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E-mail: nigmet_society@yahoo.com

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THE EFFECTS OF SOIL PARAMETERS ON THE CORROSION OF BURIED PIPE IN GIDAN KWANO, MINNA, NIGERIA

[1]Alamu S. A., [2]Abdulrahman A. S., [2]Essien U. A.

[1]Department of Mechanical Engineering, School of Infrastructure, Process Engineering and Technology and Technology, Federal University of Technology Minna

[2]Department of Material and Metallurgical Engineering, School of Infrastructure, Process Engineering and Technology, Federal University of Technology Minna

(Correspondent Author: Essien U. A. essienubong4@gmail.com)

ABSTRACT

This research investigated the effects of moisture content and soil resistivity on the corrosion rate of low carbon steel in the soil of Gidan Kwano, Minna, Nigeria. Six flat specimens (Steel coupons), were cut from the pipe with the dimension of 60mm x 40mm x 2mm each. The coupons were buried at six different locations at one meter apart from each other exposed for a period of 12weeks. Moisture content and resistivity were evaluated using oven drying method at 110°C for 24 hours, and Wenner four electrode methods respectively. The site had a moisture content of 23.73% and resistivity of 33.4ohms meter. Weight loss method was adopted in evaluating the corrosion rate of the pipe after every 2weeks interval. The weight loss at the end of each of the exposure period (time) was: 0.1, 0.2, 0.5, 0.6, 0.9, and 0.11grammes respectively, and corrosion rate calculated were: 0.062, 0.061, 0.098, 0.089, 0.100, and 0.111mm/year respectively.

Key Words: Corrosion, Rate, Moisture-content, Resistivity, Soil-type

Introduction

Buried pipelines (commonly made from carbon steel) are one of the most common channels used to convey products such as crude oil and gas from one point to another. These underground pipelines are exposed to various environment hazards such as seawater (offshore) and soil (onshore) that may lead to experience corrosion attack. Steel pipelines deterioration due to corrosion attack is well known as a common and serious problem, involving considerable cost and inconvenience to industrial growth and great loss to the economy. There is always a chance that pipelines could leak or rupture and a pipeline failure can constitute serious hazards to the environment, assets and even humans due to explosion and leakage [Hopkins, 1995; National Energy Board, 1996; Yahaya *et al.*, 2009].

Pipeline corrosion is most prevalent when breakdown of coating, inhibitors or cathodic protection take place in corrosive environment. The most common types of corrosion that can occur in a buried pipe includes; Pitting corrosion owing to material in homogeneity, chloride and sulphate induced stress corrosion cracking, corrosion by concentration cell in soil arising out of difference in oxygen concentration in the soil adjacent to the pipe at different region, microbiologically induced corrosion under anaerobic condition by sulphate reducing bacteria and acid forming bacteria (Ahammed and Melchers, 1997).

Corrosion is recognized as one of the most dominant forms of deterioration process and has been identified as one of the major causes of loss containment for offshore steel pipe lines (Ahammed, 1998).

The study of the soil as a corrosive environment is necessary due to the large number of buried pipelines, tank and other structures, as their deterioration can represent a real economic and environmental problem throughout the years. Soil corrosion is complex with number of factors involved. There are several parameters that can induce the corrosion in the soil, such as resistivity, pH, redox potential, moisture content, type of soil, chloride and others (Ferreira et al; 2007).

Ikechukwu et al. (2014) examined the relationship of soil properties towards metal loss of API 5L X42 carbon steel coupons. An aggregate of four specimens of X42 coupons were set in four distinctive soil tests taken from four unique states of the Niger Delta district for 2352 hours, to consider the impact of soil properties towards metal loss by means of weight loss method. The soil coupons were covered in the soil samples put in a plastic bag, permitted to corrode normally and afterwards recovered at regular intervals. The impact of soil pH and resistivity were assessed utilizing the weight loss method to assess the consumption rate on coupons in the diverse soil tests. Results demonstrated that both parameters had an impact on covered steel yet soil resistivity had a commanding impact contrasted with soil pH.

Anyanwu et al. (2014) found from the ANOVA that soil resistivity had a noteworthy commitment to corrosion response in soil. A mathematical model was created utilizing multiple regression analysis. The outcome demonstrated that the model created was suitable for forecast of corrosion development rate with oil pH and resistivity as the two independent variables; since the coefficient of determination (R_2) 0.8129 was significantly high.

From the evidence gathered in the literature, it is pertinent that the parameters that influence the corrosion of buried pipe and their potential effects be investigated for a particular area where a project that involves the utilization of buried pipes is to be sited; since these parameters varies based on soil type and geographical location.

Experimental Procedure

The equipment used in this research includesManual Power Saw, Analytical Balance (sensitivity, 0.1g), Laboratory Bench Oven, Moisture Cans and Desiccator.

Soil Samples

Six samples of the soil were collected and labeled as 'SS-1, SS-2, SS-3, SS-4, SS-5, and SS-6', for laboratory test. The samples were taken from the depth of one meter from the ground level at six different locations on the site (July, 2017) and preserved with the desired inherent conditions.

Pipe samples

A Low Carbon Steel pipe was used as a case study for this research. Six test specimens 'steel coupon', with a dimension of (60 mm × 40 mm × 2 mm) each, were cut from the pipe using the manual power saw. To evaluate the corrosion rate of the steel pipe, the coupons were buried on the actual site to corrode naturally for a period of twelve weeks (2016 hours). The mechanical and chemical properties of the commercially used Low CarbonSteel pipe are shown in Table 1 as specified in A106 specifications.

***Table1**: Mechanical and chemical properties of Mild steel pipe*

C %	Mn %	Si %	S %	P %	Fe %	Yield strength, (MPa)	Tensile Strength, (MPa)
0.040	0.12	0.032	0.007	0.012	Balance	240	415

Moisture Content Testing

Moisture tests were performed in the Civil Engineering Laboratory, Federal University of Technology Minna. The devices used in this test were Analytical Balance (sensitivity, 0.1g), laboratory bench oven, and desiccator. The test measures the water present in a soil as percentage between the amounts of absorbed water through soil mass to the same amount of soil mass without water.

Sample preparation

This started with the fragmentation of the soil to smaller parts by hammers prepared for test, saving the samples in a non-corrosive container and preventing air contact with the soils, at a temperature between (3-30) °C, in a place far away from exposure to direct sunlight. The test samples were taken after mixing and mass selection was done. Table 2 shows the relation between sieve number and recommended mass of moist specimen.

Table 2: *Moisture test specimen masses (ASTM D 4643-08)*

Size of Particles more than 90% passing IS Sieve	Minimum quantity of soil specimen
425 micron	25g
2mm	50g
4.75mm	200g
10mm	300g
20mm	500g
40mm	1000g

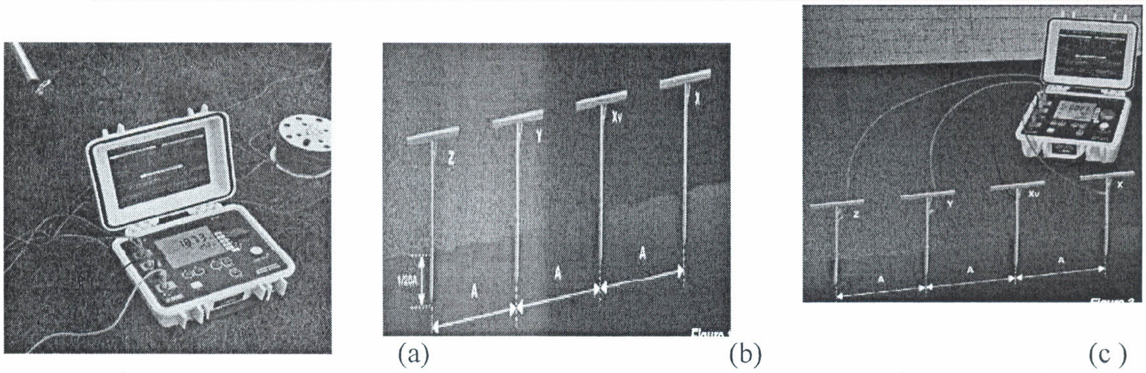
Identified soil samples were used in clean, dry container (Moisture can) and weighed using an Analytical Balance. After the determining the amount of soil sample to be tested according to Table 2,30g of soil sample was put into the container and the mass of the container together with the sample was recorded. The sample was then placed inside a700 W oven dryer and dried for 24 hours at a temperature of 110 °C.After drying, the moisture cans were removed from the oven and put in a desiccator to cool for about 20-30 minutes To calculate the soil moisture contents, Equation 1 was used;

$$W = [(M_2 - M_3) / (M_3 - M_1)] \times 100\% = [M_w / M_d] \times 100\% \quad (1)$$

Where W = *Water content percentage,*
M_1 = *Mass of container,*
M_2 = *Mass of container and wet soil,*
M_3 = *Mass of container and dry soil,*
M_w = *Mass of wet soil,*
M_d = *Mass of dry soil.*

Soil Resistivity Test

The soil composition, moisture content and temperature was taken into consideration before going into the actual test. A ground resistance instrument capable of testing using four electrodes commonly referred to as a four point or four pole testers, shown in Plate 3a, was used in this research. Four auxiliary electrodes and four spools of wire were also used for the test. Using Four Point (Wenner) Method, and conducted at a depth of3.05 meter, the four electrodes were spaced in a straight line 3.05 metersapart, as depicted in Plate 3b. The depth of the test electrodes was at 1/20th the spacing of the rods in the ground, and the terminals of the instrument were connected to the rod using the spools of wire provided, as depicted in Plate 3c. After turning the instrument on, the selector switch was placed in the soil resistivity test position and the test button was pressed. After a few seconds of observation, the resistance reading was measured. The measurements were taken for five times in a square pattern and then one on an inside diagonal of the square



(a) (b) (c)

Plate 3: (a)** Four Point Ground Resistance Test Instrument.* ***(b)*The four electrodes spaced at 10feet apart.* ***(c)*** *Terminals connect*

The results are given by the simplified formula,

$$\rho = 2\pi AR. \quad (2)$$

Where; P = ohm-cm
π is a constant = to 3.142
A = the spacing of the electrodes (in centimeters)
R = the resistance value of the test in ohms.

Weight Loss and Corrosion Rate Determination

The metal coupons were buried in the soil environments for a maximum of 12 weeks, and upon the observation period each of the coupons was retrieved at 2 weeks interval for evaluation. Interval monitoring of the buried coupons was to determine what corrosion effect had taken place on the coupons at the end of each exposure period and to compare the effect of time on the rates of corrosion on the steel pipe in the soil environments under study. After retrieval from the soil samples, the coupons were taken to the laboratory for cleaning and analyses to determine the weight loss and corrosion rates.

The corrosion rate was calculated in mils per year (mpy) from the weight loss using the formula;

$$CW = \frac{W \times k}{(D \times A \times t)} \quad (3)$$

Where: W = weight loss in grams
K = constant (22,300)
D = metal density in g/cm^3
A = coupon area (inch^2)
T = time (days)

RESULTS AND DISCUSSION

Moisture Test Result

Three tests were carried out with the collected soil samples, and the data obtained tabulated as in Table 3;

Table 3: Mass of Samples before and after drying

Test Number	I	II	III
Moisture can Number	A70	B11	JK5
Weight of can, W_1 (g)	24.6	24.0	24.1
Weight of can + wet soil, W_2 (g)	67.8	69.2	55.4
Weight of can + dry soil, W_3 (g)	59.6	60.3	49.5
Weight of moisture, $(W_2 - W_3)$ g	8.2	8.9	5.9
Weight of dry soil, $(W_3 - W_1)$ g	35.0	36.3	25.4

The calculated moisture content in the soil according to equation 3.1 were as shown in Table 4;

Table 4: Soil Tests and their moisture contents

Soil Tests	Moisture content, %
I	23.43
II	24.52
III	23.23

The actual moisture content of the site was evaluated by taking the average of the three tests.

AverageMoisture Content, $W = \frac{WI+WII+WIII}{3}$

$= \frac{23.43+24.52+23.23}{3} = \frac{71.18}{3} = 23.73\%$

The weight loss result revealed that the site has 23.73 percentage of moisture content in the soil. Since the moisture content of the soil is high, and then it has a key role in determining the corrosion rate of the buried steel metal pipes.

Resistivity Test Result

The values for initial voltage V_0, final voltage V_i, current I as measured, and resistance R as calculated from the resistivity test were as shown in Table 5;

Table 5: The value of voltage, current and resistance at each point

Test Points	Initial Voltage (V)	Final Voltage (V)	Current (A)	Resistance (Ω)
A	69	179	30.2	3.64
B	92	130	60.1	0.63
C	72	208	47.0	2.89
D	4	148	45.2	3.19
E	271	371	37.0	2.70

The resistivity at each point was obtained using the simplified formula in equation 2, where A is the spacing of the electrodes in meters and calculated as shown below;

$A = \frac{2 \times 10 feet}{3} = \frac{2 \times 3.048m}{3} = \frac{6.096m}{3} = 2.032m$

The resistivity of the soil at the different test points were as shown on Table 6;

Table 6: Resistivity of the soil at each point

Test Points	Resistivity (Ωm)
A	47
B	8
C	36
D	41
E	35

The actual resistivity of the site was evaluated by taking the average of the five tests.

AverageResistivity,

$\rho = \frac{\rho A + \rho B + \rho C + \rho D + \rho E}{5} = \frac{47+8+36+41+35}{5}$

$= \frac{167}{5}\ \rho = 33.4\ \Omega m.$

The test result obtained revealed that the resistivity of the soil is 33.4Ωm; which is very low and corrosive according to NACE Soil Corrosivity Ratings (Peabody, 2001). Since the resistivity of the soil is low, the conductivity will be high, and thereby increase the rate of corrosion of the buried steel metal pipes. Lower value of resistivity will aggravate corrosion on the outer surface of the pipelines.

Weight Loss Measurements

The coupons initial and the final weight after test and the weight loss of the metal pipe are presented on Table 7.

Table 7: Initial weight, final weight, weight loss, weight loss per unit area, and weight loss per unit area per time of the metal coupons

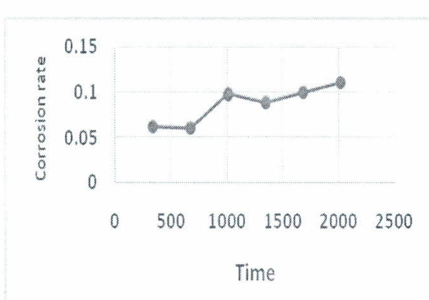
Metal Samples	Exposure Time (Hrs)	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Weight Loss /area (g/cm^2) $\times 10^{-3}$	Weight Loss /area/time ($g/cm^2/hrs$) $\times 10^{-6}$
SS-1	336	38.6	38.5	0.1	1.92	5.72
SS-2	672	39.8	39.6	0.2	3.85	5.72
SS-3	1008	41.1	40.6	0.5	9.62	9.54
SS-4	1344	40.4	39.8	0.6	11.5	8.59
SS-5	1680	43.3	42.4	0.9	17.3	10.3
SS-6	2016	39.6	38.5	1.1	21.2	10.5

The normal rate of corrosion was determined utilizing Equation 3, and the data obtained were as tabulated in Table 8.

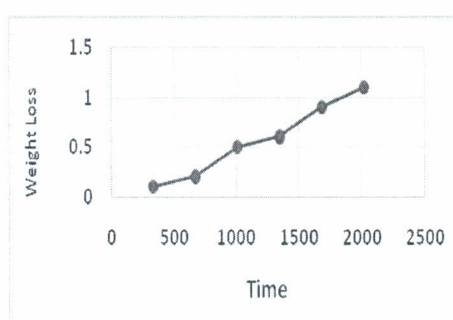
Table 8: Corrosion Rate calculation

Metal Samples	Exposure Time (Hrs)	Weight Loss (g)	Density D (g/cm^3)	Factor K (mm/year)	Surface Area (cm^2)	Corrosion Rate (mm/year)
SS-1	336	0.1	8.04	8.76×10^4	52	0.062
SS-2	672	0.2	8.29	8.76×10^4	52	0.061
SS-3	1008	0.5	8.56	8.76×10^4	52	0.098
SS-4	1344	0.6	8.42	8.76×10^4	52	0.089
SS-5	1680	0.9	9.02	8.76×10^4	52	0.100
SS-6	2016	1.1	8.25	8.76×10^4	52	0.111

Tables 7 and 8 show the graphs of weight loss against time, and graph of corrosion rate against time, respectively. The graph of weight loss against time Figure 1.0a, shows that the weight loss of the steel pipes increases with exposure time. The weight loss was at a low rate in its second week in the soil environment and continue till the sixth week (i.e an increase in weight loss was observed). There was a wide noticeable loss at the end of six and twelve weeks of observation.



(a)



(b)

Fig. 1.0: (a) Graph of Weight loss against time (b) Graph of corrosion rate against time

The graph of Figure 1.0b shows that the corrosion rate increased with time for the first two weeks and remained so for the following two weeks. It then increased to the sixth week and decreased proportionally from the sixth to eighth week, and increased again till the last week. And from table 7, it was noticed that the minimum weight loss of the steel pipes between the second and fourth week, sixth and eighth week also followed the same trend of their corresponding corrosion rate for that period of time.

CONCLUSION

Soil moisture content and resistivity were examined to study the effect of these properties on the corrosion of buried low carbon steel pipe. The results revealed that the soil had a high moisture content and low resistivity, thereby establishing that the soil is corrosive in nature. There was a direct relationship in the weight loss and corrosion rate of the exposed pipe, which showed that the moisture content and resistivity of the soil had a significant effect on the corrosion rate of the buried pipe. The experimental corrosion rate of the buried steel coupons revealed the highest corrosion rate of 0.111 mm/year when moisture content was 23.73 % and resistivity 33.4Ωm.

From the result of this research it is pertinent to suggest here that, to put corrosion under control in any medium involving the use of underground pipeline in Gidan Kwanu soil, pipelines should be treated with appropriate anticorrosion agents (such as epoxy coatings, Loose polyethylene jacketing, bituminous coal tar coatings and polyurethane coatings) against moisture content and resistivity, to ensure longer service life of the project.

However, the results of this research showed that the parameters of the soil under investigation (moisture content, and resistivity) as well as temperature varied over time were not complete until other properties of the soil such as chloride and sulfite contents, redox potential and the mineral and organic contents be studied as they could as well influenced the corrosion rate of the buried pipe; and affect the corrosion rate differently at specific seasons and time.

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