

CORROSION ANALYSIS AND CATHODIC PROTECTION
SYSTEM DESIGNING

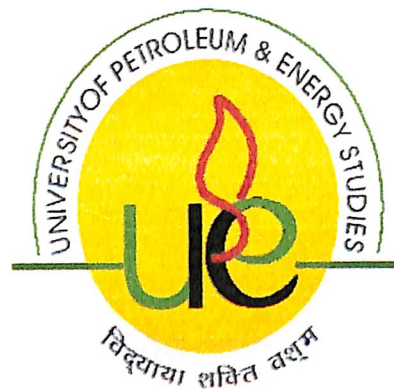
A thesis submitted in partial fulfillment of the requirements for the Degree of

Master of Technology
in
Pipeline Engineering

Under the guidance

Dr.D.N.Saraf
(Distinguished Professor)

Submitted By
ABHISHEK SINGH
(R160208002)



College of Engineering
University of Petroleum & Energy Studies
Dehradun
May, 2010

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UNIVERSITY OF PETROLEUM & ENERGY STUDIES
(ISO 9001:2000 Certified)

CERTIFICATE

This is to certify that the work contained in this thesis titled “**Corrosion Analysis and Cathodic Protection System Designing**” has been carried out by Abhishek Singh under my supervision and has not been submitted elsewhere for a degree.

Dr.D.N.Saraf

(Distinguished professor)

Date May 7, 2010

ABSTRACT

A detailed analysis of all types of corrosion encountered in oil and gas industry was undertaken. the extent of corrosion in any particular corroded region was estimated. A Cathodic protection system was designed for a 133 km long .75 in diameter R-LNG spur line.

A permanent Cathodic system(PCP) can only be provided after the pipeline laying is completed. however this leaves the pipeline exposed to corrosion during construction to protect the pipeline from corrosion during construction phase a temporary Cathodic protection system(TCP) was designed. Resultant designed were compared with those provided by design company and the agreement was found to be good.

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ABHISHEK SINGH

TABLE OF CONTENTS

Chapter 1: Introduction	1-4
1.1 Basics About Corrosion	
1.2 Importance of Cathodic protection system and Corrosion Control	
1.3 Methodology Involved in Cathodic Protection System Designing	
1.4 Problems investigated in this thesis	
Chapter 2: Literature Review	5-6
Chapter 3 : Theoretical Development	7-27
3.1 Nature of Corrosion reactions	7
3.1.1 Corrosion By Water	
3.1.2 Voltage Source	
3.1.3 Electrical Circuits	
3.1.4 Polarization	
3.2 Nature of Metals	8
3.2.1 In homogeneities in Metal Surfaces	
3.3 Effect Of Electrolyte Composition	8
3.3.1 Conductivity	
3.3.2 Dissolved Gases	
3.4 Physical Variables	9-10
3.4.1 Temperature	
3.4.2 Pressure	
3.4.3 Velocity	
3.5 Forms of Corrosion	10-18
3.5.1 Uniform Corrosion	
3.5.2 Pitting Corrosion	
3.5.3 Bimetallic Corrosion	
3.5.4 Flow Enhanced Corrosion (Erosion Corrosion)	
3.5.5 Cavitation Corrosion	
3.5.6 Intergranular Corrosion	
3.5.7 Hydrogen Induced Failures	
3.5.8 Sulphide Stress Cracking (SSC)	
3.5.9 Stress Corrosion Cracking (SCC)	
3.5.10 Corrosion Fatigue	
3.5.11 Microbiologically Influenced Corrosion (MIC)	
3.5.12 Oxygen Corrosion	
3.5.13 Sweet Corrosion	
3.5.14 Sour Corrosion	

3.6 Cathodic Protection	19-27
3.6.1 Advantages and Uses of Cathodic Protection	
3.6.2 Basic Requirements for Cathodic Protection	
3.6.2.1 A galvanic system requires	
3.6.2.2 An impressed-current system requires	
3.6.3 Design Factors	
3.6.3.1 Initial considerations	
3.6.3.2 Potential level and distribution	
3.6.3.3 Economics of decisions	
3.6.3.4 Problems to be avoided	
3.6.4 Monitoring and Maintenance	
Chapter 4: Computational	28-46
4.1 Temporary Cathodic protection	
4.2 Calculations for Permanent Cathodic Protection	
4.3 Determination of maximum allowable longitudinal extent of corrosion	
Chapter 5 : Results and Discussion	47
Chapter 6 : Conclusions and Recommendation	48
References	
Appendices	
1)Appendix A	
2)Appendix B	

LIST OF FIGURES/TABLES

Figure 1	Procedure of corrosion
Figure 2	Pitting Corrosion
Figure 3	Stress Corrosion Cracking
Figure 4	Corrosion Cell
Figure 5	Zinc Copper Corrosion Cell
Figure 6	Polarization Curve
Figure 7	Corrosion Rate of steel V/S pH
Figure 8	Cathodic Protection
Figure 9	Longitudinal Extent of Corrosion
Figure 10	Method of determination of value of 'B'
Table 1	Anode Current Values

NOMENCLATURE

Nomenclature	Description
TCP	Temporary Cathodic protection
PCP	Permanent Cathodic protection
SRB	Sulfate reducing Bacteria
MAOP	Maximum allowable operating Pressure
BS	British Standard
IS	Indian standard
ASTM	American Society for Testing and Materials
API	American petroleum Institute
DIN	Deutsches Institut für Normung(dutch std)
DNV	Det Norske Veritas
NACE	National association for corrosion Engineers

Pipelines have become an efficient, economic and safe means of transporting liquid and gaseous materials (particularly crude oil, refined petroleum products and natural gas) for long distances over land, underground, and sub-sea from production locations to the market. When properly maintained and operated, pipelines provide the transporters advantages of economy of scale, because an increase in volume of materials being transported can be affected cheaply through an increase in pumping volumes. Pipelines therefore have become competitive and complementary to other forms of transportation (such as ocean tankers, rail, and road trucks) for oil and gas

The most commonly experienced failures, or threatened failures, are associated with either internal or external corrosion of the pipe wall. Other failures may involve other metal loss mechanisms, such as erosion, fretting/chafing or gouging. A pipe line buried in the earth represents a challenge. It is made of steel—a strong, but chemically unstable, material—and is placed in an environment which is non-uniform, non-protective, and non-yielding. Many installations face problems with corrosions. As a result, system life, reliability, efficiency, and safety are reduced. Many of these corrosion problems are preventable through properly designed and installed Cathodic protection systems.

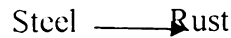
So this thesis will provide and give solution of the problem that may occur due to corrosion specially in Dadri-Panipat R-LNG spur line. it will also focus on the areas like remedial measures that can be taken to prevent against typical type of corrosion. Basically the Cathodic protection system installation is the most vital and efficient way to prevent corrosion by calculating the current required by the medium and dividing it by current produced will give the number of anode. Also the longitudinal extent of corrosion will give an idea about the maximum value up to which pipe will work without failure.

1.1 Basics about Corrosion

What we all know about corrosion

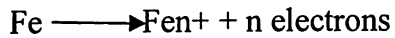
We have all seen corrosion and know that the process produces a new and less desirable Material from the original metal and can result in a loss of function of the component or System. The corrosion product we see most commonly is the rust which forms on the surface

Of steel.



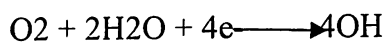
Technically

For this to happen the major component of steel, iron (Fe) at the surface of a component undergoes a number of simple changes. Firstly,

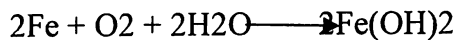


the iron atom can lose some electrons and become a positively charged ion. This allows it to bond to other groups of atoms that are negatively charged.

We know that wet steel rusts to give a variant of iron oxide so the other half of the reaction must involve water (H₂O) and oxygen (O₂) something like this



This makes sense as we have a negatively charged material that can combine with the iron and electrons, which are produced in the first reaction are used up. We can, for clarity, ignore the electrons and write



Iron + Water with oxygen \longrightarrow Iron Hydroxide
dissolved in it

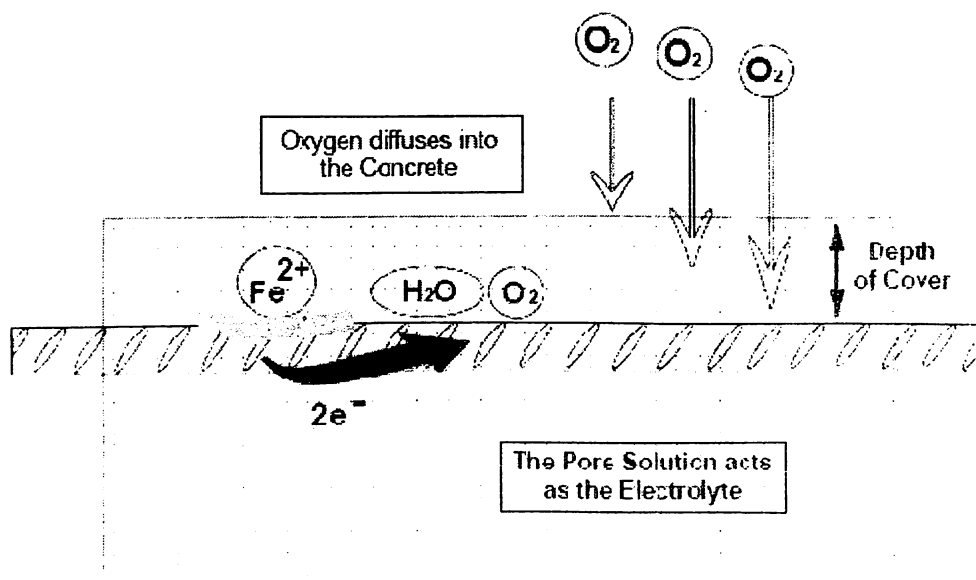


Figure 1: Procedure of corrosion

1.2 Importance of Cathodic protection system and Corrosion Control

During the laying of the pipeline the temporary Cathodic protection system is very necessary as because corrosion not only makes the pipeline unsafe for transmission of products but it also accounts for around 5.7% for breakdown problems. Generally the maximum amount of corrosion takes place during laying but mostly companies do not reckon it and leave the pipeline uncovered and directly design the permanent cathodic protection system. This causes the corrosion rate to increase inexplicably and installing the permanent cathodic protection will not help improve the situation.

So a better and cost effective temporary cathodic protection system has to be designed which will give the basic idea of the protection requirements and will effectively highlight the necessity for the protection from corrosion.

For the analysis of corrosion a methodology is developed which will give a brief idea about how to proceed in corrosion related problems.

1.3 Methodology Involved in Cathodic Protection System Designing

Firstly the surface area of the pipe is calculated.

Then the current required to protect the pipe from the corrosion is calculated.

After this the weight of anode required is calculated

Then the number of anode required by ground bed resistance is calculated.

Anode to backfill (gypsum, bentonite) resistance is calculated.

Cable resistance is calculated after that

Now these all resistances added together to give total resistance value.

By simply applying ohm's law i.e. $V=IR$ we can get the value of current delivering capacity.

The output current is divided with required current to get the value of number of beds required to protect pipeline from corrosion.

1.4 Problems investigated in this thesis

- Different types of corrosions in oil and gas pipelines and their remedial measures that can taken to control or arrest corrosion.

Temporary Cathodic protection system designing for 133 kms, 30 " dia,dadri-panipat R-LNG Spur line, software development.

Permanent Cathodic Protection system designing for 133 kms, 30 " dia,dadri-panipat R-LNG Spur line, software development.

Designing of longitudinal Extent of Corrosion in pipeline a case study, designing with assumptions.

Over last three decades many of researchers, scientists have performed several numbers of experiments and there is a vast development in this field as

Fontana & Greene in year 1978 has given eight forms of corrosion and their ill effects.

Baeckmann and Schewnk in year 1971 has given idea about the implementation of Cathodic protection in the field of buried pipelines; storage tanks; tank farms; telephone, power and gas-pressurized cables; ships; harbour installations; and the internal protection of water tanks and industrial plants and the problems of high-tension effects on pipelines

Kelly, Scully, Shoesmith and Buchheit in year 1990 emphasized on practical fundamentalist hat make it possible to determine whether electrochemical techniques are of use for a given problem of corrosion

Jones in year 1992-96 has given different polarization methods to measure corrosion rate.

Talbot in year 1998 has given a new approach as the interaction of metallic substances with the environment they are subjected to this helped in a great deal in preventing and arresting corrosion.

Schweitzer in year 2003 has given an idea about how corrosion is not only restricted to metallic materials but also to material of construction.

Bardal in year 2004 emphasized on the wet corrosion being most dangerous form of corrosion.

Perez in year 2004, has given an idea about corrosivity-passivity relationships.

An Indian scientist Joshi in year 2005 working as a corrosion specialist in Bry Air (asia) Pvt Ltd has presented a paper which focussed on economic aspects of corrosion, emerging areas/applications where corrosion prevention is becoming a “must” as well as the corrosion phenomenon and its prevention through humidity control.

Eltron Research & Development in year 2007 has given an idea of Ceramic coatings as it can withstand the combination of high temperature and corrosive environments. However, adhering ceramic coatings to a metal surface is difficult due to the difference in thermal expansion of the materials.

Argent in year 2008 has performed experiments to check the feasibility and viability of different coatings to prevent against corrosion.

In its broadest sense, corrosion can be defined as the deterioration of a substance or its properties because of a reaction with its environment. Primarily in the oilfield, it is more specific to say the concern is with the destruction of metal by a chemical reaction with a given environment, caused by existence of an electrochemical mechanism. This overview specifically addresses metallic corrosion. Deterioration of non-metallic materials is beyond the scope of this document.

3.1 Nature of Corrosion reactions

3.1.1 Corrosion by Water

Nearly all corrosion problems which occur in oilfield production operations are due to the presence of water. In order to corrode, the metal surface must be in contact with a water phase. For example, if a well produces at a high oil-to water ratio, very little corrosion is likely to occur because the water is mixed with oil as an oil-external emulsion. On the other hand, in low oil-to-water ratio wells, corrosion occurs because free water contacts the metal surface.

3.1.2 Voltage Source

The source of voltage (driving force) in the corrosion process is the energy stored during the refining process. Due to the difference of free energy values of various metals, these voltages are different for each metal. Potential values are a function of both the metal and the chemical and physical characteristics of the water.

3.1.3 Electrical Circuits

A **metallic return path** is necessary for the electrons generated at the anode to travel to the cathode where they are consumed. Electrical current flow is actually this passage of electrons

through the metallic path. In corrosion terminology, the conventional or positive current is usually used to indicate the direction of current flow. Therefore, corrosion currents flow from the anode to the cathode in the electrolyte and from cathode to anode in the metallic circuit.

3.1.4 Polarization

As was explained in the previous Section, an electrical circuit is formed between the Cathode and anode, thus allowing a potential difference to be established between them. It is this shift in potential as the corrosion current flows that is termed polarization.

The effects of polarization are also important in galvanic (bimetallic) corrosion.

3.2 Nature of Metals

3.2.1 in homogeneities in Metal Surfaces

Metal atoms do not necessarily dissolve at a single point on a metal surface, nor are cathode areas restricted to one area on the surface. The reason certain areas of the metal surface act as anodes centres on the in homogeneities in the metal surface, in the electrolyte or both. Potential differences on the metal surface are a natural result and are a primary cause of the initiation of localized corrosion cells. The type of corrosion that occurs usually gives a clue as to the major cause.

3.3 Effect of Electrolyte Composition

There are two aspects to the effects of electrolyte composition on the corrosion circuit. The first is the conductivity of the electrolyte and the effect of electrolyte on the base corrosion potential of the system. The second has to do with the presence or absence of oxidizing agents which are necessary for the cathodic portion of the corrosion cell. The anodic reaction cannot occur in the absence of a corresponding reaction at the cathode, regardless of the Conductivity of the cathode.

3.3.1 Conductivity

The electrical resistance of typical electrolytes is usually much higher than that of metal; therefore the resistance of the electrolyte will normally predominate in the corrosion cell reaction. The more conductive the electrolyte, the easier current can flow and the faster corrosion will occur. The amount of metal that dissolves is directly proportional to the amount of current flow between anode and cathode.

3.3.2 Dissolved Gases

Oxygen, carbon dioxide, or hydrogen sulphide gases, when dissolved in water, increase its corrosivity. Dissolved gases are the primary cause of most corrosion problems in oil and gas production.

3.4 Physical Variables

The variables of temperature, pressure, and velocity need to be accounted for when designing and implementing a corrosion control program always.

3.4.1 Temperature

Like most chemical reactions, corrosion rates generally increase with temperature. For example, in a system open to the atmosphere, the corrosion rate generally increases with increasing temperature until the concentration of dissolved gases decreases.

3.4.2 Pressure

Pressure also affects the rates of corrosion reactions. More gas goes into solution as the pressure increases, which may, depending on the dissolved gas, increase the corrosivity of the solution.

3.4.3 Velocity

Velocity has a significant effect on corrosion rates. Stagnant or low velocity fluids usually give low general corrosion rates, but pitting rates may be high. Corrosion rates generally increase with increasing velocity due to the depolarising effect on the cathode.

3.5 Forms of Corrosion

3.5.1 Uniform Corrosion

Uniform corrosion is a weight loss corrosion where the area of metal loss is spread over a relatively large area so that the surface is attacked uniformly. This type of corrosion can be common in atmospheric corrosion of industrial or marine locations. Strong uninhibited acids will uniformly corrode steel very rapidly. In general, however, uniform corrosion occurs gradually thus failures take longer to occur. Uniform corrosion can be addressed in original design criteria by adding a corrosion allowance to design metal thickness.

3.5.2 Pitting Corrosion

Pitting is the most common cause of corrosion failures occurring in oil and gas industry production equipment. It occurs when the metal undergoing corrosion suffers metal loss at localized areas rather than over a large area or the entire surface area. The entire driving force of the corrosion reaction is concentrated at these localized areas. The corrosion rate at these areas will be many times greater than the average corrosion rate over the entire surface. Pitting is much more dangerous than uniform corrosion because the pitted area can become penetrated in a short time.

Stainless steels are the most susceptible ferrous alloys to pitting, primarily because of the very properties that make them stainless. Stainless steels derive their corrosion resistance from the formation of a thin iron chromium oxide film and the ability to maintain that film. If the film becomes destroyed at local areas, those areas become anodic and pitting results.

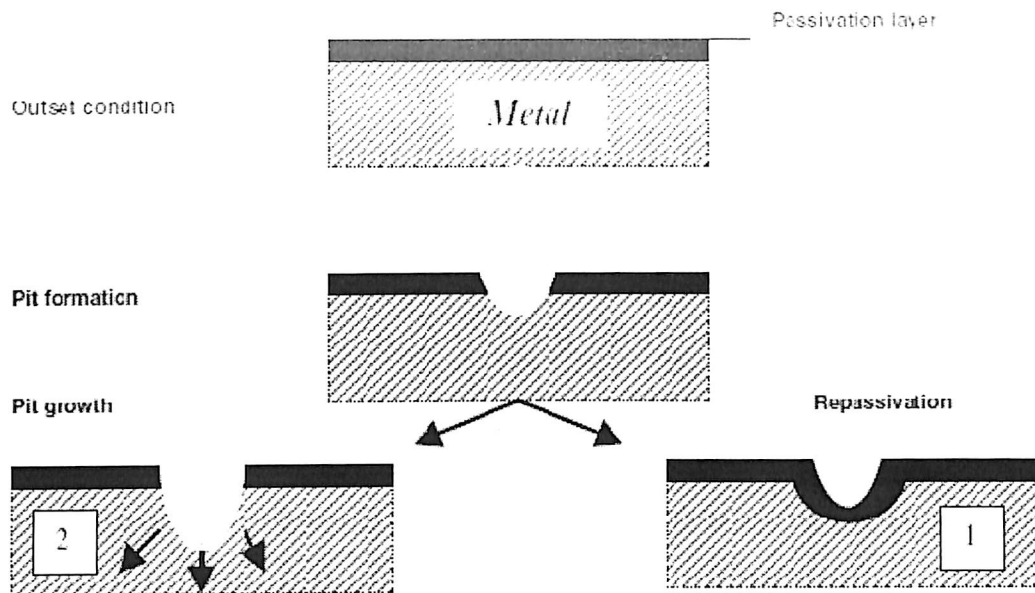


Figure 2:Pitting Corrosion

3.5.3 Bimetallic Corrosion

When two dissimilar metals are placed in electrical contact in electrolyte containing an oxidizing agent, the more reactive one will corrode and the other may either not corrode at all, or will corrode at reduced rate, depending upon the extent of polarization of the cathode. This coupling of dissimilar metals is referred to as a bimetallic couple or a galvanic cell. It can be destructive, accelerating the corrosion rate of the more reactive of the two metals.

It is important to know that coupling dissimilar metals together in a neutral pH, non-aerated fluid may not cause corrosion. The fluid has to be corrosive to at least one member of the dissimilar metal couple for bimetallic corrosion to occur.

3.5.4 Flow Enhanced Corrosion (Erosion Corrosion)

Most metals depend on the formation and maintenance of a protective scale for corrosion resistance. Removal of this scale at local areas can lead to accelerated attack. High velocity flow or turbulence can erode away the protective scale to expose fresh metal to corrosive attack. The combination of the erosion of the scale and corrosion of the underlying metal is

termed flow enhanced corrosion (erosion corrosion). Carbon steel piping systems and down hole tubing must be designed to maintain velocities below the API RP 14E critical velocity.

3.5.5 Cavitation Corrosion

Although corrosion normally plays a minor role in the rate of cavitation damage, it is important to recognize its effect. Cavitation is the formation and collapse of vapour bubbles in fluids because of rapid changes in pressure. It can occur whenever the absolute pressure at a point in the liquid stream is reduced to the vapor pressure of the fluid so that bubbles form, and this is followed by a rapid rise in pressure resulting in bubble collapse.

3.5.6 Intergranular Corrosion

Intergranular corrosion is preferential attack of a metal's grain boundaries. Intergranular corrosion can occur in the absence of stress. It is caused by precipitation of impurities at grain boundaries, or changes in the alloying elements at the grain boundary areas. For example, depletion of chromium in the grain boundary of stainless steel can be lead.

3.5.7 Hydrogen Induced Failures

Hydrogen atoms may be produced on a metal surface in an aqueous environment by a corrosion reaction, Cathodic protection, electroplating or acid pickling. Some of the hydrogen atoms combine to form gaseous molecular hydrogen (H_2) on the metal surface and are released to the environment. A portion of the atoms are absorbed by the metal and this entry of hydrogen atoms into the metal may have some very undesirable effects. Hydrogen induced cracking (HIC) and hydrogen embrittlement are two types of phenomena that can occur.

Hydrogen entry into high strength steels or steels with a hardness above 22 HRC can result in hydrogen embrittlement. A material can fail in a brittle manner at stresses well below its nominal yield strength. Hydrogen embrittlement is normally limited to high strength materials due to the fact that these materials reach tensile strengths high enough to initiate the failure

3.5.8 Sulphide Stress Cracking (SSC)

Sulphide stress cracking is a spontaneous brittle failure that occurs in steels and high strength alloys when exposed to moist hydrogen sulphide. This phenomenon is also referred to as sulphide cracking, sulphide corrosion cracking, and sulphide stress corrosion cracking. All the names refer to the same corrosion phenomenon, hydrogen embrittlement which requires that hydrogen sulphide be present, water (even in minute quantities) a high strength material, and tensile stress (either applied or residual). Sulphide stress cracking (SSC) may occur very rapidly after exposure to a sour environment, or it may take place after considerable time has passed.

3.5.9 Stress Corrosion Cracking (SCC)

Stress corrosion cracking is caused by the synergistic action of a corrosive medium and applied tensile stress; that is, the combined effect of the two is greater than the sum of the single effects. In absence of the corrodent, the alloy could easily support the stress. The stress is always a tensile stress and can be either applied or residual. When a metal suffers stress corrosion cracking, metal loss from corrosion is generally very low, although most likely, pits will occur and the cracks will develop in the base of the pits. All alloys are subject to stress corrosion cracking. Stress corrosion cracking results from exposure of a particular alloy to a particular corrosive medium.

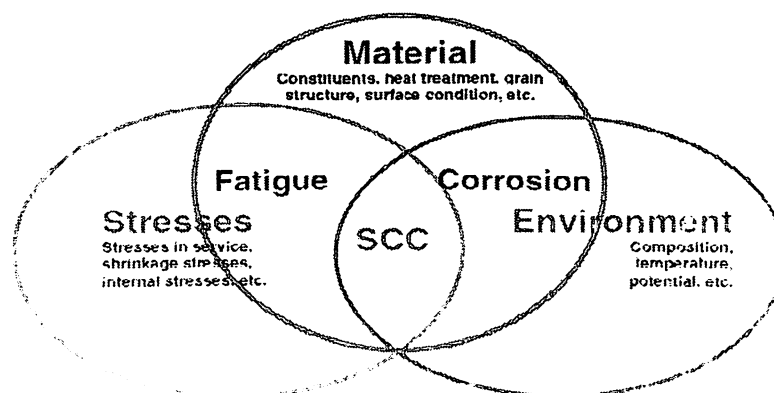


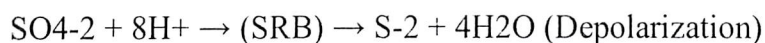
Figure 3 : Stress Corrosion Cracking

3.5.10 Corrosion Fatigue

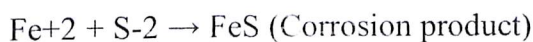
When metals are repeatedly stressed in a cyclic manner, they will fail in a brittle manner at stresses far below the yield or tensile strength of the material. There exists a limiting stress below which steel may be cyclically stressed indefinitely without failure. This stress is called the endurance limit and is always lower than the yield and tensile strengths. The fatigue life of metal is substantially reduced when the metal is cyclically stressed in a corrosive environment.

3.5.11 Microbiologically Influenced Corrosion (MIC)

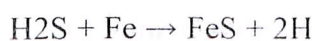
Microbiologically influenced corrosion is pitting type corrosion. Microorganisms can exert considerable influence on the corrosion rate. The type of bacteria most commonly associated with corrosion in oilfield operations is the sulphate reducing bacteria (SRB). The metabolic process of the SRB reduces sulphates to sulphides and consume large quantities of hydrogen in the process to produce H₂S. The polarization film in the cathode areas provide the hydrogen; therefore, the SRB act as strong depolarizes which causes accelerated corrosion rates. Bacteria can be controlled with bactericides. The following describes the SRB depolarization process:



In addition to the depolarizing effect, the production of hydrogen sulphide (H₂S) will accelerate the corrosion process as shown below:



or simplified H₂O



3.5.12 Oxygen Corrosion

Water produced with oil seldom contains dissolved oxygen; however, oxygen corrosion can be found in downhole and surface facility equipment. It is usually caused by careless operating techniques, faulty equipment or by oxygen rich wash water used for desalting. The presence of CO₂ or H₂S drastically increases the rate of oxygen corrosion.

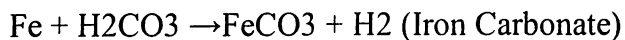


OR



3.5.13 Sweet Corrosion

Sweet corrosion results from the presence of water containing dissolved carbon dioxide. Dissolved carbon dioxide (CO₂) in water decreases the pH of the water and increases its corrosivity.



It should be noted that the corrosion rates experienced in reality are higher than indicated by these summary reactions.

The most serious sweet oil corrosion problem can usually be found in gas lift wells. They are usually high water producers, and corrosion can be accelerated if the injected gas lift gas contains carbon dioxide and/or small amounts of oxygen.

3.5.14 Sour Corrosion

Corrosion caused by hydrogen sulphide dissolved in water is referred to as sour corrosion. In oil well tubing, hydrogen sulphide can cause the development of scattered

pits with cone shape sides leading to a rounded bottom. Black iron sulphide (FeS) scale will usually be present. The Cathodic nature of the iron sulphide scale results in the pitting of the underlying steel. Equipment in high-pressure sour gas wells may fail due to sulphide stress cracking, hydrogen embrittlement, or hydrogen induced cracking. Severe pitting corrosion can also occur in sour gas wells. Corrosion on the interior of oil or sour water storage tank roofs (fixed roof design tanks) begins when condensed water droplets are saturated with hydrogen sulphide. The extensive pitting which results can perforate the tank deck. The interior bottoms of oil storage tanks are also subject to attack because of the layer of water which usually forms at the bottom under the oil. Additionally, corrosion scale falling from the top to the bottom of the tanks may cause corrosion concentration cells. Corrosion of the shell of oil tanks is normally negligible. However, sour saltwater tanks will be subject to roof, wall, and floor internal corrosion.

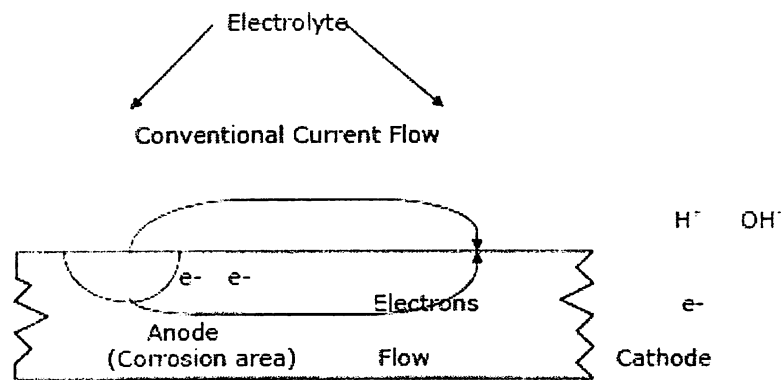


Figure 4:Corrosion Cell

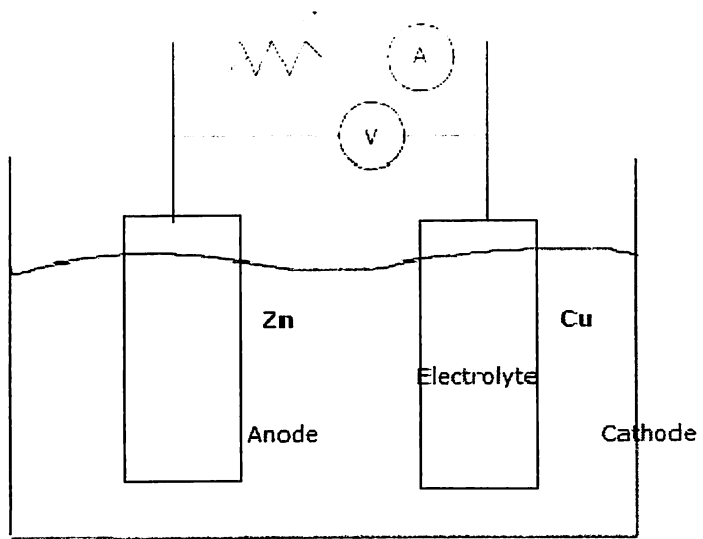


Figure 5: Zinc Copper Corrosion Cell

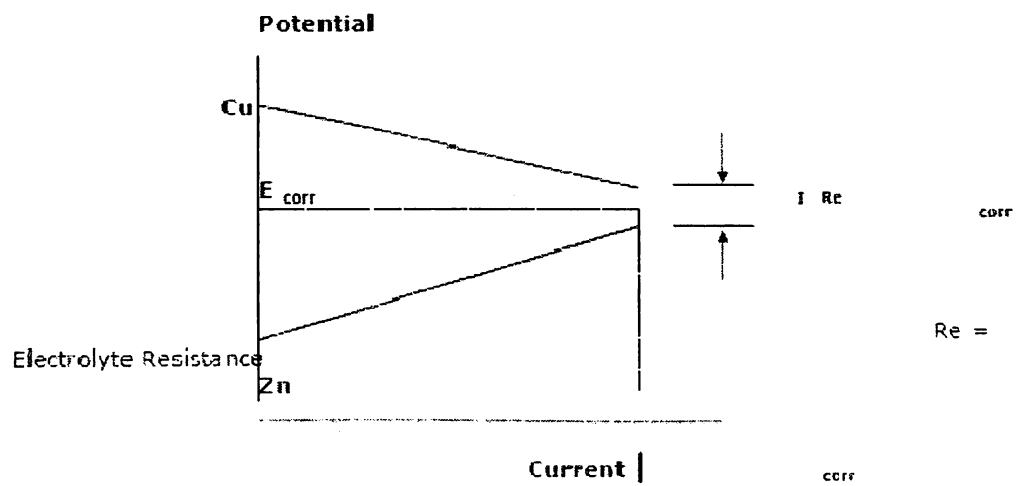


Figure 6: Polarisation Curve

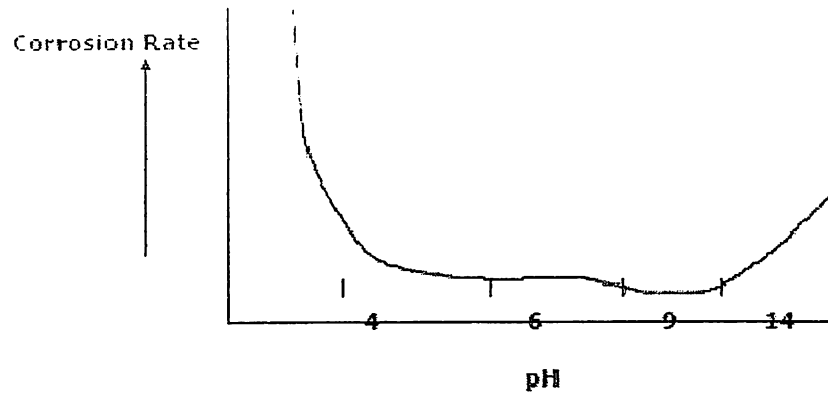


Figure 7: Corrosion Rate of steel V/S pH

3.6 Cathodic Protection

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.

Galvanic anode systems employ reactive metals as auxiliary anodes that are directly electrically connected to the steel to be protected. The difference in natural potentials between the anode and the steel, as indicated by their relative positions in the electro-chemical series, causes a positive current to flow in the electrolyte, from the anode to the steel. Thus, the whole surface of the steel becomes more negatively charged and becomes the cathode. The metals commonly used, as sacrificial anodes are aluminium, zinc and magnesium. These metals are alloyed to improve the long-term performance and dissolution characteristics. Impressed-current systems employ inert (zero or low dissolution) anodes and use an external source of dc power (rectified ac) to impress a current from an external anode onto the cathode surface. The connections are similar for the application of Cathodic protection to metallic storage tanks, jetties, offshore structures and reinforced concrete structures.

3.6.1 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 harbour 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 pipediameters, 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 harbour structures, etc.)

Control. Corrosion and Protection of Steel in Concrete and its Monitoring. Cathodic protection can be applied to copper-based alloys in water systems, and, exceptionally, to lead-sheathed cables and to aluminium alloys, where cathodic potentials have to be very carefully controlled.

3.6.2 Basic Requirements for Cathodic Protection

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:

3.6.2.1 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.

3.6.2.2 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:

Electrical continuity:-The resistance of the conductor and structure should be such as to minimise the potential drop of the return protective currents through the structure.

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 result 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.

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. Polarisation 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.

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.

3.6.3 Design Factors

3.6.3.1 Initial considerations

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.

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

3.6.3.2 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 minimise 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 grounded and, for pipelines, will attenuate towards the natural corrosion potential as the distance from the anode or grounded increases.

3.6.3.3 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 localised protection
- d)** less liable to cause interaction on neighbouring 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 aluminium 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 minimise 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 favour for small well coated, low current demand, structures or for localised, protection. Impressed current schemes are utilised 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.

3.6.3.4 Problems to be avoided

There are certain limitations to the use of cathodic protection. Excessive negative potentials can cause accelerated corrosion of lead and aluminium 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 embrittlement of the steel, with subsequent loss of strength. On some high strength steels, this may lead to catastrophic failures. It may also cause disbondment of coatings; the coating would then act as an insulating shield to the cathodic-protection currents.

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.

3.6.4 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 aeroplane, 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.

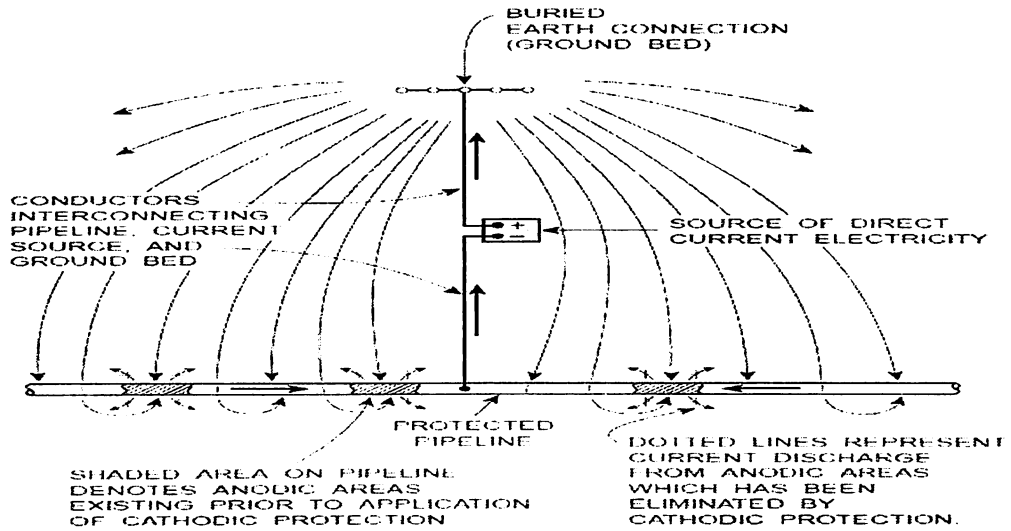


Figure 8: Cathodic Protection

DESIGNING PROCEDURE

4.1 Temporary Cathodic protection of Dadri-panipat pipeline

30",133 kms R-LNG Spur LINE

Formula

surface area of pipeline

$$Sa=3.14*D*L$$

Current requirement

$$It=Sa*Cd*Sf/1000$$

Anode weight

$$W=It*Cd*Y/Ur$$

Anode to earth resistance for multiple

anode

$$R=.159*\rho/NL\{Ln(8L/D)-1+2L/S\{Ln(.656N)\}}$$

Parameter

where

Sa=surface area

L=length of pipeline

D=diameter of pipeline

where

Cd=current

density

Sf=safety margin

where

It=total current requirement

Ca=Anode consumption rate

y=design life

Ur=utilisation

factor

where

R=resistance to earth in Ω of the vertical

anodes

in parallel

ρ =Soil resistivity in Ω -m

N=number of anodes in parallel
 L=length of anode in mt
 D=diameter of prepacked anode in mt.
 S=anode spacing in mt.

Anode to earth resistance for single anode

$$R = .159 * \rho / NL (\ln(8L/D) - 1)$$

Anode to backfill resistance

$$R_v = .159 * \rho / NL (\ln(8L/D) - 1)$$

where
 R=resistance of vertical anode to backfill in Ω
 ρ =resistivity of backfill material in Ω -m
 L=length of bare anode in mt
 D=diameter of bare anode in mt.

Cable resistance

$$R_c = (R_t * L_t) / N$$

where
 R_c=total resistance of anode tail cable in Ω
 R_t=resistance of anode tail cable in Ω
 N=no.of anodes

Driving voltage of anode

$$V_t = V_c - V_p$$

where
 V_t=Driving potential of anode
 V_c=closed circuit potential of anode
 V_p=polarised potential

Current delivering capacity of anode

$$I_a = V_t / R_t$$

where
 I_a=current delivery capacity of anode
 V_t=Driving potential of anode
 R_t=Ground bed resistance

Number of Anode by current requirement

$$N=I_t/I_a$$

where

N=number of anode

I_t =total current requirement

I_a =anode output

SPECIMEN CALCULATION

CALCULATIONS FOR TEMPORARY CATHODIC PROTECTION

Step 1-SURFACE AREA CALCULATION

Pipeline section-	Dia(m)	Chainage, KM	pipeline length,m	Coating used	Surface area,m2
DADRI-PANIPAT	0.762	0-20	20000	Dual layer FBE	47853.6
DADRI-PANIPAT	0.762	20-132	112000	Coal tar enamel	267980.16

Step 2-CURRENT REQUIREMENT

Current density considered for the temporary cathodic protection

For dual layer FBE coated pipeline 50 mA/m²

For Coal tar enamel Coated pipeline 125mA/m²

For 3LPE Coated pipeline 75 mA/m²

Safety factor -1.3

Pipeline section-	Dia(m)	Chainage, KM	pipeline length,m	Coating used	Surface area,m2	Current density,A	Current reqd,A
DADRI-PANIPAT	0.762	0-20	20000	Dual layer FBE	47853.6	0.05	3.110484
DADRI-PANIPAT	0.762	20-132	112000	Coal tar enamel	267980.16	0.125	43.546776

Step 3-ANODE WEIGHT REQUIREMENT

Consumption rate (Ct),kg/amp-year-0.79

Design Life(L),years-3

Anode utilisation factor(Uf)-0.85

Anode size(D/L),m	Chainage,KM	Individual anode weight,kgs	total anode requirement,kgs	total(nos)
0.08	0-20	7.6	26.018	11.508
0.9	20-132	7.6	391.920	173.355

Step 4-NUMBER OF ANODE REQUIRED BY GROUND BED RESISTANCE

soil resistivity(ohm-m)-10

Number of anodes in parallel-3

length of prepackaged anode,m-1.5

Diameter of prepackaged anode,m-0.185

anode spacing,m-3

resistance to earth in ohms of the vertical anodes in parallel,R-3.199001151

for 3 nos of anodes -1.066333717

Step 5-ANODE TO BACKFILL RESISTANCE

Resistivity of backfill, Ω -m-0.5

length of anode,m-0.9

diameter of anode,m-0.08

Anode to backfill resistance, R_v -0.309149854

Step 6-CABLE RESISTANCE

cable resistance of copper conductor $1C*6mm^2$, Ω/m , R_a -0.00308

length of cable,L in m-6

number of anodes-3

Total cable resistance, R_c ,ohms-0.00616

Step 7-TOTAL CIRCUIT RESISTANCE

resistance to electrolyte of groundbed, Ω ,R

number of anodes in each ground bed,N

cable resistances, R_c -

Total circuit resistance-1.175543668

Step 8-CURRENT DELIEVERING CAPACITY OF ANODE

Current output per anode bed(Amps), I_a

Driving potential for Mg anodes(1.75-.90), $V-0.85$

total circuit resistance, R_t

Current output per anode bed, $A-0.723069693$

so,total current output per anode bed, A is $.723069693 A$ and current required

is for section 1= 3.11084 and for section 2= 42.534

there fore $3.11084/.723069693=4.3022$ (5 beds) for section 1

and for $42.534/.723069693=58.82$ (59 beds) for section 2

Note:- The values of actual anode required and calculated may vary upto 12 to 14 % as the variations due to ambience can be taken into effect--so its always better to provide more protection than the actual calculated value

SPECIMEN CALCULATION

4.2 Calculations for Permanent Cathodic Protection

DESIGN FORMULA

1. Surface Area of Pipeline to be Protected - Sa (m²)

$$Sa = (\pi) \times D \times L$$

Where: D - Diameter of Pipeline(m)

L - Length of Pipeline(m)

2. Current Required for Protection - It (Amp)

$$It = Sa \times Cd \times Cbr \times Sf$$

Where: Sa - Surface Area of Pipeline(m²)

Cd - Protective Current Density(mA/m²)

Cbr - Coating breakdown ratio

Sf - Safety Factor

3 Total Circuit Resistance - RT (Ohms)

3.1 Pre-packaged Anode Bed to Earth Resistance in Vertical Configuration - Rav(ohms):

$$Rah = \frac{0.159 \times r}{L} \left[\ln\left(\frac{8L}{d}\right) - 1 \right]$$

Where: r - Soil Resistivity(Ohm-m)
 L - Length of Active Anode Column (m)
 d - Diameter of Active Anode Column (m)

3.2 Pre-packaged Anode Bed to Earth Resistance in Horizontal Configuration - R_{ah} (ohms):

$$R_{ah} = \frac{0.159 r}{L} \left[\frac{4 L^2 + 4 L (S^2 + L^2)^{0.5}}{dxS} + \frac{S}{L^{0.5}} \right] \ln \left(\frac{S + L}{S - L} \right) + 1$$

Where: r Soil Resistivity(Ohm-m)
 L - Length of Pre-Packaged Anode(m)
 d - Diameter of Pre-Packaged Anode(m)
 S - Twice Depth of Anode(m)

3.3 Resistance of single anode to backfill in vertical configuration - R_{av} (ohms):

$$R_{av} = \frac{0.159 \cdot r}{L} \left[\ln \left(\frac{8L}{d} \right) - 1 \right]$$

Where: r - Resistivity of Backfill Material (Ohm-m)

L - Length of Anode (m)

d - Diameter of Anode (m)

3.4 Cable Resistance - R_c (ohms)

$$R_c = R_a + R_{pc} + R_{nc}$$

Where:

R_a - Anode tail cable resistance (ohms)

R_{pc} - Positive header cable resistance (ohms)

R_{nc} - Negative header cable (ohms)

3.5 Anode tail Cable Resistance - R_a (ohms)

$$R_a = R \times L_m$$

Where:

R - Anode Tail cable resistance per meter (ohms)

L_m - Maximum anode tail cable length (m)

3.6 Positive header Cable Resistance - R_{pc} (ohms)

$$R_{pc} = R \times L_m$$

Where:

R - Positive header cable resistance per meter (ohms)

L_m - Maximum Positive header cable length (m)

3.7 Negative header Cable Resistance - R_{nc} (ohms)

$$R_{nc} = R \times L_m$$

Where:

R - Negative header cable resistance per meter (ohms)

L_m - Maximum Negative header cable length (m)

3.8 Total Circuit resistance - R_T (ohms)

$$R_T = R_{av} + R_{avs} + R_c$$

Where:

R_{av} - Single pre-packaged anode to earth resistance (Ohms)

R_{avs} - Resistance of single anode to backfill (Ohms)

R_c - Cable resistance (Ohms)

**4 Transformer Rectifier Unit DC output Rating As per
Ground bed design (Volts)**

$$V = I \times RT$$

Where:

I - Proposed TRU Rating(Amp)

RT - Total Circuit Resistance(Ohms)

5 Cross sectional area of pipe - A (m²)

$$A = (22/7) \times t \times (D-t)$$

Where: t - Thickness of Pipe(m)

D - Diameter of Pipe(m)

6 Linear resistance of pipe - Rs (Ohms)

$$Rs = x I / A$$

Where:

- Resistivity of Steel Pipe(Ohm-m)

I - Unit Length of pipe(1000 m)

A - Cross Section Area of Pipe(m²)

7 **Coating leakage resistance of pipe - RI (Ohms)**
RI = Rp / Sak
Where: Rp - Coating Resistance of Pipe(Ohm-m2)
Sak - Surface Area of 1 Km of Pipe(m2)

8 **Attenuation Constant - a**
a = (Rs / RI)0.5
Where:
Rs - Linear Resistance of Pipe(Ohms)
RI - Coating Leakage Resistance(Ohms)

9 **Minimum Potential Shift at End Point - Ed (Volts)**
Ed = PSPmin - PSPnat
Where:
PSPmin - Least Negative PSP at End Point(Volts)
PSPnat - Natural PSP at End Point(Volts)

10 **Maximum Potential Shift at Drain Point - Ed (Volts)**
Edp = PSPmax - PSPnat
Where:
PSPmax - Maximum Negative PSP at Drain Point(Volts)
PSPnat - Natural PSP at Drain Point(Volts)

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

$$L_p = (1/a) \times \text{Cosh}^{-1}(E_{dp} / E_d)$$

Where:

a - Attenuation Constant

E_{dp} - Maximum Potential Shift at Drain Point(Volts)

E_d - Minimum Potential Shift at End Point(Volts)

12 Electrical Remoteness of Groundbed Calculation

$$V_e = (I) / (2 \times \rho \times d)$$

Where:

V_e - Voltage at pipeline (volts)

ρ - Soil Resistivity(Ohm-m)

I - Maximum Current Output(Amp)

d - Distance between Anode bed and Pipeline (m)

IMPRESSED CURRENT CP SYSTEM

Pipeline Details

Diameter of Pipeline(Inch)	30
Diameter Pipeline(m)	0.762
Length Pipeline(m)	13300
Thickness of Pipeline(m)	0.0175
Type of coating (CTE or 3LPE)	3LPE
Soil resistivity(Ohm-cm)	1000
Step 1:- Current Required	
Surface area to be protected (m²)	31822.644
Final Protective Current density (mA/m²)	0.05
Safety margin	1.3
Total Current required to protect the entire pipeline (I_T) in Amp	2.06847186
Step 2:-Resistance Calculation	
Anode tail cable length(A1)	35
Anode tail cable length(A2)	30
Anode tail cable length(A3)	25
Anode tail cable length(A4)	20
Anode tail cable length(A5)	15
Anode tail cable length(A6)	15
Anode tail cable length(A7)	20
Anode tail cable length(A8)	25

Anode tail cable length(A9)	30
Anode tail cable length(A10)	35
Anode tail cable resistance/mtr	0.00172
Length of prepackaged anode bed column (m)	44
Diameter of prepackaged anode bed (m)	0.3
Soil resistivity (Ohm-cm)	800
Twice depth of anode (m)	4
prepackaged anode bed to earth resistance (R_{GB}) in Ohms (Vertical configuration)	1.754089E-01
Individual prepackaged anode to earth resistance (R_{GB}) in Ohms (Horizontal configuration)	0.218389228
Cable resistance (R_C) in Ohms	0.102442803
Anode tail cable resistance (R_A) in Ohms	0.004442803
Positive header cable resistance (R_P) in (Ohms)	0.0735
Specific resistance of Positive header cable (Ohm/m)	0.00049
Length of Positive header cable (m)	150
Negative header cable resistance (R_N) in (Ohms)	0.0245
Specific resistance of Negative header cable (Ohm/m)	0.00049
Length of Negative header cable (m)	50

Structure/Pipeline to earth resistance (R_s) in Ohms

Total Circuit resistance (R_T) in Ohms (Vertical or deep well)

0.277851718

Total Circuit resistance (R_T) in Ohms (Horizontal configuration)

0.32083203

Step 3:-Attenuation Calculations

Resistivity of Steel Pipeline (Ohm-m)

0.00000018

Coating Resistance of Pipeline (Ohm-m²)

18000

Natural PSP at end point (Volts)

0.9

Least negative PSP at end point (Volts)

0.45

Maximum PSP at Drain Point (Volts)

1.18

Cross Section Area of Pipeline (m²)

0.040910275

Surface Area of unit length of pipeline(m²/m)

2392.68

Linear resistance of pipe - R_s (ohms)

0.004399873

Coating leakage resistance of pipe - R_l (ohms)

7.522944982

Attenuation constant - α

0.024183887

Minimum Potential shift at end point - E_d (Volts)

0.45

Maximum Potential shift at drain point - E_{dp} (Volts) 0.73

Length of Pipeline Protected from Drain Point - L_p (kms) 44.01942343

4.3 Determination of maximum allowable longitudinal extent of corrosion

$$L = 1.12 * B * \sqrt{D * t}$$

$$B = \sqrt{\left(\frac{d/t}{\frac{1.1d}{t} - .15}\right)^2 - 1}$$

D = Nominal outside dia of the pipe, in

L = Maximum allowable longitudinal extent of the corroded area, in

d = Maximum depth of corroded area, in

t = Nominal wall thickness of the pipe, in

CALCULATIONS

$$t = 6.4 \text{ mm} = .251969 \text{ in}$$

$$d = 1.2 \text{ mm} = .0472441 \text{ in}$$

$$D = 30 \text{ in}$$

$$B = \sqrt{\left(\frac{.1220}{.2062 - .15}\right)^2 - 1} = \sqrt{3.7124} = 1.9267$$

$$L = 1.12 * 1.9267 * \sqrt{7.557} = 5.93 \text{ in}$$

So, 5.93 in is the value of maximum allowable longitudinal extent of corrosion after which pipe will fail and it will start leaking.

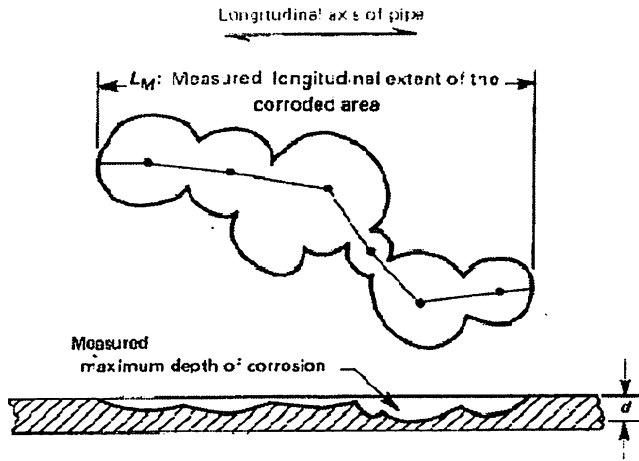


Figure 9: Longitudinal Extent of Corrosion

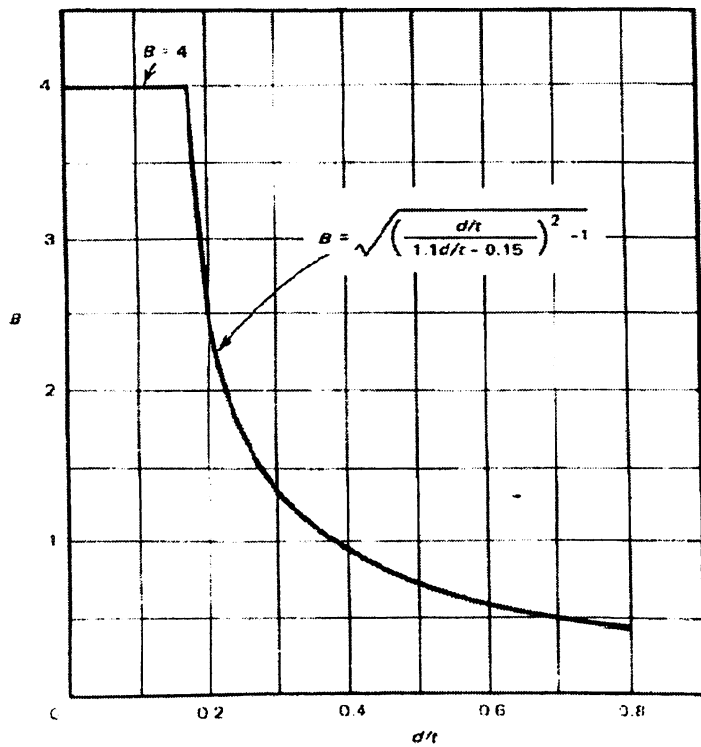


Figure 10: Method of determination of value of 'B'

A Excel programme is designed for the calculation of the required current value and the results are given below which depicts the variation in value of current with soil resistivity

Table 1 Anode current values

Soil resistivity(ohm-cm)	Anode output current amps/No. of anodes (7.6 kgs)			
	1	2	3	4
500	.319	.600	.819	1.207
700	.240	.449	.610	.763
1000	.175	.326	.441	.550
1200	.148	.372	.372	.464
1500	.120	.224	.302	.376
1800	.101	.188	.254	.316
2000	.091	.170	.229	.285
2500	.074	.137	.185	.230
3000	.062	.115	.155	.193
4000	.047	.087	.117	.145

This results concludes about:-

- 1.)The value of Current required decreases with the increase in the value of soil resistivity.
- 2.)Also with the combination of numbers of anodes in a single bed increases the value of current required.
- 3.)Designing of extent of corrosion will help in getting idea about the extent up to which a given pipeline will be corroded so, for that allowance can be given in advance to prevent it from getting corroded.

In future the the installation of Cathodic protection system in Horizontal Directional Drilling can be reviewed and work can be done thoroughly in this area.

As because during sub sea HDD installation after pipe pulling it is difficult to install CP system and inefficient improperly designed CP system always leads to an extra problem.

So, a better and cost effective system can be designed to meet these kind of problems.

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APPENDIX A

GALVANIC SERIES

(It helps in selecting the type of Anode)

Noble

(least active)

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 (passive)

67NI-33Cu alloy

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

Nickel (passive)

Silver solder

M-Bronze

G-Bronze

70-30 cupro-nickel

Silicon bronze

Copper

Red brass

Aluminum bronze

Admiralty brass

Yellow brass

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

(most 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

Magnesium

APPENDIX B

Various Applicable Codes Used

- ✓ **BS : 729** Zinc coating on iron and steel articles.
- ✓ **BS : 1589** Marking of main connections and small wiring.
- ✓ **IS : 7098** XLPE insulated cables
- ✓ **BS :CP:2008** Protection of iron and steel structures from corrosion.
- ✓ **BS :7361** Cathodic Protection
- ✓ **RS:CP:1013** Earthing
- ✓ **NACE RP-01-69** Recommended Practice control of External underground or submerged metallic piping systems.
- ✓ **NACE RP-02-86** The electrical Isolation of cathodically protected pipelines
- ✓ **ASTM -D 512 (81)** Test method for chloride Ions in water.
- ✓ **ASTM D 516 (82)** Test method for sulphate Ions in water.
- ✓ **ASTM D 1125 (82)** method for electrical conductivity and resistivity of watr
- ✓ **ASTM D 1126 (80)** Test method for hardness in water.

- ✓ **ASTM D 1293 (84)** Test method for pH of water.
- ✓ **ASTM D 1888 (78)** Test method for particulate and dissolved matter in water.
- ✓ **ASTM G 51 (84)** Test method for pH of soil for use in corrosion testing.
- ✓ **ASTM G 57 (84)** Method for field measurement of soil resistivity