Chapter one
Introduction and literature review

1. Introduction

Corrosion is degradation of materials' properties due to interactions with their environments, and corrosion of most metals (and many materials for that matter) is inevitable. While primarily associated with metallic materials, all material types are susceptible to degradation. Degradation of polymeric insulating coatings on wiring has been a concern in aging aircraft. Even ceramics can undergo degradation by selective dissolution. Like death and taxes, corrosion is something we hope to avoid; but ultimately it is something we must learn to deal with. The fundamental cause or driving force for all corrosion is the lowering of a system's Gibbs energy .the production of almost all metals and engineering components made of metals) involves adding energy to the system. As a result of this uphill thermodynamic struggle, the metal has a strong driving force to return to its native, low energy oxide state. This return to the native oxide state is what we call corrosion and even though it is inevitable, substantial barriers (corrosion control methods) can be used to slow its progress toward the equilibrium state. Thus it is the rate of the approach to equilibrium that is often of interest. This rate is controlled not only by the nature of the metal surface, but also by the nature of the environment as well as the evolution of both [1]. Among the corrosion problems, one of the most important present in the refining oil industry, is specifically the related to the sour water generated in primary distillation plants. Despite the efforts made in the industrial field, and in fundamental studies; the different operating conditions as well as different concentrations of pollutants, makes their control very complicated. The studies that have been trying to simulate the operating conditions in sour waters [2-4] have increased in the last ten years, in which the characteristics of the raw obtained, have changed resulting in corrosive environments much more aggressive than before.The purpose of these studies was to try to find ways, in which various agents affect or minimize corrosion, with the purpose of determining the predominant mechanism of corrosion in such environments.

Corrosion is a natural process, which converts refined metal to their more stable oxide. It is the gradual destruction of materials (usually metals) by chemical reaction with their environment. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Rusting, the formation of iron oxides, is a well-known example of electrochemical corrosion. This type of damage typically produces oxide(s) orsalt(s) of the original metal. Corrosion can also occur in materials other than metals, such as ceramics or polymers, although in this context, the term degradation is more common. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface. Because corrosion is a diffusion-controlled process, it occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface, such as passivation and chromate conversion, can increase a material's corrosion resistance. However, some corrosion mechanisms are less visible and less predictable [5]. Corrosion, typically defined as the deterioration of metals through the combined actions of oxygen, other metals and salts, has a major impact on industrial economies. But despite the damage it does, and the seriousness of the issue in economic terms, awareness of ways corrosion can be controlled is in surprisingly short supply. In the United States, Japan, Great Britain and Australia, studies of the economics of corrosion have indicated that its cost to the economy runs in the vicinity of 3-4 per cent of Gross National Product. Further, in a world where businesses are looking for ways to simultaneously stretch budgets and address concerns about the sustainability of their processes, corrosion presents another problem. Of the new steel consumed every year around the world, it is estimated that roughly 20 per cent is used to replace metal lost to corrosion [1]. As is often the case, the reality on the ground is a lot messier than the scientific explanation. In theory, corrosion processes are easy to describe, but the truth of the matter is that corrosion is a multi-phased process that can sometimes result in secondary chemical agents that are as damaging as the corrosion itself. Hydrogen evolution is a good example of this. While corrosion is the main culprit, the resultant processes further weaken metallic components. Likewise, the

corrosion resistance properties of various metals – often thought of as a cut-and-dry matter – are much more complex than they appear at first glance. Considering the cost it exacts on our economy, it is surprising that corrosion is such a misunderstood process, and that it is often treated as an uncontrollable cost of doing business. By acquiring knowledge of the corrosion process, we can better understand how to limit its negative effects. This paper provides a brief overview of corrosion and explores how best to control it by examining its impact on the three most commonly used metals in electrical installations: copper, steel and aluminum.

1.1. Side effect of Corrosion:

Some important consequences of corrosion are summarized below:

■ Plant shut downs. Shutdown of nuclear plants, process plants, power plants and refineries may cause severe problems to industry and consumers.

■ Loss of products, leaking containers, storage tanks, water and oil transportation lines andFuel tanks cause significant loss of product and may generate severe accidents and hazards. It is well known that at least 25% of water is lost by leakage.

■ Loss of efficiency. Insulation of heat exchange rtubings and pipelines by corrosion products reduces heat transfer and piping capacity.

■ Contamination Corrosion products may contaminate chemicals, pharmaceuticals ,dyes , packaged goods, etc. with dire consequences to the consumers.

■ Nuclear hazards. The Chernobyl disaster is a continuing example of transport of radioactive corrosion products in water, fatal to human, animal and biological life.

The magnitude of corrosion would depend upon the sensitivity of a particular metal or alloy to a septic environment. For instance, copper corrodes rapidly in the presence of ammonia and it is a serious problem in agricultural areas. Many historical statues made from bronze have been destroyed by ammonia released from fertilizers. Environmental conditioning offers one method of controlling corrosion, such as the use of inhibitors and oil transmission pipelines [6].

1.2. Importance of Corrosion Studies:

The importance of corrosion studies is two folds. The first is economic, including the reduction of material losses resulting from the wasting away or sudden failure of piping, tanks, metal components of machines, ships, hulls, marine , structures…etc. The second is conservation, applied primarily to metal resources, the world's supply

of which is limited, and the wastage of which includes corresponding losses of energy and water resources accompanying the production and fabrication of metal structures.

Five Good Reasons to Study Corrosion

(1) Materials are preciousre sources of acountry. Our material resources of iron, aluminum, copper, chromium, manganese, titanium, etc. are dwindling fast. Some day there will be an acute shortage of these materials. An impending metal crisis does not seem anywhere to be a remote possibility but a reality. There is bound to be a metal crisis and we are getting the signals. To preserve these valuable resources, we need to understand how these resources are destroyed by corrosion and how they must be preserved by applying corrosion protection technology.

(2) Engineering knowledge is incomplete without an understanding of corrosion. Aeroplanes, ships, automobiles and other transport carriers cannot be designed with out any recourse to the corrosion behavior of materials use din these structures.

(3) Several engineering disasters, such as crashing of civil and military aircraft, naval and passenger ships, explosion of oil pipelines and oil storage tanks, collapse of bridges and decks and failure of drilling platforms and tanker trucks have been witnessed in recent years. Corrosion has been a very important factorin these disasters .Applying the knowledge of corrosion protection can minimize such disasters. In USA, two million miles of pipe need to be corrosion-protected for safety.

(4) The designing of artificial implants for the human body requires a complete understanding of the corrosion science and engineering. Surgical implants must be very corrosion-resistant because of corrosive nature of human blood.

(5) Corrosion is athreat to the environment .For instance, water can become contaminated by corrosion products and unsuitable for consumption. Corrosion prevention is integral to stop contamination of air, water and soil. The American Water Works Association needsUS\$325billioninthenexttwentyyears to up grade the water distribution system [7].

1.3. Basic Causes of Corrosion:

1.3.1. Conditions necessary for corrosion:

For the purpose of this manual, electrochemical corrosion is the most important classification of corrosion. Four conditions must exist before electrochemical corrosion can proceed:

1- There must be something that corrodes (the metal anode).

2- There must be a cathode.

3- There must be continuous conductive liquid path (electrolyte, usually condensate and salt or other contaminations).

4- There must be a conductor to carry the flow of electrons from the anode to the cathode. This conductor is usually in the form of metal-to-metal contact such as in bolted or riveted joints.

The elimination of any one of the four conditions will stop corrosion.

Throughout this process the metallic ions may also react with elements in the electrolyte to form other compounds. Rust is a good example. Rust (also known as FeOOH) is created when iron ions react with various elements in the water.

As the electrons flow across the low-resistance metallic path to the cathode, the cathode is reduced and the formation of metal ions is halted. When the metal is not in a positively charged ionized form, it is much less reactive. This is why the cathode develops an inherent protection from metal loss to corrosion.Oxygen is frequently involved in the corrosion process because most metals in ore form are typically oxides. For example iron and aluminum exist in nature as an oxide (Al_2O_3 and Fe_2O3 respectively). Copper, on the other hand, is typically found as copper sulfate. This means that in the presence of sulfur, copper will readily react with sulfur to return back to its natural state of copper sulfate [8].

1.3.2. Effect of material selection:

One of the fundamental factors in corrosion is the nature of the material. Materials are usually selected primarily for structural efficiency, and corrosion resistance is often a secondary consideration in design.

1.3.3.Water intrusion:

Water intrusion is the principal cause of corrosion problems encountered in the field use of equipment. Water can enter an enclosure by free entry, capillary action, or condensation. With these three modes of water entry acting and with the subsequent confinement of water, it is almost certain that any enclosure will be susceptible to water intrusion.

1.3.4. Environmental factors:

At normal atmospheric temperatures the moisture in the air is enough to start corrosive action. Oxygen is essential for corrosion to occur in water at ambient temperatures. Other factors that affect the tendency of a metal to corrode are:

1- Acidity or alkalinity of the conductive medium (pH factor).

2- Stability of the corrosion products.

3- Biological organisms (particularly anaerobic bacteria).

4- Variation in composition of the corrosive medium.

5- Temperature.

The presence of salts and acids on metal surfaces greatly increases the electrical conductivity of any moisture present and accelerates corrosion. Moisture tends to collect on dirt particles [9].

1.4. Classification of Corrosion:

All metallic materials consist of atoms having valiancy electrons which can be donated or shared. In a corrosive environment the components of the metallic material get ionized and the movement of the electrons sets up a galvanic or electrochemical cell which causes oxidation, reduction, dissolution or simple diffusion of elements.

The metallurgical approach of corrosion of metals is in terms of the nature of the alloying characteristics, the phases existing and their inter-diffusion under different environmental conditions. In fact, the process of corrosion is a complex phenomenon and it is difficult to predict the exclusive effect or the individual role involved by any one of the above mentioned processes.

Based on the above processes, corrosion can be classified in many ways as low temperature and high temperature corrosion, direct oxidation and electrochemical corrosion, etc. The preferred classification is: Dry or chemical corrosion and wet or electrochemical corrosion.

1- Chemical corrosion: In which the metal is converted into its oxide when the metal is exposed to a reactive gas or non-conducting liquids.

2- Electrochemical corrosion: The formation of hydrous oxide film occurs when the metal is immersed in a conducting liquid containing dissolved reactive substance. The reaction is considered to take place at the metal solution interface, due to the heterogeneity on the metal surface, which creates local anodic and cathodic sites on the metal.

1.5. Environmental corrosion:

Corrosion cannot be defined without a reference to environment. All environments are corrosive to some degree. Following is the list of typical corrosive environments:

(1) Air and humidity.

(2) Fresh, distilled, salt and marine water.

(3) Natural, urban, marine and industrial atmospheres.

(4) Steam and gases, like chlorine.

(5) Ammonia.

(6) Hydrogen sulfide.

(7) Sulfur dioxide and oxides of nitrogen.

(8) Fuel gases.

(9) Acids.

(10) Alkalies.

(11) Soils.

It may, therefore, be observed that corrosion is a potent force which destroys economy, depletes resources and causes costly and untimely failures of plants ,equipment and components [10]

1.6. Factors affect corrosion rate:

There are several factors that affect corrosion rate. These factors can be divided into physical and chemical factors.

16.1. Physical factors:

1.6.1.1. Temperature:

Temperature can have significant temperature effect on corrosion rate .As temperature increase, so dose the corrosion is an electrochemical phenomenon, an increase in temperature will cause an increase in corrosion rate. If the oxygen in the water has some where to go, the corrosion rate increase linearly with temperature up to maximum value. Beyond this point the rate decrease because of reduced oxygen solubility at the much higher temperature. If the oxygen cannot escape, corrosion rate increase steadily with temperature [11].

1.6.1.2. Fluid velocity:

Fluid velocity is another factor affecting corrosion particles in fast moving fluid are likely to wear away any chemical coatings put on the protect it .Solid in slow moving fluid are likely to settle out on to metal surfaces preventing chemical treatments from reaching the metal [12].

1.6.1.3. Deposits:

Deposits as will as preventing chemical treatments reaching metal surfaces, also lead to corrosion in more the reatening way. Anode can form secretly beneath the deposits and deep localized pitting results.

1.6.1.4. Nature of the metal:

The tendency of metal to corrode in an aqueous solution is related to its characteristic electrode potential as listed out in the electrochemical series.

According to this series metal with more positive potentials are relatively stable and those with more negative potentials are unstable. In the corrosion processes where hydrogen evolution is cathodic reaction , hydrogen over potential (resistance to hydrogen evolutions) is another important affecting factor in corrosion. The metal with low hydrogen over potential in given environment corrodes faster than the metal with high hydrogen potential [13].

1.7. General corrosion:

With general corrosion (sometimes called uniform corrosion). Anodic distributed over the entire metallic surface. The corrosion rate is nearly constant at all location [14]

1.8. Theories of Corrosion:

(1) Direct chemical attack or Chemical or Dry corrosion. (2)Electrochemical theory or Wet corrosion. (3) Differential aeration or Concentration cell corrosion.

1.8.1. Direct Chemical Attack or Chemical or Dry Corrosion:

Whenever corrosion takes place by direct chemical attack by gases like' oxygen, nitrogen and halogens, a solid film of the corrosion product is formed on the surface of the metal which protects the metal from further corrosion. If a soluble or volatile corrosion product is formed, then the metal is exposed to further attack. For example, chlorine and iodine attack silver generating a protective film of silver halide on the surface. On the other hand, stannic chloride formed on tin is volatile and so corrosion is not prevented. Oxidation corrosion is brought about by direct action of oxygen at low or high temperatures on metals in the absence of moisture. Alkali metals (Li, Na, K, etc.) and alkaline earth metals (Mg, Ca, Sn, etc.) are readily oxidized at low temperatures. At high temperatures, almost all metals except Ag, Au and Pt are oxidized. Alkali and alkaline earth metals on oxidation produce oxide deposits of smaller volume. This results in the formation of a porous layer through which oxygen can diffuse to bring about further attack of the metal. On the other hand, aluminum,

tungsten and molybdenum form oxide layers of greater volume than the metal from which they were produced. These non-porous, continuous and coherent oxide films prevent the diffusion of oxygen and hence the rate of further attack decreases with increase in the thickness of the oxide film. The protective or non-protective nature of the oxide film is determined by a rule known as the Pilling-Bed worth rule. The ratio of the volume of the oxide formed to the volume of the metal consumed is called the Pilling-Bed worth rule. According to it, if the volume of the oxide layer is greater than the volume of the metal, the oxide layer is protective and non-porous. On the other hand, if the volume of the oxide layer formed is less than the volume of the metal, the oxide layer is non protective and porous.

1.8.2. Electrochemical Theory or Wet Corrosion:

According to the electrochemical theory, the corrosion of a metal in aqueous solution may be a two-step process, one involving oxidation and another reduction. It is known that two metals having different electrode potentials form a galvanic cell when they are immersed in a conducting solution. The emf of the cell is given by the difference between the electrode potentials. When the electrodes are joined by a wire, electrons flow from the anode to the cathode. The oxidation reaction occurs at the anode, i.e. at the anode the metal atoms lose their electrons to the environment and pass into the solution in the form of positive ions

$$Fe \rightarrow Fe^{2+} + 2e^- \qquad (1.1)$$

Thus, there is a tendency at the anode to destroy the metal by dissolving it as ions. Hence corrosion always occurs at anodic areas.

The electrons released at the anode are conducted to the cathode and are responsible for various cathodic reactions such as electroplating (deposition of metals), hydrogen evolution and oxygen absorption:

(i) Electroplating: The metal ions at the cathode collect the electrons and deposit on the cathode surface.

$$Cu^{2+} + 2e\text{-} \rightarrow Cu \qquad (1.2)$$

(ii) Liberation of hydrogen: In an acid solution, (in the absence of oxygen) hydrogen ions accept electrons and hydrogen gas is formed.

$$2H^+ + 2e\text{-} \rightarrow H_2 \qquad (1.3)$$

In a neutral or alkaline medium, (in the absence of oxygen) hydrogen gas is liberated with the formation of OH- ions.

$$2H_2O + 2e- \rightarrow H_2 + 2OH^- \qquad\qquad (1.4)$$
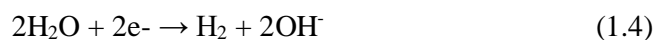
(iii) Oxygen absorption: In the presence of dissolved oxygen and in an acid medium, oxygen absorption reaction takes place.

$$4H+ + O_2 + 4e^- \rightarrow 2H_2O \qquad\qquad (1.5)$$

In the presence of dissolved oxygen and in a neutral or weakly alkaline medium, OH^- ions are formed.

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^- \qquad\qquad (1.6)$$

Thus it is clear that the essential requirements of electrochemical corrosion are as follows: (a) Formation of anodic and cathodic areas. (b) Electrical contact between the cathodic and anodic parts to enable the conduction of electrons. (c) An electrolyte through which the ions can diffuse or migrate. This is usually provided by moisture.

1.8.3. Differential Aeration or Concentration Cell Corrosion:

Anodic and cathodic areas may be generated even in a perfectly homogeneous and pure metal due to different amounts of oxygen reaching different parts of the metal which form oxygen concentration cells. In such circumstances, those areas which are exposed to greater amount of air become cathodic while the areas which are little exposed or not exposed to air become anodic and suffer corrosion [15].

1.10. Types of Corrosion:

1.10.1. General or uniform corrosion:

Differences in electrical potential occur on the surface of a piece of metal due to small differences in chemical composition, phase differences, amount of cold work, etc. These differences set up small corrosion cells each with an anode and cathode. Corrosion continues until the metal is consumed or the film of rust formed on the surface sets up a barrier to the electrolyte.

1.10.2. Pitting corrosion:

Pitting corrosion is a complex but important problem that is at the root of many corrosion failures. It has been studied in detail for many years, yet crucial phenomena remain unclear. In pitting corrosion the surface of the metal is attacked in small-localized areas. Organisms in water or breaks in a passive film can initiate corrosion. In pitting corrosion very little metal is removed from the surface but the effect is marked. In passivated metals or alloys that are exposed to solutions containing aggressive anions, primarily chloride, pitting corrosion results in local dissolution leading to the formation of cavities or (holes). The shape of the pits or cavities can

vary from shallow to cylindrical holes and the cavity is approximately hemispherical . The pit morphology depends on the metallurgy of the alloy and chemistry of the environment as well as the leading conditions. As observed first by McAdam in 1928, these pits may cause local increase in stress concentration and cracks may nucleate from them. Pitting is considered to be autocatalytic in nature; once a pit starts to grow, the conditions developed are such that further pit growth is promoted. The anodic and cathodic electrochemical reactions that comprise corrosion separate spatially during pitting. The local pit environment becomes depleted in cathodic reactant (e.g. oxygen), which shifts most of the cathodic reaction to the boldly exposed surface where this reactant is more plentiful. The pit environment becomes enriched in metal cations and an anionic species such as chloride, which electromigrates into the pit to maintain charge neutrality by balancing the charge associated with the cation concentration. The pH in the pit is lower owing to cation hydrolysis and the absence of a local cathodic reaction. The acidic chloride environment thus generated in pits is aggressive to most metals and tends to propagate the pit growth.

1.10.3. Stress corrosion cracking:

Failure is due to the simultaneous influence of static tensile stresses and a corrosive environment and this is specific to a particular metal. The stresses may be internal such as those caused by cold work, welding, heat treatment or external forces caused by mechanical stresses set up by assembly practices. A good example of this form of corrosion is 316 stainless steel in marine environments. 316 stainless steel was developed to withstand attacks in chloride environments, but if stressed the steel will fail by stress corrosion cracking.

1.10.4. Intergranular corrosion:

Corrosion occurs at the grain boundaries due to a difference in potential between the anodic grain boundaries and the cathodic grains. "Sensitized" stainless steels, where carbides have been precipitated in the grain boundaries during improper heat treatment or in the heat-affected zone of a weld, are particularly susceptible to intergranular corrosion.

1.10.5. Filiform corrosion:

Filiform corrosion appears as a network of corrosion trials, of a wormlike structure, particularly beneath thin organic coatings. Salts containing chlorides, which have been left on the surface prior to coating, are suspected.

1.10.6. Crevice corrosion:

Crevice corrosion occurs when there is a difference in ion, or oxygen, concentration between the metal and its surroundings. Oxygen starvation in an electrolyte at the bottom of a sharp V-section will set up an anodic site in the metal that then corrodes rapidly.

1.10.7. Galvanic or bi-metallic corrosion:

Galvanic corrosion takes place between two different metals, or coatings, which are joined together in the presence of an electrolyte. Each metal has a potential different from any other metal when placed in an electrolyte. A series can be built up of all the metals relative to each other.

1.10.8. Fretting corrosion:

Fretting corrosion occurs when two or more parts rub against each other. The rubbing action removes the corrosion products and exposes new metal to the electrolyte.

1.10.9. Erosion corrosion:

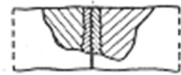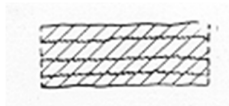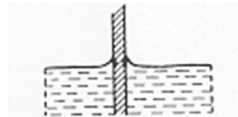Erosion is the removal of metal by the movement of fluids against the surface. The combination of erosion and corrosion can provide a severe rate of corrosion.

1.10.10. Selective leaching or demetalification:

Demetalification is the removal of one of the alloying elements in an alloy by the electrolyte. This results in a "spongy" metal. Typical example is the removal of zinc in chloride waters from brass [16].

Table1-1: The various types of corrosion are listed in the following:

Uniform corrosion	Localized corrosion (pitting corrosion)	Wide pitting corrosion
The reaction starts at the surface andproceeds uniformly.	The basis metal is eaten away and perforated in	The corrosioncauseslocalized scarring.

	places in the mannerofholes, the rest of the surface being affected only slightly or not at all.	
Intergranular corrosion Imperceptible or barely perceptible from outside, since the corrosion proceeds at the grain boundaries.	**Transgranular or intragranular corrosion** The grain boundary material is retained, since the corrosion proceeds preferentially within the grain.	**Galvanic corrosion** Increased corrosion in crevices or cracks or at contact surfaces between two metal articles.
Selective corrosion Corrosive attack on structural constituents	**Exfoliation corrosion** Occurs in deformed articles. Corrosion follows "fiberorientation".	**Interfacial corrosion** Frequently observed at water-air interfaces[17]

1.11. Corrosion of metal:

To reduce it to simplest possible terms, corrosion is really nothing more than the inherent tendency of metals to revert from a processed, metallic state to their more natural state, which we commonly call "ore". Most metals, with the exception of precious metals, such as gold and platinum, do not occur in metal form in nature – they exist as ore. When ore is processed into metal, the refining process transfers its latent energy to the ore. It is the taking on of this latent energy that transforms ore into metal, but by taking on this energy, the metal elevates to a higher energy state, which means it also becomes less thermodynamically stable. Corrosion is really nothing more than the inherent tendency of metals to revert from a processed, "metallic" state to their more natural "ore" state. The process of metal, in its new high-energy state, reverting to its lower energy (ore) state is what we call corrosion. It is, quite simply, the means by which metal returns to its more stable, lower energy mineral state through the release of the latent energy acquired in refinement. Precious metals such as gold and platinum exist naturally in their metal state and have intrinsic thermodynamic stability. All other metals are prone to corrosion. In some cases, metals can form oxide films as part of the corrosion process. Some metals form oxide films that are porous while other metals form oxide films that buckle and flake off . In both cases, the underlying metal is subject to continued oxidation process and results in metal loss. But there can be an upside to oxide films as well. Metals that form a tightly adhering layer of surface oxides are much more corrosion resistant because the adhering layer – known as the passivation layer - offers significant protection by isolating the metal from the corrosive environment [18]

1.13. Cost of Corrosion:

Corrosion is not only dangerous, but also costly, with annual damages in the billions of dollars! If this is difficult to believe, consider some of the direct and indirect effects of corrosion which contribute to these costs:

1- Replacement of corroded equipment.

2- Unscheduled plant shutdowns for replacement.

3- Process upsets resulting from corrosion.

4- Product contamination.

5- Product loss from a vessel that has corroded.

6- Otherwise unnecessary preventive maintenance.

7- Over design to allow for corrosion.

8- Inability to use otherwise desirable materials.

While the economic costs are frightening, we must consider them to be of secondary importance to the potential loss of life and damage to the environment problems, which can have widespread effects upon modern industrial businesses. It is essential, therefore, for operators of industrial process plants to have a program for controlling corrosion. The direct corrosion cost was estimated to be around 276 billion dollars, approximately 3.1% of the national gross domestic product. [19-20]. Based on an extensive survey conducted by Battelle Columbus Laboratories, Columbus, Ohio, USA and National Institute of Standards and Technology (NIST), in 1975,the cost was estimated to be 82 billion US dollars, which would have exceeded 350 billion US dollars in view of price in flation over the last twenty-five years. Because of the long time involved in conducting cost structure, it is not possible to update the information every year. However, both studies show that corrosion costs are staggering and a figure of about 350 billion dollars appears to be a reasonable estimate for another two to three years. At least 35% of the above amount could have been saved by taking appropriate corrosion control measures. In united kingdom UK, the corrosion cost is estimated to be 4–5% of the Gross National Product GNP [21].In Japan, the cost of corrosion is estimated to be 5258trillion Yenper   year .Form ostindustrialized nations, the average corrosion cost is 3.5–4.5%of the GNP [7] .

1.14. The Electrical Metals: Steel, Aluminum and Copper:

Steel, aluminum and copper are the three main metals used in electrical applications. Steel is typically used in housing, enclosure and support systems (struts and cable trays). Copperas   often used in conductors. And aluminum can be found most often in conductors, conduits, armor and supports (cable trays). Each of these metals is susceptible to corrosion and there are many misconceptions about the corrosion resistance of each. The electrical industry generally considers copper to be corrosion resistant in virtually all environments while regarding steel and aluminum as non-resistant.

However, this is an over-generalization. of the three metals copper is the most cathodic , or noble, and is typically less affected by galvanic reactions. As a result, the electrical industry generally considers copper to be corrosion resistant in virtually all environments while regarding steel and aluminum as non-resistant. However, this is an overgeneralization in what should be thought of in more relative terms. The truth of the matter is that copper tends to get a free ride at the expense of other metals". Were it to be used in contact with more noble metals such as passive nickel, passive stainless 316 and 304 stainless steel or titanium, copper would galvanic ally deplete just as readily as steel or aluminum do.

1.15. Atmospheric, Soil and Galvanic Corrosion:

In general, atmospheric, soil and galvanic corrosion represent the major types of corrosion metals are exposed to in the electrical industry.

1.15.1 Atmospheric Corrosion of Steel:

Steel typically corrodes or rusts rapidly in moist environments, and the rate of corrosion accelerates with exposure to salt water. As mentioned previously, Fe_2O_3 forms on the surface of iron or steel to act as a passivating layer.

However, in the presence of water, oxygen, and sulfur dioxide and carbon dioxide solutions, the protective Fe_2O_3 layer becomes non-protective rust (FeOOH) due to the formation of Fe_3O_4.This layer is continually faking of at the surface to expose fresh metal to corrosion. This process carries on until either all of the iron or all of the oxygen, water, carbon dioxide, or sulfur dioxide in the system is removed or consumed in electric lap**.**

1.15.2 Atmospheric Corrosion of Aluminum:

Only beryllium, potassium, sodium and magnesium are more thermodynamically reactive than aluminum. However, a signature property of aluminum is its tendency to form a strongly bonded passivating oxide fi lm on its surface. For this reason, it offers excellent resistance to corrosion and providesyears of maintenance-free service in natural atmospheres. At an ambient temperature of 25 degrees C, the normal surface film formation is only about 2-50nm thick. If damaged – by a fresh abrasion for example – this corrosion-protective film re-forms immediately in most environments and ensures continued protection.

As a result, aluminum and its alloys are used in a wide range of applications that include buildings, power lines, large ship superstructures, truck transports, railroad and subway cars, water pipelines, beverage containers(soft drink and beer cans), and chemical industry tanks ,piping, barges, reaction vessels, and distillation columns2. In applications where exposure to the elements – particularly water – is a factor, you can be sure you will find aluminum being used. For an excellent example of aluminum's time-proven resistance to corrosion at work in the electrical industry, look no further than bare aluminum transmission conductors, which have been hard at work and resisting corrosion now for over 100years[22] .

1.16. Corrosion of Carbon Steel:

Carbon steel, the most widely used engineering material, accounts for approximately 85%, of the annual steel production worldwide.

Despite its relatively limited corrosion resistance, carbon steel is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction and metal-processing equipment

The cost of metallic corrosion to the total economy must be measured in hundreds of millions of dollars (or euros) per year. Because carbon steels represent the largest single class of alloys in use, both in terms of tonnage and total cost, it is easy to understand that the corrosion of carbon steels is a problem of enormous practical importance. This is the reason for the existence of entire industries devoted to providing protective systems for irons and steel. Carbon steels are by their nature of limited alloy content, usually less than 2% by weight for total of additions. Unfortunately, these levels of addition do not generally produce any remarkable changes in general corrosion behavior. One possible exception to this statement would be weathering steels, in small additions of copper, chromium, nickel and phosphorus produce significant reduction in corrosion rate in certain environments.

Because corrosion is such a multifaceted phenomenon, it is generally useful to attempt to categorize the various types. This is usually done on environmental basis. In this article, atmospheric corrosion, aqueous corrosion and some other corrosion types of interest, such as corrosion in soils, concrete and boilers and heating plants will be addressed.

1.16.1 Atmospheric corrosion:

Atmospheres are often classified as being rural, industrial or marine in nature. Two decidedly rural environments can differ widely in average yearly temperature and rainfall patterns, mean temperature, and perhaps acid rain, can make extrapolations from past behavior less reliable. The corrosion of carbon steel in the atmosphere and in many aqueous environments is best understood from a film formation and brake down standpoint. It is an inescapable fact that iron in the presence of oxygen and water is thermodynamically unstable with respect to its oxides. Because atmospheric corrosion is an electrolytic process, the presence of an electrolyte is required. This should not be taken to mean that the steel surface must be awash in water; a very thin adsorbed film of water is all that is required. During the actual exposure, the metal spends some portion of the time awash with water because of rain or splashing and a portion of the time covered with a thin adsorbed water film. The portion of time spent covered with the thin water film depends quite strongly on relative humidity at the exposure site. This fact has led many corrosion scientists to investigate the influence of the time of wetness on the corrosion rate. Rusting of iron depends on relative humidity and time of exposure in atmosphere containing 0.01% SO_2. The increase in corrosion rate produced by the addition of SO_2 is substantial. Oxides of nitrogen in the atmosphere would also exhibit an accelerating effect on the corrosion of steel. Indeed, any gaseous atmospheric constituent capable of strong electrolytic activity should be suspected as being capable of increasing the corrosion rate of steel. Because carbon steels are not very highly alloyed, it is not surprising that most grades do not exhibit large differences in atmospheric-corrosion rate. Nevertheless, alloying can make changes in the atmospheric-corrosion rate of carbon steel. The elements generally found to be most beneficial in this regard are copper, nickel, silicon, chromium and phosphorus. Of these, the most striking example is that of copper, increases from 0.01-0.05%, decrease the corrosion rate by a factor of two to three. Additions of the above elements in combination are generally more effective than when added singly, although the effects are not add itive.

1.16.2 Aqueous Corrosion:

Carbon steel pipes and vessels are often required to transport water or are submerged in water to some extent during service. This exposure can be under conditions varying temperature, flow rate, pH, and other factors, all of which can alter the rate of

corrosion. The relative acidity of the solution is probably the most important factor to be considered. At low pH the evolution of hydrogen tends to eliminate the possibility of protective film formation so that steel continues to corrode but in alkaline solutions, the formation of protective films greatly reduces the corrosion rate. The greater alkalinity, the slower the rate of attack becomes. In neutral solutions, other factors such as aeration, became determining so that generalization becomes more difficult. The corrosion of steels in aerated seawater is about the same overall as in aerated fresh water, but this is somewhat misleading because the improved electrical conductivity of seawater can lead to increased pitting. The concentration cells can operate over long distance, and this leads to a more nonuniform attack than in fresh water. Alternate cycling through immersion and exposure to air produces more pitting attack than continuous immersion [23].

1.15.3. Plain Carbon Steel

The two types of carbon steels are plain carbon steel and alloy steel. Plain carbon steel is one which contains in addition to carbon and iron certain elements notably manganese, phosphorus, supphur and silicon in small quantities. It may also contain traces of elements like: copper, boron, cobalt and so on [24].

Plain carbon steel is divided into three groups:

1) Low carbon steel

2) Medium carbon steel

3) High carbon steel.

1.17. Corrosion of aluminum:

Although aluminum is a very reactive metal with a high affinity for oxygen, the metal is highly resistant to most environments and to a great variety of chemical agents. This resistance is due to the inert and protective character of the aluminum oxide film which forms on the metal surface. In most environments, the rate of corrosion of aluminum decreases rapidly with time. In only a few cases, e.g. caustic soda, does the corrosion rate approximate to the linear.. Although the oxide film is extremely thin, between 50 and 100 Angstroms, it forms a protective barrier between the metal and the surrounding medium as soon as the metal comes into contact with an oxidizing environment, such as water. The physical-chemical stability of the oxide film determines the corrosion resistance of the aluminum. This stability is dependent upon the pH value of the environment, since the oxide film is stable within the pH range of

about 4 to 8. Below and above these values, acid dissolution yields Al^{3+} ions and the alkaline dissolution leads to the formation of Al $(OH)_4$ions [25]

1.18. Corrosion Inhibitors:

A corrosion inhibitor is a substance when added in a small concentration to an environment reduces the corrosion rate of a metal exposed to that environment. Inhibitors often play an important role in the oil extraction and processing industries where they have always been considered to be the first line of defense against corrosion [26]. A corrosion inhibitor is a material that attaches or coats the metal surface, providing a protective barrier film, which in turn stops the corrosive reaction from developing. Temporary coatings are often used to prevent corrosion during storage and shipment, and between machining or processing operations. The most effective corrosion inhibitor coatings, at one time, were oil or solvent-based materials. In recent years water based products have been developed and are being used with success [27].

1.18.1 Types of corrosion inhibitors:

1.18.1.1. Anodic inhibitors:

Anodic inhibitors usually act by forming a protective oxide film on the surface of the metal causing a large anodic shift of the corrosion potential. This shift forces the metallic surface into the passivation region. They are also sometimes referred to as passivators. Chromates, nitrates, tungstate, molybdates are some examplesanodic inhibitors.

1.18.1.2. Cathodic inhibitors:

Cathodic inhibitors act by either slowing the cathodic reaction itself or selectively precipitating on cathodic areas to limit the diffusion of reducing species to the surface. The rates of the cathodic reactions can be reduced by the use of cathodic poisons. However, cathodic poisons can also increase the susceptibility of a metal to hydrogen induced cracking since hydrogen can also be absorbed by the metal during aqueous corrosion or cathodic charging. The corrosion rates can also be reduced by the use of oxygen scavengers that react with dissolved oxygen. Sulfite and bi sulfite ions are examples of oxygen scavengers that can combine with oxygen to form sulfate.

Hard water that is high in calcium and magnesium is less corrosive than soft water because of the tendency of the salts in the hard water to precipitate on the surface of the metal forming a protective film. The most common inhibitors of this category are

the silicates and the phosphates. Sodium silicate, for example, is used in many domestic water softeners to prevent the occurrence of rust water. In aerated hot water systems, sodium silicate protects steel, copper and brass. However, protection is not always reliable and depends heavily on pH. Phosphates also require oxygen for effective inhibition. Silicates and phosphates do not afford the degree of protection provided by chromates and nitrites, however, they are very useful in situations where non-toxic additives are required.

1.18.1.3 Mixed Inhibitors:

Mixed inhibitors work by reducing both the cathodic and anodic reactions. They are typically film forming compounds that cause the formation of precipitates on the surface blocking both anodic and cathodic sites indirectly. Hard water that is high in calcium and magnesium is less corrosive than soft water because of the tendency of the salts in the hard water to precipitate on the surface of the metal forming a protective film. The most common inhibitors of this category are the silicates and the phosphates. Sodium silicate, for example, is used in many domestic water softeners to prevent the occurrence of rust water. In aerated hot water systems, sodium silicate protects steel, copper and brass. However, protection is not always reliable and depends heavily on pH. Phosphates also require oxygen for effective inhibition. Silicates and phosphates do not afford the degree of protection provided by chromates and nitrites, however, they are very useful in situations where non-toxic additives are required.

1.18.1.4. Volatile Corrosion Inhibitors:

Volatile Corrosion Inhibitors (VCI), also called Vapor Phase Inhibitors (VPI), are compounds transported in a closed environment to the site of corrosion by volatilization from a source. In boilers, volatile basic compounds, such as morph line or hydrazine, are transported with steam to prevent corrosion in the condenser tubes by neutralizing acidic carbon dioxide or by shifting surface pH towards less acidic and corrosive values. In closed vapor spaces, such as shipping containers, volatile solids such as salts of di cyclo-hexylamine, cyclohexylamine and hexamethyleneamine are used.

When these inhibitors come in contact with the metal surface, the vapor of these salts condenses and is hydrolyzed by any moisture to liberate protective ions. It is desirable, for an efficient (VCI), to provide inhibition rapidly while lasting for long periods. Both qualities depend on the volatility of these compounds; fast action wanting high volatility while enduring protection requires low volatility[26].

1.19. Literature Review:

Patil and Sharma have undertaken a study on the corrosion kinetics of iron in acidic and basic media using weight loss method [28]. Potassium hydroxide, sulfuric acid, and nitric acid solutions were used in carrying out the research. The study was done at different intervals of time, within a temperature range of 25.0 °C to 30.0 °C. They observed that there was a variation in the rate of corrosion with different time intervals and different acid-base concentrations, andthat iron corroded most in nitric acid, followed by sulfuric acid, and lastly potassium hydroxide which was the least corrosive of the three solutions. By further studies, they noticed a first order kinetics for iron in all three solutions.

The kinetics of mild steel corrosion in aqueous acetic acid solutions has been studied by Singh and Mukherjee using weight loss and polarization techniques at 25, 35, and 45 °C; and an exposure time of 24 and 168 hours [29]. The results revealed that mild steel corroded significantly at room temperature (25 °C). Mild steel therefore showed poor corrosion resistance in acetic acid. Maximum corrosion rate was observed in 25% acetic acid solution at all three experimental temperatures. There was a decrease however in the rate of corrosion after the attainment of a maximum value, and this could be attributed to the deposition of corrosion product on the surface. In conclusion, there was an observed dependence on concentration for the corrosion behavior of mild steel.

Samina et al have undertaken a research to study the corrosion of iron, copper, and brass alloy in different media by weight loss method [30]. The different media which were used include nitric acid, hydrochloric acid, acetic acid, sulfuric acid, phosphoric acid, benzoic acid, sodium hydroxide, and potassium hydroxide amongst others. The solutions were prepared in concentrations between 0.1 to 4N, and the experiment was carried out for different timings of 1 to 5 hours. The following conclusions had been arrived at from the research: the rate of corrosion increased with increasing concentration of the acid; the rate of corrosion increased with increase in time; the

order of corrosion in the media which had been used was- $HNO_3 > H_3PO_4 > H_2SO_4$ $>HCl> CH_3COOH >$ oxalic acid > benzoic acid > succinic acid > salicylic acid > $KOH >NaOH$; the corrosion rate increased in the order Fe > Cu > Brass; and finally metals were highly corroded in acids, as compared to bases and neutral solutions.

The corrosion of aluminum in aqueous chloride and nitrate media, and its inhibition by nitrite has been investigated by Afzal et al [31]. The commercial grade aluminum was observed through the potentio dynamic method to be affected in both media at pH 4 and 10. Results showed increase in the corrosion rate of aluminum with increase in concentrations of chloride and nitrate ions. It was also observed that for both media, corrosion behavior appeared to be significant at higher pH value due to the instant dissolution of metal ions as complex. In order words, aluminum was comparatively more corrodible in basic condition than in acidic condition. Finally, it was deduced that nitrite serves as an important corrosion inhibitor in both chloride and nitrate media, and that the inhibition is more prevalent at lower pH and at higher concentrations of nitrite.

Mohammed et al have investigated the effectiveness and efficiency of ethyl ester of lard in inhibiting the corrosion of mild steel in a mixture of petroleum and water [32]. They carried out weight loss tests at different inhibitor concentrations (0.1, 0.2, 0.3, 0.4, and 0.5 g/L), and different temperatures (303, 313, 323, and 333 K). They concluded hat the efficiency of inhibition increased with an increase in inhibitor concentration and a decrease in temperature conditions, and that the inhibition approximated a first order reaction.

The corrosion behavior of various metals and alloys in marine-industrial environment was researched by Natesan et al using weight loss techniques [33]. The work dealt with atmospheric corrosion to assess how ferrous and nonferrous metals and alloys are degraded by air pollutants. The investigation was carried out using the following materials: galvanized iron, zinc, aluminum, copper, mild steel, and copper-zinc alloys. The research was carried out where the metals had been exposed to marine and industrial environment. Weight loss method was used to determine seasonal (1 to 12 month) metal/alloy losses due to corrosion. Strong corrosion was observed on mild steel, galvanized iron, copper, and zinc. A minor effect was however observed on aluminum and Cu-Zn alloys. Mild steel was in particular observed to have higher degrees of weight loss for every three months increase in time of exposure.

DunyaEdan has carried out an investigation about the corrosion behavior of carbon steel in 1M HCl solution containing various concentration of methyl urea range $(10^{-3} \rightarrow 5 \times 10^{-2})$M at temperature range (285-313)K was investigated. The corrosion inhibitive action of methyl urea on carbon steel was studied using weight loss measurement and atomic absorption analysis to find the amounts of dissolved metal in acidic solution in presence and absence of methyl urea. The results showed that urea caused protection efficiency reached to 82% when (10^{-3}) M methyl urea concentration was used. The coverage ($\square$) of metal surface by methyl urea could be obtained from the rate of corrosion in the presence and absence of methyl urea in the acid solution. Results obtained by gravimetric and .atomic absorption are in good agreement.

The continuous search for better corrosion inhibitors, due to vast differences in the media encountered in industry remains a focal point in corrosion controlhasbeenreported by Loto et al. The use of organic compounds to inhibit corrosion has assumed great significance due to their application in preventing corrosion under various corrosive environments. These compounds have great potential to inhibit aqueous corrosion due to film formation by adsorption on the metal surface. This paper reviews the inhibitive effect of thiourea and thiadiazole derivatives. This group of organosulphur and heterocyclic compounds and derivatives has important theoretical and practical applications, but their inhibition mechanism is not fully understood, despite extensive study. The effect of these compounds on the corrosion of metallic alloys was evaluated through assessment of various journals and experimental techniques. The corrosion rate was found to be a function of different variables. Due attention was paid to the systematic study of inhibitor action of derivatives with much emphasis on the functional groups of the molecular structure. From the comprehensive discourse presented, it is concluded that the derivatives fulfill the basic requirements for consideration as an efficient corrosion inhibitor [34].

Fouda and shalabi have investigated the corrosion behaviour and mechanism for mild steel in hydrochloric acid solutions was studied by chemical (hydrogen evolution, HE & mass loss, ML) and electrochemical (electrochemical impedance spectroscopy &potentio dynamic polarization) methods at 25°C. The chemical results revealed that mild steel corrodes in HCl solutions with a rection constant of 0.56 and the corrosion rate increases with the increase in acid concentration. Microstructural studies for mild steel after immersion in HCl solutions of different concentrations showed general and

pitting corrosion and the latter becomes more pronounced at higher level of HCl concentration[35].

Aim of the research:

The objectives of the present study can be summarize as flow:

1-studying the corrosion of steel and aluminum in different aqueous medium which includes: diluted nitric acid, sulfuric acid, hydrochloric acid and sodium chloride solutions.

2-Calculate the corrosion rate, kinetic and half life time values.

3-studying the inhibition efficiency (IE %) for the above samples by urea and acetanilide.

Chapter two

2. Experimental details:

2.1chemicals:

The following chemicals nitric acid (HNO$_3$), hydrochloric acid (HCl), sodium chlorides (Nacl), sulfuric acid (H$_2$SO$_4$), distilled water and acetone, urea, and acetanilidewere used in this research.

2.2. Apparatus:

250,100 mL beakers, ring stand, iron ring, wire gauze, , test tubes, Petri dish

2.3. Sample:

The Aluminum and iron sheet were collected from local market, the parts of the plates were cut into small pieces 2x2 cm^2 and dried at room temperature for few weeks.

Table (2-1): shows the chemical composition of aluminum used in this study by XRF.

Element	Al	Si	S	P	Mn	Ni	Sb	Pb
Wt%	98.11	1.6545	0.118	0.076	0.013	0.008	0.008	0.013

Table (2-2): shows the chemical composition of iron used in this study by XRF.

Element	Fe	Si	P	S	Ti	Cr	Mn	Co	Pb
Wt%	97.23	1.180	0.0410	0.0740	0.1130	0.0620	0.214	0.0340	0.012

2.3.1. Corrosion of Samples:

Seventy plastic bowls were provided for seventy groups of sample products. Specimens were weighed with electronic weighing balance, with exposed surface area calculated. The compressed samples were again measured to determine the changes in lengths with new diameters calculated. The samples were arranged in three subscripts i.e. tap water, salt solution and moist soil respectively. Care was taken not to allow samples to touch one another in order not to initiate galvanic action. As corrosion of

samples proceeded day after day ,distilled water was added to the salt solution or tap water solution to make up for losses due to evaporation[36].

2.4. Solution Preparation:

The most important aspects of the solution are the reagents used to produce it. They should be of high purity and quality, and weighed as accurately as possible. When purchasing readily hydrated materials, such as calcium chloride, etc., for use in aqueous environments, they should be purchased in the hydrated state. By doing so, errors caused by the gradual absorption of water by the stock container will be avoided. Solution concentrations are commonly expressed in term of the molarity of specific species within the solution (i.e., the number of moles of a given component per liter of solution), although molality (moles of each component per liter of solvent) and normality (moles of each component divided by their hydrogen equivalent per liter of solution) are also used. The purity of the bulk environment (i.e., water, etc.) is also very important. Water may be purified in a number of ways. Possibly the most commonly applied purification technique is distillation. A deionization system will result in further purification. Finally, in many cases the solution is electrolyzed using two platinum electrodes to remove impurities which may deposit on the working electrode during the course of an experiment. In any event, all constituents and their purity should be documented to aid in the diagnosis of any unexpected results [37].

2.5. Determination of corrosion:

No corrosion of sample was noticed the first day, corrosion was noticed the third day and care was taken to remove only the corrosion products. The samples were weighed with electronic weighing balance to determine their new weights. The weight loss of each of the samples was determined and recorded. The process of washing, drying, weighing, determination of weight loss and recording was repeated for the 3rd, 5th, 7th, 9th days [30].

2.6. Determination of Corrosion Rate:

The most common method for estimating a corrosion rate from mass loss is to weigh the corroding sample before and after exposure and divide by the total exposed area and the total exposure time making sure that appropriate conversion constants are used to get the rate in the required units [38].

2.7 Method:

2.7.1. Weight loss method:

The metal specimens were first of all pretreated by polishing with sand paper, and cleaning with tissue paper and clean cloth. They were washed first with tap water, then distilled water, and finally washed with acetone in order to degrease them. The specimens were then completely air dried, and weighed on an analytical balance to four decimal places. The weights of the specimens were noted, and they were dipped into test solutions of HCl, NaCl, HNO_3, and H_2SO_4. At 1430 minutes interval (up to 100 minutes), the specimens were removed from the test solutions and first washed with tap water. This was followed by washing in distilled water, cleaning with fine cloth, washing again with distilled water, and further washing with acetone. The specimens were finally weighed on an analytical balance, and the differences in weights at each interval were noted.

2.7.2. Weight loss method with inhibitors:

Aluminum and iron sheets were cut into 4 x 4 cm. They were mechanically polished with emery paper, washed with distilled water and finally dried between filter papers and weighed. Aluminum   and iron pieces were immersed in 100 ml of the test solution of HNO_3, H_2SO_4,HCl, and NaCl. with the inhibitors first test with urea (0.3,0.5,1,1.5) g and the second test with acetanilide (0.3,0.5,1,1.5 g) for 1430 min. After the test, the pieces were removed, washed with distilled water, dried as before and weighed again.

2.7.3. Evaluation method:

The weight loss was calculated   using the following equation:

$$W_{.L} = (W_b - W_a) \tag{2.1}$$

Where:

W_b and W_a are the weights before and after immersion in mg.

The percentage inhibition efficiency (% IE) and the degree of surface coverage (R) of the investigated surfactant compounds were calculated from the following equations:

$$\% \ IE = (CR \ uninhibited - CR \ inhibited/ \ CR \ uninhibited) \ x100 \tag{2.2}$$

Where

CR uninhibited=corrosion rate of uninhibited system.

CR inhibited= corrosion rate of   inhibited system.

The rate of corrosion penetration in millimeter per year (mpy) was calculated using the following equation

$$R=87.6 \ W/YAT \hspace{4cm} (2.3)$$

Where

R= rate of corrosion penetration in millimeter per year.

W= millimeter per year.

Y=density.

A=weight loss in mg.

T=time in hours.

Chapter three

3. Results and Discussion:

The calculated weight loss of iron and Aluminum in four different concentrations each of HCl, NaCl, HNO$_3$, and H$_2$SO$_4$are plotted in figure(3 -1 to 3-16). It could be observed that corrosion of iron and Aluminum takes place in all concentrations of HCl, NaCl HNO$_3$, and H$_2$SO$_4$ due to considerable decrease in the specimen's original weight.
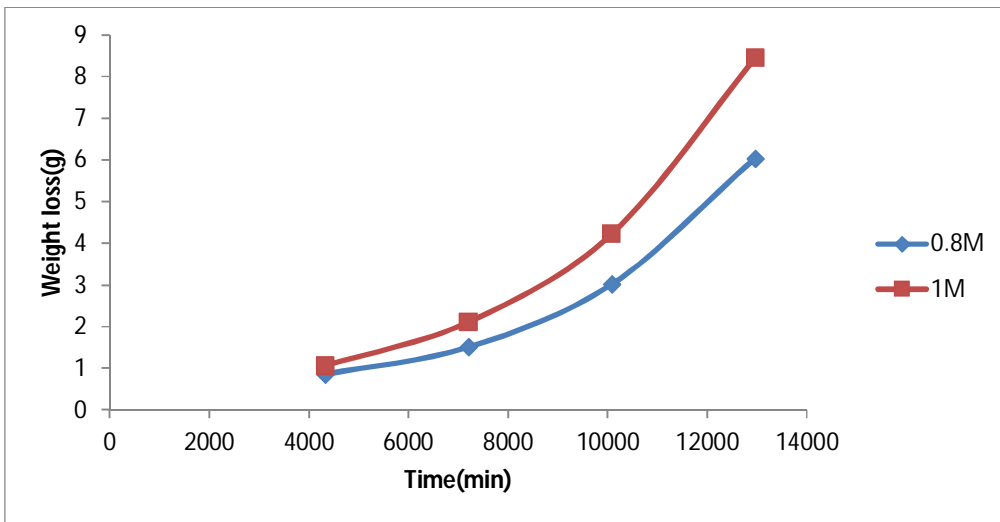
3.1. Corrosion of Aluminum:

The calculated weight loss of Aluminum in four different concentrations each of HNO$_3$, H$_2$SO$_4$, HCl and NaCl are plotted in (figures 3-1to 3-8). It could be observed that corrosion of Aluminum takes place in all concentrations of HNO$_3$, H$_2$SO$_4$, HCl and NaCl due to considerable decrease in the specimen's original weight.

Table 3-1: Weight loss of the corrosion of Aluminum in HNO$_3$.

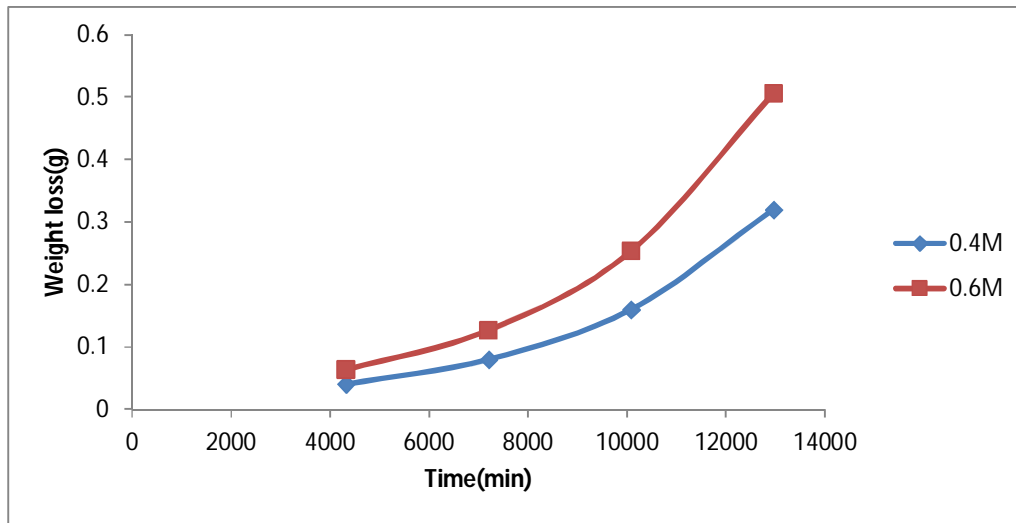| Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	0.160	0.4548	0.8548	1.0564
7200	0.32	0.9096	1.5095	2.1128
10080	0.64	1.8192	3.0192	4.225
12960	1.28	3.6384	6.0384	8.4512
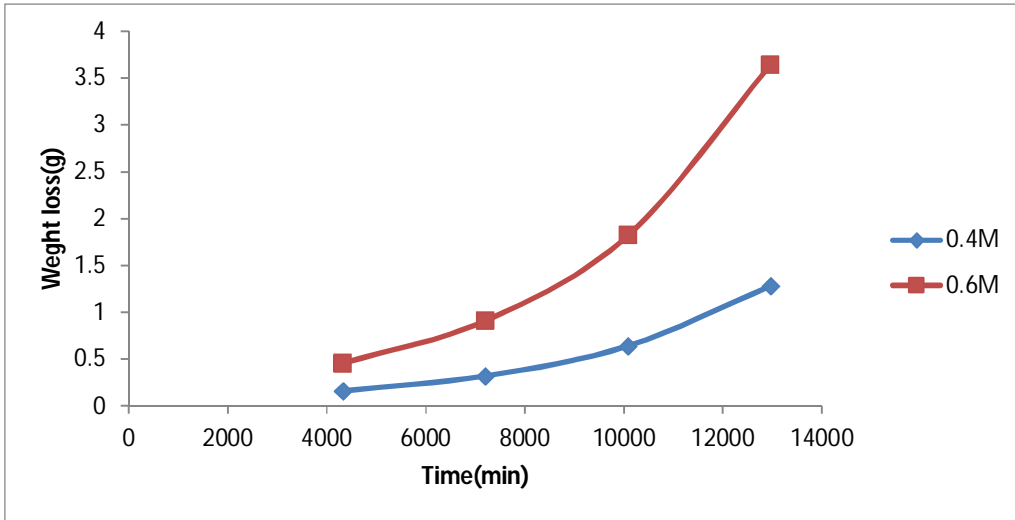
Figure3-1: Weight Loss of Aluminum in 0.4M and 0.6M HNO$_3$

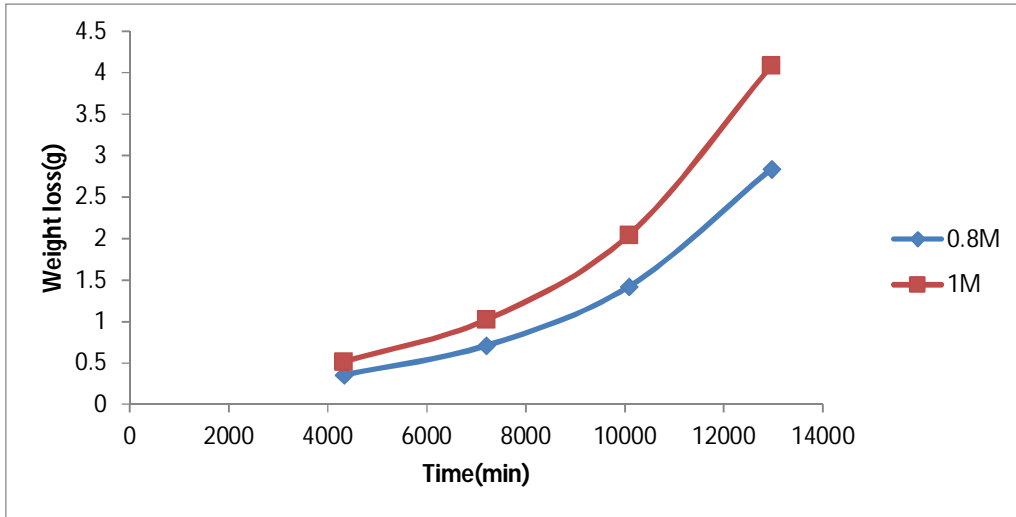**Figure3-2:** Weight Loss of Aluminum in 0.8M and1M HNO$_3$

Table3-2: Weight loss of the corrosion of Aluminum in H_2SO_4.

Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	0.4	0.0632	0.3548	0.5164
7200	0.08	0.1264	0.7097	1.0208
10080	0.16	0.252	1.4194	2.0417
12960	0.32	0.505	2.8388	4.0834

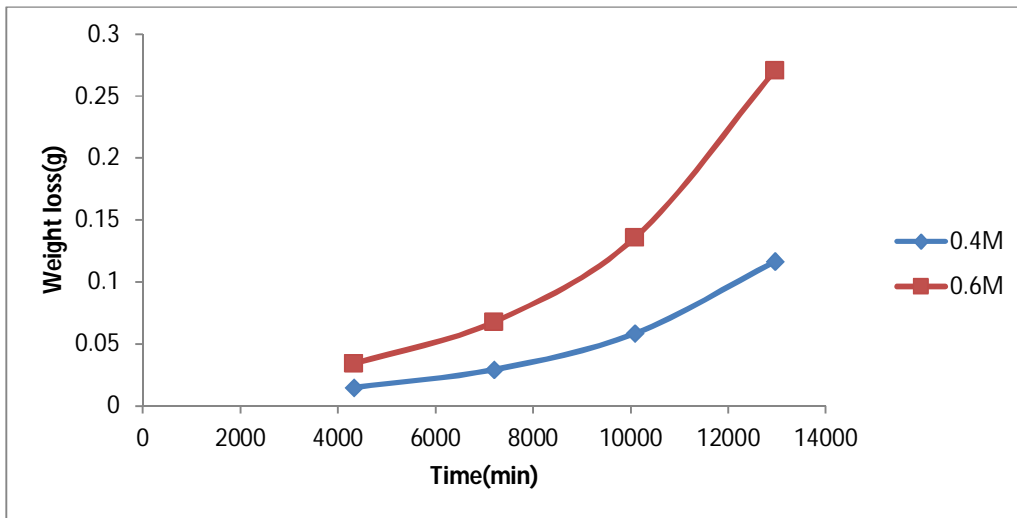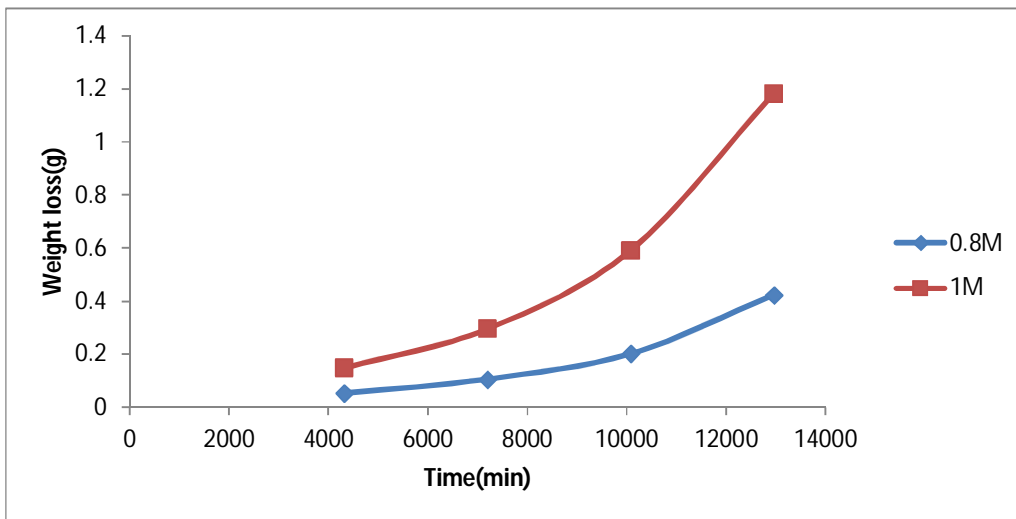**Figure 3-3:** Weight Loss of Aluminum in 0.4M, 0.6M H_2SO_4

Figure3-4: Weight Loss of Aluminum in 0.6M and 1M H_2SO_4

Table3-3: Weight losses of the corrosion of Aluminum in HCl.

| Concentration (M) Time (min)	0.4	0.6	0.8	1
4320	0.0145	0.0338	0.053	0.1478
7200	0.0291	0.0677	0.106	0.2957
10080	0.0582	0.1354	0.212	0.59414
12960	0.1165	0.2708	0.424	1.1828

Figure3-5: Weight Loss of Aluminum in 0.4M and 0.6M HCl

Figure3-6: Weight Loss of Aluminum in 0.8M and 1M HCl

Table3-4: Weight losses of the corrosion of Aluminum in NaCl.

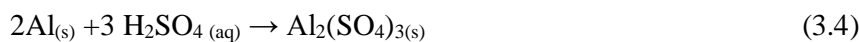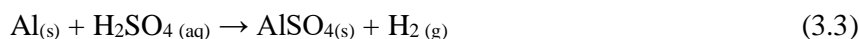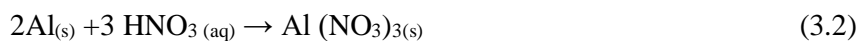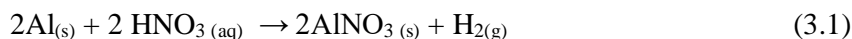| Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	0.008	0.0102	0.0158	0.0214
7200	0.0162	0.0205	0.0317	0.0428
10080	0.0325	0.0411	0.0634	0.0857
12960	0.0651	0.0822	0.1268	0.1714
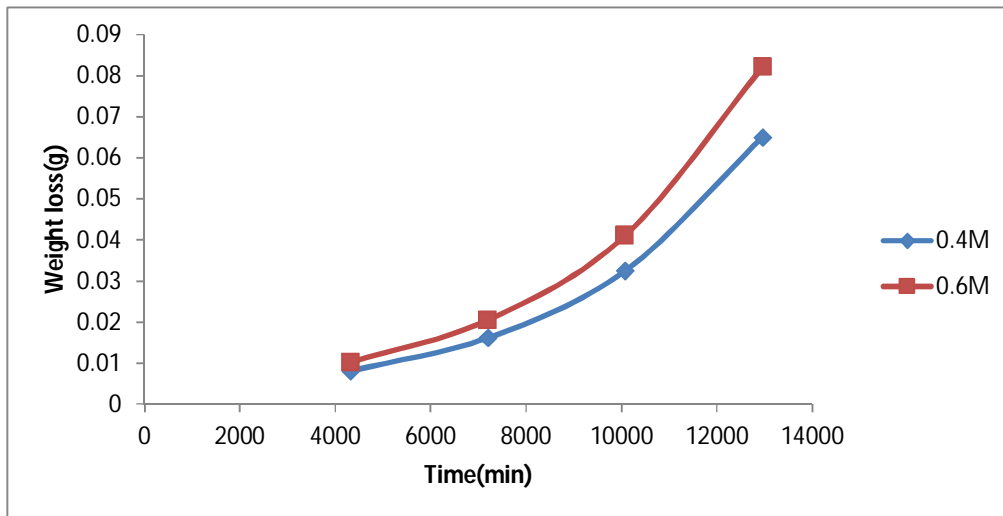
Figure3-7: Weight Loss of Aluminum in 0.4M and 0.6M NaCl
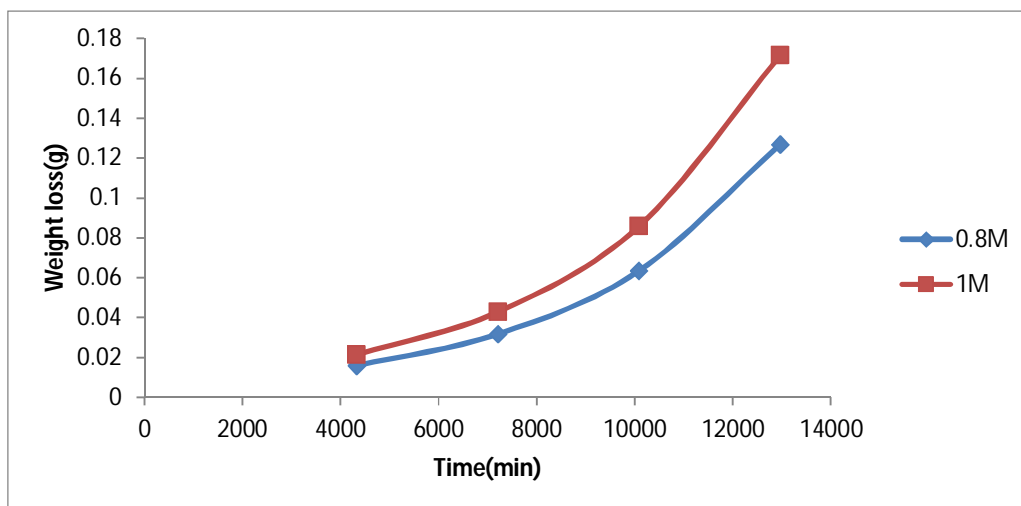
Figure3-8: Weight Loss of Aluminum in 0.8M, 1M NaCl

Aluminum reacts slowly with HCl due to oxide layer formation on it .Although as immersion time increases, aluminum begins to react with HCl-first forming Aluminums chloride and eventually Aluminumic chloride. Aluminum responds faster to concentration increase in H_2SO_4 than in HCl and NaCl as it could be observed that H_2SO_4 corrodes aluminum at a faster rate than HCl and NaCl corrodes aluminum at a slow rate than HCl. This results from the difference in the oxidizing properties of the three inorganic acids, and the fact that H_2SO_4 has more strength than HCl; therefore it has higher activity. HNO_3 has impacted the highest weight loss on the test specimen. This excessive corrosiveness of the acid solution is as aresult of its powerful ability to readily oxidize materials, thereby violently attacking the surface of aluminum.

One can conclude that the reaction of aluminum with different acidic solutions can be symmetries as follow:

$$2Al_{(s)} + 2\ HNO_{3\ (aq)} \rightarrow 2AlNO_{3\ (s)} + H_{2(g)} \qquad (3.1)$$

$$2Al_{(s)} + 3\ HNO_{3\ (aq)} \rightarrow Al\ (NO_3)_{3(s)} \qquad (3.2)$$

$$Al_{(s)} + H_2SO_{4\ (aq)} \rightarrow AlSO_{4(s)} + H_{2\ (g)} \qquad (3.3)$$

$$2Al_{(s)} + 3\ H_2SO_{4\ (aq)} \rightarrow Al_2(SO_4)_{3(s)} \qquad (3.4)$$

$$2Al_{(s)} + 2\ HCl_{(aq)} \rightarrow 2AlCl_{(s)} + H_{2(g)} \qquad (3.5)$$

$$Al + 2HCl_{\ (aq)} \rightarrow AlCl_{3(s)} \qquad (3.6)$$

$$Al_{(s)} + NaCl_{(aq)} \rightarrow AlCl_{(s)} + Na^+ \tag{3.7}$$

$$Al_{(s)} + 3\ NaCl_{(aq)} \rightarrow Al\ Cl_{3(s)} \tag{3.8}$$
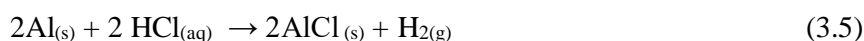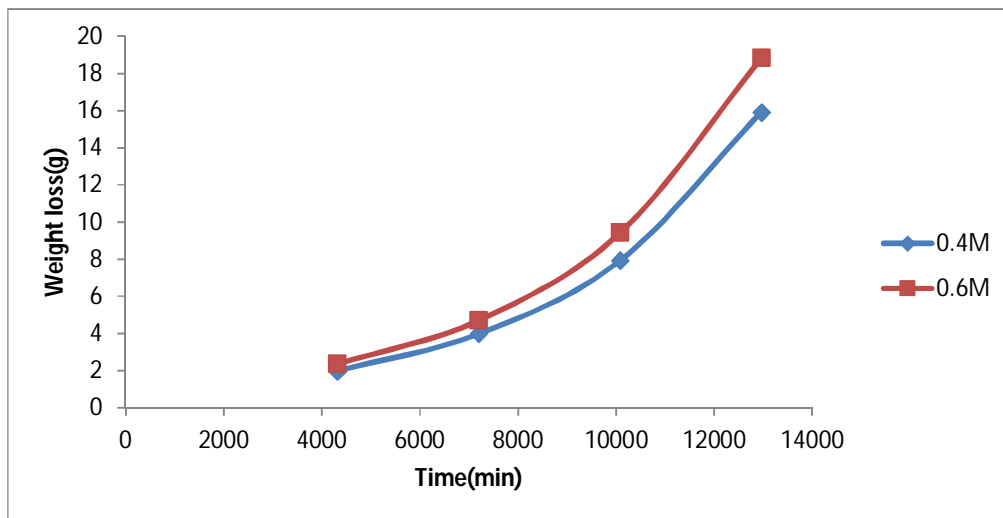
3.2. Corrosion of Iron:

Figures (3-9 to 3-16) represent weight loss plots of iron inHNO_3, H_2SO_4,HCl, and NaCl. The illustrations show that Increase in concentration increases weight loss per area of metal specimen. The weight loss also increases proportionally with increase in immersion time or period of time the metal is exposed to the acid solutions. HNO_3 has proved to cause the most devastating corrosion or weight loss on iron similarly to what has been experienced in the case of Aluminum.

Table3-5: Weight losses of the corrosion of iron in HNO_3.

Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	1.990	2.354	2.651	3.235
7200	3.981	4.708	5.303	6.47
10080	7.962	9.417	10.607	12.94
12960	15.925	18.834	21.215	25.88

Figure3-9: Weight Loss of Iron in 0.4M and 0.6M HNO$_3$
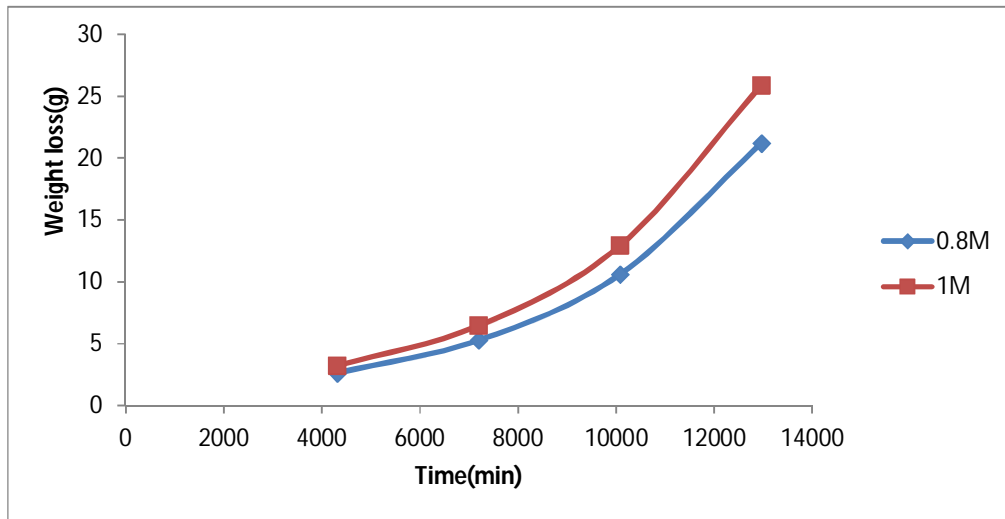
Figure3-10: Weight Loss of Iron in 0.8M and 1M HNO$_3$

Table3-6: Weight losses of the corrosion of iron in H$_2$SO$_4$.

Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	1.390	1.454	1.651	2.235
7200	2.781	2.908	3.303	4.47
10080	5.562	5.817	6.607	8.94
12960	11.125	11.634	13.215	17.88

Figure3-11: Weight Loss of Iron in 0.4M and 0.6M H_2SO_4

Figure3-12: Weight Loss of Iron in 0.8M and 1M H_2SO_4

Table3-7: Weight losses of the corrosion of iron in HCl.

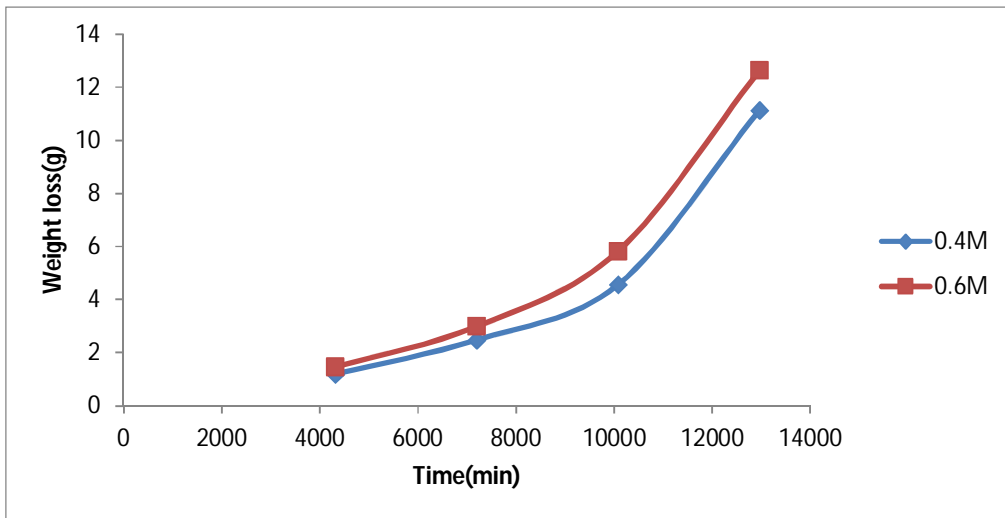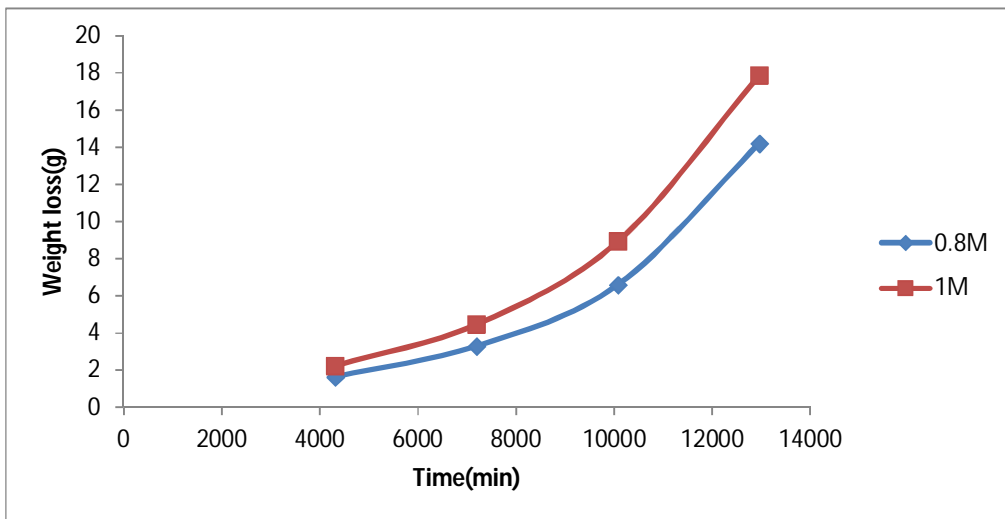| Concentration (M) Time (min)	0.4	0.6	0.8	1
4320	0.645	1.035	1.163	1.33384
7200	1.290	2.070	2.326	3.368
10080	2.580	4.141	4.650	5.736
12960	5.160	8.283	9.304	10.472
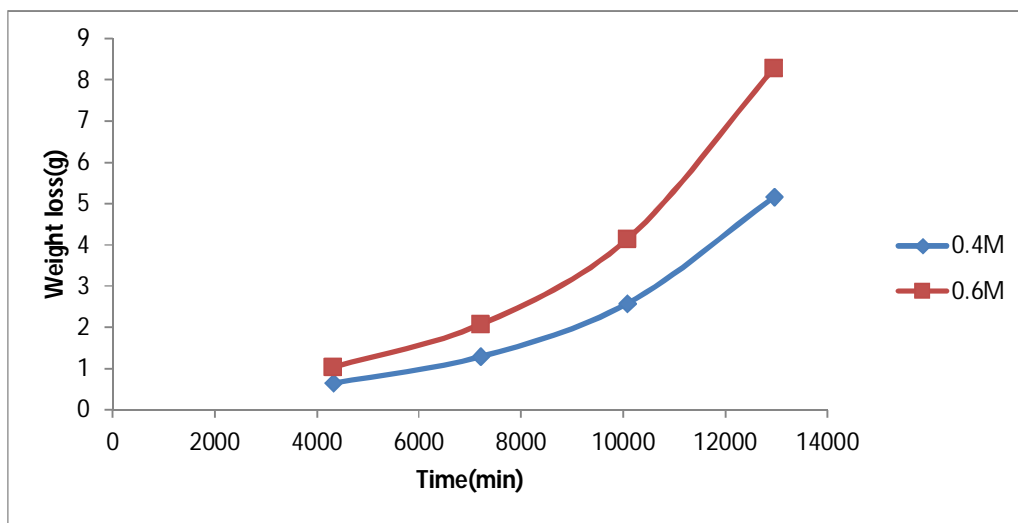
Figure3-13: Weight Loss of Iron in 0.4M and 0.6M HCl
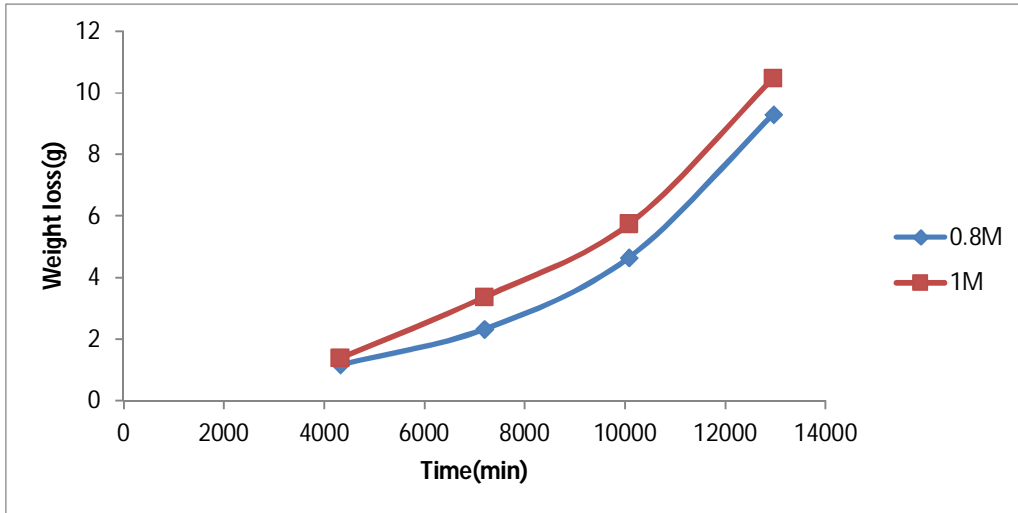
Figure3-14: Weight Loss of Iron in 0.8M and1M HCl

Table3-8: Weight losses of the corrosion of iron in NaCl.

Concentration (M) / Time (min)	0.4	0.6	0.8	1
4320	0.067	0.107	0.133	0.153
7200	0.135	0.214	0.266	0.307
10080	0.271	0.428	0.532	0.614
12960	0.542	0.856	1.064	1.228
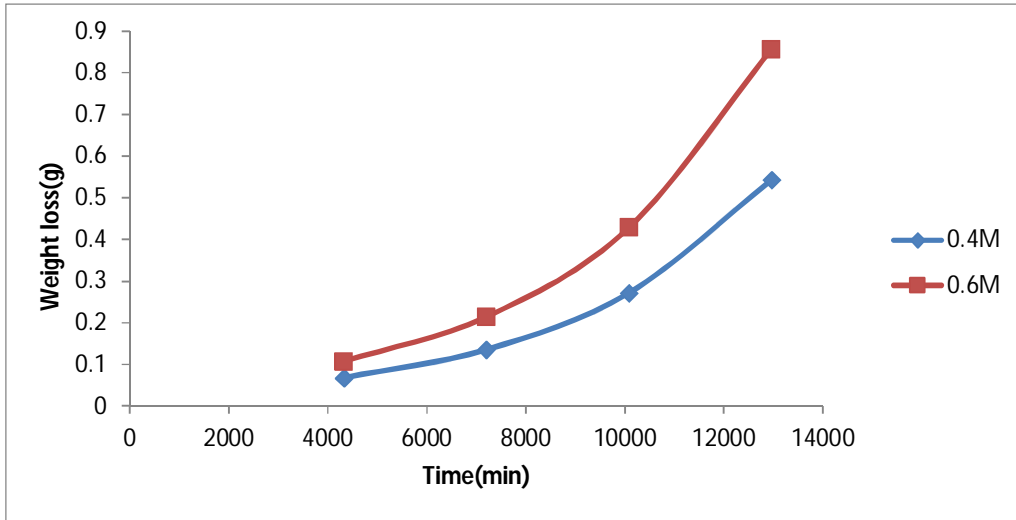
Figure 3-15: Weight Loss of Iron in 0.4M and 0.6M NaCl
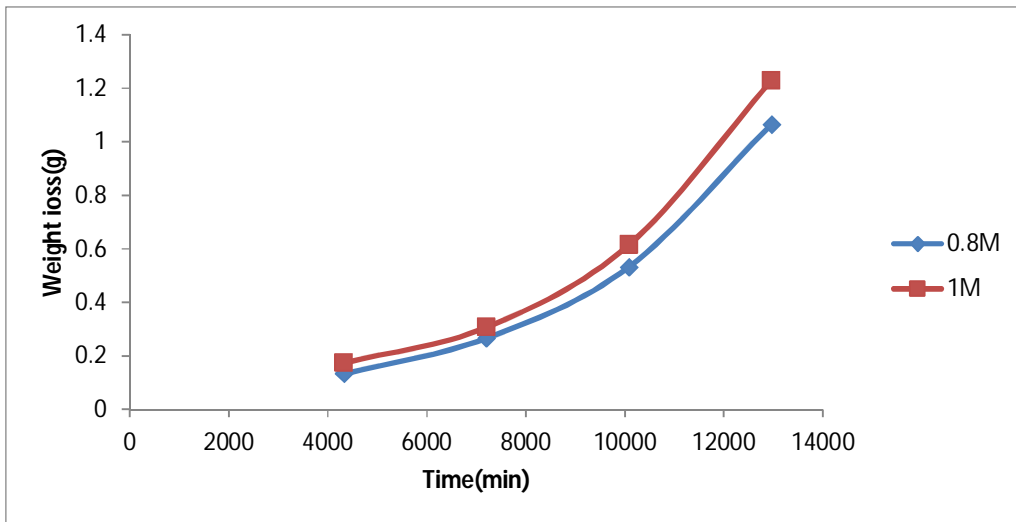
Figure 3-16: Weight Loss of Iron in 0.8M and 1M NaCl

The weight loss also increases proportionally withincrease in immersion time or period of time the metal is exposed to the acid solutions. HNO_3 has proved to cause themost devastating corrosion or weight loss on iron similarly to what has been experienced in the case of aluminum.

One can conclude that the reaction of iron with different acidic solutions can be symmetries as follow:

$$2Fe_{(s)} + 2\ HNO_3\ (aq) \rightarrow 2Fe\ NO_{3\ (s)} + H_{2(g)} \qquad (3.9)$$

$$Fe_{(s)} + 2\ HNO_3\ (aq) \rightarrow 2Fe\ (NO_3)_{2\ (s)} \qquad (3.10)$$

$$Fe_{(s)} + H_2SO_{4\ (aq)} \rightarrow Fe\ SO_{4(s)} + H_{2\ (g)} \qquad (3.11)$$

$$2Fe_{(s)} + 2HCl_{(aq)} \rightarrow 2FeCl_{(s)} + H_{2(g)} \qquad (3.12)$$

$$Fe_{(s)} + 2HCl_{\ (aq)} \rightarrow FeCl_{2(s)} \qquad (3.13)$$

$$Fe_{\ (s)} + NaCl_{\ (aq)} \rightarrow Fe\ Cl_{(s)} + Na^+ \qquad (3.14)$$

$$Fe_{\ (s)} + 3\ NaCl_{\ (aq)} \rightarrow Fe\ Cl_{2(s)} \qquad (3.15)$$
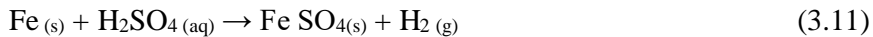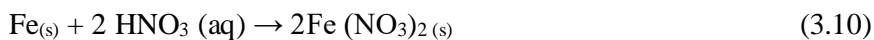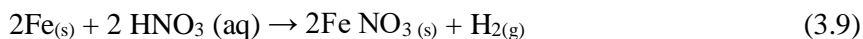
3.3. Kinetic Study:

The initial weight of the specimens and weight of specimens at various instants of time in all concentrations of the four acid media were used in calculating the specific reaction rate values, using first order rate expression; $k = (2.303/t)\ Log\ [(initial\ weight\ of\ specimen)/(weight\ at\ time,\ t)]$. The half life time values were then calculated using the formula $t_{1/2} = 0.693/k$.
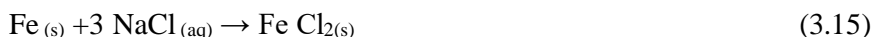
Table 3-9: Kinetics of the corrosion of Aluminum in HNO_3

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	5.37×10^{-4}	1.29×10^3
2	0.6	2.83×10^{-4}	2.44×10^3
3	0.8	1.72×10^{-4}	4.09×10^3
4	1	8×10^{-5}	8.66×10^3

Table3-10: Kinetics of the corrosion of Aluminum in H_2SO_4

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	$8.37x10^{-4}$	$8.07x10^2$
2	0.6	$7.46x10^{-4}$	$9.28x10^2$
3	0.8	$3.41x10^{-4}$	$20.30x10^2$
4	1	$2.46x10^{-4}$	$28.07x10^2$

Table3-11: Kinetics of the corrosion of Aluminum in HCl

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	$10.87x10^{-4}$	$0.637x10^3$
2	0.6	$8.82x10^{-4}$	$0.838x10^3$
3	0.8	$8.22x10^{-4}$	$0.842x10^3$
4	1	$5.33x10^{-4}$	$1.299x10^3$

Table3-12: Kinetics of the corrosion of Aluminum in NaCl

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	$12.20x10^{-4}$	$5.68x10^3$
2	0.6	$11.60x10^{-4}$	$5.97x10^3$
3	0.8	$10.51x10^{-4}$	$6.59x10^3$
4	1	$9.76x10^{-4}$	$7.10x10^3$

Table3-13: Kinetics of the corrosion of Iron in HNO_3

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	4.24×10^{-4}	1.63×10^3
2	0.6	3.75×10^{-4}	1.84×10^3
3	0.8	3.40×10^{-4}	2.03×10^3
4	1	2.86×10^{-4}	2.42×10^3

Table 3-14: Kinetics of the corrosion of Iron in H_2SO_4

S/N	Concentration (M)	Specific reaction rate (min_{-1})	Half life, $t_{1/2}$ (min)
1	0.4	5.07×10^{-4}	1.36×10^3
2	0.6	4.86×10^{-4}	1.48×10^3
3	0.8	4.53×10^{-4}	1.52×10^3
4	1	3.71×10^{-4}	1.86×10^3

Table3-15: Kinetics of the corrosion of Iron in HCl

S/N	Concentration (M)	Specific reaction rate (min^{-1})	Half life, $t_{1/2}$ (min)
1	0.4	6.90×10^{-4}	1.00×10^3
2	0.6	5.76×10^{-4}	1.20×10^3
3	0.8	5.21×10^{-4}	1.32×10^3
4	1	5.00×10^{-4}	1.38×10^3

Table3-16: Kinetics of the corrosion of Iron in NaCl

S/N	Concentration (M)	Specific reaction rate (min-1)	Half life, t1/2 (min)
1	0.4	11.85×10^{-4}	5.84×10^2
2	0.6	10.75×10^{-4}	6.44×10^2
3	0.8	10.22×10^{-4}	6.78×10^2
4	1	9.78×10^{-4}	7.07×10^2

Tables(3-9 to 3-16) illustrate these data. It could be observed that the specific reaction rate, k increases as acid concentration increases. There is then a corresponding decrease in the half-life time values, thus confirming the first order kinetics for the corrosion of iron, and Aluminum in all four solutions [39, 45]. In addition, it has been confirmed that HNO_3 corrodes these metals the most because it has the highest k values, and the lowest half-life times at all concentrations. The specific reaction rates follow this order for the four acids used: $HNO_3 > H_2SO_4 > HCl > NaCl$.

3.4. Study the effectiveness of inhibitors:

3.4.1. Inhibitors used urea:

The inhibitors urea (0.3, 0.5, 1, 1.5 g) were mixed with the corrosive (1M H_2SO_4, 1M HNO_3, 1M HCl and 1MNaCl respectively. The urea specimens were taken out after immersion 1430 min in the mixed solution, removed the patina, dried at room temperature and weighed. As a reference, the specimens immersed in the corrosive without any inhibitors were also tested under the similar conditions.

Table3-17: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for aluminum in (1M) HNO_3 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.8121	23.12	2.24×10^{-2}
0.5	0.7012	33.62	2.09×10^{-2}
1	0.5347	49.38	1.59×10^{-2}
1.5	0.3182	69.87	9.49×10^{-3}

Table3-18: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for aluminum in (1M) H_2SO_4 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.3745	27.47	1.11×10^{-2}
0.5	0.3161	38.78	9.43×10^{-3}
1	0.2354	54.41	7.02×10^{-3}
1.5	0.1532	70.33	4.57×10^{-3}

Table3-19: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for aluminum in (1M) HCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.1145	22.53	3.41×10^{-3}
0.5	0.0901	39.03	2.68×10^{-3}
1	0.0732	50.47	2.18×10^{-3}
1.5	0.0468	68.73	1.39×10^{-3}

Table3-20: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for aluminum in (1M) NaCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.0167	21.96	4.98×10^{-4}
0.5	0.0133	37.85	3.96×10^{-4}
1	0.009	57.94	2.68×10^{-4}
1.5	0.0061	71.49	1.81×10^{-4}

Many organic inhibitors work by an adsorption mechanism. The resultant film of chemisorbed inhibitor is then responsible for protection either by physically blocking the surface from the corrosion environment or by retarding the electrochemical processes. The main functional groups capable of forming chemisorbed bonds with metal surfaces are amino [46] ($-NH_2$), carboxyl ($-COOH$), and phosphonate ($-PO_3H_2$) although other functional groups or atoms can form co-ordinate bonds with metal

surfaces. The protective properties of such compounds depend on the electron densities around the adsorption center.

The higher electron density at the center, the more effective the inhibitor.The corrosion rate values in the presence of 1mm of urea in acidic medium cause to increase the active sites on the metal surface by reducing the activation energy of rate determining step (rds) of the anodic or cathodic corrosion reaction. The reduction in the dissolution of metal in the presence of methyl urea may be attributed to nitrogen and oxygen atoms present in the functional group. Corrosion inhibition occurred as a result of the adsorption of molecules of plant extracts onto the metal surfaces. It is known that the adsorption isotherms are very important for the understanding of the mechanism of corrosion inhibition. The action of inhibitor in acid solutions is generally agreed to be adsorption on to the metal surface which is usually oxide free in acid solutions. The adsorption of an inhibitor species on the metal surface interface can be expressed as a place exchanger process between the inhibitor molecules in the aqueous solutions and the water molecule on the metallic surface.

Tables shows that the values of (IE %) were shifted to lower values with reference to the blank in the presence of urea as a corrosion inhibitor. From this table, it can be indicated that the urea inhibits the corrosion mechanism by predominantly controlling cathodic reactions and blocking cathodic sides of the metal surface. The (IE %) values in crease with increasing the weight of inhibitor and the optimum concentration of urea was 1.5 g.

Table3-21: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for iron in (1M) HNO_3were calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	2.554	21.05	2.61×10^{-2}
0.5	2.262	30.07	2.31×10^{-2}
1	1.724	46.70	1.78×10^{-2}
1.5	0.986	69.52	1.00×10^{-2}

Table3-22: The inhibition efficiency (IE %) and corrosion rate (R) values of iron urea in (1M) HSO_4 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	1.744	21.96	1.78×10^{-2}
0.5	1.381	38.21	1.41×10^{-2}
1	0.895	59.95	9.16×10^{-3}
1.5	0.594	73.42	6.07×10^{-3}

Table3-23: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for iron in (1M) HCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.999	27.88	1.02×10^{-2}
0.5	0.855	38.22	8.75×10^{-3}
1	0.621	55.13	6.35×10^{-3}
1.5	0.423	69.43	4.32×10^{-3}

Table3-24: The inhibition efficiency (IE %) and corrosion rate (R) values of urea for iron in (1M) NaCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Urea (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.1212	21.04	1.24×10^{-3}
0.5	0.0987	35.70	1.01×10^{-3}
1	0.0765	50.16	7.83×10^{-4}
1.5	0.0489	68.14	5.00×10^{-4}

As the weight of inhibitor increases, the rate of corrosion decreases because the inhibitor molecules prevent the dissolution of iron by effective adsorption of plant extract on the metal surface area. The adsorbed organic molecules prevent the further interaction of the acid with metal.

3.4.2. Inhibitors used acetanilide:

Table 3-25: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for aluminum in (1M) HNO$_3$ calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.862	18.39	2.57×10^{-2}
0.5	0.763	27.76	2.27×10^{-2}
1	0.632	40.16	1.88×10^{-2}
1.5	0.419	60.28	1.25×10^{-2}

Table 3-26: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for aluminum in (1M) H_2SO_4 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.4032	21.92	1.20×10^{-2}
0.5	0.3567	30.92	1.06×10^{-2}
1	0.2831	45.17	8.44×10^{-3}
1.5	0.1875	63.69	5.59×10^{-3}

Table 3-27: The inhibitor efficiency (IE%) and corrosion rate (R) values of aluminum acetanilide in (1M) HCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.1211	18.06	3.61×10^{-3}
0.5	0.0998	32.42	2.97×10^{-3}
1	0.0798	46	2.38×10^{-3}
1.5	0.0573	61.22	1.70×10^{-3}

Table 3-28: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for aluminum in (1M) NaCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.0172	19.62	5.13×10^{-4}
0.5	0.0149	30.37	4.44×10^{-4}
1	0.0113	47.19	3.37×10^{-4}
1.5	0.0099	53.73	2.95×10^{-4}

Corrosion inhibitors are found to protect aluminum corrosion in acid solutions by adsorbing themselves on aluminum surface where the adsorption of the organic molecules occurs as the interaction energy between molecule and metal surface is higher than that between the water molecules and the surface [47], and it is regarded as substitution adsorption process between the organic molecules in the aqueous phase (org_{aq}) and the water molecules adsorbed onthe aluminum surface $(H_2O)_{ads}$[27].

Table 3-29: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for iron in (1M) HNO_3 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	2.803	13.33	2.86×10^{-2}
0.5	2.362	26.95	2.41×10^{-2}
1	1.724	46.70	1.50×10^{-2}
1.5	1.181	63.44	1.20×10^{-2}

Table 3-30: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for iron in (1M) H_2SO_4 calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	1.803	19.31	1.84×10^{-2}
0.5	1.461	34.63	1.49×10^{-2}
1	0.964	56.86	9.86×10^{-3}
1.5	0.726	67.47	7.44×10^{-3}

Table3-31: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for iron in (1M) HCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	1.121	19	1.14×10^{-2}
0.5	0.948	31.46	9.70×10^{-3}
1	0.712	48.55	7.28×10^{-3}
1.5	0.512	63	5.24×10^{-3}

Table 3-32: The inhibitor efficiency (IE%) and corrosion rate (R) values of acetanilide for iron in (1M) NaCl calculated from weight loss measurements at room temperature the immersion 4320 min.

Weight of Acetanilide (g)	Weight loss (g)	IE %	R (mpy)
0.3	0.1255	18.24	1.28×10^{-3}
0.5	0.1023	33.35	1.04×10^{-3}
1	0.0868	43.45	8.88×10^{-4}
1.5	0.0533	65.27	5.45×10^{-4}

It is clear from the table that the percentage inhibition efficiency increases with weight of the inhibitors. The compounds exhibited a maximum inhibition efficiency of 18-65% at a concentration of 1.5g. The increase in inhibition efficiency with increasing weight of the inhibitors at room temperature is due to an increase in surface coverage resulting in retardation of the metal dissolution. The efficiency of the inhibitors follow the order0.3 >0.5 >1 > 1.5

4. Conclusions:

The corrosion behavior and mechanism of iron and aluminum have been studied under different media by weight loss method. Four different concentrations 0.4M, 0.6 M, 0.8 M, 1M, were used for different timings 3 to 9 days. From the research study, the following conclusions have been arrived at.

• Metals are highly corroded in acid solutions.

• Corrosion rate or weight loss increases with increasing acid concentration and decreases with increasing time of exposure.

• The order of corrosion activity under the different acid media has been found to be: $HNO_3 > H_2SO_4 > HCl > NaCl$.

• The order of reactivity on the metals has been found to be: iron > aluminum.

• Rate of corrosion reaction (specific reaction rate) of metals increases with a first order degree as acid concentration increases. The half life time on the other hand decreases with an increase in concentration.

• The investigated surfactant compounds act as inhibitors for the corrosion of aluminum and iron in nitric acid, sulfuric acid, hydrochloric acid and sodium chlorides solutions.

• The inhibitors increase the value of activation energy of corrosion and consequently, decrease the rate of dissolution of aluminum and iron in four solutions.

• The inhibition efficiencies obtained from weight loss measurements of urea are in good agreement with each other.

Recommendation

a) To eliminate or reduce errors in future investigations of corrosion properties of materials by weight lost per unit area method, the following are suggested:

b) The use of a better means of removing adherent corrosion products, say by the use of chemical means.

c) An open building with the roof covered for better air circulation than the present laboratory should be

provided for the experiment to allow better free circulation of air and real atmospheric condition to play their natural parts in corrosion process without rain necessarily disrupting the project set up.

d) It is suggested that future researchers wishing to investigate properties of materials formulate mathematical relations existing between the extent of corrosion attack and time as well as investigation of corrosion properties of other steel products of and other local steel producing companies.

References:

[1] Shaw, B.A. and Kelly, R.G., 2006. What is corrosion?. *Interface-Electrochemical Society*, *15*(1), pp.24-27.

[2] Veloz, M.A. and Gonzalez, I., 2002. Electrochemical study of carbon steel corrosion in buffered acetic acid solutions with chlorides and H 2 S. *Electrochimica Acta*, *48*(2), pp.135-144.

[3] Zúñiga, E.E., Rodríguez, M.V., Chavarín, J.U. and Cruz, V.R., 2011. Corrosion of carbon steel in sour water from the oil industry: the effect of temperature. *Int. J. Electrochem. Sci*, *6*, pp.5016-5030.

[4] Feyerl, J., Mori, G., Holzleitner, S., Haberl, J., Oberndorfer, M., Havlik, W. and Monetti, C., 2008. Erosion-corrosion of carbon steels in a laboratory: three-phase flow. *Corrosion*, *64*(2), pp.175-186.

[5] Galvanic corrosion CorrosionCliniecomRetriered on 2012-07-15.

[6] Walsh, F., 1991. Faraday and his laws of electrolysis. *Bulletin of Electrochem*, *7*(11), pp.481-489.

[7] Zaki, A., 2006. Principles of corrosion engineering and corrosion control.

[8] Speller, F.N., 1925. A Study of Corrosion Factors and the Electrochemical Theory. *Industrial & Engineering Chemistry*, *17*(4), pp.339-346.

[9] Cotton, F.A. and Wilkinson, G., 1963. *Advanced inorganic chemistry: a comprehensive text*. Interscience.

[10] A.S. Beansunas and N. E. Hammer; (1970); "Basic corrosion course" (10), NACE, Houstom, texas.

[11] F.N. Speller; (1951), "corrosion causes and phevention", (13)3rd edition, Mc. Graw. Hill, N. Y. PP304.

[12] H. H. Whlig and R.W Revice; (1985) "An Introduction to corrosion scince and Engineering ", 3rd edition, John wiley, New york, PP110-112.

[13] Abhijeet, S.B., Balasubramaniam, R. and Gupta, M., 2008. Corrosion behaviour of Mg–Cu and Mg–Mo composites in 3.5% NaCl. *Corrosion Science*, *50*(9), pp.2423-2428.

[14] "Corrosion of metals" by Richard E. Ricker, M ark R. Stoudt, James F. Dante, James L. Fink, Carlos R. Benuchamp and Thomas P. Maffat Materials scince and Engineering laboratory.

[15] "Type of corrosion " contact-provider legal notice. C. Gasamtve band der Deutschengswiertsch e, v, (GDV), Berlin 2002-2016, 2015.

[16] Corrosion of carbon steel, e 1999-2010 key to Metals AGRights Reserved.

[17] Curatolo, B., 2011. UV Technology for High-Performance Industrial Applications. *RadTech Report*, *25*(4), p.24.

[18] Federal Highway Administration (FHWA), Office of the Infrastructure and Development (2001).ReportFHWA-RD-01-156.

[19] Xi, Y. and Xie, Z., 2002. *Corrosion effects of magnesium chloride and sodium chloride on automobile components* (No. CDOT-DTD-R-2002-4,). Colorado Department of Transportation, Research [Branch].

[20] Corrosion of carbon steel, e 1999-2010 key to Metals A. B Rights Reserved.

[21] Cotton, F.A. and Wilkinson, G., 1963. *Advanced inorganic chemistry: a comprehensive text*. Interscience.

[22] Mak, A., 2002. Corrosion of Steel, Aluminum and Copper in Electrical Applications. *General Cable*.

[23] Xu, D., Li, Y. and Gu, T., 2016. Mechanistic modeling of biocorrosion caused by biofilms of sulfate reducing bacteria and acid producing bacteria. *Bioelectrochemistry*, *110*, pp.52-58.- See more at: http://www.corrosionjournal.org/doi/abs/10.5006/1.3293640#sthash.flSmYCVE.dpuf

[24] Mannuzza, S., Klein, R.G., Bessler, A., Malloy, P. and LaPadula, M., 1993. Adult outcome of hyperactive boys: educational achievement, occupational rank, and psychiatric status. *Archives of general psychiatry*, *50*(7), pp.565-576.

[25] Davis, J.R. ed., 1999. *Corrosion of aluminum and aluminum alloys*. Asm International.

[26] P. Agarwal, D. Landolt, Corrosion Science, 260 (1998), 673-691Date 1 July 2011COR05 Page 2

[27] "Selecting A Corrosion Inhibitor" Milacron Marketing Co. Technical Report No. 2/03

[28] Patil, D.B. and Sharma, A.R., 2011. Study on the Corrosion Kinetics of Iron in Acid and Base Medium. *Journal of Chemistry*, *8*(S1), pp.S358-S362.

[29] Siwach, A.K. and Kumar, S., 2015. Bibliometric analysis of research publications of Maharshi Dayanand University (Rohtak) during 2000-2013. *DESIDOC Journal of Library & Information Technology*, *35*(1).

[30] Samina, M., Karim, A. and Venkatachalam, A., 2011. Corrosion study of iron and copper metals and brass alloy in different medium. *Journal of Chemistry*, *8*(S1), pp.S344-S348.

[31] Afzal, S.N., Shaikh, M.A., Mustafa, C.M., Nabi, M., Ehsan, M.Q. and Khan, A.H., 2007. Study of aluminum corrosion in chloride and nitrate media and its inhibition by nitrite. *Journal of Nepal Chemical Society*, *22*, pp.26-33.

[32] Undiandeye, J.A., Chior, T.J., Mohammed, A. and Offurum, J.C., 2014. Kinetics of the corrosion of mild steel in petroleum-water mixture using ethyl ester of lard as inhibitor. *AU Journal of Technology*, *17*(3).

[33] Natesan, M., Selvaraj, S., Manickam, T. and Venkatachari, G., 2016. Corrosion behavior of metals and alloys in marine-industrial environment. *Science and technology of advanced materials*.

[34] Loto, C.A., Loto, R.T. and Popoola, A.P.I., 2012. Corrosion inhibition of thiourea and thiadiazole derivatives: A Review. *Journal of Materials and Environmental Science*, *3*(5), pp.885-894.

[35]Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498 Vol.5, No.6, December 2015 863 'Study the Effect of Urea as Inhibitor for Corrosion in Mild Steel in 2204-Tank' Abdulrazzaq S. Abdullah Petrochemical Engineering Department STU, Technical Engineering College of Basrah, ,Basrah, Iraq e-mail:abdalmaliky_80@yahoo.com

[36] Uzorh, E.D.A., 2013. Corrosion properties of plain carbon steels. *The International Journal of Engineering and Science*, *2*(11), pp.18-24.

[37] Chuka, C.E., Odio, B.O., Chukwuneke, J.L. and Sinebe, J.E., 2014. Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments. *International Journal of Technology Enhancements and Emerging Engineering Research*, *3*(7), pp.306-310.

[38] Chuka, C.E., Odio, B.O., Chukwuneke, J.L. and Sinebe, J.E., 2014. Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments. *International Journal of Technology Enhancements and Emerging Engineering Research*, *3*(7), pp.306-310.

[39] Patil, D.B. and Sharma, A.R., 2011. Study on the Corrosion Kinetics of Iron in Acid and Base Medium. *Journal of Chemistry*, *8*(S1), pp.S358-S362.

[40] Samina, M., Karim, A. and Venkatachalam, A., 2011. Corrosion study of iron and copper metals and brass alloy in different medium. *Journal of Chemistry*, *8*(S1), pp.S344-S348.

[41] Ajide, O.O. and Agara, K.W., 2012. Comparative Study of Corrosion Characteristics of MCS and KS7 SS In Selected Acid Media. *International Journal of Metallurgical Engineering*, *1*(1), pp.7-11.

[42] Abdulmaruf, S. and Dajab, D.D., 2007. Corrosion behavior of Copper immersed in different environment. *Materials Society of Nigeria (MSN) Zaria chapter book of proceedings,*, pp.67-70.

[43] Usman, A.D. and Okoro, L.N., A Review: ,2013.Weight Loss Studies on the Corrosion Behavior of Some Metals in Various Media.

[44] Usman, A.D. and Okoro, L.N., A Review: 2014.Weight Loss Studies on the Corrosion Behavior of Some Metals in Various Media.

[45] Noor, E.A. and Al-Moubaraki, A.H., 2008. Corrosion behavior of mild steel in hydrochloric acid solutions. *Int. J. Electrochem. Sci*, *3*(1), pp.806-818.

[46] Schmitt, G, 1984,"Appliction of inhibitor for acide media", Br. Cobros. J. , 19, 4, 165-176.

[47] Leidheiser, H., 1979. *Corrosion Control by Coatings: Papers Presented at a Meeting on Corrosion Control by Coatings Held November 13-15, 1978 at Lehigh University, Bethlehem, Pennsylvania*. Science Press.