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Estimation of Corrosion Induced Flaw Sizes on Buried Gas Pipeline in the Nigerian Sector of Niger Delta

[1]U.F. Evans, [2]A.A. Okiwelu, [3]I.A. Ude and [3]J.O. Abima
[1]Department of Science, Maritime Academy, Nigeria
[2]Geophysics Unit, Department of Physics, University of Calabar, Nigeria
[3]Department of Physics, University of Calabar, Nigeria

Abstract: A geoelectrical survey was conducted to investigate pipeline corrosion in the coastal plain sands of the Nigerian sector of the Niger Delta. The objective is to estimate corrosion flaw sizes on the pipeline quantitatively instead of direct excavation of the pipeline and eventual use of measuring tape to measure the flaws on the pipeline. The pipelines buried in the Benin sands at Ikot Abasi, South of the Niger Delta Basin became instructive for this study. The survey consisted of electrical potential profiling using Close Interval Pipe-Soil potential survey (CIPS) and Horizontal Electrical Profiling (HEP) according to Wenner electrodes arrangement. Two permanent test points (PS) were used for the study and the flaw sizes were estimated at points delineated to be of high corrosion risk in the study area. The data for close interval potential and HEP were analyzed and interpreted in line with the threshold protective potential (-850 mV) as well as the American Water Works Association (AWWA) soil corrosivity rating. Results indicate high risk zones due to external corrosion at pipeline length 25-30 m from PS1 and 80 m from PS2. These locations contain significant saline groundwater that facilitates corrosion of metal pipes buried within the area. The results also suggest that the corrosion protection systems for the pipeline need to be reinforced to mitigate further growth of the flaws on the pipeline segment. The impact of the flaws could be severe if allowed to continue.

Key words: Cathodic, corrosivity, geoelectrical, pipe-soil, potential, resistivity

INTRODUCTION

Pipeline used for transportation of high pressure fluid (petroleum product) are usually buried to prevent it from obstructing the dwellers or to protect it from being damaged. The integrity, safety and reliability of buried pipeline can be predicted from the flaw sizes at various segments of the pipeline. The flaw sizes can further predict the extent of external corrosion. The corrosion of external portions of buried pipeline can be controlled by a combination of pipeline coating and cathodic protection. The cathodic protection system becomes important where there are defects in coating (flaws or holiday). Flaws site exposes the pipeline to electrochemical reaction within its environment which normally result in pipeline thinning (corrosion). Early detection of flaws on pipeline can in real time enhance the reliability of pipeline (Bullard *et al*., 2005). Monitoring and inspection techniques for flaws on pipeline do not only provide a way to measure the effectiveness of the external corrosion control systems but also an early warning when changing conditions may be causing pipeline thinning (Ahmad *et al*., 2011). Flaws on external surfaces of buried pipelines are evidence of pipeline thinning and they reduce the integrity of the pipe as well as the potential service life of the pipeline. However, with more than 90% of the pipelines buried underground, locating potential flaws on pipeline can pose a major challenge. In-line inspection technologies are necessary to locate the flaws on buried pipelines without resorting to excavation of the pipeline. One of such technologies is the Close Interval Potential Survey (CIPS). A typical close interval potential survey employs non-polarizable (reference) electrode to scan a buried structure for flaws. For a continuous evaluation of a pipeline (without gaps) the maximum survey interval shall be less than three and a half times the depth of burial of the pipeline (Fraebel, 2009). However, some corrosion professional bodies suggested that polarized measurements for close interval potential survey should be taken at every 1m or 5m to provide a continuous pipe-to-soil potential profile of the pipeline section.

The potential can be recorded with Cathodic Protection (CP) system permanently energized (the ON mode) during survey. The data obtained from such measurements usually include the voltage drop error informed by the flow of cathodic protection currents in the soil. To eliminate this error from measured potentials, Makar and Chagnon (1999), Pikas (2009) and Moghissi

Corresponding Author: U.F. Evans, Department of Science, Maritime Academy, Nigeria

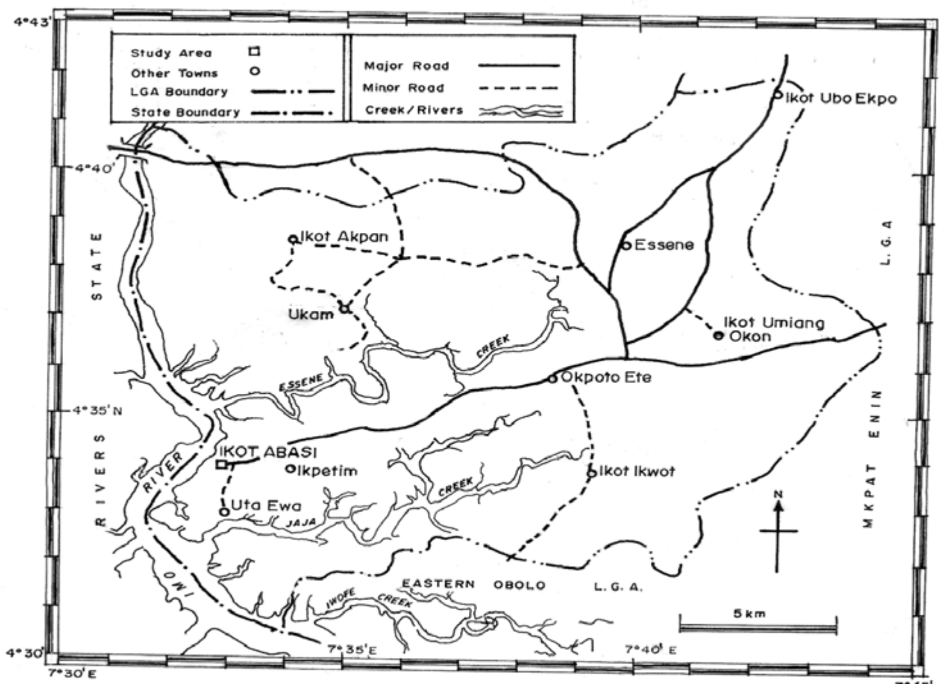

Fig. 1: Location map of the study area

et al. (2009) recommended an independent potential measurement to be carried out with the CP interrupted (OFF). This potential (ON or OFF) should be sufficiently cathodic to ensure adequate corrosion protection. However, when the potential is excessively cathodic to produce coating damage (cathodic disboundment) or hydrogen embrittlement, the pipeline is at risk of severe external corrosion. External pipeline corrosion is widespread when the breakdown of coatings or cathodic protection takes place in a corrosive subsurface environment (low resistivity geomaterials). Hence the knowledge of the subsurface resistivity of the materials hosting the pipeline as well as the ON and OFF electrical potentials at flaw site along a pipeline is useful in estimating the flaw size on buried pipelines. Flaw size estimation gives meaningful quantitative interpretation to close interval potential survey which had been exclusively qualitative. Booth (1971) refined the mathematical model for the diffusion of oxygen through the tarnish layers formed on copper to corrosion pit growth law given as

$$C(t) = At^B \tag{1}$$

where $c(t)$ is the pit depth, t is time and A and B are constants. Equation (1) forms the basis for modeling of long term atmospheric corrosion loss. Application of this model to subsurface corrosion requires burying of coupon in the study area. Corrosion investigation through buried coupon often takes time and will neither indicate pipeline flaws nor unveil the integrity of the pipeline. Moghissi *et al.* (2009) developed corrosion model for predicting flaw size using External Corrosion Direct Assessment (ECDA) survey data. The parameters obtained from ECDA survey are very useful in the estimation of flaw size for buried pipelines. For close interval potential survey the flaw size is given by:

$$flawsize(in^2) = \frac{\exp(1.62x10^{-3}x\rho_s(k\Omega\, cm))}{(-0.592xDoB(ft)+5.44)}x\left[\frac{Dip_{on}-Dip_{off}}{IR_{Total}}x100\right]^2 \tag{2}$$

where DoB is the depth of burial of the pipe, Dip_{on} is the dip of the anomaly in ON mode, Dip_{off} is the anomaly dip in the OFF mode, IR_{total} is the drop in potential between the ON and OFF modes and ρ_s is the soil resistivity.

The detection of corrosion provides pipeline operators with information regarding the areas vulnerable to external corrosion and eventual failure of the pipeline. However, it is the rate of corrosion that will influence how quickly those flaws can grow to critical size and cause failure (Medved *et al*., 2004; Burns *et al*., 2001). Thus the rate of corrosion provides valuable input to several aspects of pipeline integrity management. Van Delinder (1984) estimated the corrosion rate of affected portion of buried pipeline using the relation:

$$mpy = k/\rho A \tag{3}$$

where *mpy* is the corrosion rate in miles per year, ρ is the electrical resistivity at the pipe-to-soil interface, *A* is the flaw size measured by direct method (tape) and *k* is electrochemical constant which is a function of the metal. This equation evaluates corrosion rate without necessary burying coupon.

The strategic location of Ikot Abasi as one of the industrial towns in the Niger Delta makes it suitable for this study. It is attracting rapid development including its suitability as site for the Aluminum Smelting Company. It is bounded by Latitudes 4º30′ - 4º43′ N and Longitudes 7º30′ - 7º45′E (Fig. 1). The study was conducted in 2010 within the tropical rainforest belt and the near surface geology of the area is typical of the Nigerian coastal plain sands. Deeper sediments host aquifers which are adequately recharged by the high rainfall in the area especially during the wet season. The water bodies within the study area are saline. Analysis of atmospheric corrosion by (Ogbonna, 2008) showed that the area is highly corrosive to zinc coated iron sheets.

The objective of this study is to estimate corrosion flaw sizes on the pipeline quantitatively instead of direct excavation of the pipeline and eventual use of measuring tape to measure the flaws on the pipeline. Additional objective of this study is to show how pipe-soil potential can serve as a means of predicting the integrity and continuous monitoring of pipeline. This study is necessary due to large number of buried pipelines and petroleum storage tanks in the study area as their rupture can be a threat to economical, environmental and human safety. Hence the study serves as a proactive measure to curb corrosion threat of buried pipeline.

MATERIALS AND METHODS

The materials used for measurement of pipe-to-soil potential were high impedance multimeter, trailing copper wire, half cell and permanent test stations. While the MacOhm terrameter and its accessories were used to determine the soil resistivity. The pipe-to-soil potential measurements were carried out in two modes (the ON and the OFF modes) using the configuration presented in Fig. 2. In theory, the reference electrode (porous pot) used to scan any buried structure is assumed to be planted at the vertex of a 120º cone. This establishes a scan segment of such structure (pipeline) as the base diameter (D) of the cone. Mathematically, the base diameter of a cone is given by

$$D = 2 * \sqrt{3} * h \qquad (4)$$

where h is the altitude of the cone (in practice, the depth of burial of the pipeline).

Using Eq. (4), a survey spacing of 5 m was considered good enough to conduct close interval

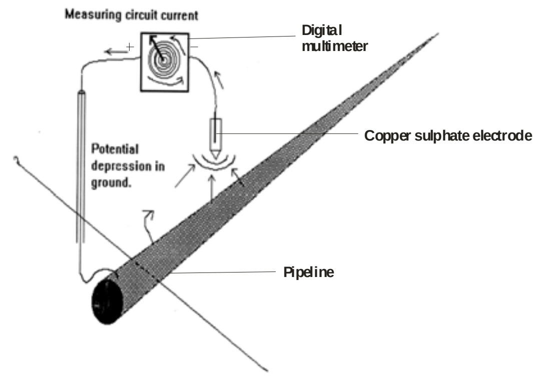

Fig. 2: Field procedure for close interval pipe-to-soil potential measurement

potential profiling on the 2 m buried pipeline. The data for ON mode were collected with the cathodic protection system on. The implication is that the measured potential is convoluted with IR error arising from the cathodic protection system. To correct the error, the instantaneous OFF potential (the cathodic protection current temporally interrupted) was carried out.

The soil resistivity was measured by arranging the terrameter and its accessories to form the Wenner array. This array was used to conduct electrical resistivity profiling along the pipeline length. Based on the minimum penetration depth of 1/3 of the current electrodes spacing approximated for the four pin profiling with Wenner array as well as the relatively shallow depth of the target (about 2 m), a current electrodes spacing of 6 m was considered appropriate for investigating the electrical resistivity of the soil hosting the buried pipeline. The potential electrodes were 2 m spaced and nested within the current electrodes. Therefore, all the electrodes were successively spaced 2 m from each other. Resistivity values obtained were plotted against distance along pipeline. The resistivity data were analyzed qualitatively with the aid of the signature generated from the plot of resistivity against pipeline length. Interpretation of resistivity data was based on American Water Works Association standards for soil corrosivity rating. The electrical resistivity and the potential values at critical corrosion site along the pipeline were deduced from the field data (primary data) and used as the secondary data for the estimation of corrosion flaw size of the pipeline segment. Equation (5) aided the quantitative interpretation of secondary data in terms of the flaw sizes on the pipeline.

$$flawsize(cm^2) = \frac{\exp(1.62 \times 10^{-3} \times \rho_s(k\Omega\, cm))}{(-0.02797 \times DoB(m) + 0.843)} \times \left[\frac{Dip_{on} - Dip_{off}}{IR_{Total}} \times 100 \right]^2 \qquad (5)$$

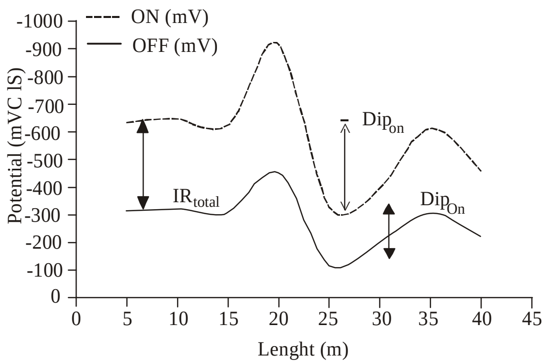

Fig. 3: Graph of potentials against pipeline length measured from PS1

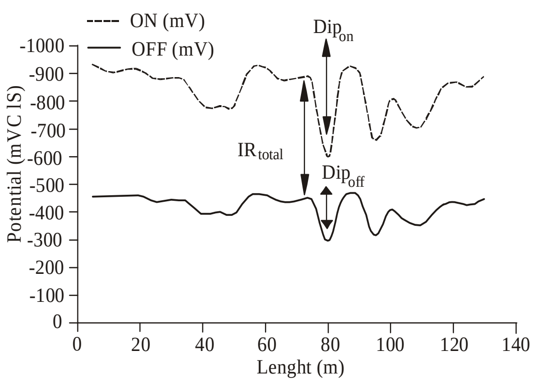

Fig. 4: Graph of potential against pipeline length measured from PS2

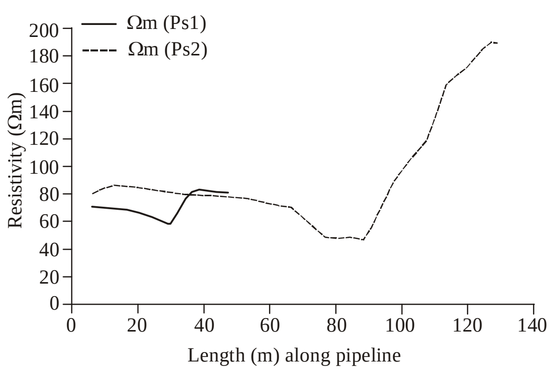

Fig. 5: Graph of resistivity against length measured along the pipeline

This study was conducted at Ikot Abasi, Southeastern, Nigeria in 2010.

RESULTS AND DISCUSSION

The results for electrical potential profiling along the pipeline are presented in Table 1. Graph of potential against pipeline length (Fig. 3) shows that the electrical potential measured within pipeline length 25-30 m from permanent test station 1 (PS1) was below the threshold protective potential. A similar result was obtained at about 80 m from PS2.

Table 1: ON and OFF mode potential surveys

	ON mode survey		OFF mode survey	
Pipeline length (m)	PS1(mV	PS2(mV)	PS1(mV)	PS2(mV)
5.0	-630	-919	-315	-450
10.0	-642	-899	-321	-449
15.0	-622	-902	-310	-451
20.0	-911	-899	-453	-450
25.0	-331	-865	-120	-433
30.0	-400	-874	-205	-437
35.0	-610	-860	-305	-430
40.0	-460	-779	-220	-390
45.0		-880		-392
50.0		-776		-388
55.0		-903		-452
60.0		-910		-455
65.0		-865		-433
70.0		-869		-432
75.0		-865		-433
80.0		-600		-290
85.0		-892		-446
90.0		-897		-448
95.0		-638		-310
100.0		-800		-400
105.0		-720		-360
110.0		-700		-350
115.0		-810		-405
120.0		-860		-430
125.0		-840		-430
130.0		-880		-440

This is an indication of external corrosion threat on the pipeline segments (Fig. 4). Electrical resistivity results show that the subsurface within these areas have low resistivity values at the pipeline depth. The results strongly agree with those obtained by Okiwelu *et al*. (2011). Low resistivity soil had been described as pointer to high soil corrosivity (Evans *et al*. 2010); also low resistivity values obtained by Okiongbo *et al*. (2011) for second layer in Yenagoa City, Nigeria were noted to be very corrosive to buried pipeline. The relationship between soil resistivity and soil corrosivity can further be explained by the least resistance path seeking nature of galvanic currents. Thus galvanic currents will always flow from the flaw site of pipeline to low resistivity soil. Lilly *et al*. (2007) reported that pipelines or metallic structures that discharge current are at risk of accelerated corrosion. When currents leave pipeline segment, such segment becomes anodic with respect to other segments (cathodic) of the same pipeline or any closely buried metal. The anodic segments are sacrificed (corrode) at flaw site to protect the cathodic portions. Medved *et al*. (2004) noted that flaws on pipeline grows over time and can lead to severe corrosion threat if allowed to continue. The variation of soil resistivity along the pipeline segment

Table 2: Parameters for estimating flaw sizes at inferred corroding segments of the pipeline (secondary data)

Soil resistivity (kΩcm)	Depth of burial (m)	Dip of CIS'ON'potential (mV)	DIP of CIS'OFF' potential (mV)	Total IR drop(mV)
(a) Parameters for estimating flaw size for PS1				
4.5	1.8	300	200	320
(b) Parameters for estimating flaw size for PS2				
6.0	1.8	300	150	450

studied is presented in Fig. 5. From this figure, the lowest pipeline length 25-30 m from PS1 and 80 m from PS2. These length correspond to areas of more positive potential than -850 mV recommended protective criteria. Ahmad (1996) observed that pipe-to-soil potential values more positive than -850 mV measured with copper-copper sulphate electrode indicates low protective potential for the pipeline segment, hence, corrosion, while pipe-to-soil potential values more negative than -850 mV are evidences of effective protection of the pipeline segment. The combination of results from the study suggests that more positive pipe-to-soil potential values than the protective criteria are identified with low resistivity soil. Together they point to corrosion risk zone of the pipeline.

Secondary parameters used to estimate the size of the corrosion induced flaws on the pipeline were obtained from the combination of the results from electrical profiling and potential profiling (ON and OFF modes). These parameters are presented in Table 2. The Dip_{on} and Dip_{off} are corrosion critical points delineated along the pipeline by pipe-to-soil potential survey in the ON and OFF modes respectively. Flaw size estimated within 25-30 m along the pipeline length measured from PS1 was 5552.7 cm^2. Similarly, flaw size estimated within 80m length measured from PS2 was 1604.0 cm^2. Theses areas are interpreted as zones of active electrochemical reaction between the pipeline and the subsurface environment. Such environments are characterized by reduced aeration, excessive electrolytes (saline), high or low pH value, sulphide reducing bacterial or mineralization.

CONCLUSION

Geoelectrical methods have been recognized as fast, reliable and cost effective means of detailed investigations of the subsurface electrical properties. These have been used in this study to estimate the flaw size on buried pipeline. The results show that the pipeline segment is within corrosive environment. Since corrosion is a time dependent process, it is imperative to reinforce the functioning corrosion protective systems for the pipeline, as flaws can easily grow to consummate pipeline failure. However a routine survey for pipeline integrity can help in monitoring corrosion actions on the pipeline. Thus, direct corrosion inspection is further recommended to complement this study.

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