Evaluation of microbiological corrosion of carbon steel in salt water in industrial environment, Niger delta region

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ABSTRACT

The main objective of this study was to evaluate the microbiologically influenced corrosion of carbon steel in salt water. The corrosivity of carbon steel using Pseudomonas aeruginosa as sulfate-reducing bacteria (SRB) in salt water was investigated and evaluated in this research work as presented in this paper. The result of corrosion analyses shows the corrosion rates of carbon steel in salt water polluted with heavy industrial waste are more effective than that in control water (laboratory). The carbon steel surfaces which are under the corrosion medium (rivers water) were compared with control medium. The result of microbiological analyses shows the slides that made from the biofilm (product of corrosion) under microscopic appear small amount of bacteria, whereas culturing test shows small colonies with 2.5µm in diameter of bacteria have an appearance and green pigments as well as the result from biochemical tests. These facts indicate that Pseudomonas aeruginosa bacteria are correlated with the type of corrosion occurring in the carbon steel in the rivers water. The present of Pseudomonas aeruginosa initiate corrosion in the carbon steel as well facilitate corrosion in such environment.

INTRODUCTION

Corrosion has been the subject of scientific study for more than 150 years, Hoeppner, (2009). It is a naturally occurring phenomenon commonly defined as the deterioration of a material (usually a metal) or its properties because of a reaction with its environment. Like other natural hazards such as earthquakes or severe weather disturbances, corrosion can cause dangerous and expensive damage to everything from pipelines, bridges, and public buildings to vehicles, water and wastewater systems, and even home appliances. Unlike weather-related disasters, however, there are time-proven methods to prevent and control corrosion that can reduce or eliminate its impact on public safety, the economy, and the environment. (MIC) is an acronym for microbiologically influenced corrosion, a mode of corrosion incorporating microbes that react and cause the corrosion or influence other corrosion processes of metallic materials. Bacterial corrosion most frequently occurs on cargo oil tank bottom plating (Gentil, 1996; Bieberich & Hardies, 1998). It occurs also in water ballast tanks, primarily on up-facing, horizontal surfaces. Microbiological corrosion is caused by bacterial microbes in combination with four other environmental conditions: metals (host location), nutrients, water, and oxygen (although some types of bacteria need only very small amount of oxygen (Beech, 2004; EPA, 1992; DPR, 2002; Koch, et al; 1994; Summitt, et al; 2002).

These bacteria are ubiquitous in the environment and piping materials. When all of these environmental conditions are present, then microbial growth will occur.
When the nutrients in the system are consumed, the microbes may become dormant. When the environmental conditions, i.e., nutrients or oxygen, are replenished, the microbial growth resumes. Examples of this replenishment include: flow testing, draining and refilling of systems, addition of water to replenish losses from leaks or maintenance, or the periodic filling of dry fire sprinkler systems. Microbial reactions depending on the type will only occur at certain temperature ranges (Oblinger &Koburger, 1975; Beech, 2004; Boyd & Fink, 1978; Hoeppner & al.; 2009; Pourbaix, 1999). Temperature influences greatly the growth and survival of microorganism. There is a minimum temperature below which growth no longer occurs, an optimum temperature at which the growth is most rapid and a maximum temperature above which growth is not possible. Microorganism can be divided into groups in relation to their temperature optima. Psychrophiles (eg flavor bacterium spp. with optimum growth at 13°C). Mesophiles (eg Escherichia coli with optimum growth at 39°C). Thermophiles (e.g. bacillus spp with optimum growth at 60°C), and Hyperthermophiles (Thermococcus spp. and pyrodictum spp. with optimum growth at 88°C and 105°C respectively). There effects are more common in salt water environment (Okoko & Nna, 1998; Mittelman, 2003; Roberge, 2000).

**Evaluation**: is the comparison of actual impacts against strategic plans. It looks at original objectives, at what was accomplished and how it was accomplished. It can be formative that is taking place during the life of a project or organization, with the intention of improving the strategy or way of functioning of the project or organisation. It can also be summative, drawing lessons from a completed project or an organisation that is no longer functioning. Evaluation is inherently a theoretically informed approach (whether explicitly or not), and consequently a definition of evaluation would have to be tailored to the theory, approach, needs, purpose and methodology of the evaluation itself.

**Microbiology**: is the study of micro-organisms, microorganism are living organism too small to be clearly seen by the unaided eye (1mm). Micro-organisms facilitate many important chemical reactions in nature: making of cheese, yoghurt, and bread, production of alcohol, retting of flax (coconut husks), and breaking down organic matter e.g. Biochemical Oxygen Demand (BOD).

Micro-organisms exist everywhere in nature: soil, air, water, the table top, your stomach. Micro-organisms in water directly impact water quality: transmission of diseases (pathogens), bad tastes, or odours (e.g. hydrogen sulphide) and corrosion or bio fueling of surfaces. Etc (Potkhina, 1999).

**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. The first evaluation of the cost of corrosion (the Hoar-Report), which was conducted in the early 1970s, revealed that 3 to 4% of the Gross Domestic Product (GDP) of industrialized countries is lost annually to corrosion. All similar evaluations performed later by different organizations basically came to the same conclusion. The last cost of corrosion study was published by the U.S. Federal Highway Administration (FHWA) in 2011 with support from National Association of Corrosion Engineering (NACE) International. The findings clearly documented that in the United States, 3.14% of the Gross Domestic Product (GDP) equal to $276 billion is lost annually to corrosion. This sum includes only the direct costs for replacing damaged material and components. The indirect costs, such as loss of production, environmental impacts, transportation disruptions, injuries, and fatalities, were estimated to be equal to the direct costs. Corrosion costs worldwide are therefore on the order of $U.S. 552 billion.2 (Postgate, 1984; Sterlson, 1993; Videla, 1996)

**Microbiological corrosion**: Microbial corrosion, also called bacterial corrosion, bio-corrosion, microbiologically-influenced corrosion (MIC), is corrosion caused or promoted by microorganisms, usually chemautotroph’s. It can apply to both metals and non-metallic materials. A large number of different species of bacteria and other microorganisms normally co-exist in watery environments in some natural balance based principally on competition and cooperation. Under conditions which are especially suitable for one or a few species, this or these species will take precedence over others and start reproducing at a formidable rate.

**Carbon steel**: also called plain-carbon steel is steel where the main interstitial alloying constituent is carbon. The American Iron and Steel Institute (AISI) defines carbon steel as; “Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60. The term “carbon steel” may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy papers. As the carbon content rises, steel has the ability to become harder and stronger through heat treating, but this also makes it less ductile. Regardless of the heat treatment, higher carbon content reduces weld ability. In carbon steels, the higher carbon content lowers the melting point (Torres & Franca, 2002).

**Salt water**: in simple terms, salt water means water with salt in it. If you take a glass of water from your kitchen and add salt, you’ve got saltwater. Salts (both ordinary table salt and other salts) are chemicals that fall apart into electrically charged particles (called ions) in water. One big difference between salt water and plain water (fresh water) is that these ions make the salt water conduct electricity much better than pure water. The seawater in the ocean has a lot of other interesting things in it than just salt, though - in addition to...
fish, plants, and plankton (microscopic sea critters), there’s all sorts of minerals and other elements. One of the really neat things about saltwater is that things float in it more easily than in regular water. For example, there is an especially high concentration of salt in the Dead Sea, so it’s very easy to float there.

**Niger Delta Region**: Niger Delta, a 30 000 km² wetland of global ecological significance is located at the southern most part of Nigeria. The delta is dissected by a dense network of rivers and creeks basically salt water and fresh water, which maintain a delicate but dynamic equilibrium between saline, estuarine and freshwater surface bodies with complex underground extensions. The region which is rich in biodiversity and natural resources is ecologically fragile and is presently inhabited by about seven million people. This high resident population, concentrated in the two urban cities of Rivers State (Port Harcourt) and Warn is attributed to the rapid growth in the oil and gas industries (Sterlson, 1993).

The main aim of this research work is to evaluate the behavioural structure of microbiologically influenced corrosion on carbon steel in saltwater environment, signs of bacterial corrosion and to recommend possible ways of avoiding it. The lakes, rivers and creeks along the Kalabari communities of Rivers State are salt water; hence, this project work shall be carried out in this area of the Niger Delta Region. This project work shall cover the concept of microbiological corrosion structure, the formation, types, the effects and control of microbiological corrosion of carbon steel in saltwater environment.

Microbes or micro-organisms are living organisms so small in size that they can only be observed using a microscope. They include bacteria, microscopic algae, fungi and “animals” like amoeba. Microbes are found practically everywhere, in the oceans, lakes, rivers and any natural waters, and even in the air. The bacteria are frequently implicated in accelerated corrosion of carbon steel and non-ferrous metals. It requires that if any tubercles or slimes are observed, they shall be tested for indications of MIC, hence this project work shall evaluate these possible indications of the presence of bacterium in the salt water environment of the Niger Delta Region (Kalabari Area, Buguma Community). The project shall be limited to the different types of microbiological corrosion that affects carbon steel in saltwater environment in the Niger Delta Region (Rivers State Buguma communities).

**MATERIAL AND METHODS**

The deterioration of metal due to microbial activity is termed biocorrosion or microbiologically influenced corrosion (MIC). Owing to its economic and environmental importance, especially for the oil industry, MIC has been the subject of extensive studies for the past five decades and several models have been proposed to explain mechanisms governing biocorrosion. Researchers have verified that bacteria of the *Pseudomonas species*, usually found in water environments, are also related to cases of biocorrosion. The *Pseudomonas* species, in particular *Pseudomonas aeruginosa* and *Pseudomonas fluorescens*, are potential producers of exopolysaccharides that promote the adherence of the *Pseudomonas* and other microorganisms, resulting in the subsequent colonization of the metallic surface. Its accelerated growth under aerobic conditions leads to the consumption of oxygen, thus establishing in the base of the biofilm the anaerobic conditions that are necessary for the development of Sulphate Reducing Bacteria (SRB). Additionally, the presence of extracellular material in the biofilms formed on the metallic surface reduces the access of the biocides which complicates the elimination of the microorganisms adhered to the surface, thereby favoring the corrosion process. In the chapter, the weight loss principle will be used to study and evaluate microbiological corrosion of carbon steel in salt water environment.

**Apparatus**


**Material**

- Salt water, Carbon steel, Sodium Chloride (NaCl₂)
- Accelerator Bacteria (The *Pseudomonas* species, in particular *Pseudomonas aeruginosa* and *Pseudomonas fluorescens*).

**Procurement of material**

20 liters salt water was collected from Buguma River of Asari Toru Community of Rivers State using a properly washed plastic can. Carbon steel was gotten from steel mill for proper Accelerator (Sodium Chloride (NaCl₂)) and microorganisms (*Bacillus spp, pseudomonas spp, mixed consortium*), were sourced from specimen left in the Microbiology Laboratory at the faculty of science, Rivers State University of Science and Technology (RSUST), Nkpolu-Orowurukwo Port Harcourt.

**Preparation of corrosion coupon**

pieces of carbon steel pipe each having a length of 200mm, 100mm width and thickness of 3mm was selected as the coupons were treated using sand paper, to properly clean the surface and after the process all coupon samples were washed with distilled water, alcohol and dried for 2mm. Bacteria were cultured in a mineral salt medium at a temperature of 15°C to 45°C at the laboratory. Tests were carried out on the collected salt water and the following parameters were considered. Temperature, pH, Total solid, Biological oxygen demand (BOD), Bacteria Content

**Experimental procedures**

Steps, 10 liters of collected samples salt water was poured into 4 transparent plastic container and labeled A to D., 5mg of sodium chloride (NaCl₂) was added to the salt water samples to accelerate the corrosion process and increase conductivity, 5ml of culture bacteria were added into the water sample. The coupons (carbon steel) was weighed
samples. The sample was kept under a temperature slightly above room temperature for a period of 3 weeks after which the following parameters will be determined. pH of the solution, temperature, bacteria content, weight of the coupons, Another set of 4 coupons were placed in the river that the sample water was collected and labeled A to D. Coupons sample were also kept for three weeks. at the end of three week, coupon in sample container A was brought out and also the coupon in the River Labeled A was also brought and the weight loss was recorded and this process was continued for 6 weeks, 9 weeks and the coupon in sample D and coupon in the river labeled D was removed at 12 weeks.

Weight Loss Method: The samples were weighted before immersion in the water using ± 0.0001 g accuracy electric balance, and after (15;30) days of immersion, the samples removed from the water and weighted. The corrosion rates of the metal are calculated in mils per year according to the following formula: the corrosion rate is calculated assuming uniform corrosion over the entire surface of the sample (19)

\[ \text{Corrosion rate (mpy)} = \frac{W}{K \times A} \times \frac{1}{D} \times \frac{1}{t} \]

where: W = Weight loss (g), K = 3450000 (corrosion rate in mils per year), A = Expanded surface area, D = Density of metal sample (g cm\(^{-3}\)).

### RESULTS AND DISCUSSION

### Parameters Tested

**Temperature:** The rates of biological and chemical processes depend on temperature. Aquatic organisms from microbes to fish are dependent on certain temperature ranges for their optimal health. Optimal temperatures for fish depend on the species: some survive best in colder water, whereas others prefer warm water. Benthic macro-invertebrates are also sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside this optimal range for a prolonged period, of time, organisms are stressed and can die. Temperature is measured in Fahrenheit (F) or degree Celsius (°C). Microorganisms are classified into three categories based on the temperature range in which they survive, which is as follows: 15°C - 35°C Mesophilic, 35°C - 75°C Thermophilic and 75°C - 105°C Superthermophilic. This shows that microorganisms can survive at even higher temperatures.

Low pH values help in effective chlorination but cause problems with corrosion. Values below 4 generally do not support living organisms in the marine environment. Drinking water should have a pH between 6.5 and 8.5. Harbour basin water can vary between 6 and 9.

**Dissolved oxygen:** Oxygen is as essential to aquatic life as it is to life on land. The amount of oxygen in water is called the dissolved oxygen (DO) concentration and is dependent on the water temperature (the colder the water the more oxygen it can hold). Oxygen is added to water in two ways: it is taken directly from the air, a process that is enhanced in areas of turbulent water (i.e. waterfalls), and it is produced as the result of photosynthesis by aquatic plants and algae. Oxygen is removed from water by the respiration of aquatic organisms and the decomposition of wastes and dead plants and animals. The addition and removal of oxygen are generally balanced in normal, healthy streams, and the DO remains high. Organic material such as that found in wastewater, uses oxygen for decomposition. The amount of oxygen required to decompose waste is called Biochemical Oxygen (BOD). When the BOD of the waste exceeds that available oxygen, the DO in the stream is reduced or depleted and is unavailable for fish and invertebrates. Very low DO can cause fish death in the salt water medium as presented in this research work and other organisms in the system.

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Corrosion rate = wkIATD

Where: W = Weight loss (g), K= 3450000 (corrosion rate in mils per year), t=time of exposure (h), A = Expanded surface area (cm²), D= Density of metal sample (g cm⁻³).

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Corrosion rate = wk/A TD

Where: W = Weight loss (g), K= 3450000 (corrosion rate in mils per year), t=time of exposure (h), A = Expanded surface area (cm²) and D= Density of metal sample (g/ cm³).

The corrosion rate of carbon steel in control water obtained from the weight loss study is shown in table 2, the corrosion rates of carbon steel were 1.632mpy, 1.958mpy at 3 weeks and 6weeks respectively. Table 3 shows the corrosion rate of carbon steel in rivers water obtained from the weight loss study, the corrosion rates of carbon steel were 4.516, 4.720 at 3weeks and 6weeks respectively. Comparing the corrosion rates result in table 2 and table 3 it is noticed that the corrosion rate of carbon steel in rivers water is approximately (2.767) times more than that in control water for 3 weeks; furthermore the corrosion rate of carbon steel in the rivers water is approximately (2.41) times more than that in control water for 6weeks. The surface between the columnar structures of the biofilm may be in contact with oxygenated electrolyte. These areas with relatively high oxygen concentrations within the biofilm are cathodic relative to areas with less oxygen. Beneath a microbial colony, oxygen is depleted as it is used by the organisms in their metabolism.

**CONCLUSIONS**

The best way of preventing corrosion on carbon steel in salt water, including bacterial corrosion, is to apply a high quality coating, preferably during new building. Coating of pipelines and tank bottom plating and structures of existing ships is also carried out to stop pitting attacks. Epoxy based coatings, applied on a properly washed and blast cleaned surface may shown good results. The level of salt contamination on the surface should be kept as low as possible. Installation of sacrificial anodes on steel and generally in water ballast tanks is recommended in order to avoid pitting at locations of coating imperfections. Keeping tanks as clean as possible, avoiding accumulation of dirt, sludge, and foul watery deposits, will reduce the risk. Using biocides for killing bacteria in commercial shipping is not realistic, considering the handling aspects and environmental impact. According to result of present study, the following can be concluded: It is clear from this study that the corrosion rate of carbon steel in rivers water higher than in control water. Corrosion current of carbon steel in rivers water more than in control water. Pseudomonas aeruginosa bacteria isolated from the corrosion product. The activities of biofilm play important role in degree of corrosion.

**REFERENCES**


