STUDY OF THE CATHODIC PROTECTION SYSTEM OF UNDERGROUND STORAGE TANKS (UST) IN NIGERIAN FUEL STATIONS.

BY

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DEDICATION

I wish to dedicate this work to Almighty Allah for His guidance, and for seeing me through my academic pursuit.

Also, to my entire family, for their unconditional love.

DECLARATION

I hereby declare that this is my original work and to the best of my knowledge has never been presented anywhere for the award of any degree, diploma or certification at any university or institution. Information from published or unpublished work has been duly referenced.

30-11-2007

SANNI KEHINDE .K.

DATE

CERTIFICATION

This is to certify that this research project was carried out by **Sanni Kehinde .K.** for the partial fulfillment of the award of Bachelor Degree in Chemical Engineering.

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ABSTRACT

The study of corrosion and corrosion control is very important in all process industries. Corrosion is one of the main causes of equipment failure in process industry. For fuel stations in Nigeria, it is the main cause of leakages of their USTs. They tend to loose most of their resources through leakages, largely as a result of corrosion. All the major fuel stations round the country pay less attention to their USTs, mainly because they feel the tanks have been protected by coating from their dealers or their installation engineers. This work is aimed at recommending the cathodic protection system for the protection of USTs as a more effective, reliable, durable and economical method of corrosion control when compared to the conventional coating method. It has been established as a fact, that the cost of applying cathodic protection for USTs is far less than that of the coating method offering equal assurance of protection. Laboratory tests on soil PH and soil conductivity were carried out on five different soil samples fetched round the vicinities of fuel stations located in strategic parts of Nigeria. The results showed that USTs tend to corrode more as we move towards the southern part of the country than it does in the north. This is as result of the low soil resistivity in the south. The soil resistivity test is the most important parameter for the initial design stage of the cathodic protection system. Besides the indication of environmental corrosiveness, it also helps in the determination of the rate of anode consumption, as well as the current requirement for the cathodic protection scheme.

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1.0 INTRODUCTION

1.1 Background

The first practical use of cathodic protection is generally credited to Sir Humphrey Davy in the 1980s, on British naval ships. The most rapid development of cathodic protection systems was made in the United States of America to meet the requirements of the rapidly expanding oil and natural gas industry. Cathodic protection system has also been used in most Nigerian oil and gas industries, mainly for the protection of buried petroleum pipelines.

Cathodic protection is one of the various ways or methods of protecting metallic structures against corrosion. Corrosion itself can be referred to as the gradual degradation of a metal as a result of the reaction between the metal and its environment. In other words, it can be said to be the gradual degradation of a metal by an electrochemical reaction with its environment. Environment referred to here, can be an aqeous environment like water or dry environment like the soil, as in the case of buried structures. For Underground Storage Tanks (UST), corrosion is due to an electrochemical reaction between the tank and the surrounding soil where it is been buried. In this regard, corrosion can be said to be the problem and cathodic protection, a method of protecting such problem.

Cathodic protection system has been found to be the most reliable and effective of all approaches to corrosion control. Thus, it involves employing a suitable metal, usually known as the sacrificial anode, which is made to corrode in place of the desired metal, i.e. the material being protected. This achieved by making the desired metal, the cathode, whereas the new metal serves as the anodic material. In practice, cathodic protection can, in principle, be applied to any metallic structure in contact with a bulk electrolyte. Its main use is to protect steel structures buried in soil or immersed in water. Commonly protected are the exterior surfaces of pipelines, ships' hulls, jetties and offshore platforms, it is also used on the interior surfaces of storage tanks, hence it can be employed for USTs in Nigerian fuel stations where the conventional coating method has been applied over the years.

In the case of buried structures, the sacrificial anode employed for the cathodic protection system, will exchange current with the soil, instead of the electrons from the buried structure being protected. Consequently, the anodic material corrodes in place of the structure being protected. Thus, since corrosion processes are electrochemical in nature, it is important to perform chemical analysis of soil samples from the vicinity of a proposed site for the installment of this system. Values of soil resistivity of soil samples from this vicinity can play a very important role in determining cathodic protection design parameters. Soil PH values of these samples are also recommended, as it can be related to the corrosion potential of soils.

By cathodically protecting structures like the USTs, cost of protection control can be minimized to an important amount, because the cost of applying cathodic protection is far less than any other means offering equal assurance of protection.

1.2 Objectives

The objectives of this work are;

(a) To proffer cathodic protection as a more reliable and effective method of protecting Underground Storage Tanks (UST) against corrosion in Nigerian fuel stations.

(b) To determine the degree of environmental corrosiveness of different parts of Nigeria.

1.3 Scope of Work

The scope of work includes;

a. The determination of soil PH and soil resistivity for different soil samples around the vicinity where fuel stations are situated within Nigeria.

b. Importance of corrosion control to fuel stations.

c. Economic advantage of cathodic protection of USTs over the conventional coating method.

d. Choice of cathodic protection /cost analysis.

1.4 Approach

Laboratory tests on soil PH and soil resistivity is carried out on five different soil samples fetched around the vicinities of fuel stations in strategic areas around Nigeria. Soil samples from Kaduna, Abuja, Ondo, Abia and Rivers states were used for this test. The PH test indicates the degree of corrosiveness of these environments. Soil resistivity also indicates the degree of the environmental corrosiveness, but most importantly, it is carried out to determine the anodes' current output over the design life of the system. The soil resistivity test is the first step in the detailed design of cathodic protection.

Suspensions of each sample are prepared in 25ml each of distilled water and of calcium chloride CaCl2. PH of each sample is determined with a PH meter using a glass rod electrode. For the resistivity test, a conductivity meter is used to determine the conductivity of each sample; this is because the equipment for resistivity is not functional. Thus, only the suspensions prepared in distilled water were used for this test. Conductivity results were taken with the conductivity meter, using glass rod electrode. Generally, soil resistivity is the best indicator of USTs' corrosion potential.

CHAPTER TWO

LITERTURE REVIEW

2.0 Corrosion

The most important material in general engineering is, without any doubt, metals and their alloys. Most of the equipments used in the process industry are majorly made from metals and their alloys; therefore, a study of corrosion and corrosion control is very important. As long as metals will be used in the process industry, corrosion is inevitable, but the good news is that, it can be controlled if properly managed. This is necessary because, corrosion constitutes one of the major causes of material losses in process industry. The cost of replacing metals lost to corrosion is in the multi-billions of naira per year.

Corrosion is the term applied to metal rust caused by an electrochemical process. It has been defined in various ways; it is termed

- the destruction of a material arising from its reaction with its environment,
- the deterioration of intrinsic properties in a material due to reaction with its environment,
- the oxidation of metals in contact or reaching with water or oxygen,
- the gradual degradation and deterioration of a metal as a result of an electrochemical reaction between the metal and its environment,
- an electrical and chemical deterioration of metal.

2.1 Basic Principles of Corrosion

Corrosion in metals, whether in the atmosphere, under-water or underground, is caused by a flow of electricity from one metal to another metal, or from one part of the surface of a piece of metal to another part of the same metal, when condition permits the flow of electricity. Corrosion of buried structures is associated with both the flow of electricity and the chemical processes within the soils surrounding the structure.

Underground Storage Tanks (UST) corrodes due to an electrochemical reaction between the tank and the surrounding soil. The process of corrosion occurs due to small voltage differences on the steel surface that result in the flow of DC current from one location to another. Where current flows from the tank into the soil, the tank begins to corrode. When a tank corrodes, the main atoms break away from the steel surface; overtime this leaves pits in the steel which eventually becomes holes on the surface of the tank.

Since corrosion is an oxidation reaction, it can be described as the anodic process of the galvanic set up, with the soil as the electrolyte. Thus, when corrosion occurs on one part of the metal, it is due to the small voltage differences on the steel surface, the unaffected part is termed the cathode area. The progress of corrosion is determined by the amount of current flowing between the anode and the cathode. Corrosion rates are generally higher in wet soil environments, since the conductivity of the soil promotes the flow of DC current in the corrosion circuit. Low corrosion rates are usually measured in dry soil environments; this is due to the resistivity of the soil. Also, an acidic soil; that is soil with low PH value, promotes corrosion processes.

For corrosion to occur, the following conditions are necessary;

(a) there must be an anodic path and a cathodic path where oxidation and reduction reactions take place respectively,

(b) there should be an amount of potential difference between the anode and the cathode,

(c) A metallic path, electrically connecting the cathodic and the anode,

(d) An electrically conductive electrolyte.

2.2 Factors Affecting Corrosion

Corrosion does not only occur due to the electrochemical reaction between a metal and its environment, it may be influenced by some other factors.

Effect of dissolved carbon dioxide, CO_2

Carbon dioxide has been disregarded as a factor which can aid or initiate the corrosion reaction in natural water or in the atmosphere. The small amount of CO_2 normally present in hard water affects the rate of corrosion largely by accelerating the electrochemical interaction. Thus, CO_2 in appreciable concentration accelerates the corrosion of a metallic structure. CO_2 promotes pitting attack on the metal and forms insolute corrosion by-products that result in equipments failing.

Hydrogen ion concentration (PH)

PH is an important index of the corrosiveness of an environment. Hydrogen ion concentration influences corrosion in two ways.

(a) Directly; increasing the hydrogen ion concentration causes the potential of the hydrogen electrode to become more positive. Decreases in PH will enhance the cathodic process of hydrogen and oxygen depolarization. This leads to an increase in the rate of corrosion, particularly if the corrosion process is chiefly controlled by the process of hydrogen ion discharge.

(b) Indirectly; changes in PH values of a solution influences the solubility of the corrosion products and the possibility of the formation of a protective film. Depending on the nature of a metal oxide, corrosion rate increases with either an increase or decrease in the solution PH value.

Temperature and Pressure

Both temperature and pressure affects corrosion processes directly. The rate of corrosion tends to increase with increased temperature. It also has a secondary effect on corrosion, as it influences the solubility of air (O_2), which is the most common oxidizing substance influencing corrosion. An increase in temperature does not only change the intensity of electrochemical corrosion of some metals, but also the polarity of the electrodes.

In a similar way, as the pressure increases, the tendency of a gas to go into solution to cause corrosion increases. This condition is expressed as partial pressure.

Corrosion products

As corrosion process proceeds, there will be formation of films which accumulates on the metallic surface. Corrosion rate is controlled by the nature of the film formed.

Effects of dissolved salt

Salt of alkaline metals added to aerated water, at first increases the corrosion rate of a metal. As the salt concentration increases, the rate of corrosion goes through a maximum and thereafter, decreases.

2.3 Corrosion Control Methods

Although corrosion is said to be inevitable, but it can be controlled or prevented. The general principle, irrespective of the method applied, is aimed at attempting to save a metal from becoming anodic, because anodic regions dissolve and destroys the structural integrity of the metal, by corrosion. There are basically two common methods of corrosion control namely; coating and cathodic protection.

2.3.1 Coating

Coating is the primary corrosion control method used for many structures. It involves coating a metal structure with paints or some other non-conducting coating, which prevents the electrolyte from reaching the metal surface, that is, **IF** the coating is complete. Coating of USTs reduces the area of the tank exposed to the electrolyte (soil); as a result, corrosion is reduced. Coatings may take the form of paints, greases, bitumen, or coal tar. Bitumen or coal tar coatings are the most widely used for buried structures. Specifically, most fuel stations in Nigeria apply coal tar for coating their USTs.

All coatings are required to have a high electrical resistance, should resist abrasion and should be alkali resistant in certain types of soil. When applied to underground structures, coatings are required to adhere strongly to the surfaces to be protected. Coatings are applied to metallic structures either prior to or upon arrival at site.

As with many other offshore structures, the coating method can be backed up by a cathodic protection system that takes care of exposed steel at coating defects. When designing the cathodic protection system for a particular structure, it is necessary to predict the efficiency of the coating system applied to the structure. The provision an insulating coating to the structure will greatly reduce the current demand for cathodic protection system. Thus, special attention must be paid to the compatibility of the coating system with cathodic protection system; this is particularly true of impressed current systems. When first applied, coatings will often contain flaws, and in service, further defects will develop over a period of time. The co joint use of coatings and cathodic protection takes the advantage of the most attractive features of each method of corrosion control. Thus, the bulk of the protection is provided by the coating and cathodic protection provides protection to flaws in the coating. As the coating degrades with time, the activity of the cathodic protection system develops to protect the deficiencies in the coating. A combination of coating and cathodic protection will always result in the most economic protection system.

2.3.2 Cathodic protection system

Cathodic protection is an alectrochemical means of corrosion control in which the oxidation process in a galvanic is concentrated at the anode, thereby suppressing the corrosion of the cathodic path of the same cell. This is the technique used to control the corrosion of a metal using a sacrificial anode, which is made to corrode in place of the desired metal. When applied, it is required to shift the corrosion potential of the electrodes towards the anodic path by applying an external electromotive force.

As discussed earlier, cathodic protection is often applied to coated structures, with the coating providing the primary form of protection. The cathodic protection current requirements tend to be excessive for uncoated structures. For the protection of USTs, or other buried systems, the current requirement greatly dependent on the soil electrical resistivity of the environment. Corrosion rates tend to be high in conductive soil environments and low resistive soil environments. As a result, the current requirement for the cathodic protection is high in conductive environments where high corrosion rate is expected. USTs of fuel stations situated in such environments are said to require high protection compared to environments with appreciable amount of resistivity. An important variable also required to determine the current requirement for cathodic protection is the surface area that requires protection. For coated structures, the total current requirement obviously decreases with increasing quality of the surface coating.

2.3.2.1 Principles of cathodic protection

Corrosion in aqueous solutions proceeds by an electrochemical process, and anodic and cathodic electrochemical reactions must occur simultaneously. Also, the rates of the anodic and cathodic reactions are equal.

Anodic reactions involve oxidation of metal to its ions, e.g. for steel the following reaction occurs;

$$Fe \rightarrow Fe^{2+} + 2e \qquad (1)$$

The cathodic process involves reduction and several reactions are possible. In acidic water, where hydrogen ions (H^+) are plentiful, the following reaction occurs;

$$2H^+ + 2e \rightarrow H_2 \qquad (2)$$

In alkaline solutions, where hydrogen ions are rare, the reduction of water will occur to yield alkali and hydrogen.

$$2H_2O + 2e \rightarrow H_2 + 2OH^- \qquad (3)$$

Reactions (1) and (2) shown schematically in fig 1 where anodic and cathodic sites are nearby on the surface of a piece of metal. The rate of these two reactions can be changed by withdrawing electrons or supplying additional electrons to the piece of metal. It is an established principle that if a change occurs in one of the factors under which a system is in equilibrium, the system will tend to adjust itself so as to annul, as far as possible, the effect of that change. Thus, if electrons are withdrawn from the piece of metal the rate of reaction (1) will increase to attempt to offset the action and the dissolution of iron will increase, whereas reaction (2) will decrease. Conversely, if additional electrons are supplied from an external source to the piece of metal, reaction (1) will decrease to give reduced corrosion and reaction (2) will increase. The latter case will apply to cathodic protection. Thus, to prevent corrosion, electrons will have to be supplied to the steel continuously from an external source to satisfy the requirements of the cathodic reaction. It should be noted that the anodic and cathodic processes are

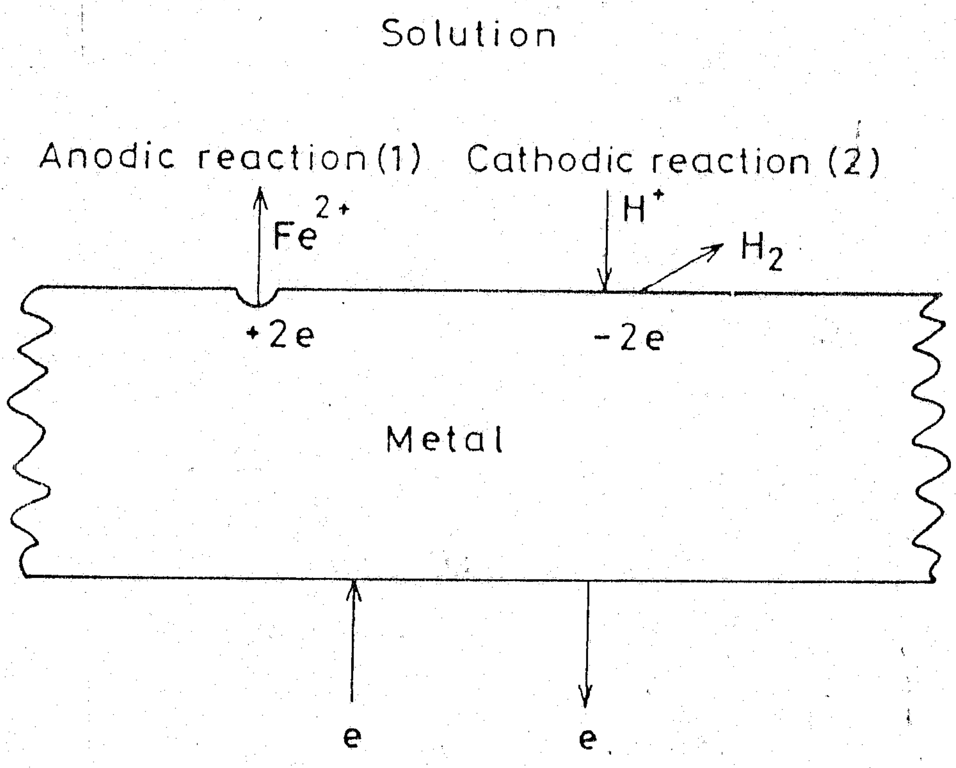


Fig 1 Anodic and cathodic reactions at a metal surface

inseparable. Reducing the rate of the anodic process will allow the rate of the cathodic process to increase.

The cathodic protection principle is such that electrons are supplied to the steel by a DC source and an auxiliary anode. Electric current flows along the electric cables connecting the anode to the cathode and ionic current flow in the soil between the anode and the cathode to complete the circuit.

2.3.2.2 Methods of applying cathodic protection

Cathodic protection may be achieved in either two ways. By the use of an impressed current from an electrical source, or by the use of sacrificial anode.

Impressed Current

For this method, cathodic protection is applied by means of an external power source. The arrangement for protecting buried structures is such that the structure receives current from a DC power source via an auxiliary inert electrode buried in the ground alongside the structure of interest. The arrangement for protecting a buried pipeline is illustrated in fig 2. The structure becomes the cathode and the auxiliary electrode as the anode. The anode consumption is usually required to be minimal, unless a scrap iron is used. In this case, the iron will dissolve from the anode by reaction (1), and the electrode is described as a consumable anode. Thus, a negligible anode consumption rate is actually a key requirement for long system life. Impressed current systems are favoured under high current requirement and for high resistance electrolyte.

A range of materials have been used as non-consumable anodes for impressed current systems. The sorts of properties required by these anodes are;

a. good electrical conduction,

b. low rate of corrosion,

c. good mechanical properties, able to stand the stresses which they maybe subjected to during installation and in service,

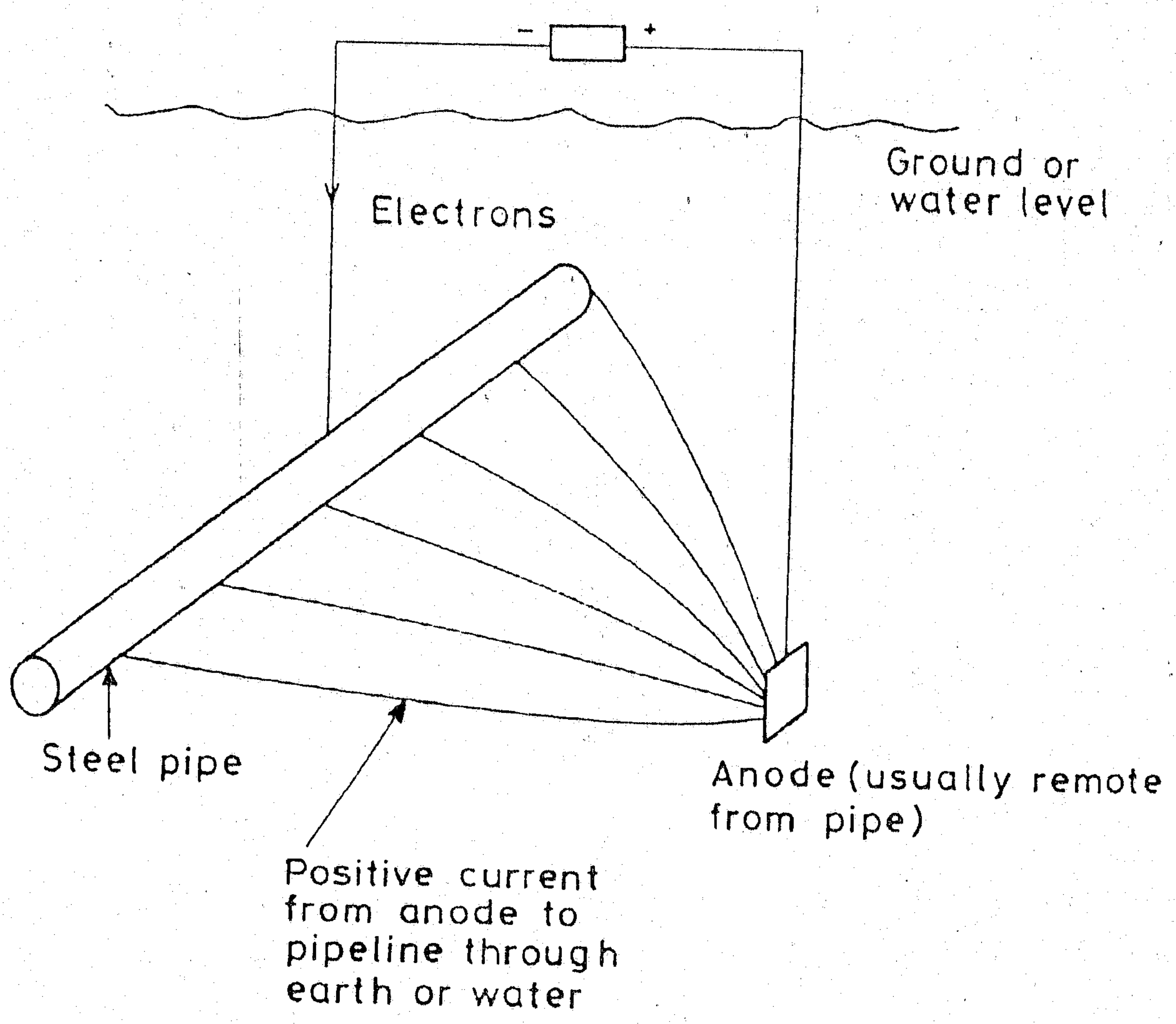


Fig 2 Application of cathodic protection by an impressed current

d. readily fabricated into a variety of shapes,

e. low cost.

The following materials have been used as anodes; graphite, lead alloys, platinised materials (e.g. Titanium), high silicon iron (14- 18% si). Platinum, with its high resistance to corrosion, will be an ideal anode material, but has the major disadvantage of very high cost. Thus, large areas of a structure can be protected from a single anode, and because of high driving voltage, the anode can be placed remote from the structure. The advantages of the impressed current system include;

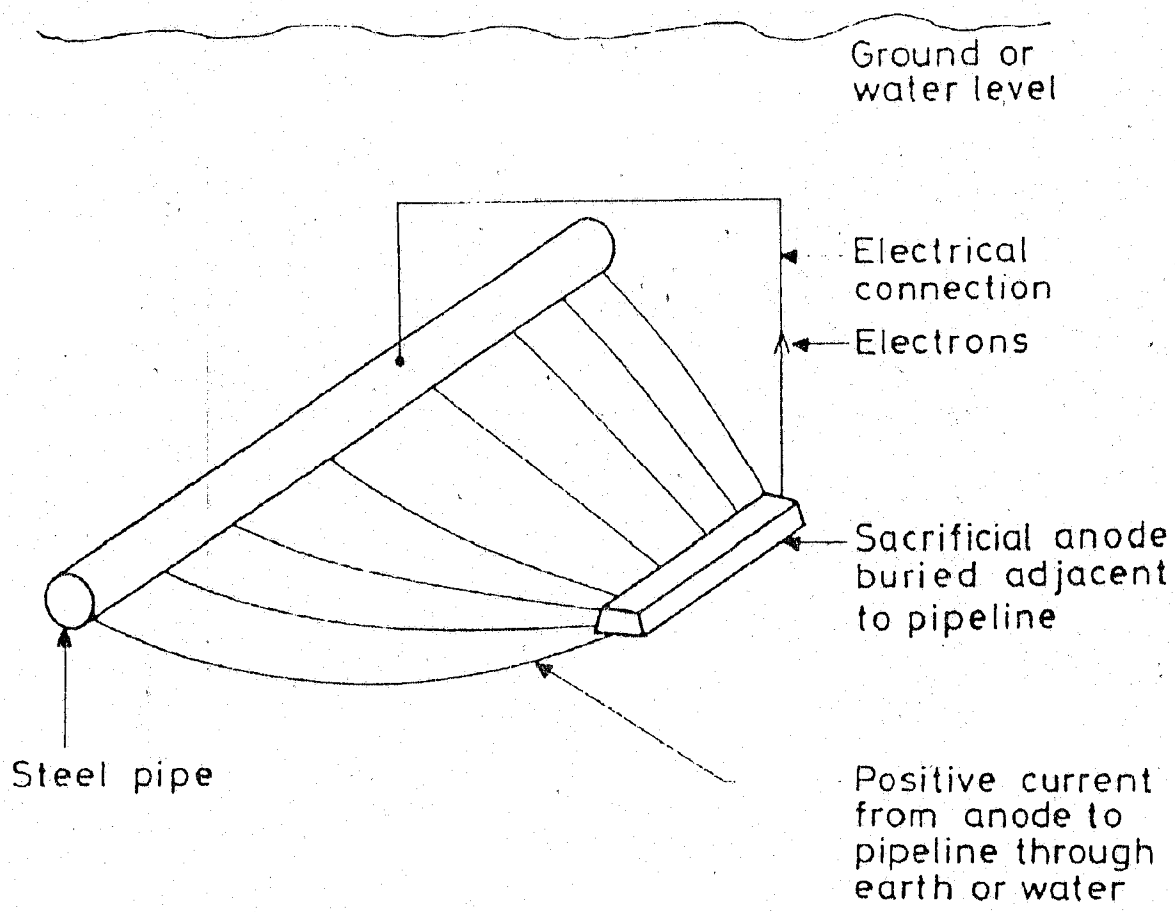
1. the large driving force available can protect a large, even uncoated, structure in high resistivity environment,
2. comparatively few anodes are needed,
3. the voltage may be adjusted to allow for environment and coating changes.

However, the impressed current system has problems of allowing considerable over-protection, and considerable variation of potential over the structure is difficult to avoid. The major limitation of this method is the relatively high risk of causing interference effect; that is, interference with structures close to the system.

Sacrificial Anode

Cathodic protection can be applied to structure by connecting a sacrificial anode to the structure. Basically, the principle is to create a galvanic cell, with the anode representing the less noble material that is consumed in the galvanic interaction. The cathodic protection of a steel pipe with sacrificial anodes is illustrated in fig 3. Electrons are supplied to the buried structure via the electrical connection, and a corresponding amount of the anode material goes into solution as metal ions, as a result, the sacrificial anode material corrodes in place of the desired metal.

To understand the action of sacrificial anode for cathodic protection, it is necessary to have in mind the electrochemical series of metals. Most buried structures,



$Zn \longrightarrow Zn^{2+} + 2e$

$Al \longrightarrow Al^{3+} + 3e$

$Mg \longrightarrow Mg^{2+} + 2e$

Fig 3 Application of cathodic protection by sacrifical anodes such as the USTs, are mostly made from steel; hence the anodic materials employed for the sacrificial anode system are mainly zinc, aluminum and magnesium, due to their positions in the electrochemical series. Since they are higher than steel in the electrochemical series, they are increasingly able to supply electrons to the steel in the galvanic set up, thus, the steel structure will be protected and the anode material corrodes due to oxidation reaction. In practical application, a number of anodes usually have to be attached to a structure to ensure overall protection levels. The system has advantages of being;

1. simple to install,
2. independent of any source of electric power,
3. suitable for localized protection

The most severe limitation of the sacrificial anode is the small driving force which restricts its use to conductive environment or well coated structures. To protect a large structure, such as a petroleum pipeline, with sacrificial anodes, a large number of the anode material would need to be distributed along it, leading to multiplicity of electrical connections and considerable installation work.

Generally, sacrificial anode scheme has been favoured for small, well coated, low current demand structures, with the impressed current scheme being utilized for large complex structures which may be barely or poorly coated. Practical example of where this is applied in Nigeria is for NNPC petroleum pipelines.

2.3.2.3 Design of cathodic protection

For buried structures, such as USTs, certain preliminary investigations will be required to be carried out. For detailed design of a cathodic protection system. These investigations are;

Protection potentials

In practice, the structure-to-electrolyte potentials are measured using a standard reference electrode based on copper/copper sulphate, silver/silver chloride, or pure zinc. The reference electrode should be very close to the surface whose potential is being measured. For steel in an aerobic electrolyte of nearly neutral PH a commonly accepted protection potential is -850mV. Some potential values for protection of other metals are; copper alloys -500 to-650mV, lead -600mV, aluminum -950 to -1200mV.

Current Density

The current density required to maintain the protection potential is very dependent on local conditions. Increased availability of oxygen at the surface of the metal will directly increase current density. Increased availability of oxygen may occur because of increased concentration of oxygen in the environment, increased water flow or turbulence. Thus, current densities to structures in sea water, acidic solution, etc are likely to vary continuously. The PH of the environment will also be important. The presence of coatings will have profound effect on current density.

Having decided on the appropriate current density, the total anode current can be determined from the area of the structure. The size of the anodes can then be determined if a sacrificial anode scheme is to be employed, taking into account the working life of the protected structure.

Choice of cathodic protection system

In the design of a cathodic protection scheme, a decision must be made as to whether the scheme should be a sacrificial anode or impressed current system or a mixture of the two systems.

Sacrificial anode systems have the advantage of being

- simple to install
- does not require a source of electric power
- it is suitable for localized protection

- less liable to cause interaction on neighbouring structures.

It is difficult to over-protect the structure and moderately easy to obtain a uniform electrode potential across the structure. The limitation of the sacrificial anode is its restriction to conductive environments or well coated systems. Also, if employed for large structures, a large number of anodes would need to be distributed along it, resulting to multiplicity of electrical connections and lots of installation work.

The advantages of the impressed current system is that

- it can protect a large, even uncoated, structure in high resistivity environments
- comparatively few anodes are needed

The impressed current system may allow considerable over protection, and is liable to cause interaction on neighbouring structures.

Anode material

Generally, there are numerous materials available for use a anodes for cathodic protection. Sacrificial anode and impressed current systems have different requirements for their type of anode material. For sacrificial anode system, the material must be anodic to the structure to be protected, must be a less noble metal when compared to the structure to be protected and be able to continuously current to the structure. Materials applicable for this method include magnesium, zinc and aluminium alloys, which are for steel structure. Magnesium anodes are mainly used for buried structures. Zinc is used cathodic protection in fresh and marine water e.g. for protection of ships. Aluminium is used for offshore structures where its light weight provides significant advantages.

For impressed current system, the material does not need to be anodic to the structure, although low consumption rate is required. anodes for industrial use are usually conveniently packaged in bags prefilled with suitable backfill material. This is important, because it is designed to maintain low resistivity and to minimize localized corrosion on the anode.

Anode resistance

One of the most important parameters in the design of cathodic protection systems is the electrical resistivity of the environment. Measurement of the resistivity of the environment and calculation of the electrical resistance between the anodes and the structure due to the electrolyte must be made at an early stage in the design of the scheme to ensure that adequate current output will be obtained from the anodes over the design life of the structure.

Ground beds, as cathodic protection electrodes set in the earth are called, can be considered to lie in a semi-infinite electrolyte and the resistances of the electrodes to infinite earth or sea water have been calculated for a number of anode shapes. Thus, if the anodes are remote from the structure, these anode resistances can be used, together with the difference between the required protection potential and the anode potential, to determine current output of anodes using Ohm's law. If, however, the anodes are positioned close to the structure, then some correction to the resistance is required.

When current flows from small anode to large metal structure, the current density is at a maximum near the surface of the anode. Hence, a major portion of the potential drop between anode and structure occurs in the vicinity of the anode. This factor probably enables values of anode-resistance to infinite earth to be used reasonably successfully even when anode and structure are not well separated. A further consequence of this factor is that surrounding an anode with a backfill of conducting material greatly reduces the anode resistance in soils.

In practice, the distribution of current to a structure is difficult to control. If we consider the protection of a pipe by an anode, it should be clear that there will be a higher current density at the point on the pipeline nearest the anode than elsewhere. Clearly, to ensure that the ends of the pipe are protected, the center of the pipe, nearest the anode, must be overprotected to some degree. The effect can be minimized by using several anodes spaced along the pipe, but this will greatly increase installation costs.

Dangers to be avoided

Consideration must also be given to spark hazards created by the introduction of electric currents into structures situated in hazardous atmosphere.

Any secondary structure residing in the same electrolyte may receive and discharge the cathodic protection direct current by acting as an alternative low resistance path. Corrosion will be accelerated on the secondary structure at any point where current is discharged to the electrolyte. This phenomenon is called interaction.

Interaction may be minimized by careful design of the cathodic protection system, in particular, by design of a scheme to operate at the lowest possible current density and by maintaining the greater separation between the protected structure and the secondary structure, and between the ground beds or anodes and the secondary structure. It is an advantage of sacrificial anode schemes that they are not prone to creating interaction problems. Methods and procedures are available for overcoming interaction, and testing must be carried out in the presence of all interested parties, so that the choice of remedial measures may be agreed if and when the acceptable limit of interaction is exceeded.

2.4 Importance of Corrosion Control to Fuel Stations.

Corrosion is a major problem in most or all fuel stations in Nigeria. If not properly managed, it causes material losses, not only in fuel stations, but in all major process industries, particularly in oil and gas industries. For fuel stations, corrosion of USTs is usually in the form of a pitting attack, which causes the development of holes around the surfaces of the tank; as a result, we have tank leakages. Leakage of USTs leads to product losses, mainly through oil spillage. Fuel stations loose most of their products through corrosion, and if proper care is not taken, oil spillages can result to fire outbreak.

Thus, it is important to prevent corrosion of USTs in fuel stations, because the cost of replacing them is in the hundred thousands of naira. If proper evaluation is made, it will be obvious that, the cost of preventing the corrosion of these tanks is much less than the cost of replacing them. Hence, it is required to monitor the tanks for corrosion, and a very reliable method should be employed to prevent them from corroding. The most suitable method, as proffered in this work is, without any doubt, cathodic protection system, which is applied to complement the conventional coating method.

2.5 Economic Advantage of Cathodic Protection of USTs over the Conventional Coating Method.

The coating method has been the mostly widely used method of protecting USTs against corrosion in all fuel stations in Nigeria. After proper investigation and consultation, it was discovered that, the USTs were coated by the manufacturers at the point of construction and not the fuel stations themselves, who pay less attention to the maintenance of the USTs, all they are concerned with is just the purchase and installation of the USTs and sale of their products contained in it. Although, the protective coating, when applied prevents corrosion of the USTs, but it is commonly recognized that protective coatings will deteriorate with time, depending on the coating utilized, surface preparation employed, application techniques, temperature experienced and environmental conditions tolerated. In real sense of it, a defect free coating is impossible to be economically obtained. Due to the application errors on installation damage, as a result this shortcoming, coating is described to be economically wasteful when compared with the cathodic protection system, which assures a typical life of at least 20-25 years after the first installation. From inquiries made from most fuel stations in Nigeria, a well coated UST spends about 7 years before leakages are experienced.

Another problem with the coating method is that preparation may be expensive, frequently tanks must be cleaned to a near-white state to ensure sufficient adhesion of a coating, time spent preparing the coatings at a manufacturing facility is wasted, because coatings will inevitably be damaged in the harsh construction transportation and installation environment. Also, preparation of a coating on-site demands substantial delays caused by not only the coating process itself, but also by weather conditions. The cathodic protection system has been applied in major oil and gas industries in Nigeria like the NNPC, and has been proven to be reliable and cost effective. This method is still applied for petroleum pipelines up till date.

However, a combination of cathodic protection and protective coating has been recommended as the most practical and economical overall protection system.

Choice of cathodic protection system.

The choice of the most economical method between the sacrificial anode and the impressed current system is made based on their advantages and disadvantages. Thus, for cost effectiveness, the following comparison can be made;

Sacrificial anode	impressed current
(1) Independent of an external power source.	requires an external Power source.
(2) Involves high rate of anode consumption.	anode consumption Should be minimal.
(3) Requires lesser maintenance.	Requires adequate maintenance, because Of the power source employed.
(4) For large structures, it requires high capital, due to the large amount of anodes required.	less capital investment for large structures.
(5) Most suitable in conductive or well coated systems.	suitable in high resistivity environments, even for uncoated structures.

From the comparisons made above, the most economical and cost effective method for USTs in fuel stations is obviously the sacrificial anode, mainly due to the fact that it does not require an external power source, it is self operational and requires lesser maintenance compared to the impressed current system.

CHAPTER THREE

3.0 Laboratory Test On Soil Ph And Soil Conductivity

Laboratory tests on soil PH and soil conductivity were carried out with 25ml each of distilled water and 0.01M $CaCl_2$. These tests were conducted on five different soil samples from Kaduna, Abuja, Ondo, Abia and Rivers states. A PH meter was used to determine the values of PH, while a conductivity meter was used to determine the conductivity of the samples; both tests were done with a glass rod electrode. For the PH test, buffer solutions of PH 4 and 7 were used to calibrate the PH meter for the acidic PH and the neutral PH side respectively.

3.1 Procedures and Methodology for Soil Ph

Apparatus; 2mm sieve, electronic weighing balance, 50ml beakers, glass rod electrode, PH meter.

Reagents; distilled water, 0.01M $CaCl_2$, buffer 4 and 7.

Procedure

(a) The soil samples were sieved using a 2mm sieve to remove stone pellets in the soils.

(b) 10g each of the sieved soil samples were measured with the electronic weighing balance in duplicates into 50ml beakers.

(c) 25ml of distilled water added to one duplicate of each sample, similarly, 25ml of 0.01M $CaCl_2$ was also added to the other duplicate of each sample.

(d) The samples were well stirred to form suspensions of each soil sample. This is done to release the hydrogen ions in the soil samples into their suspension.

(e) The stirred samples are allowed to stand for 30 minutes.

(f) The PH meter is then calibrated with both buffer 4 and 7 solutions. Calibration is done by connecting the glass rod electrode to the PH meter, and then the glass rod electrode is dipped into each buffer solution to measure PH values of 4 and 7 respectively. The PH meter is set at 33°C

(g) The calibrated PH meter is then used to determine the PH values of each sample. It is done by dipping the glass electrode into each partially-settled suspension and the PH value of each suspension is taken and recorded accordingly.

3.2 Procedures and Methodology for Soil Conductivity.

Apparatus; conductivity meter, glass rod electrode

The suspensions prepared for each sample using distilled water, from the previous soil PH test was used for the conductivity test.

Procedure

(a) The suspensions are stirred and allowed to stand for 30minutes.

(b) The glass rod electrode is connected to the conductivity meter, which is set at 30.4°C

(c) The values for conductivity are then taken by dipping the electrode into each sample.

(d) The values are read from the conductivity meter and recorded accordingly.

3.3 General Precautions

The following are the precaution measures taken when the tests above were performed;

(1) the suspensions were not stirred when readings were being taken for both tests

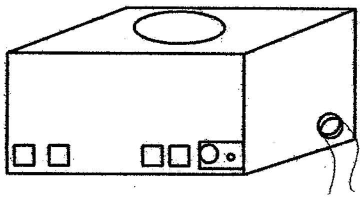
(2) it was ensured that the electrode was rinsed with distilled water and wiped dry with a clean tissue paper after each successive reading.

(3) during the measurement of the parameters, it was ensured that the electrode was dipped into the suspension and not the soil sediments.

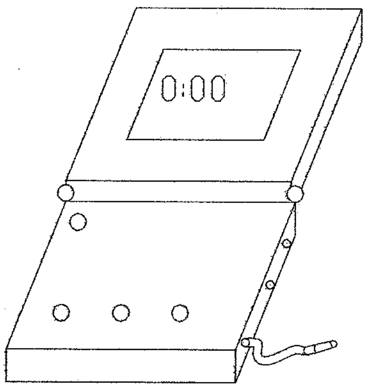
3.4 EQUIPMENTS

Thefollowing were the equipments used forthese analysis.

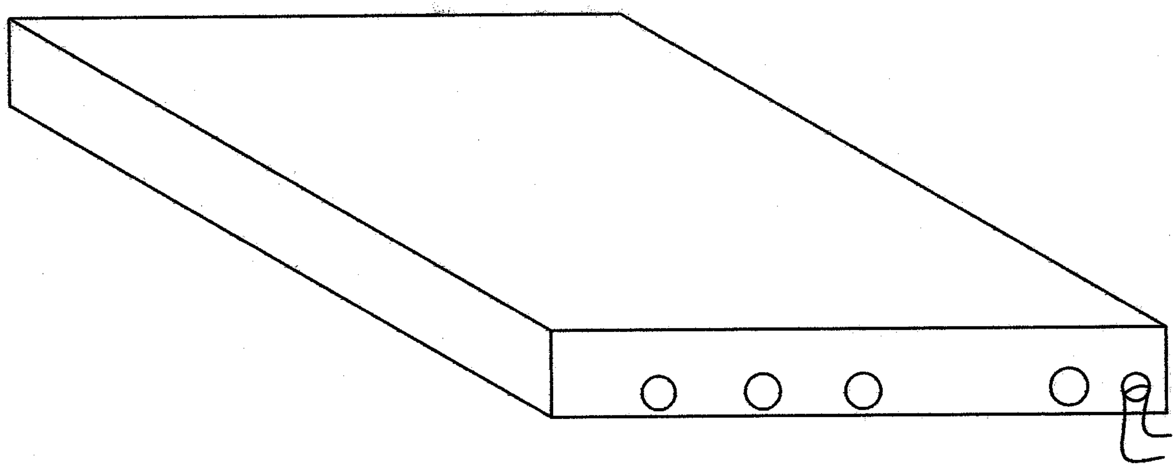
electronic weighing balance.



PH meter with a glass electrode



Conductivity meter with a glass rod electrode



CHAPTER FOUR

4.0 RESULTS AND DISCUSSION OF RESULTS

4.1 Results

Soil PH determination

Temperature = 31°C

S/No	Description of sample	H_2O	0.01M $CaCl_2$
1	Abuja city	7.48	6.07
2	Aba	4.23	2.95
3	Kaduna metropolis	8.07	6.28
4	Akure	6.72	5.56
5	Porthacourt	5.06	3.87

Electrical Conductivity of soil

S/No	Description of sample	Conductivity, µs/cm
1	Abuja city	57.0×10^{-2}
2	Aba	118.8×10^{-2}
3	Kaduna metropolis	43.0×10^{-2}
4	Akure	85.0×10^{-2}
5	Porthacourt	92.4×10^{-2}

4.2 Discussion of Results

The soil PH analysis indicates the degree of corrosiveness of an environment where structures such as USTs are installed. The soil PH test results clearly shows that USTs tend to corrode most in Abia state as a result of its low soil PH. The least corrosion potential is in Kaduna state where the soil PH is highest.

The soil conductivity test shows that the soil in Kaduna state is the most resistive. This means that the soil carries minimal electric current from the UST to the soil; as a result, the corrosion rate is very low. Whereas, the soil in Abia state has the lowest resistivity as it tends to conduct electric current the most. Hence, the corrosion USTs in that area is severe.

From the conductivity results shown, the coating method will not be a reliable method to prevent the electrochemical reaction between the soil and the tank for a long time in most parts of Nigeria, especially towards the south of Nigeria, but if accompanied by cathodic protection system, the entire corrosion control system will be economical. If cathodic protection is installed, the anode consumption tends to be low in high soil resistivity environments, thereby making the entire system durable.

CHAPTER FIVE

5.0 Conclusion

Within the limit of experimental error, laboratory tests on soil PH and soil resistivity were carried out to ascertain the degree of corrosiveness of different soils in strategic areas within Nigeria. From the results obtained, the tendency of corrosion of USTs is higher in the southern part of the country than it is in the northern part. This is largely due to the dryness of the soils in the north, which makes them very resistive to electric current. Corrosion rate can be said to be inversely proportional to soil resistivity.

From all indications, the cathodic protection scheme for USTs in fuel stations is more reliable and economical, when compared to the conventional coating method alone. This is true because if coating alone is to be applied to achieve equal amount of protection offered by cathodic protection system, then the entire corrosion control scheme will be on the high. However, it is recommended that both methods be used to compliment each other. The cathodic protection protects the UST where the coating faults.

5.1 Recommendation

(1) Nigerian fuel stations should pay more attention to their USTs. They should put in place adequate maintenance scheme to check corrosion and avoid leakages due to corrosion.

(2) The soil resistivity test should be carried out on-site using the 4-electrode Wenner method for more accurate results.

(3) Several soil resistivity test should be made on various parts of the site where UST will be installed, because soil resistivity changes dramatically within small areas.

(4) A compliment of both coating and cathodic protection should be considered for protection of USTs in fuel stations.

(5) The cathodic protection system should be checked at the completion of construction and at intervals of not more than five years.

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