

PERFORMANCE EVALUATION OF HALF CELL REFERENCE ELECTRODES VARIATION IN CATHODIC PROTECTION SYSTEMS

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ABSTRACT

Reference electrodes are needed in all cathodic protection systems, to measure the current flow potentials of all kinds of metals. Different metals have different electrical potential and their relative positions in most aqueous environments are as follows; Magnesium (mg) > zinc (Zn) > Aluminium (Al) > iron (Fe) > steel (mild) > Tin (Sn) > Lead (Pb) > Brass (Cu-Zn) > copper (Cu) > Silver (Ag) > Gold (Au). Considering that Magnesium, Aluminium and Zinc are negative to mild steel; hence they are considered usable against mild steel. Magnesium, Aluminium or Zinc is used as auxiliary anodes that are directly electrically connected to the steel structure to be protected. To ascertain a given level of protection in line with specifications this must not be too high or too low. Embedded cells are more convenient than surface cells where access to the protected surface of the structure is difficult, and they are essential when potential-controlled rectifiers or remote monitoring systems are being used. This study gives the results of a series of laboratory exercises, outdoor exposure and field tests to evaluate the suitability of embedded reference cells for use in Yam Minisett Machines, stationary Ginger Splitting Machines and general metal protection. Zinc-zinc sulfate, silver-silver chloride, lead-lead oxide cells and graphite electrodes were evaluated. In all, the magnesium, carbon, graphite and coke with were found to be the most stable over time and the least influenced by changes in temperature.

Key Words: Temperature, Reference Electrode, Variation, Potential, Food processing, Protection

1.0 INTRODUCTION

One of the most efficient ways of monitoring a cathodic protection system is by the use of half-cell reference electrodes. When collecting electrochemical field data, there is a need for quality products to perform surveys properly. Copper in a saturated solution of copper sulphate is a complete cell. The term “half cell” means half of the components that are required to constitute a cell. The reaction potential of this cell is known when referred to a standard reference electrode in a closed circuit, in a laboratory under controlled conditions. This demonstration shows conditions similar to those found in cathodic protection fieldwork. The conditions replicated cannot be controlled but the electrical equilibrium of the corrosion systems.

Cathodic protection can be achieved in two ways: By the use of galvanic (sacrificial) anodes or by “impressed current”

Galvanic anode systems involve the connection of dissimilar metals in an electrolyte (soil or water) (Sheir *et al.*, 2000). Current flows between the two dissimilar metals because of dissimilar electrode potentials. The metal with more electronegative (active) metal will corrode. Different metals have different electrical potential and their relative positions in most aqueous

environments are as follows. Magnesium (mg) > zinc (Zn) > Aluminium (Al) > iron (Fe) > steel (mild) > Tin (Sn) > Lead (Pb) > Brass (Cu-Zn) > copper (Cu) > Silver (Ag) > Gold (Au). Considering that Magnesium, Aluminium and Zinc are negative to mild steel; hence they are considered usable against mild steel. Magnesium, Aluminium or Zinc is used as auxiliary anodes that are directly electrically connected to the steel structure to be protected. The difference in natural electrical potentials between the anode and steel, as indicated by their relative positions in the electrochemical series, causes a positive current to flow in the electrolyte, from the anode to the steel. Thus, the whole surface of the steel becomes more negatively charged and becomes the “cathode” of the galvanic cell (Kuhn, 2006). In other words, a material of higher electro-negativity is electrically connected to the structure to be protected to give it a longer-lasting life. As stated above, the metals commonly used as sacrificial anodes are Aluminium, Zinc and Magnesium. These metals are alloyed to improve their long-term performance and dissolution characteristics. Impressed current systems employ inert (zero or low dissolution) anodes that are used as the external source of direct current (dc) power (rectified alternating current) to

impress a current from an external anode unto the cathode surface. The protected structure is made electrically negative so that it acts as a cathode. A second electrode is made electrically positive and

completes the circuit as an auxiliary anode (Umezuruike, 2008). Figure 1.1 below shows the relationship between pipeline corrosion and current flow.

Figure 1.1 shows the Schematic diagram of basic cathodic protection (CP) installation.

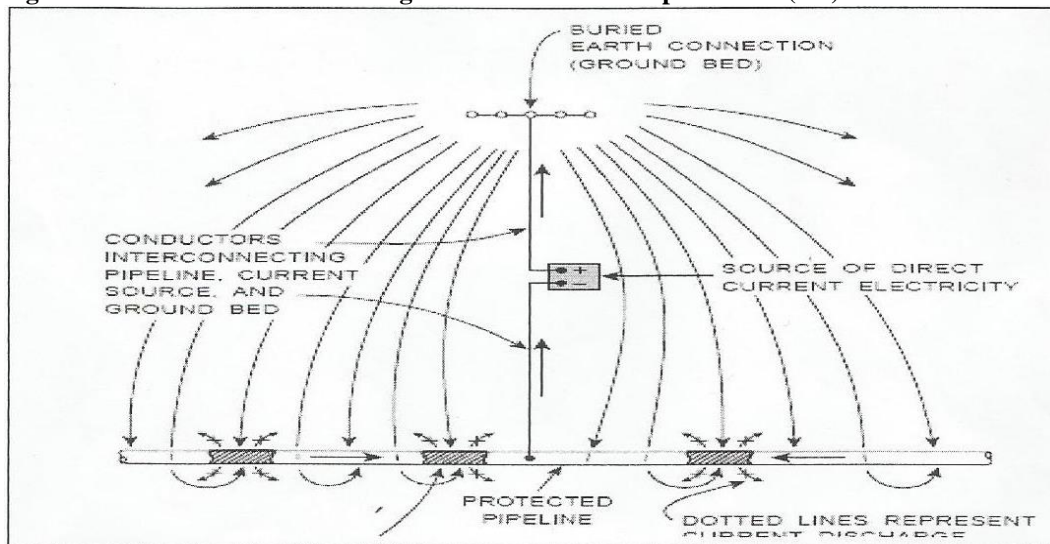


Figure 1.1 Schematic diagram of basic cathodic protection (CP) installation

The diagram shows a fully charged CP system. The ground bed of the installed system was prepared with the right specification and distancing as recommended with the anode kept at a distance where would not encourage overprotection and/or underprotection.

1.1 Metal Conductivity

Conductivity in metals must follow ohm's law, which states that the current is directly proportional to the electric field applied to the metal. The law, named after German physicist Georg Ohm, appeared in 1827 in a published paper laying out how current and voltage are measured via an electrical circuit. The variable in applying Ohm's law is a metal's resistivity. Resistivity is the opposite of electrical conductivity, evaluating how

strongly a metal opposes the flow of electric current. This is commonly measured across the opposite faces of a one-meter cube of material and described as an Ohm meter ($\Omega \cdot m$). Resistivity is often represented by the greek letter rho (ρ).

Electrical conductivity, on the other hand, is commonly measured by Siemens per meter ($S \cdot m^{-1}$) and represented by the Greek letter sigma (σ). One Siemens is equal to the reciprocal of one ohm. Sacrificial anode cathodic protection is possible because different metals have different electrical potentials and relative positions in most aqueous environments encountered in practice. These are summarized in the partial galvanic series below.

Table 1.1: Practical galvanic series for metals in neutral soils and water

Metal	Potential (V) (Cu/CuSO ₄ Electrode)
Carbon, Graphite, Coke	+0.3
Platinum	0 to -0.1
Mild Scale on Steel	-0.2
High Silicon Cast Iron	-0.2
Copper, Brass, Bronze	-0.2
Mild Steel in Concrete	-0.2
Lead	-0.5
Cast iron (not Graphitized)	-0.5
Mild steel (Rusted)	-0.2 to -0.5
Mild steel (clean & shiny)	-0.5 to -0.8

Al alloy (5% Zn)	-1.05
Zinc	-1.1
Mg Alloy (6% Al, 3% Zn, 0.15%Mn)	-1.6
Commercially pure Mg	-1.75

Source: Peabody, 2001

1.2 FACTORS RESPONSIBLE FOR CORROSION IN PIPELINES

The rate of corrosion on a piping system is related to these factors:

- (i) **The pH of the water:** The acidity of the water sample is measured on a pH scale. The pH of the scale 7 represents the neutral point. Acidity increases from neutral toward zero.
- (ii) **Amount of oxygen in the water:** Dissolved air in the water consists of about 30% oxygen and the rest is mostly nitrogen, which is non-corrosive. Oxygen degrades metals through an electrochemical process of internal oxidation.
- (iii) **The chemical makeup of water:** Dissolved minerals in the water and the basic chemical composition of the water may have differing effects on the corrosive force at play. A moderate to the high level of calcium would help form a protective coating on the pipe which could slow down the corrosive effect. However, high levels of calcium may cause calcium build-up in the pipe.
- (iv) **Dissimilar metals galvanic corrosion:** Galvanic corrosion, also known as electrolysis, occurs when different metals come into contact with each other. When dissimilar metals come in contact, one of the metals tends to give up electrons. Basically, at the point of contact, the metal giving up the electrons dissolves over time.
- (v) **Water velocity:** Water velocity problems are usually associated with a “closed” loop piping system where the need to pump or circulate the water is required. Erosion corrosion occurs at locations where water turbulence develops. Turbulence can be caused by excessive velocity, sudden change in direction (sharp turns, elbows) and through “flow” obstacles such as burrs and solder excess.
- (vi) **Water temperature:** The higher the water temperature, the faster the rate of oxidation. Experience shows that corrosion is more pronounced in hot water lines.

The invention and first application of cathodic protection with the help of half cell are attributed to Davy in 1824 in a project financed by the British Navy which succeeded in preventing the corrosion of copper sheathing of the wooden hulls of the British Naval ships (Peabody, 2001). About 1820 the Navy Board was anxious to find the reason why copper sometimes got fouled, whilst the iron was dissolving, and at other times the copper was dissolving rather too quickly. A

committee was formed with the Royal Society, of which sir Humphrey Davy was president. Davy had already in 1806 advanced the hypothesis that chemical and electrical changes may be identical and late convinced Berzelinis of this idea, assisted by Michael Faraday, he began to experiment with copper and other metals, such as iron and zinc in various saline solutions and found the electrochemical reactions he had expected. Sir Humphrey Davy advocated a small quantity of zinc, or even cheaper-malleable iron, should be placed in contact with copper and thereby prevents its corrosion (Beckmann *et al.*, 1997). The cathodic protection (CP) effectiveness of protecting steel in soils has been demonstrated in the early 1940s when CP was applied to an old natural gas piping network that had been developing leaks at an increasing rate, so much so that the abandonment was seriously been considered. The observed restriction in the number of leaks immediately after the CP installation was impressive. A similarly impressive reduction in the frequency of leaks on a cast iron water main was achieved in about the same period (Ashworth, 1994). Kuhn made considerable research in connection with the corrosion of cast iron pipes in the soil. Those studies indicated that galvanic currents of great magnitude circulated a corroding pipe and that these currents discharge at the points of corrosion and collected in other areas. He stated that ordinary corrosion could be prevented by reversing these currents. In 1933, Kuhn postulated that the potential needed to step corrosion is probably in the range of -850mV (Kuhn, 2006). Schewedtfeger and McDorman carried out a verification experiment to validate the -850mV protection criterion in the early 1950s. they concluded that for the copper-copper-sulfate (Cu/CuSO₄) electrode, “the protective potential of approximately -850mV is in agreement with the practice for cathodic protection (CP) used by many corrosion engineers, in those cases where the measurements are free of current drop, external to the electrical boundary of the corrosion circuit” (Gummow *et al.*, 2010). The work of stern and Geary on the principles of electrode kinetic provided the foundation for the theory of cathodic protection. They used electrode kinetics-theory to justify controlled constant potential cathodic protection in cases where corrosion is controlled by diffusion of dissolved oxygen. Their work also showed that anodic polarisation behaviour can be used to characterise the performance of sacrificial anodes for cathodic protection (Paul *et al.*, 2013). Shrier reviewed

the theories of cathodic protection and concluded that gradual improvement has taken place in the description of the fundamental principle (Shreir, 2001). Recent studies showed that cathodic polarization of -100mV free ohmic IR interference was the most universally applicable criterion for the protection in a laboratory soil test. It was felt that some contributions could be made in this area in which some other criteria and parameters necessary for the cathodic protection of buried steel structures could be examined (Gummow *et al.*, 2010). Peabody reported that the attempts to control tapelines or exposed areas where the coating could not cover relied on the use of coating materials and the reasoning that if the pipeline metal could be isolated from contact with the surrounding earth, no corrosion will occur (Peabody, 2001).

This concept is entirely reasonable and logical. A coating would be completely effective as a means of stopping corrosion of the coating material.

- a. Is an effective electrical insulator
- b. Can be applied with no breaks whatsoever and will remain so during the backfilling process.
- c. Constitutes an initially perfect film that will remain so with time.

1.3 PRACTICAL APPLICATION OF CATHODIC PROTECTION

Cathodic protection may be achieved either by; Sacrificial anode method (SACP) or by Impressed current method (ICCP).

1.3.1 Processes Involved in the SACP System

Corrosion cell resulting from contact of dissimilar metals leads to a cell in which one is active (negative) to the other. In cathodic protection, the above stated is taken advantage of by purposely establishing dissimilar metal cells normally existing on metal plates. This is accomplished by connecting a very active metal to the

2.

structure. This metal will corrode and in so doing will discharge current to the preferred metal. Cathodic protection does not eliminate corrosion; rather it displaces corrosion from the structure being protected to sacrificial anodes. Under normal circumstances, the current available from sacrificial anodes is limited. For this reason, cathodic protection by sacrificial anodes normally is used where the current required for protection is small (typically less than 1 Ampere) and in areas where soil resistivity is low enough (typically less than 10,000 Ohm-cm) to permit obtaining the desired current with a reasonable number of anodes. Similarly, the driving voltage existing between the steel pipe and the galvanic anode is limited. Therefore, the contact resistance between the anodes and the earth must be low for the anode to discharge a useful amount of current. This means that, for normal installations, galvanic anodes are used in low-resistivity soils (Peabody, 2001; Kuhn, 2006; Gummow *et al.*, 2010; Ovi and Iroh, 2011). Sacrificial anode cathodic protection is possible because different metals have different electrical potentials and relative positions in most aqueous environments encountered in practice.

Types of corrosion in buried pipelines

1. **Pitting:** This is a form of extremely localized corrosion that leads to the creation of small holes in the metal. The driving power for pitting corrosion is the de-passivation of a small area, which becomes anodic while an unknown but potentially vast area becomes cathodic, leading to very localized galvanic corrosion. The corrosion penetrates the mass of the metal, with limited diffusion of ions. The mechanism of pitting corrosion is probably the same as crevice corrosion. Figure 2.2 shows the actions of corrosion on a piece metal sheet.

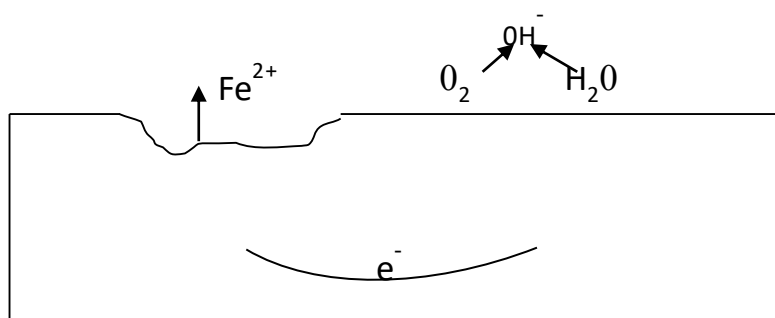


Figure 1.1: Diagram showing a mechanism of localized corrosion developing on metal in a solution containing oxygen.

This kind of corrosion is extremely insidious, as it causes little loss of material with small effect on its surface, while it damages the deep structures of the metal. The pits on the surface are often obscured by corrosion products. Table 2.2 shows the corrosion potential range of some metals

Table 1.2 Corrosion potential range of some elements

ANODIC or Least Noble	Corrosion Potential Range in Millivolts
Mg and Mg Alloys	-1600 to -1630
Zinc	-980 to -1030
Al alloys	-760 to -1000
Cadmium	-700 to -730
Mild steel	-600 to -710

3. **Galvanic corrosion:** Galvanic corrosion or dissimilar metal corrosion occurs when two different metals are located together in a corrosive electrolyte. A galvanic couple forms between the two metals, where one metal becomes the anode and the other the cathode. The anode, or sacrificial metal, corrodes and deteriorates faster than it would alone, while the cathode deteriorates more slowly than it would otherwise. Three conditions must exist for galvanic corrosion to occur:

- The metals must be in electrical contact
- It must be exposed to an electrolyte
- Electrochemically dissimilar metals must be present

Other types of corrosion includes; Environmental Cracking, High Temperature Corrosion, Filiform Corrosion, Crevice Corrosion and Stress Corrosion Cracking.

Advantages of sacrificial anode CP systems (Paul *et al.*, 2013)

- Self-powered, so no external power source is required.
- Easy field installation (relatively low installation cost).
- Low maintenance costs
- Capital investment is low.
- Less likely to cause stray current interference problem on other structures.
- Danger of over protection is reduced
- Suitable where low current is required
- System is essentially self-regulating
- Suitable for localized protection
- Relatively uniform potential distribution

There is no one process involved in cathodic protection that will not require a half-cell reference electrode to ascertain the relationship between the protected metal and the sacrificial metal. Over the years, there have been arguments on the stability of results the half cells produce. Under exact electrochemical and soil conditions, the data collected using Cu-CuSO₄ differs from that of Zn-ZnSO₄. Having sampled different half

cells, graphite cells are the best because of their consistency with the result. There is better electrolyte communication between the half cell reference electrodes and the chemical reaction in the buried cathodic environment.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

For a typical half-cell reference electrode survey to be achieved, the following tools were used: Single packaged magnesium anode (with chemical backfill), Polyethylene tape (with coal tar enamel), Test post, PVC-PVC cable, Multi-meter, Bolt and nut, CADweld mould and CADweld powder, CADweld disc, Copper-copper sulphate reference electrode (Cu/CuSO₄), Soil resistivity meter (DETS5/4R and DET5), Test cables (0.025m flexible cable), Measuring tape, Hammer, Plier, Cutlass, and Peg and line.

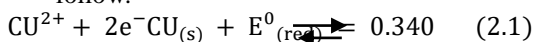
2.2 METHODS

(i) **Magnesium anode:** Magnesium anodes come in all shapes and sizes. The magnesium in a packaged anode weighs from 0.454kg to 22.680kg. The most commonly used anode in the United States weighs 7.711kg. The backfill consists of 75% powdered gypsum, 20% powdered bentonite clay and 5% sodium sulphate. This mixture is a low-cost, non-hazardous, electrically conductive earth backfill. Based on the length of the structure to be considered for this project, a minimum packaged anode of 5-7.5kg will be needed. The description of the tools used in the study are as follows:

- Polyethylene tape:** Polyethylene tape is a type of tape which has a waterproof backing with a rubber adhesive. This is used for all purpose applications, including; Sealing, Colour coding, Protection and Moisture proofing. **Test-Post:** The test-post is the signboard which displays the connections between the structure to be protected and the magnesium anode. It can either be made of wooden material or plastic.
- PVC-PVC wire cable:** This is a double coated wire cable which is specially produced for cathodic protection works. It is made of

copper wire and it is thermally very conductive. PVC is commonly used as the insulation on electrical cables; PVC used for this purpose needs to be plasticized.

3. **Multi-meter:** A multi-meter or a multi-tester, also known as a VOM (volt-ohm meter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multi-meter would include features such as the ability to measure voltage, current and resistance. DT-9205A will be the model of the multi-meter needed to calculate the current flow between the metal and anode.
4. **Bolt and nut:** Bolt and nut are tools used to hold two ends (be it joints, elbow etc.). For this project, bolts and nuts will be needed to fasten the PVC wire cable to the signboard (Test Post).
5. **CADweld mould:** CADweld mould as a tool is used (with the aid of gun powder) called CADweld powder for sealing the exposed region on the structure where the PVC wire cable was connected directly to the mild steel pipe
6. **CADweld disc and powder:** CAD weld disc is a conically shaped metal disc which melts alongside CADweld powder in an effervescence manner. The disc acts as a timing device to allow the welding powder to heat to a proper temperature suitable to cause metal fusing. Technically, it is called exothermic welding.
7. **Copper-copper sulphate reference electrode:** It is used for measuring electrode potential and is the most commonly used reference electrode for testing cathodic protection corrosion control systems. The corresponding equation 2.1 can be presented as follow.



This reaction is characterized by reversible and fast electrode kinetics, meaning that a sufficiently high current can be passed through the electrode with the 100% efficiency of the redox reaction. Figure 2.1 shows the potential of a Cu/CuSO_4 electrode is + 0.314 volt to the standard hydrogen electrode.

2.3 SOIL ANALYSIS

A detailed soil resistivity survey was carried out within the premises of the works and services department of the Michael Okpara University of Agriculture, Umudike. This was done to know the physio-chemical and microbial properties of the area under study.

2.3.1 Laboratory Testing

These following tests were carried out to achieve this work:

(i) **pH:** For a given resistivity, acid soils, (pH less than 7) are more conducive to steel corrosion. At a pH value below 4, the rate of corrosion accelerates rapidly. At pH values above, 10, the environment tends to inactivate the steel.

(ii) **Chloride Ion:** Chloride ions destroy the passive film on steel and cause pit corrosion.

(iii) **Sulphide Ion:** Sulphide ions present in the soil are indicative of anaerobic conditions. Under these conditions, sulphate-reducing bacteria can greatly accelerate the rate of corrosion.

Moisture Content: The moisture content is a significant parameter in determining the degree of corrosiveness of the environment under consideration. When soil samples are collected, they are immediately protected from environmental interference and escape of moisture content.

Procedure: The soil resistivity meter gives the value of the soil resistance R (Ω), directly. The grass around the survey area was cleared, and four (4) probe rods/spikes are pushed into the ground using a hammer. With aid of a peg, line and tape, the spikes were in a straight line and equidistant from each other with the spikes' depth equal to spacing "a" divided by twenty (20m) as recommended in the manual of the soil resistivity meters used.

Resistance R (Ω) at different depths are taken and their resistivity calculated using equation 2.2. (Michael *et al.*, 1994)

$$\begin{aligned} P &= 2\pi aR \\ \text{Where } P &= \text{Soil resistivity} \\ &(\text{ohm-m}) \\ a &= \text{distance between} \\ &\text{spikes/probes} \\ R &= \text{Soil resistance } (\Omega) \\ &(\text{instrument reading}) \\ \pi &= 3.142 = \text{constant} \end{aligned} \quad (2.2)$$

If the soil is sandy, loose, or muddy, the top layer should be scrapped to ensure that the probe spikes are driven into firm soil to guarantee close contact with the group. The test was conducted two times and the average value for each depth was taken to determine the depth that gives a minimum of $15\Omega\text{m}$ and maximum value of $20\Omega\text{m}$ resistivity which is ideal for magnesium anode. The installation depth was 1.3m which gave the desired value.

2.3.2 Calculation of corrosion rates

The corrosion rate depends on the kinetics of both anodic (oxidation) and cathodic (reduction) reactions. There is a linear relationship between the metal dissolution rate (m) and corrosion rate (CR) which is directly proportional to the corrosion current. (Corrosion rate conversion) the corrosion rate is calculated in (millimetre per year) (mm/yr) (1 mpy = 0.0254 mm/yr = 25.4microm/yr)

(mpy = dissolution rate per year)

The corrosion rate from the metal loss was calculated using equation 2.3.

$$CR = 87.6 \times \left(\frac{W}{DAT} \right) \quad (2.3)$$

Where:

W = weight loss in kg
D = metal density in g/m³
A = area of sample in m²
T = time of exposure of the metal sample

in hours

CR = corrosion rate in mm/yr.

Total current required to protect the pipe; I_T is given in equation 2.4

$$I_T = (S_A \times I_D \times FS)(mA) \quad (2.4)$$

Where:

I_D = current density
FS = factor of safety
S_A = surface area

Anode required current I_A, is given in equation 3.5

$$I_A = S_A \times I_D \times FS \quad (2.5)$$

Where;

S_A = surface area of pipe
I_D = current density
FS = factor of safety

The mean current for pipe protection, I_M is given in equation 2.6

Where:

CE = Coating efficiency

$$I_M = I_D \times S_A \times \frac{100 - CE}{100} \quad (2.6)$$

3.0 RESULTS AND DISCUSSION

Table 3.1 shows that the change in the value of the soil resistivity value was directly proportional to depth. This also applies to the resistance of the soil which shows upward sloping to distance.

Table 3.1: Soil resistivity survey results

Spacing (m)	“a”	Depth (a/20) (m)	Resistance R (Ω)	Resistivity, ρ (2ππR)(Ωm)
1.00		0.050	2.110	13.2592
1.100		0.055	2.120	14.6543
1.200		0.060	2.150	16.4227
1.300		0.065	2.200	17.9722
1.400		0.070	2.250	19.7946
1.500		0.075	2.260	21.3028
1.600		0.080	2.290	23.0246
1.700		0.085	2.330	24.8909
1.800		0.090	2.350	26.5813
1.900		0.095	2.370	28.2969
2.000		0.100	2.390	30.4146

The resistivity values at 1m, 6m and 11m, were 13.2592, 21.3028 and 30.4146 respectively. From the soil resistivity and corrosivity relationship (Peabody, 2001), it was stipulated that values within (20.00-100.00 Ω m) are mildly corrosive. Comparing the results obtained with the stipulated value of (20.00-100.00 Ω m), it is

evident that the chosen area for CP system installation is conducive.

The following are the results obtained from the cathodic protection system installation using a metal-to-soil potential survey for 20 weeks with readings taken every 2 weeks. Results are gotten from Anode-to-Electrode ground bed as shown in Appendix A.

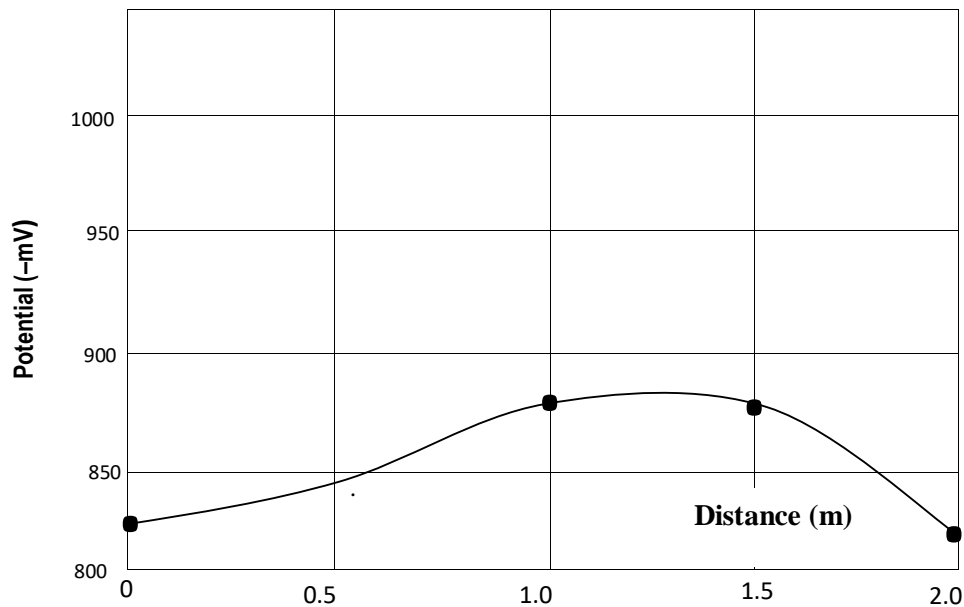


Figure 3.2 Plot of potential (-mV) against distance (m)

Figure 3.2 shows the instability of protection potentials as a result of the non-homogenous flow of protective current, caused by dispersed polarization. It is, therefore, imperative to always allow the installed CP system a minimum of 2 weeks to attain full polarization before

readings can be taken. The graph shows also a failing slope like that of the stress-strain curve. This is a result of the distance of the reference electrode to that of the buried pipeline and anode.

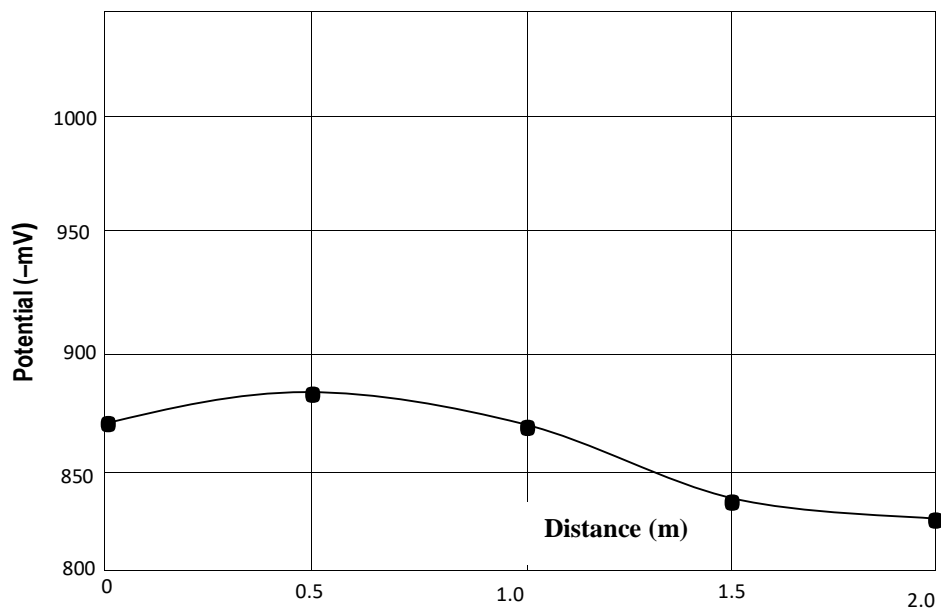


Figure 3.3 Plot of potential (-mV) against distance (m)

The figure 3.3 shows fluctuation in the potential (-mV) values due to the non-availability of adequate moisture content in the soil. Microorganisms present in the interiors of the pipeline can induce localised changes in the aqueous environment which can alter the concentration of the electrolyte components) leading to localised corrosion known as microbiologically influenced corrosion. The metabolic by-products of these microorganisms found in biofilms on steel

surfaces affect the kinetics of cathodic and/or anodic reactions. The sacrificial anode goes through this rapid corrosion circle to protect the desired metal. At this point 0, the protection was adequate. This is because the reference electrode was placed at the point where the pipe was buried. At that, uniform polarization is yet to be achieved. Do not forget also that copper-copper sulfate is not best for the experiment above.

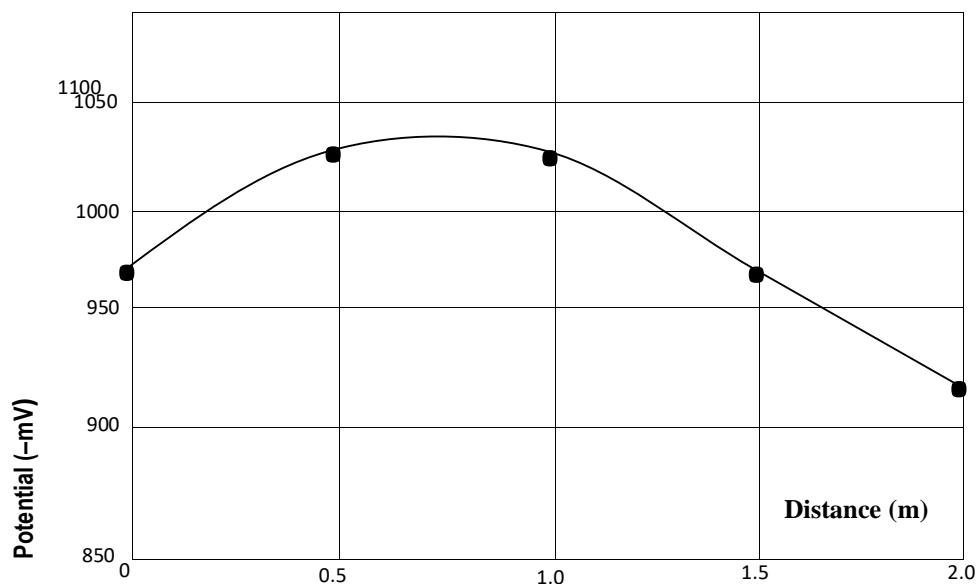


Figure 3.4 Plot of potential (-mV) against distance (m)

Figure 3.4 shows adequate protection from the sacrificial anode but not a favourable drop in the value of the last reading. This sharp drop is expected because the electromagnetic force of lead is lesser when compared to the electrochemical process required to

create a synergy between the anode and the half cell. If at distance (2.0m), we obtained a value above -1000mV, there might be tendencies of overprotection at the regions of protection exactness.

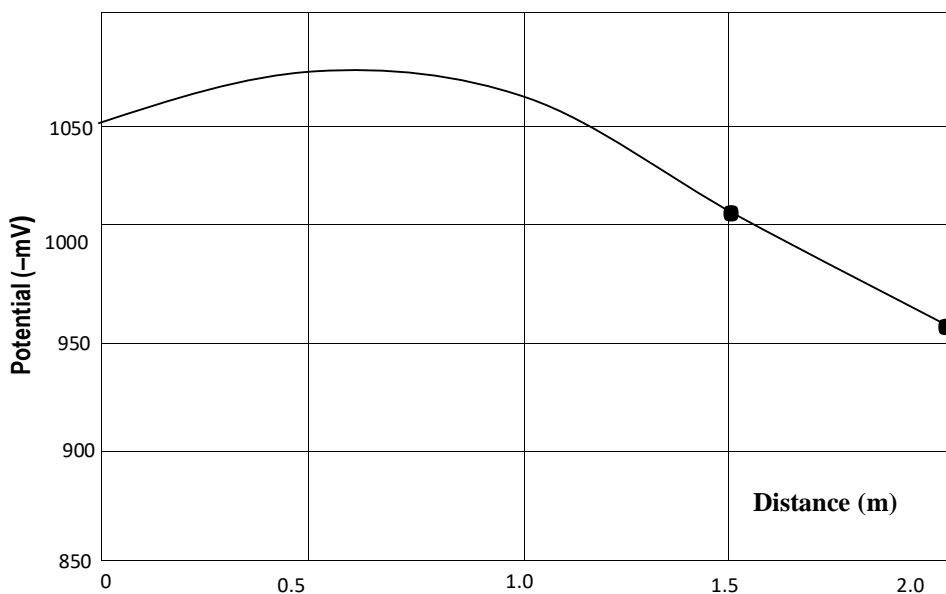


Figure 3.5 Plot of potential (-mV) against distance (m)

Figure 3.5 shows a sequential drop in the values of the distance (1.0, 1.5 and 2.0). This is a result of the decrease in strength of the sacrificial anode on the pipe to distance. At 1.0m, 1.5m and 2.0m away from the pipe,

the values were -1060mV, -1010mV, and -980mV respectively. The data show a fluctuation in the reading because of the pseudo-relationship between the sacrificial anode and the external reference electrode.

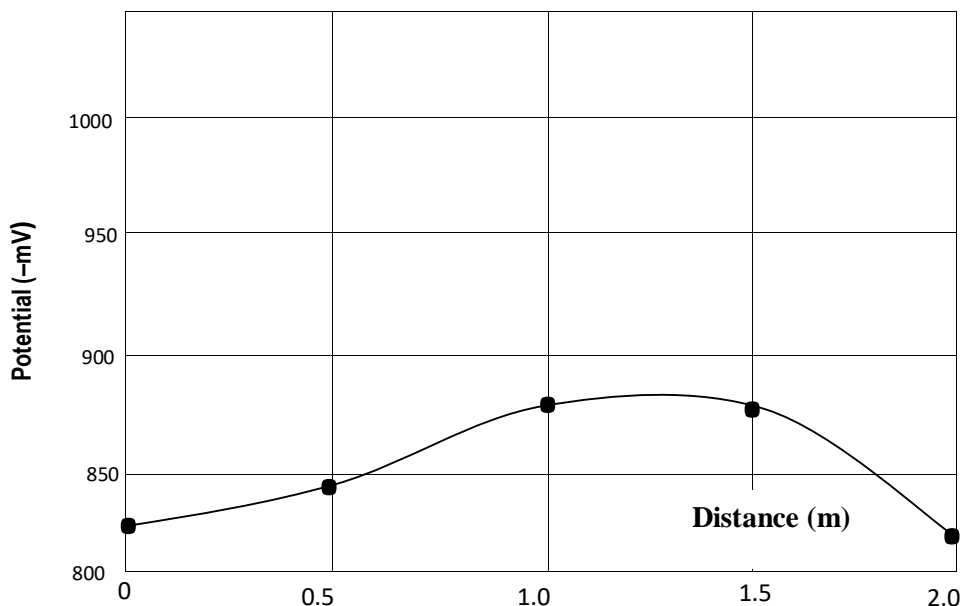


Figure 3.6 Plot of potential (-mV) against distance (m)

Figure 3.6 shows the stability of protection potentials as a result of the homogenous flow of protective current, as a result of the slurry-like environment with adequate oxygen. The graph shows the stress-strain curve, this represents a close and expected reading in an environment created for cathodic protection to take place. The graphite electrode shows no disparity in data collection across the distances where the reading was taken. This experiment recommends strongly the use of graphite reference electrodes for cathodic protection processes.

4.0 CONCLUSION

1. It was observed that about 2 weeks after installation, the protection potentials stabilized. This happened when the system became well polarized and this showed that installed CP systems should be allowed for at least two weeks to polarize before taking readings.
2. Burying the anode very close to the pipe affects the performance of the CP system. From the installation of the system, the distance between the anode and pipe was 1.0m instead of the conventional 0.5m
3. In the course of this experiment, it was observed that the soil must be moistened for

uniform polarization of pipe-to-soil potential to occur. Therefore adequate watering is required for polarization to occur.

4. It was observed that the lead cable otherwise known as the PVC-PVC cable can lose current as a result of half hazard coating process or handling along the cable chain. This was observed and corrected by replacing it from the point it got damaged.
5. Do not expect optimum performance from the half cell if the installation is faulty which may give rise to hydrogen embrittlement, cathodic disbandment, over protection, cable failures etc.

4.1 RECOMMENDATIONS

This study recommends that;

1. The graphite reference electrode is best for cathodic protection data collection.
2. Pipe-to-soil potential measurement using the -850mv criterion is adequate to evaluate the cathodic protection performance of any structure under such test or protection.
3. Instruments used for data collection or for taking readings should be cleaned after use. This is to ensure accuracy when taking subsequent readings. For example, the half-cell reference electrodes

gather soils at the tip immediately after it touches the earth. It is then advisable that it should be kept neat especially if it is not to be used frequently.

4. The graphite half-cell reference electrode should not be stored in a moist environment or a place where it may come in contact with water or rainfall.

5. Installing the anode very close to the pipe affects the performance of the CP system, the distance between the anode and pipe was supposed to be (0.5m). If this standard is not obeyed, potential readings will not conform to expected results.

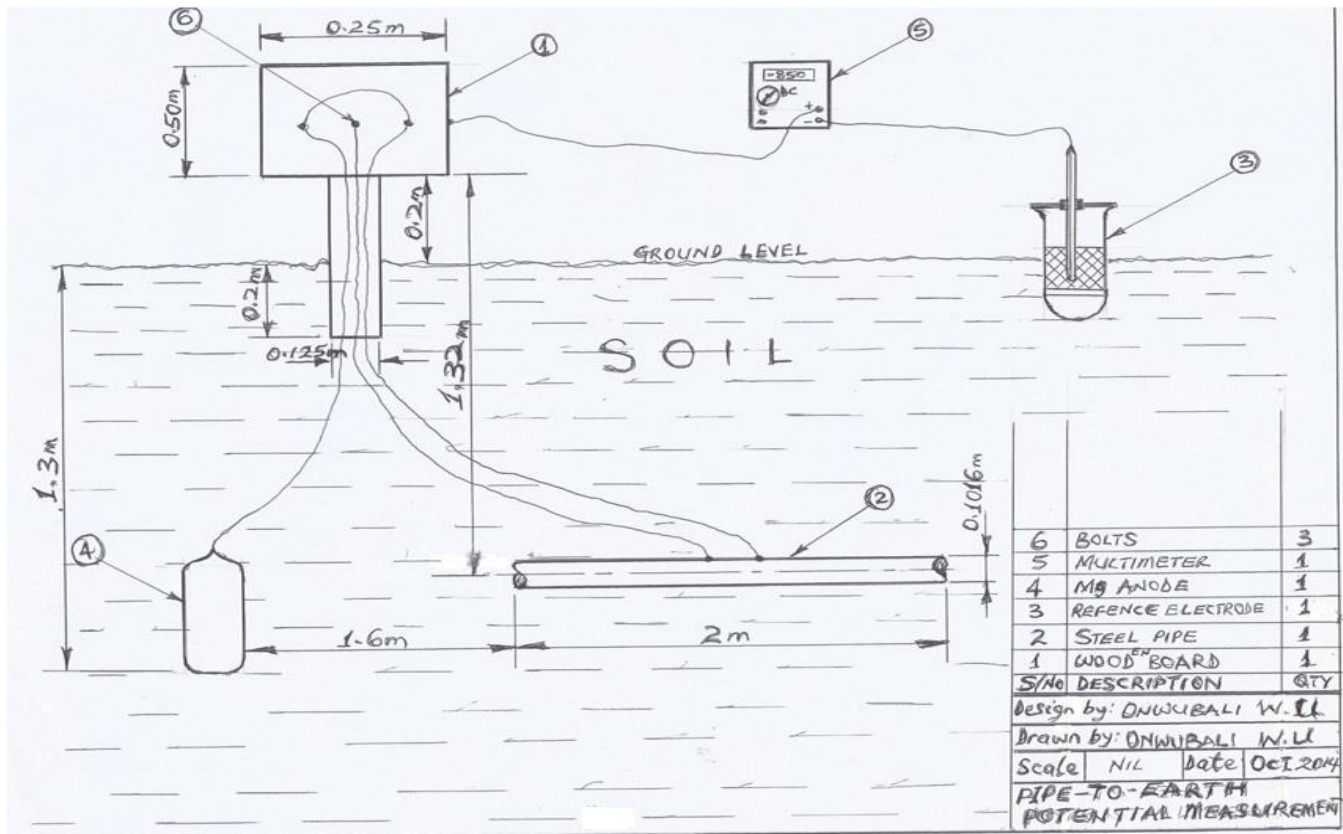
6. During the dry season, it is advisable to water the SACP zone for optimum values(s) to be achieved. To achieve set objectives, more attention needed to be paid to the purchase and handling of the following materials: Half Cell, Multimeter, Handicap, PVC-PVC Cables, Anode quantity, Site preparation. In the time past have been some of the problem students who undertook such projects encountered.

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Appendix A

Typical ground bed showing reference electrode relationship with anode



Source: Onwubali, W.U. (2016)