CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The corrosion of metals is an unavoidable but controllable process. In many industries corrosion cost billions of dollars each year for prevention, replacement and maintenance (Roberge, 2008). Acid solutions are wide used in acid pickling and indusrial cleaning. Hydrochloric acid and sulphuric acid are widely used for this purpose and most acid media cause metal corrosion (Bertiss et al, 2006; Khaled and Harkerman, 2003; Quraishi and Sadas, 2003). To avoid the attack of acid to the metal, inhibitors are generally added.

Corrosion inhibitors are substance which when added in small concentrations to corrosive media decrease or prevent the reaction of the metal with the media. It has been observed that adsorption depends mainly on certain physiochemical properties of the inhibitor group such as functional groups, electronic density at the donor atom, T-orbital character and the electronic structure of the molecule. Though many synthetic compounds showed good Anti corrosive activity, most of them are highly toxic to both human beings and the environment (Raja and Sethuraman, 2008). The known hazardous effect of most synthetic corrosion inhibitors are the motivation for the use of some natural products as corrosion inhibitors. Plant extracts have become important because they are environmentally acceptable, inexpensive, readily available and renewable.

Moreover, they can be extracted by simple procedures with low cost. Plants are source of naturally occurring compounds and are mostly known to have inhibition action, some with complex molecular structure and having different chemicals, biological and physical properties. Their extracts have become important and studies reveal that most organic compounds especially those with nitrogen sulphur, phosphorous and oxygen shows significant inhibition efficiency (Bellaoucho et al, 2001; Munoz et al, 2010; Ameer and Fekry 2010; Ameer et al, 2002; Khanis et al, 2000).

Several corrosion inhibition studies of mild steel by plant extracts in acidic media has been carried out and reported (Hui et al 2012) has proved the use of herbs as new type of green inhibitors for acidic corrosion of steel.

Mild steel is one of the major construction materials, which is extremely used in chemical and allied industries for the handling of acid, alkali and salt solutions (S.D Sheltty et al.., 2006). Hydrochloric acid is the most difficult of the common acids to handle form the standpoints of corrosion and material of constructions. Extreme case is required in the solution of materials to handle the acid by itself, even in relatively dilute concentrations or in process solutions. Containing appreciable amount of hydrochloric acid. This acid is very corrosive to most of the common metals and alloys (M.G Fontana, 1987).

1.2 STATEMENT OF THE PROBLEM

Over the years, corrosion of mild steel and other metals has been a major concern over the use of these materials for building and construction works. This is as a result of the fact that, there have been several reported accidents caused by corroded structures leading to loss of lives and property. The use of chemical inhibitors to prevent corrosion of metals has been a concern due to its toxicity which affects the living organisms as well as poisoning the environments, since some of them contain heavy metals and are non-biodegradable. Hence there is need for alternative inhibitors, which are more environmental friendly.

1.3 AIM AND OBJECTIVES OF THE STUDY

This research work is aimed at assessing the corrosion inhibitive potentials of sour sop seed extract on mild steel in acidic medium.

Also, the objectives of this study is to utilize this organic corrosion inhibitor as a substitute for chemical corrosion inhibitors which contains toxic compounds, and for determining the corrosion inhibition efficiency of the sour sop seeds extract using weight loss method.

1.4 SIGNIFICANCE OF THE STUDY

The significance of this research work cannot be over-looked. Hence, this research work conducted will boost our economy because the sour sop seed extract used as corrosion inhibitor are environmentally friendly and rich in natural synthesized chemical components and do not contain heavy metals or toxic compounds. Besides, the method is simple with low cost advantage.

1.5 JUSTIFICATION OF THE STUDY

The justification of this research work cannot be over-looked. Hence, this research work conducted will boost our economy because the sour sop extract used as corrosion inhibitor are environmentally friendly and rich in natural synthesized chemical components and do not contain heavy metals or toxic compounds. Besides, the method is simple with low cost advantage.

1.6 SCOPE OF THE STUDY

The scope of this research work is centered and not limited to the assessment of corrosion inhibitive potentials of sour sop seed extract on mild steel in acidic medium.

Mild steel was chosen due to its wide range of application, low cost and easy availability. Hydrochloric acids, sulphuric acid and phosphorous acid are the most commonly used acids in pickling baths at high temperatures up to 60ºC. These acids are widely used for pickling such as removal of oxide from the metallic parts before coating, to remove unwanted scale such as rust or mill scale formed during manufacture. Inhibitors are used in industrial process to maximize both the metal loss and acid consumption.

Also this research work considers the extraction of corrosion inhibitor from sour sop seeds using ethanol as solvent extractor.

1.7 LIMITATION OF THE STUDY

Some of the inhibition of this study was insufficient fund to purchase the absolute reagent or chemical to be used and inadequate equipment to extract the liquid instead of the powder sour sop seed in the laboratory.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

Corrosion is as old as the earth itself known to people as rust, corrosion is an undesirable phenomenon which destroys the luster and beauty of the materials and lessens their life. Since ancient times, corrosion has affected not only the quality of daily lives of the people but also their technical progress. It is a natural process of destruction like earthquakes, floods, volcanic eruptions etc. with one major differences that we can be only a silent spectator to the above processes of destruction, whereas corrosion can be prevented or at least controlled. Corrosion is the loss of useful properties such as malleability, ductility, electrical conductivity and optical reflectivity by metal due to attack of the environment.

2.2 DEFINITION OF CORROSION

The process whereby a materials break into its constituent atoms because of the chemical reactions with its surrounding is called corrosion. Rusting of a metal is a commonly known type of electrochemical corrosion. In rusting, the metal actually undergoes electrochemical oxidation with oxygen as an oxidant. The metal oxide (rust) is then formed. This metal oxide (rust) is the damage that is of serious concern to most industries all over the world.

Corrosion is not only limited to metals. It can also take place on other materials such as polymers and ceramics. Amongst many metals, corrosion is experienced strongly in iron and steel. This is because the oxide that is formed during the process of oxidation does not hold firmly to the surface of the metal, as a result it moves off the metal easily.

Corrosion is an irreversible interfacial reaction of a material or its dissolution into the material of a component of the environment. It is the natural tendency of the elements of a material to return to their most thermodynamic stable state (West 1986). It involves an electrochemical process governed by reactions on an atomic level, and basic stress environments variables like PH, temperature, pressure add to the complexity of corrosion.

The term corrosion is also sometimes applied to the degradation of plastics, concrete and wood, but generally refers to metals. Metallic corrosion is the natural process of the metal going to its oxidized state (Shrier 1978). The metal gets corrode by exposure to corrosive atmosphere like moist air, salty water, refinery oil, various acids etc. The most widely used metal is iron (usually as steel).

2.3 THE CONSEQUENCES OF CORROSION

The consequences of corrosion are many and varied, and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple loss of a mass of metal. Failures of various kinds and the needs for expensive replacement may occur even though the amount of metal destroyed is quite small. Some of the major harmful effects of corrosion can be summarized as follows:

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

2.) Leaking containers, storage tanks, water and oil transportation lines and fuel tanks cause significant loss of product and may generate severe accidents and hazards.

3.) Loss of time in availability of profit-making industrial equipment.

4.) Reduced value of goods due to deterioration of appearance

5.) Corrosion products may contaminate chemicals, pharmaceutical, dyes packaged goods with direct consequences to consumers.

6.) Perforation of vessels and pipes allowing escape of their contents and possible harm to the surrounding etc.

2.4 CHEMISTRY OF CORROSION

Metals are opaque, history elements that are good conductors, malleable and ductile. In chemistry, metals may be defined as elements that readily form Cat ions (positive ions) and form metallic bonds with other metal atoms and ionic bonds with non-metals. Metals may also be described as a lattice of positive ions surrounded by a cloud of localized electrons. The metallurgist considers metals as elements that have overlapping condition bond and valence bonds in their electronic structure.

Metals are obtained from their ore by the expenditure of large amount of energy. Metals store heat as potential energy during the melting and refining process and release this energy during the corrosion process after reacting with the environment. These metals can therefore be regarded as being in a meta-stable state and will tend to lose their energy by reverting to compounds more or less similar to their original states, for example the starting material for iron and steel making and the corrosion product rust has the same chemical composition (Fe_2O_3). The energy stored during melting and release during corrosion supplies the driving potential for thee corrosion process to take place. Since most metallic compounds and especially corrosion products have little mechanical strength, a severely corroded piece of metal is quite useless for its original purpose. Metals such as Mg, Al, Zn, and Fe which require larger amount of energy for refining are more susceptible to corrosion than metals which require lesser amount for refining such as Gold, silver, platinum.

2.4.1 CORROSION COMPONENTS

No metal would corrode while it has the following four essential components which constitute a corrosion cell.

- Anode
- Cathode
- Electrolyte
- Metallic path

1.) **ANODE:** it is the site where oxidation occurs. An anodic reaction is accompanied by loss of electron. Typical anodic reaction is given below:

$Fe \longrightarrow Fe^{2+} + 2e^-$

$Al \longrightarrow Al^{3}+ + 3e^-$

$Zn \longrightarrow Zn^{2}+ + 2e^-$

$Mg \longrightarrow Mg^{2}+ + 2e^-$

2.) **CATHODE:** it is the site where reduction takes place. The electrons released at the anode travel to the cathode by a metallic path where they react with the loss in the electrolyte and causes reduction of the positive ions. The cathode reaction is accompanied by a gain of electrons. The following are the major cathode reactions in corrosion of metals in aqueous solution.

$2H^+ + e^- \longrightarrow H_2$

$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$ (in acid solution)

$H_2O + O_2 + 4e- \longrightarrow 4OH-$ (in neutral solution)

3.) **ELECTROLYTE:** it provides a conductive medium for passage of ions which acts as charge carriers, like Fe^{2+}

ions, which carry a positive charge and flow from anode to cathode.

4.) **METTALLIC PATH:** it provides the flow of electron from the anode to cathode. All metals provide the electron path.

2.4.2 MECHANISM OF CORROSION

Iron and steel are important construction materials and it is necessary to understand how they corrode in an aqueous media.

All corrosion reactions are electrochemical in nature. At anodic sites on the surface, the iron goes into solution as ferrous ions, thus constituting the anodic reaction. The loss of electron leaves positively charged ions at the anode which travel from the anode to cathode through the water and carry a positive current. The electrons which are released on the anode travel from the anode to cathode through the metallic circuit. These electrons are utilized in the reduction of oxygen present in the water which is in contact with the cathodes.

At Cathodic sites, the electrons react with some reducible component of the electrolyte and are themselves removed from the metal. The corroding piece of metal is described as a “mixed electrode” since simultaneous anodic and Cathodic reactions are proceeding on its surface. Ion can serve as an anode and oxygen gas as the cathode in an electrochemical cell with the salt bridge as an aqueous solution of ions. The most common and important electrochemical reactions in the corrosion of iron are thus;

Anodic reaction

$$Fe \xrightarrow{\qquad\qquad} Fe^{2+} + 2e^{-}$$

Cathodic reactions

$$O_2 + 4H^{+} + 4e^{-} \xrightarrow{\qquad\qquad} 2H2O \text{ (if water is acidic)}$$

$$O_2 + H_2O + 4e^{-} \xrightarrow{\qquad\qquad} 4H^{+} \text{ (if water is basic)}$$

The negatively charged OH- ions react with the positively charged Fe^{2+} ions to form $Fe\ (OH)_2$

$$4Fe^{2+} + 2OH^{-} \xrightarrow{\qquad\qquad} 4Fe\ (OH)_2 \text{ white or}$$

$$4Fe(OH)_2 + O_2 + H{=}O \xrightarrow{\qquad\qquad} 2Fe_2\ O_3 \text{ (Brown)}$$

The end product of FeO_3 is called “rust”, the rust is formed a little away from the surface. The corrosion produced layers are insulators and the iron is protected as long as it is covered by thin layer of oxides, however, as soon as the oxides layer is damaged, corrosion are accelerated.

In dry conditions (where there is no moist) such as in place like desert, corrosion is much less slower than in a moist area. Carrying oxygen (O_2). There are many other factors that influence the rate of corrosion of mild steel, including the presence of salt. This is true because the molten salt increases the conductivity of the aqueous solution that is formed at the surface of the metal because the conductivity is increased, the rate of electrochemical corrosion increases the temperature of the system also affects the rate of corrosion of mild steel.

2.4.3 FORMS OF CORROSION

It is convenient to classify corrosion by the forms in which it manifests itself. It is classified into two forms (Fontana 1987).

1.) Intrinsic mode of corrosion: general corrosion, pitting corrosion, inter-granular corrosion, de-alloying and stress corrosion cracking.

2.) Extrinsic mode of corrosion: Galvanic corrosion, crevice corrosion. Fretting corrosion and corrosion due to fatigue.

2.4.3.1 INTRINSIC MODE OF CORROSION

1.) General Corrosion: this general corrosion also called a uniform attack by the most common form of corrosion. It is normally characterized by a chemical or electrochemical reaction which proceeds uniformly over the entire exposed surface or over a large area. The metals become thinner and eventually fail.

2.) Pitting Corrosion: Pitting is a form of extremely localized attack that results in holes. In metal, these holes may be small or large in diameter, but in most cases they are relatively small. Pits are sometimes isolated or so close together that they look like a rough surface. Pitting is one of the most destructive and insidious form of corrosion.

3.) Inter-granular corrosion: localized attack at the adjacent to gain boundaries, with relatively little corrosion of the grains, is inter-granular corrosion, the alloys disintegrates (grain fall out) and/or losses its strength.

Inter-granular corrosion can be caused by impurities of the grain boundaries, enrichment of one of the alloying elements of depletion of one of these elements in the grain boundary areas.

4.) De-alloying: de-alloying otherwise known as parting or selective leading is the removal of one element from a solid alloy by corrosion processes. It is a rare form of corrosion found in copper alloys, cast iron and some other alloys. It occurs when the alloy loses the active component of the metal and retains the most corrosive resistance component as a porous “sponge” on the metal surface. The best examples are dezincification and Graphitization. Aluminum alloys, copper-nickel, copper silicon and stainless steel alloys are affected by this type of corrosion.

a.) Dezincification: this occurs in copper-zinc alloys containing more than 15% zinc content. Zinc is more reactive than copper when exposed to appropriate environmental conditions, zinc readily bleaches from brass, leaving pure copper with poor mechanical properties. It is easily recognized by red colour surface.

b.) Graphitization: it is the selective leaching of iron from grey cast iron leaving weak, porous and inert graphite. It is a slow process and occurs in relatively mixed corrosion environment. When old graphitized pipes are disturbed, hazardous chemicals escape and contaminate the surrounding soil and sometimes cause fatal explosion and fire.

5.) Stress-corrosion cracking: stress corrosion cracking refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosion medium.

During stress-corrosion cracking, the metal or alloy is virtually attacked ever most of its surface, while fine cracks progress through it.

2.4.3.2 EXTRINSIC MODE OF CORROSION

1.) **Galvanic or bi-metal corrosion**: A potential difference exists between two dissimilar metals in electrical contact, when placed in an electrolyte and results in the flow of current between them. Several investigations have shown that corrosion is directly proportional to the area ratio of the Cathodic metal to anodic metal. Galvanic corrosion is maximum at the junction of the two metals. The attack decrease with increasing distance from the junction. The metals higher in electrochemical series undergo corrosion.

2.) **Crevice corrosion**: intense localized corrosion frequently occurs within crevices and other shielded areas on metal surface exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and river heads.

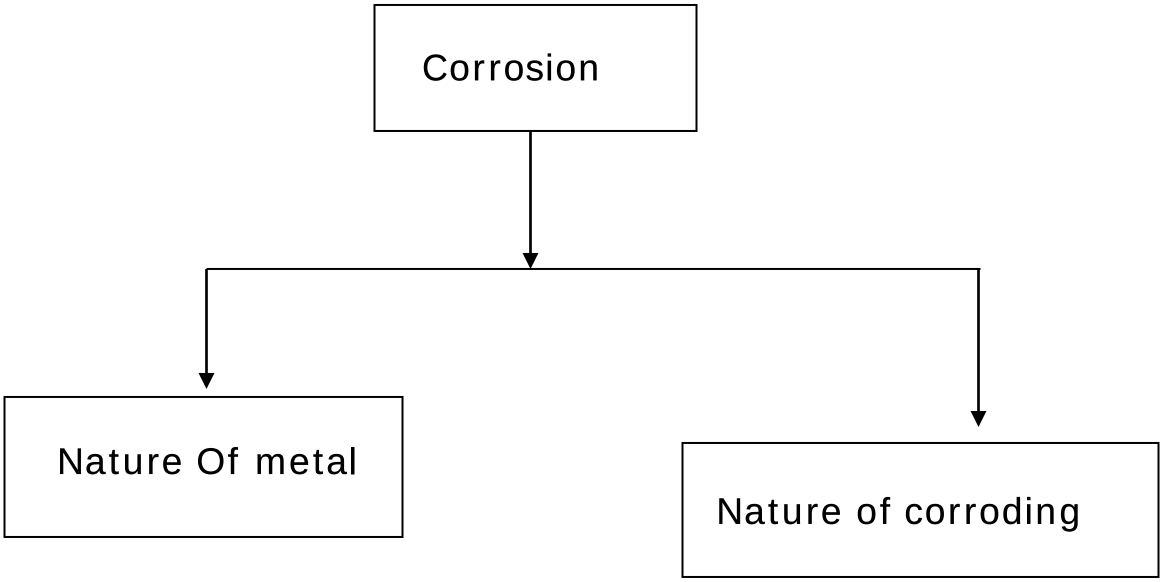
3.) **Fretting Corrosion**: the rapid corrosion that occurs at the interface between contacting highly loaded metals surface when subjected to slight vibrating motions is known as fretting corrosion. It is another form of erosion corrosion.

Erosion corrosion is the acceleration or increase in rate of deterioration or attack on a metal because of relative surface. This movement is quite rapid and the mechanical wear effects or abrasions are involved. Metal is removed from the surface as dissolved ions or it forms solid corrosion products which are mechanically swept from the metal surface. Erosion corrosion is characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits a directional pattern. It is also called impingement corrosion.

3.) **Corrosion fatigue**: corrosion fatigue is a special case of stress corrosion caused by the combined effects of cyclic stress and corrosion. This results in the drastic reduction in the fatigue life of the metal parts which are dynamically loaded in the moist or corrosive environment.

2.4.4. FACTORS INFLUENCING CORROSION

The extent and rate of corrosion depend on nature of metals and environment.



2.4.4.1 NATURE OF THE METAL

1.) Position in galvanic series

2.) Over voltage

3.) Relative area of anodic and cathodic parts

4.) Purity of the metal

5.) Physical stage of the metal

6.) Nature of the surface film

7.) Passive character of the metal

8.) Solubility of corrosion product

9.) Volatility of corroding environment

2.4.4.2 NATURE OF CORRODING ENVIRONMENT

1.) Temperature

2.) Humidity of air

3.) Presence of impurities in water

4.) Presence of suspended particles in atmosphere

5.) Influence in PH

6.) Nature of dissolved gases, dissolved salts, pollutants etc

7.) Conductance of the corroding medium

8.) Formation of oxygen concentrated cell

9.) Flow velocity of process steam

10.) Polarization of electrodes

2.4.4.3 RATE OF CORROSION

The process of corrosion involves a weight loss of the material or substance. This loss per unit time is used to express the rate of corrosion. The rate of corrosion depends on the material being corroded. There are materials that are not capable. The rate of corrosion in those substances that have the ability to form a passive film is much slower in comparison to those that do not have the capability to produce the passive film. When a thin protective layer oxide (passive film) is formed on the surface of the metal, the phenomenon is known as passivation.

The rate at which the attack takes place is of prime importance and is usually expressed in one of the two ways:

i.) Weight loss per unit area per unit time, usually MDD (milligram per square diameter per day).

ii.) Decrease in thickness per unit time i.e. rate of penetration or the thickness of metal lost. This may be expressed in American unit. MPY (mils per year) or in metric units or MMPY (millimeters per year).

2.4.4.4 CORROSION CONTROL METHODS

Corrosion is destructive and silent operating processes. It poses problems to big as well as small industries. Since corrosion is impracticable to stimulate the effective corrosion science and engineering lies in controlling rather than preventing it. The practical methods available for the protection of metal against corrosion are diverse. They may be broadly based on:

1.) Selection of materials
2.) Modification of metals
3.) Modification of design
4.) Use of inhibitors
5.) Modification of corrosive environment
6.) Modification of surface

The methods can be used individually or in combination. Among the various methods of corrosion control, use of inhibitors is the most efficient and cost effective.

2.4.4.5 FACTORS CONTROLLING CORROSION RATE

Certain factors tend to accelerate the action of a corrosion cell, these include:

1.) Establishment of well-defined locations on the surface for the anodic and cathodic reactions. Metals having a more positive (noble) potential in the galvanic series will tend to extract electrons from a metal which is in a more negative (base) position in the series and hence accelerate its corrosion when in contact with it.
2.) Stimulation of the anodic or cathodic reaction. Aggressive ions such as chloride tend to prevent the formation of protective oxide films on the metal surface and thus increase corrosion.

2.5. CORROSION INHIBITORS

2.5.1 DEFINITION OF INHIBITOR

An inhibitor is a substance which when added to acid solutions minimizes the loss of metal, reduces the extent of hydrogen embrittlement, protects the metal against pitting, reduces over pickling and acid fumes resulting from excessive reaction between the acid and basic metals and reduces acid consumption.

Corrosion inhibitors are substance which when added in small quantity to corrosive environment lower the corrosion rate. They reduce corrosion by either acting as a barrier by forming an absorbed layer or retarding the cathodic and/or anodic process (Sastri, 1998).

National association of corrosion engineering defines inhibitor as a substance which retards corrosion when added to an environment even in small concentration (NACE 1965).

Any corrosion retardation process or the reduction in the oxidation rate of thee metal by addition of a chemical compound to the system is caused by corrosion inhibitors.

The use of corrosion inhibitors is one of the best methods of combating corrosion. In order that they can be used effectively, three factors must be considered, namely:

1.) Identification of the corrosion problems
2.) The economics of the inhibition process

3.) The compatibility of the inhibitor with the process being used.

Generally, three of the four components of a corrosion cell (anode, cathode, electrolyte, and electronic conductor) May be affected by corrosion inhibitors in order to reduce corrosion. The inhibitor may cause:

1.) Anodic inhibition by increasing the polarization of the anode.
2.) Cathodic inhibition by increasing the polarization of the cathode
3.) Resistance inhibition by increasing the electrical resistance of the circuit while forming a thin or thick deposit on surface of metal.
4.) Diffusion restriction by restricting the diffusion of depolarizer (e.g. Dissolved oxygen) to the surface of the metal. By so doing the inhibitors play a dual role.

However there are several factors to be considered when choosing an inhibitor:

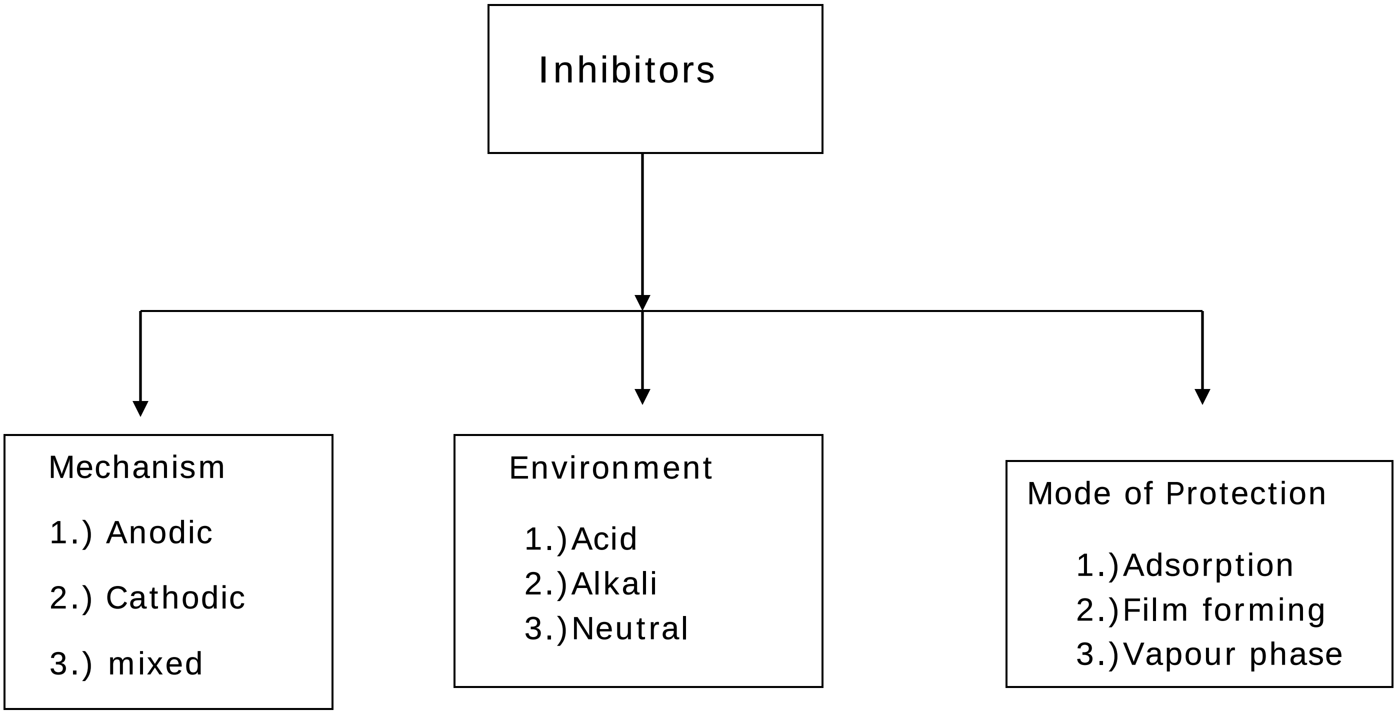
1.) Cost of the inhibitor
2.) Toxicity of the inhibitor can cause an effect on human beings and other living species.
3.) Availability of the inhibitor determines the selection of it
4.) Inhibitor should be environmentally friendly.

2.5.2 CLASSIFICATION OF INHIBITORS

The corrosion inhibitors can be chemicals either synthetic or natural and could be classified by:

1.) The chemical nature as organic or inorganic
2.) The mechanism of action as anodic, cathodic, cathodic or anodic-cathodic mix and by adsorption action, or,
3.) As oxidants or not oxidants (V. Gentil, 2003).

Corrosion inhibitors are briefly classified as follows:



2.5.3 BASED ON ELECTRODE PROCESS

1.) **ANODIC INHIBITORS**: An anodic inhibitor increases anodic polarization and hence moves thee corrosion potential to the cathodic direction and hence also called as passivating inhibitors. A number of inorganic inhibition such as Orthophosphates silictees etc. fall and anodic type even though anodic inhibitors are widely used, a few of them have some undesirable property. If such inhibitors are used very low concentrations, they cause stimulation of corrosion such as pitting and for this reason anodic inhibitors are denoted as dangerous, 2.) **Cathodic Inhibitors**: Cathodic inhibitor shift the corrosion potential to the anodic direction. Here, the cations migrate towards the cathode surfaces where they are precipitated chemically or electrochemically and thus block these surfaces. The inhibiting action of cathodic inhibitors takes place by three mechanisms, namely: Cathodic poisons, cathodic precipitates and oxygen scavenger.

3.) **Mixed inhibitors**: these inhibitors retard both the anodic and cathodic processes. The shift in the potential is smaller and the direction is determined by the relative size of the anodic and cathodic sites. Such inhibitors will have the advantage over other inhibitors in that they control both the cathodic and anodic corrosion reactions and hence, very safe to apply.

2.5.3 BASED ON ENVIRONMENT

1.) Acid Inhibitors: which are of two types namely:

a.) **Inorganic Inhibitors**: the compounds such as AS_2O_3, Sb_2O_3 have been reported as inhibitors in acid media. The action of these compounds has been attributed to the deposition of the metal in iron and steel by reduction and raising the hydrogen overvoltage and thereby reducing the corrosion. In strong acid solutions, bromide and iodide have been found to be effective inhibitors.

b.) **Organic Inhibitors**: usually the corrosion of metals and alloy s in acid solution is very severe and this kind of attack can be inhibited by a large number of organic substances. In general, oxygen, nitrogen and sulphur containing compounds with a hydrocarbon part attached to the polar group are used as inhibitors. Triple bonded hydrocarbons, acetylenic alcohols, thiourea, aromatic or heterocyclic compounds containing nitrogen and many other families of simple organic compounds and condensation products formed by the reaction between two different species such as aldehydes and amines are mostly used.

2.) Alkaline Inhibitors: the metals which form amphoteric oxides are prone to corrosion in basic solution. Many naturally occurring organic compounds are often used as inhibitors for metals in basic solutions. Tannis, gelatins, saponins. Agar-agar etc. and compounds such as thiourea, substitute phenols, napthols, ß-adiketones, etc. have been used as effective inhibitors in basic solutions due to the formation of metal complexes.

3.) **Neutral Inhibitors**: Inhibitors which are effective in acidic solution do not function effectively in neutral solutions, since the mechanism is different in the two solutions. In neutral solutions, the interaction of inhibitors with oxide covered metal surfaces and prevention of oxygen reduction reactions of cathodic sites take place. Such inhibitors protect the surface layer from aggressiveness. Some surface active chelating inhibitors have been found to be efficient inhibitors in near-neutral solutions.

2.5.4 BASE ON MODE OF PROTECTION

1.) Chemical Passivators: substances which usually have a sufficient high equilibrium potential (redox or electrode potential) and sufficiently low over potential decrease corrosion rate on attainment of passivity and are called chemical passivity. Examples are:

a.) nitrites are used as inhibitors for antifreeze cooling waters b.) chromates are mostly used as inhibitors for recirculating cooling waters

c.) zinc molybdate is used as an inhibiting pigment for paints.

2.) Adsorption Inhibitors: these represent the most widely used class of inhibitors. In general, they are organic compounds which get adsorbed on the metal surface and provided a blanketing effect over the entire surface, i.e. both in cathodic and anodic cases.

E.g. compounds containing one pairs of electron such as nitrogen atoms in amines, quinolines, sulphur atoms in thio compounds and oxygen atoms in aldehydes.

3.) Film forming inhibitors: In contrast to the adsorption inhibitors which form the straight forward adsorbed film of the inhibiting species, many substances called film forming inhibitors, appear to stop corrosion by forming a block or a barrier film of a material other than the actual inhibiting species itself. Such materials tend to be specific either to the cathode or to the anode. Zinc and calcium salts are the most common examples of cathodic film forming inhibitors. Benzoate is the common example of film forming inhibitor, which exhibits corrosion during voyages.

4.) **Vapour Phase Inhibitors**: Atmospheric corrosion of metals in closed spaces as in parcels during storage and shipment can be prevented by the use of certain substances called vapour phase inhibitors also called volatile inhibitors.

There are substances of low but significant vapour pressure. The vapour comes in contact with the surface of the metal and the adsorption of the inhibitor takes place the moisture then hydrolyzed it and releases protective ions which have corrosion inhibiting properties.

Examples

a.) Dicyclohexylamine chromate and bezotriazole for protecting copper.
b.) Phenyl thiourea and cyclo hexylamine chromate for brass
c.) Dicyclohylamine nitrate for ferrous and non ferrous parts.

2.5.5 INHIBITORS FOR MILD STEEL

1.) A number of nitrogen, oxygen containing compounds has been examined as corrosion inhibitors for mild steel.

2.) Several salts of acsines, phosphines and triple bonded hydrocarbons, acetylenic alcohols, thiourea, aromatic heterocyclic compounds are used as corrosion inhibitors for mild steel.

3.) There are many naturally occurring substance which are used as inhibitor for mild steel. These are heterogenous or compounds having higher basicity and electron density on the hetero atom.

2.6 MILD STEEL

Mild steel also known as carbon steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.12-2.0%. the American iron and steel institute (AISI) definitions says steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40

percent, or when the maximum content specified for any of the following elements does not exceed the percentages noted; manganese 1.65, silicon 0.60, copper 0.60 (Knowles and Peter 1987).

The term carbon steel may also be used in reference to steel which is not stainless steel. As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile regardless of the heat treatment, a higher carbon content reduces weldability. In carbon steels, the higher carbon lowers the melting point (Knoeles and Peter 1987).

2.6.1 TYPES OF CARBON STEEL

1.) **Mild and low carbon steel**: Mild steel also known as plain-chain steel is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Lower-carbon steel contains approximately 0.05-0.25% carbon. Making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; surface hardness can be increased through carburizing (Dagarmo et al, 2003). It is often used when large quantities of steel are needed, for example as structural steel. The ability of mild steel is approximately 7.85g/cm^3 and the young's modulus is 210 Gpa (30,000,000 psi). (Elert and Glenn, 2009).

2.) **Higher Carbon Steels**: Carbon steels which can successfully undergo heat-treatment have a carbon content in the range of 0.30-1.70% by weight. Trace impurities of various other elements can have a significant effect on the quality of the resulting steel. Trace amount in particular make the steel red-short, that is, brittle and crumbly at working temperatures. Low alloys carbon steel, such as A36-grade, contains about 0.05% sulfur and melts around 1426-1538^{o}C (2599-2800^{o}F). (Brady et al 1997) manganese is often added to improve the hardenability of low carbon steels. These addition turn the material into a low alloy steels by some definitions, but AISIS definition of carbon steel allows up to 1.65% manganese by weight.

2.6.2 HEAT TREATMENT OF CARBON STEEL

The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength, or impact resistance. Note that the electrical and thermal conductivity are only slightly altered.

The following is a list of the types of heat treatment possible:

1.) **Spheroidizing:** spheroidizing forms when carbon steel is heated to approximately 700°C for over 30 hours. Spheroidite can form at lower temperatures but the time needed drastically increases, as this is a diffusion controlled process. The purpose is to soften higher carbon steels and allow more formability.

2.) **Full annealing:** carbon steel is heated to approximately 40°C above Acm for 1 hour; this ensures all the ferrite transforms into austerite. Fully annealed steel is soft and ductile, with no internal stresses, which is often necessary for cost effective forming. Only spheroidized steel is softer and more ductile (Alvarenge AD et al 2009) and (Smith et al 2006).

3.) **Process annealing**: A process used to relieve stress in a cold-worked carbon steel with less than 0.3 wt% C. The steel is usually heated up to 550-650^oC for 1 hour, but sometimes temperatures as high as 700^oC.

4.) **Isothermal annealing**: it is a process in which hypoeutectoid steel is heated above the upper critical temperature and this temperature is maintained for a time and then the temperature is brought down below critical temperature and is again maintained. Then finally it is cooled at room temperature.

5.) **Normalizing:** Carbon steel is heated to approximately 55^oC above Acm for their; this ensure the steel is completely transforms to austenite. Normalized steel has a higher strength than annealed steel; it has a relatively high strength and annealed steel; it has a relatively high strength and hardness (Smith et al 2006).

6.) **Quenching:** Carbon steel with at least 0.4wt% C is heated to normalized temperatures and then rapidly cooled (quenched) in water, brine, or oil to the critical temperature.

7.) **Martempering (marquenching):** Martempering is not actually a tempering procedure hence the term “marquenching”. It is a form of isothermal heat treatment applied after an initial quench of typically in a molten salt bath at a temperature right above the “mastensite start temperature”.

8.) **Quench and Tempering**: this is the most common heat treatment encountered, because the final properties can be precisely determined by the temperature and time of the tempering. Tempering involves reheating quenched steel to temperature below the eutectoid temperature then cooling (Smith et al 2006).

9.) **Austempering**: the Austempering process is the same as martempering process, except the steel is held in the molten salt bath through the bainite transformation temperatures, and then moderately cooled. The resulting bainit steel has a greater ductility, higher impact resistance less distortion. The disadvantage of austempering is, it can only be used on a few steels, and it requires a special salt bath. (Smith et al, 2006).

2.7 DESCRIPTION OF SOUR SOP

Soursop, also commonly known as graviola, guabanana, and Brazilian paw paw, is a tropical fruitthat has been used as an herbal treatment for stomach ailments and fever. If you have traveled extensively in Mexico, the Caribbean, or parts of South America, then you have most likely seen the soursop tree, which is an evergreen tree with the scientific name *Annona muricata.* The taste of the soursop fruit is a delicious combination of strawberry and pineapple, with other sweet and citrus notes that make it very popular in these parts of the world. It is also cultivated in Africa, and occasionally in Southeast Asia, and even in Florida. However, it is most popularly grown for individual consumption as a garden fruit. The soursop is only one type of *Annona*, and one of the largest as well, with a number of different uses. The soft pulp and fiber of the fruit are used for beverages, desserts, smoothies, and candy, as well as a wealth of traditional medical treatments that are used in many parts of the world.

While the flavor is enough to make this a popular fruit, the rich vitamin and nutrient content of the fruit includes vitamin C, vitamin B, and a number of antioxidant compounds. The juice from soursop has been used topically, while pulverized seeds and decoctions made of leaves are also popular forms of natural remedies. You can also use the leaves and pulverized seeds to brew a powerful tea, which also has a number of impressive effects on the human body.

The benefits and uses of soursop seeds, also known as graviola or guyabano.

1. Soursops are extremely healthy fruits which are grown in many tropical counties. These are well known for their health benefits but there are also some uses for the seeds.
2. The seeds within this fruit should not be eaten as they contain toxic yellow oil which contains annonacin. This has been linked to Parkinson’s disease and eye inflammation.

3. The seeds are most commonly used as a pesticide. They can be pressed to release the oil using a pestle and mortar.

4. The oil can be mixed with a little coconut water and shampooed into the scalp to destroy head lice.

5. The people of Brazil often use this seed oil to destroy bedbugs by shampooing this into sheets and furniture with some warm water.
6. Cockroaches and other pets around the home can also be destroyed using this same method.
7. The seeds can also be used to grow new soursop or graviola trees. Simply collect and wash soursop seeds ready for planting. Plant these in pots of soil which is kept moist at all times. These seeds will germinate within 15 to 30 days. When they are around 12 inches high, separate them into individual pots. These will take three to five years to produce fruit, but this is worth it for the medicinal fruit.

8. The leaves and fruit of this plant are used in herbal medicine to treat many different problems.

Health Benefits of Soursop (Graviola)

Controls Parasites

The anti-parasitic nature of soursop has made it a popular treatment in many of the rural areas of Latin and South America, particularly in areas where parasitic infections are more common. By brewing a tea from the leaves of the fruit, you can cleanse your gut and ensure that your gastrointestinal system is running smoothly. This benefit is confirmed by a study published in the International Journal of Molecular Sciences.

Anti-inflammatory Properties

Researchers from Brazil conducted an experiment on animal models and proved the anti-inflammatory properties of soursop. So, if you are suffering from joint pain or inflammation, particularly from conditions like gout or arthritis, then rubbing a decoction of soursop on the affected area can be a wonderful way to find some relief. The anti-inflammatory compounds found in soursop can quickly speed healing in affected areas, while also soothing pain and improving flexibility.

Relieves Respiratory Distress

If you are struggling with a cough, cold, or other forms of the respiratory ailment, then soursop’s anti-inflammatory properties can help clear out your airways, relieve congestion, and soothe irritation. Acting partially as an expectorant, soursop is a reliable way to eliminate phlegm and mucus, where many pathogens can live. By reducing inflammation of the nasal cavities and respiratory tracts, it can also speed healing.

Treats Insomnia

Soursop tea has been used as a stress relieving strategy for centuries. There are certain anti-inflammatory and soothing properties of soursop that make it very effective if you are suffering from excessive stress and anxiety. Stress hormones in the body can be detrimental and can mess with your natural metabolic cycles, as well as your sleep schedule. If you're suffering from insomnia or restless sleep, soursop tea is a wise choice.

Skin Care

You can pulverize the seeds of the soursop fruit into a powder, which can then be formulated into a skin astringent, helping you reduce lines and wrinkles, and improving the appearance of age spots and blemishes. Topically apply this paste to the affected areas regularly and feel the glow on your skin return. It also protects your skin from bacterial and microbial infections.

Prevents Cancer

The most interesting benefits of soursop are related to its antioxidant activity, which comes from acetogenins, as well as quinolones and alkaloids. These have been directly linked to cancer prevention and a reduction in the size of tumors. Extensive research has been done on the unique organic compounds of soursop and it has been widely studied as an alternative cancer treatment. The acetogenins present in them are actually unique to the Annonaceae plant family, which is what makes them so fascinating. They can apparently cut off blood flow to foreign or non-normal cellular growths, and have already been positively associated with treating breast, pancreatic, prostate, and lung cancers.

2.8 WEIGHT LOSS METHOD

The weight loss control is the most reliable method. This method is still widely used since many different materials can be exposed at one site and unambiguous data on the form of corrosion on the specimen can be obtained. The difference in weight of metal due to corrosion is measured by exposing the metal specimen of known area of the corrosive environment for a known period of time. The corrosion rate is exposed in millimeter per year and is calculated by

$$\text{Corrosion rate} = \frac{87.6 \times W}{DAT} \quad (mm/y)$$

Where,

Mm/y = millimeter per year

W = weight loss of the metal in milligrams

D = Metal density in g/cm^3 (7.86g/cm^3)

A = Area of the sample in cm^2

T = time of exposure of the metal surface in hours

87.6 = conversion factor.

Inhibition efficiency:

Inhibition efficiency (%)

$$= \frac{\text{weight loss without inhibitor} - \text{weight loss with inhibitor}}{\text{Weight loss without inhibitor}} \times 100$$

2.8.1 PLANT EXTRACT INHIBITOR

Some investigations which have been made recent into the corrosive characteristics of some plants including seeds, leaves, fruits, bark and their tubers and also their inhibiting properties. In addition, parts of some plants have been used as addition agent in the electrodepositing of zinc on steel.

Specifically in some cases, the inhibitive effect of some plant solution extract has been attributed to the presence of tannis, alkaloids, pigment, organic and amino acids and most are known to have inhibitive action. Because of the toxic nature and high cost of some chemicals currently in use, it is necessary to develop environmentally acceptable and less expensive inhibitors in mentally acceptable and less expensive inhibitors. Naturally products can be considered as good source for this purpose. It has been found coconufera juice inhibits the corrosion of mild steel in hydrochloric acid solution. The inhibitive behavior of tobacco extract on corrosion of mild steel in acidic medium by fruit steel corrosion in an acidic and salty media has been carried out. The inhabitant of mild steel corrosion in an acidic medium by fruit juice of citrus paradise has been studied. The amount of a given plant extract absorbed depends on its concentration, temperature, fluid flow rate, as well as on the nature of the absorbent that is, solid surface.

2.9 IMPORTANCE OF CORROSION STUDIES

Corrosion studies have also become important due to increasing awareness of the need to conserve the world’s metal resources. Virtually all metals suffer corrosion, so its effect permeates in nearly every aspect of human endeavor and this fact alone should make the study of corrosion more important.

It is necessary to pay more attention to metallic corrosion than it was done earlier due to:

i.) Increasing use of metals in all fields of technology

ii.) Use of rare and expensive metals whose protection requires special precautions.

iii.) Strict safety standards of operating equipment which may fail in a catastrophic manner due to corrosion.

iv.) Use of new high strength alloys which are usually more susceptible to certain types of corrosive attack

v.) Increasing pollution of air and water resulting in a more corrosive environment.

CHAPTER THREE

METHODOLOGY

3.1 MATERIALS/REAGENTS

i.) Sulphuric Acid (H_2SO_4)

ii.) Sour Sop seeds extract as inhibitor

iii.) Distilled water

3.1.1 EQUIPMENT/APPARATUSES

i.) Conical flask (250ml and 500ml)

ii.) Measuring cylinder (200ml)

iii.) Beaker (200ml)

iv.) Digital weighing balance

v.) Bottles (6 pieces) or Bama bottles (6 pieces)

vi.) Threads

vii.) Mild steel (6 pieces)

3.2 PREPARATION OF MILD STEEL

The mild steel used for this research work was obtained from the market, and cut into 3cm square at the engineering workshop of Imo Poly. The mild steels were of the thickness 1mm each and were later cleaned with emergy paper (i.e. sand paper) to remove dirt and rust on them.

After which a small hole was bore at the centre of the mild steel pieces, then weighed on a digital weighing balance to obtain their initial masses. Therefore, the mild steel pieces were suspended in Bama bottles with a thread tied to a stick and covered to prevent atmospheric corrosion before experimentation properly commenced.

3.2.1 PREPARATION OF SOUR SOP SEED

The fresh Sour sop seeds were obtained from Sour sop fruits, then cracked to obtain the inner part (mesocarp) and was allowed to sundry for five days so as to remove all the moisture/water content in the seeds.

After drying, the dried seeds were then crushed in a mortar using a pistil and afterwards, it was ground in a blender to get very fine and small sized particles which were latter filtered with a sieve having little pore space to get the finest particle size of the seed powder which was latter used to obtain the extract.

3.2.2 REAGENT PREPARATION

The corrosion medium was prepared by diluting the concentrated tetraocosulphate (vi) acid with distilled water in appropriate proportions to obtain concentrations of 5M, of each of the bama bottles respectively.

Where 1 mol of H_2SO_4 =98g

5 mol of H_2SO_4 = 98 x5 = 490g

A weighing balance was used to get the amount of the concentrated H_2SO_4 acid to be used

490/1000 = 0.49kg.

Also, using a measuring cylinder, 800ml of distilled water was measured three (3) times to dilute the 5 mol of concentrated tetraoxosulphate (vi) acid. After undergoing dilution process, a beaker of 500ml was used to measure the dilute acids into each bama bottles containing the mild steel metal.

3.3 EXPERIMENTAL PROCEDURE

After weighing the mild steel pieces and recording each value of each mild steel piece to be used. Also the Sour sop seed extract was weighed for each number of bama bottles to be used in the experiment.

After weighing the Sour sop, 10.0g powder of the Sour sop was put into bottle 1 containing 0.5m of the dilute tetraoxosulphate (vi) acid.

20.0g of the Sour sop seed powder was added to bottle 2, containing 0.5m of the dilute tetraoxosulphate (vi) acid.

Also, 30.0g of the Sour sop seed powder was added to bottle 3, containing 0.5m of dilute tetraoxosulphate (vi) acid.

40.0g of the Sour sop seed powder was added to bottle 4, containing 0.5m of the dilute tetraoxosulphate (vi) acid.

And 50.0g of the Sour sop seed powder was added to bottle 5, containing the dilute tetraoxosullphate (vi) acid.

Finally, bottle 6 contained the mild steel metal and the dilute tetraoxosulphate (vi) acid without the inhibitor.

After suspending the mild steel metal in the same concentration in each bottle and its content was left to stand for 24 hours, each metal in the bottle was brought out, cleaned and weighed. The results obtained were recorded; then each metal was re-suspended in the bottles and made air tight with their covers.

Thus, this procedure was repeated for another six days at 24 hours interval. Hence the results obtained was tabulated and analyzed in chapter four.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 RESULT

The table below shows the mass of mild steel before being suspended in the bottle, and also the mass at 24 hours time interval, while those of the weight loss, inhibition efficiency and corrosion rate at varying experimental concentrations are presented below respectively.

Table 4.1: Result of soursop seed extract as an inhibitor in acidic medium

Extract Ml	**Mass of mild steel before suspension (g)**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
15	6.80	5.70	4.60	3.50	2.40	1.30	0.20	0
30	6.80	5.80	4.70	3.60	2.50	1.40	0.30	0
45	6.80	5.80	4.90	4.00	3.10	2.20	1.30	0.40
60	6.80	5.90	5.10	4.30	3.50	2.70	1.90	1.10

75	6.80	6.00	5.30	4.60	3.90	3.20	2.50	1.80
Blank	6.80	5.00	3.20	1.40	0	0	0	0

The tables below shows the weight Loss, inhibition efficiency and corrosion rate of soursop extract at 24 hours time interval for 7 days.

Table 1. At 24 hours (Day 1)

Weight Loss (g)	**Inhibition Efficiency (%)**	**Corrosion Rate (kg/hr)**
1.10	84	4.6x10^{-5}
1.00	85	4.2x10^{-5}
1.00	85	4.2x10^{-5}
0.90	87	3.8x10^{-5}
0.80	88	3.3x10^{-5}

Table 2. At 48 hours (Day 2)

Weight Loss (g)	**Inhibition Efficiency (%)**	**Corrosion Rate (kg/hr)**
2.20	68	$4.6x10^{-5}$
2.10	69	$4.4x10^{-5}$
1.90	72	$4.0x10^{-5}$
1.70	75	$3.5x10^{-5}$
1.50	78	$3.1x10^{-5}$

Table 3. At 72 hours (Day 3)

Weight Loss (g)	**Inhibition Efficiency (%)**	**Corrosion Rate (kg/hr)**
3.30	51	$4.6x10^{-5}$
3.20	53	$4.4x10^{-5}$
2.80	59	$3.9x10^{-5}$
	63	$3.5x10^{-5}$

2.50		
2.20	68	3.1x10^{-5}

Table 4. At 96 hours (Day 4)

Weight Loss (g)	Inhibition Efficiency (%)	Corrosion Rate (kg/hr)
4.40	35	4.6x10^{-5}
4.30	37	4.5x10^{-5}
3.70	46	3.9x10^{-5}
3.30	51	3.4x10^{-5}
2.90	57	3.0x10^{-5}

Table 5. At 120 hours (Day 5)

Weight Loss (g)	Inhibition Efficiency (%)	Corrosion Rate (kg/hr)
5.50	19	4.6x10^{-5}

5.40	20	$4.5x10^{-5}$
4.60	32	$3.8x10^{-5}$
4.10	40	$3.4x10^{-5}$
3.60	47	$3.0x10^{-5}$

Table 6. At 144 hours (Day 5)

Weight Loss (g)	**Inhibition Efficiency (%)**	**Corrosion Rate (kg/hr)**
6.60	2	$4.6x10^{-5}$
6.50	4	$4.5x10^{-5}$
5.50	19	$3.8x10^{-5}$
4.90	28	$3.4x10^{-5}$
4.30	37	$3.0x10^{-5}$

Table 7. At 168 hours (Day 7)

Weight Loss (g)	**Inhibition Efficiency (%)**	**Corrosion Rate (kg/hr)**
6.80	0	$4.1x10^{-5}$
6.80	0	$4.1x10^{-5}$
6.40	6	$3.8x10^{-5}$
5.70	16	$3.4x10^{-5}$
5.00	26	$2.9x10^{-5}$

4.2 DISCUSSION OF RESULT

From the results obtained, the weight loss of the mild steel pieces was suspended in the same solution with the same concentration and some bottles containing both the mild steel and inhibitor while bottle 6 contains only the dilute acid solution and the mild steel piece. The specimens bottles contain 15g, 30g, 45g, 60g and 75g of the extract of sour sop which some show significant weight loss of the specimen bottles.

The mild steel piece in bottle 1 containing the mild steel piece, dilute acid and sour sop extract, after being suspended suddenly begins to corrode with respect to the environment. The inhibition increases as the sour sop concentration increases thus, increases the corrosion rates of the mild steel piece in bottle 1. Also, bottle 2, 3, 4 and 5 was suspended with various concentration of the sour sop extract in the acid solution, which shows significant weight loss of the mild steel piece from day 1 till day 7. And bottle 6 containing the dilute tetraoxosulphate (vi) acid (H_2SO_4) and mild steel with no inhibition corrodes rapidly with respect to no inhibitor (sour sop extract) from day 1 to day 7.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research study was concluded with the following;

- The sour sop seed extract as an inhibitor does not completely stop the corrosion of the mild steel metal in tetraoxo sulphate (vi) acid but at high concentration of the inhibitor could stop the corrosion of the mild steel.
- There was excessive increase in weight loss of the mild steel metal which resulted in or lead to a decrease in the inhibition efficiency.
- There was complete corrosion of the mild steel metal in the bottle containing the dilute tetraoxo sulphate (vi) acid with no inhibitor (Blank).

Hence, the sour sop seed extract is not a suitable inhibitor to prevent and protect the corrosion of mils steel metal in the same concentration of dilute tetraoxo sulphate (vi) acids.

5.2 RECOMMENDATIONS

It is recommended that better inhibition efficiency can be achieved by increasing the inhibitor in a bid to reduce weight loss, prevent corrosion penetration rate and maintain inhibition efficiency.

Therefore, the utilization of sour sop seed extract as a corrosion inhibitor is not suitably recommended for preventing the corrosion of mild steel metal in the same solution, but at different or various acidic solution, it will prevail.

This research work can be further improved upon by carrying out more research on the seed to know why it could inhibit the corrosion of this mild steel in different acidic solution concentration depending on the type of acids used e.g. H_2SO_4 and HCL.

Further studies can be carried out also to see if the sour sop seed extract could be used to produce a paint that can prevent corrosion.

REFERENCES

Caparros-Lefebvre, Dominique; Elbaz, Alexis (1999). "Possible relation of atypical parkinsonism in the French West Indies with consumption of tropical plants: A case-control study". The Lancet. ***354*** *(9175): 281–6.*

Champy, Pierre; Melot, Alice; Guérineau Eng, (2005). "Quantification of acetogenins in Annona muricata linked to atypical parkinsonism in guadeloupe". Movement Disorders. ***20*** *(12): 1629–33.*

Lannuzel, A.; Höglinger, G. U.; Champy, P.; Michel, P. P.; Hirsch, E. C.; Ruberg, M. (2006). "Is atypical parkinsonism in the Caribbean caused by the consumption of Annonacae?". Journal of Neural Transmission. Supplementa. Journal of Neural Transmission. Supplementa. ***70*** *(70): 153–7.*

Lannuzel, A; Michel, P.P; Höglinger, G.U; Champy, P; Jousset, A; Medja, F; Lombès, A; Darios, F; Gleye, C; Laurens, A; Hocquemiller, R; Hirsch, E.C; Ruberg, M (2003). "The mitochondrial complex i inhibitor annonacin is toxic to mesencephalic dopaminergic neurons by impairment of energy metabolism". Neuroscience. ***121*** *(2): 287–96.*

Le Ven, J.; Schmitz-Afonso, I.; Touboul, D.; Buisson, D.; Akagah, B.; Cresteil, T.; Lewin, G.; Champy, P. (2011). "Annonaceae fruits and parkinsonism risk: Metabolisation study of annonacin, a model neurotoxin; evaluation of human exposure". Toxicology Letters. ***205***

Matsushige, A; Kotake, Y; Matsunami, K; Otsuka, H; Ohta, S; Takeda, Y (2012). "Annonamine, a new aporphine alkaloid from the leaves of Annona muricata". Chem Pharm Bull. ***60*** *(2): 257–9.*

APPENDIX

Calculation on corrosion inhibition, weight loss and corrosion rate in the mild steel, the inhibition efficiency was determined using the formula below;

$$\text{Inhibition efficiency (\%)} = \frac{\text{weight loss without inhibition} - \text{weight loss with inhibition}}{\text{Weight loss without inhibitor}} \text{ x } \frac{100}{1}$$

The weight loss was determined by finding the difference between the initial mass and the final mass of the mild steel pieces.

W = Initial Mass – Final Mass

The corrosion rate was also determined by the relationship shown,

$$\text{Corrosion Rate} = \frac{\text{Initial mass} - \text{Final mass}}{\text{Time (hr)}} = \frac{\text{corrosion}}{1000} \text{ (kg/hr)}$$

Weight Loss (g), inhibition efficiency and corrosion rate calculation of sour sop seed extract at 24 hour time interval.

Table 1: At 24 hours (Day 1)

Weight Loss (g)	Inhibition efficiency (%)	Corrosion Rate (kg/hr)
6.80– 5.70= 1.10	$\frac{6.80 - 1.10}{6.80}$ x $\frac{100}{1}$ = 84	$\frac{6.80 - 5.70}{24} = \frac{0.0458}{1000} = 4.6 \times 10^{-5}$

6.80– 5.80=1.00	$\frac{6.80 - 1.00}{6.80} \times \frac{100}{1} = 85$	$\frac{6.80 - 5.80}{24} = \frac{0.0417}{1000} = 4.2 \times 10^{-5}$
6.80– 5.80= 1.00	$\frac{6.80 - 1.00}{6.80} \times \frac{100}{1} = 85$	$\frac{6.80 - 5.80}{24} = \frac{0.0417}{1000} = 4.2 \times 10^{-5}$
6.80– 5.90= 0.90	$\frac{6.80 - 0.90}{6.80} \times \frac{100}{1} = 87$	$\frac{6.80 - 5.90}{24} = \frac{0.0375}{1000} = 3.8 \times 10^{-5}$
6.80– 6.00= 0.80	$\frac{6.80 - 0.80}{6.80} \times \frac{100}{1} = 88$	$\frac{6.80 - 6.60}{24} = \frac{0.0333}{1000} = 3.3 \times 10^{-6}$

Table 2: At 48 hours (Day 2)

Weight Loss (g)	Inhibition efficiency (%)	Corrosion Rate (kg/hr)
6.80– 4.60= 2.20	$\frac{6.80 - 2.20}{6.80} \times \frac{100}{1} =68$	$\frac{6.80 - 4.60}{48} = \frac{0.0458}{1000} = 4.6 \times 10^{-5}$
6.80– 4.70= 2.10	$\frac{6.80 - 2.10}{6.80} \times \frac{100}{1} = 69$	$\frac{6.80 - 4.70}{48} = \frac{0.0438}{1000} = 4.4 \times 10^{-5}$
6.80– 4.90= 1.90	$\frac{6.80 - 1.90}{6.80} \times \frac{100}{1} = 72$	$\frac{6.80 - 4.90}{48} = \frac{0.0396}{1000} = \times 10^{-5}$
6.80– 5.10= 1.70	$\frac{6.80 - 1.70}{6.80} \times \frac{100}{1} = 75$	$\frac{6.80 - 5.10}{48} = \frac{0.0354}{1000} = 3.5 \times 10^{-6}$

6.80– 5.30= 1.50	$\frac{6.80 – 1.50}{6.80}$ x $\frac{100}{1}$ =78	$\frac{6.80 – 5.30}{48}$ = $\frac{0.0313}{1000}$ = 3.1 x 10^{-6}

Table 3: At 72 hours (Day 3)

6.80– 3.50= 3.30	$\frac{6.80 – 3.30}{6.80}$ x $\frac{100}{1}$ = 51	$\frac{6.80 – 3.50}{72}$ = $\frac{0.0458}{1000}$ = 4.6 x 10^{-5}
6.80– 3.60= 3.20	$\frac{6.80 – 3.20}{6.80}$ x $\frac{100}{1}$ = 53	$\frac{6.80 – 3.60}{72}$ = $\frac{0.0444}{1000}$ = 4.4 x 10^{-5}
6.80– 4.00= 2.80	$\frac{6.80 – 2.80}{6.80}$ x $\frac{100}{1}$ =59	$\frac{6.80 – 4.00}{72}$ = $\frac{0.0389}{1000}$ = 3.9 x 10^{-5}
6.80– 4.30= 2.50	$\frac{6.80 – 2.50}{6.80}$ x $\frac{100}{1}$ = 63	$\frac{6.80 – 4.30}{72}$ = $\frac{0.0347}{1000}$ = 3.5 x 10^{-5}
6.80– 4.60= 2.20	$\frac{6.80 – 2.20}{6.80}$ x $\frac{100}{1}$ =68	$\frac{6.80 – 4.60}{72}$ = $\frac{0.0306}{1000}$ = 3.1 x 10^{-5}

Table 4: At 96 hours (Day 4)

6.80– 2.40= 4.40	$\frac{6.80 – 4.40}{6.80}$ x $\frac{100}{1}$ = 35	$\frac{6.80 – 2.40}{96}$ = $\frac{0.0458}{1000}$ = 4.6 x 10^{-5}
6.80– 2.50= 4.30	$\underline{6.80 – 4.30}$ x $\underline{100}$ = 37	$\underline{6.80 – 2.50}$ = $\underline{0.0448}$ = 4.5 x 10^{-5}

	6.80 1	96 1000
6.80– 3.10= 3.70	$\frac{6.80 - 3.70}{6.80} \times \frac{100}{1} = 46$	$\frac{6.80 - 3.10}{96} = \frac{0.0385}{1000} = 3.9 \times 10^{-5}$
6.80– 3.50= 3.30	$\frac{6.80 - 3.30}{6.80} \times \frac{100}{1} = 51$	$\frac{6.80 - 3.50}{96} = \frac{0.0344}{1000} = 3.4 \times 10^{-5}$
6.80– 3.90= 2.90	$\frac{6.80 - 2.90}{6.80} \times \frac{100}{1} = 57$	$\frac{6.80 - 3.90}{96} = \frac{0.0302}{1000} = 3.0 \times 10^{-5}$

Table 5: At 120 hours (Day 5)

6.80– 1.30= 5.50	$\frac{6.80 - 5.50}{6.80} \times \frac{100}{1} = 19$	$\frac{6.80 - 1.30}{120} = \frac{0.0458}{1000} = 4.6 \times 10^{-5}$
6.80– 1.40 = 5.40	$\frac{6.80 - 5.40}{6.80} \times \frac{100}{1} = 20$	$\frac{6.80 - 1.40}{120} = \frac{0.0450}{1000} = 4.5 \times 10^{-5}$
6.80– 2.20= 4.60	$\frac{6.80 - 4.60}{6.80} \times \frac{100}{1} = 32$	$\frac{6.80 - 2.20}{120} = \frac{0.0383}{1000} = 3.8 \times 10^{-5}$
6.80– 2.70= 4.10	$\frac{6.80 - 4.10}{6.80} \times \frac{100}{1} = 40$	$\frac{6.80 - 2.70}{120} = \frac{0.0342}{1000} = 3.4 \times 10^{-5}$
6.80– 3.20= 3.60	$\frac{6.80 - 3.60}{6.80} \times \frac{100}{1} = 47$	$\frac{6.80 - 3.20}{120} = \frac{0.0300}{1000} = 3.0 \times 10^{-5}$

Table 6: At 144 hours (Day 6)

6.80– 0.20 = 6.60	$\frac{6.80 - 6.60}{6.80} \times \frac{100}{1} = 2$	$\frac{6.80 - 0.20}{144} = \frac{0.0458}{1000} = 4.6 \times 10^{-5}$
6.80– 0.30 = 6.50	$\frac{6.80 - 6.50}{6.80} \times \frac{100}{1} = 4$	$\frac{6.80 - 0.30}{144} = \frac{0.0451}{1000} = 4.5 \times 10^{-5}$
6.80– 1.30= 5.50	$\frac{6.80 - 5.50}{6.80} \times \frac{100}{1} = 19$	$\frac{6.80 - 1.30}{144} = \frac{0.0382}{1000} = 3.8 \times 10^{-5}$
6.80– 1.90 = 4.90	$\frac{6.80 - 4.90}{6.80} \times \frac{100}{1} = 28$	$\frac{6.80 - 1.90}{144} = \frac{0.0340}{1000} = 3.4 \times 10^{-5}$
6.80– 2.50 = 4.30	$\frac{6.80 - 4.30}{6.80} \times \frac{100}{1} = 37$	$\frac{6.80 - 2.50}{144} = \frac{0.0299}{1000} = 3.0 \times 10^{-5}$

Table 7: At 168 hours (Day 7)

6.80– 0 = 6.80	$\frac{6.80 - 6.80}{6.80} \times \frac{100}{1} = 0$	$\frac{6.80 - 0}{168} = \frac{0.0405}{1000} = 4.1 \times 10^{-5}$
6.80– 0 = 6.80	$\frac{6.80 - 6.80}{6.80} \times \frac{100}{1} = 0$	$\frac{6.80 - 0}{168} = \frac{0.0405}{1000} = 4.1 \times 10^{-5}$

$6.80 - 0.40 = 6.40$	$\frac{6.80 - 6.40}{6.80} \times \frac{100}{1} = 6$	$\frac{6.80 - 0.40}{168} = \frac{0.0381}{1000} = 3.8 \times 10^{-5}$
$6.80 - 1.10 = 5.70$	$\frac{6.80 - 5.70}{6.80} \times \frac{100}{1} = 16$	$\frac{6.80 - 1.10}{168} = \frac{0.0339}{1000} = 3.4 \times 10^{-5}$
$6.80 - 1.80 = 5.00$	$\frac{6.80 - 5.00}{6.80} \times \frac{100}{1} = 26$	$\frac{6.80 - 1.80}{168} = \frac{0.0298}{1000} = 2.9 \times 10^{-5}$