

# Effect of Stray Currents on Underground Pipelines within the Niger Delta Region

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## Abstract

This study was undertaken to determine the effects of stray currents on underground pipelines within the Niger Delta area. Two gas pipelines were selected for this experiment to investigate the presence of stray currents. The Stationary data logger and the Close Interval Potential Survey tool were used in measuring dynamic stray currents and static stray currents respectively. The sections on the pipelines for survey were selected based on their proximity to possible sources of stray currents. Three sections were surveyed for the first pipeline and two sections for the second pipeline. On survey of the pipelines, significant amount of stray current were detected, sufficient enough to cause corrosion on the pipelines. Furthermore, the effects of the stray current on the pipeline due to weight loss and errors in pipe to soil potential readings were determined. Finally, the sources of the stray currents were investigated and suitable control measures proffered in a bid to protecting the pipelines.

**Keywords:** Niger Delta, corrosion, direct current, stray current, cathodic protection.

## 1. Introduction

The Niger Delta area is a very densely populated region. It is located at an elevation of 96 meters above sea level with coordinates  $4^{\circ}49'60''\text{N}$  and  $6^{\circ}0'0''\text{E}$  in Degree Minutes Second (DMS) or 4.83333 and 6 in decimal degrees. The Niger delta extends over 70,000 km<sup>2</sup> and makes up 7.5% of Nigeria's total land mass (NNPC, 1983). The area accommodates over 20 million people and 40 different ethnic groups (Pagaebi, 2014). It consists of present day Bayelsa, Delta, Rivers, Abia, Akwa-Ibom, Cross River, Edo, Imo and Ondo States.

Oil spills are common occurrences in the Niger Delta area, they occur due to a number of causes including corrosion of pipelines and tankers (accounting for 50% of all spills), sabotage (28%), and oil production operations (21%), with 1% of the spills being accounted for by inadequate or non-functional production equipment, (NNPC, 1983). The largest contributor to the oil spills is the rupturing or leakage of production infrastructures that are old and lack regular inspection and maintenance.

The problem of electrolytic corrosion caused by stray currents is the subject of an increasing number of scientific publications. It is one of the more important present day corrosion problems. Thus, it also is an economic and social problem. The fact that stray currents can indirectly cause a significant ecological hazard is being more fully appreciated (Darowicki and Zakowski, 2000).

Stray currents are major agents of electrolytic corrosion of pipelines, (Richard & Bonds, 1997). They are direct currents flowing through the earth from a source not related to the pipeline being affected as shown in figure 1.1. It is important to note that for stray currents to cause corrosion, they must flow onto the pipeline in one area as shown in figure 1.3, travel along the pipeline to some other area or areas where they then leave the pipe (with resulting corrosion) to reenter the earth and complete the circuit to their ultimate destination. The amount of metal lost from corrosion is directly proportional to the amount of current discharged from the affected pipeline, (Richard & Bonds, 1997). Stray currents can impact the ability to protect a pipeline or other buried metallic structure from corrosion. Stray currents are particularly destructive at the location the current leaves the pipeline; the area of exit of the stray currents creates a localized anodic area on the pipeline which can overcome the cathodic protection applied. Often these areas are in close proximity to the generator of the stray currents or at a defect in the coating or at a crossing of lines.

## 2. Literature review

Stray current is one of the most important present day corrosion problems. The fact that stray currents can indirectly cause significant ecological hazard is being more fully appreciated.

Researches on stray currents have been widely reported in various publications but little emphasis on pipelines laid around the equator which are also prone to stray current due to errors in pipe to soil potential readings caused by the telluric effects of the sun.

Bonds (1997) investigated the effects of stray currents on ductile iron pipes. This study involved rectifiers and anodes located close and far away from the pipelines. All investigations indicated that the amount of influence by the stray currents on the Ductile Iron pipes was negligible for cases where rectifiers and anodes were located far away from the pipelines. For installations located close to the pipelines, the investigations show that the pipelines were influenced by factors such as rectifier output, soil resistivity, diameter of the respective

pipelines, condition of the pipeline coating etc.. The most significant part of this study was the recommendation of rubber gasket joints and polyethylene encasement in deterring stray currents from Ductile Iron pipelines.

Darowicki and Zakowski (2000) presented a paper on methods of evaluating corrosion hazards caused by stray currents to metal structures containing aggressive media. This study described the interaction of stray currents; it suggests possibilities of investigating potentials in the time-frequency domain with the use of most recent mathematical tools. In this way obtaining data is expected on electrode processes taking place on the surface of metal structures endangered by the harmful interaction of stray currents.

Darowicki and Zakowski (2001) presented a new method using Short Time Fourier Transformation (STFT) in detecting stray currents. This particular kind of signal analysis makes the determination of changes of the spectral power density of a signal (e.g. structure to electrolyte potential) in function of time possible. In the paper the results of joint time-frequency analysis of the potential of pipeline in the field of stray currents generated by tram-line were presented. The presented results unambiguously show the possibility of accurate identification of sources of stray currents and its interference on the underground metal construction.

Klean and Davies (2005) presented a paper on the basic principles of cathodic protection, the areas of use and the general factors to be considered in the choice and design of a cathodic protection system. It gave a basic introduction and simple technical data on cathodic protection.

Fagot and Schmitt (2008) developed Elyca's CatPro® and CPMaster® softwares to assess the influence of stray current on sheet piling structures.

Qingjun and et al. (2011) carried out a research to analyse abnormal variation of pipe-to-soil potentials of an oil transfer pipeline. This research showed that both AC and DC stray currents affect underground pipelines. This study further explained that potential gradients cannot indicate stray current corrosion under all circumstances. O'Flaherty and et al. (2011) carried out an analysis of stray currents induced by cathodic protection on steel-framed masonry structures. This paper presented both experimental and numerical studies into the risk and extent of stray current corrosion in steel-framed masonry structures when subjected to impressed current cathodic protection. The objective was to optimise CP systems so that interference could be minimised without compromising the technical or cost benefits of this method of corrosion control.

Demirel and et al. (2013) carried out a research on telluric effects arising along the cathodically protected natural gas pipeline between Karadeniz Ereğli and Duzce. This study was aimed at ascertaining the existence, arising frequency, and magnitude of telluric interference going in and out of the natural gas pipeline between Duzce and Karadeniz Ereğli in Turkey. The gas pipeline is well coated with polyethylene; it is 60 km long and has a diameter of 40.64cm. In this study, the pipe/ground potential values, electrical currents coming from the anode bed, and soil resistivity values were measured at different times and regions along the pipeline. This study proved that the natural gas pipeline between Duzce and K.Ereğli included interference currents caused by the magnetic field effect (telluric effects) from time to time and also, the pipeline/ground potential values showed that the aforementioned magnetic field strength changes over short periods.

The present work covered the stray current intensity and distribution on underground pipelines, effects of stray currents on pipelines, and the telluric effect of the sun to errors in pipe to soil potential readings within the Niger Delta region using different stray current measuring tools and mathematical models with MATLAB and Microsoft Excel softwares.

### 3. MATERIALS AND METHOD

An experiment was conducted on two gas pipelines to measure stray currents on underground pipelines within the Niger Delta region. A stationary data logger and a Close Interval Potential Survey tool were the instruments used to measure dynamic and static stray currents respectively. The first pipeline was of 457mm diameter and 1.2km long. This pipeline linked SPDC Imo River Flow Station to NGC Owaza Compressor Station as shown in figure 3.1. The second pipeline was of the same diameter but 4km long. It linked Umudi Intermediate Pigging Station to Alaoji Pressure Reduction and Metering Station. The sections on the pipelines for survey were selected based on their proximity to possible sources of stray currents. Three sections were investigated for stray currents for the first pipeline; the sections consisted of kp 0+000 to kp 0+018; kp 0+255 to kp 0+273; and kp 0+602 to kp 0+620. Two sections were investigated for the second pipeline; the sections consisted of kp 20+570 to kp 20+588 and kp 23+420 to kp 23+438. The experiment was carried out two times daily in both dry and wet seasons in the months of November and May respectively for a period of 4days each. The measurements were done in accordance with test procedures outlined by Nicholson (2010) and Nicholson (2003).

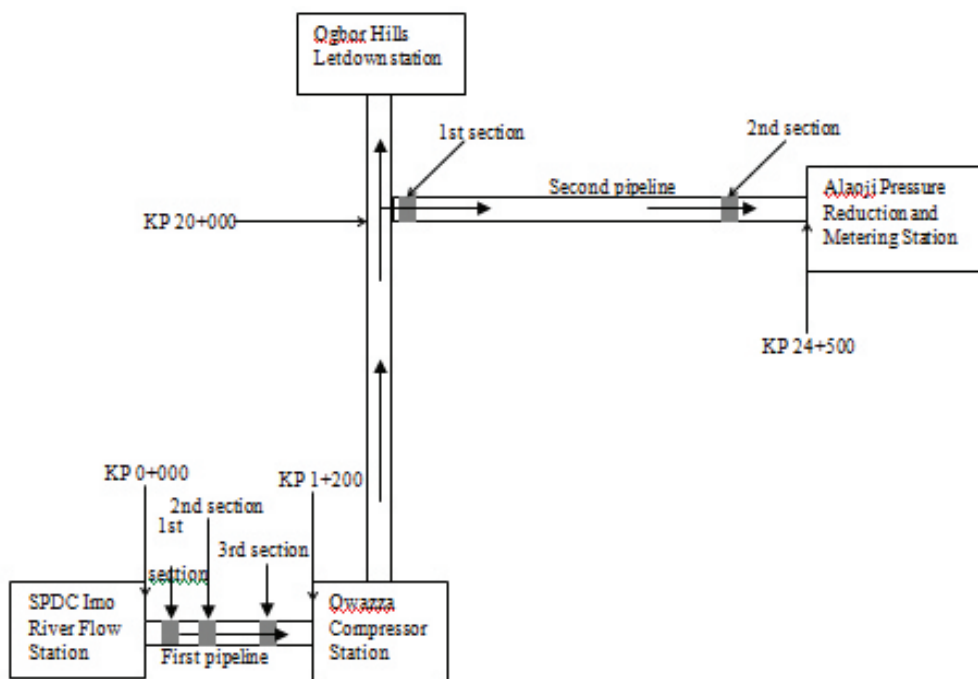


Figure 3.1: General arrangement for pipelines under survey.

### 3.2 Test Station

The test station is a point along the pipeline “right of way” where cables connected to the pipeline are drawn to the surface (above the ground); this is to enable pipe to soil potential measurement. Sacrificial anodes are also located at this point for temporary cathodic protection or stray current mitigation cases. The number of test stations located on a pipeline are dependent on the risk of possible stray current influence. The first pipeline surveyed had more than one test station within one kilometer considering the multiple pipeline crossings from the Imo River Flow Station. The second pipeline had one test station to one kilometer.

#### a. Instruments used for measurement

##### i. Stationary data logger (Smart Logger II)

The stationary data logger is a product of Cathodic Technology Limited Canada, it measures dynamic stray current in millivolts. This instrument has two terminals; one of the terminals is connected to the potential monitoring cable from the pipeline and the other is connected to the soil with a reference electrode.

##### ii. Close Interval Potential Survey Instrument (Cath-Tech Hexcorder Millennium GPS)

The Close Interval Potential Survey Instrument measures static stray currents in millivolts. This instrument also has two terminals; one of the terminals is connected to the potential monitoring cable from the pipeline and the other is connected to the soil with a reference electrode.

##### iii. Portable GPS Current interrupter

This instrument synchronises the GPS enabled Stationary data logger and the Close Interval Potential Survey tool to the rectifier to ensure that the readings of the dynamic stray currents and the static stray currents are taken at the same time over the period of survey. This instrument is a product of Rohrback Cosasco Systems California, USA and has an accuracy of  $\pm 5$  milliseconds.

### 3.4 Factors considered in experiment

Two factors were considered in selecting the sections on the pipeline for survey.

Proximity of the section to:

1. other pipelines or underground steel structures under impressed current cathodic protection.
2. construction sites where welding machines could be in use. Notably, “grounding” welding machines could be a major source of stray current

These two considerations were for potential sources of static and dynamic stray currents respectively.

#### a. Procedure for measurement

- 1) After the selection of the sections on the pipeline the CIPS equipment and the Stationary data logger were connected to the potential monitoring cable from the underground pipeline at the test station close to the section on the pipeline to be surveyed.
- 2) The Current Interrupter was then initiated to synchronize all measuring equipment (CIPS equipment and the

stationary data logger) to the potential source of static stray current (rectifier) to ensure that the measurements were taken at the same time.

3) Lastly, the pipe to soil potential readings were taken by walking down the line with the CIPS equipment connected to the test station and the surrounding soil with a trailing wire.

### 3.5 Correcting CIPS for stray currents

Close interval potential survey (CIPS) is the backbone of pipeline integrity, because it determines the effectiveness of the cathodic protection system which provides protection against external corrosion. CIPS is widely used to monitor the level of cathodic protection on the pipeline. The goal of the survey is to measure the instant off (rectifier off) potential, which minimizes any effect from the other resistances in the circuit. The difference between the on potential and the instant off is called the IR drop. When dynamic stray or telluric currents influence CIPS survey results, accurate interpretation of the results may be difficult if not impossible. Fluctuation of the pipe-to-soil potential due to dynamic stray or telluric current makes it difficult for the corrosion engineer to validate the integrity of the cathodic protection system protecting a valuable asset (Nicholson, 2007).

The correction of CIPS data was done in accordance with the procedure outlined in a paper on Stray Current Detection and Correction (Nicholson, 2010).

Through using the GPS synchronized data from CIPS and the stationary data logger, the CIPS data was corrected by removing the dynamic stray current effects. This gave a more accurate pipe to soil reading as it removes the influence by external interference. A correction factor was calculated from the stationary logger data that was then applied to the CIPS data. The on and the off values were calculated separately. The correction factor was calculated by finding the average of all the day's entries for the logger, then finding the difference between each reading and the average. For each CIPS reading, the correction factor from the logger data was added or subtracted as necessary. The on and off readings had different correction factors and it was ensured that the readings from the measuring instruments were taken at the same time.

$$CF = \frac{\sum(SDL)}{n(SDL)} \quad (1)$$

$$D = CIPS - CF \quad (2)$$

$$correct\ CIPS = CIPS - D \quad (3)$$

Where

SDL = Stationary data logger values

D = Deviation

CF = Correction Factor

### 3.7 Data Analysis

The static stray current data from the CIPS equipment were presented as voltage differences at Rectifier On/Instant OFF with time. For the dynamic stray current including telluric interference the data from the GPS stationary data logger were also presented as voltage differences at Rectifier On/Instant OFF with time.

For the static stray current, the voltage differences at Rectifier on and Rectifier off were plotted against time to get the voltage difference distribution with time and the result is that, if there is no stray current interference, there should not be any difference between the on and off readings. Where there is a current pickup point, the pipe will show an on reading higher than the off. Where there is a current discharge point, the on readings will go below the off readings (Nicholson, 2010).

For the dynamic stray current, the voltage differences at Rectifier on and Rectifier off were also plotted against time to get the voltage difference distribution with time. From the plot if there are spikes in the voltage during likely work period, the grounding system of DC welding machines used for fabrication/construction works should be checked, when the readings seem to be random, sunspot activities (telluric interference) should be investigated. Further investigation for the source of the stray currents can be done with the cooperation of other potential parties. Loggers can be set out to monitor for longer periods to see if there are any changes to the level of activity during overnight periods or on weekends.

## 4. Result and discussion

### 4.1 Presentation of data for the first pipeline (all measurements in negative millivolts)

Three sections were selected for investigation for the presence of stray current for the first pipeline. The sections were: Section 1 (kp0+000 to kp0+018), Section 2 (kp0+255 to kp0+273), and Section 3 (kp0+602 to kp0+620). The measurements were taken two times daily (afternoon and evening) for a period of four days during the dry and wet seasons.

#### 4.1.1 Results of stray current measurement for the first pipeline

Table 4.1. Section 1(kp0+000 to kp 0+018); Day 1 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIAT ION	OFF DEVIAT ION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
743	750	728	761	-22.3	18.4	765.3	731.6	762	764
750	758	726	751	-24.3	8.4	774.3	749.6	745	756
732	757	745	745	-5.3	2.4	737.3	754.6	771	781
701	730	763	723	12.7	-19.6	688.3	717.3	734	750
743	752	762	732	11.7	-10.6	731.3	762.6	745	759
734	840	757	741	6.7	-1.6	727.3	841.6	776	777
724	730	751	742	0.7	-0.6	723.3	730.6	756	760
735	740	768	749	17.7	6.4	717.3	733.6	783	784
750	757	762	749	11.7	6.4	738.3	750.6	756	763
723	749	741	733	-9.3	-9.6	732.3	758.6	761	766

Table 4.2. Section 1 (kp0+000 to 0+018); Day 1 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
753	762	756	762
757	761	765	770
759	760	745	757
762	777	768	781
770	781	738	746
734	750	753	769
745	748	745	752
749	761	758	764
750	782	759	760
753	754	754	770

Table 4.3. Section 1 (kp0+000 to 0+018); Day 2 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
777	790	761	767
745	749	743	750
753	761	749	753
746	750	761	772
771	772	771	782
777	781	765	783
766	773	768	783
767	780	746	752
781	783	762	765
782	791	772	779

Table 4.4. Section 1 (kp0+000 to 0+018); Day 2 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
745	750	745	751
765	766	756	762
744	750	748	755
755	764	745	760
762	771	762	763
765	772	747	754
765	769	752	757
770	779	750	757
754	760	764	768
756	760	749	755

Table 4.5. Section 1(kp0+000 to kp 0+018); Day 3 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
744	750	730	760	-22	7.7	766	742.3	723	730
754	785	731	750	-21	-2.3	775	787.3	731	737
762	794	743	745	-9	-7.3	771	801.3	745	750
783	793	761	724	9	-28.3	774	784	770	772
760	783	762	763	10	10.7	750	772.3	762	770
781	790	756	760	4	7.7	777	782.3	755	761
800	801	750	755	-2	2.7	802	798.3	782	785
770	782	764	767	12	14.7	758	767.3	734	740
800	811	782	749	30	-3.3	770	814.3	756	761
781	789	741	750	-11	-2.3	792	791.3	757	760

Table 4.6. Section 1 (kp0+000 to kp 0+018); Day 3 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
755	760	746	752
754	760	748	753
754	767	751	760
765	771	755	758
760	771	760	763
765	790	762	764
758	760	763	767
748	750	763	764
783	785	754	761
754	760	746	759

Table 4.7. Section 1(kp0+000 to kp 0+018); Day 4 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
733	753	740	755	-13.7	-1.5	746.7	754.5	761	777
756	757	755	751	1.3	-5.5	754.7	762.5	753	760
732	780	743	745	-10.7	-11.5	742.7	791.5	756	763
745	783	757	730	3.3	-26.5	741.7	779.7	745	749
760	783	758	769	4.3	12.5	755.7	770.5	756	759
782	791	756	760	2.3	3.5	779.7	787.5	784	785
801	790	751	756	-2.7	-0.5	803.7	790.5	745	754
777	782	765	766	11.3	9.5	765.7	772.5	734	754
790	810	770	782	16.3	25.5	773.7	784.5	756	757
781	788	742	751	-11.7	-5.5	792.7	793.5	757	767

Table 4.8. Section 1 (kp0+000 to kp 0+018); Day 4 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
737	750	743	750
745	757	745	750
745	753	752	757
754	760	745	752
756	760	759	765
760	762	761	763
754	769	762	769
746	750	743	750
751	753	756	760
753	754	756	763

#### 4.1.2 Discussion on section 1 of the first pipeline

The results for section 1 for both the dry and wet seasons show that the on readings (readings taken while the rectifier was on) were below the off readings (readings taken while the rectifier was off) as shown in all the table readings for this section implying a current discharge section. Furthermore, the readings for the measurements done in the afternoons as shown in all the tables for readings taken during the day for the dry season indicated presence of dynamic stray currents from construction sites where welding machines were in use. For the evenings, there was no presence of dynamic stray current because no welding activity was going on within the area.

Table 4.9. Section 2 (kp 0+255 to kp 0+273); Day 1 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
776	760	762	751	9.1	5	766.9	755	765	760
765	760	756	749	3.1	3	761.9	757	756	751
756	743	754	749	1.1	3	754.9	740	771	766
765	755	761	755	8.1	9	756.9	746.9	745	741
785	770	745	738	-7.9	-8	792.9	778	746	742
765	759	749	740	-3.9	-6	768.9	765	756	754
754	750	748	741	-4.9	-5	758.9	755	759	756
765	760	750	745	-2.9	-1	767.9	761	770	763
769	760	751	742	-1.9	-4	770.9	764	765	752
753	751	753	750	0.1	4	752.9	747	755	751



Table 4.10. Section 2 (kp 0+255 to kp 0+273); Day 1 for wet season

CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
754	750	756	751
756	751	765	762
764	759	756	751
754	749	768	761
759	749	777	765
746	736	764	758
754	750	754	749
749	740	759	750
751	745	760	754
752	748	754	746

Table 4.11. Section 2 (kp 0+255 to kp 0+273); Day 2 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
760	754	745	741
755	750	756	750
750	745	746	739
758	751	755	751
762	756	761	755
761	758	765	754
751	743	768	755
762	755	740	738
765	760	743	740
760	754	766	756

Table 4.12. Section 2 (kp 0+255 to kp 0+273); Day 2 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
745	740	769	760
755	752	765	761
746	739	758	752
754	748	765	760
756	754	758	755
751	746	770	761
752	745	753	745
753	746	750	745
758	750	761	752
756	751	750	745

Table 4.13. Section 2 (kp 0+255 to kp 0+273) Day 3 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
755	751	732	730	-18.8	-12.9	773.8	763.9	754	751
754	750	731	729	-19.8	-13.9	773.8	763.9	756	749
761	758	745	735	-5.8	-7.9	766.8	765.9	748	741
754	751	759	746	8.2	3.1	745.8	742.8	756	749
760	745	762	755	11.2	12.1	748.8	732.9	761	752
770	761	758	751	7.2	8.1	762.8	752.9	751	741
764	753	751	739	0.2	-3.9	763.8	756.9	743	738
765	760	764	755	13.2	12.1	751.8	747.9	744	738
768	762	765	755	14.2	12.1	753.8	749.9	749	739
770	762	741	734	-9.8	-8.9	779.8	770.9	752	745

Table 4.14. Section 2 (kp 0+255 to kp 0+273); Day 3 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
755	750	747	739
754	750	748	740
753	749	768	761
745	741	768	762
760	755	767	760
764	759	754	751
759	749	759	752
748	744	763	761
754	750	754	750
748	742	759	751

Table 4.15. Section 2 (kp 0+255 to kp 0+273) Day 4 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
755	750	740	735	-7.6	-5.4	762.6	755.4	761	777
756	749	755	746	7.4	5.6	748.6	743.4	753	760
746	740	746	743	-1.6	2.6	747.6	737.4	756	763
748	741	752	748	4.4	7.6	743.6	736.6	745	749
756	752	754	743	6.4	2.6	749.6	749.4	756	759
759	750	743	737	-4.6	-3.4	763.6	753.4	784	785
761	755	750	739	2.4	-1.4	758.6	756.4	745	754
756	752	743	731	-4.6	-9.4	760.6	761.4	734	754
756	749	742	734	-5.6	-6.4	761.6	755.4	756	757
747	739	751	748	3.4	7.6	743.6	731.4	757	767

Table 4.16. Section 2 (kp 0+255 to kp 0+273); Day 4 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
745	740	765	761
747	732	761	755
750	749	755	750
751	745	758	751
753	752	754	752
754	746	761	754
745	740	763	755
745	739	756	750
751	747	765	760
760	751	763	760

#### 4.1.3 Discussions on section 2 of the first pipeline

The results for section 2 for both the dry and wet seasons show that the on readings were higher than the off readings as shown in all the table readings for this section implying a current pickup section. Furthermore, the readings for the measurements taken in the afternoons for the third and fourth days as shown in Tables 4.25 and 4.29 indicated presence of dynamic stray currents from construction sites where welding machines were in use.

Table 4.17. Section 3 (kp 0+602 to kp 0+620); Day 1 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIAT ION	OFF DEVIAT ION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
770	760	763	755	9.4	8.9	760.6	751.1	765	759
763	759	760	749	6.4	2.9	756.6	756.1	754	748
757	743	754	746	0.4	-0.1	756.6	743.1	763	757
765	755	761	755	7.4	8.9	757.6	747.6	749	742
777	767	750	746	-3.6	-0.1	780.6	767.1	746	740
756	759	745	740	-8.6	-6.1	764.6	765.1	756	748
756	750	748	741	-5.6	-5.1	761.6	755.1	760	752
768	766	750	743	-3.6	-3.1	771.6	769.1	770	763
769	760	752	742	-1.6	-4.1	770.6	764.1	766	752
754	751	753	744	-0.6	-2.1	754.6	753.1	766	760

Table 4.18. Section 3 (kp 0+602 to kp 0+620); Day 1 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
760	753	755	751
756	750	765	762
762	755	756	749
755	753	765	759
759	750	777	770
750	744	764	758
754	750	750	739
749	748	759	750
753	750	760	755
752	741	759	742

Table 4.19. Section 3 (kp 0+602 to kp 0+620); Day 2 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
764	754	750	742
755	747	746	740
755	745	759	748
758	746	756	751
764	750	761	755
765	758	770	760
751	743	766	756
762	757	740	736
754	749	744	735
760	754	765	755

Table 4.20. Section 3 (kp 0+602 to kp 0+620); Day 2 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
743	740	756	745
746	739	754	743
746	740	760	752
754	751	765	760
750	742	758	745
752	739	750	745
760	755	753	749
753	749	748	740
758	750	761	752
755	751	750	743

Table 4.21. Section 3 (kp 0+602 to kp 0+620)Day 3 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIAT ION	OFF DEVIAT ION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
753	748	732	730	-18.8	-12.9	771.8	760.9	759	751
765	750	731	729	-19.8	-13.9	784.8	763.9	748	739
761	751	745	735	-5.8	-7.9	766.8	758.9	756	746
764	750	759	746	8.2	3.1	755.8	741.8	760	755
760	755	762	755	11.2	12.1	748.8	742.9	763	755
770	762	758	751	7.2	8.1	762.8	753.9	765	761
777	770	751	739	0.2	-3.9	776.8	773.9	743	740
765	762	764	755	13.2	12.1	751.8	749.9	750	743
768	760	765	755	14.2	12.1	753.8	747.9	749	743
771	762	741	734	-9.8	-8.9	780.8	770.9	753	748

Table 4.22. Section 3 (kp 0+602 to kp 0+620); Day 3 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
744	740	750	740
754	749	748	743
755	750	765	761
745	741	767	762
760	755	768	760
765	759	750	743
745	737	759	752
750	744	750	745
739	735	754	750
740	735	757	750

Table 4.23. Section 3 (kp 0+602 to kp 0+620); Day 4 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIAT ION	OFF DEVIAT ION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
759	751	740	735	-7.6	-5.4	766.6	756.4	761	777
755	749	755	746	7.4	5.6	747.6	743.4	753	760
746	738	746	743	-1.6	2.6	747.6	735.4	756	763
746	742	752	748	4.4	7.6	741.6	737.6	745	749
760	756	754	743	6.4	2.6	753.6	753.4	756	759
759	755	743	737	-4.6	-3.4	763.6	758.4	784	785
752	741	750	739	2.4	-1.4	749.6	742.4	745	754
756	749	743	731	-4.6	-9.4	760.6	758.4	734	754
756	745	742	734	-5.6	-6.4	761.6	751.4	756	757
765	758	751	748	3.4	7.6	761.6	750.4	757	767

Table 4.24. Section 3 (kp 0+602 to kp 0+620); Day 4 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
750	740	750	743
744	732	765	750
750	740	753	745
746	739	758	751
753	752	751	743
754	746	759	751
763	750	763	746
766	755	760	755
768	761	765	760
760	751	763	760

#### 4.1.4 Discussion on section 3 of the first pipeline

The results for section 3 for both the dry and wet seasons show that the on readings were higher than the off readings as shown in all the table readings for this section implying a current pickup section. Furthermore, the readings for the measurements taken in the afternoons for the first and third days as shown in Tables 4.33 and 4.41 indicated presence of dynamic stray currents from construction sites where welding machines were in use.

#### 4.2 Presentation of data for the second pipeline (all measurements in negative millivolts)

Two sections were selected for investigation for the presence of stray current for the second pipeline. The sections were: Section 1 (kp20+570 to kp20+588), and Section 2 (kp23+420 to kp23+438). The measurements were also taken two times daily (afternoon and evening) for a period of four days during the dry and wet seasons.

#### 4.2.1 Results of stray current measurement for the second pipeline

Table 4.25. Section 1 (kp 20+570 to kp 20+588) Day 1 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRECT RECT ON	CORRECT RECT OFF	CIPS RECT ON	CIPS RECT OFF
780	771	546	399	-56.6	-217.1	836.6	988.1	764	753
760	755	640	657	37.4	40.9	722.6	714.1	765	745
755	750	750	546	147.4	-70.1	607.6	820.1	743	756
765	761	649	763	46.4	146.9	718.6	714.6	765	742
782	773	453	647	-149.6	30.9	931.6	742.1	762	742
765	761	747	646	144.4	29.9	620.6	731.1	762	748
792	781	648	342	45.4	-274.1	746.6	1055.1	756	756
745	739	300	658	-302.6	41.9	1047.6	697.1	771	761
765	756	747	759	144.4	142.9	620.6	613.1	766	765
777	747	546	744	-56.6	127.9	833.6	619.1	763	746

Table 4.26. Section 1 (kp 20+570 to kp 20+588); Day 1 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
763	753	734	730
757	756	765	755
761	755	765	755
756	748	754	751
759	763	760	755
750	748	764	762
745	740	755	749
749	748	745	739
756	750	761	755
752	741	759	742

Table 4.27. Section 1 (kp 20+570 to kp 20+588) day 2 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRECT RECT ON	CORRECT RECT OFF	CIPS RECT ON	CIPS RECT OFF
756	751	654	644	83.5	-48.3	672.5	799.3	756	764
756	750	300	764	-270.5	71.7	1026.5	678.3	774	764
743	740	250	478	-320.5	-214.3	1063.5	954.3	756	756
761	755	450	748	-120.5	55.7	881.5	875.5	764	751
754	747	567	658	-3.5	-34.3	757.5	781.3	791	755
759	751	634	746	63.5	53.7	695.5	697.3	746	761
766	760	764	647	193.5	-45.3	572.5	805.3	782	761
769	761	729	765	158.5	72.7	610.5	688.3	745	736
756	745	613	739	42.5	46.7	713.5	698.3	777	745

Table 4.28. Section 1 (kp 20+570 to kp 20+588); Day 2 for wet season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT	CIPS RECT	CIPS RECT
781	765	756	745
782	771	765	754
770	763	760	752
753	750	768	760
746	742	744	735
782	774	750	745
756	751	753	749
764	760	756	740
764	750	761	752
756	751	748	745

Table 4.29. Section 1 (kp 20+570 to kp 20+588); Day 3 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRECT RECT ON	CORRECT RECT OFF	CIPS RECT ON	CIPS RECT OFF
751	748	644	546	93.6	0.2	657.4	747.8	765	753
764	750	763	627	212.6	81.2	551.4	668.8	764	741
759	751	647	342	96.6	-203.8	662.4	954.8	756	746
742	752	321	455	-229.4	-90.8	971.4	981.4	763	755
748	755	647	566	96.6	20.2	651.4	734.8	763	756
764	762	455	362	-95.4	-183.8	859.4	945.8	777	761
777	771	674	645	123.6	99.2	653.4	671.8	755	745
765	762	754	748	203.6	202.2	561.4	559.8	751	762
768	763	255	624	-295.4	78.2	1063.4	684.8	749	743
772	762	344	543	-206.4	-2.8	978.4	764.8	753	760

Table 4.30. Section 1 (kp 20+570 to kp 20+588); Day 3 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
785	775	765	750
764	757	783	760
754	751	742	735
771	765	756	745
763	760	777	760
756	749	750	743
768	761	760	753
764	753	756	745
739	735	754	749
750	736	743	738



Table 4.31. Section 1 (kp 20+570 to kp 20+588); Day 4 for dry season

AFTERNOON		EVENING							
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT	DATA LOGGER RECT	ON DEVIATION	OFF DEVIATION	CORRE CT RECT	CORRE CT RECT
735	754	754	743	555	355	-2.8	-301.1	756.8	1044.1
765	749	744	731	625	637	67.2	-19.1	676.8	750.1
765	764	756	752	647	637	89.2	-19.1	666.8	771.1
743	751	742	735	321	667	-236.8	10.9	978.8	971.8
765	756	761	755	647	647	89.2	-9.1	671.8	764.1
756	743	746	735	355	763	-202.8	106.9	948.8	628.1
752	741	777	761	674	838	116.2	181.9	660.8	579.1
756	761	765	760	673	737	115.2	80.9	649.8	679.1
761	745	756	751	737	737	179.2	80.9	576.8	670.1
765	745	772	770	344	543	-213.8	-113.1	985.8	883.1

Table 4.32. Section 1 (kp 20+570 to kp 20+588); Day 4 for wet season

AFTERNOON								EVENING	
CIPS RECT	CIPS RECT	DATA LOGGER	DATA LOGGER	ON DEVIATION	OFF DEVIATION	CORRE CT	CORRE CT	CIPS RECT	CIPS RECT
765	760	657	684	49.8	151.4	715.2	608.6	751	745
747	740	765	456	157.8	-76.6	589.2	816.6	765	749
756	751	345	435	-262.2	-97.6	1018.2	848.6	759	745
768	760	657	564	49.8	31.4	718.2	710.2	768	765
756	750	748	645	140.8	112.4	615.2	637.6	771	758
765	761	657	564	49.8	31.4	715.2	729.6	759	750
777	755	456	646	-151.2	113.4	928.2	641.6	763	746
760	751	673	444	65.8	-88.6	694.2	839.6	763	755
756	751	737	345	129.8	-187.6	626.2	938.6	765	759
782	770	377	543	-230.2	10.4	1012.2	759.6	756	755

Table 4.33. Section 2 (kp 23+420 to kp 23+438); Day 1 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
760	771	745	752
756	765	768	771
765	771	768	773
756	769	784	791
756	762	764	772
765	771	762	771
782	789	756	760
756	760	765	768
768	791	764	768
748	752	763	770

Table 4.34. Section 2 (kp 23+420 to kp 23+438); Day 1 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
784	791	756	761
757	763	765	774
755	768	783	790
756	766	765	770
768	775	760	771
750	761	764	774
745	758	765	774
749	756	745	759
789	792	780	782
752	763	759	765

Table 4.35. Section 2 (kp 23+420 to kp 23+438); Day 2 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
761	768	756	764
751	755	774	780
763	771	762	770
761	768	756	762
764	769	782	791
755	762	756	761
764	771	763	769
758	770	750	763
759	771	760	768
748	759	765	769

Table 4.36. Section 2 (kp 23+420 to kp 23+438); Day 2 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
785	792	765	772
784	788	784	790
770	781	760	764
753	760	783	792
756	762	744	755
782	791	750	762
756	765	765	769
785	789	764	769
764	770	761	768
784	791	748	750

Table 4.37. Section 2 (kp 23+420 to kp 23+438); Day 3 for dry season

AFTERNOON		EVENING	
CIPS RECT ON	CIPS RECT OFF	CIPS RECT ON	CIPS RECT OFF
753	761	765	771
764	773	764	769
759	761	756	761
762	771	782	791
756	761	763	772
764	769	764	769
777	781	755	761
784	789	751	760
756	761	765	743
772	774	753	760

Table 4.38. Section 2 (kp 23+420 to kp 23+438); Day 3 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
785	790	765	771
777	801	783	792
765	775	750	765
781	784	768	786
745	765	777	784
765	770	750	765
768	771	765	778
764	770	756	768
790	804	765	768
750	754	743	768

Table 4.39. Section 2 (kp 23+420 to kp 23+438); Day 4 for dry season

AFTERNOON								EVENING	
CIPS RECT ON	CIPS RECT OFF	DATA LOGGER RECT ON	DATA LOGGER RECT OFF	ON DEVIATION	OFF DEVIATION	CORRE CT RECT ON	CORRE CT RECT OFF	CIPS RECT ON	CIPS RECT OFF
764	769	655	673	131.1	140.8	632.9	628.2	756	762
759	768	674	454	150.1	-78.2	608.9	846.2	744	756
765	769	455	373	-68.9	-159.2	833.9	928.2	756	762
756	761	277	546	-246.9	13.8	1002.9	1007.9	765	771
768	775	647	648	123.1	115.8	644.9	659.2	761	768
789	793	455	546	-68.9	13.8	857.9	779.2	746	756
765	780	645	234	121.1	-298.2	643.9	1078.2	782	789
765	775	754	647	230.1	114.8	534.9	660.2	765	770
789	791	333	658	-190.9	125.8	979.9	665.2	756	762
772	783	344	543	-179.9	10.8	951.9	772.2	772	779

Table 4.40. Section 2 (kp 23+420 to kp 23+438); Day 4 for wet season

AFTERNOON		EVENING	
CIPS RECT	CIPS RECT	CIPS RECT	CIPS RECT
765	771	753	762
784	792	758	772
789	812	759	763
754	765	768	781
763	770	765	768
765	771	756	765
777	780	763	785
764	781	762	775
756	764	743	767
789	790	756	768

#### 4.2.2 Discussion on the two sections of the second pipeline

The random readings for the second pipeline show telluric effect of the sun due to sunspot activities on the earth magnetic field. This can create an error in the pipe to soil potential readings by making the pipeline appear to have better or worse cathodic protection than it actually has.

#### 4.3 Data analysis

This study sought to investigate the amount of current entering or leaving the pipe surface to enable it compute the rate of metal loss (corrosion rate) of the pipeline

##### 4.3.1 Total current entering or leaving the pipe surface

$$\Delta\phi = 0.734\rho j \quad (4)$$

Where  $\Delta\phi$  = measured potential difference

$\rho$  = resistivity of the soil

$j$  = current entering or leaving the pipe surface

$$\text{Therefore } j = \frac{\Delta\phi}{0.734\rho}$$

##### 4.3.2 Rate of pipe thickness loss

$$W = kt \quad (5)$$

Where;

$W$  = weight of metal reacting in gram

$k$  = electrochemical equivalent (constant)

$I$  = current entering or leaving the pipe surface in ampere

$t$  = time in seconds

$k$ , for carbon steel =  $4.29 \times 10^{-4}$

## 5. Conclusion

This study outlined appropriate methods to measure pipe to soil potential difference, soil resistivity, and pipe thickness loss. It further articulated the likely sources of stray currents within the Niger Delta region, the telluric effect of the sun to errors in pipe to soil potential readings, and suitable control measures against stray currents. The values obtained for the first pipeline were within the range of negative 710mV-810mV and were enough to cause corrosion on the pipeline. The second pipeline had this range of values except that they were random. The second pipeline had a higher corrosion rate of  $1.72 \times 10^{-6}$ g compared to that of the first pipeline of  $1.42 \times 10^{-6}$ g due to the telluric effect of the sun.

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