Economic Impact of Corrosion in Oil Sectors and Prevention: An Overview

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Abstract.
The oil and gas industry is facing many corrosion problems. They have been faced with contaminants such as H2S and CO2 which deteriorate pipe lines and machine components. Over time, corrosion can occur on these machines’ inner surfaces. The pipelines must transport large amounts of crude oil which must be able to withstand large amount of pressure. The storage containers for the oil and gas are made of aluminium and steel which must be protected because of their susceptibility to corrosion which impacts directly or indirectly on the economy. Steel and aluminium are important metals used from manufacture to distribution of final products in almost every part of the oil and gas industry. This paper reviews the effect of corrosion on metal and some of the approaches towards corrosion control in engineering sectors.

Keywords: Steel, Surfaces, Metals, Chemicals, Corrosion.

1. Introduction
Corrosion, according to [1] is damaging to metals due to the attack by environmental reactions on material or metals, as well as by natural latent threats accompanied by oil and gas production and transportation. Corrosion represents an expensive problem for the industries of manufacture, chemical plants, oil industry and many more metal-using industries. Chemical leakage, oil pipelines breakdown and even fire can cause most corrosion problems: when exposed to electrical components and materials corroded. Different corrosion types include uniform corrosion, galvanic corrosion, corrosion of the crack, pitting, intergranular corrosion, and erosion. Catholic and anodic chemical reactions between metals and their surroundings reduce corrosion of metals. The most important corrosion agents are water, air humidity, oppressive metal polishing, acids, oils, some solids, base salts, fluid chemicals, and even some sulphur, ammonia and acidic-pH gaseous materials. Corrosion can also be defined as material collapse, usually air oxidation, and, sometimes, when it comes to water, acidic and alkaline mediums [2]. All engineering materials in service, except gold, often give the superficial impressions of permanence but are chemically unstable. This state of thermodynamic instability results in their inevitable tendency to revert to their ore (natural combined form) form from which they were extracted. The process, corrosion, initiated by the interaction of the material with its prevailing environment leads to loss of the desired structural properties, tampers with its functional integrity and performance when engaged in engineering designs and [3]. Recently, exploring plant-derived natural products as cheap eco-friendly corrosion inhibitors has become an essential field of study and of great interest to researchers. Plant products are not only environmentally acceptable and environmentally friendly, but also cheap, readily available and are renewable sources of materials [4].

Acids and bases are employed in numerous industrial operations and processes. Mineral acids are used for treatment of various materials such as pickling, de-scaling, refrigerant and acid-well oxidizing etc. Ammonium hydroxide is widely used in the industry for etching of circuit board, used in the food industry and serves as industrial cleansers etc. Mild steel is one of the most commonly used ferrous metals in the industries- for fabrications and other
engineering applications due to its relatively lower cost, availability and efficiency. The most common form of corrosion is the corrosion of mild steel, especially in acid solution. This tends to limit its industrial applications on process safety and economics grounds coupled with environmental safety [5]. The penalties of corrosion failures including safety hazards and interruptions in plant operations have attracted the attention of researchers to the control and prevention of corrosion processes. Unfortunately, it is almost impossible to prevent corrosion. Therefore, controlling the rate at which it occurs has been identified as the most economical solution to its rising challenges. The cost factor associated with the selection and utilization of highly corrosion resistant material (metals), the safest means of mitigating corrosion and other corrosion monitoring and control techniques, makes corrosion inhibition the best alternative. It allows for the use of cheap and readily available engineering materials in industrial applications with minimal environmental effects [6]. Over the years, the inhibitive effects of many chemicals have been successfully exploited to fight corrosion. However, the use of chemicals as corrosion inhibitors has been limited by its inherent toxicity, availability and cost. Additionally, the increasing environmental awareness calls for green inhibitors of zero environmental effects in place of the traditional chemicals used as corrosion inhibitors. Natural products of plant origin have been confirmed to have excellent inhibitive effects and are much eco-friendlier. This trend of using green inhibitors (plant extracts) as alternatives to the use of chemicals has gained wide acceptance among scholars and researchers on the basis of its availability, non-toxicity, lower cost and environmental friendliness. Against this backdrop, several research works – [7-9] etc. have been done on the corrosion inhibition of mild steel in acidic and alkaline media.

1.1 Economic Impact of Corrosion

It is a general belief that corrosion is a universal enemy that should be accepted as a process that is inevitable. As products and production processes become more complex and the penalties for corrosion failures have become more expensive and increased awareness has been generated. [10] underscores the above assertion and further argues that corrosion is like corruption, when both are left uncontrolled, they eat deep into the fabrics of a nation’s economy in an irreversible manner that recovery most often becomes an unrealizable mirage. Moreover, an average of 10 percent of the total metal output in the world is estimated to be lost in corrosion. This affects the economy of a nation and her assets: infrastructures, transportation, utilities, nuclear and military facilities, and production and manufacturing plants. According to [11], the cost of corrosion in industrialized nations is about 3-4% of their GDP. Deductively, third world countries spend ten times the above estimate to fight corrosion. To lend credence to this assertion, a survey was carried out in 2003 in the most technologically advanced country, US, to find out the cost of corrosion; the result revealed that the US spent about thirteen (13) times the gross productivity of Nigeria, which was at about $41.9 billion. Corrosion costs are partly related to attempts to give an attractive look to engineering equipment, structures and designs. Partly because of the direct replacement and maintenance costs and concurrent losses due to interruption to plant operation and additional costs associated with the use of expensive materials and other preventive measures. Applied research, education, information, knowledge transfer, technology and technical development are required here. [12] classified the economic costs of corrosion into two:

- **Direct Cost/Losses**: Those that can be quantitatively accounted for. Such as replacement cost, protection cost, corrosion inhibition, research and development.
- **Indirect Cost/ Losses**: These cannot be quantitatively evaluated. Examples are loss of products to spill and fire, loss of revenue due to downtime, loss of efficiency of equipment, contamination of products, environmental pollution, over-design to make allowance for metal loss and delays that may arise from lawsuits and ill-will etc.
Estimate of the avoidable costs of corrosion ranges between 10-40%. Although, most studies have focused on the direct costs of corrosion, it is agreed that the indirect impact of corrosion are much more significantly greater. The neglect of indirect costs is because of the inherent difficult in its estimate.

2. **Concept of Corrosion**

Corrosion deteriorates materials inevitably by the chemical interaction with their environments. It is the returning of the materials to its original form (stable state) to the mother earth [11]. In his contribution, [13] submits that for non-metals, corrosion emanates from chemical causes, but for metals, it embraces all forms of interactions of metals or alloys with its environment which is unintentional and deleterious. Moreover, it is the reaction of solids to their environment in the context of corrosion science, while corrosion engineers define corrosion as the reaction of engineering materials to their environment with a consequent deterioration of their properties. The International Union of Pure and Applied Chemistry (IUPAC) defines corrosion as the irreversible interfacial reaction of a material (metal, ceramic, polymer, etc.) to its environment resulting in the material being consumed or dissolved into the environmental component. Therefore, corrosion can be defined as the gradual wearing away of the component(s) of a material as a result of the unfavourable interaction with its environment which interferes with structural properties and functional integrity of the material.

2.1. **Corrosion environment**

While a material for engineering designs and applications can be selected on the basis of its mechanical, physical and chemical properties, it remains unquestionable that the effect of the material's interaction with the environment can be completely neglected. This material-environment interaction is of vital importance in the optimal design and performance of the engineering material; this is because the usefulness and retention of those properties cannot be divorced from the prevailing environmental conditions. Any fundamental approach to the corrosion phenomenon must therefore take into account the structural characteristics of the engineering materials, the nature of the environment and the reactions of the material to the environment [13].

Furthermore, [14] asserts that all environments are relatively corrosive and therefore, corrosion must be defined with reference to the environment. Corrosion environment can be broadly classified into two:

- Aqueous environment
- Atmospheric environment

However, many factors as identified by [13, 14] are common to both classifications. The author concluded temperature, pressure, fluid (water, acids, alkalis, salts, steam and gases) flow velocities, air and humidity, concentration of reactive species are the major factors that influence corrosion.

3. **Classifications of Corrosion**

3.1. **Dry Corrosion**

In dry corrosion, the environment is a dry gas that is often referred to as chemical corrosion. It occurs when the metal reacts with oxygen in the air. This results in the formation of oxide layer-rust, which eventually stops further corrosion. This phenomenon is called passivation. Dry corrosion or chemical corrosion is a slow and steady process which occurs on heterogeneous and [6].

3.2. **Wet Corrosion**
In this case, the water, acid or alkaline solution with dissolved species is aqueous in the environment. The liquid is a purely electrolyte-like corrosion process. This consists of two opposite but complementary reactions: oxidation (anodic reaction) and reduction (cathodic reaction). At the anodic site, the metal is oxidized or dissolved into the electrolyte while the cathodic reaction involves reduction of oxygen etc. Nevertheless, there is yet to be a unique of classifying corrosion. It is often convenient to classify corrosion by the different forms in which it occurs. The basis of these classifications is the appearance of the corroded metal as identified by visual observation or otherwise [15].

3.3. Uniform and Localized Corrosion
This is the form of corrosion in which the exposed surface area is entirely corroded. The attack takes place evenly or at a relatively same rate over the entire surface area or a large part of the entire surface area until a failure happens. It is relatively easier to detect and predict, thus, making disastrous failures relatively rare. Examples of this class are atmospheric corrosion, galvanic corrosion, high temperature corrosion, oxidation of metals in acid and biological corrosion etc. Uniform corrosion is responsible for 30% corrosion failures [16]. Localized corrosion occurs when a certain or specific part(s) of a material (metal) surface is corroded at a higher rate than other parts. These forms of corrosion are not easily detectable, thus, more difficult to control than the general forms. They are responsible for 70% corrosion failures in the industry.

3.4. Crevice Corrosion and Filiform Corrosion
Crevice corrosion is associated with a micro-environmental stagnant solution or corrosion of materials such as gaskets, washing machines, clamps, lap joints, bolts, rivet leads etc (Liu et al., 2014). Filiform corrosion is a particular type of crevice corrosion that occurs under protective films and coatings like paints. It is majorly caused by contaminants left on the surface or trapped between two (2) surfaces that came in contact with each other before the coating was applied. Once trapped by the coating, corrosion sets in and assumes the look of a spidery growth under the coated surface [17].

3.5. Pitting corrosion
This is an extremely localized corrosion of a metal surface confined to a point or a small area, manifesting in the form of pits, holes or cavities. It could be an open-mouth (uncovered) or contained in the corrosion products semi-permeable membrane. The various shapes of such pits could be hemispherical or cup-shaped and flat-walled etc. It’s It was harder to detect, predict and prevent frequent corrosion failures. In the ratio from deepest to average penetration, the extent of damage is often described as calculated from weight loss. This quotient is called is called pitting factor. Pitting occurs in passive metals such as stainless steel [18, 19]

3.6. Selective Leaching and an Erosion Corrosion
In selective leaching corrosion an alloy matrix can be removed or washed from one component (usually the most active). Examples are cast iron dezincification and graphitization [20]. Erosion corrosion refers to the repetitive formation (a corrosion process) and destruction (a mechanical process) of a metal's protective film or coating. It is the cumulative damage caused by electrical and mechanically active corrosion reactions, by the relative movement of the corrodent to the corrosion surface. In engineering systems such as piping (bends, elbows and joints), valves, pumps, heat exchanging turbine blades etc., it is common to find corrosion examples of this class of fretting and cavitation [21].
3.7. Inter-granular Corrosion and Stress Corrosion Cracking
Inter-granular corrosions are local attacks that take place at or near grain borders, while most grains are not affected. This type of corrosion is usually associated with a chemical separation effect (impurity tends to be enriched at grain limits) or certain phases precipitated on grain borders, which in the immediate vicinity produce reduced corrosion resistance areas (Wang et al., 2013). Stress corrosion cracking describes the phenomenon occurring when several alloys are subject to static surface tensile stress in a corrosive medium. The cracks are caused by the combined effects of the tensile stress on the surface [22].

4. Corrosion Control and Prevention Techniques
In practice, it is almost impossible to eliminate corrosion. However, it can be minimized to a certain degree. Some of the protection and control techniques can be broadly grouped into:

- Removal of oxidizing agent
- Prevention of surface reactions: techniques for cathodic and anodic protection
- Surface reaction inhibition: use of chemical inhibitors and control of certain process/system variables such as pH control.
- Protective coatings: coatings, electroplating, galvanizing, metal spraying, anodizing and conversion.
- Metal modification e.g. alloying
- Surface condition modification: maintenance to remove corrosive agents, design to prevent crevices, design to avoid interactions or reactive metal combinations.

The most economical way to mitigate corrosion has been identified as corrosion inhibition. It is a well-known fact in surface chemistry that the presence or introduction of foreign molecules strongly affects surface reactions. Therefore, because corrosion is a surface reaction, it means that it can be manipulated or controlled by the introduction of foreign molecular inhibitors. A corrosion inhibitor is any chemical aid or substance that can effectively reduce corrosion without interrupting the system if introduced to a corrosion environment in small concentrations [11]. In a broad sense, corrosion inhibitors can be classified into organic and inorganic inhibitor.

4.1 Organic and Inorganic Inhibitor
Organic inhibitors are inhibitors of long chain hydrocarbons; these contain heteroatoms i.e. nitrogen, sulphur, hydrogen and oxygen. They are film forming agents and are neither anodized nor cathodic [5]. By forming hydrophobic film on a metal surface, organic inhibitors protect the metal. The efficiency of these products depends on the chemical compositions, molecular structure and their metal surface affinities. Organic inhibitors generally affect the whole surface of the metal at adequate concentration. It can be sub-divided into organic anionic inhibitors e.g. sodium sulfonates, phosphonates or mercaptobenzotriazole (MBT) and organic cationic inhibitors. The later either be in liquid state or wax-like solids when in their concentrated form. Its active portion usually consists of large aliphatic or aromatic compounds with positive amine groups. Inorganic inhibitors typically involve crystalline chemical salts such as sodium chromate, phosphate or molybdate. Only the negative ions of the compounds reduce metal corrosion. Furthermore, inhibitors can also be grouped based on their chemical functionality or inhibition mechanism.

4.2 Cathodic Inhibitor
These inhibitors can either slow down the cathodic reaction by themselves or precipitate cathodic areas selectively in order to increase the superficial impedance and reduce the spread of reducible species to those areas. Catholic poisoning, cathodic precipitation or as oxygen scrub can be the basis for inhibition. Some cathodic inhibitors e.g. antimony or Arsenic act by
increasing the difficulty in recombining and releasing hydrogen. While other cathodic inhibitors like Ca$^{2+}$, Zn$^{2+}$, Mg$^{2+}$ form precipitate or oxides generating protective layer(s) on the metal while oxygen scavengers prevent cathodic depolarization often caused by oxygen e.g. sodium sulphite [11].

4.3 Passivating or Anodic and Precipitation Inhibitor
Passivating cause a large anodic shift of the potential for corrosion to force the metal surface into the passive region. Passivators can be oxidizing ions such as chromates, nitrite and nitrate i.e. They act with oxygen or non-oxidizing ions such as phosphate, fungstate or molybdate that do not require oxygen. They are the most effective and widely used inhibitors. However, when the concentration falls below the minimum limits (0.016%), it can induce or accelerate pitting form of corrosion. Film-forming compounds are precipitation-inducing inhibitors. Precipitation Inhibitor act on both the anodic and cathodic sites indirectly by blocking the metal surface. E.g. silicates and phosphate etc. they are non-toxic but less effective than passivating inhibitors.

4.4 Volatile Corrosion Inhibitors
They are inhibitors of vapour phase and generally are carried through volatilization into the corrosion site e.g. morphine or hydrazine. They either neutralize acid oxides or move pH to a lower acidic value. When they are in contact with metals, they condense and hydrolyze to release protective ions with any available moisture. High volatility gives fast reactions while low volatility ensures enduring protection [11, 14, 15]

5. Conclusion
This paper has identified the cause and types of corrosion in oil and gas industries. Various methods of combating corrosion were also summarized. Corrosion was discovered to have direct and indirect influence on the nation and world economy. Estimate of the avoidable costs of corrosion ranges between 10-40%. Although, most studies have focused on the direct costs of corrosion, it is agreed that the indirect impact of corrosion are much more significantly greater. The neglect of indirect costs is because of the inherent difficult in its estimate.

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