Soil Physico-Chemical Charateristics And Metalic Corrosion In Parts Of The Niger Delta

Irunkwor T. C, Ngerebara O. D

*Abstract*— Soil physico-chemical parameters such as pH, organic matter, chloride and sulphate contents were investigated to assess their effect on buried metallic pipes for a proposed gas processing plant facility at Ovade-Ogharefe, Delta State, Nigeria. Ten sampling points along the pipeline route were investigated. Thus, a total of 10 borings each to a depth of 10.0m were drilled along the pipeline route using the Shell-and-Auger Percussion Rig to collect subsurface soil samples for laboratory analyses for physico-chemical characteristics. Soil pH was determined in-situ electronically using the glass electrode method with a standard calibrated pH meter. On the average, the soil is sandy clayey in nature and the results of the parameters tested are as follows: pH (5.2-7.5), chloride (8.9-85.4ppm), sulphate (126.3-266.5ppm) and organic matter content (0.41-0.42%). The low pH values of 4.2, 5.2, 5.3 and 5.5 as well as the high sulphate contents above permissible limit respectively at locations BH7, BH8, BH9 and BH10 implies that the soil is acidic and deleterious to buried metallic pipes which is characteristic of clayey soils. It is recommended that the metallic pipes along the pipeline route be buried within the depth of 2.0 to 3.0m because that is the zone or layer of high pH, low chloride and low sulphate contents. However, the impressed current cathodic protection method is therefore recommended to minimize corrosion impact on the proposed gas pipeline.

Index Terms— Cathodic Protection, Corrosion, Metallic Pipes, Soil Resistivity

I. INTRODUCTION

Statistics have shown that the quantity of gas flared in Nigeria exceeds 40% of the gas flared annually across Africa, which amounts to above $7billion in waste [1]. As a measure to curb this environmental problem, the Pan-Ocean multi-national oil company decided to take advantage of the economic benefits in converting the flared gas into liquefied natural gas, domestic cooking gas and other uses. This has necessitated the construction of gas transportation pipelines where metallic pipes are buried underground to transport the gas by land from the production area to the distribution terminal. All such pipelines are buried beneath the earth surface to a depth of about 1.5 meters for the purpose of security and safety. However, variations in soil properties and characteristics can have a major impact on corrosion process of any buried metallic structures. Typically, according to [2], the most corrosive soils are those with low resistivity, low pH, high concentration of chlorides and sulphates. Wet conditions are particularly difficult since these can result in concentration of corrosive species and mechanical action that

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tend to breakdown protective corrosion films and coatings on the metal surface. Iron rusts when it comes into contact with air and water because electrochemical cells are set up at the surface of contact [3]. Thus corrosion is an electrochemical process that involves the passage of electric currents on a micro or macro scale. The change from the metallic to the combined form according to [4] occurs by 'anodic' reaction:

$$Fe \longrightarrow Fe^{2+} + 2\bar{e}$$
(metal)   (soluble salt)   (electron)
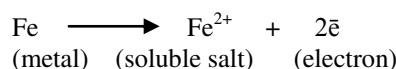
This reaction produces free electrons, which passes within the metal to another site on the metal surface (the cathode) where it is consumed by the cathodic reaction. In acid solutions, the cathodic reaction is:

$$2H^+ + 2\bar{e} \longrightarrow H_2$$
(Hydrogen ions in solution)   (gas)
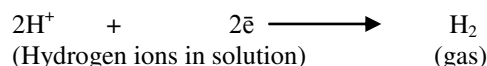
In neutral solutions, the cathodic reaction involves the consumption of oxygen dissolved in the solution:

$$O_2 + 2H_2O + 4\bar{e} \longrightarrow 4OH$$
(Alkali)
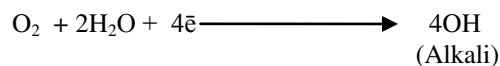
Corrosion thus occurs at the anode, but not at the cathode (unless the metal of the cathode is attacked by alkali).

Sometimes the anode and cathode in a corrosion process may be on two different metals connected together to form a bimetallic couple, or as with rusting of steel, they may be close together on the same metal surface [4].

Most pipelines are made up of low carbon steel allied with C-Mn. Low carbon steel, although susceptible to corrosion is widely used because of its low cost, high strength and the ease of field make up by welding. Crude oil and gas pipelines in Nigeria are usually protected externally by wrapping with cement or polyamide or epoxy resin coating couple with a cathodic protection system with minimum specific potential of -850mv (Cu/CuSO$_4$). Corrosivity of soils to buried structures is mainly influenced by 6 soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride contents and sulphate contents [5], [6], [7], [8], [9] and [10] opined that it is important to maintain the structural integrity and prolong the effective lifetime of pipeline systems through the design and installation of cathodic protection (CP) systems.

Cathodic Protection is an effective method of preventing stress corrosion cracking such that electrochemical potential is measured with reference electrode. Copper – Copper (II) sulphate electrode are used for structures in contrast with soil or fresh water. Silver chloride electrodes are used for sea water applications [11], [12].

The objective of this study therefore is to determine the soil physico-chemical properties with respect to corrosion of the metallic gas pipeline and to recommend appropriate control/mitigative measures.

II. THE STUDY AREA

Ovade-Ogharefe, in Ethiope West Local Government Area of Delta State, Nigeria, is located approximately on Latitude 06^0 25' North of the Equator and Longitude 05^0 43' East of the Greenwich Meridian (Figure 1).
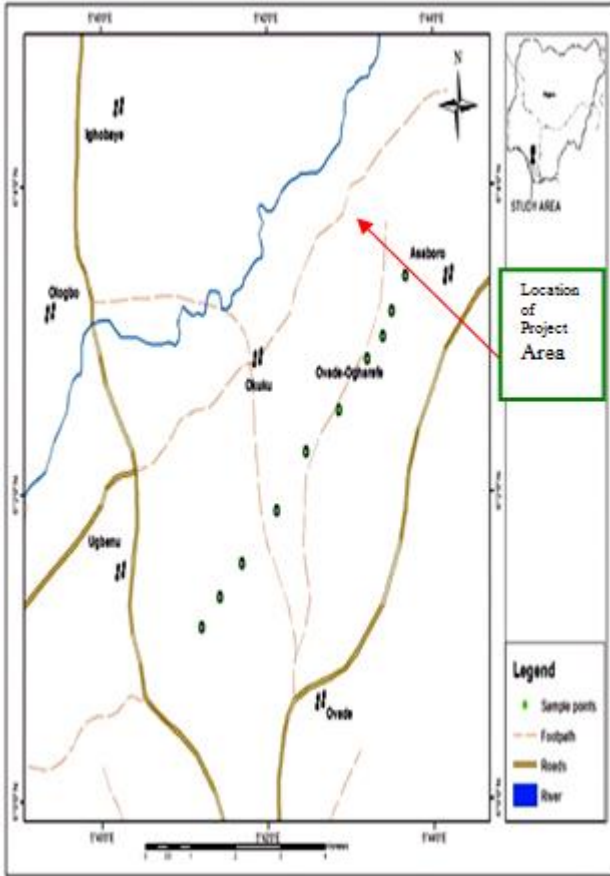

Figure 1: Location of the study Area in Ethiope West Local Government

2.1 Regional Soil in the Niger Delta

The site sits astride section of the *Benin Formation* often called *the Coastal Plain Sands* (Qp) of the lower Quaternary (Pliocene-Pleistocene) and Aluvium of the upper Quaternary (Recent Sediments) and consists of silty clayey sands, sand and gravels. The general topography is relatively flat lying and the sediments are partly marine and partly fluvial in origin. The region is traversed by flat-floored river Ethiope that drains into the Atlantic Ocean. The river Ethiope is prone to flooding especially during the wet season, mainly because of the heavy rainfall, high ground water table and the flat-floored valleys (figure 1). The soil of the area is poorly drained and low in nutrient due to leaching effect resulting from high precipitation [13]. Soil types in Nigeria are influenced by topography and follow very broadly, the climatic and vegetation zones of the country. The Nigerian soils have been classified into four major groups which are: (i) northern zone of sandy soils (ii) interior zone of laterite soils; (iii) southern belt of forest soils; and (iv) zone of alluvial soils [14], [15]. The Niger Delta region where the study area is located lies within the southern belt of forest soils and zones

of alluvial soils. The southern belt of forest soils broadly represents those of the humid, tropical forest climate zones. Variations in local soil types in this zone depend largely on parent rock. The forest soils yield cocoa, oil palm, rubber and they are of considerable importance in Nigerian agriculture. The alluvial soils found in this zone do not depend highly on climate and vegetation for their formation [16]. The underlying parent rock is the most important factor in their formation. Soils in this zone have characteristics of fresh-water soil of grey to white sand, grey clay and sandy clay with humic topsoil. Another soil group consists of brownish to black saline mangrove soils, with a mat of rootlets [16].

III. MATERIALS AND METHODS

Ten sampling points along the pipeline route were investigated. Soil sampling is done by means of drilling, using Shell-and-Auger percussion Rig to enable the determination of the soil physico-chemical properties. The soil pH was determined in-situ electronically using the glass electrode method with a standard calibrated pH meter. This is because the chemistry of soil is sensitive to environmental changes [17].

Soil samples were collected through boring at intervals of 1.5meter to a depth of 10 metres for a total of 10 sampling points at 2.0 meters apart. Soil samples were taken into an air-tight polythene bag and were subjected to laboratory test for physico-chemical properties. The concentration levels of chloride ion, sulphate ion, organic matter content, soil moisture content and the pH were determined.

IV. RESULTS AND DISCUSSION

The results acquired from soil pH, chloride ion concentration, sulphate ion concentration and organic matter contents are presented in table 1.

Table 1: Chemical Contents of Soils from the Project Site

Sample Location	Depth of Samples (m)	pH Value	Cl⁻ (ppm)	SO₄²⁻ (ppm)	Organic Matter (%)
BH_1	0-1	7.5	8.9	126.3	0.43
BH_2	1-2	6.4	8.9	127.7	0.41
BH_3	2-3	6.2	8.9	129.3	0.42
BH_4	3-4	6.2	9.5	139.5	0.43
BH_5	4-5	6.1	10.7	153.2	0.42
BH_6	5-6	6.8	13.9	185.4	0.4
BH_7	6-7	5.5	28.4	221.7	ND
BH_8	7-8	5.3	45.7	228.6	ND
BH_9	8-9	5.2	51.4	236.5	ND
BH_{10}	9-10	4.2	26.2	242.7	ND
Mean Value		5.9	21.3	179.1	

*ND – Not Detected

Sulphate Content

The sulphate contents of the soil materials were observed to vary from 126.30 ppm to 242.70 ppm. The recommended permissible standard by AASHTO T-290-291 is 200 ppm, meaning that the concentration level is higher at certain depth which portends some serious corrosion effect on metals. However, from the surface to a depth of six meters (6.0m) the sulphate concentration is below AASHTO T-290-291 recommended permissible standard and this is within *pH* medium of of 7.5 to 6.8 (an acidic environment) the soil becomes mildly corrosive (table 2).

Chloride Content

The Chloride Contents ranged from 8.9 ppm to 51.4 ppm with an average of 21.30 ppm, indicating that chloride level is below the maximum level of 100 ppm as recommended by AASHTO T-290-291; hence it has no serious corrosive effect on buried metals. However, in an acidic environment this level of chloride in the soil is seen to be mildly corrosive (table 2). Although chloride values are low, the presence of chloride in the soil also tends to

decrease the soil resistivity which makes it to be potentially harmful to buried metallic pipes.

Organic Acid (Matter) Content

The organic matter contents of the soil materials in terms of Total Carbon were observed in some borings to be between 0.40% and 0.43% and at some points not indicated at all, which indicates absence of any trace of crude oil pollution within the area at the time of investigation. According to AASHTO T-267-86, for Total Organic Content to preclude the formation of anaerobic pockets, it should be limited to 1% by weight of the total soil fraction.Therefore, the presence of organic matter in the area will not be deleterious to the buried metal pipes.

Table 2: Degree of Corrosivity as a Function of Soil resistivity, Soil pH, Water Soluble Chloride and Sulphate Concentrations in the Soil [18]

Soil Resistivity (Ωm)	Water Soluble Chloride Concentration (ppm)	Water Soluble Sulphate Concentration (ppm)	pH Level	Degree of Corrosivity
0.5	Over 5,000	Over 10,000	-	Very Severe
5-10	1,500-500	1,500-10,000	<5.5	Severe
10-20	500-1,500	120-1,500	5.5-6.5	Moderate
20-100	Below 500	-	6.5-7.5	Mild
Above 100	-	0-150	> 7.5	Negligible

pH Values

Water table was not reached at the depth of boring, but the pH of soil samples were obtained with an average value of 5.9. [19] suggested that acidic environment with pH < 6 are more corrosive than pH from 6-8 or alkaline (pH > 8). When compared with the pH scale in table 3, the soils are seen to be moderately acidic which are characteristic of clayey soils and this will create un-conducive environment for buried metal pipes.

Table 3: pH Scale [20]

pH	Denomination or Classification
<3.5	Ultra Acidic
3.5-4.4	Extremely Acidic
4.5-5.0	Very Strongly Acidic
5.1-5.5	Strongly Acidic
5.6-6.0	Moderately Acidic
6.1-6.5	Slightly Acidic
6.6-7.3	Neutral
7.4-7.8	Slightly Alkaline
7.9-8.4	Moderately Alkaline
8.5-9.0	Strongly Alkaline
>9.0	Very Strongly Alkaline

V. CONCLUSION

Corrosion risk assessment has been estimated by [18] where the soil resistivity, chloride ion concentration, sulphate ion concentration and pH values are used to predict the degree of corrosivity of soil as described in table 3. Comparing tables 1 and 3 we observe that the chloride ion concentration, sulphate ion concentration and pH values of the soil for this study falls in the category of mild to moderate degree of soil corrosivity. The aggregate effect of clayey soil, acidic environment, low sulphate concentration and low chloride concentration in the soil within the area makes for increased reactivity that will trigger off corrosion on any buried metallic pipe. Thus, clayey soils have low resistivity and high corrosivity at low pH, and those that are contaminated with crude oil and saline water are severely corrosive at low pH values less than 5.5. To mitigate/control the effect of any corrosion, the impressed current cathodic protection method is recommended since the average soil resistivity value of 50Ω-m (which is the threshold value between the impressed current cathode protection and the sacrificial (Galvanic) anode cathodic protection) can be achieved in this environment.

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