

Effects of Soil Properties on Corrosion Rate of Buried Steel Pipes - A Case Study of Bauchi State Nigeria

¹Hassan Usman, ²Shamsuddeen A. A. and ³Kaulaha Abdu,
^{1,2}University Lecturer, ³Student,
^{1,2,3}Abubakar Tafawa Balewa University Bauchi, Bauchi, 740, Nigeria

Abstract: Corrosion behavior 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. Variability in soil physical and chemical properties causes different rates, types and extent of corrosion and other damages to buried pipes. These variations are usually not considered during the design, construction, purchase and installation of the pipes thereby causing excessive waste of resources. Experiments were conducted to investigate the correlation of soil properties towards metal loss of mild steel pipes, with emphasis on soil pH and resistivity. A total of three pieces of mild steel pipes were placed in three different soil samples gotten from three different areas of Bauchi state, northeastern part of Nigeria for 672 hours, to study the influence of soil properties towards metal loss through weight loss method, predict metallic pipe corrosion from the properties of the soil surrounding the pipe. The mild steel pipes were first buried in the soil samples placed in a plastic container and were allowed to corrode naturally and then retrieved after every 168 hours. The influence of soil pH value and resistivity were evaluated using the weight loss method to evaluate the corrosion rate on mild steel pipes in the different soil samples. Results showed that both parameters had an influence on buried mild steel pipes but soil resistivity had a dominating influence compared to soil pH. This experimental study revealed explicitly the relationship between corrosion rate and time. The weight loss of soil from Bauchi has the highest corrosion rate which is an indicative of the inherent properties of the soil. But based on the trend with time, Alkaline sample would be the most corrosive.

I. INTRODUCTION

Corrosion is a naturally occurring process in which a refined metal is converted into a more chemically stable form such as its oxide, hydroxide or sulfide. It is the slow degradation and destruction of materials (usually metals) by an electrochemical reaction between them and their environment. Corrosion is also considered as a means in which electrochemical oxidation of metal in reaction with an oxidant such as oxygen or sulfates. Corrosion can however, occur in a non-metallic material such as ceramics, polymers, etc., though in this case the term "degradation" is more appropriate (Lark & Zoitis, 1992). Corrosion degrades material useful properties such as strength, appearance and permeability to liquid or gases (Breakell et al., 2005).

The corrosion behavior 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 (Syed, 2006). Soil which is the electrolyte is a complex environmental material which has made the study of corrosion in carbon steel vague. 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. The importance of corrosion can also be seen in daily life. Corrosion causes accidents in industry, on highways, and in homes.

A body of theory exists that can be very helpful in solving corrosion problems, but in the final analysis, most decisions are based on the results of empirical tests. Stainless steel does not corrode, rust or stain with water as ordinary steel does, but despite the name, it is not fully stain-proof. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and resistance to corrosion are required. Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure. Steel Corrosion Iron and steel, the most commonly used metals, corrode in many media including most outdoor atmospheres. Usually, they are selected not for their corrosion resistance but for such properties as strength, ease of fabrication, and cost. These differences show up in the rate of metal lost due to rusting. All steels and low-alloy steels rust in moist atmospheres. In some circumstances, the addition of 0.3% copper to carbon steel can reduce the rate of rusting by one quarter or even by one half.

Due to the high regulatory scrutiny, degradation of buried piping is a large concern for numerous industries including nuclear, oil and gas, wastewater, etc. Current condition assessment is an important part of the life-cycle management of aging pipelines and includes an assessment of the external pipe surface. External corrosion direct assessment (ECDA) for pipelines is a non-trivial task as the pipelines tend to be buried so that inspection is time-consuming and costly. ECDA of buried pipeline typically follows NACE guidelines that include a four-step process. These steps include pre-assessment, indirect inspection, direct examination, and post-assessment. Data collection is part of the pre-assessment and includes evaluation of soil/environment parameters to determine its level of corrosivity. Factors that affect corrosion of metals in the soil include pH, temperature, and halide ions (e.g. chloride

ions). Knowledge of soil parameters can help determine the locations of the highest corrosion risk. Thus, this information can be used to determine where inspections should be conducted. In addition to identifying locations for inspections, measurements of soil corrosivity along with corrosion rates can be used to establish the intervals between successive evaluations. Soil resistivity was found to have greater influence than soil pH towards the acceleration of corrosion reaction in most soil samples examined by (Mbamalu & Edeko, 2004).

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.

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 was 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 (Farah, 2011)

Noor, et al., (2012) investigated the relationship between soil properties and corrosion of carbon steel. The test focused on three types of major soil properties towards metal loss of X70 carbon steel coupons. The three 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

II. METHODOLOGY

This study will employ a quantitative analysis method to determine the corrosion rate of pipelines buried in three soil samples obtained from different locations namely; Alkaleri, Azare and Bauchi all area of Bauchi state using weight loss method. This involved exposing the pipeline sample to the three test mediums (soil) and loss of weight of the pipe material as a function of time (one month) was measured. The measurement of the specimens was carried out during exposure and after removal according to ASTM G162-99 (American Standard for Testing of Materials 2000a).

Burial of samples

The mild steel pipes were totally buried inside plastic containers containing the respective soil samples obtained from the three above mentioned locations in Bauchi state in a laboratory and were closely monitored. A total of three mild steel pipes were buried and allowed to corrode naturally for a period of seven days (168 hours).



Figure 1: soil samples in plastic containers

Retrieval of mild steel pipes

Mild steel pipes 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.



Figure 2: Retrieval of mild steels from the soil

Weight loss measurement

To remove accumulated impurities and corrosion products from the mild steel pipes, two cleaning techniques were employed, which included mechanical cleaning and chemical cleaning as shown in Figure below



Figure 3: Washing the mild steel pipe

The mechanical cleaning was carried out to remove the soil particles on the surface of samples using a soft brush. After washing, all the mild steel pipes were neutralized by 5% sodium carbonate and again washed with water. After neutralization, the mild steel pipes were soaked in Acetone for 5 minutes and then allowed to dry properly in sun.

The weight of the sample (W_1) before and after (W_2) being exposed to soil environment were recorded using an electronic weighing scale to determine the weight loss from corrosion. 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.

$$W = W_1 - W_2(1)$$

Where

W = weight loss

W_1 = initial weight loss

W_2 = final weight after exposure to soil with time

Corrosion rate determination

The surface area of each mild steel pipe was calculated using:

$$\text{Surface area } A = \frac{\pi d^2}{4} (2)$$

Where,

A = cross sectional area.

d = external diameter of the mild steel pipe.

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

$$C_r = \frac{97.6 \times \text{weight loss}}{\text{Area} \times \text{time} \times \text{Density}} \quad (3)$$

Where:

Cr = Corrosion rate in millimeter per year (mmpy)

A = Cross sectional area of the mild steel pipe.

T = Time taken in the soil of the mild steel pipe.

d = Diameter of hole in mild steel pipe.

D = Density

W = weight loss

Chemical analysis of experimental soils

Experiments and measurements were conducted on the three soils to determine their pH, temperature, soil resistivity, chloride and sulphate.

Soil pH measurement

Measurement was carried out in 1:1 soil to water suspension by means of a Win Lab pH meter (**Win Lab 192363, Germany**) using APHA 10076 standard method. The pH meter was always calibrated in the laboratory prior to each test and the calibrations were checked by measuring standard buffer solutions.

Soil resistivity measurement

Electrical resistance measurements were carried out based on **APHA-2540-C** standard. Measurement was carried out in 1:1 soil to water suspension by means of an insulation tester which was also calibrated in the laboratory before the experiment. Calibration was checked by measuring standard resistance reference solutions.

The formula below was used to determine the resistivity.

$$\text{Resistivity} = \frac{RA}{L} \quad (4)$$

Where

A cross sectional area of sample $= \frac{\pi d^2}{4}$

R = Resistance

L = Length

d = Diameter

Temperature measurement

The temperatures of three different soil samples were measured by taken 10g of each soil sample and mixed with 100ml of water, then stirred and allowed to settle for the period of 24 hours. After this, the temperature of each sample was taken using a digital thermometer.

Sulfate measurement

Sulfate test was carried out based on Standards **APHA Method-8051-C**. The procedure for sulfate was carried out by 1:1 soil to water suspension by means of a calorimeter which was also calibrated in the laboratory before the experiment. Calibration was checked by testing the sulfate of each soil samples.

Sieves analysis

The complete range of sieves specified by the British Standard is given in Table 1.4. It is not necessary to use all sieves for every test, but the sieves used for this study adequately cover the range of aperture sizes for each particular soil. The sieves used were selected to suit the size of the sample and the type of material. Sieve frames used were able to fit snugly one inside the other, to prevent an escape of dust. Sieves were nested together with the largest aperture sieve at the top, and a receiving pan under the smallest aperture sieve at the bottom.

Permeability test

The permeability of each sample was measured using a constant head permeameter setup.

Moisture content

The objective of the test is to determine the water content of the soil sample as it was sampled in the field or at the moment of testing for the accurate determination of in-situ water content, the sampling, storage, transporting and handling precautions were such that the water content remains within 1% of the in-situ value. Apparatus used include; a balance of accurate up to 0.01 g, sample container (watch glasses or tins), oven (24 hr at 105°C ± 5°C), desiccator.

$$\text{Moisture content} = \frac{\text{Mass of Water}}{\text{Dry Mass of sample}} = \frac{M_2 - M_3}{M_3 - M_1} \times 100\% \quad (5)$$

Where:

M1 = mass of sample container

M2 = Mass of container and sample

M3 = Mass of container and sample after oven drying.

III. RESULT AND DISCUSSION

Soil samples characterization

The procedures followed in preparing the soil medium as described above is in accordance with ASTM G162-99. The physical and chemical properties of each sample were determined and are shown in tables 1.1 and 1.2 respectively.

1.1 Physical characteristics of experimental soils

Location	Sand %	Silt %	Clay %	Moisture %	Porosity %	Permeability [cm/s]
Alkalari	60	21.5	10.5	18	30.5	2.12 X 10 ⁻⁹
Azare	65.9	29.5	9.9	17.8	21.5	2.52 X 10 ⁻⁷
Bauchi	50.5	19.5	19.9	17.9	35	6.36 X 10 ⁻⁹

1.2 Chemical characteristics of experimental soils

Parameters	Alkalari	Azare	Bauchi
Redox Potential [mV]	140.5	130.5	148.6
Temperature [°C]	20.3	20.4	20.3
Chloride [mg/L]	0.88	2.20	0.00
Sulfate [mg/L]	2	0.5	5
pH	7.5	7.6	7.7
Resistivity [Ω.cm]	0.3474	0.2750	0.2320

Determination of moisture content

This was performed in accordance with ASTM D2216. And 300g of the soil samples were weighed into three different moisture containers and placed in an oven (**MRC DNO-50**) at 105°C for 24hrs. The samples were then removed and weighed until constant weights were observed. The moisture contents were calculated using equation (5) as the percentage of mass of water loss, the results are shown in table 1.3

Table 1.3 Moisture content of soil samples

Local Govt	Moisture %
Alkalari	18
Azare	17.8
Bauchi	17.8

Soil Classification-Sieve Analysis

The tests were conducted according to **ASTM D422**. known masses of dry soil were weighed accurately to 0.1g (W) and were transferred into a stack of sieves. The stack sieves were run through a shaker for about 10 to 15 minutes and the amount of soils retained on each sieve were weighed and recorded as in table 1.4

Table 1.4 Sieve analysis results

Sieve size	Mass retained	Percent retained	Percent passing
6.3	0	0	100
3.35	205.7	41.1	58.9
2	81.4	16.3	42.6
1.18	52.9	10.6	32
0.6	54.2	10.8	21.2
0.3	48.8	9.8	11.4
0.15	31.5	6.3	5.1
0.08	11.9	2.4	2.7
Receiver	13.6	2.7	0

Weight loss and corrosion rate of pipe samples

In order to see the influence of soils from different locations on the mild steel pipes buried, the initial weights of the mild steelsamples were recorded and the weight differences were checked with time. Effects of soil properties on corrosion rate were also determined. Figure 1.5 shows the relation between corrosion rates and pH values for the three locations.

Table 1.5 Corrosion rate against pH for the three locations

Alkalari		Azare		Bauchi	
pH	Corrosion rate (mmpy)	pH	Corrosion rate (mmpy)	pH	Corrosion rate (mmpy)
5.50	1.2529	7.00	1.2118	7.66	1.1949
6.30	0.6146	7.35	0.5983	6.80	0.5918
6.70	0.3962	7.38	0.3944	7.00	0.3921
7.00	0.2950	7.67	0.2940	6.50	0.2915

From results shown in table 1.5 show that corrosion rate decreases with decrease in pH values, and this is true for all the three locations. Table 1.6 shows the effects of soil resistivity against the rate of pipe corrosion.

Table 1.6 Corrosion rate against resistivity for the three locations

Alkalari		Azare		Bauchi	
Resistivity (ohm.cm)	Corrosion rate (mmpy)	Resistivity (ohm.cm)	Corrosion rate (mmpy)	Resistivity (ohm.cm)	Corrosion rate (mmpy)
0.3040	1.2529	0.1740	1.2118	0.1740	1.1949
0.1160	0.6146	0.1590	0.5983	0.2030	0.5918
0.1450	0.3962	0.1450	0.3944	0.1010	0.3921
0.2320	0.2950	0.1303	0.2940	0.2030	0.2915

Table 1.7 Corrosion rate against time for all locations

Time (hr)	Corrosion rate (mmpy)		
	Alkalari	Azare	Bauchi
0	0.0000	0.0000	0.0000
168	1.2529	1.2118	1.1949
336	0.6146	0.5983	0.5918
504	0.3962	0.3944	0.3921
672	0.2950	0.2940	0.2915

Table 1.8 Weight loss (mg) against time (hrs)

Time (hr)	Weight loss (mg)		
	Alkalari	Azare	Bauchi
0	448.36	448.36	448.36
168	439.67	425.23	419.32
336	431.34	419.88	415.34
504	417.13	415.22	412.82
672	414.03	412.62	409.15

Results in table 1.8 show that the weight of the mild steel pipe reduces with time of burial in soil. This occurred as the result of increase in corrosion rate with time.

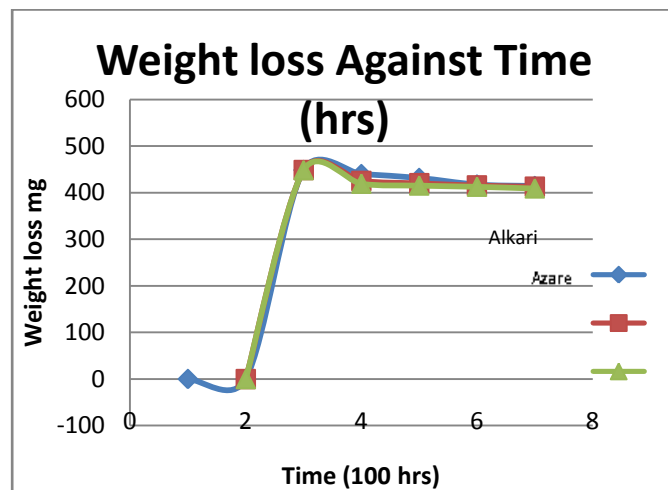


Figure 4: Weight loss Against Time (hrs)

From the results of the experiment, it could be seen that as time goes on the weight loss for all samples as shown in the figure 4 keep increasing until around 400 hours when the rate of the loss becomes steady with time.

From figure 5 soil pH appears to increase with corresponding time. Azare sample has the highest values of pH while Alkali sample has the least pH values although there are minor fluctuations. These values have a huge influence on the corrosion rates of the mild steel.

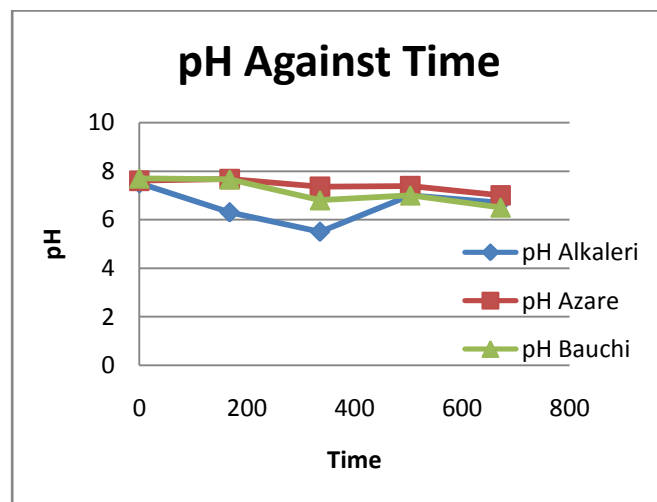


Figure 5: pH Against Time (hrs)

Soil resistivity is 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, the results of the experiment show that the resistivities gradually dropped with time thus leading to a steady rise in the corrosion rate see figure 6.

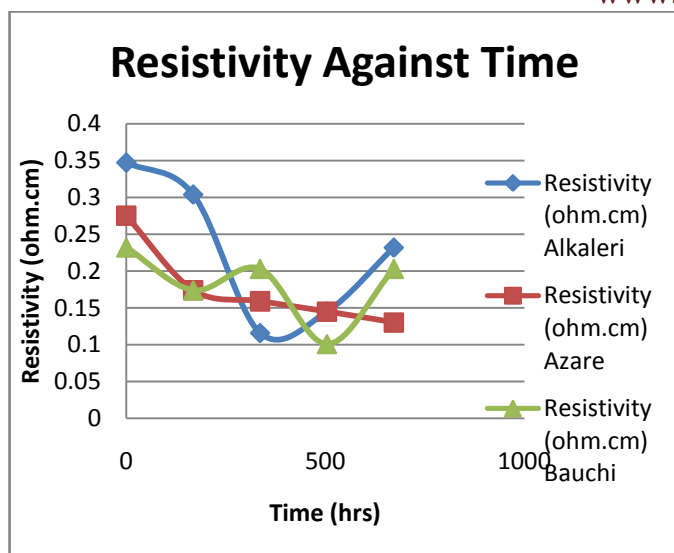


Figure 6: Resistivity (ohm .cm) Against Time (hrs)

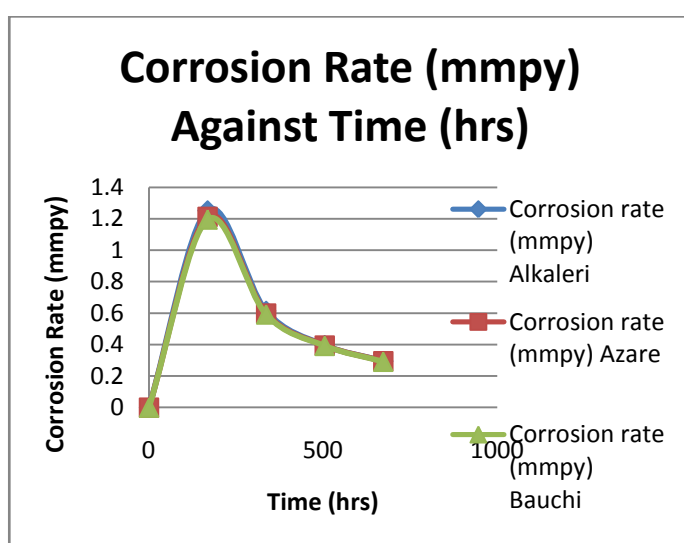


Figure 7: Corrosion Rate (mmpy) Against Time (hrs)

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 7 shows explicitly the relationship between corrosion rate and time. From the figure below weight loss of soil from Bauchi had the highest corrosion rate which is an indicative of the inherent properties of the soil. But based on the trend with time, alkali sample would be the most corrosive.

CONCLUSION

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 a distinct pattern of relationship between variations of averaged corrosion rates and soil properties. Also, time plays a major role in the corrosion rate of steel buried underground.

From this research, it was observed that soil obtained from Bauchi area is more corrosive compared to soils obtained from Alkali and Azare due to the fact that it has the highest sulfate content coupled with low resistivity.

It was also observed that the measured corrosion rates from the loss of weight of buried steel pipes may be dominantly caused by factors such as fungi, bacteria, chloride content, sulphate content, organic content and salinity.

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