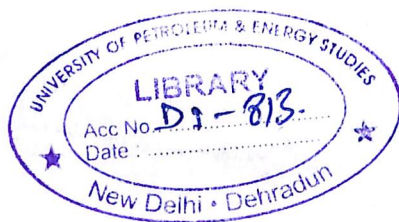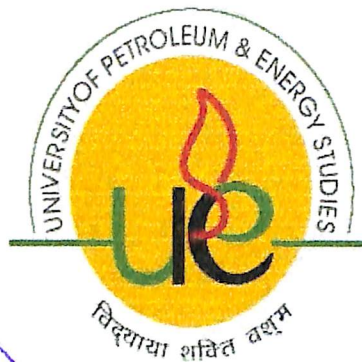# DESIGN OF CATHODIC PROTECTION IN NATURAL GAS PIPELINE

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## College of Engineering
## University of Petroleum & Energy Studies
## Dehradun
## May, 2008

# DESIGN OF CATHODIC PROTECTION IN NATURAL GAS PIPELINE

A thesis submitted in partial fulfillment of the requirements for the Degree of
Bachelor of Technology
(Gas Engineering)

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May, 2008

# CERTIFICATE

This is to certify that the work contained in this thesis titled **"DESIGN OF CATHODIC PROTECTION IN NATURAL GAS PIPELINE"** has been carried out by MR. GAURANG SWAMI under my supervision and has not been submitted elsewhere for a degree.

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# Acknowledgement

This report bears imprints of many people.

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At last I extend my thanks to all my colleagues who motivated me through the hard times and who were a constant source of help.

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**DEHRADUN**

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| cm | centimeter |
| CP | Cathodic protection |
| DOD | Department of Defense |
| gal | gallon |
| GN2 | gaseous nitrogen |
| HF | hydrofluoric acid |
| HNO3 | nitric acid |
| in | inch |
| IVD | ion vapor deposition |
| kg | kilogram |
| KSC | John F. Kennedy Space Center |
| Ksi | kips per square inch |
| MIL | military |
| m3 | cubic meter |
| mm | millimeter |
| MPa | mega Pascal |
| NACE | National Association of Corrosion Engineers |
| NH4HF2 | ammonium bifluoride |
| oz | ounce |
| psi | pounds per square inch |
| SCC | stress corrosion cracking |
| SPEC | specification |
| SSPC | Steel Structures Painting Council |
| STD | standard |
| TM | technical manual |
| UTS | ultimate tensile strength |
| M | micrometer |
| C | degree Celsius |

# NOMENCLATURE

S - Depth in meters. (Represented by spacing between electrodes (spikes))

R - Earth resistance in ohms

$S_a$ - Surface Area of Pipeline ($m^2$)

D - Diameter of Pipeline (m)

L - Length of Pipeline (m)

I - Current Output in Amps

V - Driving voltage of Mg. Anode (0.55 V)

$R_T$ - Total Circuit resistance in ohms

## SUBSCRIPTS

T – Total

a – Area

d – Density

m – Margin

f – Factor

# ABSTRACT

There are 3.5 million km of transmission pipelines around the world. This system has been providing safe reliable transport for hydrocarbons for 100 years. A large proportion of that pipeline system has reached, or will soon reach, the end of its design life. Many of the pipelines operate in harsh environments, transport corrosive products, and as a result have suffered extensive corrosion damage. The main advantage of cathodic protection over other forms of anti-corrosion treatment is that it is applied simply by maintaining a dc circuit and its effectiveness may be monitored continuously. Cathodic protection is commonly applied to a coated structure to provide corrosion control to areas where the coating may be damaged. It may be applied to existing structures to prolong their life. Therefore Cathodic Protection is required.

In this project work of mine I will be discussing about the corrosion, prevention, monitoring & cost of corrosion. Later we have discussed about the design considerations & design study of the data of BJPL pipeline of Gujarat State Petronet Ltd. In this project work the study is done for the detail design of TCP & PCP design for the 110.20 km pipeline Bharuch to Jamnagar comprising of 108 test station along the pipeline. In the result we want a design of PCP lasting for 40 years.

# 1. INTRODUCTION

## 1.1 PIPELINE SCENARIO IN WORLD

There are 3.5 million km of transmission pipelines around the world. This system has been providing safe reliable transport for hydrocarbons for 100 years. A large proportion of that pipeline system has reached, or will soon reach, the end of its design life. Many of the pipelines operate in harsh environments, transport corrosive products, and as a result have suffered extensive corrosion damage. Oil and gas reserves are predicted to last for another 40 to 60 years. Consequently, much of the worlds existing pipeline infrastructure will be required to continue operating for many years to come. Inspection and rehabilitation are therefore critical for ensuring continued, safe reliable operation.

## 1.2 PIPELINE NETWORK IN INDIA

The increasing energy demand driven by high economic growth has widened the demand supply gap. The demand of natural gas & crude oil has been rising because of former environment friendly nature, making it a competitive fuel & feed stock for power & fertilizer sectors & latter being a very efficient fuel. However with low level of indigenous production, there is a need for importing them in either the liquefied form or through the pipelines.

In our country the major players in pipeline are IOCL having a product pipeline network of about 6139 km & crude oil network of about 2813 km. In natural gas we have GAIL having a network of 4500 km, ONGC having a network of 810 km, GSPL having a network of 1134 km, ASSAM GAS having a network of 600 km & GGCL having a network of 73 km .The major natural gas pipelines are HBJ pipeline, South Bassein-Hazira, Gujarat gas grid & Northeast.

Presently 7890 km natural gas pipelines are under implementation stage by various pipeline operating companies which includes pipeline from KG basin at Kakinada to various part of India.

## HBJ Pipeline

The HBJ gas pipeline network was first cross country gas pipeline project that was commissioned to utilize the vast resources of natural gas in the country in order to strengthen the national economy & to improve the living standard of the people. The HBJ pipeline was initially designed to transport the 18.2 MMSCMD of natural gas. By providing additional compression facilities & laying a loop line of 505 km from Vijaipur to Dadri, the capacity has been expanded to 33.4 MMSCMD under gas rehabilitation & expansion project (GREP) at the cost of US$ 545 million. Today it supplies gas to the fertilizer & power plants enroute, besides providing opportunities for LPG plants, petrochemical complexes & city gas distribution at Delhi & industrial area at Agra & Ferozabad. Natural gas is being supplied to Mathura refineries under the Taj trapezium zone from the growing pollution.

The HBJ pipeline system passes through four states namely Gujarat, Madhya Pradesh, Uttar Pradesh & Rajasthan & also through different terrains, several road crossings, river crossings & canal crossings. The pipeline system consists of pipes of various sizes ranging from 18" to 36" diameter. Six compressor stations have been provided along the required locations along the HBJ pipeline for boosting up the pressure of the gas for efficient transmission & for meeting up the contractual pressure requirements of different customers.

## 1.3. PIPELINE CONSTRUCTION

### 1.3.1 MATERIAL

A broad picture is presented of the current worldwide scene and future plans for oil and gas pipelines. Notwithstanding recent events, oil and gas consumption will continue to expand. As exploration moves into more remote areas of the world, longer and larger diameter pipelines will be required. Such areas are climatically increasingly hostile, throwing great demands on the performance of pipeline materials and equipment. The challenge to the metallurgist to produce low cost pipeline materials with the requisite levels of strength, toughness and weld ability is being met. Developments in pipe steels technology which have been substantial during the past ten years will provide the basis for pipeline construction in the years ahead. The fracture behavior of pipelines has received considerable attention in recent years. As a fracture can be inadvertently initiated by earth moving machinery, pipeline design is usually based upon demanding fracture arrest criteria. Full scale tests have led the way to the development of effective laboratory scale assessment methods which now find wide use in quality control procedures. Offshore pipelines present additional problems to the engineer. Relatively thick wall pipes are required to resist buckling stresses during laying and collapse loads during operation in deep water. Apart from problems of attaining the necessary high levels of toughness in such thick wall pipes, the requirements of offshore pipelines are unlikely to present major new challenges to the metallurgist. Overall, the principal requirements are for quality, reproducibility and reliability at reasonable cost.

### 1.3.2 PIPELINE CONSTRUCTION PROCESS

Pipeline construction projects can span hundreds of miles or can consist of shorter connections linking a distribution center to a storage facility. Regardless of the length, the installation must be carefully choreographed to meet construction schedules and seasonal weather conditions.

1. In order to make the right-of-way into a suitable work area, a **clearing and grading** crew prepares the corridor so the construction equipment can operate safely.

2. Next, the mechanical excavation of a ditch, dug to a specified depth for pipe placement, is done by the **ditching** crew. Occasionally, rock drilling and blasting is required to break rock in a controlled manner. During the backfill operation, the pipe will be covered with the material excavated from the ditch.

3. After the pipe is delivered to the right-of-way, the contractor **"strings"** sections of steel pipe along the ditch that had previously been delivered to a central storage location.

4. A **bending** machine is used to tailor the shape of the pipe to conform to the contours of the terrain or to make changes in the direction of the line.

5. The pipe sections are cleaned and coated and the ditch bottom is cleared of rocks and debris or padded with soft dirt and the pipe is **lowered-in** to the ditch by side-boom tractors using belts or cradles in a carefully coordinated action.

6. The trench is then backfilled. When soil conditions are not suitable to be directly placed on the pipe, specialized equipment designed to pad the pipe and protect it from sharp rocks and abrasion is utilized.

7. The final phase of the construction involves replacing topsoil, replanting the right-of way, removing construction material, and restoring the area, as closely as possible, to its original pre-construction condition.

8. Completed pipelines must be tested to ensure they will operate at designated pressures without leaking. Pressure tests are usually conducted using water (hydrostatic). The test is carefully monitored and once completed, the pipe is cleaned and dried and ready to be put into service.

# 2. CORROSION PROCESSES, PREVENTION & MONTORING

## 2.1 WHAT IS CORROSION?

Corrosion is deterioration of essential properties in a material due to reactions with its surroundings. In the most common use of the word, this means a loss of an electron of metals reacting with water or oxygen. Weakening of iron due to oxidation of the iron atoms is a well-known example of electrochemistry (a branch of chemistry that studies the reactions that take place when an ionic and electronic conductor interfere) corrosion. This is commonly known as rust. This type of damage usually affects metallic materials, and typically produces oxide(s) and/or salt(s) of the original metal. Most structural alloys corrode merely from exposure to moisture in the air, but the process can be strongly affected by exposure to certain substances (see below). Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area to produce general deterioration. While some efforts to reduce corrosion merely redirect the damage into less visible, less predictable forms, controlled corrosion treatments such as passivation and chromate-conversion will increase a material's corrosion resistance.

## 2.2 ELECTROCHEMICAL THEORY

One way to understand the structure of metals on the basis of particles is to imagine an array of positively-charged ions sitting in a negatively-charged "gas" of free electrons. Columbic attraction holds these oppositely-charged particles together, but the positively-charged ions are attracted to negatively charged particles outside the metal as well, such as the negative ions (anions) in an electrolyte. For a given ion at the surface of a metal, there is a certain amount of energy to be gained or lost by dissolving into the electrolyte or becoming a part of the metal, which reflects an atom-scale tug-of-war between the electron gas and dissolved anions. The quantity of energy then strongly depends on a host of variables, including the types of ions in a solution and their concentrations, and the number of electrons present at the metal's surface. In turn, corrosion processes cause electrochemical changes, meaning that they strongly affect all of these variables. The

overall interaction between electrons and ions tends to produce a state of local thermodynamic equilibrium that can often be described using basic chemistry and knowledge of initial conditions.

## 2.3 CORROSION PROCESS

Corrosion process is the chemical reactions that those takes place at the surface of a metal & obey well-established chemical laws. The fact that the corrosion is a surface phenomenon means that its course may be controlled by the properties of corrosion product. The metal compound formed may act as a barrier layer increases with time: this is frequently observed in the reactions of metals with gaseous environments. If, however corrosion product may be removed from the site of reaction, the corrosion rate cannot be expected to diminish with time. This is the case soluble corrosion products are formed by the corrosion of certain metals and aqueous solutions.

All metals are prone to corrosive attack if the environment is sufficiently aggressive, e.g. noble metals are unaffected by most media, but they can be dissolved in aqua regia.

In practice, corrosion reactions are most undesirable as they effectively destroy metal or render it useless. For instance, steel girders will lose their strength & ultimately fail if rusting takes place extensively, water tanks made from steel will leak if only minute areas are destroyed by corrosion. It will be appreciated that the economic losses resulting from corrosion are very large & the methods of combating it are all expensive.

## 2.4 TYPES OF CORROSION

**General corrosion**

General corrosion is a uniform attack of the entire metal surface. It is least dangerous because of rates of corrosion can be measured & predicted.

## Galvanic corrosion

Galvanic corrosion occurs when two different metals are in electrical contact & immersed in the same corrosive solution.

## Erosion/abrasion corrosion

Erosion/abrasion corrosion is a combination of mechanical & corrosive attack. Abrasive particles in suspension, or high velocities, expose fresh metal surfaces which then suffer high rates of corrosion.

## Intergranular corrosion

Intergranular corrosion is due to the formation of chromium carbides at high temperatures (450 to 850 degree centigrade). These form preferentially at the grain boundaries thus reducing the chromium content & resulting in a path of lower corrosion resistance around the grains. With correct choice of material & care during fabrication this form of corrosion should not occur.

## Pitting corrosion

Pitting corrosion is dangerous, much localized form of corrosion which results in small holes or perforations through the material, but with little measurable general metal loss. Some corrosive environments have the ability to attack localized weak points in the passive film. Due care in the selection of material should be taken if aggressive ions are present, especially in acidic solutions at elevated temperatures. If conditions which promote pitting corrosion cannot be modified, materials with higher alloy content, such as the duplex stainless steels & the stainless alloys, will often give a solution to the problem.

## Crevice/shielded corrosion

Crevice/shielded corrosion occur where the surface is shielded or occluded thus preventing the free access & availability of oxygen to the surface. The passive film therefore tries to break down in these areas. Any conditions which give rise to crevice should be avoided.

## Microbiologically induced corrosion (MIC)

MIC results from the attraction & adherence of bacteria to the surface of the metal. A condition similar to the crevice is thereby produced. Certain bacteria produce aggressive metabolic products which aggravate the situation.

## Stress corrosion cracking (SCC)

Both pitting & crevice corrosion can lead to SCC under certain conditions. Stress corrosion cracking is a brittle fracture occurring in an otherwise ductile material.

The austenitic crystal structure is prone to SCC whereas the ferric crystal structure prevents its development.

SCC requires the three factors for development:

-The presence of tensile stress. This can be either applied or residual stress occurring as a result of the metal forming, fabrication & welding procedure.

-The minimum temperature – generally SCC does not occur less than 60 degree centigrade.

-The presence of a particular ion, e.g. the chloride ion. It is often difficult to even quantify the exact chloride concentration needed, but localized concentration of chlorides will often initiate SCC.

These three factors are synergistic to a degree. SCC is a process by which whereby initiation may take considerable time. However once the pit has been developed it acts as a local stress raiser, the pit yawns open & fresh

electrolyte reaches the anodic tip of the pit. Corrosion occurs locally at the tip of the pit where further yawning & possible branching occurs.

Eventually the progress of attack reaches such a degree that the yield stress of the material is exceeded due to the residual of sound material.

High resistance to SCC is obtained by the use of duplex stainless steels, stainless alloys & super ferritic material.

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## 2.5 CORROSION PREVENTION

### 2.5.1 EXTERNAL CORROSION

The principle methods to prevent external corrosion of pipelines are coatings & cathodic protection. In recent installations coatings & CP have normally been used together in a complementary fashion, since high quality coatings substantially reduce the CP current requirements & application of a functioning CP system allows some relaxation in the requirement for 100% holiday free coatings.

The NACE Standard RP0169-96 [1] lists most of desirable characteristics of a pipeline coating. These include the following:

- The coating should have a high electrical resistance & high dielectric strength.
- The coating must have an effective moisture barrier.
- The coating should have been reasonably easy to apply & the application process should not change the properties of the pipe.
- The coating should exhibit good adhesion to the pipe.
- The coating should be resistant to chemical & physical damage degradation during installation & service.
- The coating should be reasonably easily to repair in the field.
- The use of coating should not present any environmental or health risks.

Pipeline coatings have been used for more than 70 years & numerous systems have been developed. The coating systems that are currently being applied include the following:

- Coal tar enamels containing embebbed glass fibre mats.
- Mill-applied tape system.
- Extruded polyethylene & polypropylene coatings.
- Fusion-bonded epoxy coatings.
- Multilayer; FBE under Extruded polyethylene & polypropylene coatings.

The last three coating system listed above are reportedly currently experiencing increasing acceptance by customers & their future use should therefore expand.

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## 2.5.2 INTERNAL CORROSION

Internal corrosion in a pipeline requires the presence of liquid water within the line. In gas transmission system line, internal corrosion generally signals the presence of significant pressure of carbon dioxide & hydrogen sulphide in the transmission line.

One method to reduce the danger of internal corrosion by acid gases, carbon dioxide & hydrogen sulphide, is to reduce the concentration of acid gases in the gas transmission stream by a process known as "gas sweetening". Many gas sweetening process have been developed & used. These include, for example:

- Solid bed adsorption ( using iron sponge , molecular sieves or zinc Oxide),
- Chemical solvents (such as mono ethanol amine, di ethanol amine, potassium carbonate.
- Proprietary physical solvents ,
- Conversion of hydrogen sulphide .to sulphur
- Distillation

A second effective method used to prevent internal corrosion of gas transmission pipelines is thus dehydration of the gas prior to the introduction into the line. The aim of the dehydration process is to reduce the water content of the gas. To a low enough level that the water will not condense in the line under the lowest pressure & temperature that the gas will experience in the line.

By far most common dehydration process of natural gas involves contacting the gas with a hygroscopic liquid such as glycol. The most common glycol used for dehydration is the tri-ethylene glycol.

# 2.6 CORROSION MONITORING

Survey methods that are commonly used to evaluate the external corrosion conditions of pipelines include:

- Pipe-to-soil potential measurements (PSP) ,
- Soil resistivity measurements ,
- Measurements of D.C. currents flowing through the pipeline ,
- "Bell hole" examinations of the pipe.

Pipe –to –soil potential measurements are typically made using a saturated copper-copper sulfate (CSE) reference electrode that is placed in the soil directly over the line. The potential measurements are made with a high input impedance voltmeter. Hooking the negative terminal of the voltmeter to the CSE electrode & the positive terminal to the pipeline gives reading with the normally used sign convention.

In pipe – to –soil potential surveys of pipe that is not under cathodic protection, the points on the line with the largest negative potential values will normally be the areas with highest corrosion rates. Newly installed pipe , usually have pipe-to-soil potential that are more substantially more negative than older sections of line & the pipe-to-soil potential of new pipelines will usually tend to decrease in magnitude with the passage of time .

Soil resistivity measurements can be made either using either two terminal or four terminal meters. Ether an AC or DC power supply can be used in conjunction with an instrument that accurately measures the current & potential between the test electrodes. Four terminal instruments are usually used when larger soils are examined or when resistivity at a greater depths are desired.

Corrosion rates of buried pipes are generally higher in lower resistivity (higher conductivity) soils. Because of the possibilities of error caused by voltage drops in soil

due to the flow of CP currents, it is recommended that soil resistivity measurements be made with CP systems shut off.

Line current measurements are typically made using test stations that are installed at the time the pipe was laid. Electrical leads are connected to both ends of the pipe test span. The electrical resistance of the test span is either estimated or measured & the net electrical current in test span is calculated using ohm's law. The sign of the voltage drop indicates the direction of the current flow through the test span. In order to eliminate the effects of any active CP system, line current measurements should be made with those systems shut off.

The currents detected in the line currents measurements are "long-line" currents that are typically caused by widely separated "macro" electrodes or by interferences from "foreign" D.C. fields in the earth. Long-line currents are not caused by the local anodes & cathodes that produce the corrosion normally observed on the line. However, at locations where the pipe leaves the long line currents leave the pipe, the resulting corrosion rates can be very high.

# 2.7 COST OF CORROSION

### 2.7.1 PIPELINE ECONOMICS

| Line pipe (material) | Rs.35700/tonne |
|---|---|
| Coating costs | Rs.1050/m^2 |
| Compressor costs | Rs.75.6/kW |
| Construction costs | Rs.10500 + 4.8 x D (inches)/per meter |
| Horizontal directional drilling (HDD) | Rs.105 million per river crossing |
| Operations & maintenance costs | 1 percent of Capital expenditure (includes 0.3 percent insurance) |
| Construction of pipelines | 1.5 km / day per spread + 120 days for right of way , permitting, commissioning, etc. |

As almost all the fixed cost related to pipeline material are proportional to the pipeline diameter, there is significant opportunity in pipeline projects to improve the pipeline economics by increasing the pipeline diameter. The incremental steel cost will be proportional to the diameter of the pipe whereas the incremental flow will be proportional to the square of the diameter.

As a thumb rule the pipeline installation cost is derived as below:

Onshore pipeline = Rs.10, 50,000/inch. Diameter/Km.

Offshore pipeline = Rs.21, 00,000/inch. Diameter/Km.

## 2.7.2 CORROSION ECONOMICS

A recent review of the economic effects of corrosion on the U.S economy has been published. The result of this review indicates that the corrosion of metals & alloys costs U.S. companies a total cost of approximately $ 300 billion per year. It was also concluded that approximately one third of the total costs could be significantly reduced or eliminated by the use of current best available corrosion prevention techniques & materials.

In the review, it was estimated that the pipeline industry accounted for something less than 1 percent of the total industry wide corrosion costs. This would thus probably put the total costs for corrosion in pipeline industry somewhere in the range of $2 billion to $3 billion per year .It also seems thus possible that the use of improved materials & corrosion prevention techniques in the pipeline industry might reduce the total costs of corrosion in this industry segments by as much as $600 million to $900 million.

In case of the pipeline industry , as in several other industry segments , although the need for corrosion related repairs & recoating had apparently gone down in recent past , the savings due to the drop in repairs had been essentially balanced by the use of more expensive original materials of construction .

In our opinion, the development of more sensitive & more accurate inspection techniques & the possible regulatory requirement for the use of these more sensitive inspections techniques could substantially increase the repair cost associated with the future operation of aging gas transmission pipelines.

# 3. CATHODIC PROTECTION

## 3.1 PURPOSE

The purpose of cathodic protection (CP) is to provide corrosion protection to underground or submerged metallic structures, either bare or coated & exposed to soil or water through voids or "Holidays" in their dielectric coating. Critical structures which shall be evaluated for the necessity and compatibility of CP include underground piping systems.

## 3.2 WHAT IS CATHODIC PROTECTION?

Cathodic protection (CP) is a technique to control the corrosion of a metal surface by making that surface the cathode of an electrochemical cell. Cathodic protection systems are most commonly used to protect steel, water/fuel pipelines and storage tanks; steel pier piles, ships, offshore oil platforms and onshore oil well casings. A side effect of improperly performed cathodic protection may be production of molecular hydrogen, leading to its absorption in the protected metal and subsequent hydrogen embitterment. Cathodic protection is an effective method of preventing stress corrosion cracking.

## 3.3 ORIGINS

The first use of CP was in 1824, when Sir Humphrey Davy, of the British Navy, attached chunks of iron to the external, below water line, hull of a copper clad ship. Iron has a stronger tendency to corrode (rust) than copper and when connected to the hull, the corrosion rate of the copper was dramatically reduced. Davy found that he could preserve copper in seawater by the attachment of small quantities of iron, zinc or tin. The copper became, as Davy put it, "catholically protected". It was quickly abandoned because by protecting the copper its antifouling properties became retarded, hence reducing the streamline of the ships, as they began to collect marine growths.

The most rapid development of Cathodic protection was made in the United States of America and by 1945, the method was well established to meet the requirements of the rapidly expanding oil and natural gas industry, which wanted to benefit from the advantages of using thin-walled steel pipes for underground transmission.

In the United Kingdom, where low-pressure, thicker-walled cast iron pipes were used extensively, very little cathodic protection was applied until the early 1950s. The increasing use of cathodic protection in modern times has arisen, in part, from the initial success of the method as used from 1952 onwards to protect about 1000 miles of wartime fuel-line network. The method is now well established and is used on a wide variety of immersed and buried facilities and infrastructure, as well as reinforced concrete structures, to provide corrosion control.

## 3.4 THE PRINCIPLES OF CATHODIC PROTECTION

Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale. The change from the metallic to the combined form occurs by an "anodic" reaction:

$$M \longrightarrow M^+ + e^-$$
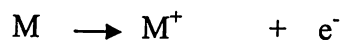
(Metal) (Soluble salt) (Electron)

A common example is:

$$Fe \longrightarrow Fe^{++} + 2e^-$$
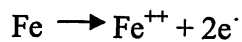
This reaction produces free electrons, which pass within the metal to another site on the metal surface (the cathode), where it is consumed by the cathodic reaction. In acid solutions the cathodic reaction is:

$$2H^+ + 2e^- \longrightarrow H_2$$

(Hydrogen ions in soln.) (gas)
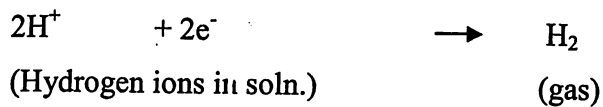
In neutral solutions the cathodic reaction involves the consumption of oxygen dissolved in the solution:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$
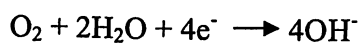
(Alkali)

Corrosion thus occurs at the anode but not at the cathode (unless the metal of the cathode is attacked by alkali).

The anode and cathode in a corrosion process may be on two different metals connected together forming a bimetallic couple, or, as with rusting of steel, they may be close together on the same metal surface.

This corrosion process is initially caused by:

Difference in natural potential in galvanic (bimetallic) couples .Metallurgical variations in the state of the metal at different points on the surface.

Local differences in the environment, such as variations in the supply of oxygen at the surface (oxygen rich areas become the cathode and oxygen depleted areas become the anode).

Electron (e-) flow in metal

$$2M \longrightarrow 2M^{++} + 4e^-$$

(Corrosion)

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$
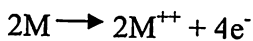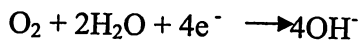
The principle of cathodic protection is in connecting an external anode to the metal to be protected and the passing of an electrical dc current so that all areas of the metal surface become cathodic and therefore do not corrode. The external anode may be a galvanic anode, where the current is a result of the potential difference between the two metals, or it may be an impressed current anode, where the current is impressed from an external dc power source. In electro-chemical terms, the electrical potential between the metal and the electrolyte solution with which it is in contact is made more negative, by the supply of negative charged electrons, to a value at which the corroding (anodic) reactions are stifled and only Cathodic reactions can take place. In the discussion that follows it is assumed that the metal to be protected is carbon steel, which is the most common material used in construction. The Cathodic protection of reinforcing carbon steel in reinforced concrete structures can be applied in a similar manner.

Cathodic protection can be achieved in two ways:

- By the use of galvanic (sacrificial) anodes, or

- By "impressed" current.

## 3.5 GALVANIC CP

Today, galvanic or sacrificial anodes are made in various shapes using alloys of zinc, magnesium and aluminum. The electrochemical potential, current capacity and consumption rate of these alloys are superior for CP than iron.

Galvanic anodes are designed and selected to have a more "active" voltage (technically a more negative electrochemical potential) than the metal of the structure (typically steel).

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For effective CP, the potential of the steel surface is polarized (pushed) more negative until the surface has a uniform potential. At that stage, the driving force for the corrosion reaction is halted. The galvanic anode continues to corrode; consuming the anode material until eventually it must be replaced. The polarization is caused by the current flow from the anode to the cathode. The driving force for the CP current flow is the difference in electrochemical potential between the anode and the cathode.

A **sacrificial anode**, or **sacrificial rod**, is a metallic anode used in a cathodic protection where it is intended to be dissolved to protect other metallic components.

More scientifically, a sacrificial anode can be defined as a metal that is more easily oxidized than the protected metal. Electrons are stripped from the anode and conducted to the protected metal, which, for this reason, is forced to become the cathode. As a result, the protected metal is prevented from corroding.

For example when zinc and iron are put together (in contact) in the presence of oxygen, the zinc and iron will lose electrons at the same time. However, as iron is less reactive than zinc, it tends to replace its own lost electrons with electrons from the zinc. Therefore, iron acts as a neutral atom and zinc as a cation (positive ion) and reacts with oxygen; the iron is "safe" until all of the zinc has corroded.

One example is the galvanic anode used in a cathodic protection system, where the intended purpose is to prevent corrosion of the protected metal (such as a ship's hull, an oil pipeline, or a hot-water heater's tank) by being less electronegative than the desired metal. Commonly used metals for such protective purposes are zinc, aluminum and magnesium. Another example is the anode in an electroplating process, whereby the metal from the anode replaces the metal depleted from the plating solution as it is deposited on the cathode.

## 3.6 IMPRESSED CURRENT CP

For larger structures, galvanic anodes cannot economically deliver enough current to provide complete protection. Impressed Current Cathodic Protection (ICCP) systems use anodes connected to a DC power source (a cathodic protection rectifier). Anodes for ICCP systems are tubular and solid rod shapes or continuous ribbons of various

specialized materials. These include high silicon cast iron, graphite, mixed metal oxide, platinum and niobium coated wire and others.
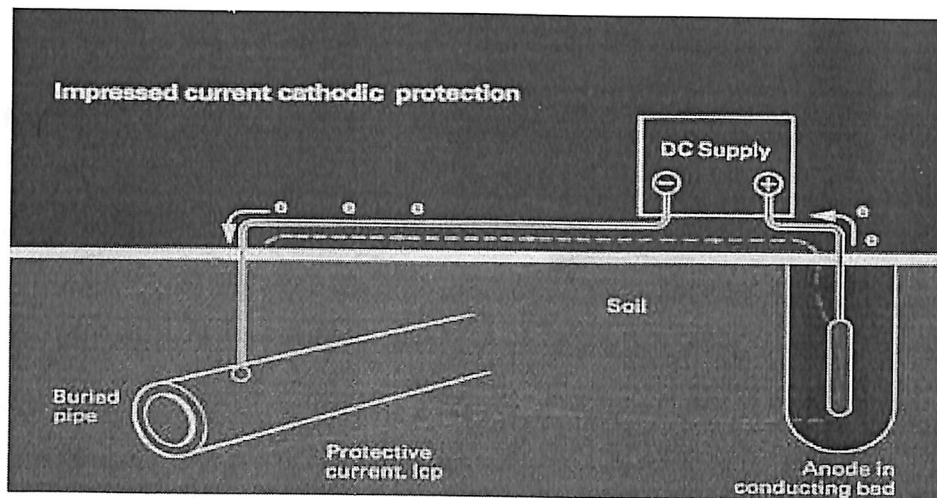


Fig.3.1

A typical ICCP system for a pipeline would include an AC powered rectifier with a maximum rated DC output of between 10 and 50 amperes and 50 volts. The positive DC output terminal is connected via cables to the array of anodes buried in the ground (the anode groundbed). For many applications the anodes are installed in a 60 m (200 foot) deep, 25 cm (10-inch) diameter vertical hole and backfilled with conductive coke (a material that improves the performance and life of the anodes). A cable rated for the expected current output connects the negative terminal of the rectifier to the pipeline. The operating output of the rectifier is adjusted to the optimum level by a CP expert after conducting various tests including measurements of electrochemical potential.

Telephone wiring uses a form of cathodic protection. A circuit consists of a pair of wires, with forty-eight volts across them when the line is idle. The more positive wire is grounded, so that the wires are at 0 V and -48 V with respect to earth ground. The 0 V wire is at the same potential as the surrounding earth, so it corrodes no faster or slower than if it were not connected electrically. The -48 V wire is cathodically protected. This means that in the event of minor damage to the insulation on a buried cable, both copper conductors will be unaffected, and unless the two wires short together, service will not be interrupted.

If instead the polarity were switched, so that the wires were at 0 V and +48 V with respect to the surrounding earth, then the 0 V wire would be unaffected as before, but the +48 V wire would quickly be destroyed if it came into contact with wet earth. The electrochemical action would plate metal off the +48 V wire, reducing its thickness to the point that it would eventually break, interrupting telephone service. This choice of polarity was not accidental; corrosion problems in some of the earliest telegraphy systems pointed the way.

## 3.7 ADVANTAGES AND USES OF CATHODIC PROTECTION

The main advantage of cathodic protection over other forms of anti-corrosion treatment is that it is applied simply by maintaining a dc circuit and its effectiveness may be monitored continuously. Cathodic protection is commonly applied to a coated structure to provide corrosion control to areas where the coating may be damaged. It may be applied to existing structures to prolong their life.

Specifying the use of cathodic protection initially will avoid the need to provide a "corrosion allowance" to thin sections of structures that may be costly to fabricate. It may be used to afford security where even a small leak cannot be tolerated for reasons of safety or environment. Cathodic protection can, in principle, be applied to any metallic structure in contact with a bulk electrolyte (including concrete). In practice, its main use is to protect steel structures buried in soil or immersed in water. It cannot be used to prevent atmospheric corrosion on metals.

However, it can be used to protect atmospherically exposed and buried reinforced concrete from corrosion, as the concrete itself contains sufficient moisture to act as the electrolyte.

Structures that are commonly protected by cathodic protection are the exterior surfaces of:

- Pipelines
- Ships hulls
- Storage tank bases
- Jetties and harbor structures
- Steel sheet, tubular and foundation pilings
- Offshore platforms, floating and sub sea structures

Cathodic protection is also used to protect the internal surfaces of:

- Large diameter pipelines

- Ship's tanks (product and ballast)

- Storage tanks (oil and water)

- Water-circulating systems.

However, since an internal anode will seldom spread the protection for a distance of more than two to five pipe diameters, the method is not usually practical, or suitable, for the protection of small-bore pipe work. Cathodic protection is applied to control the corrosion of steel embedded in reinforced concrete structures (bridges, buildings, port and harbor structures, etc.) Cathodic protection can be applied to copper-based alloys in water systems, and, exceptionally, to lead-sheathed cables and to aluminum alloys, where cathodic potentials have to be very carefully controlled.

# 4. BASIC REQUIREMENTS & DESIGN BASIS FOR CATHODIC PROTECTION

## 4.1 BASIC REQUIREMENTS

The essential features of cathodic protection to metals that are surrounded by a conducting electrolyte, in each of the two types of system are as follows:

**a)** A galvanic system requires:

i) Sacrificial anodes

ii) Direct welding to the structure or a conductor connecting the anode to the structure

iii) Secure and minimum resistance connections between conductor and structure, and between conductor and anode.

**b)** An impressed-current system requires:

i) Inert anodes (clusters of which, connected together often in a backfill, are called the "groundbed").

ii) A dc power source.

iii) Electrically well insulated, minimum resistance and secure conductors between anodes and power source.

iv) Secure and minimum resistance connections between power source and structure.

In both cases, fundamental design decisions must be made to select the type of system and the most suitable type of anode appropriate to that system. Also required, is the determination of the size and number of the power sources, or sacrificial anodes, and their distribution on the structure.Other requirements that must be met to ensure that Cathodic protection is applied in the most economic and reliable manner are:

**a)** Electrical continuity. The resistance of the conductor and structure should be such as to minimize the potential drop of the return protective currents through the structure.

**b)** Coatings. The provision of a protective/insulating coating to the structure will greatly reduce the current demanded for cathodic protection of the metallic surface. The use of a well-applied and suitable coating, increases the effective spread of cathodic protection current. A combination of applying both a coating and cathodic protection will normally results in the most practical and economic overall protection system. Ideal coatings are

those that have a high electrical resistance, are continuous and will adhere strongly to the surface to be protected. Other desirable coating characteristics include; stability in the environment, abrasion resistance, and compatibility with the alkaline environment created or enhanced by cathodic protection.

**c)** Structure isolation. It is often desirable to limit the spread of cathodic protection. For pipelines and tanks, this may be achieved by the insertion of monolithic electrical isolation joints in the structure. Insulating flange kits are sometimes used though they often require regular maintenance. Polarization cells that restrict low voltage cathodic protection dc currents, but allow passage of high voltage ac currents, may be used to isolate low-resistance earthing systems from a well-coated protected structure.

**d)** Test facilities. It is important to consider the location of test facilities, test stations, corrosion monitoring coupons, permanent half cells (reference electrodes), and the manner that data can be routinely collected or viewed.

## 4.2 Types of equipment

Various galvanic anode alloys of magnesium, aluminum or zinc are available in a variety of block, rod or wire forms. These alloys are cast around steel inserts to enable fixing of the anode and to maintain electrical continuity and mechanical strength towards the end of the anode life. The insert may be directly welded or bolted to the structure to be protected, or

Anodes may be connected to the structure by means of an insulated lead, usually of copper, as for onshore and offshore pipelines. Impressed-current ground beds in soils have traditionally consisted of high-silicon cast iron. However, mixed metal oxide (MMO) anodes are becoming increasingly popular for all environments because of their good mechanical and electrical characteristics and compact size. For seawater applications and areas where chlorides are present, MMO anodes work well as do high-silicon cast iron alloyed with chromium. Other anodes consist of lead alloy and platinum formed in a thin layer on a titanium or niobium base There are many possible sources of dc power; the most popular is the selenium plate or silicon-diode rectifier with transformer unit in conjunction with an existing ac supply or diesel- or gas engine-driven

alternator. For most applications, a constant dc voltage or constant current systems are used. In remote areas, power sources include thermo- electric generators, closed-cycle vapor turbines, and solar or wind generators. The latter two are used in conjunction with lead acid or similar storage batteries. The choice is dependent on power requirements, maintenance capabilities, and environmental conditions. There are also automatic control units available that will adjust current output in accordance with potential changes at a half cell.

TABLE 4.1

| Type of T.L.P | Function |
|---------------|----------|
| A | Simple |
| B | Simple |
| C | Foreign line |
| D | Casing |
| E | Insulation junction ( I . J.) |
| G | Simple |
| H | High tension |
| I | Simple |

## 4.3 DESIGN FACTORS

### Initial considerations

Modifications to the structure to incorporate requirements, such as those discussed in section 5, are best made at the early design and pre-construction phase of the structure. For underground structures it may be necessary to visit the proposed site, or for pipelines the proposed route, to obtain additional information on low-resistivity areas, availability of electric power, and the existence of stray dc current or other possible interaction. It is common practice for a survey to be made before design.

This survey is often combined with a study to establish economic justification for the recommended anti-corrosion proposal while the principal data necessary for design (chemical and physical) are also collected.

If the structure already exists, measurement of existing structure-to-soil potentials is essential to give valuable information as to which areas are anodic and which are cathodic. In addition, with the application to the structure of temporary cathodic-protection current, using any convenient dc

Source and a temporary anode system (groundbed), a more accurate assessment of current demand and the likely spread of protection to the structure may be assessed.

Design of a cathodic-protection system for a new structure should include the calculation of:

-Current demand

-Resistance to earth of the anodes

-Quantity and location of anodes or anode systems

-Electrical supply requirements

-Test and monitoring facilities.

In the case of onshore pipelines and other structures, negotiation with landowners, public authorities, or other interested parties, for easements and way leaves for groundbeds, cable routes, transformer-rectifier sites, and electricity supplies should also be undertaken at the design stage.


## Potential level and distribution

In practice, the structure-to-electrolyte potentials are measured using a standard half-cell (reference electrode). For example, a common protection criterion used for steel in an aerobic electrolyte of nearly neutral pH is a negative value of minus 850 mV. When exposed to sulphate-reducing bacteria, steel would require a more negative potential of minus 950 mV. Both values are with respect to a copper/copper sulphate half-cell. Ideally, to attain a high degree of accuracy and in order to minimize measurement errors, the half-cell should be very close to the surface at which the potential is being measured.

The potential values measured on a cathodically protected structure will be dependent on the anodic and cathodic reactions, structural geometry, and internal electrical resistance. However, the provision of a protective coating will have by far the greatest effect on the potential for a given applied current. The potentials will generally be most negative at a point nearest to the anode or groundbed and, for pipelines, will attenuate towards the natural corrosion potential as the distance from the anode or groundbed increases.

An example of potential attenuation is that, in the case of a power-impressed system, a single cathodic-protection installation may supply cathodic protection to as much as 150 km of extremely well coated pipeline, whereas for similar sizes of bare (uncoated) pipelines it may be necessary to have installations at only 2 km intervals.

## 4.4 ECONOMICS OF DECISIONS

At the design stage of a cathodic-protection scheme, a decision must be made as to whether the scheme will be a galvanic or impressed-current system. In specific circumstances, the use of both types of systems may be appropriate, but care is required to avoid interaction between them.

Galvanic systems have the advantage of being –

**a)** Simple to install

**b)** Independent of a source of external electric power

**c)** Suitable for localized protection

**d)** Less liable to cause interaction on neighboring structures.

However, the current output available from the practical size and weight of galvanic anodes is relatively small and depends principally on the electrical resistivity of the electrolyte (local environment if buried / submerged / concrete). Thus, galvanic anodes of aluminum and zinc, which have similar driving emfs to steel of approximately 0,5V, are limited to use in electrolytes of less than 5 Ohm-m resistivity. The anodes are usually self regulating because their current output is usually less than their maximum output capability and is controlled by the difference in potential between the two metals. The current from the anodes is not normally controllable; thus changes in the structure, such

as the deterioration of a coating, that causes an increase in protection current demand, may necessitate the installation of further sacrificial anodes to maintain protection. Impressed-current installations have the advantage of being –

a) Able to supply a relatively large current

b) Able to provide of high dc driving voltages (up to 50V).Enables it to be used in most types of electrolytes

c) Able to provide a flexible output that may accommodate changes in, and additions to, the structure being protected .Generally, however, care must be taken in the design to minimize interaction on other structures and, if no ac supply is available, an alternative power source (solar, diesel, etc.) is required. Impressed current systems require regular maintenance and monitoring.

Generally, galvanic systems have found favor for small well coated, low current demand, structures or for localized protection. Impressed current schemes are utilized for large complex structures, which may be of bare metal or poorly coated. However, in North Sea offshore work, it has been found cost effective to provide galvanic protection to large uncoated platforms, and similar structures, where the initial cost of coating and the cost of maintenance are very high. In addition, the galvanic anodes offer easy to install robust systems, which being independent of a power source, provide protection immediately on "float-out" of the structure.


## 4.5 PRECAUTIONS

There are certain limitations to the use of cathodic protection. Excessive negative potentials can cause accelerated corrosion of lead and aluminum structures because of the alkaline environments created at the cathode. These alkaline conditions may also be detrimental to certain coating systems, and may cause loss of adhesion of the coating. Hydrogen evolution at the cathode surface may, on high-strength steels, result in hydrogen embitterment of the steel, with subsequent loss of strength. On some high strength steels, this may lead to catastrophic failures. It may also cause disbandment of coatings; the coating would then act as an insulating shield to the cathodic-protection currents. Consideration must also be given to spark hazards created by the introduction of electric currents into a structure situated in a hazardous area. Generally sacrificial anode

systems do not cause problems, as they are self-regulating and are often regarded as systems that can be 'fit and forget'. They must, however, be inspected at periodic intervals to ensure they are capable of supplying continued protection. 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 (interaction). Corrosion will be accelerated on the secondary structure at any point where current is discharged to the electrolyte. This phenomenon is called "stray current corrosion". Interaction may occur, for example, on a ship that is moored alongside a cathodically protected jetty, or on a pipeline or metal-sheathed cable that crosses a cathodically protected pipeline.

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 good separation between the protected structure and the secondary structure, and between the groundbeds or anodes and the secondary structure. It is an advantage of sacrificial-anode schemes that they are not prone to creating severe interaction problems and therefore they are popular for protection in congested and complex locations Methods and procedures are available for overcoming interaction, and testing should be carried out in the presence of interested parties, so that the choice of remedial measures may be agreed, if and when the acceptable limit of interaction is exceeded.

## 4.6 Monitoring and Maintenance

Cathodic protection systems may be monitored effectively by the measurement of structure-to-electrolyte potentials, using a high input impedance voltmeter and suitable half-cell. The standard practical half-cells are copper/copper sulphate, silver/silver chloride/seawater, silver/silver chloride/ potassium chloride and zinc.

Adjustments are made to the cathodic-protection current output to ensure that protective potentials are maintained at a sufficiently negative level as defined by the project specification.

The level of protection in soils and water is accepted at steel potentials of minus 850 mV (wrt. Cu/CuSO4) or minus 800 mV (wrt. Ag/AgCl/seawater).

Transformer rectifier outputs may be displayed by telemetry at central control stations. Many cathodic protection systems are increasingly being controlled and monitored by remote computers and modem links. Other communication systems that enable, for example, pipe-to- soil potentials to be monitored from a helicopter or light aero plane, are available. Galvanic-anode outputs may also be monitored, as can currents in electrical bonds between structures. Tests to measure interaction are usually conducted annually where areas are at risk or after adjustments to cathodic protection current output.

Maintenance includes the mechanical maintenance of power supply equipment and the maintenance of painted surfaces of equipment.

It is good practice to inform all owners of cathodic protection systems and infrastructure in the area of influence of any new cathodic protection systems, or of significant changes to existing systems, so that the effect on these facilities may be assessed.

# 5. DETAILED DESIGN BASIS

Scope of work includes Design and detail engineering, testing and commissioning of the temporary Cathodic protection system using Mg anodes CP system shall protect the external surface of the pipeline for minimum 2 year or till commissioning of PCP and Design detailed engineering, supply, installation, testing and commissioning of the permanent Cathodic protection system by impressed current method. The CP system shall protect the external surface of the pipeline and under ground piping of terminal against corrosion for 40 years. The scope includes carrying out the soil resistivity survey for design of anode ground beds, interference detection and mitigation, coating conductance survey, close interval potential logging survey, Pearson Survey and DCVG survey etc.

Test Stations complete in all respects will allow accurate and consistent Potential monitoring , Interference monitoring , Sacrificial anode installation , Bonding of Pipelines & various other functions as detailed in the design. 108Test Stations are proposed to be installed for the pipeline.

The further calculations & analysis work presents the design for the Temporary and Permanent Cathodic Protection System using Magnesium Anodes and certain PCP items like protection at cased crossing, Cables, HT earthing, CTSU, ER Probe etc. for Bharuch – Jamnagar pipeline Spread – 3.

## 5.1 TEMPORARY CATHODIC PROTECTION SYSTEM

The system is designed using Magnesium anodes to be installed horizontal & perpendicular to the pipeline.

**CP SYSTEM OVERVIEW**

TABLE 5.2

| Design Life | 2 Year or till commissioning of PCP whichever is later for TCP. |
|---|---|
| | For PCP design life is 40 Years |
| Protective Current Density | **TCP/PCP** |
| | 0.02 mA/m$^2$ for Normal Soil TCP. 0.035 mA/m$^2$ for Marshy Soil for TCP |
| Pipeline Length | 110200 mtrs. |
| Pipeline Dia. | 762 mm |
| No. of Test Stations | |
| No. of Insulation Joints | 5 Nos |
| No of surge diverters | 5 Nos |
| CTSU | 5 Nos |
| CTSU Reader | 1 Nos |
| ER Probe | 3 Nos |
| ER Reader | 1 Nos |
| Selection of Type of Anodes | Soil Resistivity 0 - 10 ohm-mtr Zinc anodes shall be provided. |

|  | Soil Resistivity 10 - 49 ohm-mtr magnesium anodes shall be provided.<br><br>50 ohm-mtr and above magnesium ribbon anodes shall be provided. |
|---|---|
| Dimensions of Magnesium Anodes | 178 mm (length) x 89 mm (width) x 76 mm (height), 2.0 Kgs (Approx.) (net wt. Of Mg excluding core wt.)<br><br>Mg Anode |
| Proposed No. of Magnesium Anodes | 77 nos. Mg anode each of 2 kg |
| No. of HT line crossings. | 14 Nos |
| Earthing at HT line Crossing | 20 kg of zinc anode shall be provided in each HT Line Crossing. |
| Cased Crossings | All the Casing annulus shall be filled with Bentonite + sand mixture or petroleum jelly to control ingree of moisture in the annulus. However, for casing longer than 20 m, additional sacrificial anodes as per the design. |

TABLE 5.3

| CP SYSTEM OVERVIEW FOR PCP | | | |
|---|---|---|---|
| Design Life | 40 Years | | |
| Protective Current Density | **<u>PCP</u>** | | |
| | 0.020 mA/m² for Normal Soil. | | |
| | 0.035mA/m² for Marshy Soil | | |
| CP Station Details | Bharuch To Jammnagar Spread- 3 | | |
| | 1 Nos | | 1 Nos |
| | TR Unit rating 10V/10A | | TR Unit rating 10V/10A |
| | Anode bed rating is 12.5 Amps | | Anode bed rating is 12.5 Amps |
| | Location : GSPL Station at Bharuch | | Location : Bhattai Sv-4 Station . at Navsari |
| Current | Total Current requirement in Bharuch network is calculated as 0.424Amps including a safety margin of 1.3 | | Total Current requirement in Navsari network is calculated as 3.56 Amps including a safety margin of 1.3 |
| No of surge diverters for IJ | 4 nos. | | 6 Nos |
| Selection of Type of Anodes | MMO Strip Anode | | MMO Strip Anode |

| Dimensions of Anodes | 750 mm x 20mm x 3 mm | | 750 mm x 20mm x 3 mm |
|---|---|---|---|
| Proposed No. of MMO Anodes | 5 nos. in each anode ground bed | | 5 nos. in each anode ground bed |

**Summary of CP Station:**

TABLE 5.4

| CP St'n. Locat-ion | Current Requi red – Amp. | Soil Resistivity (Ohm – mtr.) | Type Of Ground Bed | Proposed No. Of Anode | Length/ Depth Of Ground Bed(mtr.) | Total Ckt. R'tance (Ohm) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Actual | Allowable as per CP unit rating |
| GSPL Station at Bharuch | 0.424 | 15 | Deep well | 5 | 42 | 0.171 | 1 |
| Bhatt-ai Sv-4 Station at Navs-ari | 3.56 | 25 | Deep well | 5 | 42 | 0.222 | 1 |

## 5.2 CORROSION SURVEY REPORT

### SOIL RESISTIVITY VS DEGREE OF CORROSIVITY
(Ohm- cm)

TABLE 5.5

| 0-500 | Very Corrosive |
|-------|----------------|
| 500-1,000 | Corrosive |
| 1,000-2,000 | Moderately corrosive |
| 2,000-10,000 | Mildly corrosive |
| Above 10,000 | Negligible |

### 5.2.1    Method of Survey

1. The soil resistivity measurements have been carried out at intervals not exceeding 500 meters for TCP . However, intermediate random readings have been taken at many locations.

2. The soil resistivity measurements have been carried out using Wenner's 4 pin method. The resistivity checks for each location were carried out at pin spacing of 1, 2 and 3 meters along the pipeline route.

### 5.2.2    Instrument Used for the Survey

| | | |
|---|---|---|
| Megger | - | Digital Earth Tester (Soil Resistivity Meter) |
| Model | - | DET 5/4D |
| Make | - | AVO |
| Ref. no. | - | 6210-178/996399/2729 |

### 5.2.2.1 Depth of Electrode Insertion

Maximum upto $1/20^{th}$ of the spacing.

### 5.2.2.2 Relationship used for Resistivity Calculations

$$\text{Resistivity in ohm-mtrs} = 2 \times \pi \times S \times R$$

Where:

S - Depth in mtrs. (Represented by spacing between electrodes (spikes))

R - Earth resistance in ohms

Based on soil resistivity report pipeline is divided in to following section.

TABLE 5.6

| Sn | From Ch in KM | To Ch in KM | Resisitivity |
|---|---|---|---|
| 1 | 0 | 6.00 | In between 10- 50 ohm – mtr |
| 2 | 6.000 | 8.000 | Above - 50 ohm – mtr |
| 3 | 8.000 | 20.000 | In between 10- 50 ohm – mtr |
| 4 | 20.000 | 40.000 | In between 10- 50 ohm – mtr |
| 5 | 40.000 | 60.000 | In between 10- 50 ohm – mtr |
| 6 | 60.000 | 80.000 | In between 10- 50 ohm – mtr |
| 7 | 80.000 | 100.000 | In between 10- 50 ohm – mtr |
| 8 | 100.00 | 104.000 | less than 10 ohm – mtr |
| 9 | 104.00 | 105.600 | In between 10- 50 ohm – mtr |
| 10 | 105.600 | 107.952 | less than 10 ohm – mtr |

## 5.3. DESIGN DATA AND CRITERIA

### 5.3.1 GENERAL PIPELINE DETAILS

The General Pipeline details for Rajkot to Jammnagar are summarized as under:

TABLE 5.7

| Pipeline Section | Dia in mm | Length (KM) | Coating Scheme |
|---|---|---|---|
| Rajkot to Jammnagar | 762 | 110.20 | 3LPE |

### 5.3.2 CATHODIC PROTECTION SYSTEM DESIGN LIFE

#### 5.3.2.1 Temporary & Permanent Cathodic Protection System

In accordance with the project specification, the Temporary Cathodic Protection System shall have a design life of two (2) years or till commissioning Of PCP whichever is later. Design life for PCP shall be 40 years.

### 5.3.3 CODES AND STANDARDS

The Design generally conforms to the TECPL Specifications for Cathodic Protection System.

The design, selection and installation of equipment and materials shall also conform to the requirements of the latest relevant applicable standards of:

- BIS specifications
- BS specifications and codes of practice
- ANSI specifications
- NFPA publications

- NACE publications
- IEC publications
- DNV publications
- IEEE publications
- DIN publications
- ASTM specifications
- OISD Standards & CCE Norms
- API Model code of safe practices
- GSPL Safety Standards
- Other applicable standards.

**5.3.4 Site Conditions:**

The Equipment will be designed for the following site conditions:

Max/Min .Temperature       -----------       50°C/4 °C

Design Temperature       -----------       55°C

Relative Humidity       -------------       100 %

Altitude above Sea level       -----------       Less than 1000 mtr.

Atmospheric pollution       -----------       Tropicalised to withstand the site
condition, dust,

                                        vapour etc

Hazardous Area classification       -----------       Zone-2, Gas Group II A, II B,

for plant       ----------       Temp, Class T3

Control Room/Electrical Room/
D.G.Area/Guard Room/

Battery room         -------------       Safe rear

The potential and consumption rate of Magnesium anodes shall be as below:

- ➢ Anode Open Circuit Potential -    -1.5 Volts
- ➢ Anode Consumption Rate    -    7.9 Kg / Amp – Year
- ➢ Anode Utilization Factor    0.85

## 5.3.5    CATHODIC PROTECTION CURRENT DENSITIES

Entire Bharuch - Jamnagar Pipeline is coated with Polyethelene coating. The current densities considered for the design are:

TABLE 5.8

| Soil | TCP | PCP |
|------|-----|-----|
| Normal soil | $0.020 mA/m^2$ | $0.020 mA/m^2$ |
| Marshy soil | $0.035\ mA/m^2$ | $0.035\ mA/m^2$ |

A safety margin of 1.3 i.e. 30% shall be provided for in the current calculations over and above the specified protective current densities.

## 5.3.6 SYSTEM DETAILS.

### 5.3.6.1 Temporary Cathodic Protection System

The TCP system may include the following major equipment/sub systems.

- ❖ Sacrificial Anode (Mg or Zn ) ground beds in carbonaceous back fill
- ❖ Test Stations (TLP)
- ❖ Junction Boxes with shunt and resistors.

- ❖ Permanent Reference Cell Cu-CuSo4 Electrodes.

- ❖ Pin Brazing Epoxy encapsulated

- ❖ Grounding Cells

- ❖ Interconnecting Cables

- ❖ Cable to Pipe Connection by Pin Brazing

- ❖ Markers

- ❖ CP System at Cased Railway Crossing

### 5.3.6.2 Permanent Cathodic Protection

The PCP System may include the following major equipment /sub system

- ➢ Computerized Test Stations (CTSU) with reader

- ➢ Junction boxes (CJB)

- ➢ Permanent Reference Cell Cu-CuSo4 Electrodes.

- ➢ Pin Brazing for Pipe to cable connection (epoxy encapsulated)

- ➢ Surge Divertor/Sprak gap Arrestor

- ➢ Grounding Cell

- ➢ Polarization Cell (Soil state ) at A.C.Interference Locations

- ➢ Polarization Coupons with Toggle (reed) Switch

- ➢ Interconnecting cables

- ➢ Markers

## 5.4.    DESIGN CALCULATION

The following formulas have been used to design the Cathodic Protection system.

### 5.4.1    TEMPORARY CATHODIC PROTECTION SYSTEM

#### 5.4.1.1    Anode Requirement Calculation

##### 5.4.1.1.1  Surface Area

$$S_a = \pi \times D \times L$$

Where:

$S_a$ - Surface Area of Pipeline ($m^2$)

D - Diameter of Pipeline (m)

L - Length of Pipeline (m)

TABLE 5.9

| Pipeline Section | Diameter (Mtr) | Pipeline Length (Mtrs.) | Coating | Surface Area ($m^2$) |
|---|---|---|---|---|
| Rajkot to Jammnagar | 0.762 | 110200 | 3LPE | 263807.075 |

##### 5.4.1.1.2  Current Requirement

$$It = Sa \times Id \times Sm / 1000$$

Where:

$I_t$ - C.P. current requirement (Amps)

$S_a$ - Surface area of Pipeline ($m^2$) .

$I_d$ - C.P. protective current density

(0.035 mA/$m^2$ )

$S_m$ - Safety Margin (1.3)

TABLE 5.10

| Pipeline Section | Diameter in Mtr | Pipeline Length (mtrs.) | Coating | Surface Area ($m^2$) | Protective Current Density (mA / $m^2$) | Current Required (Amp.) |
|---|---|---|---|---|---|---|
| **For Temporary Cathodic Protection** | | | | | | |
| Rajkot to Jammnagar | 0.762 | 110200 | 3LPE | 263807.075 | 0.035 | 12.00 |

### 5.4.1.1.3 Anode Weight Requirement for TCP

The total anode weight requirement is calculated using the following formula:

$$W = It \times Ct \times L / Uf$$

$$= 12.00 \times 7.9 \times 2 / 0.85$$

$$= 223.11 \text{ Kg}$$

Where:

W - Total Anode Weight Requirement (Kg.)

$I_t$ - C.P. current requirement (Amps.)

$C_t$ - Consumption Rate of Anode

(7.9Kg/Amp-Years for Mg.)

L    -    Design Life (2 year for TCP)

Uf    -    Anode Utilization factor (0.85)

### 5.4.1.1.4   No. of Anodes Required.

Total No of Mg Anode = 223.11/2

=112 Nos

The Magnesium Anodes shall have a   cross-section of 176 mm (Length) x   89 mm (width) x 92 mm (height), Net Anode body wt. of 2.3 Kg. Excluding the wt. of core

**However we provide 112 Nos of Mg anodes in every 1.00 Km**

TABLE 5.11

| Mg   Anode calculations | |
|---|---|
| Resistivity | Less than 50 Ohm-Mtr. |
| Design  Life  - years | 2 Years |
| Pipe Line  Details | 3LPE |
| Pipe  Dia –  Mtr | 0.762 |
| Pipeline Length in Mtr. | 110200 |
| Coating | 3LPE |
| **Surface  Area – m2** | 263807.075 |
| Current density - mA/m2 | 0.030 |
| Safety Margin | 1.3 |
| Current Requirement  -  Amps | 12.00 |
| **Total Weight requirement of** | 223.11 |

| Mg Anode ·· Kg. | |
|---|---|
| Weight of 1 Mg anode – kg | 2 |
| Required nos. Of Mg. anodes | 112 |
| Total Weight of Mg anodes proposed-Kg | 223.11 |

### 5.4.1.1.5 Total Circuit Resistance

**Groundbed Resistance Calculations**

<u>Resistance in Horizontal Configuration - Rah (ohms)</u>

$$Rah = \frac{0.159\,\rho_s}{Lpa}\left[Ln\frac{4\,Lpa^2 + 4\,Lpa\,(S2^2 + Lpa^2)^{0.5}}{dpa\,S2} + \frac{S2}{Lpa} - \frac{(S2^2 + Lpa^2)^{0.5}}{Lpa} - 1\right]$$

Where:

$\rho_s$ - Resistivity of Soil (5 ohm-mtr)

Lpa - Length of Prepackaged Anode ( 1.5 mtrs)

dpa - Diameter of Prepackaged Anode ( 0.2 mtrs)

S2 - Twice Depth of Anode Axis ( 3 mtrs)

Rah = 1.403 sample calculation for 5 ohm-m resistivity.

## Resistance of single anode to backfill - Ri (ohms)

$$Ri = \frac{0.159 \, \rho b}{La} \left[ Ln \, \frac{8 La}{da} - 1 \right]$$

Where:

$\rho b$ - Resistivity Backfill Material ( 0.5 ohm-mtr)

Lpa - Length of Anode ( mtrs) – 176 mm

dpa - Diameter of Anode ( mtrs) – 89 mm

Ri = 0.796 ohm

## Cable Resistance - Rc (ohms)

$$Rc = (Rt \times Lm) / Na$$

Where:

Rt - Tail cable resistance per meter ( 0.0032 ohms)

Lm - Maximum Anode Tail Cable Length (10 mtrs worst case)

Na - Number of Anodes per Ground bed (1 worst-case)

Rc = (0.0032 x 10) / 1 = 0.032 ohms.

Value is small, hence it is negligible.

Total Circuit resistance  RT(ohms)

$$R_T = Rah + Ri/N$$

Where:

$R_T$ - Total Circuit resistance. (ohms)

Rah - Anode Ground bed Resistance (ohms)

Rc - Cable Resistance (ohms)

N - Number of Anodes.

Rt = 2.199

Hence single anode installation will lead the total circuit resistance of 2.199 ohm for soil resistivity of 5 Ohm-m.

TABLE 5.12

| Soil Resistivity (Ohm-m) | Total Ckt Resistance in Ohm. |
|---|---|
| 10 | 3.601 |
| 30 | 9.211 |
| 50 | 14.826 |

**5.4.1.1.6    Total Current output**

$$I = (V/R_T)$$

Where:

I    =    Current Output in Amps

V    =    Driving voltage of Mg. Anode (0.55 V)

$R_T$    =    Total Circuit resistance in ohms

$$I = 0.55/2.199$$

$$= 0.250 \text{ Amp.}$$

Hence installation of 1 no. anode in Horizontal configuration for 5 Ohm – Mtr resistivity shall result in current output of 0.25 A.

Current output table for other resistivity is as under:

TABLE 5.13

| Soil Resistivity (Ohm-m) | Total Current out put in mAmps |
|---|---|
| 10 | 152.735 |
| 30 | 59.711 |
| 50 | 37.096 |

From the above it can be observed that actual current output and anode weight is higher than the requirement of Design values.

We proposed 112 -nos. Mg anodes

The change wise anode details are tabulated in section 5 along with the test station and the type of test station used.

## 5.4.2 Permanent Cathodic Protection System

### 5.4.2.1 Surface Area

$$S_a = \pi \times D \times L$$

Where :

$$S_a \quad - \quad \text{Surface Area of Pipeline } (m^2)$$

$$D \quad - \quad \text{Diameter of Pipeline } (m)$$

$$L \quad - \quad \text{Length of Pipeline } (m)$$

**Current Requirement**

$$It \quad = \quad Sa \times Id \times Sm / 1000$$

Where:

$$I_t \quad - \quad \text{C.P. current requirement (Amps)}$$

$$S_a \quad - \quad \text{Surface area of Pipeline } (m^2)$$

$$I_d \quad - \quad \text{C.P. protective current density}$$
$$( 0.035 \text{ mA/m}^2 )$$

$$S_m \quad - \quad \text{Safety Margin (1.3)}$$

TABLE 5.14

| Network | From | To | Diameter Mtr | Pipeline Length (mtrs.) | Coating | Surface Area (m²) | Protective Current Density (mA / m²) | Current Required (Amp.) |
|---|---|---|---|---|---|---|---|---|
| Bharuch | GSPL Metering Station | GNFC CNG | 0.1524 | 3370 | PE | 1613.18 | 0.200 | 0.419 |
| Bharuch | GNFC | CNG | 0.1016 | 50 | PE | 15.956 | 0.200 | 0.004 |
| Navsari | SV-4 Station | Mafatlal | 0.2032 | 16178 | PE | 10325.63 | 0.200 | 2.68 |
| Navsari | Bhattai Tap-off | CNG Station | 0.1524 | 4000 | PE | 1914.75 | 0.200 | 0.50 |

| Navsari | Top-2 | Luncigui | 0.1524 | 3000 | PE | 1436.07 | 0.200 | 0.37 |
|---|---|---|---|---|---|---|---|---|
| **TOTAL CURRENT REQUIREMENT IN BHARUCH NETWORK ( AMPS)** | | | | | | | | **0.424** |
| **TOTAL CURRENT REQUIREMENT IN NAVSARI  NETWORK ( AMPS)** | | | | | | | | **3.56** |

The calculations for the circuit resistances at all CP Stations configuration are tabulated as follows:

TABLE 5.15

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| **CP St'n. Location** | **Soil Resistivity (ohm-mtr)** | **Proposed No. of Anodes** | **Type Of Anode Bed** | **Anode backfill column length/depth in mtrs.** | **Ground bed R'tance - R (ohms)** |
| GSPL Station at Bharuch | 15 | 5 | Deep well | 42 | 0.38 |
| Bhattai Sv-4 Station at Navsari | 22 | 5 | Deep well | 42 | 0.56 |

TABLE 5.16

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| CP St'n. Location | Anode to backfill R'tance - $R_V$ /N(ohms) | Cable R'tance - $R_C$ (ohms) | Total Current of each ground bed – Amp. | Rating Of CP St'n. Volt/Amp | Total Circuit Resistane – Rt (Ohm) | |
| | | | | | Actual | Allowed |
| GSPL Station at Bharuch | 0.499 | 0.112 | 11.25 | 10/10 | 0.171 | 1 |
| Bhattai Sv-4 Station at Navsari | 0.499 | 0.112 | 11.25 | 10/10 | 0.222 | 1 |

**No. and Rating of CP stations**

One CP Station in Bharuch Network consisting of One TR Unit of Rating 10V/10A, associated anode bed capable of delivering minimum 11.25 Amps current, using MMO anodes, AJB, associated cabling etc. shall be provided . Indoor Type TR Unit may be installed at the GSPL Station at Bharuch.

Hence there is a total current delivering capacity of 11.25 Amps as against the requirement of 0.424 Amps.

Another CP Station in Navsari Network consisting of One TR Unit of Rating 10V/10A, associated anode bed capable of delivering minimum 11.25 Amps current, using MMO anodes, AJB, associated cabling etc. shall be provided . Indoor Type TR Unit may be installed at the Bhattai Sv-4 Station at Navsari

Hence there is a total current delivering capacity of 11.25 Amps as against the requirement of 3.56 Amps.

**Anode Requirement by Current output**

The requirement of LIDA Strip anodes of 750mm x 20mm x 3mm for Deep well Strip Configuration shall be as under.

**Current O/p Calculation for MMO anode**

$$\text{Log (L)} = 3.477 - \text{Log (i)}$$

Where:

L = Life of MMO anode

i = Operating current density in A/m2

Log (40) := 3.477 − Log (i )

Log (i) =3.477-1.60206

i = inv log 1.87

i = 75 A/m2

Surface area of MMO anode

$S_a$ = 2 x L x B

Where :

Sa   -   Surface Area of MMO anode ($m^2$)
B    -   Width MMO anode  (m)
L    -   Length of MMO anode (m)

Sa = 2 x 0.750 x 0.020 = 0.03 m2

Current O/p per anode = i x Sa  = 2.25 amp.

**Based on above calculation it can observed 2.25 amp current o/p per anode for 40 years design life.**

**Total No. of anode required in Bharuch Network**   = Total Current / Current
o/p of one anode

= 0.424 / 2.25
= 0.212 nos.

We have proposed 5 nos. anodes in one ground bed.

**Total No. of anode required in Navsari Network** = Total Current / Current o/p of one anode

$$= 3.56 / 2.25$$
$$= 1.58 \text{ nos.}$$

**We have proposed 5 nos. anodes in one ground bed**

The requirement of LIDA strip anodes of 750 mm X 20 mm X 3 mm for deep well Configuration shall be as under.

TABLE 5.17

| Location | Ground bed Configuration | Max. current delivered/ Anode for 40 yr. of design life (Amp.) | Proposed no. of anodes | Max. current delivered / ground bed – amp. | Current required as per calculation |
|---|---|---|---|---|---|
| GSPL Station at Bharuch | Deep well | 2.25 | 5 | 11.25 | 0.424 |
| Bhattai Sv-4 Station at Navsari | Deep well | 2.25 | 5 | 11.25 | 3.56 |
| **TOTAL CURRENT in AMP(Bharuch Network)** | | | | **11.25** | **0.424** |
| **TOTAL CURRENT in AMP(Navsari Network)** | | | | **11.25** | **3.56** |

## 5.4.2.2    Total Circuit Resistance

### 5.4.2.2.1 Anode Bed Resistance in Deep well Configuration - R

The resistance of deep well anode bed to electrolyte is calculated by the following formula:

$$R = \frac{0.159\,\rho}{L}\left[\left(Ln\ \frac{8\,L}{D} - 1\right)\right]$$

Where:

R    -    Resistance to earth of the deep well anode bed. (Ohms)

ρ    -    Soil Resistivity (15 ohm-mtrs)

L    -    Length of anode bed (42 mtrs)

D    -    Diameter of anode bed (0.15 mtrs)

**R = 0.38  Ohm.**

### 5.4.2.2.2    Resistance of the anode to backfill

$$R_V = 0.159\,p\,/\,1\,(Ln\ (8l/d) - 1)$$

Where

$R_V$    =    Resistance of vertical anode to backfill in ohms

p    =    Resistivity of backfill material (0.5 ohm-m)

$$l \quad = \quad \text{Length of anode in m (0.75 m)}$$

$$d \quad = \quad \text{diameter of anode in m (0.02m)}$$

$$R_V \quad = \quad \frac{(0.159 \times 0.5)}{0.75} \quad (Ln \quad \frac{8 \times 0.75}{0.02} \quad - \quad 1)$$

$$= \quad \textbf{0.499 ohm}$$

Therefore, the resistance of a single vertical anode to backfill is **0.499 Ohms.**

### 5.4.2.2.3 Cable resistance

The main anode header and cathode header cables will be 35 mm$^2$ which has a resistance of 0.00056 ohms per meter.

A 130 meter anode cable and 70 meter cathode cable run will result in cable resistance calculated as follows:

$$R_C \quad = \quad (L_P \times R_N) + (L_n \times R_N)$$

Where

$$R_c \quad = \quad \text{Total resistance of cable (ohms)}$$

$$L_P \quad = \quad \text{Length of anode cable run (130 m)}$$

$$L_n \quad = \quad \text{Length of cathode cable run (70 m)}$$

$$R_N \quad = \quad \text{Resistance of cable (0.00056 o/m)}$$

$$R_C \quad = \quad (130 \times 0.00056) + (70 \times 0.00056)$$

$$= \quad \textbf{0.112 Ohms}$$

Hence Cable resistance shall be considered as 0.112 **ohms**

### 5.4.2.2.4    **Total Circuit Resistance**

The total circuit resistance for each anode bed is calculated as under:

$$R_T = R + R_V / N + R_C$$

Where:

$R_T$    = Total circuit resistance (Ohms)

R    = Resistance to electrolyte of groundbed (Ohms)

$R_v$    = Single anode to backfill resistance. (Ohms)

N    = Number of anodes in each groundbed

$R_C$    = Cable Resistance

Total Circuit Resistance $R_T$

$R_T$ =   0.38 + 0.499/5 + 0.112

   = **0.171 Ohm**   For Deep well configuration

**Sample Attenuation Calculations for 30" Dia Pipe Line**

**Length of Pipe line Protected from Drain Point :**

Formulas used for the calculations of 30" Dia Pipe Line as follows:

1    Surface Area of 1 KM  Pipe Line - A (m2)

$$A = \pi \times d \times 1000$$

$$= 3.14 \times 0.762 \times 1000$$

= 2393.89 m2

Where:

D - Diameter of Pipe (mtrs)

Cross section area of pipe - A (m2)

$A = \pi \times t \times (D - t)$
= 3.14 X 0.0133 (0.762 – 0.0133)
= 0.031 m2

Where:

t - Thickness of Pipe (mtrs)

D - Diameter of Pipe (mtrs)

2    Linear resistance of pipe - Rs (ohms)

$Rs = \rho s \times 1 / A$
= 2.2 X 10 –7 X 1000/2393.89
= 0.0070

Where:

ρs - Resistivity of Steel pipe (ohm-mtr)

1 - Unit Length of Pipe (1000 mtrs)

A - Cross Section Area of Pipe (m2)

3    Coating leakage resistance of pipe - Rl (ohms)

$Rl = Rp / Sak$
= 22000/2393.89

$$= 9.190$$

Where:

Rp - Coating resistance of Pipe (ohm- m2)

Sak - Surface Area of 1 km of Pipe (m2)

4      Attenuation constant - $\alpha$

$$\alpha = (Rs / RI)0.5$$
$$= (0.0070/ 9.190)0.5$$
$$= 0.028$$

Where:

Rs - Linear Resistance of Pipe (ohms)

RI - Coating Leakage Resistance (ohms)

5      Minimum Potential shift at end point - Ed (Volts)

$$Ed = PSPmin - PSPnat$$
$$= (- 0.95) - (- 0.45)$$
$$= - 0.5$$

Where:      PSPmin - Least negative PSP at end point (Volts)

PSPnat - Natural PSP at end point (Volts)

6      Length of Pipeline Protected from Drain Point - Lp (kms)

$$Lp = (1/ \alpha) \times Cosh\text{-}1 (Edp / Ed)$$
$$= (1/0.0.028) \times Cosh -1 (- 1.5/- 0.5)$$
$$= 54.36$$

Where:

α - Attenuation Constant

Edp - Max. Potential at Drain Point (volts)

Ed - Potential Shift at End Point (volts)

From the above it can observed that 30" Pipe line section shall protect a span of 54.36Km On either side i.e 108.72 considering both sides. Hence entire pipe line is cathodically covered or protected

## 5.4.3    HT LINE CROSSING

At the crossing or parallel running of pipeline and overhead HT line of 66 KV and above, inducing A.C on the under ground pipe line ,shall be mitigated using solid state polarization cell/ device. To mitigate A.C interference, Soild State polarization cell shall be installed at every KM or as required for A.C interference mitigation in the section where interference is detected.

Locations along pipe line where continuous induced over voltage due to HT line etc. is expected &/or observed during commissioning ,the pipe line shall be earthed through solid state polarization cell/device to the HT tower earth system causing the voltage induction to ground or through a separate earthing system.

Where ever presence of induced A.C. voltage is beyond safe limit (more than 15 V rms A.C. as per NACE standard) is observed after Zn anode connection with pipeline. Further mitigation measures shall be provided

Interference situations shall also be identified and mitigated by comparing different sets of readings taken at same test stations at different intervals of time under identical conditions where positive potential swing exceeds 50 mV.

## 5.4.4 FOREIGN PIPELINE CROSSING/RUNNING PARALLEL

If any foreign pipelines crossing and running parallel to BJPL found then following measures shall be taken.

- For foreign pipelines having Cathodic Protection, provision for bonding shall be provided between two pipelines at the location of crossing and running parallel. For parallel running within 25 mtrs bonding shall be provided at approx. every 1 km

- In case owners of cathodically protected foreign pipelines do not agree for bonding, ON/OFF PSP shall be taken at Test Stations in the vicinity of crossings/parallel running by switching ON/OFF TR/CPPSM of foreign pipelines.

- For points having positive potential swings of 20 mV or more remedial measures shall be taken for interference.

## 5.4.5 INSULATING FLANGE

One Number surge diverter shall be provided for the protection of insulating joints located at the ends of the pipe line / at terminals.

Detailed Specification for Surge diverter shall be as under:

| | | |
|---|---|---|
| Type | : | Spark Gap |
| Current | | |
| 8/20 micro second wave | : | 100 kA |
| Spark over A.C. Voltage | | |
| 50 Hz | : | 1 kV |
| Impulse (1.2/50 Micro Second) | : | 2.2 KV |

### 5.4.6 Computerized Test Station Units

Total 10 Nos of CTSU is to be installed in Spread-3 Location of CTSU shall be enclosed in Detailed Test Station Schedule Minimum 1 Numbers with 4 Channel Computerized Test Stations With 1 Nos. reading units shall be provided

### 5.4.7    ER Probe

ER Probe, 3 nos. Shall be provided in BJPL Spread-3 the location of ER probe

One number ER Probe Reader shall be provided for downloading reading from ER Probe.

### 5.4.8 CARRIER PIPE & CASING PROTECTION

All the Casing annulus shall be filled with Bentonite + sand mixture or petroleum jelly to control ingree of moisture in the annulus. However, for casing longer than 20 m, additional sacrificial anodes as per the design calculations to be strapped to 8 or 4 "O" clock position on pipe without damaging the pipe coating, and cable connection brought out to anode junction box/TLP

Calculation of Zinc Ribbon Anode- Carrier Protection at Coated Cased Crossings (Main Line)

Table giving sample calculation for minimum required of Zinc Ribbon anodes

(Zinc ribbon anode having wt. 0.750 Kg/mtr shall be used for carrier pipe protection at cased crossing).

**(A) Sample Zinc ribbon anode calculations for 30" dia. 34 meter in length of carrier pipe   inside casing:-**

Surface area $\qquad$ = 3.141(Pi) x D x L

$\qquad$ = 3.141x0.762x34

$\qquad$ = 81.392  sq. m.

Total protective current required. = Sa x Cdx Sf/ 1000

$\qquad$ = 81.392 x 0.035 x 1.3 / 1000

$\qquad$ = 0.0037  Amps.

Anode Weight requirement $\quad = W \quad = \quad \dfrac{I_t \times C_t \times L}{U_f} \quad \dfrac{0.60}{} \quad = \quad \dfrac{0.0037 \times 11.2 \times 30}{0.60}$

$\qquad$ = 2.072 kg.

$\qquad$ = 2.072/0.75 (0.75 – Ribbon anode weight per mtr)

$\qquad$ =2.763 mtr

Total Length of Zinc(R) Anodes proposed based 1 anode per 2 mtr of pipe length

$\qquad$ Length in Mtr   =3.141XD/3x No of Locations

$\qquad$ = 0.797 x 17

$\qquad$ = 13.56 Mtr

Total Anode wt. required $\qquad$ = Wt per meter x total length required

$\qquad$ = 0.750 x 13.56

$\qquad$ = 10.17 kg.

# 6. CONCLUSION

In this study we conclude with the result that for a distance of 110.20 km from Baruch to Jamnagar the pipeline with a diameter of 762mm. & as per the given site conditions given. In case of TCP we require 112 no. of Magnesium anodes each of 2 kg at a distance of 1km & current output of 0.25 Amp.
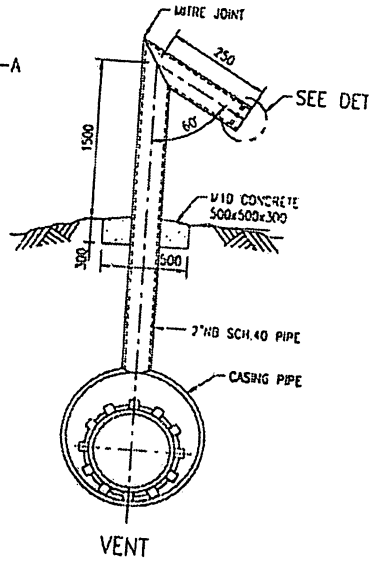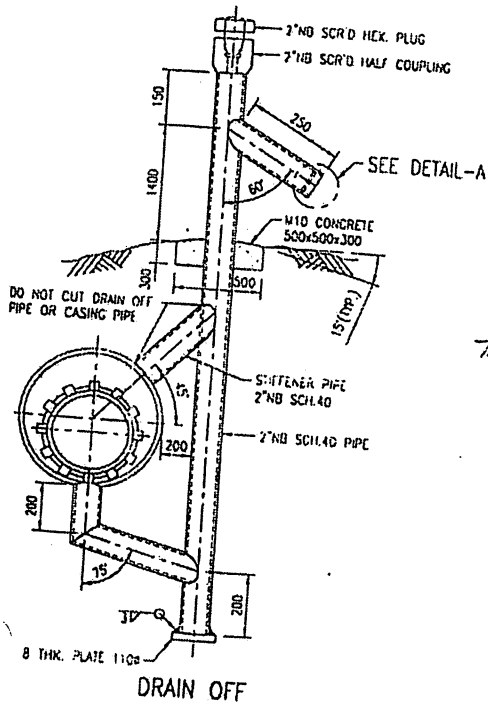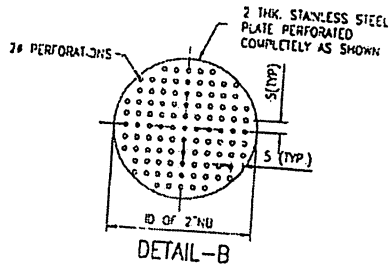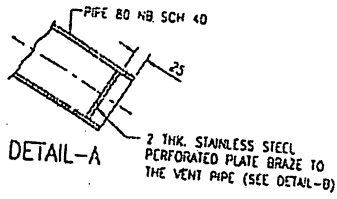
In case of PCP we require 5 anodes in one ground bed each of deep well configurations & maximum current delivered / ground bed at 11.25 amps, current requirement as per calculation 0.424 amp & 3.56 amps at the two different locations at Baruch & Navsari network. Assuming all the surveys conducted & calculation performed to be accurate, it can be said that this particular set up will last for around 40 years.

Systems with small stable current requirements (0.5 A or less per 100 lineal feet of structure) are more likely to be protected using sacrificial anode type systems. Those structures with larger current requirements (1 A or more per 100 lineal feet of structure), or where the current requirements vary considerably with time, are more likely to be protected using impressed current systems.
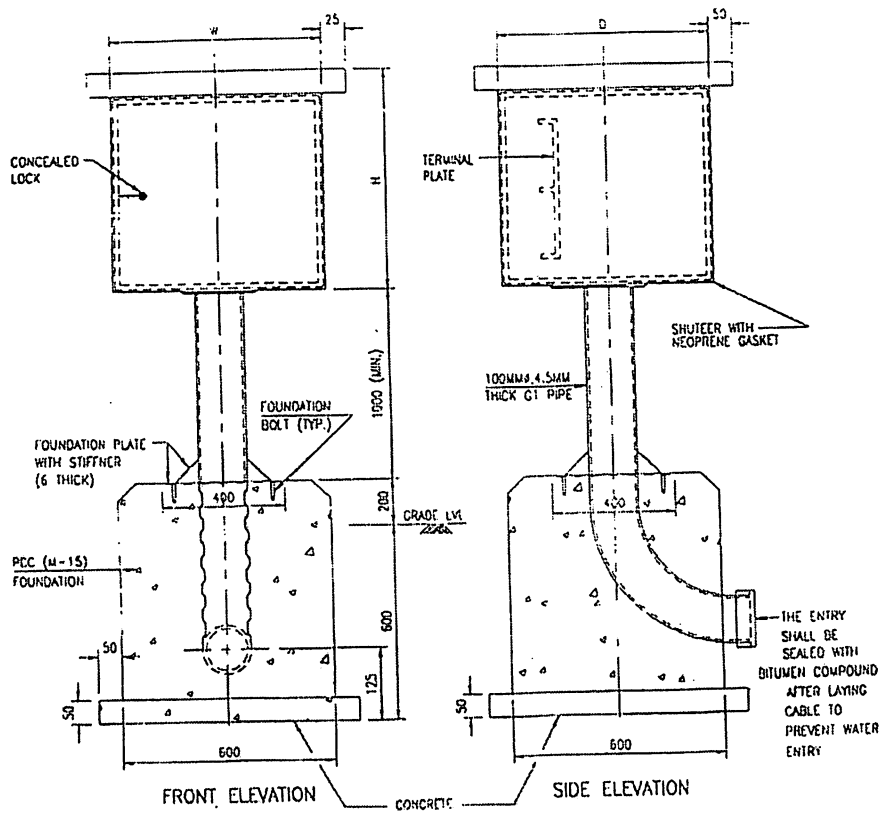
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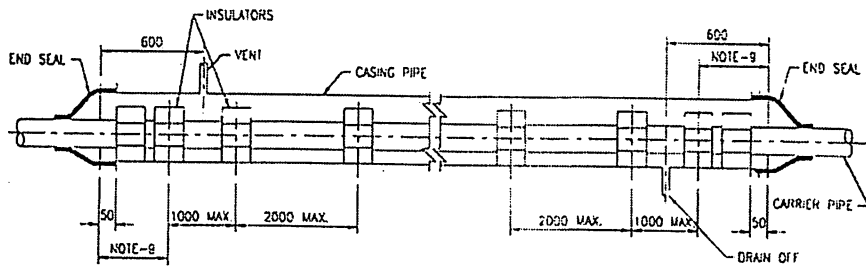➤ Private communication from B. Sheehan at San Diego County Water Authority, August 28, 2000.

DETAIL-A

PIPE 80 NB SCH 40

25

2 THK. STAINLESS STEEL
PERFORATED PLATE BRAZE TO
THE VENT PIPE (SEE DETAIL-B)

DETAIL-B

2 THK. STAINLESS STEEL
PLATE PERFORATED
COMPLETELY AS SHOWN

2∅ PERFORATIONS

S (TYP)

S (TYP.)

ID OF 2"NB

DRAIN OFF

2"NB SCR'D HEX. PLUG
2"NB SCR'D HALF COUPLING

SEE DETAIL-A

150

1400

250

60

M10 CONCRETE
500x500x300

300

DO NOT CUT DRAIN OFF
PIPE OR CASING PIPE

500

15(TYP.)

STIFFENER PIPE
2"NB SCH.40

2"NB SCH.40 PIPE

200

200

15

200

8 THK. PLATE 110∅

VENT

MITRE JOINT

250

60

SEE DET

1500

M10 CONCRETE
500x500x300

300

500

2"NB SCH.40 PIPE

CASING PIPE

# CASING DRAIN & VENT

65

# TEST LEAK POINT (T.L.P.)

| S.NO. | SIZE OF CASSING PIPE | SIZE OF CARRIER PIPE | MATERIAL |
|-------|----------------------|----------------------|----------|
| 1. | 30" x 11.1mm | 24" | API 5L Gr. B |
| 2. | 24" x 9.5mm | 18" | API 5L Gr. B |
| 3. | 18" x 9.5mm | 12" | API 5L Gr. B |
| | | | |

# CASING PIPE

## ANNEXURE IV

GALVANIC SERIES IN SEA WATER

Noble

(Least active)

(passive)

Platinum

Gold

Graphite

Silver

18-8-3 Stainless steel, type 316 (passive)

18-8 Stainless steel, type 304 (passive)

Titanium

13 percent chromium stainless steel, type 410

67NI-33Cu alloy

75NI-16Cr-7Fe alloy (passive)

Nickel (passive)

Silver solder

M-Bronze

G-Bronze

70-30 cuprous-nickel

Silicon bronze

Copper

Red brass

Aluminum bronze

Admiralty brass

Yellow brass

76NI-16Cr-7Fe alloy (active)

Nickel (active)

Naval brass

Manganese bronze

Muntz metal

Tin

Lead

18-8-3 Stainless steel, type 316 (active)

18-8 Stainless steel, type 304 (active)

13 percent chromium stainless steel, type 410

(active)

Cast iron

Wrought iron

Mild steel

Aluminum 2024

Cadmium

Alclad

Aluminum 6053

Galvanized steel

Zinc

Anodic Magnesium alloys

(Most active) Magnesium