CATHODIC PROTECTION OF UNDERGROUND STEEL STORAGE TANK

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CATHODIC PROTECTION OF UNDERGROUND STEEL STORAGE TANK

A thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Technology

(Applied Petroleum Engineering)

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CERTIFICATE

This is to certify that the work contained in this thesis titled **"Cathodic Protection of Underground Steel Storage Tank"** has been carried out by **Aamir Habib & Arjun.C** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Underground structures like pipelines and underground storage tanks tend to get degraded with time. This process of degradation can mainly be attributed to electrochemical reactions leading to corrosion. Corrosion weakens the metal structure by eating away at it leading to leaks, cracks etc.

Corrosion can be defined as the electrochemical process where the exchange of electrons takes place by chemical reactions in the circuit. These reactions takes place at the surface of the metal exposed to the electrolyte. In the case of buried structures, the soil acts as the electrolyte, the structure to be protected acts as the cathode and the metal protecting the structure acts as the anode.

Corrosion can be counteracted using cathodic protection. Using cathodic protection, we effectively protect the structure of interest by allowing an expendable anode to be corroded in its place. Thus, we move the reactions causing corrosion away from the structure to be protected to the anode.

In this project, we have dealt with the protection of an underground storage tank. The tank, as it's below the surface of the soil is subject to corrosion. The dimensional details of the tank used in the calculations are hypothetical values.

The design methodology adopted in arriving at an appropriate cathodic protection system design for this particular case is given in Chapter 5. The actual calculations have been covered under Chapter 6 in which the type of anode, number of anodes and rectifier voltage have been brought out distinctly for an impressed current type cathodic protection system for protecting the tank.

ACKNOWLEDGMENT

In this project we have made an honest and dedicated attempt to make the research material as authentic as it could and we earnestly hope that it provides useful and workable information to any person reading it. There are a few people whom we would like to make a mention of and without whose help the project would have never seen the light of day.

First of all we would like to thank our Dean ***Dr. B.P. Pandey*** *who has given us an opportunity to work on this project.*

Secondly we would like to thank our Mentor ***Prof. R. P. Shriwas.*** *Their timely response immensely helped in giving project the direction it needed.*

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CHAPTER 1

INTRODUCTION

Every metal which is extracted from the ore through many process may be by heat application or not formed in a metal reaches in high energy state has a tendency to come its own natural form i.e. low energy state. Each and every thing (like material, chemical reaction, mechanical structure) tends to that state where it has minimum internal energy content. So, because of this tendency the pure material subjected in the environment starts to deteriorate by reacting with environment.

This reaction may be Electrochemical, Electro potential, Chemical which changes the state of the reacting material. Type of reaction is based on lot of internal and external environmental factor like metallurgical properties, Aggressiveness towards environment, Chemical state, Temperature, Exposed area, Electrical properties.

In the oil and gas sector most of the equipment and facilities face this problem. The facilities that are subjected to corrosion is

- Underground fuel storage tanks and ground level tank bottoms.
- Fuel distribution systems.
- Elevated and ground level water storage tank interiors.
- Potable water distribution systems.
- Gas/liquid distribution systems.
- Compressed air distribution systems.
- Steel sheet pile seawalls, pier support/fender piles, and other submerged steel structures.
- Concrete reinforcing steel.
- Buried structures

So, to prevent this corrosion different methods are used which control, reduce the rate of corrosion. One of the methods is providing Cathodic Protection which is an electrochemical method used to prevent or control corrosion of buried or submerged metallic structures. CP systems are active systems that rely on the application of electric current to control corrosion. Properly installed and maintained cathodic protection systems dramatically reduce life cycle costs by indefinitely extending a utility's lifetime. They also reduce the government's potential liability from premature failure of utilities, environmental friendly. CP is essential to maintaining any metallic structure in a corrosive environment at the lowest life cycle cost.

UNDERGROUND STORAGE TANKS

Mounded storage: The storages for explosive and hazardous liquefied gases are often buried for safety reasons. They are called underground storage tanks or mounded tanks. These tanks are usually used for the storage of volatile and explosive materials like L.P.G, propane, ethane etc.

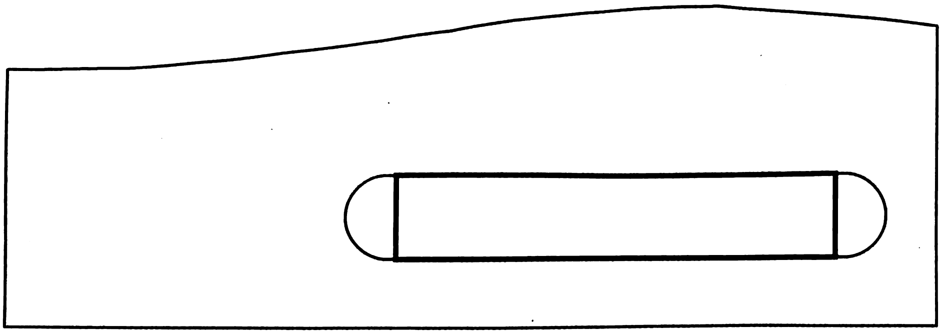

FIGURE NO.1

An underground storage tank

CHAPTER 2

CORROSION

2.1 THE CORROSION PROCESS. The corrosion of metals is an electrochemical process. It is an electrical circuit where the exchange of electrons (electricity) is conducted by chemical reactions in part of the circuit. These chemical reactions occur at the surface of the metal exposed to the electrolyte. Oxidation reactions (corrosion) occur at the surface of the anode and reduction reactions occur at the surface of the cathode.

Corrosion control systems which relocate these oxidation reactions, by making the protected structure a cathode in a larger corrosion cell, is called a "cathodic" protection system." The cathodic protection anodes are installed to become the anode in this larger corrosion cell and provide the location for all oxidation reactions in the cell.

2.1.1 **Corrosion Cell:** Corrosion is the deterioration of a material through reaction with its environment. In the case of a metal, this deterioration occurs mainly through an electrochemical process. The electrochemical process consists of four distinct parts: anode, cathode, electrolyte, and metallic path. These four parts constitute what is called the "corrosion cell". Electrochemical corrosion occurs only when all four parts of the corrosion cell are present.

2.1.1.1 **Anode.** The first part of the corrosion cell is the anode. This is the location where corrosion occurs. The anode is the point in a corrosion cell where electricity is passed by chemical means from the surface of the metal to the electrolyte.
This chemical reaction is an oxidation reaction, which is characterized by the metal losing an electron and combining with another element, usually oxygen.

In the case of steel, the resulting material is iron oxide (rust).

ANODE: An electrode where oxidation reactions (corrosion) occurs

2.1.1.2 **Cathode**: The second part of the corrosion cell is the cathode. This is the location where protection occurs. The cathode is the point in a corrosion cell where electricity is passed by chemical means from the electrolyte to the surface of the metal. This chemical reaction is a reduction reaction, which is characterized by the metal passing electrons to the electrolyte.

CATHODE: An electrode where reduction reactions (protection) occurs.

Anode/Cathode Relationship: An electrode becomes either an anode or a cathode in an electrochemical corrosion cell depending upon its electrical potential compared to the other electrode. This electrical potential difference is the **electromotive** force of the cell and is the voltage difference between the anode and the cathode. The electrode which is more electrically active, or more negative in voltage, undergoes the corrosion, so by definition is the anode. The electrode that is more noble (less negative in potential) passes electrons to the electrolyte (reduction reactions) and by definition is the cathode and does not undergo corrosion (oxidation reactions).There are four distinct parts to the electrochemical corrosion cell, all four parts must be present for a complete circuit to exist and for current to flow (corrosion to occur).

2.1.1.3 **Electrolyte**: The third part of the corrosion cell is the electrolyte. The electrolyte is the location where ions flow. The electrolyte is any material in contact with both the anode and the cathode that will allow ions to migrate. The electrolyte is the part of a corrosion cell which allows oxidation and reduction reactions to occur. The electrolyte includes the source of elements or atoms that are required for ion transfer to and from the metal electrodes (anode and cathode).

2.1.1.4 **Metallic Path**: The fourth part of the corrosion cell is the metallic path. The metallic path completes the circuit and allows the electrons to flow. The metallic path is any metal that contacts both the anode and the cathode and allows electrons to flow. This electron flow must be present for electrochemical corrosion to occur. In the case of a tank or pipeline, this can be the tank or pipe itself, or it can be a metallic bond to different metallic structure.

ELECTROLYTE: Any soil or liquid adjacent to and in contact with the anode and the cathode that allows ions to migrate (flow) .

METALLIC PATH: Any conductor that allows electrons to flow from the anode to the cathode.

When all four parts are present, a closed circuit condition exists, and current will flow through this circuit. Corrosion only occurs at the anode of the cell, which is where the oxidation reactions occur.

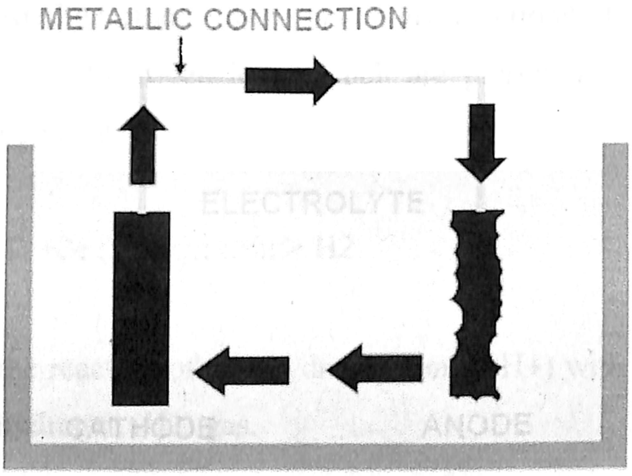

FIGURE NO.1

Galvanic corrosion Cell

Anode Reaction: At the anode the metal atoms give up one or more electrons and become metal ions. The chemical reaction is

M:::::::::::::::::::::::::::::::::> M^{n+}+ ne-

M represents a metal atom such as iron or copper in a metallic structure. Metal ions formed in the corrosion reaction leave the metal structure and enter the environment (electrolyte).The negatively charged electron released by the formation of the metal ion. The free electron that is formed in the corrosion reaction remains within the metal structure.

$$Cu::::::::::::::::::::::::::::::::> Cu^{++} + 2e-$$

This reaction represents that one copper atom form one copper ion with a charge of +2 and two electrons. It is characteristic of anodic reactions that metal ions and electrons are produced.

Cathode Reaction: At the cathode there are many reactions. The common cathodic reaction is the reaction of hydrogen ions, which are present in water solutions, with electrons to form hydrogen gas.

$$2\ H^{+} +2e\ ::::::::::::::::::::> H2$$

This represents the reaction of two hydrogen ions (2H+) with two electrons (e-) to form one molecule of hydrogen (H2) gas.

Another common reaction at the cathode is the reaction of electrons with dissolved oxygen and the breakdown of water into hydroxyl ions.

$$O2 + 2H2O + 4e::::::::::::::::::::> 4OH^{-}$$

This represents the reduction of dissolved oxygen (O2) in alkaline electrolytes where oxygen and the breakdown of two water molecules (2H2O) results in the formation of four hydroxyl ions (4OH-).

2.1.1.5 **Other Cathodic Reactions**: In other cathodic reactions, different ions may react with electrons, but the important characteristic of every cathodic reaction is the rebonding (gaining) of electrons, which is the main characteristic of a reduction reaction. Metal ion reduction and metal deposition may also occur. Note that there is no direct involvement of the metal itself in the cathodic reaction, except that if metal ions are present, they may be reduced (gain their electron(s) back) or deposited. The metal does not become an ion, does not lose an electron, and cannot combine with another atom or element (oxidize or rust). Although the cathodic reaction must occur for the corrosion reaction to proceed there is no corrosion occurring at the cathode. This reduction reaction is normally called protection; since the metal is protected from becoming an ion, it is protected from corrosion. This process also results in many factors which would otherwise slow the corrosion rate: the reduction of hydrogen ions (which causes pH to change in the alkaline direction); the formation of hydroxyl ions (which also causes pH to change in the alkaline direction); the breakdown of water (which causes an increase in resistivity in the electrolyte); and the formation of a hydrogen coating on the cathode (which causes an increase in the cathode to electrolyte resistance). The electrolyte provides the ions necessary for the cathodic reaction and serves to dissolve the metal ions formed at the anode. The most common electrolyte is water or a water based solution.

2.2 **TYPES OF CORROSION:** Corrosion can occur through a chemical reaction or three general types of electrochemical reactions. The three general types of electrochemical reactions that occur depend on the cause of the potential difference between the anode and the cathode. This potential difference can be caused by differences in the environment, differences in the metal, or by external electrical sources of DC current.

Concentration Cell Corrosion: Electrochemical cell caused by differences in the electrolyte.

Galvanic Cell Corrosion: Electrochemical cell caused by differences in the metal.

Stray Current Corrosion: Electrochemical cell caused by external electrical sources.

2.2.1 **Concentration Cell Corrosion:** This type of corrosion is caused by an electrochemical corrosion cell. The potential difference (electromotive force) is caused by a difference in concentration of some component in the electrolyte. Any difference in the electrolyte contacting the metal forms discrete anode and cathode regions in the metal. Any metal exposed to an electrolyte exhibits a measurable potential or voltage. The same metal has a different electrical potential in different electrolytes, or electrolytes with different concentrations of any component. This potential difference forces the metal to develop anodic and cathodic regions. When there is also an electrolyte and a metallic path, the circuit is complete, current flows, and electrochemical corrosion will occur.

Soil is a combination of many different materials. There are also many different types of soil, and even the same type of soil varies greatly in the concentration of its constituents. Therefore, there is no such thing as truly homogeneous soil. These soil variations cause potential differences (electromotive force) on the metal surface resulting in electrochemical corrosion cells. Liquids tend to be more uniform, but can vary in the concentration of some components such as oxygen varies by depth and flow rates. Biological organisms are present in virtually all-natural aqueous environments, these organisms tend to attach to and grow on the surface of structural materials, resulting in the formation of a biological film, or biofilm. These films are different from the surrounding electrolyte and have many adverse effects.

2.2.1.1 **Dissimilar Environment:** Pipelines tend to pass through many different types of soils. The metal exhibits different electrical potentials in different soils. The electrical potential in those soils determines which areas become anodic and which areas become cathodic. Since both the anode and cathode are electrically continuous and the electrolyte is in contact with both, current flows, resulting in oxidation and reduction reactions (corrosion and protection). The area of the pipeline or tank, which is the anode, corrodes. Since the ground tends to consist of horizontal layers of dissimilar soils, pipelines that traverse several layers of soil tend to be affected by this type of corrosion frequently.

Water and oil well casings are prime examples of this type of electrochemical corrosion cell. Other examples are pipelines that go through areas of generally different materials such as rock, gravel, sand, loam, clay, or different combinations of these materials.

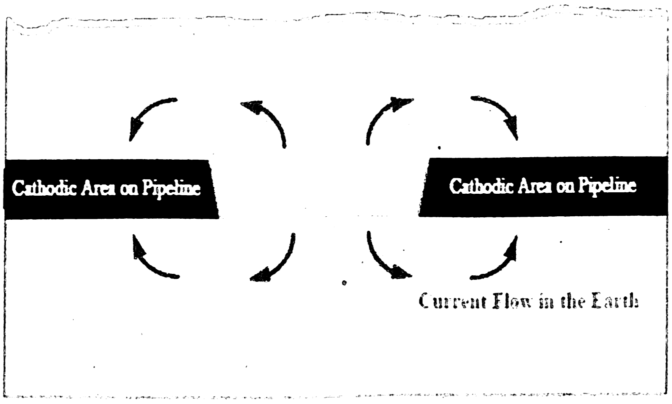

FIGURE NO.2

Cell Caused by Different Environments

2.2.1.2 **Oxygen Concentration:** Pipelines or tanks that are exposed to an electrolyte with a low oxygen concentration are generally anodic to the same material exposed to an electrolyte with high oxygen content. This is most severe when a pipeline or tank is placed on the bottom of the excavation, then backfill is placed around the remaining part of the structure. The backfill contains a relatively high amount of oxygen during the excavation and backfill operation. This can also occur when the metal is exposed to areas that have different levels of oxygen content.

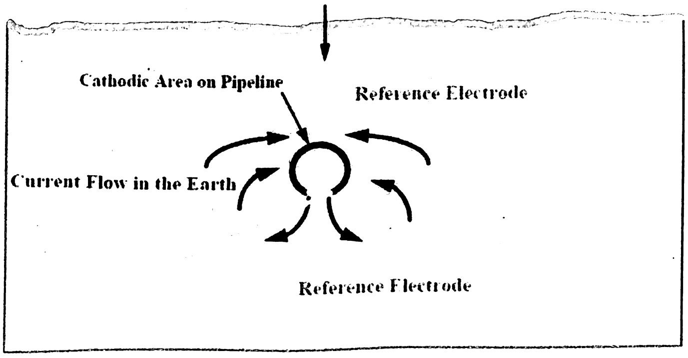

FIGURE NO.3

Cell Caused by Different Concentrations of Oxygen

2.2.1.3 **Moist/Dry Electrolyte**: Pipelines or tanks that are exposed to areas of low and high water content in the electrolyte also exhibit different potentials in these different areas. Generally, the area with more water content becomes the anode in this electrochemical corrosion cell. This is most severe when a pipeline passes through a swampy area adjacent to dry areas or a tank is located in dry soil, but the water table in the soil saturates the tank bottom.

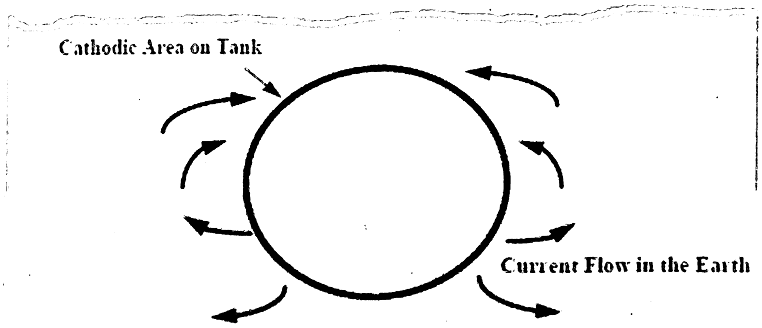

FIGURE NO.4

Cell Caused by Different Concentrations of Water

2.2.1.4 **Non-Homogeneous Soil**: Pipelines or tanks that are exposed to an electrolyte that is not homogeneous exhibit different electrical potentials in the different components of the soil. This can occur in any soil that is a mixture of materials from microscopic to substantially sized components. The area(s) with the higher potential becomes the anode in this electrochemical corrosion cell. This is most severe when a pipeline or tank is placed in an electrolyte with components that cause large potential differences or where there are small anodic areas and large cathodic areas.

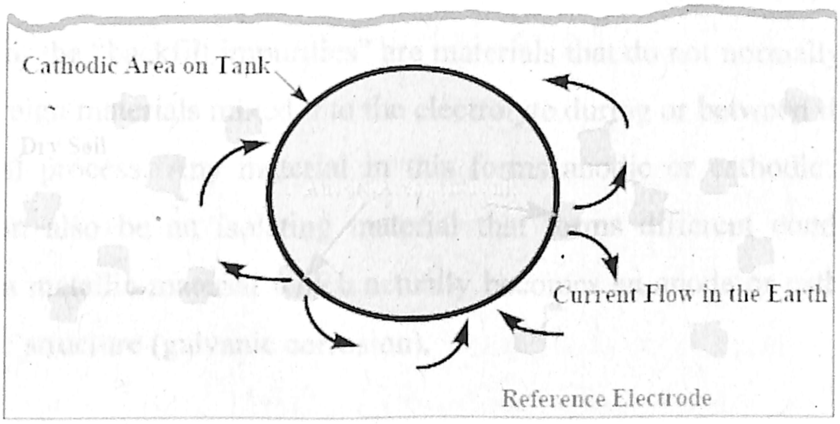

FIGURE NO.5

Cell Caused by Non-Homogeneous Soil

2.2.1.4 **Concrete/Soil Interface**: Pipelines or tanks that are in contact with cement and exposed to another electrolyte exhibit different potentials in each area. The area not in contact with cement becomes the anode in this electrochemical corrosion cell. A pipeline or tank that is in contact with concrete and soil (or water) may be a very severe corrosion cell, because of the high potential difference of the metal in the two different electrolytes.

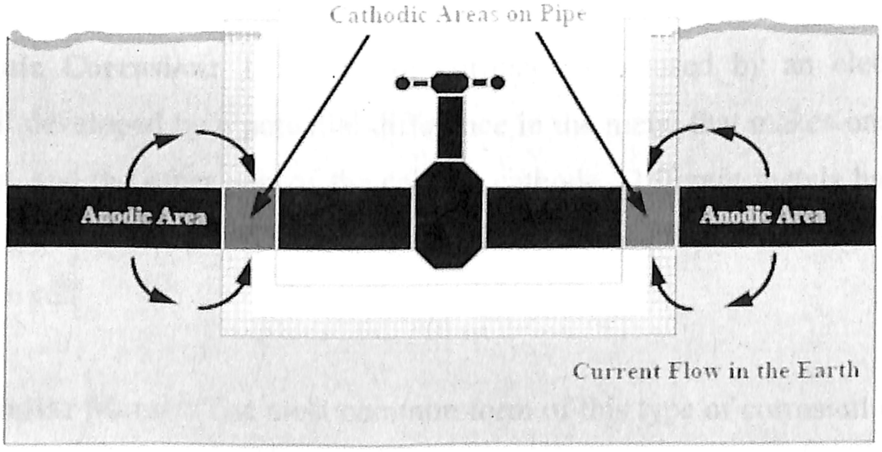

FIGURE NO.6

Cell Caused by Concrete and Soil Electrolytes

2.2.1.5 **Backfill Impurities**: This is also like the non-homogeneous soil concentration cells, except that the "backfill impurities" are materials that do not normally occur in the soil, but are foreign materials mixed into the electrolyte during or between the excavation and the backfill process. Any material in this forms anodic or cathodic areas on the structure. It can also be an isolating material that forms different conditions in the electrolyte, or a metallic material which actually becomes an anode or cathode when in contact with the structure (galvanic corrosion).

2.2.1.6 **Biological Effects:** Biological organisms may attach to and grow on the surface of a metal, causing a different environment extremely corrosive to the metal. Most bacteria that have been implicated in corrosion grow best at temperatures of 15 □C to 45 □C (60 □F to 115 □F). These bacteria may be aerobic or anaerobic. Their metabolism products influence the electrochemical reaction by forming materials or films that act as a diffusion barrier, or change ion concentrations and pH. Some bacteria are capable of being directly involved in the oxidation or reduction of metal ions and can shift the chemical equilibrium that influences the corrosion rate. Aerobic bacteria form oxygen and chemical concentration cells, and in the presence of bacteria capable of oxidizing ferrous ions, further accelerate corrosion.

2.2.2 **Galvanic Corrosion:** This type of corrosion is caused by an electrochemical corrosion cell developed by a potential difference in the metal that makes one part of the cell an anode, and the other part of the cell the cathode. Different metals have different potentials in the same electrolyte. This potential difference is the driving force, or the voltage, of the cell.

2.2.2.1 **Dissimilar Metals:** The most common form of this type of corrosion is when two different kinds of metal are in the electrolyte and metallically bonded. All metals exhibit an electrical potential; each metal has its distinctive potential or voltage according to the Electro potential series. When two different metals are connected, the metal with the most negative potential is the anode; the less negative metal is the cathode.

2.2.2.2 **Old-to-New Syndrome:** This type of corrosion occurs when due to operation problem at a certain point the pipe is changed. Steel is unique among metals because of the high energy put into the process of producing the steel. New steel is more active, than corroded steel. The potential difference between the high negative potential of the new steel and the low negative potential of the old steel is the driving force, or voltage, of this electrochemical corrosion cell. A common problem of this type of corrosion is when an old bare steel pipeline fails, and a small section of the pipeline is replaced with a coated section of new steel. The new section is the anode and corrodes to protect the large cathode, resulting in failure of the new section.

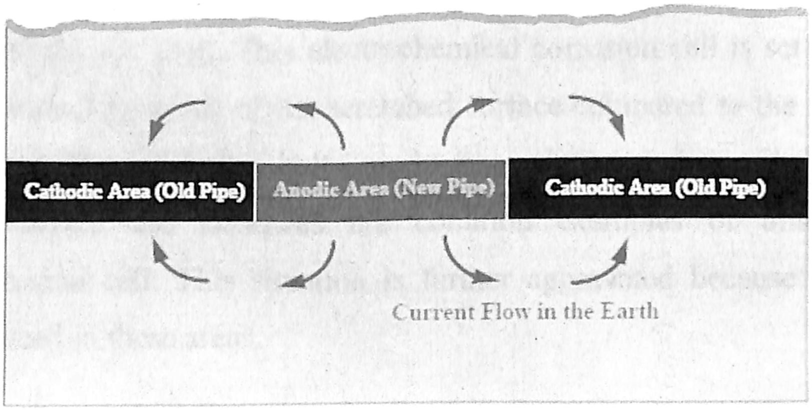

FIGURE NO.7

Cell Caused by Old and New Steel

2.2.2.3 **Dissimilar Alloys:** This is most common example of galvanic type of corrosion is different metal alloys because of the manufacturing limitation. There are over 200 different alloys of stainless steel. All these metals are not 100 percent pure. They normally contain small percentages of other types of metals. Different batches of a metal vary in content of these other metals. Different manufacturers may use different raw materials and even the same manufacturer may use raw materials from different sources. Each batch of metal may be slightly different in electrical potential. Even in the same batch of metal, the concentration of these other materials may vary slightly throughout the finished product. All these differences will produce the electromotive force for this type of corrosion to occur.

2.2.2.4 **Impurities in Metal:** No manufacturing process is perfect. Small impurities may be mixed into the metal as it is produced or cooled. Impurities at the surface of the metal may become part of the electrolyte causing concentration cell corrosion, or if metallic, they may be anodic (corrodes and leaves a pit behind), or cathodic (corroding surrounding metal).

2.2.2.5 **Marred or Scratched Surface:** A marred or scratched surface becomes anodic to the surrounding metallic surface. This is similar to the old-to-new syndrome, where new steel is anodic to the old steel. This electrochemical corrosion cell is set up by the difference in the electrical potential of the scratched surface compared to the remaining surface of the structure. Threaded pipe, bolts, marks from pipe wrenches and other tools, and marks from shovels and backhoes are common examples of this type of electrochemical corrosion cell. This situation is further aggravated because the metal thickness is also reduced in these areas.

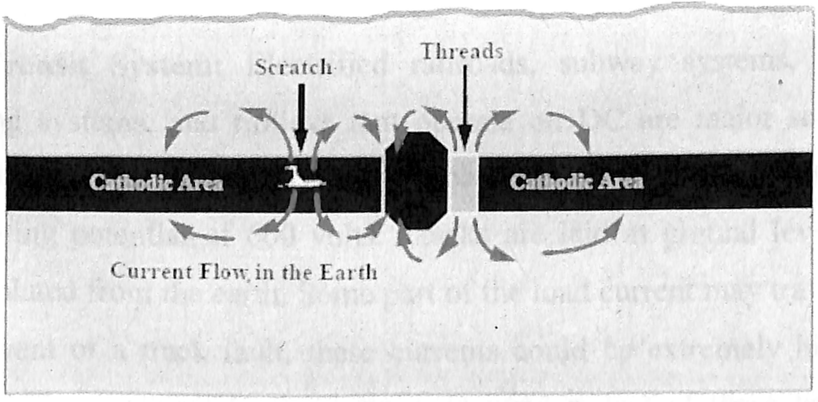

FIGURE NO.8

Cell Caused by Marred and Scratched Surfaces

2.2.3 **Stray Current Corrosion:** This type of electrochemical corrosion cell is caused by an electromotive force from an external source affecting the structure by developing a potential gradient in the electrolyte or by inducing a current in the metal, which forces part of the structure to become an anode and another part as a cathode. This type of corrosion can be extremely severe because of very high voltages that can be forced into the earth by various sources. The potential gradient in the electrolyte forces one part of the structure to pick up current (become a cathode) and another part of the structure to discharge current (become an anode).

Stray current corrosion occurs where the current from the external source leaves the metal structure and enters back into the electrolyte, normally near the external power source cathode. The external power source is the driving force, or the voltage, of the cell. Stray current corrosion is different from natural corrosion because it is caused by an externally induced electrical current and is basically independent of such environmental factors as concentration cells, resistivity, pH and galvanic cells. The amount of current (corrosion) depends on the external power source, and the resistance of the path through the metallic structure compared to the resistance of the path between the external source's anode and cathode.

2.2.3.1 **DC Transit System:** Electrified railroads, subway systems, street railway systems, mining systems, and trolleys that operate on DC are major sources of stray current corrosion. These systems may operate load currents of thousands of amperes at a common operating potential of 600 volts. Tracks are laid at ground level and are not completely insulated from the earth. Some part of the load current may travel through the earth. In the event of a track fault, these currents could be extremely high. Buried or submerged metallic structures in the vicinity (several miles) of these tracks could be subject to stray current effects. Pipelines that run parallel, cross under the tracks, or are located near the DC substation, are especially prone to these stray currents. If there are high resistance joints in the tank, the current may bypass the joint, leaving the pipeline on one side of the joint, and returning on the other side. Since the source of the stray current is moving, it may be necessary to monitor the metallic structure over a 24-hour period to see if these currents affect it.

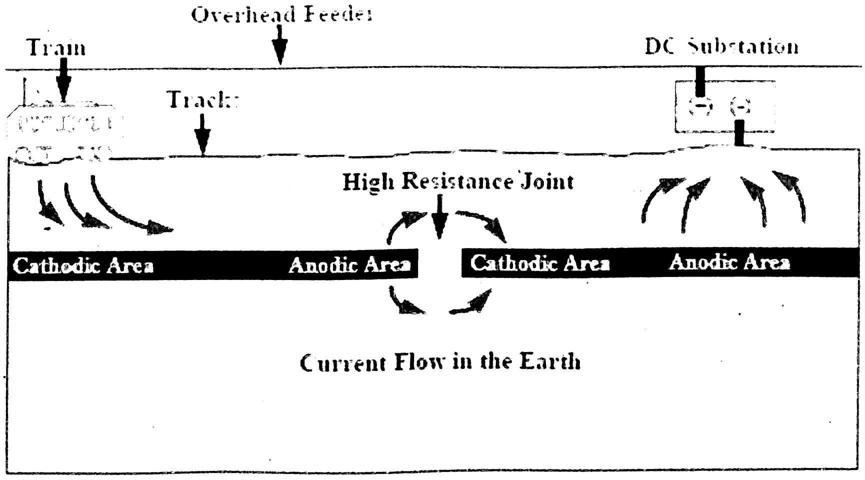

FIGURE NO.9

Stray Current Cell Caused by a DC Transit System

2.2.3.2 **High Voltage Direct Current (HVDC) Electric Transmission Lines:** Power distribution systems are another source of stray currents. Most power systems are AC, although sometimes DC systems with grounded neutral may be used. These transmission lines, under fault conditions, may use the earth as the return path for the DC current. Because DC requires only two-wire instead of three-wire transmission, it is sometimes used when large amount of power needs to be transported large distances. Conversion units are located at each end of the transmission lines. Each of these conversion units are connected to a large ground grid. Any unbalanced load would result in a current in the earth between these two ground grids. These unbalanced currents are naturally not constant—they vary in direction and magnitude. HVDC line voltages may be 750,000 volts or higher.

2.2.3.3 **By Other Cathodic Protection Systems:** Cathodic protection systems are a major source of stray current on other metallic structures. An example of this electrochemical corrosion cell is when a foreign pipeline passes near an anode, and then crosses the protected structure (cathode).

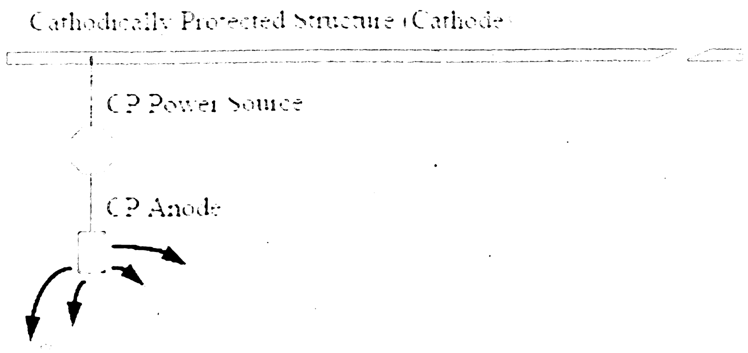

FIGURE NO.10

Stray Current Cell Caused by other CP System

2.3 **INTERNAL CORROSION:** Internal corrosion occurs due to chemical attack on the interior surface of the steel from the commodities being stored within the tank. In some cases, the corrosive liquids may be contaminants such as water or other chemicals entrained or suspended within the commodity being transported.

Internal corrosion can result in the gradual reduction of the wall thickness of the pipe and a resulting loss of pipe strength. It can occur relatively evenly over an area of the pipe surface. This loss of pipe strength could result in leakage or rupture of pipelines due to internal pressure stresses unless the corrosion is repaired, the affected pipeline section is replaced, or the operating pressure of the pipeline is reduced.

2.4 **RATE OF CORROSION:** Since almost all corrosion is an electrochemical reaction, anything that affects the speed of a chemical reaction or the amount of current flow will affect the rate of corrosion. The rate of corrosion is directly proportional to the amount of current that flows in the electrochemical corrosion cell. Current measurement can give exact metal loss. The measurement in amps or milliamps can be mathematically calculated in kilograms (pounds) per amp year. One amp year is one amp flowing for a period of one year. Different metals have different consumption rates.

METAL (ION)	WEIGHT LOSS (KILOGRAMS)	WEIGHT LOSS (POUNDS)
Magnesium	4.00	8.8
Aluminum	2.95	6.5
Zinc (Zn++)	10.66	23.6
Chromium	5.65	12.5
Cadmium	18.39	40.5
Iron (Fe++)	9.13	20.1
Cobalt	9.63	21.2
Nickel	9.58	21.1
Copper (Cu+)	20.77	45.6
Copper (Cu++)	10.39	22.8
Tin	19.39	42.7
Lead (Pb++)	33.87	74.5
Carbon (C+)	1.91	4.2
Carbon (C++++)	1.00	2.2

TABLE NO.1

Metal Consumption Rates

Data are from 'Design, Installation, Operation and Maintenance of Impressed Current deep Ground beds, NACE RP-05-72-95'

2.4.1 Factors Affecting the Rate of Corrosion

2.4.1.1 Electrical Effects on the Rate of Corrosion.

- Potential Difference.
- Resistivity of the Electrolyte.
- Contact Resistance.
- Coating of the Structure.
- Polarization of the Structure.
- Amount of Current Flow.

2.4.1.2 **Chemical Effects on the Rate of Corrosion.**

- Temperature.
- Ion Concentration.
- Electron Concentration.
- pH of the Electrolyte.
- Coating of the Structure.
- Polarization of the Structure.

2.5 **GALVANIC SERIES:** The two major factors affecting the rate of corrosion in an electrochemical corrosion cell are the electrical characteristics of the electrolyte (resistivity), and the voltage difference between the anode and the cathode. The resistivity of the electrolyte is normally not a controllable characteristic, but it is measurable. The voltage or potential of the metal anode and cathode is also a measurable characteristic. The voltage measured is the voltage difference between the two electrodes. Since this voltage is dependent only on a voltage difference, there must be a reference that all other electrodes can be measured against, to give a relational table, or series, of the potential of any given electrode. As earlier stated metals all have different potentials, and any given metal has different potentials in different electrolytes. For an electrode to be used as a reference to measure other electrodes, the metal and the electrolyte in contact with the metal must be specified. Once this is done, the electrode becomes a reference electrode.

There are many types of reference electrodes like hydrogen/hydrogen (hydrogen electrode, hydrogen electrolyte) is for lab. For field use, the copper/copper sulfate (copper electrode, fully saturated copper sulfate electrolyte) is in common use, except in salt water, where silver/silver chloride (silver electrode, silver chloride electrolyte) is used and must be adjusted by the factor or the chloride contact of the electrolyte. These references are merely stable electrodes with a known potential used to measure the potential of unknown electrodes. Using these references, the potential value of any metal in any electrolyte can be recorded for future reference and compared to other electrodes.

A table of such measurement is called a galvanic series of measurements. Each table must specify the reference electrode used to accomplish the measurements, and the electrolyte the unknown electrodes were in, to allow for interpretation by corrosion experts. This series can then be used to determine which electrode will be the anode (and corrode) in an electrochemical corrosion cell.

GALVANIC SERIES OF METALS: METAL OR ALLOY REFERENCE:	**SILVER/SILVER CHLORIDE**	**SATURATED CALOMEL**	**COPPER/COPPER SULFATE**
ELECTROLYTE	**FLOWING SEAWATER**	**SEAWATER**	**NEUTRAL SOILS AND WATER**
Pure Magnesium		-1.60 to -1.64	-1.75
Standard Magnesium			-1.55
Zinc		-0.98 to -1.04	-1.10
Aluminum Alloy	-0.79	-0.77 to -1.00	-1.05
Pure Aluminum			-0.80
Low-Carbon Steel (clean and shiny)	-0.61	-0.60 to -0.72	-0.50 to -0.80
Low-Carbon Steel (rusted)			-0.20 to -0.50

Cast Iron (not graphitized)	-0.61	-0.60 to -0.72	-0.50
Lead		-0.18 to -0.23	-0.50
Low-Carbon Steel (in concrete)			-0.20
Copper, Brass, Bronze	-0.36		-0.20
High-Silicon Cast Iron			-0.20
Carbon, Graphite, Coke	+0.25		+0.30

TABLE NO.2

Galvanic Series for Different Electrolytes

Data are from 'Thomas O. Miesner & William L. Leffler, Oil and Gas pipeline, In Non Technical language'

CHAPTER 3

CORROSION CONTROL

This corrosion is decrease the life of the underground pipe or the structure subjected to such condition.

To control the **internal corrosion** the preventive measure are done in the pipeline are

- Modern manufacturing processes for steel pipe and coatings
- Control the moisture and chemical content of the products transported through their pipelines.
- Routinely cleaning pigs through pipelines to remove accumulations of materials.
- Introduce corrosion inhibitors into the pipeline to control internal corrosion.
- By commodity's quality is controlled, internal coatings are applied, or corrosion inhibitors injection.

To, control the **corrosion on external surface** of buried pipeline generally two methods is opted. Those methods are having its own limitation.

- **Coating**
- **Cathodic protection**

3.1 **Coating:** coating is the process of applying a different material on another material to prevent it from its surrounding. Coating of pipe is to isolate the pipe line from soil and seawater and to provide a high resistance path between anodic and cathodic area. To do so coating must contain such properties.

3.1.1 Properties of Coating Material:

- Low permeability to water and salt.
- Low permeability to oxygen.
- Good adhesion to pipe steel.
- Adequate temperature stability.
- Resistance to cathodic disbondment.
- Non toxic and environmental friendly.

Some of the coating which is used in the onshore and the off shore pipeline are

- Asphalt enamel
- Coal tar epoxy
- Fusion bond epoxy
- Three layer polyethylene/polypropylene coating
- Concrete weight coating.

The application of these coating is decided by the soil condition, fluid to be transported, Operating condition (temperature, pressure), outside force etc.

3.1.2 Type of Coating Material

3.1.2.1 **Coal Tar Coating/Asphalt Enamel Coating:**_These coating are flood coating applied as a molten material a rotating pipe. These coating are 5-6 mm thick, but these are poor adhesion to steel. So to make a proper adhesion much roughened steel is prepared at time of surface cleaning.

While coating the pipe a surface is cleaned first, then molted coal tar/asphalt is applied on the surface and then one or two layer of glass reinforced fiber mating are applied on it. These are generally cheap coating having operating range 65-75^{0}c for coal tar coating and 70-80^{0}c for asphalt coating.

3.1.2.2 **Poly Ethylene Coating:** It is 3-4 mm thick coating. In this coating epoxy primer is applied on the pipe, followed by poly ethylene based adhesive on which the poly ethylene wrap is applied .Such coating is also known as 3PE or 3LPE coating.

Polyethylene has a high electrical resistance, very low moisture uptake, long life expectancy. The upper temperature tolerance of polyethylene wrap is about65^{0}C.The main problem occur in this is the undercoating corrosion, resulting from blisters, and inadequate CP current access because of high electrical resistance.

3.1.2.3 **FBE Coating:** FBE Coating are thin film coating,0.5-0.6 mm thick. The epoxy has a strong chemical bond to the steel that provided good adhesion.FBE coating in seawater can withstand temperature between 85-95^{0}C.

3.1.3 Coating damage

Damage may occur in other ways, that is, by careless or improper use of corrosion control and cathodic protection techniques.

3.1.3.1 Mechanical Damage

Probe bars for corrosion testing must not be driven into the soil to make contact with coated pipe. Damage that results from excavation of adjacent facilities must be repaired. Installation of test leads, bonding conductors, or anode leads will require coating removal. After leads have been attached, coating must be repaired.

3.1.3.2 Electrical Damage

Electrical damage to a coating may be caused by excessive voltage from a holiday detector or by excessive structure-to-earth potential applied by an impressed current system. The following empirical formula defines the voltage to be applied by the holiday detector:

$$\mathbf{V = KT^{1/2}}$$

V = peak voltage output (kilovolts)
T = thickness of coating in mils (do not include wrappers)
K = a constant depending on type of coating (1.0 for somastic, 1.25 for coal tar, 1.5 for epoxy or plastic).

The voltage will pinpoint the holidays, but will not further damage the coating. Measuring the holiday detector voltage in the field requires a special high-voltage pulse voltmeter. The above formula will determine the output voltage capacity of the holiday detector needed. To adjust the detector to the proper voltage in the field, the procedure outlined in the manufacturer's instructions should be used.

3.1.3.3 Cathodic Protection Damage/Cathodic Disbondment

In some conditions, apply excessive amounts of cathodic protection to a coated pipeline and damage the coating. There is a limiting polarization potential, called the "hydrogen over-voltage potential", beyond which free hydrogen will be developed. Gas bubbles will form on and break away from pipe metal exposed at coating defects. A developing hydrogen gas bubble can exert tremendous pressure. When this pressure is created at a coating void, there is a stripping action which can increase the area of exposed metal and result in rapid deterioration of what may have initially been an excellent coating. Polarization potential can be measured at a given location on a coated pipeline by measuring the pipeline-to-earth potential immediately (within the first second or two) after simultaneously interrupting the current output from all cathodic protection current sources affecting that portion of the pipeline. If, on steel pipelines, this potential is below approximately 1.2 volt (measured between pipe and soil as contacted by a copper-copper sulfate reference electrode), danger of coating damage is slight. If the current-off polarization potential is at or slightly above this figure, free hydrogen may be produced and possible coating damage could be expected. It is possible to cause extensive damage through improper rectifier operation. This results from maintaining excessive structure-to-electrolyte potential.

The following empirical formula specifies the maximum ferrous structure-to-earth potential at all points on a structure which will not cause coating damage:

$$\mathbf{E = (125P0.3 + 600)}$$

E = potential in millivolts

P = resistivity in ohm-cm

This will limit the ferrous structure-to-earth potential in the vicinity of the rectifier connection. The table below lists the safe maximum potential limits for specific resistivities as calculated, using the above formula:

P (ohm-cm)	**E (volts negative)**
2,000	-1.8
3,000	-2.0
5,000	-2.2
10,000	-2.6
15,000	-2.7
20,000	-3.0
30,000	-3.3
40,000	-3.6

TABLE NO.1

Potential Limits for specific Resistivities

Data are from 'Thomas O. Miesner & William L. Leffler, Oil and Gas pipeline, In Non Technical language.'

Potentials listed are too high for coated aluminum and lead structures and will result in chemical deterioration of the metal. Water storage tank "instant-off" potentials should be limited to -1.2V maximum to prevent coating damage.

3.1.3.4 **Miscellaneous Coating Damage**

Damage or defects in coatings may also be caused by:

- Damage to coating by subsequent construction (probe bars for pole installation, etc.)
- Cracks from excessive thermal or mechanical stresses.

- Action of chemicals in the earth surrounding a pipeline.
- Action of bacteria in the soil surrounding a pipeline.
- Flaws in the coating materials as applied.
- Failure to properly field-coat joints when extensions or modifications are made to a coated pipeline.

3.1.3.5 Coating Aging

As coatings age, they become less effective as electrical insulators. As the coating loses its insulating properties, it allows current to flow out of the surface of the structure and corrosion to take place under the coating film. For this reason, the amount of current needed to give adequate cathodic protection becomes greater. It is also possible for disbonded areas of coating to actually shield cathodic protection current from reaching the surface of the pipe, resulting in undetected corrosion. It is important that any breaks in a coating be carefully repaired before the structure is placed in service. During the life of the structure, any breaks found in protective coatings must be repaired.

3.2 **Cathodic protection:** Cathodic protection is the prevention of corrosion by making a metal, which would ordinarily behave like an anode and corrode, behave like a cathode and be free from corrosive attack. Essentially, CP is predetermining the anode in the corrosion cell, or making a large corrosion cell to overcome the other smaller corrosion cells. In cathodic protection this is achieved in one of two basic ways.

- Galvanic Cathodic Protection.

- Impressed Current Cathodic Protection.

CHAPTER 4

LITERATURE REVIEW

Cathodic protection utilizes a flow of direct current electricity to interfere with the activity of the electrochemical cell responsible for corrosion. Corrosion can be prevented by coupling a metal with a more active metal when both are immersed in an electrolyte and connected with an external metallic path. In this case the entire surface of the metal being protected becomes a cathode; thus the term "cathodic protection".

In order to prevent anodic reactions from occurring due to electrochemical reactions on that metal, electrons must be prevented from leaving the metal. In this case, the flow of electrons is from the external source to the metal being protected. Conventional current flow is described by the flow of imaginary positive charges in a direction opposite the electron flow. Since cathodic protection depends on the energy of electrons and their tendency to flow only from an area of high (negative) potential to one of lower (negative) potential.

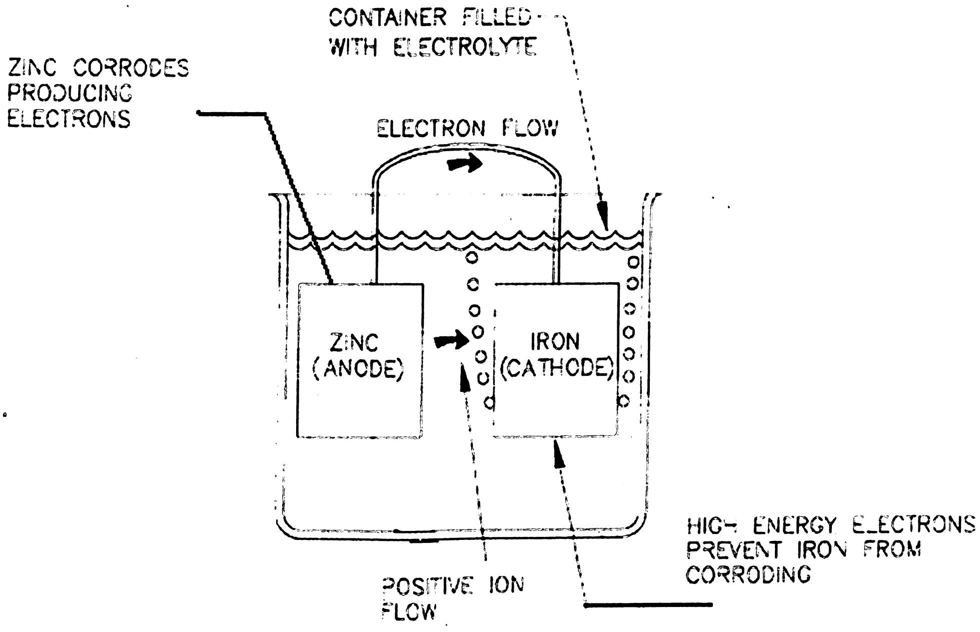

FIGURE NO.1

Principle of cathodic protection

There are the two ways to provide the cathodic protection:

- By using the galvanic series to select a more active metal, install that metal in the electrolyte and provide a metallic path. This method is called sacrificial cathodic protection, or galvanic cathodic protection. The galvanically more active metal (anode) is installed to sacrifice itself to protect the structure (cathode). The voltage (and resultant current) is merely the potential difference of the two different types of metal.

- The second method of cathodic protection is applying a source of DC current that forces the current to flow from an installed anode(s) to the structure, causing the entire structure to be a cathode. This method is called **impressed current cathodic protection**. A rectifier, solar cell, battery, generator, or some other DC power supply is installed in the circuit. The current required for cathodic protection depends upon the metal being protected and the environment.. To achieve these protective potentials, current must flow from the anode to the structure being protected. **The amount of current required to protect a given structure is proportional to the area of the structure that is exposed to the electrolyte.**

The current are usually in current densities in units of amperes or milliamperes per square meter (foot) of exposed surface. Coatings are dielectric in nature, and to some degree, isolate the structure from the electrolyte.

For coated structures, the amount of current required is much lower than for bare structures, as only those areas where the coating has been damaged or has deteriorated require or will receive current. The coating efficiency is the percent of the structure that is effectively isolated from the electrolyte. Efficiencies of coatings can vary greatly due to the type of coating, quality of surface preparation, quality of application, structure handling, structure installation, backfill techniques, and backfill material used. The cathodic protection depend on the metal being protected and the environment.

	MILLIAMPERES	**MILLIAMPERES**
ENVIRONMENT	**PER METER^2**	**PER FOOT^2**
Soil with resistivity >30,000 ohm-cm	10.7– 21.5	1- 2
Soil with resistivity 10,000 — 30,000 ohm-cm	21.5– 32.3	2- 3
Soil with resistivity 1,000 — and 10,000 ohm-cm	43.0– 64.6	4- 6
Soil with resistivity <1,000 ohm-cm	75.3– 269.1	7- 25
Highly aggressive soil with anaerobic bacteria	161.5– 430.5	15- 40
Still fresh water	21.5– 43.0	2- 4
Moving fresh water	43.0– 64.6	4- 6
Turbulent fresh water	53.8– 161.4	5- 15
Hot fresh water	53.8– 161.4	5- 15
Still seawater	10.7– 32.3	1- 3
Moving seawater	32.3– 269.1	3- 25
Concrete	5.4– 16.1	0.5– 1.5

TABLE NO.1

The **current densities** required **for cathodic protection of bare steel structures**

Data are from 'Design, Installation, Operation and Maintenance of Impressed Current deep Ground beds, NACE RP-05-72-95'

	MILLIAMPERES/ m^2 (FOOT^2)		
STRUCTURE	**BARE**	**COATED**	**COATING EFFICIENCY**
Pipeline, epoxy or other high performance coating	10.76(1)	0.010–0.054(0.001–0.005)	99.5 - 99.9
Pipeline, reinforced coal tar or asphalt enamel	10.76(1)	0.054–0.269(0.005–0.025	97.5 - 99.5
Pipeline, grease coating with Wrapper	10.76(1)	0.538–1.615(0.05–0.15)	85.0 - 95.0
Pipeline, asphalt mastic ½" Thick	10.76(1)	0.001–0.005(0.001–0.005)	99.5 - 99.9
Pipeline, old asphalt or other deteriorated coating	10.76(1)	0.538–3.767(0.05–0.35)	65.0 - 95.0
Pipeline, old paint coating	10.76(1)	1.076–0.522(0.10–0.30)	70.0 - 90.0
Steel sheet piling sea water side	53.82(5)	1.076–21.529(0.10–2.00)	60.0 - 98.0
Tank bottoms	32.29(3)	0.538–21.529(0.05–2.00)	33.3 - 98.3

TABLE NO.2

The **current densities** required **for cathodic protection of coated steel structures**

Data are from 'Design, Installation, Operation and Maintenance of Impressed Current deep Ground beds, NACE RP-05-72-95'

4.1 **GALVANIC CATHODIC PROTECTION.** In galvanic anode systems, the current required for cathodic protection is supplied by the corrosion of an active metal. Sacrificial anode systems depend upon the differences in corrosion potential that are established by the corrosion reactions that occur on different metals or alloys. the two metals are electrically connected, the potential difference between the iron and the zinc is approximately 0.5 to 0.7 volts DC, and the corrosion of the zinc becomes the source of current and prevents corrosion of the iron cathode.

Zinc, Magnesium, and Aluminum alloys all have potentials that are sufficiently more negative than iron or steel and may be useful for the protection of those structures in many environments. Other metals such as copper and copper alloys have a lower potential than iron or steel and are easily protected by steel (and many other metals). Materials such as aluminum alloys that have a higher potential than iron or steel are more difficult to protect, but even aluminum alloys can be effectively protected by magnesium alloys or commercially pure magnesium. In the process of providing electrons for the cathodic protection of a less active metal, the more active metal (anode) corrodes.

The more active metal (anode) is sacrificed to protect the less active metal (cathode). The amount of corrosion is dependent on the metal being used as an anode and is directly proportional to the amount of current supplied. Another factor is the anode efficiency, which accounts for the anode's self-corrosion rate. To provide a uniform electrolyte around an anode in soil, maintain moisture, and lower the resistance of anode-to-earth, a special backfill is used. **This backfill is normally 75 percent gypsum, 20 percent bentonite, and 5 percent sodium sulfate.** The anodes in galvanic cathodic protection systems must be periodically inspected and replaced when consumed.

For the protection of underground structures such as pipelines, the anodes are not usually attached directly to the structure, but are placed in the soil, evenly distributed a short distance from the pipeline, and are connected to the pipeline by a wire, usually through a test station.

The application of **galvanic anodes is limited** by the small potential difference **normally less than 1 volt DC**. Galvanic systems generally can only be economically used on small or well-coated structures in low resistivity electrolytes. Since the amount of cathodic protection is dependent on the current density supplied to the protected structure, the **electrolyte resistivity determines the amount of current that the limited voltage** will supply. **The amount of metal exposed to the electrolyte determines the amount of current required.** Uncoated (bare) structures may require number of anodes for adequate protection. In higher resistivity electrolytes, the small anode-structure voltage difference would yield (Ohms law) an extremely small amount of anode current, hence requiring a large amount of anodes. High purity magnesium anodes have the highest potential available, but in high resistivity soil there would not be sufficient current to protect a structure unless it had a very good coating.

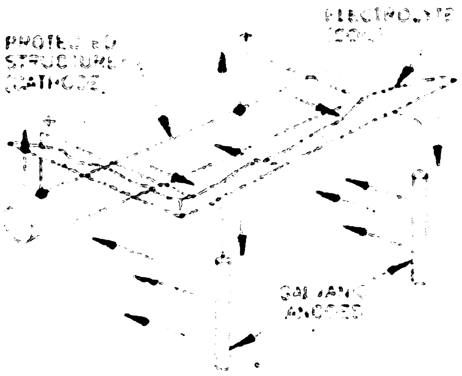

FIGURE NO.2

Galvanic Anode CP system

4.1.1 Advantages and Disadvantages of Galvanic Anode Systems

4.1.1.1 Advantages

- Economically feasible when installed with the structure.
- Very little operation or maintenance requirements (very small chance of premature failure or breakdown).
- Extremely small possibility of overprotection (which may cause coating damage or hydrogen embrittlement).
- Small likelihood of stray current causing interference damage to other metallic (foreign) structures.

4.1.1.2 **Disadvantages**

- Small driving voltage available (limited potential difference).
- Extremely small current available in higher resistivity electrolytes.
- Not economically feasible to install or replace anodes on large or extensive existing structures.

4.2 **IMPRESSED CURRENT CATHODIC PROTECTION.** Impressed current system, the protective current is supplied by a rectifier (or other DC power source) instead of by the natural potential difference of the anode to the structure. potential difference between the anode and cathode is forced from a non-reactive anode bed by the action of additional energy from a rectifier to force the electron flow that would be normally produced in the corrosion reaction. The effect of these electrons at the structure being protected is the same as that derived from the sacrificial anode type of cathodic protection system. However, the anode material serves only as a source of electrons and anodic (oxidation) electrochemical reactions. impressed current cathodic protection system anodes materials such as graphite, high silicon cast iron (HSCI), platinum or mixed metal oxide, are used for because they are slowly consumed (they have a very low kilogram (pound) per amp year weight loss). To provide a uniform electrolyte, a lower resistance to earth, and venting of gases and acids, a special backfill is used. This earth contact backfill is normally coke breeze or calcined fluid petroleum coke. Impressed current system anode leads must have a special insulation to preclude the copper lead wire from becoming part of the anode system. Since the power source is forcing everything connected to the positive terminal to act as an anode (and corrode) any defect or nick in the insulation of the anode lead wire would result in copper metal loss ending in failure of the anode system

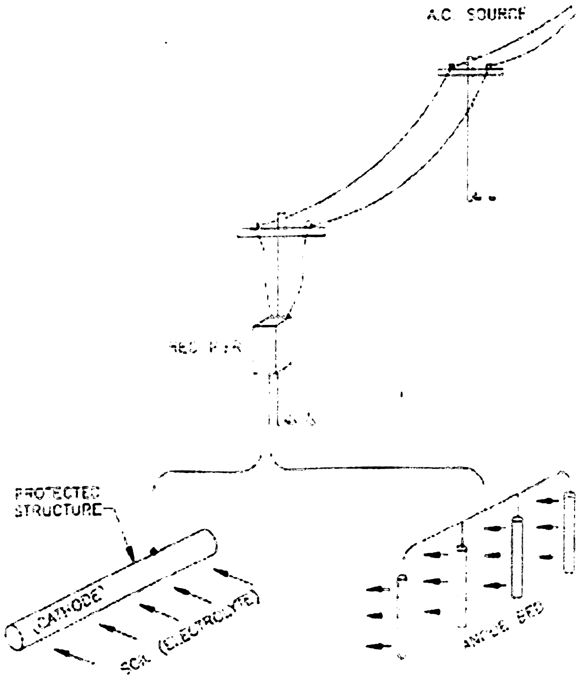

FIGURE NO.3

Impressed Current CP Systems.

4.2.1 **Type of Impressed Current Anode Bed**

4.2.1.1 **Vertical Remote Impressed Current CP Systems**. These systems are commonly used for pipelines in remote areas. Vertical placement of the anodes in the earth tends to lower the total resistance to earth of the system (versus horizontal). The distance to remote earth varies according to the resistivity of the earth, usually **91 to 213 meters (300 to 700 feet).** Soil resistivity testing should be done in the area of a proposed anode bed to locate an area of low resistance to place the anodes. Care must be taken to ensure that that low resistance area is not continuous to the protected structure. Poor current distribution may occur if this condition occurs.

In some cases, the best location for an anode bed may be in higher resistivity earth. The resistance of the anode bed can be lowered by adding additional anodes, using longer anodes, or by increasing the spacing of the anodes.

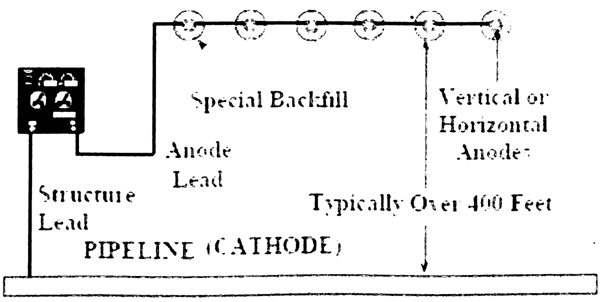

FIGURE NO.4

Vertical Impressed Current Cathodic Protection System

4.2.1.2 **Horizontal Remote Impressed Current CP Systems.** These systems are commonly used for pipelines in remote areas where a rock stratum is located near the surface or where other soil conditions would require horizontal installation to ensure the anode is in a uniform environment. This is usually the most economical choice when there are not other utilities in the area, and there is a rock strata near the surface. Horizontal placement of the anodes in the earth tends to raise the total resistance to earth of the system (versus vertical). The distance to remote earth varies according to the resistivity of the earth, usually **91 to 213 meters (300 to 700 feet).** Soil resistivity testing can be done in the area of a proposed anode bed to locate an area of low resistance to place the anodes. Care must be taken to ensure that the low resistance area is not continuous to the protected structure. Poor current distribution may occur if this condition occurs.

In some cases, the best location for an anode bed may be in higher resistivity earth. The resistance of the anode bed can be lowered by adding additional anodes, using longer anodes, or by increasing the spacing of the anodes. The anodes may have individual leads connected to a header cable or they may be installed on a continuous cable.

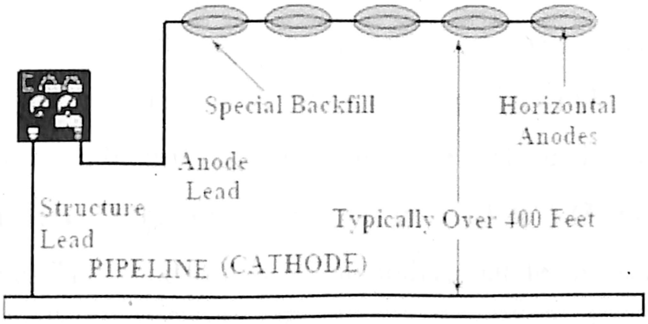

FIGURE NO.5

Horizontal Impressed Current Cathodic Protection System

4.2.1.3 **Distributed Impressed Current CP Systems**. These systems are commonly used to protect small structures. This is usually the most economical choice when the structure is small or the anodes cannot be placed in remote earth. This type of anode bed is used to protect water tank interiors, ground level tank bottoms, underground storage tanks, or a short pipeline. Anodes are distributed along the pipeline, or around the surface of the tank (interior for water tanks, exterior for underground tanks). The distance from the structure is normally **1.5 to 3 meters (5 to 10 feet)**, and the distance between anodes is normally double that distance **(3 to 6 meters [10 to 20 feet]).**

In some cases, the anode is continuous, and is placed in a grid pattern on tanks, or along the side of a pipeline.

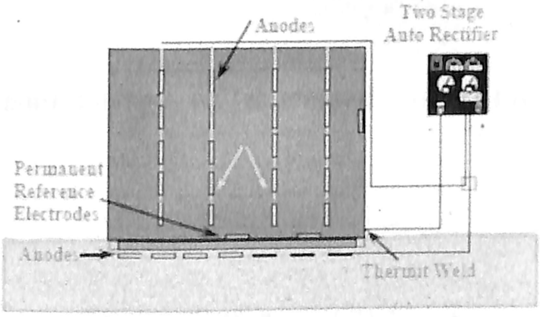

FIGURE NO.6

Anode Grid Pattern

4.2.1.4 **Deep Remote Impressed Current CP Systems**. These systems are commonly used to protect large structures in built up areas. This is usually the most economical choice when the structure is large, in an area with many other utilities, or the anodes cannot be placed near the surface. This type of anode bed is used to protect pipeline distribution systems, aboveground tank farms, and pipelines in built-up areas. The anodes are placed in remote earth by drilling deep below the surface. The typical deep anode bed is **30.5 meters (100 feet)** to the top anode, and from **61 to 183 meters (200 to 600 feet)** to the bottom anode. The anodes can be on individual leads, spaced on a continuous cable, or be a continuous anode wire. This type of anode bed can have a much higher current capacity than typical surface anode systems. This type of system minimizes interference to other metallic structures. This system requires special consideration for backfill, cable insulation, and venting.

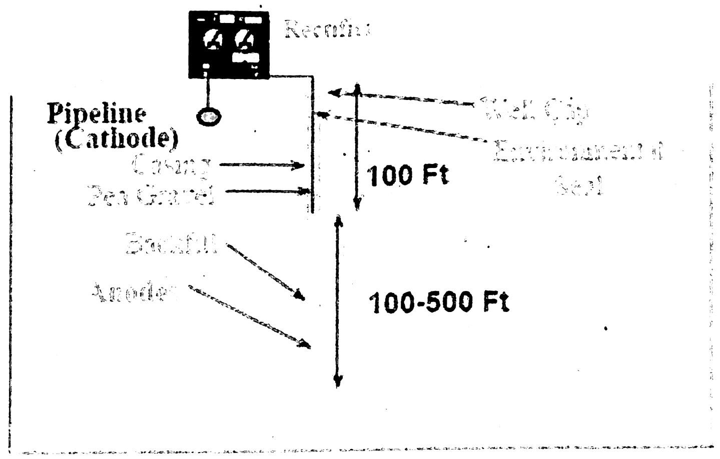

FIGURE NO.7

Continuous Anode Pattern

4.2.2 Advantages and Disadvantages of Impressed Current Anode Systems

4.2.2.1 Advantages:

- Economically feasible when installed on existing structures.
- Large voltage available (potential difference limited only by the size of power supply).
- Large current available, even in very high resistivity electrolytes.

- Can provide sufficient current to protect very large, poorly coated, or uncoated structures.
- Economically feasible to replace anode system when required.

4.2.2.2 **Disadvantages**:

- Significant operation and maintenance requirements.
- Relatively large chance of premature failure or breakdown.
- Possibility of stray current causing interference damage to other metallic (foreign) structures.

CHAPTER 5

CATHODIC PROTECTION DESIGN METHODOLOGY

Required information:

Before deciding which type, galvanic or impressed current, cathodic protection system will be used and before the system is designed, certain preliminary data must be gathered.

a. Physical dimensions of structure to be protected.

One important element in designing a cathodic protection system is the structure's physical dimensions (for example, length, width, height, and diameter). These data are used to calculate the surface area to be protected.

b. Drawing of structure to be protected.

The installation drawings must include sizes, shapes, material type, and locations of parts of the structure to be protected.

c. Electrical isolation.

If a structure is to be protected by the cathodic system, it must be electrically connected to the anode, as figure 1-2 shows. Sometimes parts of a structure or system are electrically isolated from each other by insulators. For example, in a gas pipeline distribution system, the inlet pipe to each building might contain an electric insulator to isolate in house piping from the pipeline. Also, an electrical insulator might be used at a valve along the pipeline to electrically isolate one section of the system from another. since each electrically isolated part of a structure would need its own Cathodic protection, the locations of these insulators must be determined.

d. Short circuits.

All short circuits must be eliminated from existing and new cathodic protection systems. A short circuit can occur when one pipe system contacts another, causing interference with the cathodic protection system. When updating existing systems, eliminating short circuits would be a necessary first step.

e. Corrosion history of structures in the area.

Studying the corrosion history in the area can prove very helpful when designing a cathodic protection system. The study should reinforce predictions for corrosivity of a given structure and its environment; in addition, it may reveal abnormal conditions not otherwise suspected. Facilities personnel can be a good source of information for corrosion history.

f. Electrolyte resistivity survey.

A structure's corrosion rate is proportional to the electrolyte resistivity. Without Cathodic protection, as electrolyte resistivity decreases, more current is allowed to flow from the structure into the electrolyte; thus, the structure corrodes more rapidly. As electrolyte resistivity increases. Corrosion rate decreases. Resistivity can be measured either in a laboratory or at the site with the proper instruments. Resistivity data will be used to calculate the sizes of anodes and rectifier required in designing the cathodic protection system.

g. Electrolyte pH survey.

Corrosion is also proportional to electrolyte. In general, steel's corrosion rate increases as pH decreases when soil resistivity remains constant.

h. Structure versus electrolyte potential survey.

For existing structures, the potential between the structure and the electrolyte will give a direct indication of the corrosivity. According to NACE Standard No. RP-01, the potential requirement for cathodic protection is a negative (cathodic) potential of at least 0.85 volt as measured between the structure and a saturated copper-copper sulfate reference electrode in contact with the electrolyte. A potential which is less negative than -0.85 volt would probably be corrosive, with corrosivity increasing as the negative value decreases (becomes more positive).

i. Current requirement.

A critical part of design calculations for cathodic protection systems on existing structures is the amount of current required per square foot (called *current density)* to change the structure's potential to -0.85 volt. The current density required to shift the potential indicates the structure's surface condition. A well coated structure (for example, a pipeline well coated with coal-tar epoxy) will require a very low current density (about 0.05 milliampere per square foot); an uncoated structure would require high current density (about 10 milliamperes per square foot). The average current density required for cathodic protection is 2 milliamperes per square foot of bare area. The amount of current required or complete cathodic protection can be determined in three ways:

- An actual test on existing structures using a temporary cathodic protection setup.
- A theoretical calculation based on coating efficiency.
- An estimate of current requirements using tables based on field experience.

(1)the second and third methods above can be used on both existing and new structures.

(2) Current requirements can be calculated based on coating efficiency and current density (current per square foot) desired. The efficiency of the coating as supplied will have a direct effect on the total current requirement, as equation 1 shows:

$$I = (A)(I')(1.0-CE) \tag{1}$$

where I is total protective current, A is total structure surface area in square feet, I' is required current density, and CE is coating efficiency. Equation 1 may be used when a current requirement test is not possible, as on new structures, or as a check of the current requirement test on existing structures. Coating efficiency is directly affected by the type of coating used and by quality control during coating application. The importance of coating efficiency is evident in the fact that a bare structure may require 100,000 times as much current as would the same structure if it were well coated.

(3) Current requirements also can be estimated from table 1. The table gives an estimate of current, in milliamperes per square foot, required for complete cathodic protection. That value, multiplied by the surface area of the structure to be protected (in square feet) gives the total estimated current required. Caution should be used when estimating, however, as under- or overprotection may result.

j. Coating resistance.

A coating's resistance decreases greatly with age and directly affects structure-to-electrolyte resistance for design calculations. The coating manufacturers supply coating resistance values.

k. Protective current required.

By knowing the physical dimensions of the structure to be protected, the surface area can be calculated. The product of the surface area multiplied by current density obtained previously in *I* above gives the total current required.

l. The need for cathodic protection.

For existing structures, the current requirement survey (*I* above) will verify the need for a cathodic protection system. For new systems, standard practice is to assume a current density of at least 2 milliamperes per square foot of bare area will be needed to protect the structure. (However, local corrosion history may demand a different current density.) Cathodic protection also is required for underground piping systems located within 10 feet of steel reinforced concrete because galavanic corrosion will occur between the steel rebar and the widely is based on current density required and soil pipeline.

Determining type and design of Cathodic protection system

When all preliminary data have been gathered and the protective current has been estimated, the design sequence can begin. The first question to ask is: which type (galvanic or impressed current) cathodic protection system is needed? Conditions at the site sometimes dictate the choice. However, when this is not clear, we use the current density requirements. When current density requirement is low(less than 1mA/sq ft) we can use galvanic system and for higher current densities, we use impressed current system.

Impressed current Cathodic protection system

(1)Review soil resistivity.

As with galvanic systems, this information will contribute to both design calculations and location of anode ground bed.

(2) Review current requirement test.

The required current will be used throughout the calculations. The calculated current required to protect 1 square foot of bare pipe should agree with the values in table 1.

(3) Select anode. As with the galvanic system, the choice of anode is arbitrary at this time, economy will determine which anode is best. Table 2 gives common anode sizes and specifications. The anodes used most often are made of high silicon chromium-bearing cast-iron (HSCBCI). When impressed current-type cathodic protection systems are used to mitigate corrosion on an underground steel structure, the auxiliary anodes often are surrounded by a carbonaceous backfill. Backfill materials commonly used include coal coke breeze, calcined petroleum coke breeze, and natural graphite particles. The backfill serves three basic functions;

(a) it decreases the anode-to-earth resistance by increasing the anode's effective size.
(b) It extends the system's operational life by providing additional anode material
(c) It provides a uniform environment around the anode minimizing deleterious localized attack.

The carbonaceous backfill, however, cannot be expected to increase the groundbed life expectancy unless it is well compacted around the anodes. In addition to HSCBCI anodes, the ceramic anode should be considered as a possible alternative for long-term cathodic protection of water storage tanks and underground pipes in soils with resistivities less than 5000 ohm-centimeters. The ceramic anode consumption rate is 0.0035 ounce per ampere-year compared to 1 pound per ampere-year for HSCBCI anodes.

Anode weight (lb)	Anode dimensions (in.)	Anode surface size (in.)	Package area (sq ft)
12	1 x 60	1.4	10 x 84
44	2 x 60	2.6	10 x 84
60	2 x 60	2.8	10 x 84
110	3 x 60	4.0	10 x 84

TABLE NO.1

Weights and dimensions of selected circular high silicon chromium-bearing cast iron anodes

Data are from 'Technical manual, Electrical Design, Cathodic Protection, Department of the Army, 1985'

(4) Calculate number of anodes needed to satisfy manufactuere's current density limitations. Impressed current anodes are supplied with a recommended maximum current density. Higher current densities will reduce anode life. To determine the number of anodes needed to meet the current density limitations, use equation 2.

$N=I/I_1A_1$--2

Where N is number of anodes required, I is total protection current in milliamperes, A is anode surface area in square feet per anode, and I_1 is recommended maximum current density output in milliamperes.

(5) Calculate number of anodes needed to meet design life requirement. Equation 3 is used to find the number of anodes.

$N=L*I/1000*W$--3

Where N is number of anodes, L is life in years, and W is weight of one anode in pounds.

(6) Calculate number of anodes needed to meet maximum anode groundbed resistance requirements. Equation 4 is used to calculate the number of anodes required.

$R_a= \rho K/LN +\rho P/S$--4

where R is the anodes' resistance, D is soil resistivity in ohm-centimeters, K is the anode shape factor from table 3, N is the number of anodes, L is length of the anode backfill column in feet, P is the paralleling factor from table 4, and S is the center-to-center spacing between anode backfill columns in feet.

L d	K	L d	K
5	0.0140	20	0.0213
6	0.0150	25	0.0224
7	0.0158	30	0.0234
8	0.0165	35	0.0242
9	0.0171	40	0.0249
10	0.0177	45	0.0255
12	0.0186	50	0.0261
14	0.0194	55	0.0266
16	0.0201	60	0.0270
28	0.0207		

TABLE NO.2

Shape Functions (K) for Impressed Current C.P System Anode Where 'L' is Effective Anode Length and 'd' is the Anode Backfill Diameter

Data are from 'Technical manual, Electrical Design, Cathodic Protection, Department of the Army, 1985'

N	P	N	P
2	0.00261	14	0.00168
3	0.00289	16	0.00155
4	0.00283	18	0.00145
5	0.00268	20	0.00135
6	0.00252	22	0.00128
7	0.00237	24	0.00121
8	0.00224	26	0.00114
9	0.00212	28	0.00109
10	0.00201	30	0.00104
12	0.00182		

TABLE NO.3

Anode paralleling factor(F) for various number of anodes(N) installed in parallel.

Data are from 'Technical manual, Electrical Design, Cathodic Protection, Department of the Army, 1985'

(7) Select number of anodes to be used.

The highest number calculated by equation 2, 3 0r 4 will be the number of anodes used.

(8) Select area for placement of anode bed.

The area with the lowest soil resistivity will be chosen to minimize anode-to-electrolyte resistance.

(9) Determine total circuit resistance.

The total circuit resistance will be used to calculate the rectifier size needed.

(a) Calculate anode groundbed resistance.

Use equation 4.

(b) Calculate groundbed header cable resistance.

The cable is typically supplied with a specified resistance in ohms per 100 feet. The wire resistance then is calculated from equation 5.

R_w= (ohms/100ft)*L--5

Where L is the structure's length in feet.

(c) Calculate structure-to-electrolyte resistance using equation 6.

R_c=R/N---6

Where R is the structure-to-electrolyte resistance, R is the coating resistance in ohms per square feet and N is the coated pipe area in square feet.

(d) Calculate total circuit resistance.

To calculate the total resistance, R , equation 7 is used.

R_T=R_a+R_w+R_c--7

(10) Calculate rectifier voltage. Equation 8 is used to determine voltage output (V_{rec}) of the rectifier.

V_{rec}= I*R_T*150%---8

Where I is total protection current in amperes, R_T is total circuit resistance, and 150 percent is a factor to allow for aging of the rectifier stacks.

CHAPTER 6

CATHODIC PROTECTION SYSTEM FOR UNDERGROUND STEEL STORAGE TANK

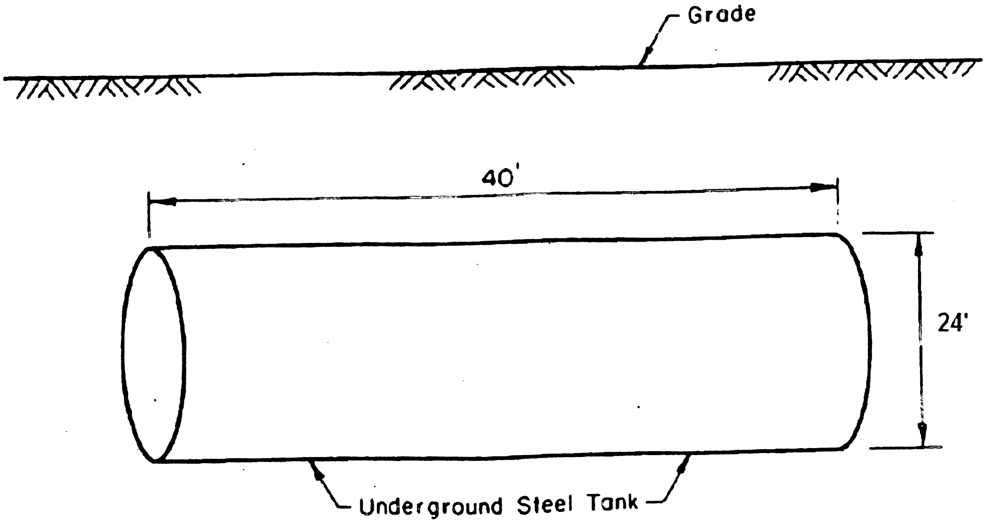

FIGURE NO.1

Underground Steel Storage Tank

Design data:

1. Tank diameter=24'.
2. Tank length=40'.
3. Design for 80% coating efficiency.
4. Design for 15 years life.
5. Anode used=HSCBCI anodes with carbonaceous backfill.
6. For bare metal, maximum protection current density=2mA/sq ft
7. Soil resistivity=2000ohm-cm
8. Anode bed not to exceed 2 ohm
9. Coating thickness=0.30"
10. Length of header cable used= 100' of No.2 AWG cable of resistance 0.0159 ohm/100ft
11. Recommended maximum current density for 12 lb HSCBCI anode=1000mA/sq ft
12. Coating resistance= 2500 ohm/sq ft.

Design calculations:

Surface area of tank= $\prod * \text{diameter} * \text{length} + \prod * \text{diameter}^2 * 2$

$= \prod * 24 * 40 + (\prod/4) * 24^2 * 2$

$= 3920.7$ sq ft

Total protection current required= $A * I' * (1 - C.E)$

$= 2 * 3920.7 * 0.2$

$= 1568.28$ mA

The number of anodes needed to meet the anode supplier's current density limitations,

$N = I / (A_1 I_1)$

$= 1568.28 / (1.4 * 1000)$

$= 1.12$

Thus N=2

Number of anodes required to meet lifetime requirement,

$N = L * I / 1000 * W$

$= 15 * 1568.28 / 1000 * 12$

$= 1.96$

Thus N=2

Number of anodes required to meet maximum anode ground bed resistance requirement,

$N = \rho K / L(R_a - \rho P / S)$

K=0.00270, for L/D=60

N = 2000*0.0270/7[2-(2000*0.00261/20)]

= 4.43

Thus N=5

Now for 5 anodes,

R_a= ρK/LN +ρP/S

= 2000*0.027/7*5 + 2000*0.00261/20

= 1.803 ohm

The ground bed resistance for a 100-foot header cable

R_w = (ohms/100 ft)(L)

R_w = (0.0159 ohm/100 ft)(100 ft)= 0.0159 ohm

Structure to electrolyte resistance,

R_c= R/N

N=coated area of the tank.

= ∏*24.05*40+ (∏/4)*24^2*2

= 3926.98 sq ft.

➔R_c= 2500/3926.98

= 0.63 ohm.

Total resistance,

R_T=R_a+R_w+R_c

= 1.803+0.0159+0.63

= 2.44 ohm

Rectifier voltage,

$V_{Rec}= I*R_T*150\%$

= 1.568*2.44*1.5

= 5.73 V

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The aim of this project was to design a cathodic protection system for an underground steel storage tank. Taking into consideration the corrosive environment surrounding the tank, an impressed current cathodic protection system using high silicon chromium-bearing cast iron anodes (HSCBCI) was seen to be best suited. From the design calculations, it was seen that a total of 5 anodes are required for efficient protection of the structure. The rectifier voltage required came out to be 5.73 V.

Impressed current system anode leads must have a special insulation to preclude the copper lead wire from becoming part of the anode system. Since the power source is forcing everything connected to the positive terminal to act as an anode (and corrode) any defect or nick in the insulation of the anode lead wire would result in copper metal loss ending in failure of the anode system.

There is possibility of stray current causing interference damage to protected structure, so special care has to be taken that other protected structures don't get affected.

CHAPTER 8

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