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Research Article

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Special Issue

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Effect of Soil Physical Properties on the Corrosion of underground API 5lx70 Steel Pipeline along Kaduna-Kano, Nigeria

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Abstract
This study was conducted along a 130km transect to assess the impact of some soil physical properties on buried API 5L X70 steel pipeline conveying petroleum products from Kaduna to Kano. Nine (9) soil samples were collected at an interval of 14.6km at a not less than one-meter depth. Laboratory analyses were carried out using pH for soil acidity or otherwise, the Gravimetric drying method using Weight differences for soil moisture and Bouyoucos method for soil texture determination. The results along the transect showed a pH range of 4.1 – 8.2, a moisture range of between 20 – 40%, and clay contents between 1- 10%. An API 5L X70 steel pipeline coupon of 60x40x10mm was then buried for 120 days in each sample to determine corrosion rates. Based on the results, corresponding corrosion rates were obtained to be between 0.0043 – 0.05mg/dm^2/yr along the transect, signifying a relative increase in corrosion along the 130km pipeline, implying relatively varied corrosion rates occurrence with all the three parameters been positive and impactful the pipeline's corrosivity.

Keywords: Soil properties, corrosion, underground API 5L X70 steel pipeline (Application Programming Interface), Kaduna-Kano

1. Introduction

The process of materials (typically metals) gradually deteriorating as a result of chemical or electrochemical reactions with their surroundings is known as corrosion. It is denoted by the degradation of a material—typically a metal—caused by an environmentally induced chemical or electrochemical reaction (NACE/ASTMG193). Despite the discovery of alternate energy sources, the need for fossil fuels grows due to the world's increasing population expansion and industrial development. According to reports, around 60% of the world's energy needs are met by oil and natural gas (Mahmoodian & Li, 2017 and Davis, 2006). As a result, there is a lot of interest in the transportation of gas and oil. Pipelines are extensively been used as means of transmission/ conveyance. The pipelines network may be as long as thousands of kilometers, passing through different environmental and geographical conditions (Vanaei & Egbewade, 2017; Satish & Sachin, 2017). The long distance travels over different climatic and edaphic conditions by the pipelines predispose them to corrosion at various categories.

Corrosion categorization range from: general, steel atmospheric, pitting, leaching, crevice, inter- granular, stress and cracking corrosion etc. Corrosion in underground pipelines is a serious worldwide issue. It accounts for a large portion of the annual expenses that gas and oil producing enterprises across the globe bear. It also results in pollution of the environment, depletion of water resources, and fatalities. Due to the heat-affected fusion's microstructural alterations, the issue is made worse if welded joints are involved. However, the welding of subterranean pipelines is unavoidable due to the growing need for the transfer of gas and oil across many places in

Nigeria. Understanding how soil characteristics and welding parameters affect the corrosion behaviour of welded pipelines is essential to allay these worries. Most often times heat affected zones (HAZ) play an important role on corrosion impact on steel pipelines. Welding technology plays a major role in the fabrication of pipelines network, especially in long-distance projects. The microstructure and properties of welded zones are often significantly different from those of the base metal (Shiranzadeh, *et. al.,* 2015). Owing to the combination of appropriate materials selection, good design and operating practices, oil transmission pipelines are safe to an acceptable level.

According to Weigang, Dilan, Annan, and Chun-Qing, (2018), corrosion is characterized by two time-independent parameters in each sample, that is, the proportionality (k) and exponent (n) factors of the power law model. Weigang, et al, (2018), classified that the exponent factor n of power law model was closely associated with the level of soil aeration. The work also found that grouping corrosion data based on soil aeration produced stronger correlations between soil properties and corrosion rates compared with that when taking all soil samples as a whole. The authors concluded that an appropriate classification of soils could benefit the identification of key factors influencing corrosion of buried iron pipes at different exposure times including heat affected zone in the pipeline.

Parameters involved in the analyses include, pH which is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, αH+. This definition was adopted according to FAO. (2021) because ion selective electrodes used to measure pH respond to activity as:

$$pH = -\log 10\ [\alpha H+] = \log\ (1/[\alpha H+\ ]) \quad (1)$$

Gravimetric or drying method was used to determine soil moisture of the respective samples. This involved direct method of determining the moisture content by drying based on loss of weight due to loss of water through heating at 105 °C ± 5 °C the soil samples and weighing after constant weight was achieved the difference between the wet and dry sample weights. This method is precise and reliable, while recommended mostly for experimental work. And according to Black, (1968) it seemed that this temperature range has been based on water boiling temperature and does not consider the soil physical and chemical characteristics. The percentage proportions of sand, silt and clay in each sample were calculated using the respective equations: Similar calculations were done by Beretta *et al.* (2014).

The aim of the study was to determine the influence of soil physical parameters on the corrosion resistance of welded API X70 pipeline steel used in oil transportation in Nigeria. The research has the following objectives of the study are: To determine which of the major soil parameters has significant effect on the corrosion resistance on the pipeline steel being of high strength steel that is frequently used in oil and gas industry's pipelines due to its superior mechanical qualities and resistance to corrosion.

2.0 Material and methods

The study area is located along Kano- Kaduna axis. Kaduna State is located at the Northern part of Nigeria's high plains. The soil is mostly loamy to sandy. A substantial amount of clay is found also (Yusuf, 2015). The Kaduna state is located between latitude 10°38'58" and 10°25'36" N of the equator and to longitude 7°22'14" and 7°32'00" E of Greenwich meridian.

The properties of soil are considered as one of the most important parameters that influence corrosion rate of welded steel pipelines included soil pH, moisture and soil texture. Through this point, the investigation of soil the characteristics in this research came out. Thus, soil properties of the terrain that carries the underground pipelines transporting the refined oil from Kaduna to Kano State of Nigeria was examined. Nine soil samples were collected along the pipeline route; the route area consists of complex terrain and agricultural lands. The samples were taken from the depth of one meter from the ground in September 2023. The soil samples were then put into an air tight polyvinyl and then preserved with the desired inherent conditions in accordance with the ASTMD 4220-95. Conformed to Reapproved, 2000 (Standard Practices for Preserving and Transporting Soil Samples) where the procedure presented in this standard were primarily developed for soil samples that are to be tested for engineering properties. The samples collected at 14.5 km intervals using odometer and Global positioning system were labeled as 'S1, S2, S3, S4, S5, S6, S7, S8 and S9'. Materials used include: For soil moisture, grounder, weighing scale, drying oven, soil pH: pH meter, standard buffer solution and for soil textural classification, *Bouyoucos* method was used.

The API 5LX70 steel pipeline coupons were then prepared and cut into the size of 60x40x10mm and then buried into the soil samples inside plastic containers for 120 days as referred to as in ASTM 01-03 in ANYAWU et al., (2014). The corrosion rate was evaluated using the formular according to National Association of Corrosion Engineers (NACE RP0775):

$$CR = \frac{K\,X\,W}{A\,X\,D\,X\,T} \tag{2}$$

Where: K = A constant

W = Weight loss in grams

T = Time of exposure in hours

A = Area in cm^2

D = Density in g/cm^3

3.0 Results and Discussions

3.1 Soil pH: Field observations showed from site A- C has relatively poor to least availability of organic matter and appeared to be highly drained due to more porosity. Analytically, from the table below, the soil pH was found to be between the ranges of 4.0 – 8.4 The samples analysed have their pH between the acidic to alkaline range (Fig. 1). Therefore, the oil pipelines buried along the study area would definitely interact with the soil environment in relation to the soil features. The corrosion rate tends to increase with decrease in pH values. The corrosion is most likely to occur when the pH is <5.5 pH range, (Norhazilan, *et al.*, 2012 & CGS, (2024). Though water table was not reached at the depth of boring sampling, the pH of the soil samples obtained with an average value of 6.2, which Bradford, (1993) suggested that, acidic environment with pH <6 is more corrosive than pH from 6-8 or alkaline (pH <8) (Bradford, 1993) as depicted in Fig 1. When compared with the pH scale in table 1.0, the soils are seen to be acidic (4 – 5.5) i.e. sites A- C, sites D- F are slightly acidic. Whereas Sites G- I are moderately alkaline, with relative clay content are also found to be corrosive. All these will create un-conducive environment for buried metal pipes for corrosion to set in.

Based on the afore mentioned, the results showed that, the pH range exceeded the corrosion tendency level of 5.5 meaning that 4 – 8.4 clearly showed that corrosion is likely to set in as long as all other pre -requisites are present. According to research conducted by Sulaiman, *et, al,* (2014), adjustment of pH for soils from acidic to alkaline lead to increase in corrosion. Also, Oguzie, (2004) study indicated that, at any pH level corrosion structure beneath the soil becomes sensitive to it. Taking into consideration of pH inside is usually of great concerned to iron scope ranging from 4- 8.5. This has become evidence where the corrosion set-in started from 0.038 – 0.05 $mg/dm^2/yr$ as shown in Fig 1.

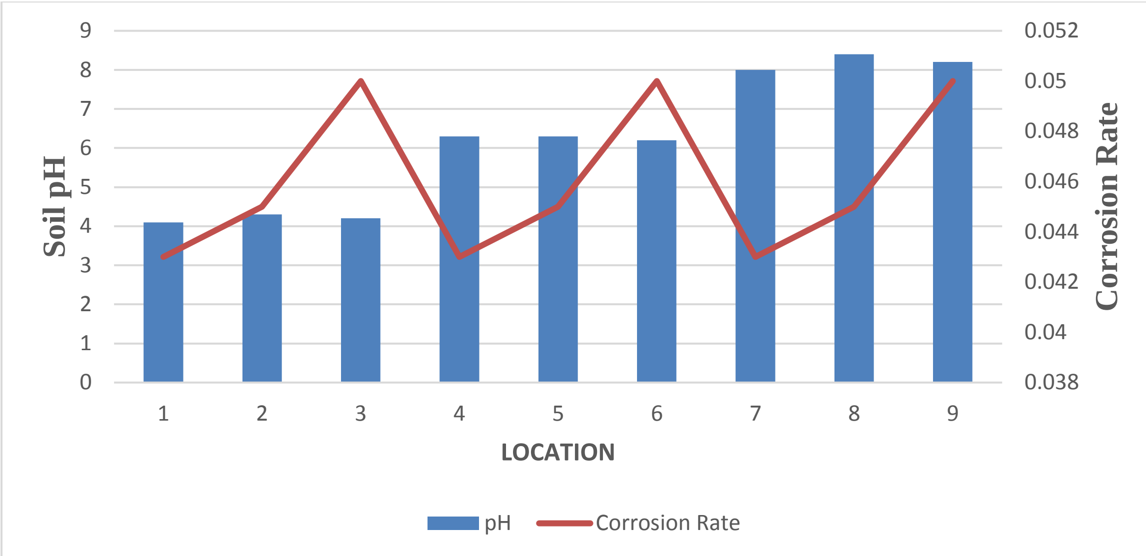

Fig. 1. Soil pH Relationship with Corrosion

3.2 Soil Moisture Relationship with Corrosion: There are several key factors that influence the extent and rate of metal corrosion in which soil moisture is of paramount importance, others being: the conductivity of the medium, pH, particle size distribution/ clay content and soil aeration. The soil moisture as a principal component of corrosion is characteristically affected by the climatic condition of the area under study. The result obtained is shown in table 4 ranged between 20 – 40% (all the sites). Metal corrodes at a much greater rate under damp conditions, this is in line with previous report by Hosni, Abdulla, Zakir and Ali El-Basir, (2020), where corrosion potentials were found to possess more negative values with rising soil moisture content. The corrosion rate kept increasing in coincidence with moisture regimes of 20- 40% moisture contents pertinent to sand, silt and with a corresponding corrosion rates of between 0.043- 0.05 mg/dm^2/yr in terms of contents in all the soils. For clay soils. From the results presented in table 4, the table showed varied percentages of soil moisture based on location which clearly show the prevalence of soil moisture in all the locations. Based on the results and chart below, it showed that the higher the soil moisture, the more likely the corrosion to increase as per Hosni et al., (2020). This result goes in line with Aisha, (2014) whose measurements indicated that the corrosion rate of X60 increases with increasing moisture contents of the studied soils.

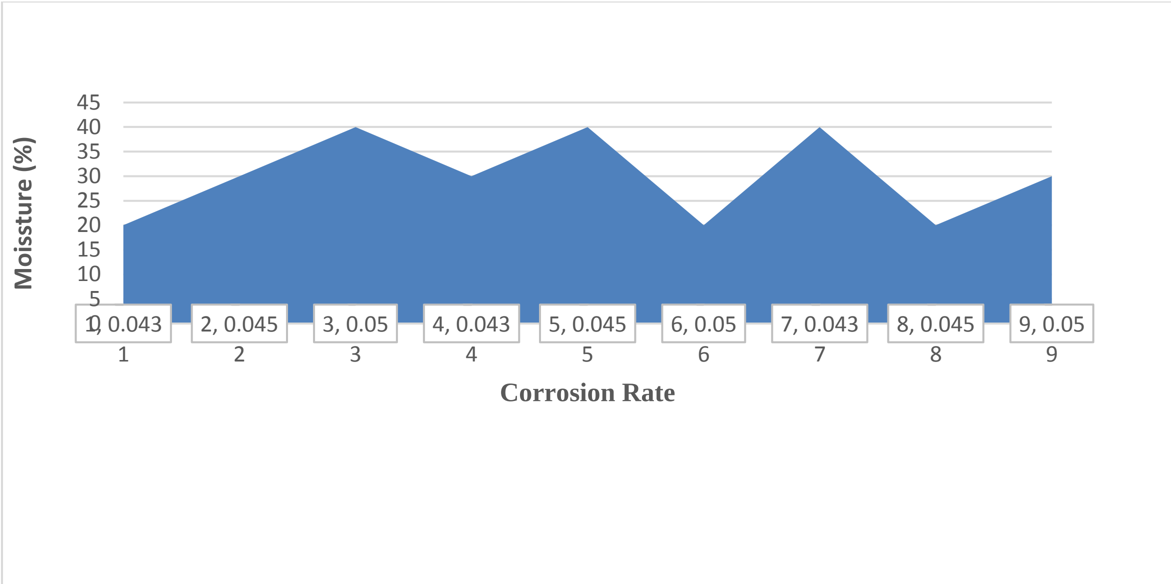

Figure 2. Moisture content with corresponding Corrosion rates along the locations

3.3 Soil Texture Classification in Relation to Corrossion: The table (1) below showed, Sites A- C has high percentage of sand between 74- 76% and also other site with a corresponding corrosion rate range of 0.00774- 0.009 mg/dm^2/yr corrosion rate and sites D-I also very least values which are far against the recommended corrosion rate by NACE at 0.4mm/year (Vanaei *et al.*, 2017). Sand is characterized by low moisture retention culminated from high porosity. The sand samples showed relatively insignificant corrosion values in relation to sand leading to lower rates on the Table 1. This could be due non presence of significant quantum of other variables in terms of moisture, clay or any other corrosion setting conditions. This result is in line with the Taguchi analysis results by Imamudeen et al. (2024) conducted where the general regression analysis showed only clay content (CC) has a statistically significant positive effect on corrosion rate, while pH and MC within the studied range did not show statistically significant linear effects according to the model. This does not mean they do not influence corrosion, but rather other factors not considered might overshadow their effects or maybe having complex relationship with the rate of corrosion in the study area.

Table 1. Showing Percentage Sand and the Relative Corrosion Rate in the Study Area

Site	**Sand %**	**Corrosion Rate (mg/dm^2/yr)**
A	76	0.00774
B	74	0.00774
C	74	0.00774
D	78	0.0081
E	74	0.0081
F	76	0.0081
G	68	0.009
H	65	0.009
I	64	0.009

Laboratory Analyses 2023.

3.3.1 The silt, Sites A- C has 22- 23% silt with a corrosion rate of between 0.0133mg/dm^2/yr and smallest quantity of clay percentage as compared to the other sites (<5%) 0.0219mg/dm^2/yr. The figures have really shown that there was corrosion activity in spite of the insignificant quantum in sand, but for silt and clay they were relatively higher. Base on this, Yahya *et. al.*, (2011) opined that, even at a low clay content level, the rate of corrosion can be initiated.

Sites D – F consisted of samples from three sites of the middle segment of the transect (DEF). The sites D- I being part of Kaduna State, are located in Northern Guinea savannah and hence having climatic features of the guinea savanna region with slightly higher rainfall and clay contents than that of the savannah. This signified higher rainfall, soil clay potentiality, vegetation and atmospheric humidity. To this extent, based on this research, table 5 showing, sites D – F has 74 - 78% sand with 0.0081mm/dm^2/yr, silt 17 - 20% with 0.014 mm/dm^2/yr, and clay ≥5% with 0.023 mm/dm^2/yr, showed relatively higher corrosion rates along the transect from Kano towards Kaduna State along the pipelines. This also fall short of the recommended corrosion rate by NACE at 0.4mm/year (Vanaei *et al.*, 2017) but still agreed with works of Yahya *et. al.*, (2011) on corrosion initiation at small clay quantum under the favourable environment.

Sites H – I is the last segment of the transect selected in the study area. The sites also form part of the Guinea savannah in Kaduna State sharing relatively same characteristics. From the results in figure 6 indicated, 64 - 68% sand with a corresponding corrosion rate of 0.009 mm/dm^2/yr, 22 - 26% with corrosion rate of 0.0155 mm/dm^2/yr silt and 10 - 11% clay with corrosion rate of 0.0255 mm/dm^2/yr, showing reasonably highest proportion of clay and silt contents compared to the other sites. This signified higher tendency of buried pipeline metal to corrosion as per as clay percentage is concerned.

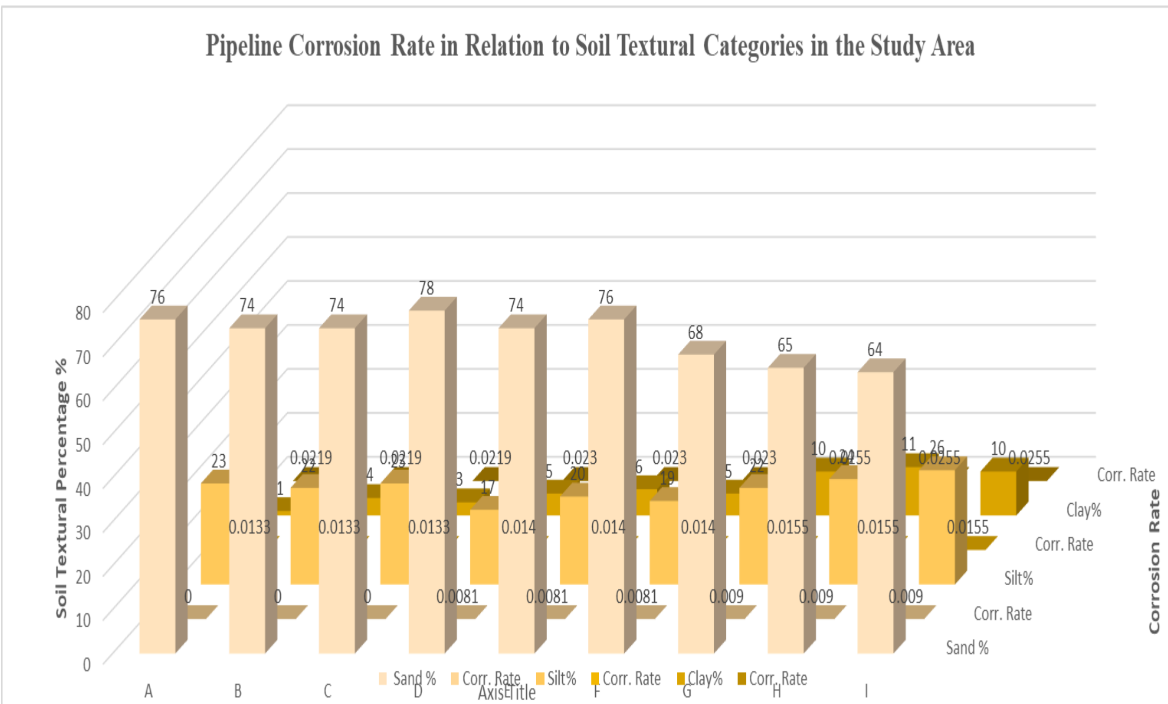

Figure 3. Corrosion Rate in Relation to Silt Percentage in the Study Area

3.4 Clay content: Physical properties of soil in terms of volume shrinkage in clay refers to the tendency of soil to start cracking on drying and swell when wet. According to Muhammad *et al.*, (2018) opined that, this is a feature of clay and loamy soil particles that, when clay/ silts soil dries, it cracks and the crack allows diffusion of air specifically oxygen to the pipe and consequently buried pipeline's susceptibility to corrosion increases. So, due to poor drainage in clay and silt which showed considerable quantum in all the samples reasoned that the tiny pores of the soils retain considerable amount of water therefore, the moisture retained in good conductivity soils harbor high content of ion leading to active corrosion attacks. In terms of corrosion variation in soil moisture between location, there is variable increase in the corrosion rate due variation in moisture regimes between the locations (Figure 3). This is in line with the work of Nordin, *et al.*, (2011) whose work showed the rapid growth of corrosion is relatively correlated with the high moisture content of soil and that, corrosion initiated at a slow rate for clayey soil. Generally, according Nordin, (2011) opined that, Soil moisture content was found more influential towards corrosion dynamic as compared to clay content based on the qualitative evaluation. This becomes evident as shown in Figure 5, the corrosion values are higher in clay than other soil components culminating into higher pipeline corrosion potential.

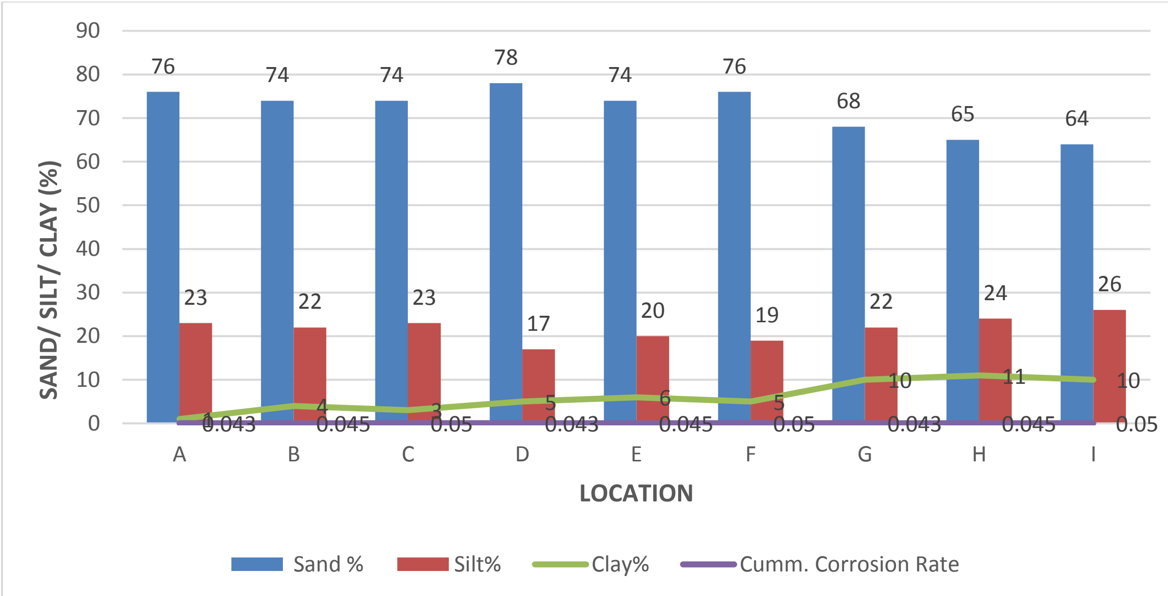

Figure 4. Cummulative Corrosion Rate in Relation to Percentage Sand, Silt and Clay in the Study Area

4.0. Conclusion

Conclusively therefore, this research showed considerable presence of corrosion on buried steel oil pipeline along Kano – Kaduna. The soil pH ranged between 4.1–8.2 along the transect, moisture range between 20 – 40% and clay contents found to be between 1- 10%. Based on the results, corresponding corrosion rates along the transect was obtained to be between 0.0043 – 0.05mg/dm^2/yr (Fig. 4) and cumulative corrosion rate range between o.043- 0.05 mg/dm^2/yr signifying relative increase in corrosion rates along the transect characterized by varied ecological classification. The results showed relatively varied corrosion rates, showing its occurrence with all the three parameters been positive and impactful.

5.0 Recommendation

The analysis of external corrosion of oil pipeline has been carried out with the assessment of soil properties for the retaining of its long life and minimizing of corrosion growth rate for Nigeria's Northwest soils. This can be used to assess the best corrosion protection that can be applied on the pipeline after the installation to a specific area site location. Hence to improve the reliability of the line at a lesser cost. An analysis of corrosion growth potential for pipeline sites can be focused.In addition, it should be noted that the pipeline materials and HAZ used in this research is only applicable to a metal having the same chemical composition and welded under the same conditions, variations in microstructure and chemical composition will exist across varying welded joints since it is dependent in factor. Furthermore, research should therefore be carried out on the effect of varying welded techniques on the microstructure of a welded joint.

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