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Comparative evaluations of the microstructure and corrosion rates of stainless steel pipe conveying saltwater and petrol

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Abstract

The study titled comparative evaluation of the microstructure and corrosion effects of stainless steel pipes conveying saltwater and petrol has been investigated. The study revealed that there were several challenges associated with an ideal stainless steel pipe when not properly protected from corrosion effect. The study also indicated that stainless steel pipes when exposed to some factors, there are bound to corrode and pose reasonable health hazards to human beings. Experimental technique was used as method to observe the effects of concentration, temperature, salinity and pH on pipes used in conveying some selected liquids under controlled environment. The aim of the experiment was to discover the factors responsible for the formation of hydrated oxides which causes corrosion on metals. At the end of the experiment, it was discovered that high salt concentration, chlorine and pH, temperature and other environmental factors were mainly responsible for the formation of these oxides that brings about corrosion. Finally, the results generated showed significantly that corrosion rates were higher under some conditions which were as results of non-availability of corrosion inhibitors.

Keywords: Saltwater, Atmosphere, pH, Temperature, Stainless Steel pipe and Corrosion

1. Introduction

The word corrosion is derived from the Latin word "*corrosus*" which means eaten away or consumed by degrees; an unpleasant word for an unpleasant process [1]. Corrosion is defined as the destruction of materials caused by chemical or electrochemical action of the surrounding environment. This phenomenon is experienced in day to day living. The most common examples of corrosion include rusting, discoloration and tarnishing [2]. Corrosion is an ever occurring material disease. It can only be reduced; it cannot be prevented because thermodynamically it is a spontaneous phenomenon. Again, Nwoye in [3] posited that most instances of corrosion in the absence of oxygen have been attributed to the sulphate reducing bacteria (SRB), of genera; disulfovibrio and *desulfotomaculum*. While [4] seconded that typical example of such an environment are natural water-logged soils and waters heavily polluted with organic matter. However, these microbes are obligate anaerobes, i.e, they will not grow in the presence of even traces of oxygen, but usually grow well at pH between 5 and 9 and temperatures between 25 and 44 ºC, although some strains (*Desulfotomaculum nigrificans)* are able to with stand higher temperatures [5].

Stainless steel is one of the most important materials in the engineering world. The material's wide applications in chemical, petrochemical, off-shore, and power generation plants prove that it is one of the most reliable materials. In particular, duplex (austenitic–ferritic) stainless steels are very popular in the oil and gas industries built after the 1970s. This expansion is associated with their excellent combination of properties, such as higher strength than austenitic stainless steel, better stress corrosion resistance, and similar price to conventional stainless steels [1]. With the aging of those structures, quantification of all factors that can contribute to the failure became more important. Two of those factors are the chloride effect and the effect of pH values. These two factors are essential components of a failure analysis tool since a lot of the failures related to environments are linked to corrosion. Understanding the effect of the pH and the chloride concentration is a key factor in life assessment as well as in the failure analysis of structures utilizing duplex stainless steel.

According to Nwoye, in [6], in aggressive environments, the stability of metals or alloys as cited in [4], basically depend on the protective properties of organic or inorganic films as well as on the layer of corrosion products. The study further argued that the ability of films to act as controlling barriers against different kinds of corrosion attack is dependent on film properties such as chemical composition, adhesion, conductivity, solubility, morphology and hygroscopicity. [7 and 8] as cited in [6] all testified that the highlighted characteristic of films in turn depends on environmental variables such as atmospheric conditions like temperature, salt content of the place, type and amount of pollutants as well as wet-dry cycle, the chemical composition and metallurgical history of the metals or alloys and physicochemical properties of coating.

As in other metals, corrosion in duplex stainless steel breaks down essential properties due to chemical reactions with its surroundings. Certain environments offer opportunities for these metals to combine chemically with elements to form compounds and return to their lower energy levels. Ultimately, it corrodes on contact with water (and moisture in the air), acids, bases, salts, oils, aggressive metal polishes, and other solid and liquid chemicals. It can also corrode when exposed to gaseous materials like acid vapors, formaldehyde gas, ammonia gas, and sulfur containing gases.

In fact, economy of any country would be drastically changed if there were no corrosion. For example, automobiles, ships, underground pipelines and house-hold appliances would not require coatings. The stainless steel industry would disappear and copper would be used for electrical applications. Although corrosion is inevitable, its cost could be reduced. Corrosion can be fast or slow. Sensitized 18-8stainless steel is badly attacked in hours by polythionic acid. Railroad tracks usually show slight rusting not sufficient to affect their performance over many years. The famous iron Delhi Pillar in India was made almost 2000 years ago and is almost as good as new. Its height is 32 feet and diameter 2 feet. It should be noted however, that it has been exposed mostly to arid conditions [9].

Stainless steel is widely used for potable water storage purposes beside other metals. The extent and cost of damage caused by leakage in storage containers has been rising during recent years. The use of stainless steel in potable water storages, heat exchangers and steam turbines is now common. Within heat exchangers and steam turbines themselves stainless steel is now generally used for vanes, blades and shafts .The corrosion resistance of stainless steel is however better than many alloys. Various studies have been carried out for determination of corrosive behavior of stainless steel in acid and basic mediums, but it is corrosion resistance in salt aqueous solutions at high concentration of salts is a little bit limited [10]. Dissolved salts and oxygen [11] mainly determine corrosive behavior of metals in aqueous solutions. In order to minimize corrosion problem in heat exchangers and steam turbine parts, it is important to identify the mechanism of corrosion rate of ions with stainless steel, the extent to which they contribute to corrosion in potable water as well as threshold limiting values to which the corrosion rate should be minimize in order to provide excellent corrosion resistance [12].

Exposure to seawater introduces a number of factors not present largely in atmospheric exposure. Selection of a stainless steel grade for sea water immersion is for more complex than selection for atmosphere service. However in stagnant sea water (particularly badly contaminated harbor waters), stainless steel are likely top it severely from befouling. Application of stainless steel in seawater includes structures, heat exchangers, piping and special items such as propellers [13].

Many stainless steel particularly the austenitic types like 316L- are used extensively for room and elevated temperature applications such as chemical processing equipment, heat exchangers and superheated tubes for power boilers. Reaction of metals with dry air or oxygen is considered as a chemical corrosion. High temperature oxidation of metals and tarnishing of metals like copper, silver etc. fall in this category. Of late this is also considered to be an electrochemical process with the diffusion of oxygen (inwards) and metal ions (outwards) through the oxide layer, the electromotive force at metal-oxide interface being the driving force. Electrochemical corrosion occurs in the presence of electrolyte. The reaction is considered to take place at the metal-solution interface with the creation of local cathodic and anodic sides on the metal surface [15].

1.1 Statement of the Problem

In the world today, lots of money are been spent on the yearly bases due to corrosion. Ijeoma, in [16] posited that corrosion constitutes a real burden to oil and gas industries and their financial loses which are incurred annually are enormous. The development in the powder coating industry mainly has focused on cost and health, environment and safety issues. Comparatively less researches regarding to product development and technical evaluations of this green technology are available compared to other liquid-based coating system. Corrosion poses a major challenge to the enactment of conveyance of fossil fuels as the primary target to the oil and gas industries. This results in downtime, lost production and poses health and safety risk to personnel. Proper characterization of corrosion of stainless steel, a likely construction material for water, petroleum and gas plants, will improve the overall feasibility of adopting a novel technology on an industrial scale aimed at reducing corrosion minimal. This study will seek to examine the corrosion behavior of stainless steel 316L in conveying different liquid media such as saltwater, atmospheric exposure and petrol under a controlled temperature system.

1.2 Corrosion in the Oil and Gas Industry

The most common form of corrosion in the oil and gas industry occurs when steel comes in contact with an aqueous environment and rusts [19]. When metal is exposed to a corrosive solution (the electrolyte) the metal atoms at the anode site loses electrons and these electrons are then absorbed by other metal atoms at the cathode site. The cathode in contact with the anode via the electrolyte, conducts this exchange in an attempt to balance their positive and negative charges. Positively charged ions are released into the electrolyte capable of bonding with other groups of atoms that are negatively charged. This anodic reaction for iron and steel is

$$Fe \rightarrow Fe^{2+} + 2e^- \qquad (1)$$

After the metal atoms at the anode site release electrons, there are four common cathode reactions [15]:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \text{ (oxygen reduction in acidic solution)} \qquad (2)$$

$$\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^- \text{ (oxygen reduction in neutral or basic solution)} \qquad (3)$$

$$2H^+ + 2e^- \rightarrow H_2 \text{ (hydrogen evolution from acidic solution)} \qquad (4)$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \text{ (hydrogen evolution from neutral water)} \qquad (5)$$

In the oil and gas industry, carbon dioxide (CO_2) and hydrogen sulfide (H_2S) are commonly present, and water is their catalyst for corrosion. When water combines with CO_2 and H_2S, the environments form the following reactions [20]:

$$H_2CO_3 \text{ Reaction: } Fe + H_2CO_3 \rightarrow FeCO_3 + H_2 \qquad (6)$$

$$H_2S \text{ Reaction: } Fe + H_2S + H_2O \rightarrow FeS + 2H \qquad (7)$$

There may be a combination of the above two reactions if both gases are present. These resulting molecules either attach themselves to the cathode or are released into the electrolyte and the corrosion process continues. It is a great challenge to classify the types of corrosion in the oil and gas industry in a uniform way. One can divide the corrosion on the basis of appearance of corrosion damage, mechanism of attack, industry section, and preventive methods. There are many types and causes of corrosion. The mechanism present in a given piping system varies according to the fluid composition, service location, geometry, temperature, etc. In all cases of corrosion, the electrolyte must be present for the reaction to occur. In the oil and gas production industries, the major forms of corrosion include [17 and 18] sweet corrosion, sour corrosion, oxygen corrosion, galvanic corrosion, crevice corrosion, erosion corrosion, microbiologically induced corrosion, and stress corrosion cracking.

2. Materials and Method

2.1 Material Selection

By definition, stainless steels are high-alloyed steels with a composition of more than 10.5 wt % chromium (Cr) and less than 1.2 wt % carbons (C). Austenitic stainless steels are non-magnetic, work-hardenable grades that show excellent strength and toughness properties. Depending on their alloying degree – typically 17 - 24 wt % Cr and 6 - 25 wt % Ni – they have a good to excellent general corrosion and pitting-corrosion resistance. Austenitic grades are the most widely used stainless steels and their applications range from electronics and electrical to the process industries. In the transport industry, they are commonly used for tank containers and bus or coach body structures. Austenitic-ferritic (i.e. duplex) stainless steels combine the best properties of ferritic and austenitic grades. Their high chromium and molybdenum content results in excellent general-corrosion and pitting-corrosion resistance and the duplex microstructure – 50/50 ferrite and austenite – yields exceptionally good stress-corrosion resistance and high mechanical strength. Duplex stainless steels are particularly suitable for dynamically loaded high-strength applications such as pump and valve shafts and for process industry equipment such as boiling tanks and wood-pulp silos. Lately, there has been some experimental use of so-called lean duplex stainless steel grades for trucks, where the high mechanical properties of the material have made it possible to minimize tare and increase payload.

The austenitic stainless steel 316L (1.4401) is however “tough” at cryogenic temperatures and can be categorized as “cryogenic steel”. This can be considered suitable for sub-zero ambient temperatures sometimes mentioned in service specifications sub-arctic and arctic applications and locations, typically down to -40 °C. This is the result of the 'fcc' (face centered cube) atomic structure of the austenite, which is the result of the nickel addition to these steels. The austenitic steels do not exhibit an impact ductile to brittle transition, but a progressive reduction in impact values as the temperature is lowered. Unlike austenitic steel, Ferritic, martensitic and duplex stainless steels tend to become brittle as the temperature is reduced, in a similar way to other ferritic / martensitic steels. The austenitics stainless steels such as 304 (1.4301) and 316 (1.4401) are however 'tough' at cryogenic temperatures and can be classed a 'cryogenic steels'.

Though the selected alloy was supposed to be tested for both Impact toughness and strength, this approach was considered less relevant due to the previously stated scope of this study. To access the suitability for cryogenic experiment, the selected sample austenites commonly referred to as stainless steel was analyzed chemically. The results of the chemical analysis carried out on them are as shown on the table below.

Table 1: Chemical composition of stainless steel pipe (316L)

Element	Fe	C	Mn	Si	Ni	Cr	V	Cu	Mo	Ti	Co	P	S
%Comp.	balanced	0.03	1.07	0.37	10.8	16.7	0.1	0.16	2.13	0.018	0.033	0.018	0.02

Source: Project Development Agency (PRODA), Enugu.

2.2 Material sourcing

The stainless steel (316L) was sourced locally from Building Materials Market, Bridge Head, Onitsha Main market, Onitsha, Nigeria and analyzed using Atomic Absorption Spectrometer (AAS). It was cut and machined to standard test sample sizes according to American Society for Testing and Materials (ASTM) standard. The stainless steel pipe was machined into 5.0g, 5.5g, 6.0g, 6.5g and 7.0g specifications respectively using lathe machine for the purpose of the experiment. The specimens were prepared by polishing with a 600 grit SiC abrasive paper, then rinsed with distilled water and dried in a stream of air. The corrosive media are 1.0 M NaCl solution, prepared by dissolving 60.0g of NaCl salt (table salt) in 1dm^3 of distilled water, and gradually mixing with any of the experimental solvents for the purpose of the experiment. The pH of solutions was adjusted to different range of values from pH 7.0 to pH 9.0 without any inhibition and all maintained constantly at a cryogenic temperature of 30 ^{o}C (Room Temperature).

2.3 Experimentation

The weight of each sample was measured using Sartorius electronic balance with an accuracy of ± 0.1mg. Prior to weighing, all samples were held overnight in glass desiccator in order to eliminate any effect of humidity on the sample weight determination. Because actual service conditions are difficult or impossible to reproduce in standard laboratory tests, results of such tests usually can serve only as a guide.

Chemical composition of the salt, temperature and the pH values should parallel those in the process; therefore, field tests in existing equipment in a comparable process should be used wherever possible, in order to duplicate anticipated conditions. Each cut sample was suspended by plastic hook in a beaker filled with test solution, for different duration of immersion for 15days each at constant temperature and concentration respectively. The specimens are weighted again after the specified period of exposure to the corrosive medium. The weighting is carried out after the specimens are cleaned with alcohol, and drying them carefully with drying paper. The repeat of the whole experimental process was necessary since concentration was kept constant and was also varied in the second stage for proper investigation.

This process was repeated several times to get several readings. Thus, diagram can be made to show weight loss with time and with corrosive mediums. The related laws are applied to find corrosion rate. Microstructure examinations are made often every specimen before and after the given tests. Result of weight loss measurement for corrosive mediums have been carried out for NaCl salts mixing them with water and petrol using (5g /liter) for each salt, in order to determine the average contribution of each salt to the corrosion rate.

Distilled water was used in the preparation of all test solution. The temperature was constantly maintained at 30 ºC while the concentration of salt and pH all varied respectively. All chemical used were of analytical grade; pH and Salt concentrations test solutions were measured. The pH values were measured by pH meter while salt concentration was calculated based on assumptions. The experiment was conducted for a period of 15days under close inspections while records of the corresponding readings were periodically taken for data analysis. In each of the containers, the samples were labeled between samples 1 to sample 10. Each of the samples containing the mediums was systematically lowered with a sample specimen of the stainless steel and were suspended with a twine.

2.4 Corrosion Rate Calculation

The rate of corrosion is expressed in several different forms. The simplest in dimensionless units is the percentage change in weight of a coupon in an exposed time interval. This figure is usually extrapolated to give the percentage change per annum. Generally the rate of corrosion is more useful if the figure reflects the impact on a system’s life span.

This corrosion rate calculation is rooted on the Faraday’s Law:
Weight of metal dissolving (g) – KxIxt

$$K = \frac{\text{Atomic weight of metal (g/mol)}}{\text{No. of electrons transferred X 96,500 Amp/Sec}}$$

Where: I = current (amps) t = time (sec)

By dividing both sides of the equation by the metal surface area, this gives the corrosion rate as equal to a constant multiplied by the current density (amp) / area (cm^2). In other words, the rate of weight loss from a given area is directly proportional to the current density.

The rate of weight loss from a given area, while valuable, does not give a direct correlation with the rate of penetration of the corrosion. When this figure is translated to the radial depth of pipe wall lost per annum, this information becomes very useful to the corrosion engineer or operator in determining the life expectancy of the system. Corrective action can then be taken and re-measured to give an acceptable time to failure/replacement.

The corrosion rate calculated using corrosion coupons on steels assumes uniform corrosion across the coupon (e.g. uniform corrosion of the pipe wall at the monitoring point). This approximation is acceptable for most circumstances to determine the average rate of corrosion. Of course, where a stainless coupon shows evidence of pitting, the pit depth rate is more useful because the area will be calculated and used as an index of corrosion.

Mathematically, the most used expression for Corrosion rate in the US is the mpy (Mils per year) which is usually expresssed as:

$$\textbf{Mpy (mils per year)} \left\{ \frac{\textbf{Weight loss of steel coupon (g)}}{\textbf{Total exposed area of steel coupon (cm}^3\textbf{)}} \right\} \textbf{X} \left\{ \frac{\mathbf{2.23x10^4}}{\textbf{Exposure time x Density of metals (g/cm}^3\textbf{)}} \right\}$$

To calculate the corrosion rate between the mpy and the equivalent in metric unit mm/y (millimeter per year):

we use the following formular
1 mpy = 0.0254 mm/y = 25.4 microm/y
To calculate the corrosion rate from metal loss:
mm /y = 87.6 x (W / DAT)

where:
87.6 is a constant represented with K.
W = weight loss in milligrams
D = metal density in g /cm^3
A = area of sample in cm^2
T = time of exposure of the metal sample in hours.

$$\text{Corrosion rate (COR) in mm/y} = \frac{\text{87.6x Weight loss in milligrams}}{\text{Density (g/cm}^3\text{) x Area (cm}^2\text{) x Time of exposure (hrs)}}$$

3. Results

Table 1-2: showing results of stainless steel in Nacl solution for 15 days

Water + Nacl kept for 15 days at constant Concentration and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.91	0.090	4.5x10^{-5}
1x 10^{-1}Nacl	7.5	30	5.5	5.389	0.111	5.8x10^{-5}
1x 10^{-1}Nacl	8.0	30	6.0	5.952	0.048	2.5x10^{-5}
1x 10^{-1}Nacl	8.5	30	6.5	6.449	0.051	2.7x10^{-5}
1x 10^{-1}Nacl	9.0	30	7.0	6.934	0.066	3.4x10^{-5}
Water + Nacl kept for 15 days at constant pH and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.89	0.11	5.7 x10^{-5}
1x 10^{-2}Nacl	7.0	30	5.5	5.289	0.211	1.1 x10^{-4}
1x 10^{-3}Nacl	7.0	30	6.0	5.852	0.148	7.7x10^{-5}
1x 10^{-4}Nacl	7.0	30	6.5	6.349	0.151	7.9x10^{-5}
1x 10^{-5}Nacl	7.0	30	7.0	6.834	0.166	8.7x10^{-5}

Table 3-4: Showing results of stainless steel sprinkled with salt when exposed to atmosphere

Atmosphere + Nacl kept for 15 days at Constant Concentration and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.940	0.060	3.1x10^{-5}
1x 10^{-1}Nacl	7.5	30	5.5	5.426	0.074	3.9x10^{-5}
1x 10^{-1}Nacl	8.0	30	6.0	5.968	0.032	1.7x10^{-4}
1x 10^{-1}Nacl	8.5	30	6.5	6.466	0.034	1.8x10^{-6}
1x 10^{-1}Nacl	9.0	30	7.0	6.960	0.040	2.1x10^{-6}
Atmosphere + Nacl kept for 15 days at Constant pH and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.930	0.070	3.7x10^{-5}
1x 10^{-2}Nacl	7.0	30	5.5	5.416	0.084	4.4x10^{-5}
1x 10^{-3}Nacl	7.0	30	6.0	5.958	0.042	2.2x10^{-5}
1x 10^{-4}Nacl	7.0	30	6.5	6.456	0.050	2.6x10^{-5}
1x 10^{-5}Nacl	7.0	30	7.0	6.950	0.05	2.6x10^{-5}

Table 5-6: showing results of stainless steel in salt solution mixed with Petrol

Petrol + Nacl solution kept for 15 days at Constant Concentration and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.955	0.045	2.3 x10^{-5}
1x 10^{-1}Nacl	7.5	30	5.5	5.444	0.056	2.9 x10^{-5}
1x 10^{-1}Nacl	8.0	30	6.0	5.760	0.240	1.3 x10^{-4}
1x 10^{-1}Nacl	8.5	30	6.5	6.474	0.026	1.4 x10^{-5}
1x 10^{-1}Nacl	9.0	30	7.0	6.980	0.020	1.0 x10^{-5}
Petrol + Nacl solution kept for 15 days at Constant pH and Temperature						
Conc. (Mdm^{-3})	**pH**	**Temp. (^{o}C)**	**Initial weight (g)**	**Final weight (g)**	**Weight loss (g)**	**Corrosion Rate (mm/y)**
1x 10^{-1}Nacl	7.0	30	5.0	4.945	0.055	2.9 x10^{-5}
1x 10^{-2}Nacl	7.0	30	5.5	5.406	0.094	4.9 x10^{-5}
1x 10^{-3}Nacl	7.0	30	6.0	5.948	0.052	2.7 x10^{-5}
1x 10^{-4}Nacl	7.0	30	6.5	6.446	0.054	2.8 x10^{-5}
1x 10^{-5}Nacl	7.0	30	7.0	6.940	0.060	3.1 x10^{-5}

3.1 Discussion of Result

3.1.1 Effects of Ph

The relationship between pH and corrosion rate of stainless steel, is shown in tables 1-6; at a pH of 7.0 to 9.0 the rate of corrosion increased gradually with a decrease in concentration. According to [21], he posited that the most important single variable affecting corrosivity is pH. In the pH range 7 to 8, changes in pH have a relatively minor effect on corrosivity to steel. Above pH 8.5 to 9.0, corrosivity decreases as pH increases.

A change in pH could be caused by various environmental factors such as water pollutions, acid rain, and industrial discharge. According to [21], many of the common constructional metals have increased corrosion in low pH solutions due to the higher availability of oxidizing H^+ and solubility of oxides while other show increased corrosion at very alkaline pH values. The surface plots of the corresponding effects of pH changes respect to changes in weight loss is shown in figures 1, 3 and 5 respectively.

3.1.2 Salinity

Sodium Chloride, NaCl is a type of salt which do not appreciably alter the pH when dissolved in water. NaCl is present in plentiful amount in seawater, brackish waters and many chemical processes involving atmosphere. The schematic effect of NaCl concentration on corrosion rate of stainless steel in aerated room-temperature solutions is shown in figure 2. The initial increase in corrosion rate is due to enhanced solution conductivity. However, further increase in dissolved salt concentration (beyond 3% of NaCl) decreases the solubility of dissolved oxygen and -hence, reduces the corrosion rate [21].

A NaCl solution of about *3.5%* is sometimes used to simulate seawater in the laboratory. However, [22] claimed that such solutions are often more aggressive than natural seawater especially towards stainless steel under controlled condition. Another difference is that in real coastal and seawaters, factors such as elevated temperature, dissolved oxygen content, currents, biological organisms and pollutants can increase corrosion rates. Synthetic seawater made up from laboratory chemicals is available as standard, but corrosively is not likely to match any particular seawater site quantitatively.

Typical steel structures exposed to saline environments gotten from review of other works are such as marine piles, offshore structures, vessels, and they all indicated that presence of chlorine in an environment contributes to corrosion effect of stainless steels. The surface plots of the corresponding effects of salt concentration effects respect to changes in weight loss is shown in figures 2, 4 and 6 respectively.

3.1.3 Atmospheric Effects

Atmospheric air is a mixture of dry air and water vapor. In industrial and sea shore places, gases such as SO_2, Cl_2 and H_2S and particulates of NaCl and other salts are present. The air humidity is characterized by the indices RH, absolute humidity, moisture content and specific air humidity [4].

The primary value of the critical relative humidity denotes that humidity below which no corrosion of the metal in question takes place. However, it is important to know whether this refers to a clean metal surface or one covered with corrosion products. In the latter case a secondary critical humidity is usually found at which the rate of corrosion increases markedly [23]. This is attributed to the hygroscopic nature of the corrosion product. In the case of stainless steel it appears that there may even be a tertiary critical humidity [10]. Thus at about 60% relative humidity rusting commences at a very slow rate (primary value) [12] at 75-80% relative humidity there is a sharp increase in corrosion rate probably attributable to capillary condensation of moisture within the rust [23,10]. At 90% relative humidity there is a further increase in rusting rate [11], corresponding to the vapour pressure of saturated ferrous sulphate solution [14], and ferrous sulphate being identifiable in rust as crystalline agglomerates [15]. The primary critical relative humidity for uncorroded metal surfaces seems to be virtually the same for all metals, but the secondary values vary quite widely.

It has been found, that at high relative humidities, aluminum and iron show no $SO_2 + NO_2$ synergism [16], and that for steel in negligible [10 and 18]. It was reported that a thick layer of water on the metal surface seems to act as a sink for SO_2, but as a barrier for NO_2 [18]. For metals with a protecting oxide film, NO_2 may even act as an inhibitor; otherwise, there seems to be synergistic effects [16]. It has been reviewed by several authors that the $SO_2 + NO_2$ synergism on copper corrosion is only active at high relative humidity (90%) [19] While steel corrosion experienced at low relative humidity is discussed in [24, 22 and 21; 25-26]. Kucera, in [27] reported that the synergistic effect of $SO_2 + O_3$ can be both stronger than $SO_2 + NO_2$, as for copper, and weaker, as for nickel but not pronounced in stainless steels. In other works no synergistic effects of simultaneous interaction of SO_2 and NO_2 with either nickel or copper have been observed [12]. This dry deposition is in most cases dominating and SO_2 exerts the strongest corrosive effect [16]. The role of NO_2 has not yet been clarified and its strong synergistic effect with SO_2, shown for many materials in different laboratory studies, has not been observed in the field exposure and may be due to the strong correlation between SO_2, NO_2 and O_3 concentrations [28].

3.2 Visual Inspection and the Corrosion Rates

Figures 1-6 represents the graphical illustrations of the various readings of the experimental results. The graphs indicated that the higher the concentration, the more the rods got corroded; however, figures 7-8 shows the visual inspections of the microstructural analysis of the stainless steels before and after immersions in saltwater and petrol respectively. Figure 9 shows the control sample of the same specimen before the treatment analysis. In general, immersion in water produces general thinning and pitting while the combination of the sodium chloride and the solvents produces a fibrous-like, feathery appearance corrosion attacks. Graphical representation of the effect of the pH is shown in Figures at the appendix. As the pH is decreasing (acidity increase), the corrosion rate is increasing. This is because low pH solutions accelerate corrosion by providing hydrogen ions. Hydrogen attacks and damages the surface of steel and increases the weight loss.

The temperature plays an important role in accelerating the corrosion rate of metals. The higher the temperature, the higher the corrosion rate but due to the fact that temperature was made constant, the effect was not apparent for physical notifications. The chloride concentration also increases the corrosion rate. The addition of chloride ions has a noticeable effect on the corrosion behavior of stainless steel in acidic solutions, since in the presence of this ion, a passivity breakdown process takes place above a certain potential that decreases with the chloride concentration. Chloride ions slowly penetrate into the surface, at which the protective film is destroyed and the steel begins to corrode. Chloride corrosion tends to evenly pit the entire surface area of the specimens with shallow, flat-bottomed, irregular shaped pits. Chloride penetration in metal is due to the presence of different mechanisms, mainly diffusion and capillary absorption. Temperature also influences the corrosion rate; this is due to temperature dependent on the chemical reactivity.

Appendixes A: Graphical illustrations

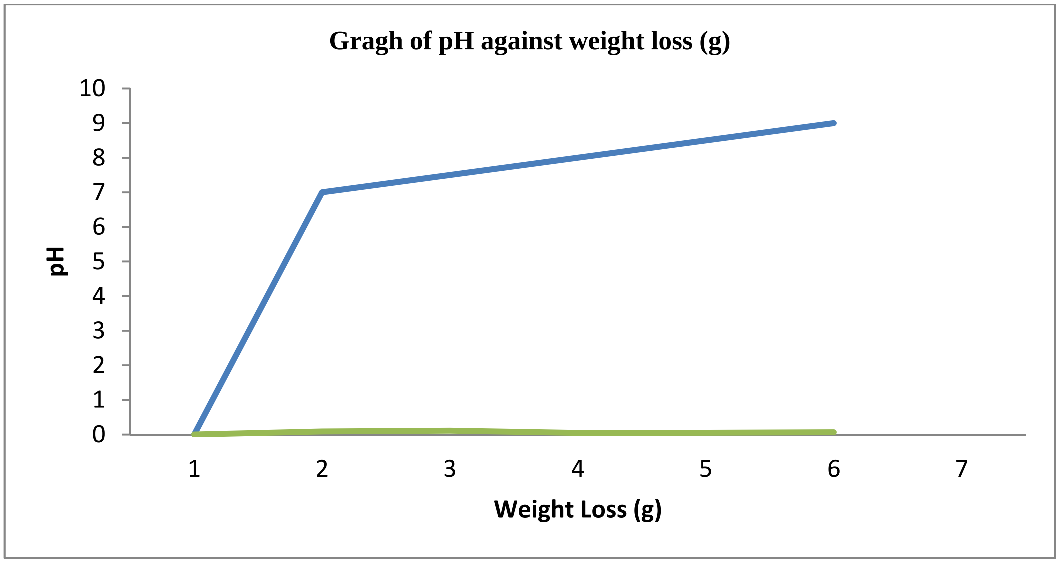

Fig1: the graph of pH against weight Loss of Stainless Steel pipe conveying saltwater under constant temperature and concentration for 15 days.

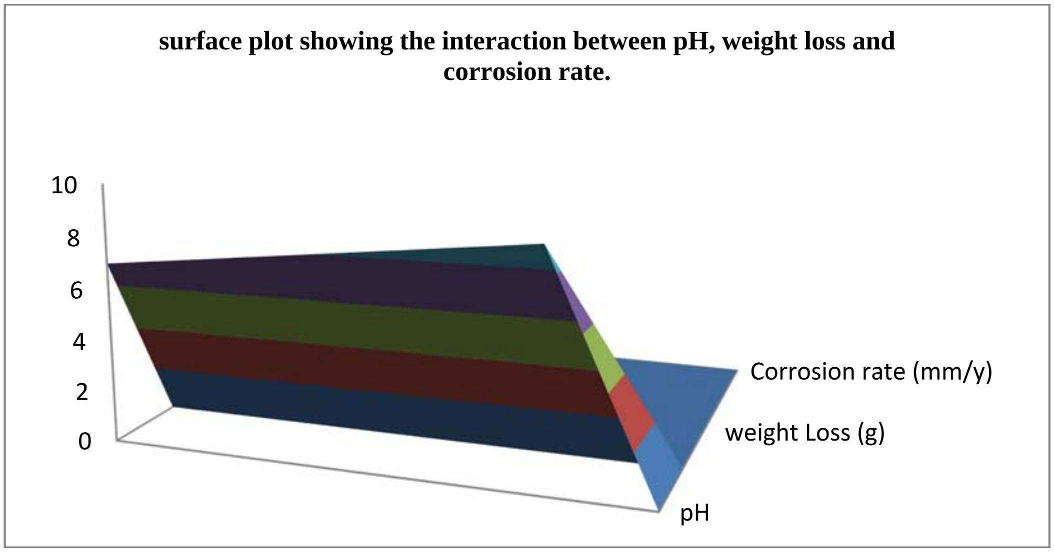

Fig 2: Surface plot of pH, Weight Loss and Corrion Rate of Stainless Steel pipe conveying saltwater under constant temperature and concentration for 15 days.

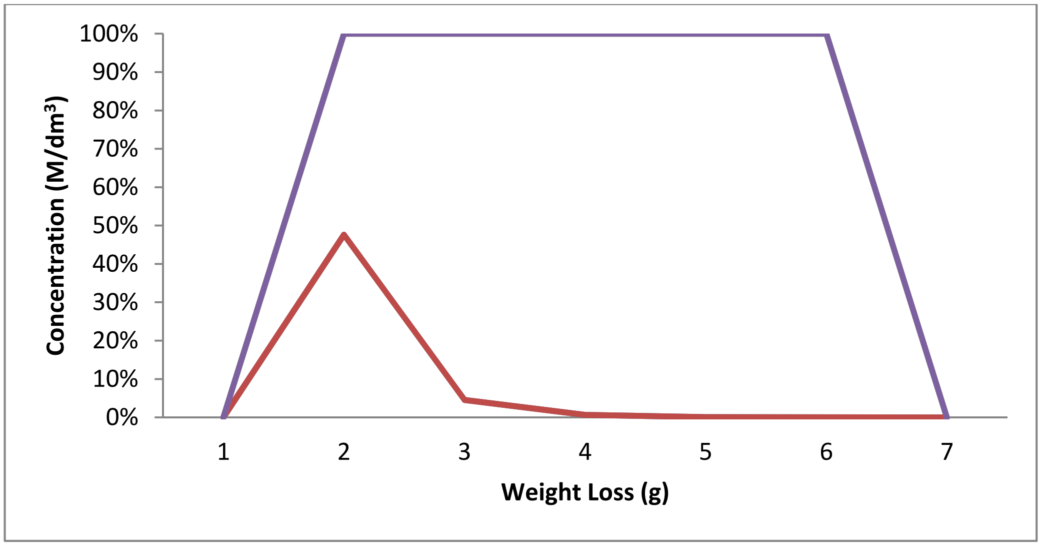

Fig 3a: The graph of Concentration against weight Loss of Stainless Steel pipe conveying saltwater under constant temperature and pH for 15 days.

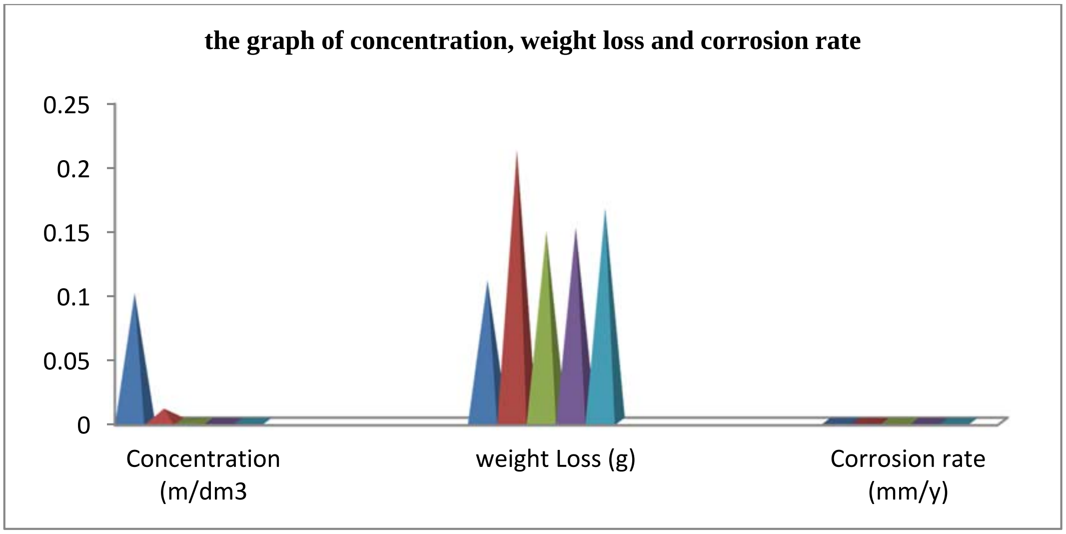

Fig 3b: the graph of Concentration, weight Loss and corrosion rate of Stainless Steel pipe conveying saltwater under constant temperature and pH for 15 days.

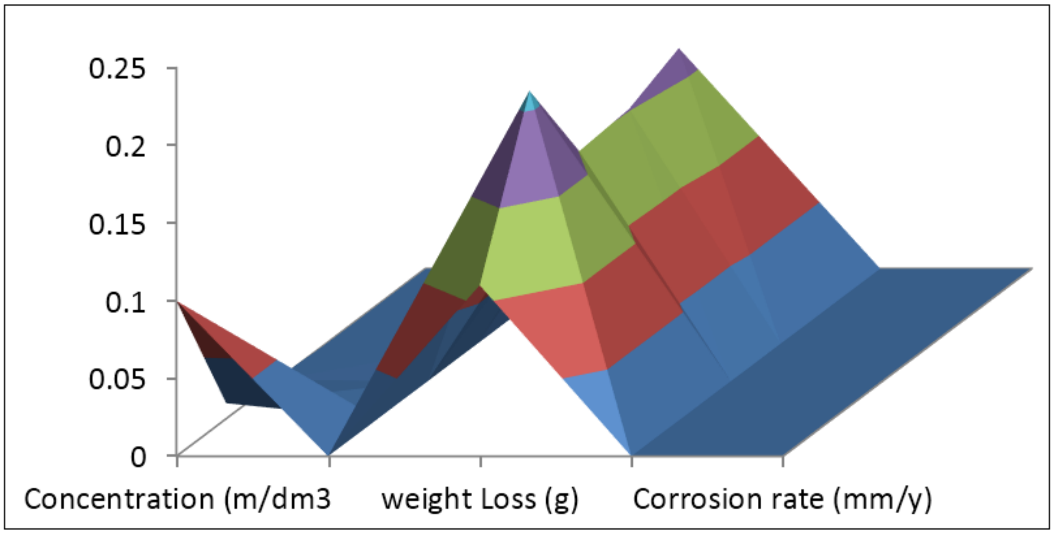

Fig 4: Surface plot of concentration, Weight Loss and Corrion Rate of Stainless Steel pipe conveying saltwater under constant temperature and pH for 15 days.

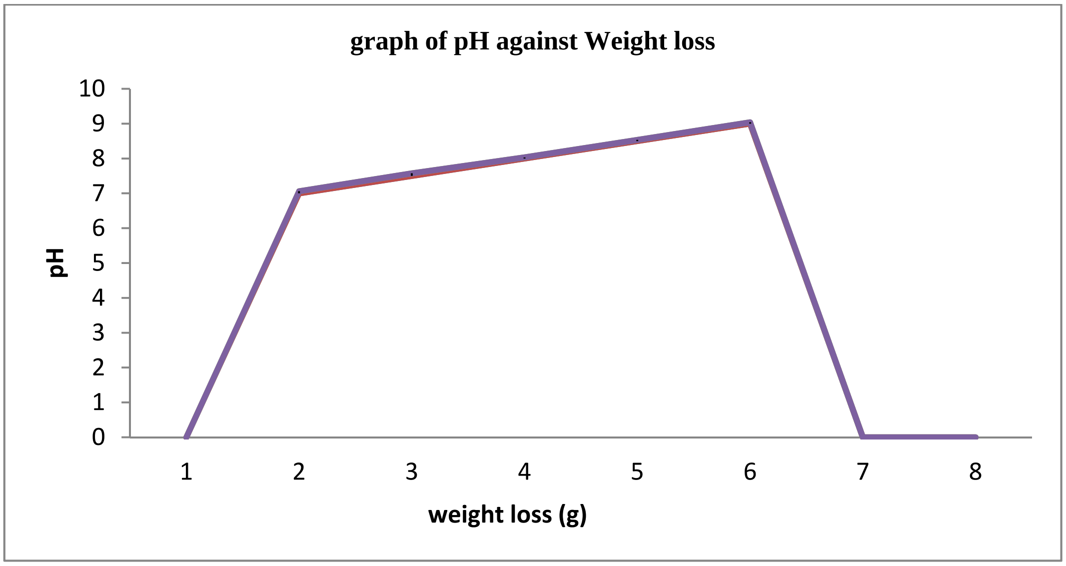

Fig 5: the graph of pH against weight Loss of Stainless Steel pipe exposed to atmosphere under constant temperature and concentration for 15 days.

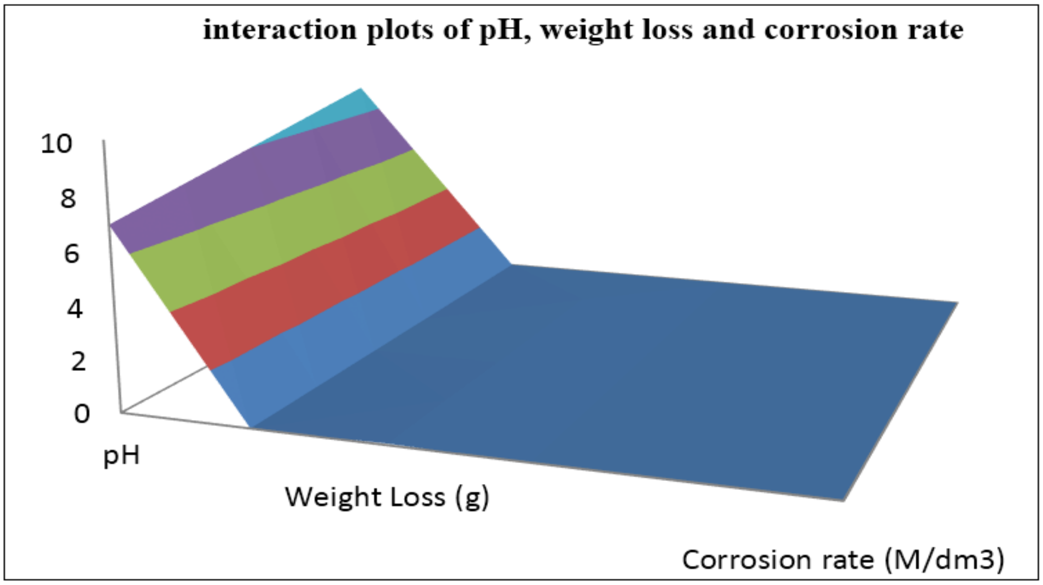

Fig 6: Surface plot of pH, Weight Loss and Corrion Rate of Stainless Steel pipe exposed to atmosphere under constant temperature and pH for 15 days.

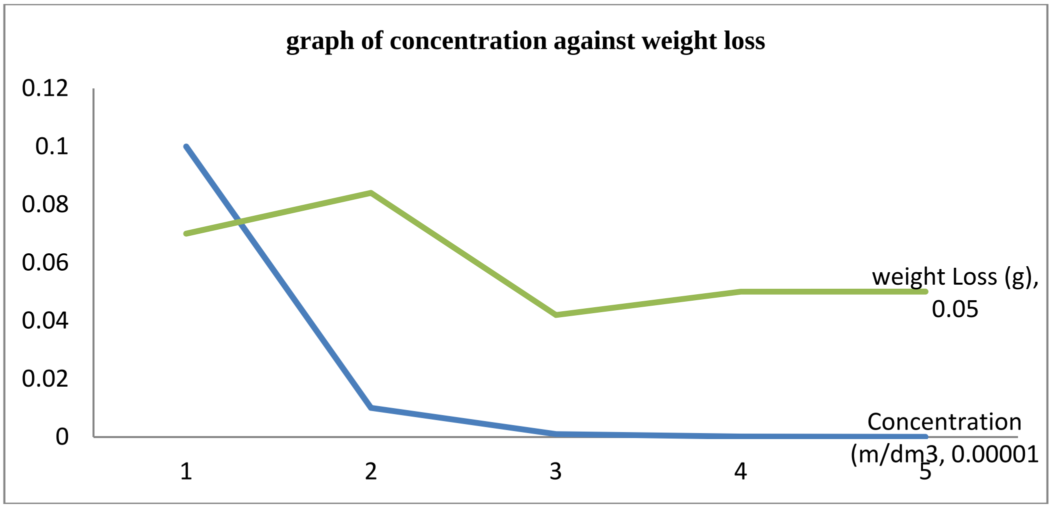

Fig 5: the graph of concentration against weight Loss of Stainless Steel pipe conveying petrol under constant temperature and pH for 15 days.

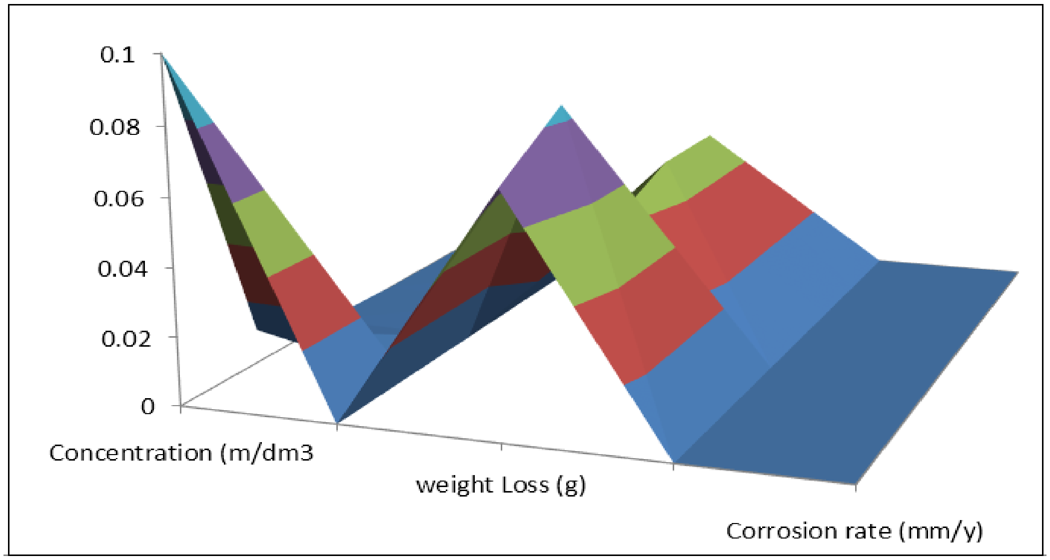

Fig 6: Surface plot of concentration, Weight Loss and Corrion Rate of Stainless Steel pipe conveying petrol under constant temperature and pH for 15 days.

Appendix B: Microstructural Inspections of stainless steel pipe under various conditions

Fig 7: microstructure of steel pipe conveying saltwater under constant concentration and temperature.

Fig 8: microstructure of steel pipe conveying petrol under constant concentration and temperature.

Fig 9: microstructure of steel pipe after before the experiments

4. Conclusion

Based on the outcome of the results, the following conclusions were made:

- From the above results it is clear that Nacl play a decisive role in determining the ease with which stainless steel (316L) undergoes dissolution upon application of some factors such as change in pH and environment.
- The effect of pH and chloride concentration on corrosion behavior of austenites stainless steel, represented by 316L, has been determined. Decreasing pH increases the corrosion rate. Similarly, increasing temperature increases corrosion rate [21]. This can be achieved by using different solutions with different temperatures and different periods of immersion, according to the ASTM G48 standard. Similarly, increasing chloride concentration increases corrosion rate.
- Corrosion preferentially attacks the austenite phase. This can be quantified easily using simple metallography analysis, as well as PREN (Pitting Resistance Equivalent Number). The effect of pH and chloride concentration on the corrosion behavior of austenite stainless steel, represented by 316L has been determined. Decreasing pH (increasing acidity) increases the corrosion rate. This can be achieved well using different solutions with different temperatures and periods of immersion, according to the ASTM G48 standard. Similarly, increasing chloride concentration increases corrosion rate.
- It was possible to detect that each metal has specific susceptibility to corrosion when exposed to the same conditions in characteristic environments typical of atmospheric conditions.

5. Recommendations

Based on the outcome of this study, the following recommendations were considered appropriate for both water treatment plants and oil industries using stainless steel pipes in conveying their products: since all stainless steel materials are coated prior to usage, it is advisable to control the environments where they are been in use to regulate the pH values of the soil, manage the chlorine or salt content of the area also. When all these factors are on constant check, the austenite stainless steel would remain intact and could not be reactive with its environment, hence will be kept at minimal rate.

However, it is rather necessary that the use of inhibitors be employed since the study has reviewed that several factors contribute to the corrosion of stainless steel when in contact with saltwater and petrol.

Finally, this work is strongly recommended for further studies to enable the researcher discover why stainless steel pipes conveying saltwater or petrol at constant pH and temperature both behaved alike and repeatedly displaying multi-collinearity.

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