SENRA Academic Publishers, Burnaby, British Columbia
Vol. 6, No. 2, pp. 2049-2056, June 2012
Online ISSN: 1920-3853; Print ISSN: 1715-9997

Canadian Journal of pure&applied sciences

Short communication

SHALLOW RESISTIVITY SURVEY FOR PROTECTION OF SUBMERGED FUEL TANKS FROM EXTERNAL CORROSION IN A COASTAL ENVIRONMENT, SOUTHEASTERN, NIGERIA

*Okiwelu AA[1], Evans UF[2], Ekanem CH[3] and Etim VB[2]
[1]Department of Physics, University of Calabar
[2]Department of Science, Maritime Academy of Nigeria, Oron
[3]Department of Physics, Akwa Ibom State College of Education, Afaha Nsit, Nigeria

ABSTRACT

Geoelectrical resistivity soundings employing Schlumberger electrodes array was used to measure resistivity distributions of geomaterials in four fuel stations located in coastal environment within the Nigerian sector of the Niger Delta basin. The aim is to find alternative solution for the mitigation of external corrosion of buried storage fuel tanks. A maximum current electrodes spacing of 40m was used for the investigations. An average depth of 10m was penetrated by the current. Analyses of results show that the storage tank (station *A*) is within non–corrosive environment. The tank may eventually suffer corrosion attack due to the 132kV electrical power lines which is in close proximity to the fuel station. The other tanks (B, *C*, and D) are within corrosive environments but the tank at station *C* is at a higher corrosion risk. This is because of the presence of conductive clay in the area. Based on the low resistivity, sites for planting of protective anodes have been delineated to protect the storage tanks from external corrosion.

Keywords: Shallow, protection, submerged tanks, corrosion, environment.

INTRODUCTION

External corrosion of buried metallic structures such as storage tanks has been one of the most challenging tasks of the petroleum product marketers in Nigeria. Generally, subsurface geologic materials show variation in the concentration of electrolyte (groundwater and dissolved salt). These differences result in vertical and lateral variations in resistivities of the subsurface rocks. Subsurface resistivity variations have direct link with the corrosion potential of the subsurface which also varies laterally and vertically (SESCO, 2002). There is therefore, the need to study the corrosion behaviour of metals when exposed to various environments (Osarolube *et al.*, 2008). Submerged materials are at risk of forming anodic and cathodic regions with the electrolyte (corrosion cell) as they traverse geologic materials of different resistivities. The risk increases as the anodic area becomes relatively small with respect to the cathodic area (Stefler, 1980). It had been shown that the anodic area is developed within soil of low resistivity which normally accelerates the flow of electric current from the buried structure to the surrounding including the cathodic area of the structure; since current flow through the path of least resistance (USDD, 2004 and FHWA, 2000). Submerged structure that receives current becomes protected, while a structure that releases current tends to be sacrificed.

Attempt to protect materials from external corrosion had been by surface coating (painting or electroplating). The main idea of coating is to isolate the material from its environment (electrolyte), thereby maintaining an open circuit in the corrosion cell, which inhibits corrosion process. However, it had been shown that with the existence of holidays [coating defect] (Lilly *et al.*, 2007) there is no amount of coating that can guarantee total protection of a buried structure (Sheir, 1993 and Bird, 2001). This explains why the over dependence of Nigerian petroleum product marketers on surface coating as an ultimate means of external corrosion protection often fails. Such failure results in loss of assets and pollution of the environment including aquifers and other environmental disaster (Alawode and Ogunleye, 2011). A standard practice recommended by Zdunrk and Barlo (1992), Lisk (1992), NACE (2003), Khan (2002) and Wansah *et al.* (2008) has been supplementing surface coating with cathodic protection system. The first class information necessary for the design of a cathodic protection system is soil resistivity, which can be measured *on-line* or *off-line*. The on-line measurements require geoelectrical resistivity measurement, while the off-line involves laboratory analysis of soil samples. This study adopted the “online” (geoelectrical resistivity technique) to measure soil resistivity values near selected fuel stations in a coastal area, Uyo (Fig.1), Southeastern,

---

*Corresponding author email: okiwelu2000@yahoo.com

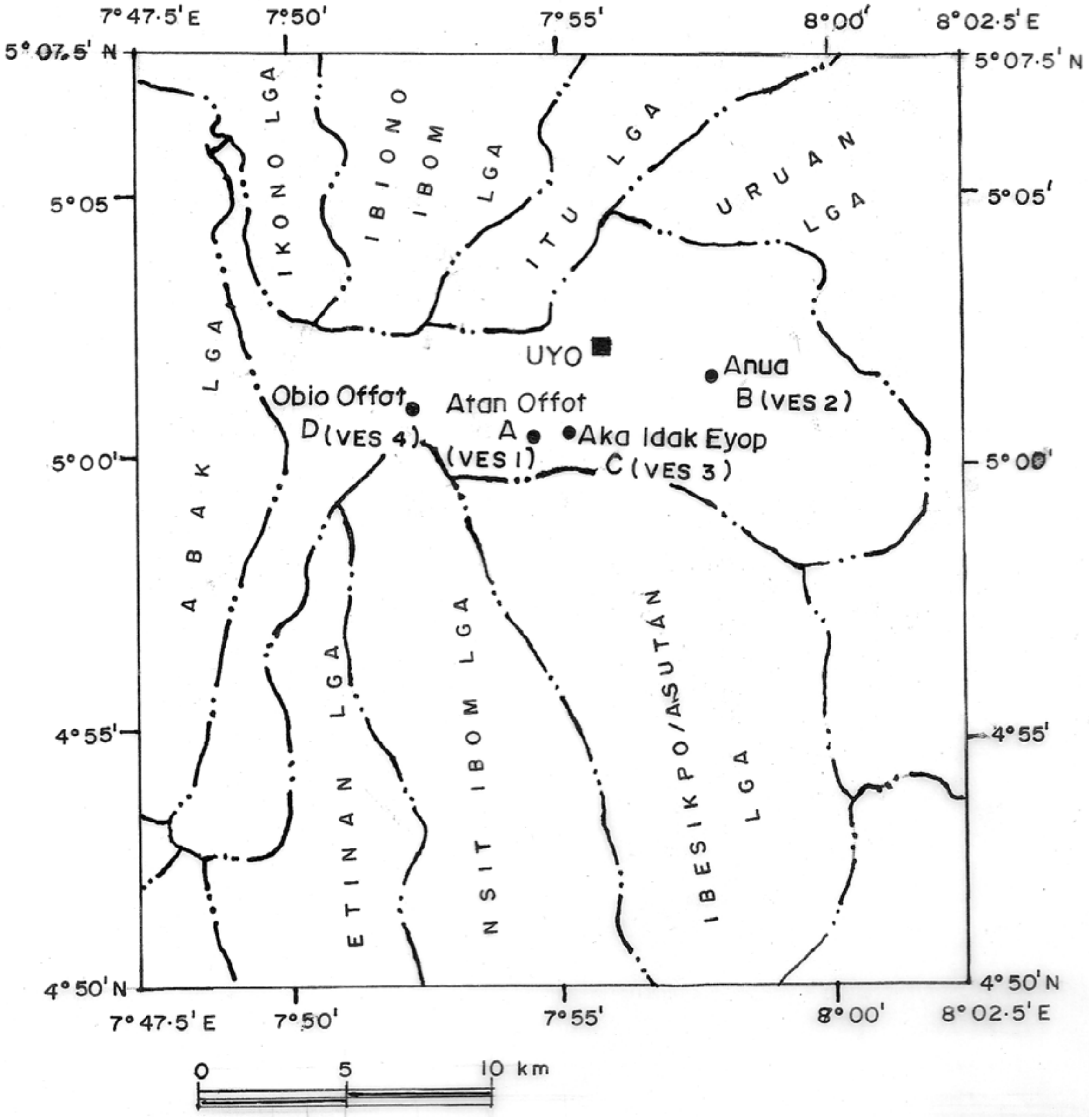


Fig. 1. Location map of the study area showing location of the tanks (A, B, C, D) and VES sounding locations at Uyo and Environs.

Nigeria in view of finding a lasting solution to underground fuel storage tank leakages. Geoelectrical resistivity soundings method have been found to be very useful for the investigation of soil corrosion of pipeline (Ekine and Emujakporue, 2010).

The study area is located in Southeastern Nigeria within Latitude $5^{o}\,01^{'}$ N-$5^{o}\,05^{'}$ N and longitude $7^{o}\,45^{'}$ E - $7^{o}\,75^{'}$ E. The tanks are located in Uyo (Fig.1) within the Niger Delta basin, Southeastern, Nigeria. The area is typical of the Niger Delta undulating plains with extensive near shore sands of various grain sizes. The thickness of this sand increases towards the depocentre. The area is also noted for seasonal variation of rainfall. Monthly rainfall data shows that the average rainfall during the dry season is 65mm against 382mm during the rainy season. Previous study of the meteorology of the area reveals the air temperature to be 25.5°C in the rainy season and 30.1°C in the dry season (Gobo, 1998). The daily relative humidity ranges from 75% in the dry season to 96% in the rainy season.

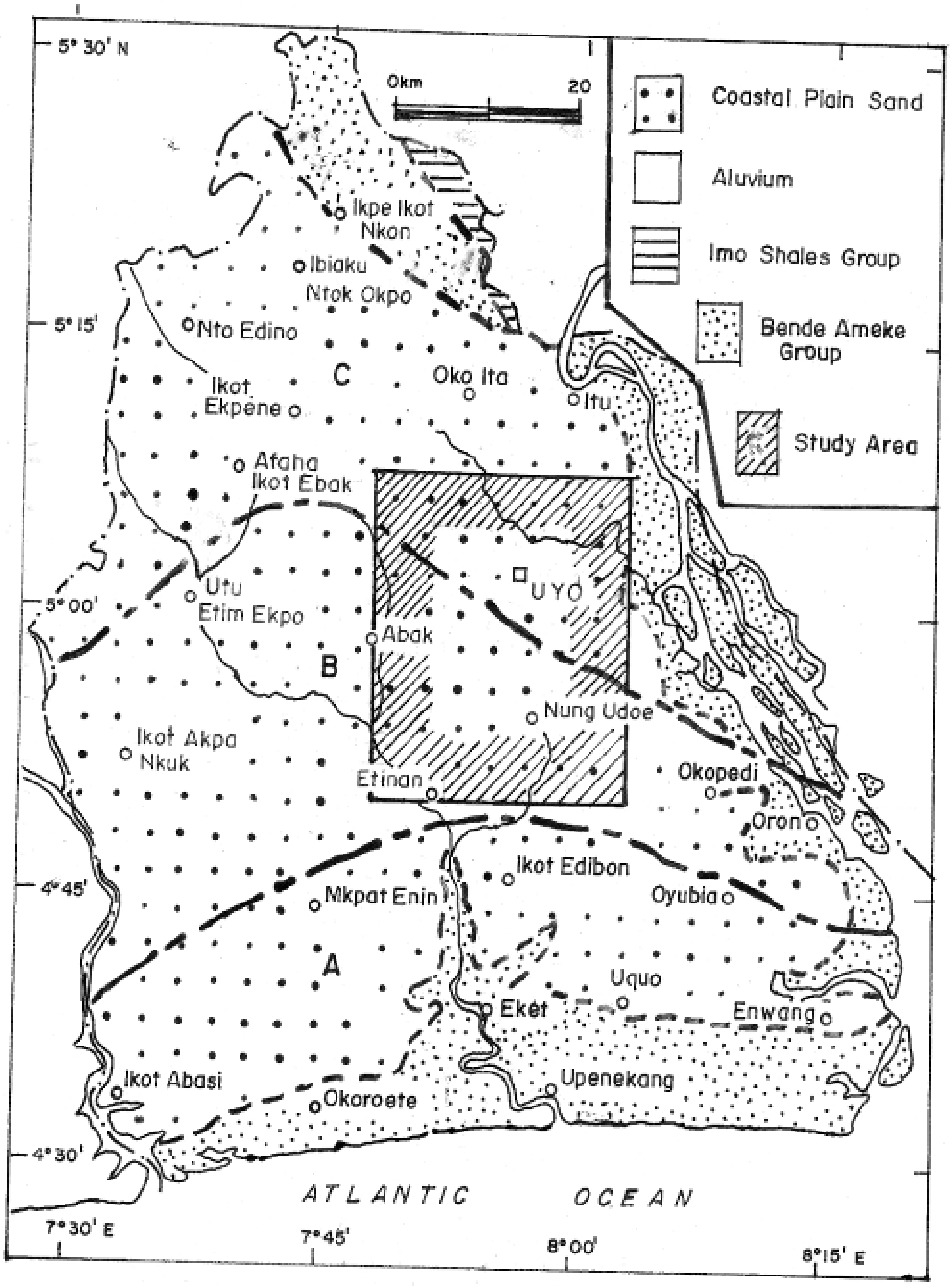
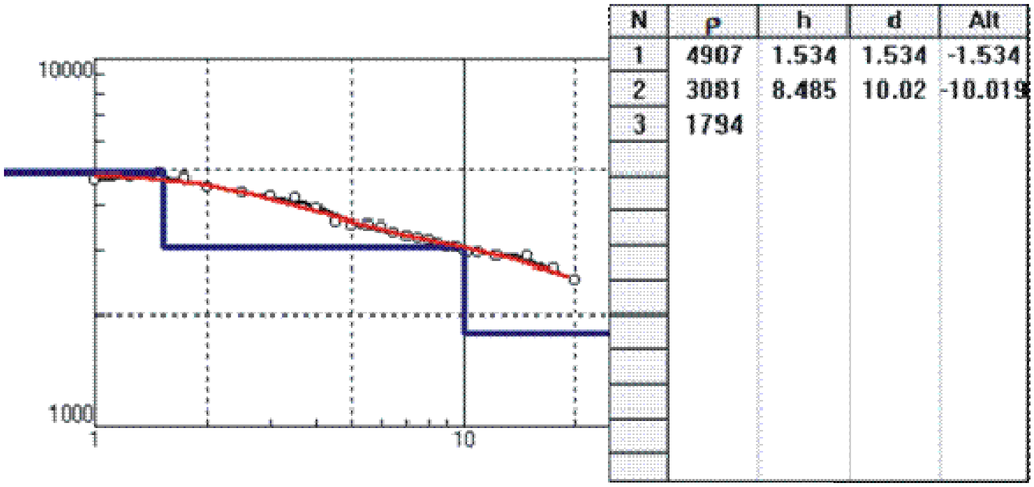


Fig. 2. Geologic map of Akwa Ibom State showing the study area.

The study area falls within the coastal plain sands of the deltaic depositional environment of the Niger Delta (Hospers, 1971; Onyeagocha, 1980; Kogbe and Buriollet, 1990) (see Fig. 2). The Benin Formation is the uppermost unit of the Niger Deltaic lithofacies and has clastic sedimentary rocks formed either as terrestrial or marine deposits (Reyment, 1965; Fetters, 1980). The sediments are predominantly sandy with minor shale intercalations. Onyeagocha (1980) describes the Benin Formation as a continental depositional environment having massive, poorly sorted sands and sandstones with thin shales, clay, and gravel which grades downwards into the delta front Agbada lithofacies.

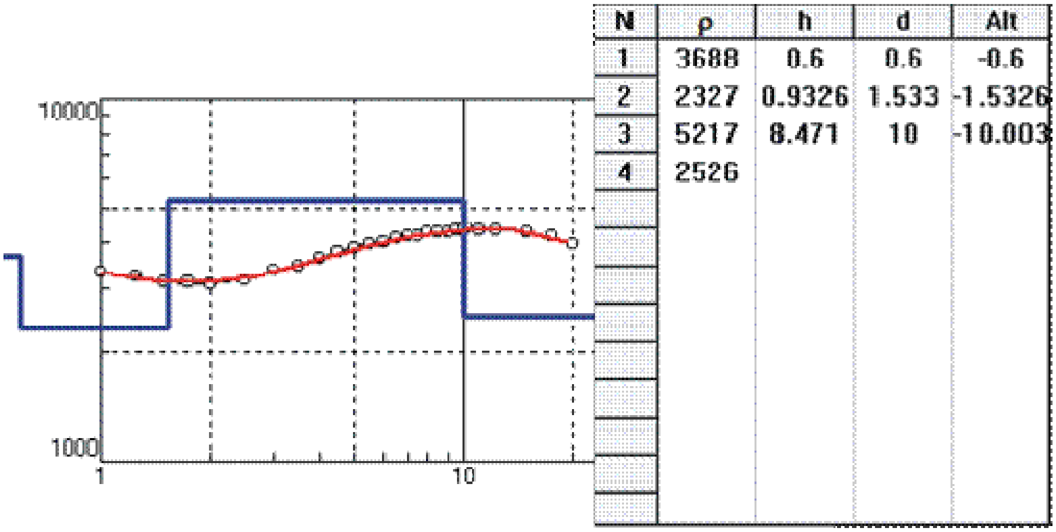
MATERIALS AND METHODS

The ABEM terrameter (model SAS 300) and its accessories arranged in the Schlumberger array were used for obtaining the vertical electrical sounding resistivity data over the four fuel tanks. The geometric array for this



N	ρ	h	d	Alt
1	4907	1.534	1.534	-1.534
2	3081	8.485	10.02	-10.019
3	1794			

Fig. 3. Modelled VES curves at location A.



N	ρ	h	d	Alt
1	3688	0.6	0.6	-0.6
2	2327	0.9326	1.533	-1.5326
3	5217	8.471	10	-10.003
4	2526			

Fig. 4. Modelled VES curves at location B.

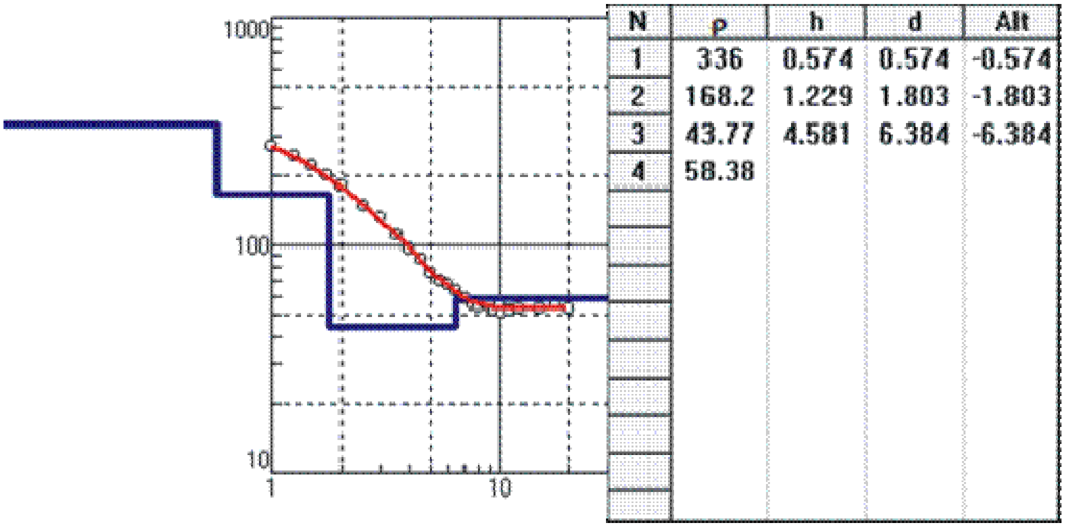
study is compatible to the software for the quantitative interpretation of field data. Hence, the conventional electrodes spacing used for vertical electrical sounding with Schlumberger array applied in groundwater investigations were modified so that it will be amenable to this study. This was necessary due to the shallow depth of burial and size (6.0m) of the buried fuel tanks. Thus, a maximum current electrodes separation of 40m was used for the study. A traverse of 5m away from the buried metallic structure and perpendicular to the structure was adopted to ensure that the structure does not contribute to the measured resistance. The K-factor for Schlumberger array enabled the calculation of the apparent resistivity from the measured resistances. For the purpose of quantitative interpretations, the apparent resistivity which is a function of current electrode spacing was modeled using IPI2win (computer software). The input parameters for the modelling were apparent resistivity values, half the current electrodes spacing as well as the potential electrodes spacing. The software at first instance performed the forward modeling and the results were used for the inverse modeling which yielded the final parameters.

RESULTS AND DISCUSSION

The results of the inverse modeling indicate variation of earth resistivity with depth (Figs. 3-6). Geoelectrical layer parameters obtained from the models are presented in table 1. These resistivity values were correlated with the ANSI/AWWA (American National Standard Institute and American water works Association C-105) standard rating for soil corrosivity (Table 2) in order to infer the corrosivity at various stations. Results suggest that tank

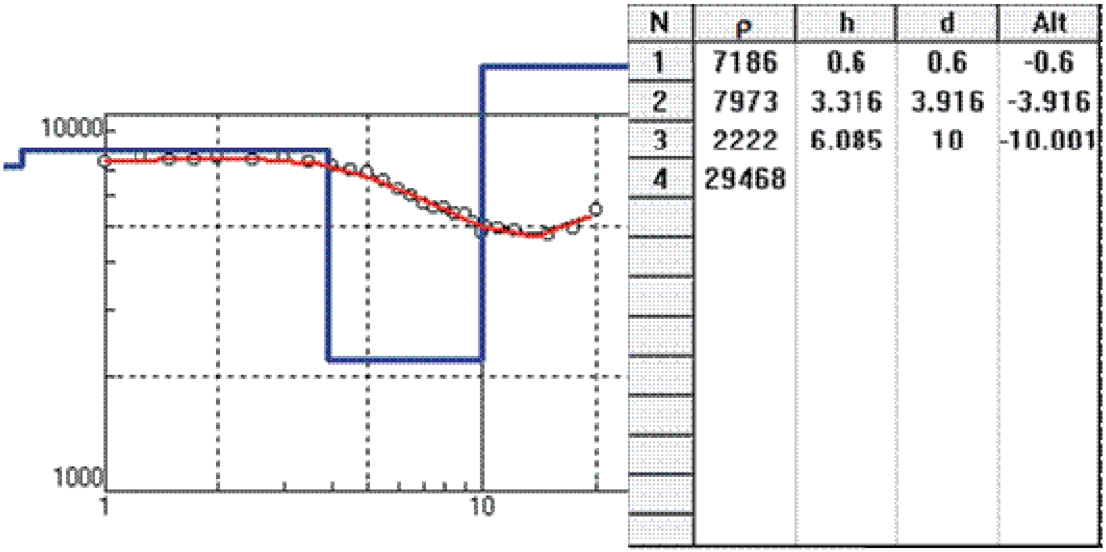
Table 1. Summary of VES modelled data.

Station	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	d_1	d_2	d_3
A	4907	3081	1784	-	1.534	8.405	-	1.5	10.02	-
B	3688	2327	5217	2526	0.6	0.932	8.471	0.6	1.53	10
C	336	168.3	43.77	58.38	0.574	1.229	4.584	0.574	1.803	6.384
D	7186	7973	2222	29468	0.6	0.9326	8.471	0.6	1.533	10



N	ρ	h	d	Alt
1	336	0.574	0.574	-0.574
2	168.2	1.229	1.803	-1.803
3	43.77	4.581	6.384	-6.384
4	58.38			

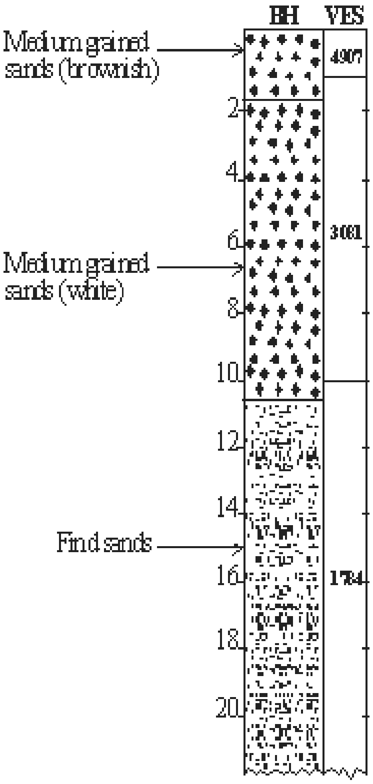
Fig. 5. Modelled VES curves at location C.



N	ρ	h	d	Alt
1	7186	0.6	0.6	-0.6
2	7973	3.316	3.916	-3.916
3	2222	6.085	10	-10.001
4	29468			

Fig. 6 Modelled VES curves at location D.

"A" is within high resistive (1784-4907Ωm) earth materials which indicate non corrosive materials. The local geology at location "A" obtained from borehole log (Fig.7) shows medium grained sand as the host of the buried tank. Resistivity values obtained for locations "B" and "D" are (2526-5217 Ωm) and (2222-29468 Ωm) respectively. However, at station "D" there is evidence of gravel deposit from the borehole log. The VES result at station C showed low resistivity (43.77-336Ωm). The lithology log at this site reveals the presence of conducting clay; hence, the subsurface environment is described as being highly corrosive.



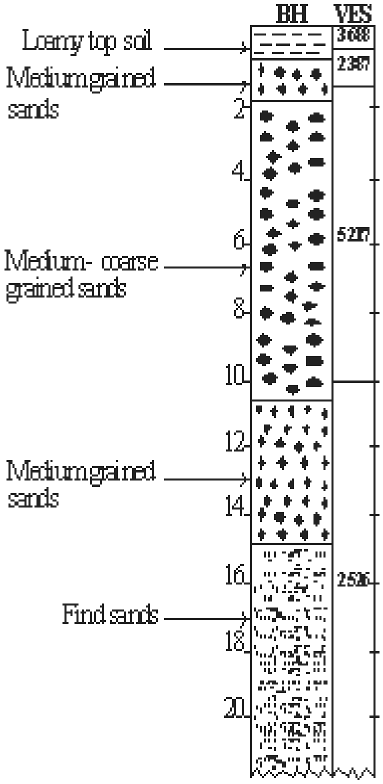
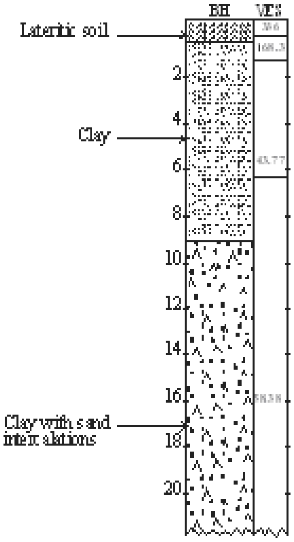


Fig. 7. Correlation of VES with borehole lithology log at location A.

Fig. 8. Correlation of VES with borehole lithology log at location B.



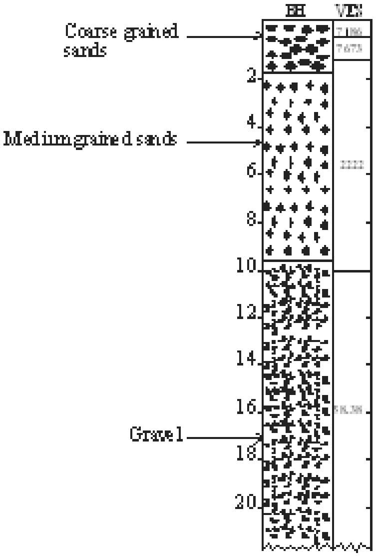


Fig. 9. Correlation of VES with borehole lithology log at location C.

Fig.10. Correlation of VES with borehole lithology log at location D.

Table 2. Standard for soil corrosivity rating (ANSI/AWWA C-105).

$\rho(\Omega m)$	Corrosivity rating
>200	Essentially non-corrosive
100-200	Mildly corrosive
50-100	Moderately corrosive
30-50	Corrosive
10-30	Highly corrosive
<10	Extremely corrosive

Tank "A" may not be subjected to adverse subsurface conditions, since the resistivity range is not wide and the soil resistivity values are high. However, the tank could corrode due to stray current effect from 132KV power line in close proximity to the storage tank.

The subsurface corrosion at the submerged tank at site B is minor because the soil resistivity at shallow depth is not only high but of minor variation. This minor variation in resistivity makes the formation of cathodic and anodic part on the tank practically difficult.

Storage tank, D shows wide range variation in soil resistivity values with the least resistivity (2222Ωm) at 1.533m depth. The segments of the tank exposed to the soil at this depth are anodic in the electrochemical circuit set up within the subsurface. Based on the principle of electrochemical corrosion, this tank segment will release electrons to protect adjacent segments of the tank exposed to high resistivity (7186 - 29468Ωm) soil. Therefore, pitting type of corrosion may set in at depth with relatively low resistivity geologic materials. Correlations of VES results with the true subsurface conditions obtained from borehole lithology logs for the different locations of the storage tanks are presented in figures 7-10.

CONCLUSION

Geo-electrical resistivity method has been applied to solving environmental problem by providing primary information needed to protect submerged fuel tanks in the study area from external corrosion. From the combination of data obtained from VES modeled curves and borehole lithology log, the only fuel tank that may be free from severe external corrosion threat is the tank buried at location "B". The tank at location "A" is at risk bowing to the induced AC voltage from the 132kV high tension power line in the area. Tank at site "C" is exposed to highly corrosive environment; hence, the tank is under a severe threat. The wide range of resistivity at station "D" gives rise to external corrosion of the tank buried in the study area. A sacrificial anode cathodic protection system should be installed for fuel tank at sites A, C and D to mitigate external corrosion of the tanks and Soil resistivity survey should always be carried out to identify potential corrosive geomaterials before establishing fuel stations. In addition, fuel tanks should not be buried close to stray current sources (such as high tensioned power lines).

REFERENCES

Alawode, AJ. and Ogunleye, IO. 2011. Maintenance, Security and Environmental Implications of Pipeline Damage and Ruptures in the Niger Delta Region. Pacific Journal of Science and Technology. 12(1):565-573.

Bird, AF. 2001. Corrosion Detection Interpretation and Repairs of Steel Pipelines. NACE International Conference Houston, Texas, USA.

Ekine, AS. and Emujakporue, GO. 2010. Investigation of Corrosion of Buried Oil Pipeline by the Electrical Geophysical Methods. Journal of Applied Science and Environmental Management. 14 (1):63-65.

Federal Highway Administration [FHWA]. 2000. Corrosion/ Degradation of Soil Reinforcements for Mechanically Stabilized Earth walls and Reinforced Soil Slopes. United States Department of Transport Publications.

Fetters, CW. 1980. Applied Hydrology. Bell and Howell Company, Columbus, Ohio, USA. 224-421.

Gobo, AE. 1998. Meteorology and Man's. Environment. Ibadan: African-Link Books. 7:101-127.

Hosper, J. 1971. Gravity field and the structure of the Niger Delta, Nigeria. Geological Society of America's Bulletin. 76:407-422.

Khan, NA. 2002. Use of Electrical Resistivity Soil Corrosion Probes to Determine the Effectiveness of Cathodic Protection. NACE International Conference, Houston Paper No. 02104.

Kogbe, CA. and Buriollet, PF. 1990. A Review of Continental Sediments in Africa. Journal of African Earth Sciences. 10:1-25.

Lilly, MT., Ihekwoaba, SC., Ogaji, SOT. and Probert, SD. 2007. Prolonging the lives of Buried Crude-oil and Natural-gas Pipelines by Cathodic Protection. Applied energy. 84 (9):958-970.

Lisk, I. 1992. The Use of Coatings and Polyethylene for Corrosion Protection. Water Online. American Water Works Association. 1-25.

National Association of Corrosion Engineers Int. 2003.Cathodic Protection Training Manual. 6.1-6.10.

Onyeagocha, AC. 1980. Petrography and Depositional Environment of the Benin Formation. Journal of Mining and Geology. 17 (2):147-151.

Osarolube, E., Owate, IO. and Oforka, NC. 2008. Corrosion Behaviour of Mild and High Carbon Steels in Various Acidic Media. Scientific Research and Essay. 3 (6):224-228.

Reyment, RA. 1965. Aspects of the Geology of Nigeria. Ibadan, University Press. 90-97.

Service Scolare (SESCO). 2002. Cathodic Protection Engineering. Tutorial Manual, Brook Park South Seminole Bartles Ville.

Sheir, LL. 1993. Corrosion Handbook. John Wiley and Sons, New York, USA. 345-401.

Stefler, FE. 1980. Accelerating Leak Rate in Ductile Cast Iron Water Mains Yields to Cathodic Protection. Materials Performance.19 (10):10-15.

United State Department of Defense (USDD). 2004. Design: Electrical engineering: Cathodic protection Unified Facilities Criteria (UFC). 3:570-602.

Wansah, J., Obi, O., Osuji, R., Okeke, C. and Oparaku, O. 2008. Soil Resistivity Measurements for Pipeline Cathodic Protection Design. Nigerian Journal of Solar Energy. 19 (2):106-110.

Zdunrk, AD. and Barlo, TJ. 1992. Effect of Temperature on Cathodic Protection. Criteria Practical Manual. 31(11):22-27.

Received: Dec 26, 2011; Accepted: April 4, 2012