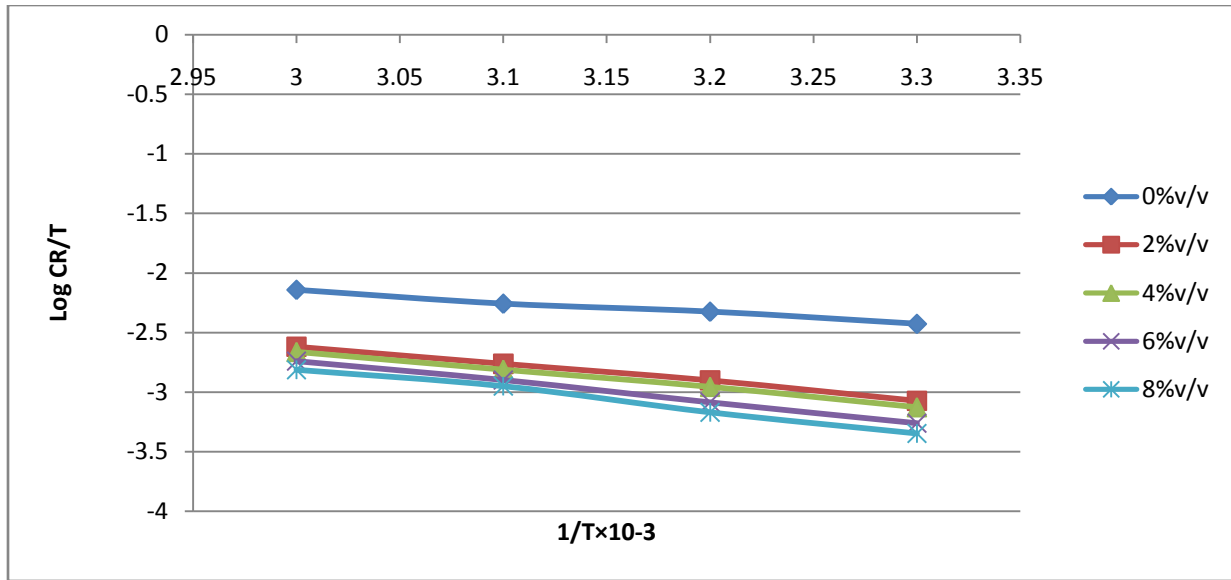


Fig.4.42: Log CR/T vs. 1/T for medium carbon steel in 0.5M NaCl in the absence and presence of *Hyptis suaveolens*

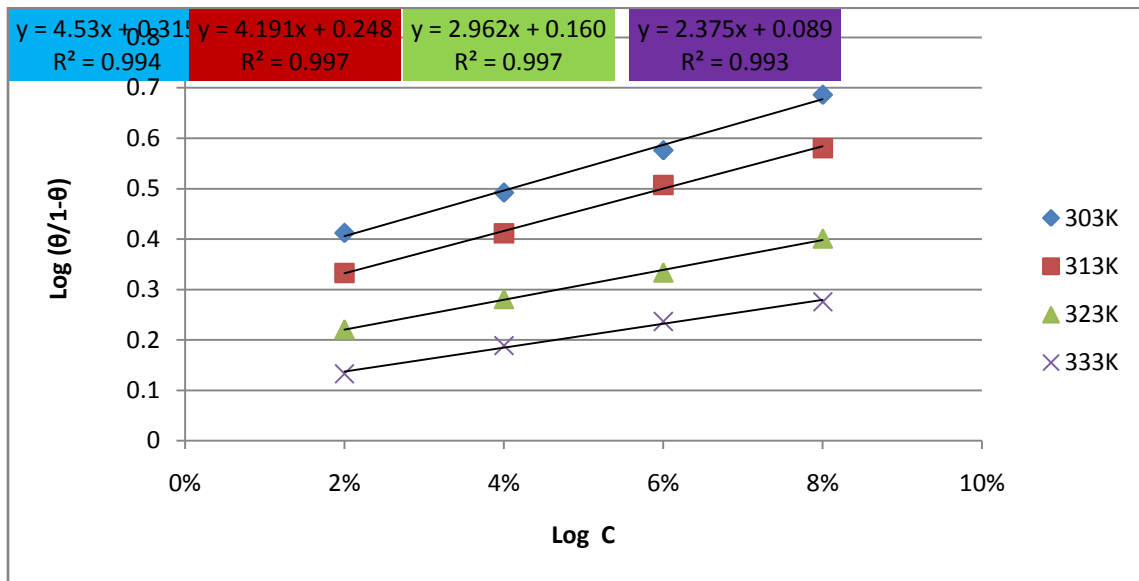


Fig. 4.43: Log ($\theta/1-\theta$) vs. Log C for medium carbon steel in 0.5M HCl containing *Ocimum gratissimumat* different temperature.

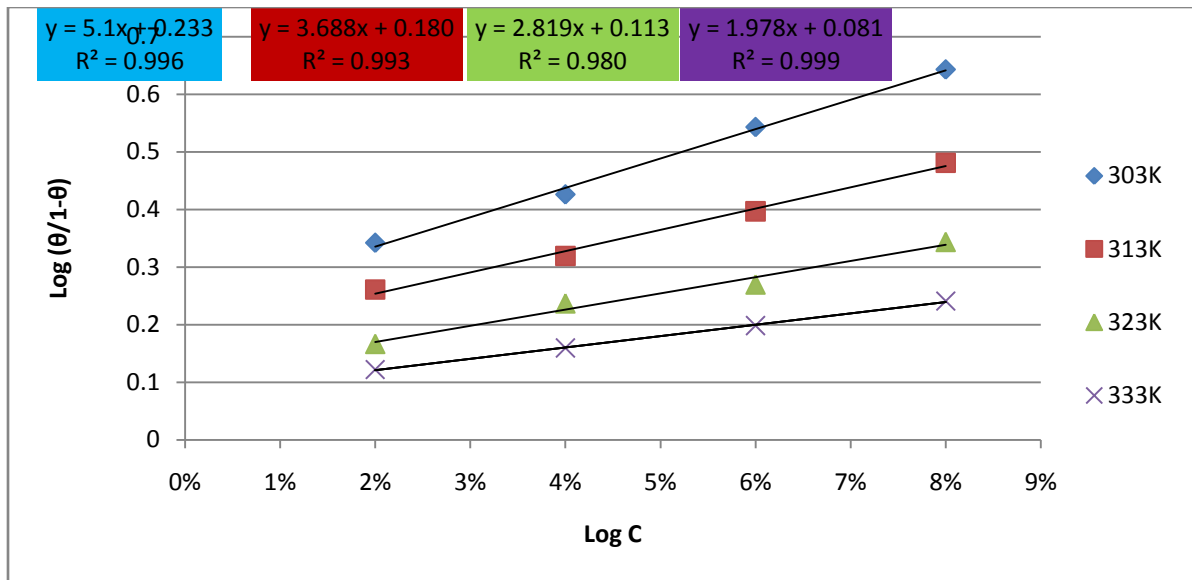


Fig.4.44:Log ($\theta/1-\theta$) vs. Log C for medium carbon steel in 0.5M HCl containing *Hyptis suaveolens* at different temperature.

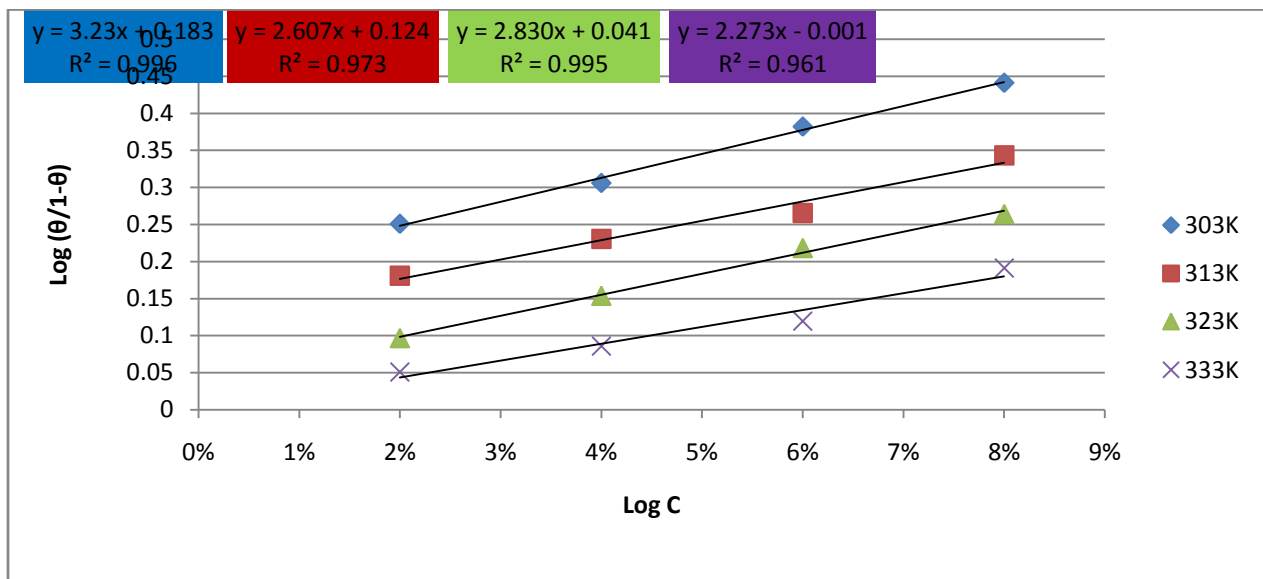


Fig.4.45:Log ($\theta/1-\theta$) vs. Log C for medium carbon steel in 0.5M H_2SO_4 containing *Ocimum gratissimum* at different temperature.

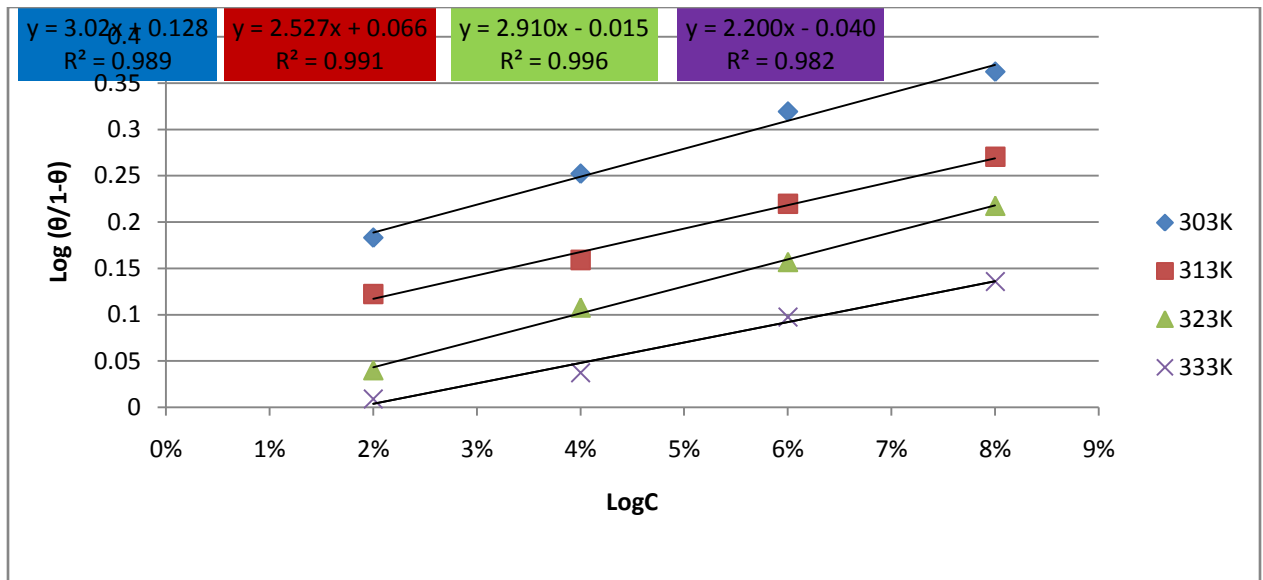


Fig.4.46:Log ($\theta/1-\theta$) vs Log C for medium carbon steel in 0.5M H_2SO_4 containing *Hyptis suaveolens* at different temperature.

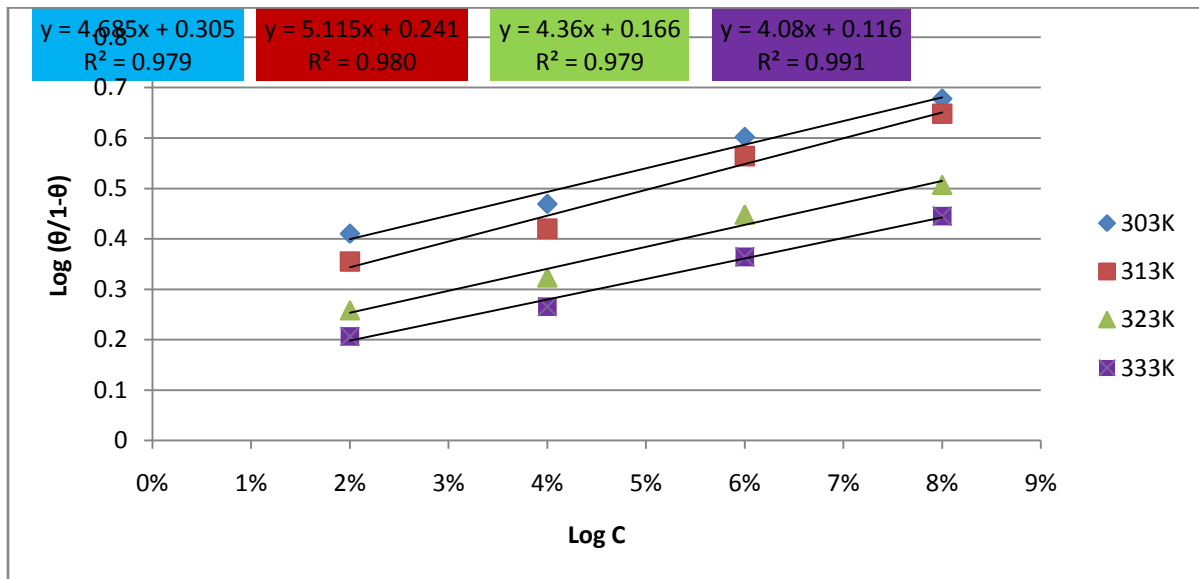


Fig.4.47:Log ($\theta/1-\theta$) vs Log C for medium carbon steel in 0.5M NaCl containing *Ocimum gratissimum* at different temperature.

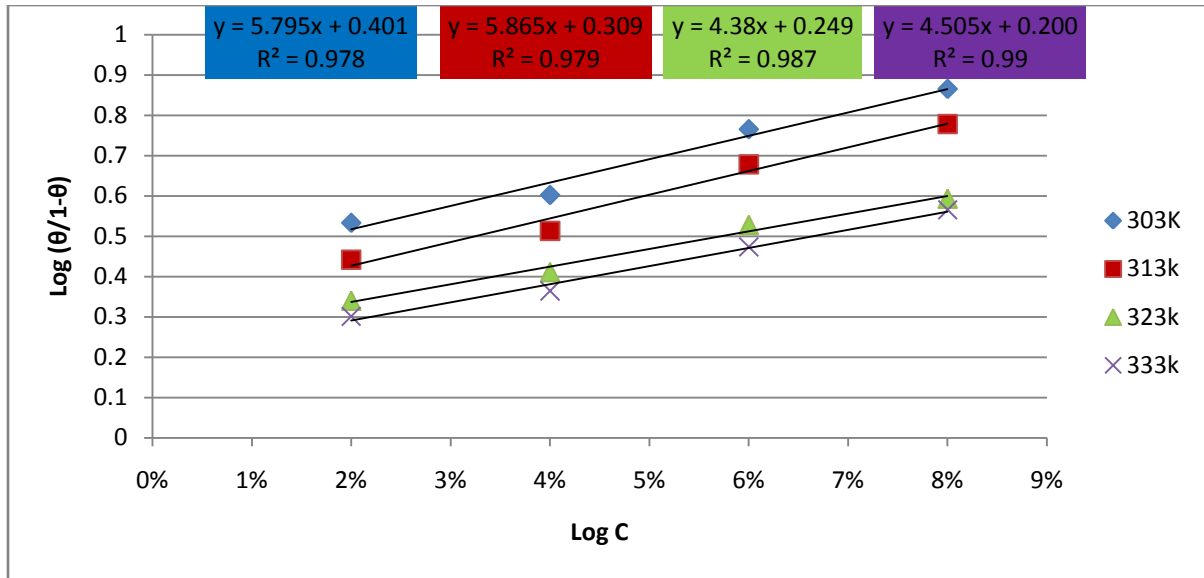


Fig.4.48: Log ($\theta/1-\theta$) vs Log C for medium carbon steel in 0.5M NaCl containing *Hyptis suaveolens* at different temperature.

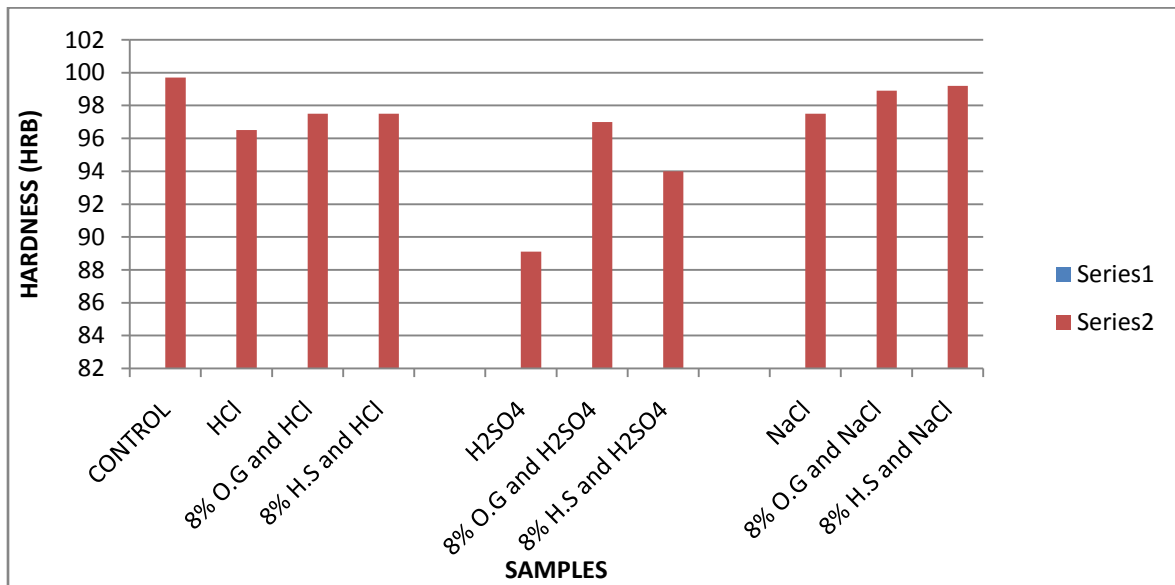


Fig.4.49: Hardness test on the specimens in the absence and presence of 8% *Ocimum gratissimum* and 8% for 25 days.

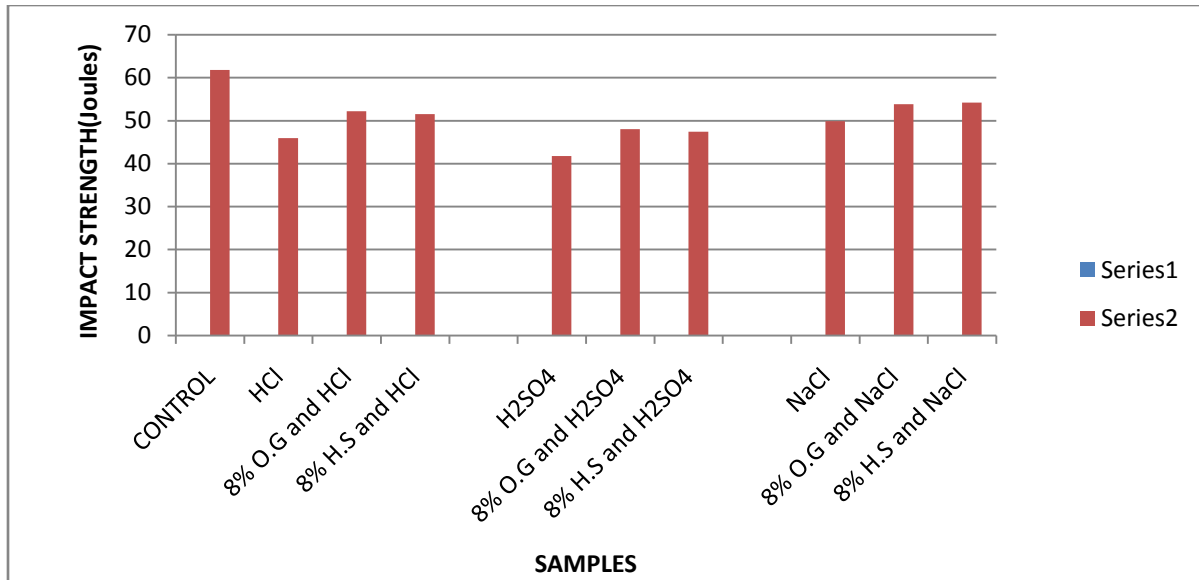


Fig.4.50: Comparison of impact strength on the specimens in the absence and presence of 8% *Ocimum gratissimum* and 8% *Hyptis suaveolens* for 25 days.

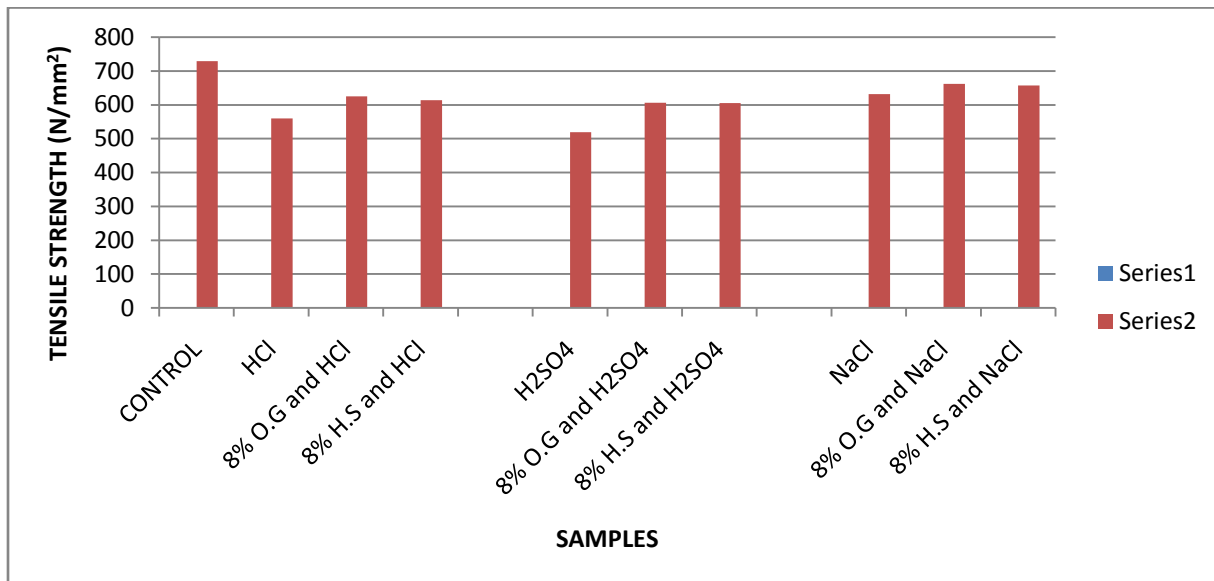


Fig.4.51: Comparison of tensile strength on the specimens in the absence and presence of 8% *Ocimum gratissimum* and 8% *Hyptis suaveolens* for 25 days.

4.1.2 Morphological Representations of some Samples

Plates ix-xiii represent the micrographs of the samples carried out in the absence and presence of *Ocimum gratissimum* leaf extract in HCl and H₂SO₄ media.

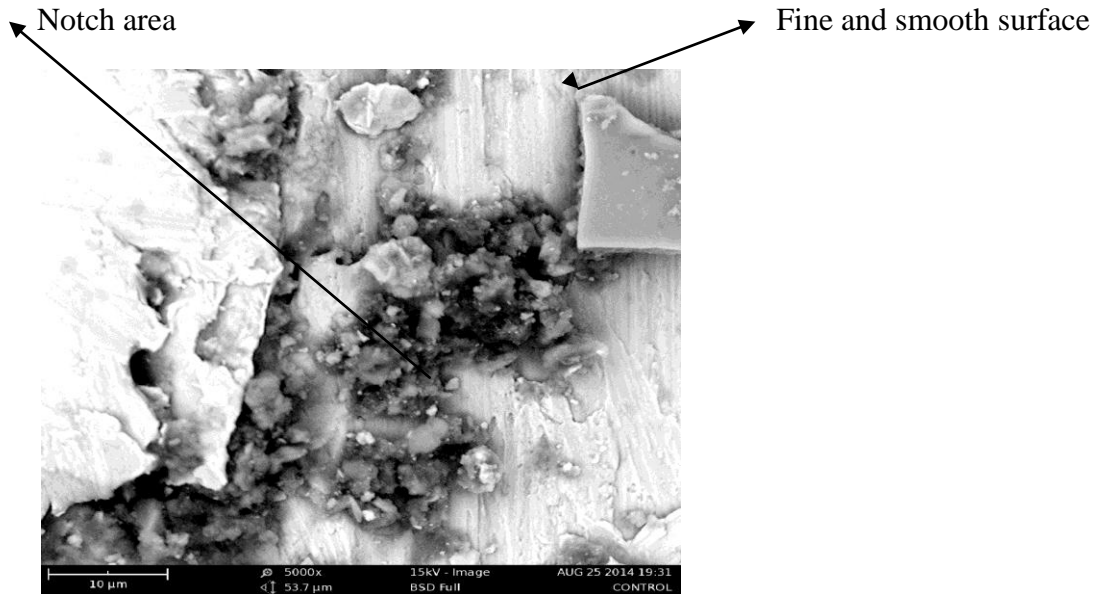


Plate IX: micrograph of original medium carbon steel

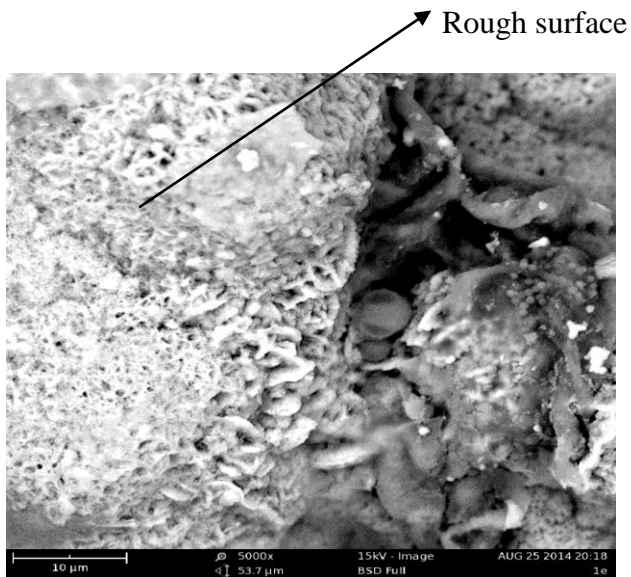


Plate X: micrograph of medium carbon steel after immersion in 0.5M blank HCl for twenty five days.

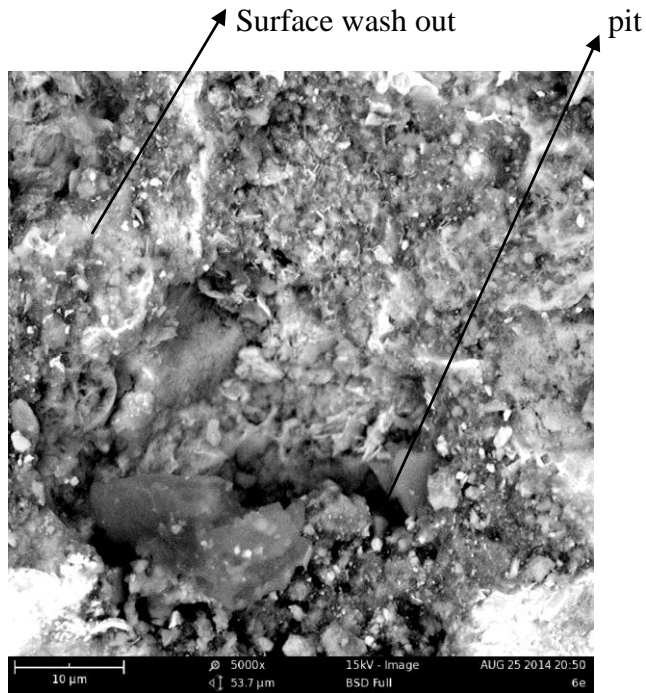


Plate XI: micrograph of medium carbon steel after immersion in 0.5M blank H₂SO₄ for twenty five days

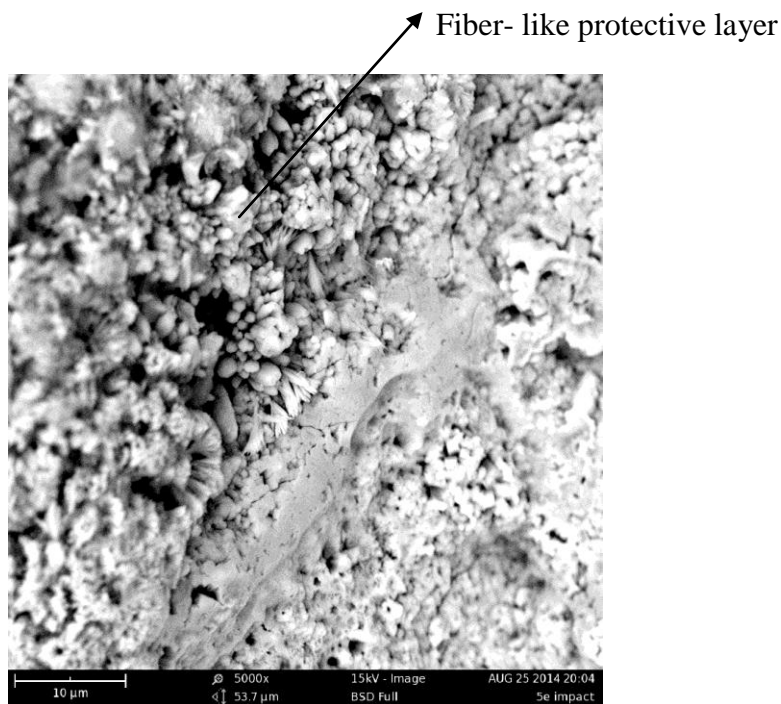


Plate XII: micrograph of medium carbon steel after immersion in 8% ocimum gratissimum + 0.5M HCl for twenty five day.

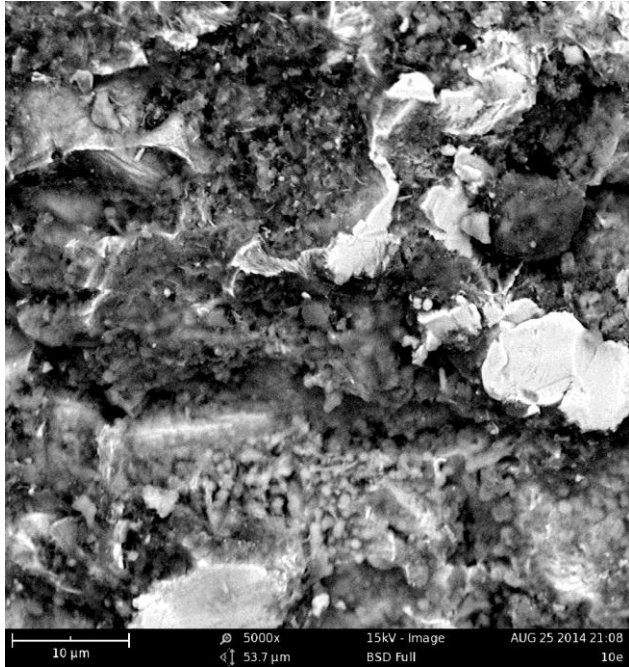


Plate XIII: micrograph of medium carbon steel after immersion in 8% *Ocimum gratissimum*+ 0.5M H₂SO₄ for twenty five days.

4.2. DISCUSSIONS OF RESULTS

4.2.1. Visual Observation of the Specimens

Visual observation of the specimens in the solution with and without inhibitor after twenty five days of exposure revealed changes in colour of the samples from initial bright grayish surfaces to dull ones. Pits were observed on the coupons which are indication of severe corrosion attack by the media. Albeit, the change in colour and presence of pits were more noticed on the samples in the solutions without inhibitor.

4.2.2. Corrosion Rate

From the results obtained on the corrosion rate against exposure time at different inhibitor concentrations plotted in Figures 4.1-4.6; it is clear that corrosion rate is high for samples without inhibitor and have better performance in inhibited solutions. As the concentration of inhibitors increased (with 2% increment), the rate of corrosion decreased (with at least 0.045mm/yr in HCl, 0.125mm/yr in H₂SO₄ and 0.0037mm/yr in NaCl) which indicates that a protective layer is formed at the surface of the coupons which prevents serious damage. This is in agreement with previous work by Yawas (2005).

4.2.3. Impact Strength, Tensile Strength and Hardness of the Specimens

Figure 4.7-4.12 and figure 4.13-4.18 showed that the mechanical properties (i.e. impact and tensile strength) of medium carbon steel decreased with increase in exposure time but increased (with at least 0.543J in HCl, 0.814J in H₂SO₄ and 0.542J in NaCl) with increase in concentration of inhibitors. The decrease in strength is attributed to the reduction in area of the rods as a result of gradual weight loss since strength is a function of exposed area (equation 3.6). Figures 4.49 - 4.51 also showed that H₂SO₄ strongly attack the specimens which in turn reduce the strength and hardness of medium carbon steel because of its high percentage of impurity, compare to those of NaCl and HCl.

4.2.4. Inhibition Efficiency

Figures 4.19- 4.30 show the performance of *Ocimum gratissimum*(O.G) and *Hyptis suaveolens*(H.S) on medium carbon steel in HCl, NaCl and H₂SO₄ at temperatures of 303, 313, 323 and 333K. Highest inhibitor efficiency of O.G was 82.9% in HCl, 73.4% in H₂SO₄ and 82.7% in NaCl at 303K and 8% concentration; lowest inhibitor efficiency of 57.6% in HCl,

52.9% in H₂SO₄ and 61.6% in NaCl were recorded at temperature and concentration of 333K and 2% respectively. *Hyptis suaveolens* (H.S) had highest inhibitor efficiency of 81.5% in HCl, 69.7% in H₂SO₄ and 88% in NaCl at 303K and 8% concentration. Lowest inhibitor efficiency of 57.0% in HCl, 50.5% in H₂SO₄ and 66.7% in NaCl were recorded at 333K and 2% concentration.

As it is observed in this work, inhibitor efficiency decreased (with at least 2.5% in HCl, 1.8% in H₂SO₄ and 1.9% in NaCl) with increase in temperature (ranging from 303-333K with interval of 10K) but increased with increase in inhibitor concentration, a trend that supports the mechanism of physical adsorption. Ergun *et al.*, (2008) attributed the decreased in inhibition efficiency with rise in temperature to an enhanced effect of temperature on the dissolution process of steel in acidic media and/or the partial desorption of the inhibitor from the metal surface. A similar trend was also reported in Umoren *et al.*, (2008).

4.2.5 Activation Energy (E_a)

A plot of the logarithm of corrosion rate against the reciprocal of the absolute temperature Figs. 4.31-4.36 gave linear graphs with slope equal to $-E_a/2.303R$. Hence the activation energy (E_a) was calculated and tabulated in appendix iii, Table 35.

These values were found to range from 32.80-53.1kJ/mol, 22.5-33.2kJ/mol and 20.3-33.0 kJ/mol for *Ocimum gratissimum* in HCl, H₂SO₄ and NaCl respectively. The values of E_a for *Hyptis suaveolens* (H.S) in HCl, H₂SO₄ and NaCl ranged from 32.80-51.6kJ/mol, 22.5-31.4kJ/mol and 20.3-37.7 kJ/mol respectively. Ebenso *et al.*, (2008) reported that values of $E_a < 80$ kJ is indicative of physical adsorption while $E_a > 80$ kJ is indicative of chemical adsorption. Thus the

activation energy values support the fact that the extracts were physically adsorbed on the medium carbon steel surface.

It is also observed that the values of activation energy in inhibited systems are higher than those for the uninhibited systems suggest that dissolution of medium carbon steel is slow which is in agreement with the findings of Abd El-Hameed (2011). Since corrosion primarily occur at surface sites free of adsorbed inhibitor molecules, the higher activation energies in the presence of inhibitors can be attributed to the decrease in surface area available for corrosion. Further as the concentration of the inhibitors increased (2% increment), the values of E_a also increased (with at least 1.8KJ/mol in HCl, 0.4kJ/mol in H_2SO_4 and NaCl). This means the presence of the inhibitors induces an energy barrier for corrosion reaction and the barrier increases with increasing concentration. At higher temperatures, there is an appreciable decrease in the adsorption of the inhibitor on the metal surface and a corresponding rise in the corrosion rate occurred.

4.2.6 Enthalpy and Entropy of Adsorption

Figures 4.37-4.42 showed plots of $\log (CR/T)$ against $(1/T)$. Linear plots were obtained with a slope equal $(-\Delta H/2.303R)$ and an intercept equal $(\log R/Nh + \Delta S /2.303R)$ from which the values of ΔH and ΔS were calculated and shown in appendix iii, Table 35. From Table 35, it was observed that the positive values of ΔH showed that the process of adsorption of the inhibitors on the carbon steel surface is an endothermic process. Thenegative values of ΔS represent association rather than dissociation of inhibitors indicating the decrease of system disorder due to the adsorption of inhibitor molecules on the carbon steel surface. The values of ΔS are higher for inhibited solutions than those for uninhibited solutions reflecting an increase in randomness

while moving from reactants to the activated complex.

4.2.7. Free Energy of Adsorption

The Gibbs free energy of adsorption (ΔG_{ads}) was calculated from equation 3.9, and shown in appendix ii, Tables 29- 34. The negative values of (ΔG_{ads}) indicate the spontaneous adsorption of the inhibitor on the surface of the carbon steel. Generally, the magnitude of ΔG_{ads} around-20KJ/mol or less negative indicates electrostatic interactions between inhibitor and the charged metal surface (i.e.physisorption). Those around -40kJ/mol or more negative are indicative of charge shearing transfer from organic species to the metal surface to form coordinate type of bond (i.e., chemisorptions) according to Abd El-Hammed (2011). In the present work, the calculated values are negatively lower than the threshold value of -40kJ/mol required for chemical adsorption; hence the adsorption of both inhibitors in HCl, H₂SO₄ and NaCl on the surface of carbon steel is spontaneous and favours the mechanism of physical adsorption.

4.2.8. Adsorption Mechanism

The interaction between inhibitor and steel surface can be well understood from the adsorption isotherms. The adsorption process is influenced by the nature and surface charge of the metal, by the type of aggressive electrolytes, temperature and by the chemical structure of the inhibitors (Rafaey *et al.*, 2004).

The values of surface coverage (θ) were calculated using corrosion rate values obtained from weight loss method. The values of θ at different concentration of *Ocimum gratissimum* (O.G) and *Hyptis suaveolens* (H.S) leaves extracts in HCl, H₂SO₄ and NaCl at temperature of 303, 313, 323 and 333K were used to explain the adsorption process. Data were tested graphically by fitting to Langmuir isotherm.

In this study, on plotting $\text{Log } \theta/1-\theta$ vs. $\text{Log } C$ (figures 4.43-4.48), linear plots with regression coefficient (R^2) nears unity were obtained for O.G and H.S in all the media. This suggests that the experimental data fit the Langmuir adsorption isotherm which reveals that there is no interaction between adsorbate and adsorbent. It indicates clearly that the inhibitor is displacing water from the metal surface.

4.2.9 Effect of Temperature

An investigation of the influence of temperature on the protective effect of an inhibitor is important in elucidating the mechanism of adsorption on a corroding metal surface.

The weight loss of medium carbon steel and the corrosion rate were found to increase with increase in temperature as shown in appendix ii, Tables 29-34. Corrosion is an oxidation reaction. It means an increase in temperature will increase the rate of oxidation reaction which in this case is the rate of corrosion. It can be seen that the efficiency of inhibition decreases with increasing temperature. This is due to the increased speed of oxidation of iron in the steel surface with increasing temperature, so the adsorbate from the extracts will easily detached from the steel surface in accordance with Umoren *et al.*, (2008).

4.3. Phytochemical Analysis of the Extracts

It is a recommended fact that the adsorption properties of the plant extracts is directly attributed to the presence of various chemical constituents. Therefore during the analysis of *Ocimum gratissimum* and *Hyptis suaveolens* leaves extracts for their adsorption properties, the determination of chemical composition is very essential. The phytochemical screening proved that the leaf extracts are rich in alkaloids, flavonoids and tannins. These compounds contain oxygen, nitrogen and sulphur atoms which possess lone pair of electrons that may facilitate the

formation of dative bonds acting as center for adsorption, thus creating a barrier between the steel surface and the corrosive media. This is in agreement with the findings of Rani and Basu (2012). The results of phytochemical screening were shown in appendix v, Table 37.

4.4. Surface Studies by Scanning Electron Microscopy

In order to evaluate the conditions of the metal surface in contact with acid solutions in the absence and presence of inhibitor, a surface analysis was carried out, using scanning electron microscope with magnification of 5000 are shown in plates IX- XIII.

The carbon steel samples in 0.5M HCl and 0.5M H₂SO₄ solutions with and without inhibitor were subjected to SEM analysis. Plate IX showed Surface morphology of the original specimen with smooth surface and fine grains. The morphologies of the steel surface exposed to blank 0.5M HCl and 0.5M H₂SO₄ for 25 days were altered during the corrosion and as expected rough, surface wash out, uneven surface covered and pits were seen (plates X and XI). However minimum corrosion products, surface wash out and pits were observed in the morphologies of samples with *Ocimum gratissimum*(platesXII and XIII). The protective film formed on the surface of medium carbon steel was confirmed by SEM studies.

The results obtained from the scanning electron micrographs of *Ocimum gratissimum* is consistent with the fact that this compound inhibited the corrosion of medium carbon steel through the mechanism of adsorption. The inhibitor tends to form adsorbed layer on the surface of the metal and protect the metal against corrosion. This is in agreement with previous work by Ameh *et al.*, (2012).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are drawn from this research work:

- I. The extracts were successfully obtained from the leaves of *Ocimum gratissimum* and *Hyptis suaveolens*. The corrosion of medium carbon steel in 0.5M HCl, 0.5M H₂SO₄ and 0.5M NaCl is inhibited by the additions of plants extracts. The inhibitors formed inhibitive barriers on the metal substrate to displace the water molecules.
- II. The results of physico-chemical and Phyto-chemical analyses showed that both *Ocimum gratissimum* and *Hyptis suaveolens* leaves extract contain tannins and other constituents which are responsible for inhibition of corrosion in carbon steel.
- III. The leaf extracts of *Ocimum gratissimum* and *Hyptis suaveolens* act as good and efficient inhibitors on carbon steel. The inhibition efficiency increases with increase in the concentration of inhibitors, but decreases with increase in temperature.
- IV. With respect to increase in temperature, the inhibitive properties of the extracts can be ranked as follows: In HCl and H₂SO₄ acid solutions, they found to be in this increasing order: H.S<O.G<while for NaCl solution the increasing order is found to be: O.G< H.S.
- V. The values of activation energy and enthalpy of adsorption were higher in the presence of the inhibitors suggesting physisorption mechanism of the extracts and that the process is endothermic.
- VI. The leaf extracts obey Langmuir adsorption isotherm which revealed that there is no interaction between the adsorbate and adsorbent.

- VII. The results of mechanical tests showed higher values of hardness, tensile and impact strength for inhibited samples than uninhibited ones. This indicated that the inhibitors displayed an effective inhibition against corrosion of the materials in the media.
- VIII. The results of SEM revealed that O.G displayed an effective inhibitive tendency against corrosion in 0.5M HCl and H₂SO₄ by forming protective layers on the steel surface, thus minimized corrosion rate.

5.2 Recommendations

Further work can be carried out in the following areas:

- i. The effect of the extracts on materials like aluminum and other non-ferrous alloys at various concentrations and temperatures could be investigated.
- ii. The uses of A.C Impedance, gasometric and Linear polarization methods to further verify the general effectiveness of the inhibitors that have been investigated are recommended.
- iii. Research should be carried out on the effects of several corrosive media such as crude oil, alkali etc. on the mechanical properties of carbon steel and other structural materials.
- iv. Proper corrosion control should be employed in the design and installation of any facility.

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APPENDIX I

RESULTS FOR IMPACT TEST SAMPLES

Table 1: initial data from original specimen

S/N	L (mm)	D ₁ (mm)	A ₁ (mm ²)	Impact strength (Joules)
1	45	8	1232.056	61.825

Table 2: Corrosion rate for medium carbon steel in 0.5M HCl in the absence of inhibitor.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	Impact Strength (Joules)
1	120	0.256	1.928	53.962
2	240	0.349	1.315	50.843
3	360	0.424	1.065	48.809
4	480	0.486	0.916	47.182
5	600	0.524	0.790	45.962

Table 3: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 2% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.089	0.671	0.652	65.2	56.266
2	240	0.142	0.536	0.593	59.3	53.826
3	360	0.186	0.468	0.561	56.1	51.657
4	480	0.221	0.417	0.545	54.5	49.623
5	600	0.255	0.385	0.513	51.3	47.454

Table 4: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 4% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	Θ	IE	Impact Strength (Joules)
1	120	0.083	0.626	0.676	67.6	56.944
2	240	0.117	0.441	0.665	66.5	55.317
3	360	0.155	0.389	0.635	63.5	52.877
4	480	0.183	0.344	0.624	62.4	50.572
5	600	0.215	0.324	0.590	59.0	48.945

Table 5: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 6% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	Θ	IE	Impact Strength (Joules)
1	120	0.075	0.563	0.708	70.8	58.029
2	240	0.108	0.409	0.689	68.9	56.402
3	360	0.141	0.355	0.667	66.7	56.402
4	480	0.168	0.317	0.655	65.5	52.199
5	600	0.192	0.290	0.634	63.4	50.979

Table 6: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 8% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.068	0.509	0.736	73.6	58.707
2	240	0.098	0.368	0.720	72.0	57.351
3	360	0.121	0.304	0.715	71.5	56.944
4	480	0.151	0.284	0.690	69.0	52.199
5	600	0.175	0.264	0.666	66.6	52.199

Table 7: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 2% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.101	0.763	0.604	60.4	55.182
2	240	0.158	0.595	0.548	54.8	52.877
3	360	0.200	0.503	0.528	52.8	51.250
4	480	0.238	0.449	0.510	51.0	49.623
5	600	0.267	0.402	0.492	49.2	46.369

Table 8: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 4% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.092	0.694	0.64	64.0	56.131
2	240	0.135	0.509	0.613	61.3	53.690
3	360	0.177	0.444	0.583	58.3	51.928
4	480	0.209	0.394	0.570	57.0	50.843
5	600	0.233	0.351	0.556	55.6	50.843

Table 9: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 6% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.081	0.612	0.683	68.3	56.944
2	240	0.117	0.441	0.665	66.5	55.317
3	360	0.150	0.376	0.647	64.7	53.419
4	480	0.177	0.333	0.636	63.6	51.928
5	600	0.211	0.318	0.598	59.8	51.521

Table 10: Corrosion rate for medium carbon steel in 0.5M HCl in the presence of 8% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.073	0.549	0.715	71.5	57.487
2	240	0.104	0.393	0.701	70.1	56.266
3	360	0.135	0.340	0.681	68.1	53.962
4	480	0.162	0.306	0.666	66.6	52.877
5	600	0.186	0.281	0.645	64.5	51.521

Table 11: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the absence of inhibitor

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	Impact Strength (Joules)
1	120	0.891	6.717	47.454
2	240	1.102	4.154	45.962
3	360	1.196	3.004	43.929
4	480	1.244	2.344	42.844
5	600	1.275	1.923	41.759

Table 12: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 2% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.319	2.405	0.642	64.2	51.928
2	240	0.415	1.565	0.623	62.3	49.487
3	360	0.483	1.214	0.596	59.6	47.318
4	480	0.525	0.989	0.578	57.8	45.013
5	600	0.552	0.832	0.568	56.8	43.386

Table 13: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 4% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.303	2.280	0.661	66.1	52.877
2	240	0.386	1.453	0.650	65.0	51.386
3	360	0.451	1.133	0.623	62.3	49.352
4	480	0.495	0.932	0.602	60.2	47.182
5	600	0.525	0.791	0.588	58.8	45.420

Table 14: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 6% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.281	2.120	0.684	68.4	54.368
2	240	0.358	1.350	0.675	67.5	52.877
3	360	0.418	1.051	0.650	65.0	51.386
4	480	0.454	0.855	0.635	63.5	49.759
5	600	0.481	0.725	0.623	62.3	46.369

Table 15: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 8% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.255	1.922	0.714	71.4	55.182
2	240	0.324	1.221	0.706	70.6	53.284
3	360	0.378	0.950	0.684	68.4	52.335
4	480	0.410	0.773	0.670	67.0	50.572
5	600	0.437	0.659	0.657	65.7	47.996

Table 16: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 2% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.349	2.629	0.609	60.9	50.979
2	240	0.443	1.671	0.598	59.8	48.809
3	360	0.514	1.292	0.570	57.0	46.505
4	480	0.547	1.031	0.560	56.0	45.013
5	600	0.568	0.857	0.554	55.4	43.251

Table 17: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 4% *Hyptissuaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.328	2.471	0.632	63.2	52.063
2	240	0.415	1.564	0.624	62.4	48.809
3	360	0.478	1.201	0.600	60.0	47.318
4	480	0.519	0.978	0.583	58.3	46.098
5	600	0.551	0.831	0.568	56.8	45.013

Table 18: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 6% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.305	2.302	0.657	65.7	53.148
2	240	0.386	1.453	0.650	65.0	51.250
3	360	0.440	1.106	0.632	63.2	49.352
4	480	0.473	0.892	0.619	61.9	47.454
5	600	0.502	0.757	0.606	60.6	47.454

Table 19: Corrosion rate for medium carbon steel in 0.5M H₂SO₄ in the presence of 8% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr)	θ	IE	Impact Strength (Joules)
1	120	0.281	2.116	0.685	68.5	54.233
2	240	0.356	1.341	0.677	67.7	52.470
3	360	0.404	1.016	0.662	66.2	50.979
4	480	0.431	0.813	0.653	65.3	48.809
5	600	0.454	0.684	0.644	64.4	47.454

Table 20: Corrosion rate for medium carbon steel in 0.5M NaCl in the absence of inhibitor.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	Impact Strength (Joules)
1	120	0.027	2.043	57.351
2	240	0.038	1.432	55.046
3	360	0.047	1.186	53.419
4	480	0.055	1.038	51.521
5	600	0.063	0.951	49.894

Table 21: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 2% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.010	0.716	0.649	64.9	58.978
2	240	0.016	0.614	0.571	57.1	57.758
3	360	0.021	0.538	0.547	54.7	55.589
4	480	0.026	0.494	0.525	52.5	53.148
5	600	0.031	0.466	0.510	51.0	51.657

Table 22: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 4% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.008	0.596	0.709	70.8	59.520
2	240	0.014	0.516	0.640	63.9	58.436
3	360	0.019	0.485	0.591	59.1	56.538
4	480	0.024	0.456	0.561	56.1	53.962
5	600	0.028	0.422	0.556	55.6	52.335

Table 23: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 6% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.006	0.482	0.764	76.4	60.063
2	240	0.012	0.445	0.690	68.9	59.249
3	360	0.017	0.415	0.650	65.0	56.944
4	480	0.020	0.379	0.635	63.5	54.775
5	600	0.023	0.353	0.629	62.9	53.148

Table 24: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 8% *Ocimum gratissimum*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.005	0.400	0.804	80.4	60.063
2	240	0.009	0.332	0.768	76.8	59.656
3	360	0.012	0.291	0.754	75.4	57.487
4	480	0.014	0.264	0.746	74.6	55.046
5	600	0.017	0.258	0.729	72.9	53.826

Table 25: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 2% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.008	0.611	0.701	70.1	58.300
2	240	0.014	0.52	0.637	63.7	56.673
3	360	0.019	0.475	0.600	60.0	55.589
4	480	0.023	0.433	0.583	58.3	53.148
5	600	0.027	0.412	0.567	56.7	51.386

Table 26: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 4% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.006	0.437	0.786	78.6	58.843
2	240	0.011	0.415	0.711	71.1	57.351
3	360	0.016	0.397	0.665	66.5	55.317
4	480	0.020	0.377	0.637	63.7	53.690
5	600	0.023	0.353	0.629	62.9	52.335

Table 27: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 6% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.005	0.400	0.804	80.4	59.385
2	240	0.010	0.358	0.750	75.0	58.300
3	360	0.013	0.332	0.720	72.0	56.402
4	480	0.017	0.311	0.701	70.1	55.589
5	600	0.020	0.300	0.685	68.5	53.419

Table 28: Corrosion rate for medium carbon steel in 0.5M NaCl in the presence of 8% *Hyptis suaveolens*.

S/N	Exposure Time (hrs)	Weight Loss (g)	Corrosion Rate (mm/yr) $\times 10^{-1}$	θ	IE	Impact Strength (Joules)
1	120	0.004	0.271	0.867	86.7	60.334
2	240	0.006	0.241	0.832	83.2	59.114
3	360	0.009	0.219	0.816	81.6	57.080
4	480	0.011	0.204	0.804	80.4	56.131
5	600	0.013	0.191	0.799	79.9	54.233

APPENDIX II

SAMPLES IMMERSED IN HIGHER TEMPERATURE SOLUTIONS

Table 29: Degree of surface coverage (θ) and inhibitor efficiencies (I.E) of *Ocimum gratissimum* in 0.5M HCl at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.0620	9.347	0	0	0.971	-1.511	0	0
	2	0.0173	2.608	0.721	72.1	0.416	-2.065	0.412	-22.370
	4	0.0151	2.277	0.756	75.6	0.357	-2.124	0.492	-21.080
	6	0.0130	1.960	0.790	79.0	0.292	-2.189	0.576	-20.550
	8	0.0106	1.598	0.829	82.9	0.204	-2.278	0.686	-20.460
313	0	0.0898	13.539	0	0	1.132	-1.364	0	0
	2	0.0285	4.297	0.683	68.3	0.633	-1.862	0.333	-22.630
	4	0.0251	3.784	0.721	72.1	0.578	-1.918	0.411	-21.290
	6	0.0213	3.211	0.763	76.3	0.507	-1.989	0.507	-20.810
	8	0.0187	2.819	0.792	79.2	0.450	-2.045	0.580	-20.500
323	0	0.1382	20.836	0	0	1.319	-1.190	0	0
	2	0.0519	7.825	0.625	62.5	0.893	-1.616	0.221	-22.660
	4	0.0475	7.161	0.656	65.6	0.855	-1.654	0.281	-21.170
	6	0.0438	6.603	0.683	68.3	0.820	-1.689	0.334	-20.400
	8	0.0393	5.925	0.716	71.6	0.773	-1.737	0.401	-20.050
333	0	0.2001	30.170	0	0	1.480	-1.043	0	0
	2	0.0849	12.800	0.576	57.6	1.107	-1.415	0.133	-22.800
	4	0.0787	11.865	0.607	60.7	1.074	-1.448	0.188	-21.230
	6	0.0735	11.081	0.633	63.3	1.045	-1.478	0.236	-20.420
	8	0.0694	10.463	0.653	65.3	1.020	-1.503	0.275	-19.870

Table 30: Degree of surface coverage (θ) and inhibitor efficiencies (IE) of *Hyptis suaveolens* in 0.5M HCl at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.0620	9.347	0	0	0.971	-1.511	0	0
	2	0.0194	2.925	0.687	68.7	0.466	-2.015	0.342	-21.960
	4	0.0169	2.548	0.727	72.7	0.406	-2.075	0.426	-20.700
	6	0.0138	2.081	0.777	77.7	0.318	-2.163	0.543	-20.360
	8	0.0115	1.734	0.815	81.5	0.239	-2.242	0.643	-20.210
313	0	0.0898	13.539	0	0	1.132	-1.364	0	0
	2	0.0318	4.794	0.646	64.6	0.681	-1.815	0.261	-22.200
	4	0.0291	4.387	0.676	67.6	0.642	-1.853	0.319	-20.740
	6	0.0257	3.875	0.714	71.4	0.588	-1.907	0.397	-20.150
	8	0.0223	3.362	0.752	75.2	0.527	-1.969	0.481	-19.910
323	0	0.1382	20.836	0	0	1.319	-1.190	0	0
	2	0.0560	8.443	0.595	59.5	0.926	-1.583	0.167	-22.320
	4	0.0507	7.644	0.633	63.3	0.883	-1.626	0.237	-20.900
	6	0.0483	7.282	0.651	65.1	0.862	-1.647	0.270	-20.010
	8	0.0431	6.498	0.688	68.8	0.813	-1.696	0.344	-19.700
333	0	0.2001	30.168	0	0	1.480	-1.043	0	0
	2	0.0861	12.981	0.570	57.0	1.113	-1.409	0.122	-22.730
	4	0.0819	12.348	0.591	59.1	1.092	-1.431	0.159	-21.050
	6	0.0776	11.699	0.612	61.2	1.068	-1.454	0.198	-20.170
	8	0.0730	11.006	0.635	63.5	1.042	-1.481	0.241	-19.650

Table 31: Degree of surface coverage (θ) and inhibitor efficiencies (I.E) of *Ocimum gratissimum* in 0.5M H₂SO₄ at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.1313	19.795	0	0	1.297	-1.185	0	0
	2	0.0472	7.116	0.641	64.1	0.852	-1.629	0.251	-21.430
	4	0.0434	6.543	0.669	66.9	0.816	-1.666	0.306	-20.010
	6	0.0385	5.804	0.707	70.7	0.764	-1.718	0.382	-19.420
	8	0.0349	5.262	0.734	73.4	0.721	-1.760	0.441	-19.040
313	0	0.1890	28.494	0	0	1.455	-1.041	0	0
	2	0.0751	11.322	0.603	60.3	1.054	-1.442	0.181	-21.720
	4	0.0700	10.553	0.630	630	1.023	-1.472	0.230	-20.210
	6	0.0665	10.026	0.648	64.8	1.001	-1.494	0.265	-19.360
	8	0.0590	8.895	0.688	68.8	0.949	-1.546	0.343	-19.080
323	0	0.2457	37.043	0	0	1.569	-0.940	0	0
	2	0.1092	16.463	0.556	55.6	1.217	-1.293	0.0969	-21.890
	4	0.1013	15.272	0.588	58.8	1.184	-1.325	0.154	-20.380
	6	0.0926	13.961	0.623	62.3	1.145	-1.364	0.218	-19.690
	8	0.0866	13.056	0.648	64.8	1.116	-1.393	0.264	-19.200
333	0	0.2961	44.641	0	0	1.650	-0.873	0	0
	2	0.1394	21.017	0.529	52.9	1.323	-1.200	0.051	-22.280
	4	0.1335	20.127	0.549	54.9	1.304	-1.219	0.086	-20.580
	6	0.1278	19.268	0.568	56.8	1.285	-1.238	0.120	-19.670
	8	0.1160	17.489	0.608	60.8	1.243	-1.280	0.191	-19.330

Table 32: Degree of surface coverage (θ) and inhibitor efficiencies (IE) of *Hyptis suaveolens* in 0.5M H₂SO₄ at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.1313	19.795	0	0	1.297	-1.185	0	0
	2	0.0520	7.840	0.604	60.4	0.894	-1.587	0.183	-21.040
	4	0.0471	7.101	0.641	64.1	0.851	-1.630	0.252	-19.690
	6	0.0426	6.423	0.676	67.6	0.808	-1.674	0.319	-19.050
	8	0.0398	6.000	0.697	69.7	0.778	-1.703	0.362	-18.580
313	0	0.1890	28.494	0	0	1.455	-1.041	0	0
	2	0.0813	12.257	0.570	57.0	1.088	-1.407	0.122	-21.370
	4	0.0774	11.669	0.591	59.0	1.067	-1.429	0.159	-19.780
	6	0.0711	10.719	0.624	62.4	1.030	-1.465	0.220	-19.090
	8	0.0660	9.950	0.651	65.1	0.998	-1.498	0.270	-18.650
323	0	0.2457	37.043	0	0	1.569	-0.940	0	0
	2	0.1172	17.670	0.523	52.3	1.247	-1.262	0.040	-21.540
	4	0.1077	16.237	0.562	56.2	1.211	-1.299	0.108	-20.100
	6	0.1009	15.212	0.589	58.9	1.182	-1.327	0.157	-19.310
	8	0.0927	13.976	0.623	62.3	1.145	-1.364	0.218	-18.920
333	0	0.2961	44.641	0	0	1.650	-0.873	0	0
	2	0.1465	22.087	0.505	50.5	1.344	-1.178	0.009	-22.010
	4	0.1417	21.363	0.521	52.1	1.330	-1.193	0.037	-20.270
	6	0.1315	19.826	0.556	55.6	1.297	-1.225	0.097	-19.530
	8	0.1251	18.861	0.578	57.8	1.276	-1.247	0.136	-18.980

Table 33: Degree of surface coverage (θ) and inhibitor efficiencies (I.E) of *Ocimum gratissimum* in 0.5M NaCl at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.0075	1.131	0	0	0.053	-2.428	0	0
	2	0.0021	0.317	0.720	72.0	-0.499	-2.981	0.410	-22.350
	4	0.0019	0.286	0.747	74.7	-0.543	-3.024	0.469	-20.950
	6	0.0015	0.226	0.800	80.0	-0.646	-3.127	0.602	-20.700
	8	0.0013	0.196	0.827	82.7	-0.708	-3.189	0.678	-21.140
313	0	0.0098	1.477	0	0	0.170	-2.326	0	0
	2	0.0030	0.452	0.694	69.4	-0.345	-2.840	0.355	-22.760
	4	0.0027	0.407	0.724	72.4	-0.390	-2.886	0.420	-21.340
	6	0.0021	0.317	0.786	78.6	-0.499	-2.995	0.564	-21.150
	8	0.0018	0.271	0.816	81.6	-0.566	-3.062	0.648	-20.910
323	0	0.0118	1.779	0	0	0.250	-2.009	0	0
	2	0.0042	0.633	0.644	64.4	-0.198	-2.708	0.258	-22.890
	4	0.0038	0.573	0.678	67.8	-0.242	-2.751	0.323	-21.430
	6	0.0031	0.467	0.737	73.7	-0.330	-2.840	0.448	-21.110
	8	0.0028	0.422	0.763	76.3	-0.375	-2.884	0.507	-20.710
333	0	0.0159	2.397	0	0	0.380	-2.143	0	0
	2	0.0061	0.920	0.616	61.6	-0.036	-2.559	0.206	-23.260
	4	0.0056	0.844	0.648	64.8	-0.074	-2.596	0.265	-21.720
	6	0.0048	0.724	0.698	69.8	-0.140	-2.663	0.364	-21.230
	8	0.0042	0.633	0.736	73.6	-0.198	-2.721	0.445	-20.950

Table 34: Degree of surface coverage (θ) and inhibitor efficiencies (IE) of *Hyptis suaveolens* in 0.5M NaCl at 303-333K, obtained from weight loss measurement after 6 hrs.

Temp(K)	% Comp	Weight Loss(g)	CR(mm/yr)	θ	IE	Log CR	Log(CR/T)	Log ($\theta/1-\theta$)	ΔG_{ads}
303	0	0.0075	1.131	0	0	0.053	-2.428	0	0
	2	0.0017	0.256	0.773	77.3	-0.591	-3.073	0.533	-23.070
	4	0.0015	0.226	0.800	80.0	-0.646	-3.127	0.602	-21.720
	6	0.0011	0.166	0.853	85.3	-0.780	-3.262	0.765	-21.640
	8	0.0009	0.136	0.880	88.0	-0.867	-3.349	0.865	-21.500
313	0	0.0098	1.477	0	0	0.170	-2.326	0	0
	2	0.0026	0.392	0.735	73.5	-0.407	-2.902	0.442	-23.280
	4	0.0023	0.347	0.765	76.5	-0.460	-2.956	0.513	-21.900
	6	0.0017	0.256	0.827	82.7	-0.591	-3.038	0.678	-21.840
	8	0.0014	0.211	0.857	85.7	-0.676	-3.171	0.778	-21.690
323	0	0.0118	1.779	0	0	0.250	-2.259	0	0
	2	0.0037	0.558	0.686	68.6	-0.254	-2.763	0.340	-23.400
	4	0.0033	0.498	0.720	72.0	-0.303	-2.812	0.411	-21.970
	6	0.0027	0.407	0.771	77.1	-0.390	-2.900	0.528	-21.600
	8	0.0024	0.362	0.797	79.7	-0.441	-2.951	0.593	-21.240
333	0	0.0159	2.397	0	0	0.380	-2.143	0	0
	2	0.0053	0.799	0.667	66.7	-0.097	-2.620	0.301	-23.870
	4	0.0048	0.724	0.698	69.8	-0.140	-2.663	0.364	-22.350
	6	0.0040	0.603	0.748	74.8	-0.220	-2.742	0.473	-21.930
	8	0.0034	0.513	0.786	78.6	-0.290	-2.813	0.565	-21.720

APPENDIX III

KINETICS AND THERMODYNAMICS RESULTS OF O.G AND H.S

Table 35: Values of Activation Energy, Enthalpy and Entropy of *Ocimum gratissimum* and *Hyptis suaveolens* on Medium Carbon Steel in 0.5M HCl, H₂SO₄ and NaCl

Inhibitor	%concentration	E _a (KJ/mol)			ΔH (KJ/mol)			-ΔS (J/mol)		
		HCl	H ₂ SO ₄	NaCl	HCl	H ₂ SO ₄	NaCl	HCl	H ₂ SO ₄	NaCl
<i>Ocimum gratissimum</i>	0	32.8	22.5	20.3	30.2	19.9	17.7	69.3	96.7	128.0
	2	44.7	30.2	29.4	42.1	27.5	26.8	40.9	80.0	108.6
	4	46.5	31.1	29.8	43.9	28.5	27.2	36.0	77.4	108.2
	6	49.3	32.7	32.3	46.6	30.1	29.6	28.5	73.1	102.2
	8	53.1	33.2	33.0	50.4	30.5	30.3	17.5	72.5	101.2
<i>Hyptis suaveolens</i>	0	32.8	22.5	20.3	30.2	19.9	17.7	69.3	96.7	128.0
	2	41.9	28.9	31.3	39.3	26.3	28.7	49.0	83.2	103.9
	4	44.0	30.3	32.1	41.3	27.6	29.4	43.3	79.6	102.6
	6	48.3	31.0	36.0	45.7	28.4	33.5	30.4	77.6	91.9
	8	51.6	31.4	37.7	48.9	28.9	35.0	21.3	77.2	88.5

APPENDIX IV

RESULTS FOR HARDNESS TEST SAMPLES

Table 36: Result of the hardness test carried out on some of the samples using Indentec Universal

Testing Machine

SAMPLES	MINOR LOAD (kgf)	MAJOR LOAD (kgf)	ROCKWELL (HRB)	BRINELL EQUIVALENCE (HB) ASTM E140
Original Sample	10	100	99.7	233.5
HCl	10	100	96.5	220
8% O.G and HCl	10	100	97.5	211.5
8% H.S and HCl	10	100	97.5	211
H ₂ SO ₄	10	100	89.1	188
8% O.G and H ₂ SO ₄	10	100	97	221
8% H.S and H ₂ SO ₄	10	100	94	204
NaCl	10	100	97.5	224.3
8% O.G and NaCl	10	100	98.9	232
8% H.S and NaCl	10	100	99.2	233.6

APPENDIX V

PHYTOCHEMICAL SCREENING OF EXTRACTS

Table 37: Result of Phytochemical Screening of the Extracts

S/N	Chemical constituent	<i>Ocimum gratissimum</i>	<i>Hyptis suaveolens</i>
1	Carbohydrates	+	+
2	Anthraquinone	-	-
3	Cardiac glycoside	+	+
4	Saponis	-	-
5	Steroid	-	-
6	Triterpene	+	+
7	Tannins	+	+
8	Flavonoid	+	+
9	Alkaloid	+	+

Key +.....indicates presence

 -.....indicates absence

APPENDIX VI

PHYSICOCHEMICAL ANALYSIS OF EXTRACTS

Table 38: Result of Physicochemical Analyses of Plant Extracts

S/N		<i>Ocimum grattissimum</i>	<i>Hyptis suaveolens</i>
1	PH	5.59	6.03
2	Boiling point	109°C/300ml	106°C/300ml
3	Density	0.95g/ml	0.94g/m
4	Acid value	9.05mg	9.05mg
5	Moisture content in %	71	64
6	Total soluble in %	76	82
7	Non tannin content in %	36	44
8	Tannin content in %	40	38

APPENDIX VII

MECHANICAL PROPERTIES OF MEDIUM CARBON STEEL USED

Table 39: Results of hardness, tensile and impact strength of medium carbon steel used in the presence and absence of inhibitor

S/N	Medium	Impact Strength (Joules)	Tensile Strength (N/mm ²)	Hardness (HRB)
1	Original Sample	61.825	734.348	99.7
2	B lank HCl	45.962	559.348	96.5
3	8% O.G and HCl	52.199	637.537	97.5
4	8% H.S and HCl	51.521	628.480	97.5
5	B lank H ₂ SO ₄	41.759	519.458	89.1
6	8% O.G and H ₂ SO ₄	47.996	619.472	97
7	8% H.S and H ₂ SO ₄	47.454	615.911	94
8	B lank NaCl	49.894	631.522	97.5
9	8% O.G and NaCl	53.826	668.311	98.9
10	8% H.S and NaCl	54.233	661.594	99.2

APPENDIX VIII

Table 40: **RANKING OF INHIBITORS ACCORDING TO INHIBITION EFFICIENCY (IE)**

S/N	HCl + 8% concentration at 30°C		H ₂ SO ₄ +8% concentration at 30°C		NaCl +8% concentration at 30°C	
	Plants	IE (%)	Extracts	IE (%)	Extracts	IE (%)
1	<i>Ocimum gratissimum</i>	82.9	<i>Ocimum gratissimum</i>	73.4	<i>Hyptis suaveolens</i>	88.0
2	<i>Hyptis suaveolens</i>	81.5	<i>Hyptis suaveolens</i>	69.7	<i>Ocimum gratissimum</i>	82.7