

Correlation between Soil Properties and External Corrosion Growth rate of Carbon Steel.

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ABSTRACT

Experiments were conducted to investigate the correlation of soil properties towards metal loss of API 5L X42 carbon steel coupons, with emphasis on soil pH and resistivity. A total of four pieces of X42 coupons were placed in four different soil samples gotten from four different states within the Niger Delta region for 2352 hours, to study the influence of soil properties towards metal loss via weight loss method. The soil coupons were buried in the soil samples placed in a plastic container, allowed to corrode naturally and then retrieved every 168 hours. The influence of soil pH value and resistivity were evaluated using the weight loss method to evaluate the corrosion rate on coupons in the different soil samples. Results showed that that both parameters had an influence on buried steel but soil resistivity had a dominating influence compared to soil pH.

KEYWORDS: Underground Corrosion, Soil, carbon Steel, pH, mils per year (MPY)

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I. INTRODUCTION

This study is the outgrowth of continuing interest throughout the oil industry, especially in the oil rich part of Nigeria in a bid to reducing the incidence of oil spillages caused by corrosion. This involves identifying the key processes and environmental conditions which mostly influences the equipment deterioration rate. Once identified, a strategy is established to routinely monitor these key processes and environmental parameters and maintain them within prescribed limits to control corrosion or material deterioration to acceptable levels [1]. In the absence of an efficient monitoring system, the dynamic progress of corrosion may cause the pipeline to leak or rupture, and a pipeline failure can cause grave human, environmental and financial losses. The word corrosion is derived from the Latin *corrosus* which means eaten away or consumed by degrees; an unpleasant word for an unpleasant process [2]. As such, when corrosion is being discussed, it is important to think of a combination of a material and an environment. The corrosion behaviour of a material cannot be described unless the environment in which the material is to be exposed is appropriately identified. Similarly, the corrosivity or aggressiveness of an environment cannot be described unless the material that is to be exposed to that environment is also identified. Summarily therefore, the corrosion behaviour of the material depends on the environment to which it is subjected, and the corrosivity of an environment depends on the material exposed to that environment. Soil which is the electrolyte is a complex environmental material which has made the study of corrosion in carbon steel vague. However, understanding the physicochemical composition of soil is a key to unravelling how a soil can influence corrosion reaction. It has become expedient that operators should examine every particular site to explain the corrosion mechanisms models resulting from the steel interaction with the soil environment which depends on several factors such as soil type, moisture content, soil resistivity soil pH, oxidation – reduction potential and microbial load.

II. LITERATURE REVIEW

A number of investigators have performed experiments which focused on the corrosion rate of steel and its interactions with soil parameters. In the light of this, it was reported that soil resistivity is by far the best criterion for estimating the corrosivity of a given soil in the laboratory, where the vital parameter of moisture can be controlled [3]. In their work, they studied a number of Indian soils so as to identify a link between the different soil properties and its corrosivity to the underground metallic structures. A research paper focussing on microbiologically influenced corrosion (MIC) of carbon steel exposed to anaerobic soil and simulated model soil has been investigated [4].

A study on the corrosion of a 10 inch crude oil pipeline by analyzing the physic-chemical characteristics of the soil environment has been investigated [5]. The study of soil concentrations, pH, temperature and other important soil parameters showed it to be clay soil environment. The corrosivity of the soil samples were evaluated using AWWA C-105 numerical scale. A total sum index of 21 recorded implied that the soil tested was extremely corrosive for low carbon steel. Also Sjögren and others (2007) in their work aimed at clarifying the resistance against external corrosion of stainless steel pipes in soil. The core of the project was actually done in-situ and the specimens buried in soil both in Sweden and in France [6]. Study on the mechanical properties of steel in aqueous corrosion showed that losses in mechanical properties for specimens exposed to sea water were higher than those exposed to fresh water for every properties tested [7]. An investigative research into the effect of a high salt concentration on corrosion from low partial pressures of hydrogen sulfide (H₂S) have also been carried out and reported [8]. The main objective was to study if the high concentration of chloride could initiate localized attack in this type of H₂S system. Their experimental results revealed that a high salt concentration significantly slowed down the reaction rate in H₂S corrosion. The effect of pH value to corrosion growth rate on API 5L X70 low carbon steel exposed to soil condition was studied [9].

Noor and others (2012) investigated the relationship between soil properties and corrosion of carbon steel. The test focussed on three types of major soil engineering properties towards metal loss of X70 carbon steel coupons. The three properties soil properties were moisture content, clay content and plasticity index. It was found that the soil moisture content had a more observable influence towards corrosion more than clay content and plasticity index [10]. A similar experiment with the aim of evaluating the corrosion resistance of the API 5L X52 steel in soil from the Serra do Ouro Branco and Minas Gerais in Brazil. According to their result findings, a corrosion product layer of iron oxide/hydroxide was identified on the surface of steel [11]. Detailed investigation of soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulphate contents on the corrosivity of buried-galvanized steels and cast iron pipelines has also been studied in an attempt to specify the corrosive nature of soils in Panga-kirtipur-Tyanglaphant areas of Municipality [12]. Corrosion behaviours of Q235 steel in indoor soil for 21 days and the soil parameter being moisture content [13] has been studied and published. In essence the authors stated that moisture had a noticeable influence on corrosion of steel. The corrosion of C-Mn steel type API X60 in simulated soil solution environment and inhibitive effect with the objective of finding out the susceptibility interactions of steel with the soil environment revealed to a great extent the influence of salt contents of soil to steel [14]. Soil corrosivity investigations carried out along a pipeline route in the Niger Delta Basin (along the Obrikom-Ebocha areas) using Geoelectrical method showed that the lower the resistivity of soil, the higher the corrosion rate [15]. The test was conducted to predict the corrosivity of the top three meters of the soil along a slumberger pipeline route using soil electrical resistivity as the parameter. Research on relationship between soil properties and corrosion rate of carbon steel in Nigeria has not received significant attention. Therefore, this research is carried out to investigate the relationship between soil pH and resistivity towards carbon steels.

III. METHODOLOGY

This study employed a quantitative analysis method to determining the corrosion rate based on weight loss method. This involved exposing the sample coupons to the test medium (soil) and measuring the loss of weight of the material as a function of time. The measurements of the specimens were taken during exposure and after removal according to ASTM G162-99 (American Standard of Material and Testing, 2000a).

IV. DESCRIPTION

Steel Sample

API 5L X42 was the specimen chosen for this investigation. The API 5L X42 steel pipe segment used for this research work was obtained from Pipeline and Product Marketing Company (PPMC) Port Harcourt, Nigeria.

Soil Sample

Four different states were chosen and soil collected from each state. All soil samples were taken from the depth of at least one (1) meter from the ground level. All of which were collected from four different sites along the Niger Delta region of Nigeria. The Niger Delta region is located at an elevation of 96 meters above sea level with latitude of 4° 49' 60"N and within longitude of 6° 0' 0" E. The soil samples were taken to the laboratory for analysis in an air tight polyvinyl bag less than 24 hours after collection from actual site.

Specimen preparation of steel sample

The steel pipe segment was sectioned (cut) into coupons of $72\text{mm} \times 35\text{mm} \times 10\text{mm}$ using a hacksaw. The cutting process was chosen so as not to alter the microstructure of the sample. To prevent inconsistent coating protection which may lead to bias result, the coatings of the samples were removed in a bid

to allowing the coupons corrode under worst case scenario. As such, the samples were thoroughly cleaned before installation to avoid any contamination or any possible entities that could affect the corrosion process. A sample was subjected to chemical analysis using the metal analyzer. This was done by exposing the well-polished surface of the sample to light emission from the spectrometer. The elements contained and their proportions in the sample were revealed on the digital processor attached to the spectrometer. The results as shown in Table 2.1 below

Table 2.1 Chemical composition of API 5L X42 carbon steel (wt %)

C	Mn	P	S	Si
0.234	1.28	0.028	0.0215	0.4375

Specimen preparation of soil sample

The procedures followed in preparing the soil medium are referred to ASTM G162-99 [16]. Since the soil samples were collected from four different sites along the Niger Delta region of Nigeria, the soils were first packaged in polyvinyl bags and transferred from its actual site to a laboratory for determination of its chemical properties. The results are shown below

Table 2.2 Chemical Analysis of Experimental Soils

Parameters	Abia State	Bayelsa State	Delta State	Rivers State
pH	5.6	5.65	5.71	5.64
Redox Potential [mV]	147.8	142.8	140.5	148.6
Temperature [°C]	29.30	28.90	29.20	28.80
Soil Resistivity [$\Omega \cdot \text{cm}$]	7013.77	6878.89	6973.50	6984.88
Chloride [mg/kg]	36.23	41.10	28.33	36.60
Sulphate [mg/kg]	11.10	12.45	9.87	13.99

Table 2.3 Mechanical and Physical Analysis of Experimental Soil

States	% Sand	% Silt	% Clay	% moisture	% porosity	Permeability [cm/sec]
Abia	61.5	23.9	14.6	10.26	68	1.7
Bayelsa	60.1	29.2	10.7	21.05	58	0.9
Delta	59.2	17.6	14.2	11.27	65	1.5
Rivers	58.8	21.3	19.9	10.41	70	1.2

Geo-Engineering and Chemical Analysis of Soil Samples

Test Procedure: Determination of moisture content

This was performed according to ASTM D2216. 20g of the soil sample was weighed into a moisture can and placed in an oven (MRC DNO-50, Isreal) at 105°C for 24hrs. The sample was removed and weighed until constant weight was observed. The moisture content was calculated as the percentage of mass of water loss.

Soil Classification-Sieve Analysis (Soil Texture)

The test was conducted according to ASTM D422. A know mass of dry soil was weighed accurately to 0.1g (W) and was transferred into a stack of sieves. The stack sieves was run through a shaker for about 10 to 15 minutes and the amount of soils retained on each sieve was weighed and recorded.

Soil Chemical Analysis

Test Procedure: Soil Ph (pH (APHA 4500 H⁺))

Measurement was carried out in 1:1 soil to water suspension by means of a Win Lab pH meter (WinLab 192363, Germany), which was calibrated in the laboratory. Calibration was checked by measuring standard buffer solutions.

Test Procedure: Soil Resistivity

Electrical Conductivity was carried out based on **APHA-2540-C** standards. Measurement was carried out in 1:1 soil to water suspension by means of a Win Lab conductivity meter (**WinLab 200363, Germany**), which was calibrated in the laboratory. Calibration was checked by measuring standard Conductivity reference solutions. Soil resistivity being reciprocal of conductivity was however computed using

$$ER = 1/EC \quad (1)$$

Where

ER = Electrical resistivity

EC = Electrical conductivity

Burial of Samples

The coupons were totally buried inside plastic containers containing the respective soils gotten from different states in a laboratory and closely monitored. A total of 4 steel coupons were buried and allowed to corrode naturally for a period of seven days(168 hours).



Fig. 1: Soil samples in containers ready for coupon burial



Fig. 2: Burial of coupon in soil samples

RETRIEVAL OF COUPONS

Coupon retrieval was carried out periodically every seven days. As such, in order to get a time-function data of metal loss, every single sample was assumed uniform in terms of strength, thickness and corrosion resistance.



Fig. 3: Retrieval of one of the coupons from soil

Weight loss measurement

To remove accumulated impurities and corrosion products from the coupons, two cleaning techniques were employed, which included mechanical cleaning and chemical cleaning as shown in Figure 4.



Fig. 4: Washing the coupons

The mechanical cleaning was carried out to remove the soil particles on the surface of samples using a soft brush. After washing, all the coupons were neutralized by 5% sodium carbonate and again washed with water. After neutralization, the coupons were soaked in Acetone for 5 minutes and then allowed to dry properly in sun. The weight of the sample prior (W_1) and after being exposed to soil environment (W_2) were recorded using an electronic weighing scale to determine the corrosion rate. The difference in weight of the sample is most often used as a measure of corrosion or the basis for calculation of the corrosion rate [19].

$$W = W_1 - W_2 \quad (2)$$

Where,

W = weight loss

W_1 = initial weight

W_2 = final weight after exposure to soil with time

CORROSION RATE DETERMINATION

The surface area of each coupon was calculated using:

$$\text{Surface Area (A)} = 2 \times [(L \times B) + (B \times T) + (L \times T)] \quad (3)$$

Where,

L = Length of the coupon.

B = Width of the coupon.

T = Thickness of the coupon.

D = Diameter of hole in coupon

The weight loss of the coupons which were used to compute the corrosion rates of the coupons was measured using the KERRO BLG 2000 electronic scale having a precision of upto 0.01gm. Hence the corrosion rate was computed using the formula:

$$\text{Corrosion rate (mmpy)} = \frac{87.6 \times \text{Weight loss}}{\text{Area} \times \text{time} \times \text{Density}} \quad (4)$$

Where:

W = weight loss in milligrams

A= area of coupon in cm^2

T = time of exposure of coupon in hours

$\rho = \text{metal density in } g/cm^3$

V. RESEARCH RESULT AND DISCUSSION

Weight loss of samples

In order to see the influence of soils from different locations on the coupons buried, the initial weight of the coupons were recorded and with time the weight differences were checked. The weight loss plotted as shown in Figure 5.

Figure 5 shows that the weight loss was highest in WLR i.e. the soil gotten from Rivers State. During the incubation periods, the coupons gained weight possibly due to moisture adsorption. But with time after 672 hours, the coupons started losing weight with WLR being the highest followed by WLA. Weight loss in WLB seemed higher than WLD during the first 2016 hours but afterwards, WLD began to be higher than WLB. This is could be traced to the fluctuations in the resistivity of the soils and other factors, knowing full well that corrosion in soil is a complex phenomenon. However with this trend, at the weight loss of coupon in delta soil would be highest since the increase with time seems increasingly fast.

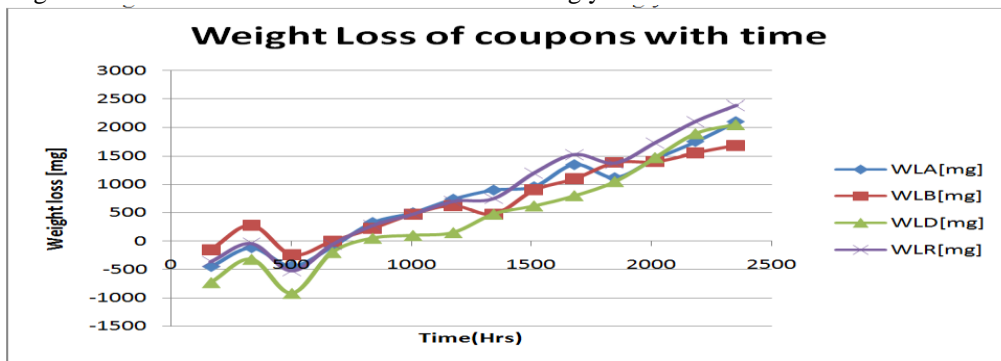


Fig. 5: Weight loss against time

Corrosion rate against soil pH

From experimental results obtained, it could be seen that as time goes on the corrosion rate of all samples as shown in the figures below kept increasing with time, as much as pH increased. This however agreed somewhat with the observations in weight loss against time, which shows a good correlation between both.

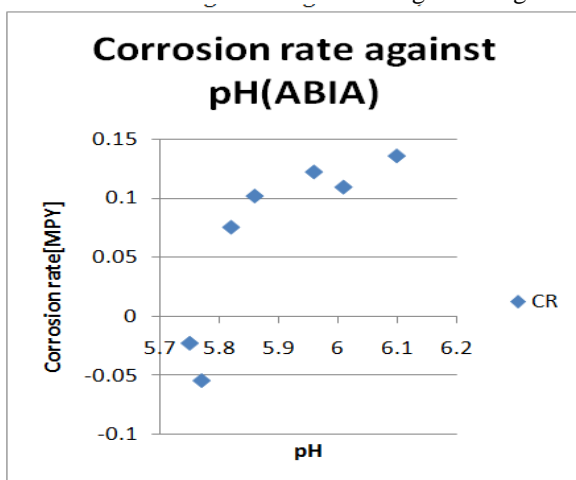


Fig. 6: Corrosion rate against pH for Abia sample

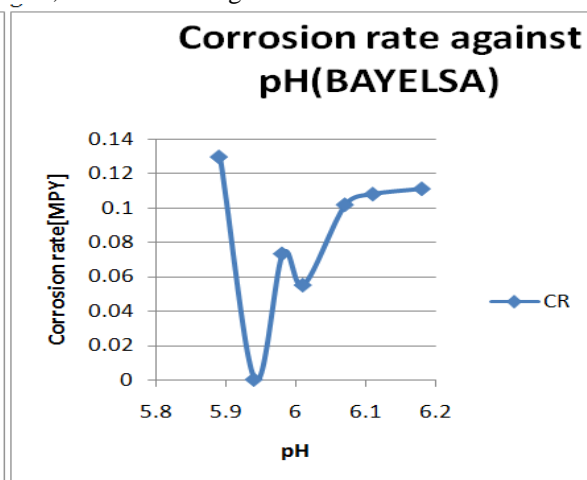


Fig. 7: Corrosion rate against pH for Bayelsa sample

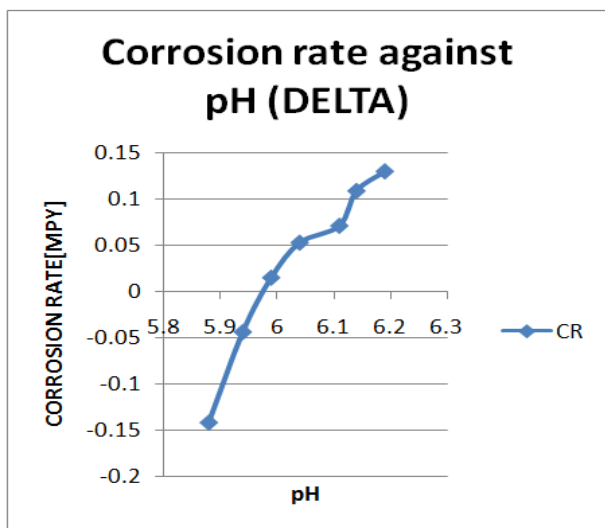


Fig. 8: Corrosion rate against pH for Delta sample

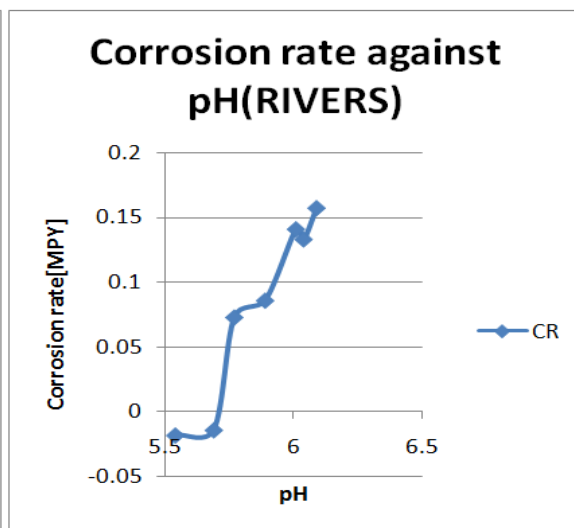


Fig. 9: Corrosion rate against pH for Rivers

pH against time

Soil pH with time appears to increase with corresponding time. Delta sample had the highest values of pH while Rivers sample had the least pH values although there were minor fluctuations. These values had a huge influence on the corrosion rates of the coupons.

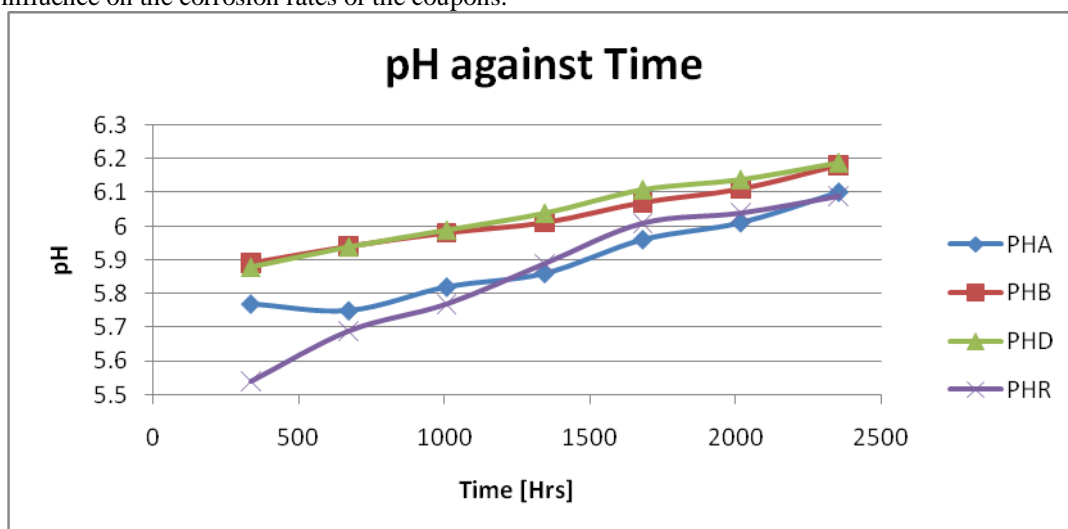


Fig. 10: Graphical depiction of pH against time for all samples.

Soil Resistivity Influence

Soil resistivity is an obviously an indicative of soil corrosivity. As such in all samples studied, the lower the resistivity the higher the weight loss and corrosion reactions. Also experimentally it appeared that the resistivities gradually dropped with time thus leading to a steady rise in the corrosion rate. This is depicted in Figure 11, 12, 13 and 14.

Corrosion rate against Resistivity

Based on the results obtained, it showed that the resistivities of most samples increased with time leading to an increase in corrosion rate. This seemed to agree with the opinion of some authors, where they opined that the lower the resistivity of a soil, the better the soil's electrolytic properties and the higher is the rate at which the corrosion can proceed [5]. Hence the progressive reduction in resistivity with time, led to corrosion increase as shown in Figure 11, 12, 13 and 14.

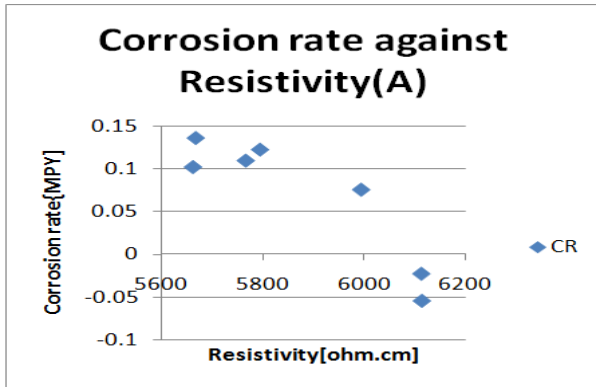


Fig. 11: Corrosion rate against Resistivity for Abia sample Bayelsa sample

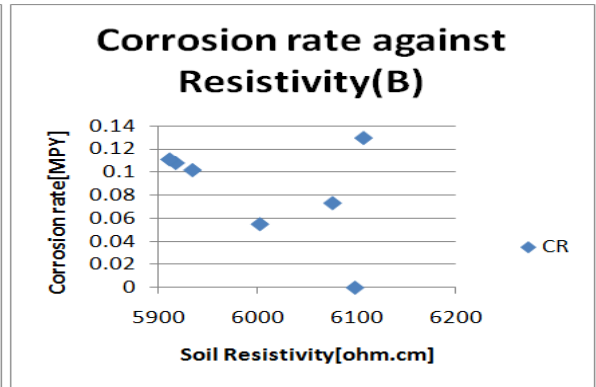


Fig. 12: Corrosion rate against Resistivity for

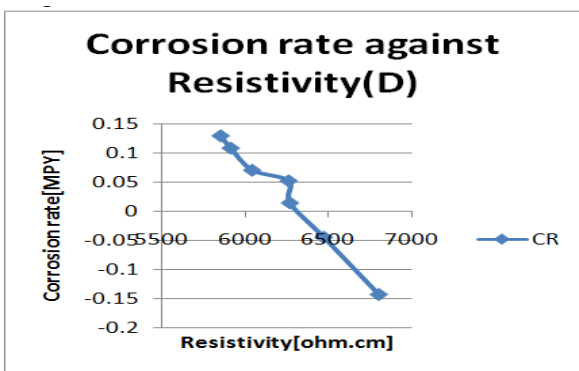


Fig. 13: Corrosion rate against Resistivity for Delta sample

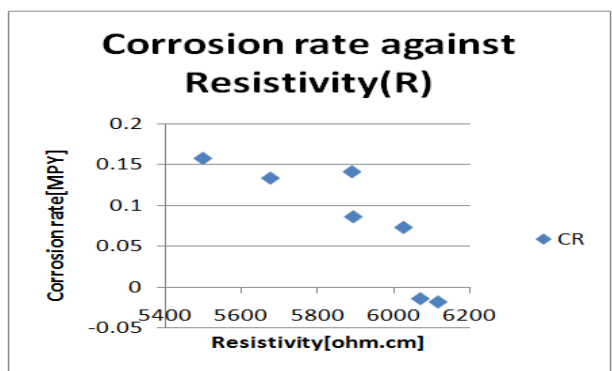


Fig. 14: Corrosion rate against Resistivity for Rivers sample

Resistivity against time

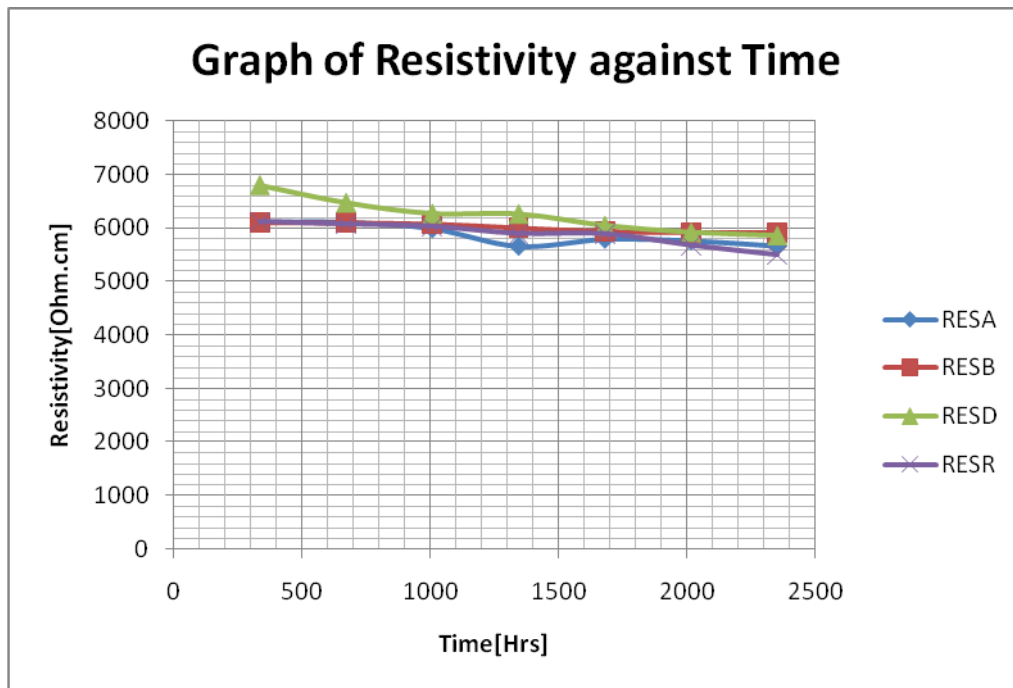


Fig. 15: Graphical depiction of Resistivity against Time for all samples

Corrosion Growth rate

Corrosion growth rate has always been a function of time. Upon inspection based experimental data recorded, it seemed evident that the corrosion rate of coupons increased with time after the initial stage. The initial phase where an increase in weight was observed instead of a loss in weight could be attributed to adsorption of moisture which invariably led to an increase in weight. Then with time, it was noticed that possibly the passivity film might have been broken down which now led to the observed weight loss. Hence this agrees with what other writers have opined, where steel naturally tries to passivate itself with respect to the environment in which it finds itself within the first few days.

Figure 16 shows explicitly the relationship between corrosion rate and time. From the figure below WLR had the highest corrosion rate which is an indicative of the inherent properties of the soil. But based on the trend with time, delta sample would be the most corrosive.

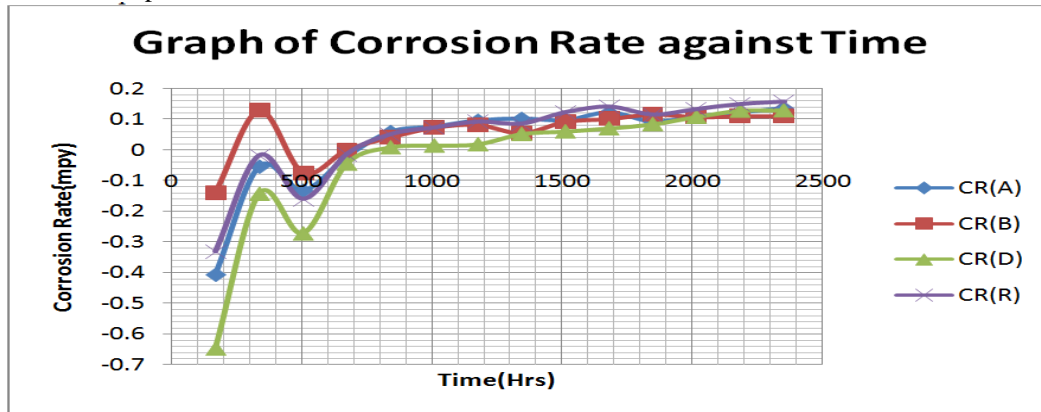


Fig. 16: Graph of corrosion rate against time

VI. DISCUSSION OF FINDINGS AND CONCLUSION

The aim of the study was to determine a relationship between soil pH and soil resistivity upon corrosion growth rate of carbon steel. As a matter of fact, this paper tried to isolated individually the above mentioned soil properties from all other possible factors which is believed to govern metal loss of buried steel coupon and later correlated with corrosion growth rate as measured through laboratory experimental data. Soil resistivity was found to have greater influence than soil pH towards the acceleration of corrosion reaction in most soil samples examined, if not all, due to distinct pattern of relationship between variations of averaged corrosion rates and soil properties. Also time plays a major role in corrosion rate of steel buried underground. Further research work is necessary to study better the influence of moisture content, soil pH and microbial load of soil as it affects corrosion of underground steel. The measured corrosion rates from the loss of weight of buried steel coupon may be dominantly caused by other factors such as fungi, bacteria, chloride content, sulphate content, organic content and salinity.

Suggestions for Future Work

In this investigation the weight loss method was used for the corrosion rate analysis, but there is need for others to adopt a modern corrosion assessment method so as to validate and further confirm the results. Consequently, the data obtained from this experimental investigation can further be used to predict the time of failure of oil steel pipes buried underground.

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