VOL. 02 NO. 2,
DECEMBER, 2023
E-ISSN 3027-1533
P-ISSN 3026-8648

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of African Innovation & Advanced Studies (JAIAS)

Corrosion Inhibition Using Hydrogen Evolution Approach in Acidic Medium

Okorie Vincent U.; Anele Trust C.; Jacob Augustine M.; & Okonkwo Chidubem L.
Department of Materials and Metallurgical Engineering, Federal University of Technology Owerri.

Abstract
This paper provides an outline of related literatures in which scientists and researchers used different types and procedure of corrosion inhibitors to reduce corrosion that takes place in various equipment made of alloys or metals. Different chemical inhibitors were used to reduce the rate of corrosion in various alloys. The inhibition rates ranged between 30-80% in acidic environments with different molar concentrations. Using a quantitative approach (including basic equations, explained and derived, and illustrative problems), this volume discusses the basic thermodynamic and electrochemical principles that cause corrosion and treats practical corrosion problems and methods of protection and prevention. The use of inhibitors for the control of corrosion of metals and alloys which are in contact with aggressive environment is an accepted practice. The emphasis is on HCl solutions, lower-grade steels, and elevated temperatures. This review is also devoted to corrosion inhibitor formulation design – mixtures of corrosion inhibitors with (mainly) surfactants, solvents, and intensifiers to improve the effectiveness of individual compounds at elevated temperatures. The information presented in this review is useful for diverse industrial fields, primarily for the well acidizing procedure, and secondly for other applications where corrosion inhibitors materials are needed.

Keywords: Corrosion, Inhibition, Hydrogen, Mild Steel, Thermodynamics

Introduction

Corrosion is the destructive attack of a material by reaction with its environment. It may be considered as the destruction of materials under the action of the environment. (Akhmetov et al, 1989). It may also be considered as a process of

destructive alteration of a metal or an alloy by chemical reaction with any substance-solid, liquid or gas. The attack pattern is largely governed by the combined influences of several factors relating to metal or alloy, condition of service and the chemical nature of the environment. Corrosion is, in fact, the "decay of a metal or an alloy in contact with the surrounding medium." Corrosion like other natural hazards such as earthquakes can cause dangerous and expensive damage to structures ranging from automobiles, home appliances, drinking water systems, pipelines, and bridges to public buildings.

Corrosion problems arise as a result of the interactions between aqueous solution and carbon steel, especially during the pickling process where the alloy is brought in contact with the highly concentrated acids (Xiang-Hong et al. 2010). There are several ways of tackling the issue of corrosion in the industry and one of such ways is the eco-friendly use of inhibitors.

In the oil and gas industry amongst others, corrosion of metal structures is a cause for major concern, as these failures may result in product spillage which is invariably harmful to society as it represents a risk to safety, hazard to the environment and substantial loss of production time and money. Hence, there is a need for proper monitoring of metallic systems and how they react to different environments in which they are used. Protective techniques are also employed to minimize or eliminate close monitoring of systems (Koch et al., 2001).

The material used in this study is mild Steel. It is natural to consider using an inexpensive, easily fabricated metal, such as plain carbon steel when selecting metals for corrosion studies. The prevailing market forces may also influence the choice of metals. Thus, mild steel is selected for use in this study because of its visual appearance–its brightness and reflectivity which most often are retained when exposed to the atmosphere.

Mild steel is an alloy of iron, containing iron, carbon, manganese, phosphorous etc. It is fairly malleable and ductile. It can be forged (shaped by hammering and pressing while hot) but cannot be hardened by heat treatment (Talbot and Talbot, 1998). It is used in making boilerplates, girders, bars, tubes, rivets nuts and bolts. Pipelines are typically made of mild steel, and it is known that under common operating conditions an oxide film forms on the iron surface. This oxide film mostly presents a hematite (α-Fe_2O_3) structure. When mild steel corrodes, there is usually a loss of the metal to a solution in some form, by a product–favoured oxidation-reduction reaction. For mild steel to corrode, anodic sites must be available for the metal to be oxidized to metal ions as electrons are produced. Anodic areas occur at cracks in the oxide coating, at boundaries between phases, or around impurities (Ita and Offiong, 1997).

Researchers in different parts of the World are however attempting to come up with the most effective but less expensive corrosion inhibitor(s) and ways of combating the

problem. Corrosion control is only one aspect of the technologies within which it is exercised, and the approaches adopted must accommodate other requirements most economically.

Statement of Problem

Corrosion causes tremendous harm to the nation's economy. About 10% of iron and steel as well as aluminum and its alloys produced annually are lost to corrosion (Onen, 2000). Bottle tops of most alcoholic and nonalcoholic drinks, food containers; industrial machine parts, etc. are found to corrode rapidly thus constituting a health hazard to the end users. Although the oil and gas, beverage and metallurgical industries sink huge sums of money into trying to control the corrosion of their engine parts and products, the problem persists. In some chemical process industries, equipment becomes obsolete after a few years owing to the normal development of new and more efficient processes and corrosion. In such cases, the choice of materials may therefore be dedicated to the consideration of product contamination where complete corrosion resistance is required.

A survey of the available literature shows that the rate laws and mechanisms of reactions of inhibitors have not been established. It is expected that this project may add to the bank in the area of corrosion inhibition for industrial use.

CONCEPTUALISATION

Corrosion Overview

Engineering materials are majorly made of metals, which comprise 25% of the earth's crust.

Due to their great economic importance, they are utilized in one way or the other in all industrial applications. All metals for structural engineering applications degrade, this degradation is what we refer to as corrosion.

According to Fontana, (2005) Corrosion; metal degradation, is the deterioration of materials as a result of a reaction with their environment.

Corrosion is an electrochemical process which occurs when four elements are present; an anode which gives up electrons, a cathode which receives electrons, an electrolyte (which is usually an aqueous solution of acids, bases, or salts) and a metallic current path (Piping Technology and Products, Inc.2020). N/B Without any of these elements, corrosion will not occur. A significant amount of energy is put into a metal when it is extracted from its ores, placing it in a high-energy state. These ores are typically oxides of the metal such as hematite (Fe_2O_3) for steel or bauxite ($Al_2O_3 \cdot H_2O$) for aluminium. One principle of thermodynamics is that a material always seeks the lowest energy state. In other words, most metals are thermodynamically unstable and will tend to

seek a lower energy state, which is an oxide or some other compound. The process by which metals convert to lower-energy oxides is called corrosion.

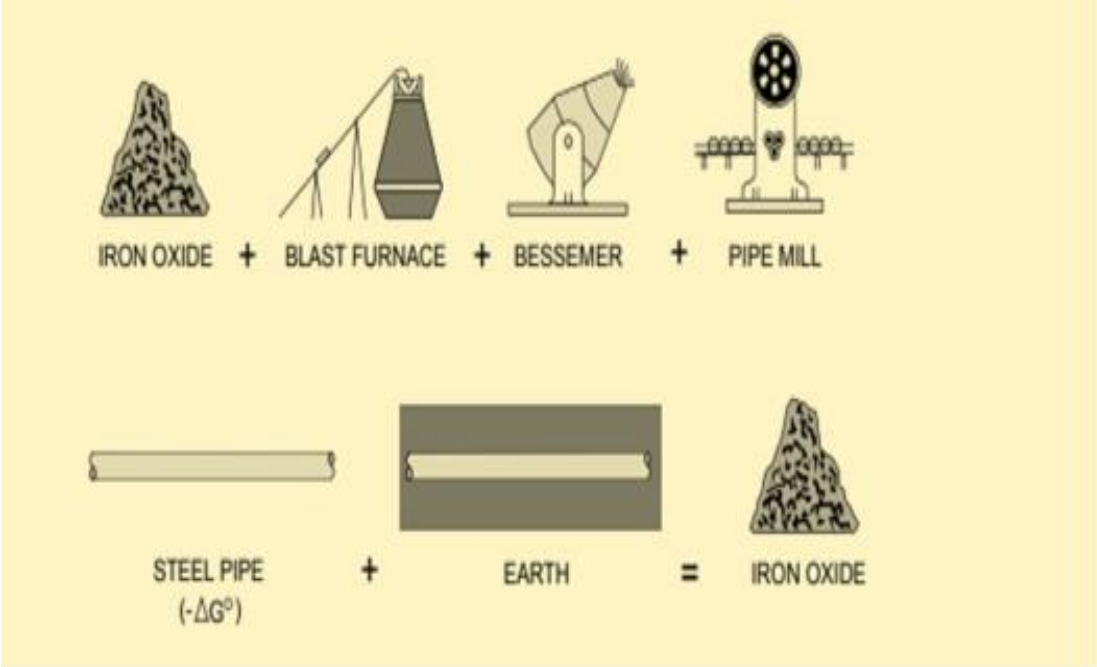


Fig 2.1 Refining Process of Steel (Source: NACE CP2)

Corrosion of most common engineering materials at near-ambient temperatures occurs in aqueous (water-containing) environments and is electrochemical. The aqueous environment is also referred to as the electrolyte and, in the case of underground corrosion, is moist soil. The corrosion process involves the removal of electrons (oxidation) from the metal and the consumption of those electrons by some other reduction reaction, such as oxygen or water reduction.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (2.1)$$

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

$$2H_2O + 2e- \rightarrow H_2 + 2OH^{-} \quad (2.3)$$

The oxidation reaction is commonly called the anodic reaction and the reduction reaction is called the cathodic reaction, which occurs at both the anodic and cathodic sites respectively. Both electrochemical reactions are necessary for corrosion to occur. The oxidation reaction causes the actual metal loss but the reduction reaction must be present to consume the electrons liberated by the oxidation reaction, maintaining charge neutrality. Otherwise, a large negative charge would rapidly develop between the metal and the electrolyte, and the corrosion process would cease.



Fig 2.2 Rusting of iron and steel (Source: NACE)

Causes of Corrosion

The causes of corrosion are complex and vary across industries. Some examples common to specific industries are listed below:

i. Corrosion in construction often occurs due to metals being exposed to outdoor elements and extreme temperatures,
ii. Underground mining is typified by an acidic water environment (often with chlorides and sulfates), combined with high humidity and temperature.
iii. Forestry corrosion often takes place in remote locations, with equipment parked on grass or soil surfaces which draw up large amounts of moisture overnight; this can corrode onboard mechanical systems and components.

Environmental conditions will also affect corrosion rates and spread. Where humidity is present, this generates moisture – causing a reaction where metals corrode much more quickly than they would in dry conditions.

Mechanism of Corrosion

For corrosion to occur, the formation of a corrosion cell, also known as an electrochemical cell, is essential (Ahmad, 2006). A corrosion cell consists of the following four components:

i. **Anode:** One of the electrodes in the electrolytic cell, represented as the negative terminal of the cell. It is the more reactive metal, where electrons are released, and oxidation (corrosion) takes place.

ii. **Cathode:** The positive terminal of the cell where electrons are consumed, and the reduction of species takes place.

iii. **Electrolyte:** The electrically conductive solution that allows the passage of positive electricity(charge) called cations from anode to cathode.

iv. **Conductor or Metallic Path (anode and cathode):** This is the metallic conductor that externally connects the electrodes.

v. let us examine the process of corrosion for a single corrosion cell consisting of a single anode and a single cathode existing on the same metallic surface in water. The metal provides the anode, cathode, and electronic path of the corrosion cell. The water provides the electrolyte to complete the corrosion cell. The electrolyte has ionized so that hydrogen (H^+) and hydroxyl (OH^-) ions are present in small amounts (10^{-7}).

Metal ions leave the anodic surface going into the electrolyte, leaving behind electrons, which flow in the metallic path to the cathodic surface. At the cathodic surface, the electrons from the anode meet hydrogen ions from the solution. One hydrogen ion accepts one electron and is converted into a hydrogen atom. The hydrogen atom may combine with another hydrogen atom to form a molecule of hydrogen gas, which may either cling to the cathodic surface or be released as a bubble. In some cases, the hydrogen atom may enter the metal lattice and lead to hydrogen embrittlement.

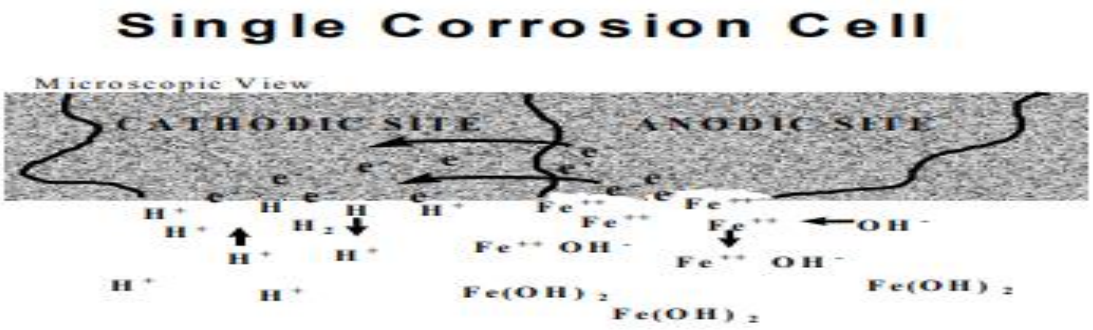


Figure 2.3 A Single Microscopic Corrosion Cell

Meanwhile, the metal ions combine with hydroxyl ions in the electrolyte to form the metal hydroxide, or rust, which precipitates onto the metal surface.

As this process continues, oxidation (corrosion) of the metal occurs at the anodic surfaces and reduction of hydrogen ions occurs at the cathodes. (NACE, 2013).

Forms of Corrosion

1. General/uniform corrosion
2. Localized corrosion

General / Uniform corrosion

This corrosion results from the continual shifting of anode and cathode regions of the surface of a metal in contact with the electrolyte and leads to a nearly uniform corrosive attack on the entire surface. An example of such corrosion is the rusting of steel plates in seawater. If the rate of metal loss is known, allowances can be made in design and maintenance to accommodate the corrosion. Although it is termed uniform corrosion, it is characterized by the average surface loss. Uniform corrosion of storage tanks [from Jones (1996)].



Fig 2.4 Uniform Corrosion

Localized Corrosion

Localized corrosion is defined as the selective removal of metal by corrosion at small areas or zones on a metal surface in contact with a corrosive environment, usually a liquid. It usually takes place when small local sites are attacked at a much higher rate than the rest of the original surface. E.g.: -

i. **Pitting Corrosion:** Pitting is the most common form of localized corrosion. It can be identified by the presence of discrete cavities or craters called pits on the metal surface. The cavities correspond to areas where small volumes of metal were removed and may or may not be associated with corrosion products. Pitting is found in many different shapes (e.g. round, elliptical or

irregular), sizes and depths. As viewed in cross section pits occur in various aspect ratios. The aspect ratio is the width of the pit divided by the depth of the pit. (NACE, 2013)

ii. **Crevice Corrosion:** This is a type of localized corrosion that occurs at narrow openings between metals. It occurs at, or immediately adjacent to, discrete sites where free access to the bulk environment is restricted. This form of corrosion, normally, can be identified visually and is recognized by the pitting or etching near, or adjacent to, locations of restricted flow. Common sites for crevice corrosion are under loose-fitting washers, flanges, or gaskets. This form of corrosion is not, however, limited to crevices formed by mated surfaces of metal assemblies. Crevice corrosion can also occur under scale and surface deposits (termed "under deposit" corrosion).

iii. **Galvanic Corrosion:** This is otherwise called bimetallic corrosion or dissimilar metal corrosion. Dissimilar metal corrosion refers to two dissimilar metals in electrical contact exposed to an electrolyte. When these dissimilar metals are in contact, the potential difference provides the driving force for increased corrosion, with the less noble corroding more rapidly, while the more noble corrodes less.

iv. **Erosion Corrosion:** This corrosion is associated with the rapid movement of a corrosive fluid over a metal, removing corrosion products. It is recognized by the appearance of grooves, trenches, etc., in the direction of fluid flow.

v. It is the removal of surface material by the action of fluid flow.

Protective Coating

Generally, coating is defined as a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. The coating itself may be an all-over coating, completely covering the substrate, or it may only cover parts of the substrate.

Protective coatings are probably the most widely used products for corrosion control. They are used to provide long-term protection under a broad range of corrosive conditions, extending from atmospheric exposure to the most demanding chemical processing conditions. Protective coatings in themselves provide little or no structural strength, yet they protect other materials to preserve their strength and integrity. The main function of a protective coating is to isolate structural reactive elements from environmental corrosives. The fact that protective coatings occupy only a very small fraction of the total volume of a system is quite telling of the heavy requirements imposed on these materials. A coating must provide a continuous barrier to a substrate, and any imperfection can become the focal point for degradation and corrosion of the substrate. (Pierre, 1999)

Use of Inhibitors

A corrosion inhibitor is a chemical substance usually added in an accurate quantity to an active corrosion cell, to retard the rate of corrosion. They are applied only to the internals of a piping system and or other installations. It can also be defined as a chemical substance that when present in the corrosion system at a suitable concentration decreases the corrosion rate, without significantly changing the concentration of any corrosive agent (C. Monticelli, 2018) C. Monticelli, in Encyclopedia of Interfacial Chemistry, 2018. It is generally effective in small concentrations.

However, some factors affect the effective use of corrosion inhibitors: -

i. **Flow regime:** when the flow is turbulent, it exposes/entraps the oxygen content in the fluid to the corrosion inhibitor (e.g.; chromate, nitrate and other oxygen scavengers). However, turbulent flows sometimes prevent the inhibitors from adhering to the metal wall/surface.
ii. **Quantity of water:** the inhibitor should be added at a measured and accurate quantity about the quantity of water present. This prevents excess input or very little input of inhibitors (which the water can easily adsorb).
iii. **Fluid composition:** the fluid may contain sand particles and other related impurities, which can be able to blast/brush out the corrosion inhibitors attached to the metal walls.
iv. **Temperature:** Some inhibitors are more soluble at higher temperatures; hence temperatures should be readjusted to suit the inhibitor for more efficiency.

Economic Importance and Cost Implication of Corrosion

Researchers think that corrosion is inescapable. Damages due to corrosion can be reduced significantly through a deeper application of the key principles of corrosion. Rather than applying control or preventive measures to corrosion issues the attention in the industry has been disproportionately placed on maintenance. A deliberate focus on corrosion prevention not maintenance or overhaul should therefore be encouraged. The effects of corrosion in our daily lives are both direct, in that corrosion affects the useful service lives of our possessions, and indirect, in that producers and suppliers of goods and services incur corrosion costs, which they pass on to consumers (Joseph 2000).

The enormous resources expended on the corrosion challenge (about $6 bn dollars annually in the US alone) is an issue of global concern, though the degree of anxiety may differ from advanced to developing countries the effort of reducing or preventing the corrosion menace is a key and critical issue the world over.

Therefore, several means of adequately combating these challenges must be deployed with extreme determination. The over-dependence on the utilization of chemical or harmful organic inhibitors must be dissuaded all over the globe, also, the huge energy investment in producing these toxic chemicals and the inconsistency, shortage and dwindling manner of these sources have made them inappropriate and unjustifiable.
Consequently, the solution is for researchers to study ways of making appropriate inhibitors massively obtainable. It therefore means that such methods must be inexpensive, easily accessible, widely available, and eco-friendly. A source of inhibitor that complies with this description is the GREEN INHIBITOR. It is a non-diminishing, readily available, non-hazardous source of valuable protection.

Green Inhibitors

The subject of toxicity of most synthetic inhibitors is an issue of concern and presently research efforts are geared towards replacing these hazardous substances partly or wholly with natural or green inhibitors. The reason is that they are proven to be cheap, easily obtained, available and applicable. Moreover, strict environmental legislation has made the focus and emphasis on the utilization of green inhibitors more relevant. The term "green inhibitor" or "eco-friendly inhibitor" refers to substances that are biocompatible with nature. The inhibitors like plant extracts possess biocompatibility properties due to their biological origin (Koch et al., 2001). Moreover, it also includes synthetic compounds with negligible toxicity. Overall, green inhibitors are not harmful to human beings and therefore friendly to the environment. These positive attributes and the need to prolong the lifespan of engineering infrastructure by using natural inhibitors have encouraged interest as well as research into these naturally occurring substances as inhibitors.
Ajayi et al. (2011a) sought to determine the effect of Vernonia amygdalina (single inhibitor) plant extract on the failure of mild steel in 2 M sulphuric acid (H2SO4) using the gasometric technique. Their result showed that while extract quantity was increasing, hydrogen gas evolution and inhibitor efficiency (IE) were also increasing. In addition, the phytoconstituent-metal interaction mechanism was best explained by Freundlich isotherm, with the 4-minute curve being the best contact time for extract phytochemicals to properly adsorb to metal surfaces across all quantities used. The microstructural studies also revealed that increasing the extracted quantity led to a considerable reduction in the dominant coarsening of the oxide of the iron phase, while the pearlite and ferrite phases were highly dispersed.
Eddy and Odoemelam (2009) investigated the inhibition of corrosion of mild steel in sulphuric acid using ethanol extract of Aloe vera. Their study was conducted at 303 and 333K using the gasometric technique and it showed the existence of a chemical adsorption isotherm. Mild steel coupons in 1 M HCl in the presence of Menta

pulegium extract were studied by Bouyanzer et al. (2006). The studies were conducted using weight loss measurements, electrochemical polarization and electrochemical impedance spectroscopy methods. Their findings revealed Menta pulegium as a cathodic inhibitor.

Also, corrosion inhibition of mild steel in 2M Sulphuric acid by aqueous extract of Ajowan (carom) seeds was studied using hydrogen evolution, Weight loss and impedance measurements at 30^0C by Al-Turkustani (2010). The results revealed that Ajowan extract inhibited the corrosion process in 2 M H2SO4 and the IE increased as concentration increased. The impedance studies further revealed that charge transfer influenced the degradation process of mild steel across the phase boundary with and without the inhibitor. The potentiodynamic polarization results indicated that ajowan seeds extract acted as mixed type inhibitor. The IE obtained from all methods utilized was in good agreement. The adsorption mechanism of ajowan extract molecules on steel surfaces is impulsive and it is attributed to the Freundlich adsorption isotherm.

MILD STEEL

Mild steel is an alloy made of iron and other elements such as carbon and traces of silicon, manganese, sulphur, phosphorous and aluminium. Steel quality, strength, ductility and hardness differ with the quantity of the alloying element. As steels deteriorate in numerous environments, their resistance to corrosion in the very common and frequently used reagents like sulphuric (H_2SO_4) and hydrochloric (HCl) acid is a vital and important economic consideration for many industries. Acids, especially phosphoric, nitric, sulphuric and hydrochloric acids are utilized in virtually every manufacturing process. They are used in the manufacture of metals, food, explosives, paper, dyes, leather and fertilizers. Fortifying steel against corrosion, as they function as pressure, reaction, transport and storage devices in the service environment where they come in contact with these ubiquitous and hostile acids, is a major consideration for all concerned industries.

KINETICS AND THERMODYNAMICS OF CORROSION INHIBITION

Thermodynamics provides part of the scientific infrastructure needed to evaluate the course and rate of the corrosion process. Its principal value is in yielding information on intermediate products of the complementary anodic and cathodic. Partial reactions that together constitute a complete process. The structures and characteristics of these intermediate products can control the resistance of a metal/alloy to attack within such wide limits as to make the difference between premature failure and sufficient life for its practical function (Talbot and Talbot, 1998).

The accumulation of electrons in the metal or alloy establishes a negative charge on the metal/alloy relative to the solution, creating a potential difference opposing further

generation of ions and promoting the reverse process, i.e. the discharge of ions. A dynamic equilibrium is established when the metal has acquired a characteristic potential relative to the solution. Conditions for equilibrium at a given temperature are derived from a form of the Van‟t Hoff reaction isotherm:

$\Delta G = \Delta G^0 + RTInJ$ (2.5)

where J is the activity quotient corresponding to free energy change, Δand G and ΔG^0 are the free energy change for all reactants in their standard states (Talbot and Talbot, 1998). The rate of any transformation is controlled by the magnitude of one or more energy barriers that every particulate entity (e.g. an atom or an ion) must surmount to transform. These peaks are the energy maxima of the intermediate transition state through which the entity must pass in transforming and the energy that must be acquired is the activation energy, Ea. An expression for reaction rate that applies to many reactions over moderate temperature ranges is Arrhenius‟ equation:

$A = \exp^{-\frac{E}{RT}}$ (2.6)

where r is the reaction rate and A is the Arrhenius constant.

MATERIALS AND METHODS

Materials collection and Preparation

The metal used for the study is mild steel. Mild steel was used because of its versatility as the material of construction. It is used widely in the construction industry because of its availability and strength. It finds widespread application in the utilities, food, chemical and petrochemical industries even though it is easily affected by the aggressive environment. Because of its strength, it is used for load-bearing applications like the shell of a pressure vessel or the rotating shaft of a machine. The chemical composition of the mild steel sheet used for this study has the following composition as shown in the standard analysis of mild steel from a steel industry (weight %): C (0.12), Mn (0.85), S (0.06), P (0.05), Si (0.09) and Fe (98.83). The metal was subsequently subjected to an inhibition test with organic inhibitors at the University of Calabar Chemistry Department Laboratory, by making use of an optical electron spectroscopy (OES).

To conduct the weight loss experiment, the mild steel was mechanically press-cut into 4cm × 0.08cm × 5cm coupons using the guillotine. These were polished with different grades (#800, #1000, #1200) of emery paper, they were then subjected to chemical treatments. The mild steel sample was degreased by immersion in absolute ethanol, dried in acetone, and stored in a moisture-free desiccator before use.

The aggressive solution, 1.0M HCl and 0.5M H_2SO_4 was prepared by dilution of analytical grade HCl and H_2SO_4 with distilled water. Distilled water was used to prepare all experimental solutions.

Preparation of Jatropha, Moringa, and Diodia Leaves

The fresh leaves of Moringa, Diodia and Jatropha were obtained from the Federal University of Technology Owerri environs, they were packed in a large polyethene bag and thoroughly rinsed with clean water to remove traces of dust and unwanted materials.

The sample was sun-dried and crushed into fine powder using a manual blender before taking it to the lab for experiments.

The ground samples of MO, JT and Diodia leaf were accurately weighed at about 200g each using a weighing balance model (AE "Adam). Each sample was soaked in 1000mls of 99% methanol for 48 hours and filtered using a Whatman No.1 filter paper. The solution was concentrated to a syrupy residue at 40-50^{o}c using a thermostatic water bath model "(F.Nr-L508.0271) until almost the entire methanol evaporated.

The leaf extract test solutions of concentration 5.0 and 10.0g/L were prepared from the stock solution by dissolving 5g and 10g of the methanol extract in 1M HCl and 0.5M H_2SO_4. This solution was kept for 24 hours, filtered using a Whatman No.1 filter paper, and stored. These solutions were then used for the corrosion inhibition test in the acidic medium.

Gasometric method (Hydrogen Evolution)

The gasometric technique was conducted using a gasometric assembly which consists of a reaction vessel connected to a burette containing paraffin oil. The burette was also connected to a paraffin oil reservoir. In the gasometric technique, the volume of hydrogen evolved was determined following procedures previously described (Obike *et al*., 2016).

100 mL of a test solution was introduced into the reaction vessel. A mild steel coupon was dropped into the solution in the chamber and the reaction vessel was quickly closed to avoid any escape of hydrogen gas. The volume of the hydrogen gas that evolved from the reaction was monitored by the depression (in mL) in the level of paraffin oil.

This depression in the paraffin oil level was recorded every minute for a maximum of 15 minutes at temperatures of 303, 323 and 333K (30°C, 50°C and 60°C). This procedure was repeated for blank and other concentrations of the test solutions for 1.0 M and 0.5 M acids. The rate of evolution of the hydrogen gas (Rh) is determined from the slope of the graph of volume of hydrogen gas evolved (Vh) versus time (t) and the inhibition efficiency (I%) is determined using the equation below.

$$E\% \left[\frac{Rhblank - Rhinh}{Rhblank}\right] \times 100 \quad (3.3)$$

Where Rh_{blank} and R_{hinh} are the corrosion rates in the absence and presence of plant extract respectively.

Conclusion

This study investigated the problems associated with the effect of corrosion on industrial chemical environments usually found in the chemical and allied petrochemical industries. Metal wastage which usually happens when entire facilities are in operational service has been associated with aggressive acidic environments like HCl and H2SO4. Though, there are other sources of metal wastage like the wearing of machine components under tensile, compressive and shearing stresses, the aggressive nature of hydrochloric and sulphuric acid cannot be said to be non-contributors to the corrosion process. Since engineering facilities (pressure vessels, hold-up tanks) have been designed to support certain load specifications in service they will ordinarily function well, but the introduction of aggressive process reagents in the petrochemical industries identified in the literature survey leads to drastic metallic wastage. This wastage ensures that metal thickness or diameter is reduced below the effective load-carrying capacity. Therefore, while in service metals fail catastrophically resulting in injuries to the workforce, product spillage, lost production hours and maintenance problems. By reducing the rate of metal wastage in an environmentally friendly way it is possible to prolong the service life of the machine component. This saves money and reduces incidences of downtime.

Specifically, the use of inhibitors apart from being the cheapest among the several techniques available offer a versatile and viable approach. However, the over reliance on the use of chemical inhibitors has brought to the fore the problems of pollution, litigation, contamination of plant and animal life as well as the burden of disposal. Therefore, this makes the use of environmentally friendly inhibitors viable and appropriate. The reason is that plant extracts are clean, cheap and sustainable sources of addressing metal wastage arising from an aggressive environment.

The results presented in this work show that the methanol extracts from *Moringa Oleifera*, *Jatropha Tanjorensis and Diodia Sermentosa* inhibit the corrosion of mild steel in 0.5M H_2SO_4 and 1M HCl solutions to an appreciable extent. The inhibition efficiencies of the plant extracts increased with an increase in extract concentration but decreased with an increase in temperature. Therefore, since the inhibition efficiency decreases with an increase in temperature it can be said that at high temperature working environment, the inhibitor is likely to fail. It was observed that the corrosion inhibition efficiency was higher in 1M H_2SO_4. The corrosion inhibition is attributed to the physical adsorption of the phytochemical components of the extracts on the surface of the metal.

Recommendations

Based on our study, we recommend that:

i. More than 2 concentrations be used in other to get the best inhibition concentration.

ii. Detailed study of the effect of the inhibitors on the corrosion of other metals in related or varied media systems;
iii. More hydrogen evolution experiments should be conducted using larger plant extract so that the analysis can be more detailed.
iv. Enough dried and ground Poe

References

Ahmad, Z. (2006) Principles of Corrosion Engineering and Corrosion Control. Elsevier Science & Technology Books Publisher/BH

Ajayi, O.O., Omotosho, O.A., & Ifepe, V.O. (2011a). Acid Failure of Mild Steel in 2 M Sulphuric Acid in the Presence of Vernonia Amygdalina. Journal of Material and Environmental Science, 2, 186-195.

Akhmetov, B.; Novichenko, Y.V; and Chapurin, V (1989). Physical and Colloid Chemistry, 1st edition, Moscow: Mir Publishers

Bouyanzer, A., Hammouti, B., Majidi, L., Haloui, B., 2010. Testing natural Fenugreek as an eco-friendly inhibitor for steel corrosion in 1 M HCl. Portugal. Electrochim. Acta 28, 165–172.

C. Monticelli, "Corrosion inhibitors." Encyclopedia of Interfacial Chemistry, Surface Science and Electrochemistry (Elsevier, Amsterdam) p. 164 (2018)

Eddy, N.O., Odoemelam, S.A., Ama, I.N., 2009. Ethanol extract of Ocimum gratissimum as a green corrosion inhibitor for the corrosion of mild steel in H2SO4. Green Chem. Lett. Rev. doi:10.1080/17518251003636428.

Ita, B.I and Offiong O.E (1997). "The Inhibition of Mild Steel Corrosion in Hydrochloric acid by 2, 2/ - pyridil and α- pyridon", Materials Chemical and Physics, 51: 203- 210.

Jones, D.A. (1996) Principles and Prevention of Corrosion, 2nd Edition, Prentice Hall, Upper Saddle River, NJ.

Joseph R. Davis (2000) Corrosion: Understanding the Basics Science and Nanoscience ASM International. ISBN 1615030689, 9781615030682 pg 563

Koch, G.H.; Brongers, M.P.H.; Thompson, N.G.; Virmani, Y.P.; Payer, J.H. Corrosion Costs and Preventive Strategies in the United States; FHWA: Washington, DC, USA, 2001

M. Al-Turkustani, S. T. Arab,R. H. Al-DahiriModern Applied Science,2010, 4(5)

M.G. Fontana, "Corrosion science and engineering", 3rd Edition, Tata McGraw-Hill, ISBN: 978- 0070607446, 2005.

NACE. 2013. NACE Standard SP0775-2013: preparation, installation, analysis, and interpretation of corrosion coupons in oilfield operations. American National Standards Institute, Washington, DC.

Obike, AI; Emeruwa, CN; Ajiwe, VIE; Igwe, JC. (2016). Corrosion Inhibition and Adsorption Behaviour of Methanol Extract of Spondias Cytherea Leaves on Mild Steel Corrosion in 5.0M H2SO4, Int. J. of Inno. Res. in Sci. Eng. Tech., 5(6): 9501-9510.

Onen, A.I (2000). "Determination of the Amount of Corrosion of Iron using Different Concentrations of two Alkali Halides with Time", Yedzaram Journal of Science and Technology, 1 (1): 74-89.

Pierre Roberege 1999 Handbook of Corrosion Engineering Publisher McGraw Hill Professional, Technology & Engineering / Chemical & Biochemical ISBN0071777075, 9780071777070 Length1072

Piping Technology and Products, Inc (2020) https://pipingtech.com/resources/ptp- blog/list/page/84/

Talbot, D and Talbot, J (1998). Corrosion Science and Technology; New York: CRS Press

Xiang-Hong Li, Shu-Duan Deng, H. Fu, Journal of Applied Electrochemical: 40 (2010) 1641.