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Evaluation of Soil Corrosion for Low Carbon Steel Pipeline in Minna Environment

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ABSTRACT

The research work was investigated to evaluate the potential corrosiveness of soil samples collected from FUTMinna forest along Bida road, Niger State, for their physicochemical properties in steel. Soil samples were collected from five different points to a depth of 1.5 meters. Standard analytical methods were employed on the determination of physicochemical parameters such as pH, resistivity, redox potential, moisture, chloride, temperature and sulphate and samples were evaluated using DVGW, Eyre & Lewis, and AWWA C105 numerical scale. The soil samples are found to be clay and they read pH (5.77-7.48), resistivity (145-193 Ω -m), moisture (4.11-5.73 %), chloride (191-375 mg/kg), and sulphate (240-684 mg/kg). From the results, resistivity, pH, chloride and moisture could be a vital role in the corrosion of buried pipelines. Approaches adopted to investigate these factors elucidate the conditions of the soil samples. Thus, buried steel structures in the area should be protected by organic coating followed by cathodic protection to prevent any form of corrosion.

Keywords: Corrosiveness, soil, resistivity, pipelines, protection

1. INTRODUCTION

Corrosion of metals in soil is the causes of durability issues of sewage, water, oil and gas distribution systems. Soil corrosion was the fundamental cause of deterioration of underlay pipelines. For instance, the ferrous metal of pipes was susceptible to soil corrosion (Song *et al.*, 2017). As the increasing of use of underground pipelines, the deterioration of pipeline steels in soils becomes an imperative problem, thus affect the normal operation of pipeline resulting to safety and economic effects (Ossai *et al.*, 2015). Soil corrosion is the fundamental cause of deterioration of buried pipeline which results in material degradation. The deterioration of material results in loss of mechanical properties like strength, ductility and impact strength, resulting to loss of material, reduction in thickness, and at times ultimate failure (Wasim *et al.*, 2018). Recent industrial catastrophes have it that industries have lost several billions of dollars as a result of soil corrosion. Reports around the globe have confirmed that some oil companies had their pipeline

ruptured which no doubt created environmental pollution, besides, resources are lost in cleaning up this environmental mess, and finally, large-scale ecological damage resulted from soil corrosion effect (Oluduro and Oluduro, 2015; Zhu *et al.*, 2015). The possibility of occurrence of corrosion has been posing a lot of concern to petroleum, chemical, and mechanical engineers. Therefore, the pipeline steels in the soil are affected by factors such as types of soil, soil water content, soil pH, electrical resistivity, salinity, chemical constituents, porosity amongst others (He *et al.*, 2017). However, the researches on the soil corrosion behaviour of low carbon steel pipeline are still inadequate. Thus, it is essential to determine some factors that influence soil corrosion; this knowledge will allow an in-depth understanding of the problem and the design of appropriate protection systems in future.

In this work, therefore, assessment of soil corrosion such as soil resistivity, moisture content, pH, redox potential, soluble ion content, and bacteria activity on



different soil samples was done. This study presents the findings of the soil corrosivity testing to determine whether the soil is acidic or alkaline in comparison with the standard methods of analysis.

2. MATERIALS AND METHODS

2.1 Sample Collection

Minna is the capital of Niger State in North-Central Nigeria, with a population of 304, 113 (in 2007), and 27% humidity. It is within latitude and longitude of 9°36'50"N and 6°33'25"E, respectively at an elevation of 2.43 meter above sea level. The main crops planted in the area are yam and maize. The soil is clay in nature. The previous study of the meteorology of the area reveals the atmospheric temperature to be 27 °C in the rainy season, 39 °C in the dry season and 21 °C during harmattan.

Soil samples were collected from five pits dug at 1.5-meter depth each from the vicinity of the Federal University of Technology, Minna (FUTMinna) forest in March 2018. They were collected into airtight polyethene bags to avoid loss of moisture content. The samples were transferred to the laboratory prior to analysis.

2.2 Soil corrosivity parameters

Adopting the DVGW, Eyre and Lewis and AWWA C105 standard methods for soil corrosivity, the following parameters were analyzed based on the buried metal pipeline; soil resistivity, moisture content, pH, redox potential, soluble ion content, temperature and bacteria activity.

2.2.1 Resistivity

Using the ASTM (G.57) standard test method for field measurement of soil resistivity, the Wenner four-electrode method was used, four steel electrode, each spaced at equal distance of 1 meter from the next are driven into the ground by the use of a sledgehammer. The electrode A and B are current electrodes which are connected to a current source (resistivity meter). Electrodes C and D are used for the voltage measurement. Here an alternating current (AC) or direct current (DC) is passed between the outer two electrodes and the corresponding potential drop (voltage DC) is measured between the two inner electrodes.

2.2.2 Moisture content

According to the ASTM G51-95, the weight-loss technique was used, where the weight differences between the soil sample before and after evaporation was regarded as the moisture. 100 g of sieved soil sample was poured into a pre-weighted beaker as W_2 , meanwhile, the empty beaker 100 cm³ was weigh W_1 . The beaker is placed in an electric oven at a temperature of 105 °C for 24hours. After the soil sample had dried, the beaker now weigh W_3 was then removed from the oven and allowed to cool in a desiccator, so that the operation of the weighing balance will not be affected. The value of moisture content was evaluated using equation 1.

$$\text{Moisture content (\%)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (1)$$

2.2.3 pH and redox potential

According to ASTM G51-95, the pH of the soil sample was determined using 2 mm sieved soil sample collected, here, 20 g air-dried soil was weighed and poured into a 50 cm³ of the beaker. 20 cm³ of distilled water was added to the soil sample in the container, the mixture was stirred with a glass rod and allowed to settle for 30 min. The pH electrode was then inserted into the solution and measured using a pH meter (model) (PHS-25). The redox potential of the sample was measured according to the standard method of BS1377-3: 1990(BSI, 1990b).

2.2.4 Bacteria activity

The laboratory experiment was performed according to BS 1377-3, about 28 g of nutrient agar was weighted into a 100 cm³ conical flask, and 100 cm³ of distilled water was added to it and corked. Also, 39 g of potatoes dextrose agar (PDA) was weighed and transferred into 100 cm³ conical flask and distilled water added to it and corked. The prepared medium was autoclaved at 121 °C for 15 min. The molten agar was allowed to cool to about 45 °C and poured into a sterilized dry petri-dish and allowed to solidify. Inoculation of the soil sample, 1g of the sample each from the five different soil samples collected was weighed and transferred into 9 cm³ of sterilized distilled water in a test tube and homogenized. A loop of the sample was taken and streak on the agar in the culture plate and incubated at 37 °C for 24 h for bacteria and 27 °C for 72 h for fungi.



2.2.5 Sulphate in Soil

According to BS 1377-3; 1990 (BS1 1990a), the soil sample pulverized to pass 500 mm sieve, 20 g of the sample was weighed and transferred into a 500 cm³ sample bottle. 400 cm³ of deionized water was then added to provide the initial dilution ratio of 1:20. The mixture is agitated for 30 min using a mechanical shaker and allowed to settle for 12 h. 10 cm³ of the collected filtrate was transferred into a clean and ripped sample vial. One sulphate test tablet was added into the vial without touching the tablet with hand and crush immediately with a white plastic rod. The vial was then capped and wiped clean with a soft tissue material and was immediately placed in the sample chamber of the colorimeter. The absorbance was obtained by the formula in equation 2.

$$Y = Mx + C \quad (2)$$

$$x = \frac{Y - C \times \text{Dilution factor}}{M} \quad (3)$$

Y = Absorbance of standard
 X = Concentration of sample
 C = Intercept on the Y-axis
 M = Slope from the graph

2.2.6 Chloride in Soil using Argentometric

Methods

In the determination of chloride in the soil sample, 100 g of dried soil sample was measured into a 500 cm³ Erlenmeyer flask and 300 cm³ of distilled water was added. The solution was placed on a mechanical shaker for 20 min vigorously and allowed to stand for 12 h. The sample was filtered using Whatman filter paper No. 42 into a 500 cm³ Erlenmeyer flask. Thereafter, the samples were titrated with 5 % potassium dichromate (K₂CrO₄) as an indicator, and with 0.014 M silver nitrate (AgNO₃). The mixture was titrated from. The end-point (yellow to reddish-brown colour) of the solution was observed and recorded. The concentration was calculated using the formula in equation 5

$$\text{Chloride (Cl}^{-}\text{)} = \frac{35.5 \times C_b \times V_b}{\text{Vol. of sample}} \times 100 \quad (4)$$

Where C_b and V_b are the concentration and volume of AgNO₃, respectively.

3. RESULTS AND DISCUSSION

The soil corrosivity parameters of the soil samples are shown in Table 1. The properties are potential environmental factors that could enhance corrosion. These factors showed no correlation of results to each other. The soil moisture content has a synergic effect on the soil aeration which is influenced by rainfall and microbial activities.

Table 1: Soil corrosivity/aggressivity values

Soil pits	pH	Resistivity (Ω-m)	Moisture content	Soil type	Chloride (mg/kg)	Sulphate (mg/kg)	Redox (mV)	Temp (°C)
1	6.63	161	4.66	Clay	188	240	-90	38
2	7.48	193	5.73	Clay	191	242	-87	38
3	6.71	151	4.22	Clay	375	680	-95	38
4	6.11	187	5.58	Clay	372	684	-80	38
5	5.77	145	4.11	Clay	234	490	-95	38



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The three (3) original assessment method of soil corrosivity assessment techniques used in this study are German Gas and Waterworks Engineers Association Standard (DVGW GW9), Modified Eyre and Lewis System and American Water Works Association (AWWA) 10 points method. From the results obtained, the following assessment was made in Table 2.

Table 2: Showing the standard used for the assessment of soil corrosivity

Standard	DVGW	Eyre & Lewis	AWWA
Resistivity	-4	-3	10
Moisture	-1	1	1
pH	0	0	0
Chloride	-1	-2	-
Sulphate	-2	-2	2
Redox	-	-4	5
TOTAL	-8	-10	23

The resistivity of soil samples was within the range of 151-193 Ω -m. Generally, high soil resistivity will slow down the corrosion activities due to less ionic content flow, between buried pipe surface and corrosive soil environment, the resistivity will decrease when the water content and concentration of certain ions increase (Wasim *et al.*, 2018). Therefore, the conductivity and corrosivity of the soil are measured by its resistivity, so the higher the resistivity value, the lower the corrosion rate, as there is more resistance to the flow of current. Result of the resistivity shows low values. Using table 3 below, the DVGW, Eyre & Lewis and AWWA show a resistivity of -4, -3 and 10 points respectively, hence the soil samples can be classified as corrosive.

The low moisture content can be attributed to the low groundwater level (as a result of collecting the soil sample in March), soil with high moisture content, has a high value of corrosion rate. From Table 2, using the standard assessment technique, the moisture content is low and assigned the points -1, 1 and 1 for DVGW, Eyre & Lewis, and AWWA C105 numerical scale for soil corrosivity.

The pH of soil generally, fall within the range of 4-10. The samples were acidic because it falls within the

range of 6.11-7.48 as shown in Table 1. The pH of the soil could cause a potential effect on pipeline corrosion. However, it is important to note that the soil slightly neutral (pH 7.48) may become acidic due to the influenced of acid rainfall and acid yielding bacterial organism in the soil. The acidity of the soil environment may have resulted from the humic acid formed from organic matter. The acidic medium of soil sample promoted its corrosivity (Soriano and Alfantazi, 2016). However, evaluating the corrosivity of the soil samples against its pH, using the standard techniques, a corrosive index of 0 was obtained as can be seen in Table 2. This implies that the soil samples were not corrosive.

Bacteria activities were noticed in the soil samples. There were some organisms present in the soil sample which will cause soil corrosion. The organisms were identified as bacteria and fungi which produce biofilm, acids and metabolites. The biofilm help bacteria to anchor to the surface, after a long time causes corrosion as a result of metal degradation (Loto *et al.*, 2017). The production of acid like acidothiobacillus causes stress cracking. Some metabolite reacts with metal and their accumulation to pipes lead to corrosion as a result of perforation.

The contents of sulphate in the soil samples gives a slightly corrosive action with readings between 240-684 mg/kg as shown in Table 1. Sulphate is generally considered to be more benign in their corrosive actions towards metabolic materials, attacks concrete and chemically change the binding compounds causing expansion, cracking and loss of strength (Moore, 2019). In reinforced concrete structures, sulphate attack may expose the rebar to corrosion by other compounds such as chloride. The experimental results are not in agreement with the finding of desiri-Eruteyan *et al.* (2020) who stated that sulphate is in the range of 156.14 to 848.50 mg/kg. Using the standard technique for assessment, as presented in Table 2, sulphate has DVGW (-2), Syre & Lewis (-2) and AWWA (2).

Chloride ions are generally harmful, as they participate directly in the electrochemical reactions that take place during the corrosion process (Xia *et al.*, 2019). The chloride content (mg/kg) in the soil samples is between 188-375 mg/kg as shown in Table



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1 and it shows the level is corrosive. Thus, this showed that the soil might destroy the stable layers of protection that can naturally form on the surface of some metals, exposing the unprotected metal to further corrosion. However, using the standard assessment method in Table 2, DVGW is -1, while Eyre & Lewis is -2.

The evaluation of soil parameter was done separately and points allocated to each depending on the extent to which it contributes to the corrosivity of the soil. In Table 2, the final corrosivity index was summed to be -8 for DVGW, to Eyre & Lewis -10, and AWWA C105 23. According to DVGW, Eyre & Lewis and AWWA C105, an index of 0 to -4 is slightly corrosive, -5 to -10 is corrosive, and -10 or less is very corrosive. From the analysis, DVGW is -8 (corrosive), Eyre & Lewis is -10 (corrosive), and AWWA C105 is 23 (corrosive). Therefore the soil samples tested are corrosive.

4. CONCLUSION

The physicochemical properties such as pH, resistivity, moisture, texture, sulphate, chloride and redox potential in soil samples were analyzed and presented in this paper. Relations were established between resistivity and moisture among the soil samples examined. From the results of the studies, it is well-known that the soil samples are the clay, categorized to possess milder corrosiveness potential towards buried steel and cast iron pipelines. The significance of this finding is that the soil samples are corrosive, therefore buried steel materials in the area must be protected by organic coating followed by cathodic protection to prevent any form of corrosion between steel surface and soil environment.

REFERENCES

He, B., Han, P., Hou, L., Zhang, D., & Bai, X. (2017). Understanding the effect of soil particle size on corrosion behavior of natural gas pipeline via modelling and corrosion micromorphology. *Engineering Failure Analysis*, 80, 325-340.

Loto, C. A. (2017). Microbiological corrosion: mechanism, control and impact-a review. *The International Journal of Advanced Manufacturing Technology*, 92(9-12), 4241-4252.

Moore, A. (2019). Effect of oxygen availability on the corrosion rate of reinforced concrete in marine exposure zones: inference from site and lab studies (Doctoral dissertation, Engineering and the Built Environment).

Odesiri-Eruteyan, E. A., Owarieta, U. V., Tochukwu, N. P., & Favour, E. (2020). The Potential Corrosiveness of Soil Physico-Chemical Properties on Pipelines. *Journal of Scientific Research and Reports*, 99-108.

Oluduro, O. F., & Oluduro, O. (2015). Oil Exploitation and Compliance with International Environmental Standards: The Case of Double Standards in the Niger Delta of Nigeria. *JL Pol'y & Globalization*, 37, 67.

Ossai, C. I., Boswell, B., & Davies, I. J. (2015). Pipeline failures in corrosive environments—A conceptual analysis of trends and effects. *Engineering Failure Analysis*, 53, 36-58.

Song, Y., Jiang, G., Chen, Y., Zhao, P., & Tian, Y. (2017). Effects of chloride ions on corrosion of ductile iron and carbon steel in soil environments. *Scientific reports*, 7(1), 1-13.

Soriano, C., & Alfantazi, A. (2016). Corrosion behavior of galvanized steel due to typical soil organics. *Construction and Building Materials*, 102, 904-912.

Wasim, M., Shoaib, S., Mubarak, N. M., Inamuddin, & Asiri, A. M. (2018). Factors influencing corrosion of metal pipes in soils. *Environmental Chemistry Letters*, 16(3), 861-879.

Zhu, Y., Qian, X. M., Liu, Z. Y., Huang, P., & Yuan, M. Q. (2015). Analysis and assessment of the Qingdao crude oil vapor explosion accident: lessons learnt. *Journal of Loss Prevention in the Process Industries*, 33, 289-303.

Xia, J., Li, T., Fang, J. X., & Jin, W. L. (2019). Numerical simulation of steel corrosion in chloride contaminated concrete. *Construction and Building Materials*, 228, 116745.