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Cathodic protection – A proven corrosion control means in immersed or buried pipelines in oil, natural gas and petrochemical industries

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Abstract : Cathodic protection (CP) is an electrochemical means of corrosion control in which the oxidation reaction in a galvanic cell is concentrated at the anode and suppresses corrosion of the cathode in the same cell. In cathodic protection, the object to be protected is the cathode. Cathodic protection can, in principle, be applied to any metal. In practice, cathodic protection is primarily used on carbon steel The effectiveness of CP allows carbon steel, which has little natural corrosion resistance, to be used in such corrosive environments as sea water, acid soils, salt-laden concrete, and many other corrosive environments. Virtually all modern immersed or buried pipelines carrying high pressure hydro carbon (natural gas and petroleum products) are coated with an organic protective coating that is supplemented by cathodic protection systems to prevent corrosion at holidays in the protective coating. This combination of protective coating and CP is used on virtually all immersed or buried carbon steel structures, with the exception of offshore petroleum production platforms and reinforced concrete structures. Off shore platforms are usually uncoated but cathodically protected. Concrete structures normally rely on the protectiveness of the concrete cover to prevent the corrosion of embedded steel. When corrosion of embedded steel occurs because of a loss of this protectiveness, CP is sometimes used to extend the life of the already deteriorated structure. This paper reviews development in cathodic protection of underground pipeline in the new millennium in oil, natural gas and petrochemical industries

Key words : *Cathodic protection, Corrosion control, Pipeline corrosion, Natural gas, Petrochemical industries.*

INTRODUCTION

Underground and underwater steel pipes commonly are protected from corrosion by a combined application of coatings and cathodic protection (CP). Corrosion occurs when the coating develops pinholes or ruptures, known as holidays. Development of a holiday is accompanied by the loss of adhesion between steel and coating in the surrounding areas. Water then flows through the holiday and initiates corrosion on the steel surface.

To properly protect steel pipes against corrosion in soil and water, electrical current must penetrate into the holiday to polarize the steel surface to a potential more negative than – 0.85 V with respect to a saturated copper – copper sulfate (Cu – $CuSO_4$) reference electrode (or – 0.78 V with respect to a silver – silver chloride (Ag-AgCl) reference electrode. The CP criterion and its developmental trend have been reviewed in this paper.

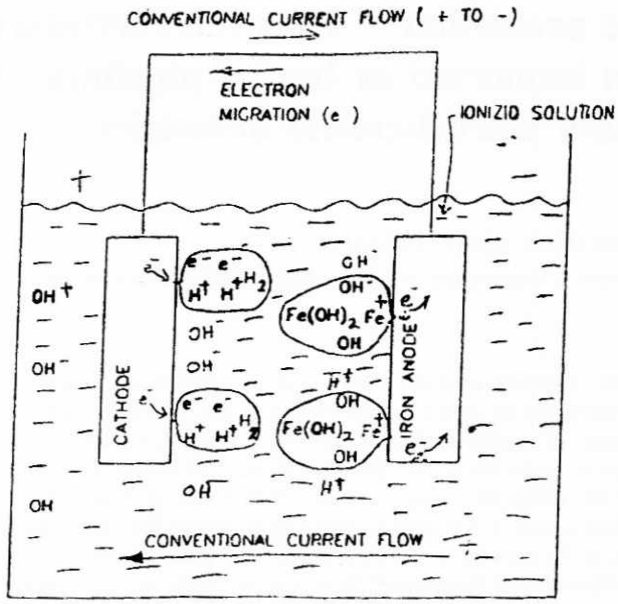

Fig. 1 : Diagramatic representation corrosion of iron.

THE BASIC CORROSION MECHANISM[1]

There are certain conditions which must be met before a corrosion cell can function as shown in Fig. 1. These are:

- There must be an anode and a cathode
- There must be an electrical potential between the anode and cathode.
- There must be a metallic path electrically connecting the anode and cathode (normally, this will be the pipeline itself)
- The anode and cathode must be immersed in an electrically conductive electrolyte.
- That conventional current flow from (+) to (-) will be from the cathodic to the anode in the metallic circuit.
- That conventional current flow from (+) to (-) will be from the anode to the cathode in the electrolyte.
- That metal is consumed where current leaves it to enter the surrounding electrolyte.
- That metal receiving current from the surrounding electrolyte does not corrode (except certain materials such as aluminium and lead (called amphoteric) which can corrode if receiving excessive amounts of current).

Types of Corrosion Cells on Pipelines

Dissimilar Metal Corrosion Cells

In emf and practical galvanic series, the one upper most normally will be the anode and the lower one the cathode e.g. an underground plain steel pipeline is built with copper

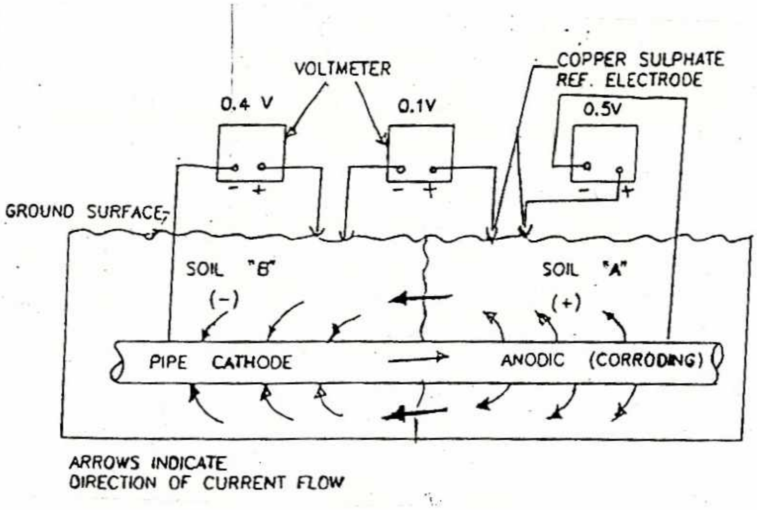

Fig. 2 : Corrosion from dissimilar soils.

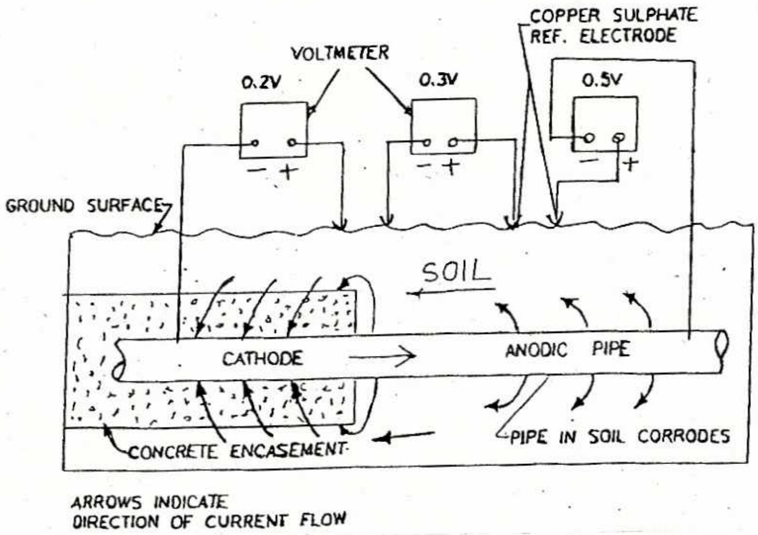

Fig. 3 : Steel in concrete.

branch lines (such as a steel gas distribution main with copper services). Unless the copper lines are electrically insulated from the steel pipe (insulating fittings are commercially available to accomplish this), conditions for dissimilar metal corrosion exist. That iron (steel) appears in the emf series above copper, indicating that steel will be anode and would corrode. In a low resistivity soil, the copper lines could produce aggravated corrosion of the steel main.

Corrosion resulting from dissimilar soil as shown in Fig, 2 and Fig. 3. Corrosion from differential aeration and corrosion of new steel in contact with old steel is shown in Figs. 4 and 5 respectively.

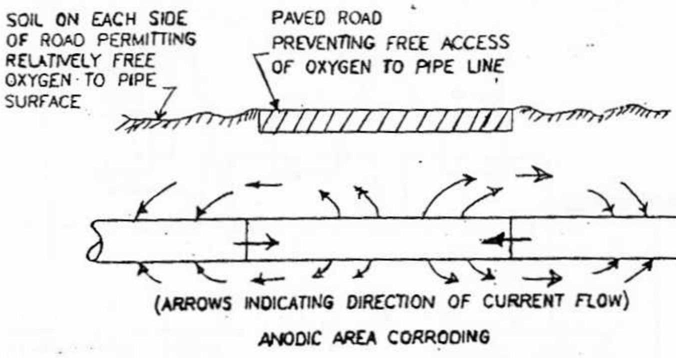

Fig. 4 : Corrosion from differential aeration.

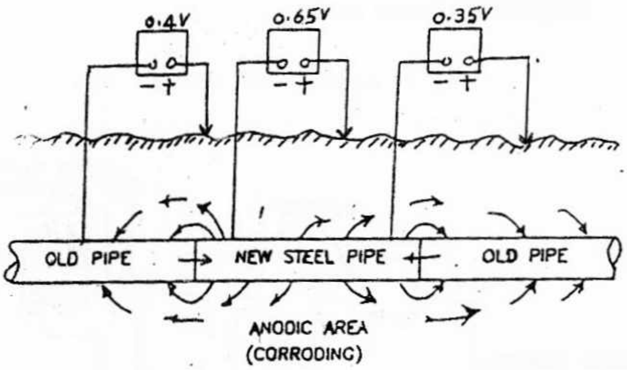

Fig. 5 : Corrosion of new steel in contact with old steel.

Corrosion Control Methods

Coatings

Gives a continuous film of an electrically insulating material over the metallic surface to be protected. This isolate the metal from direct contact with the surrounding electrolyte and also provide high electrical resistance in the anode-cathode circuit that there will be no significant corrosion current flowing from the anode to the cathode.

Insulated Joints

Insulated joints are used to break the metallic electrical connection between the anode and cathode and thereby prevent the flow of current as between the two. This method has limited applications. Insulated joints can, for example, be used at the junction of two dissimilar metals but obviously would not be effective in the control of localized corrosion cells on the surface of the structure.

Cathodic Protection

Cathodic protection is, very simply, the use of direct current electricity from an external source to oppose the discharge of corrosion current from anodic areas. When a cathodic protection system is installed, all portions of the protected structure collect current from

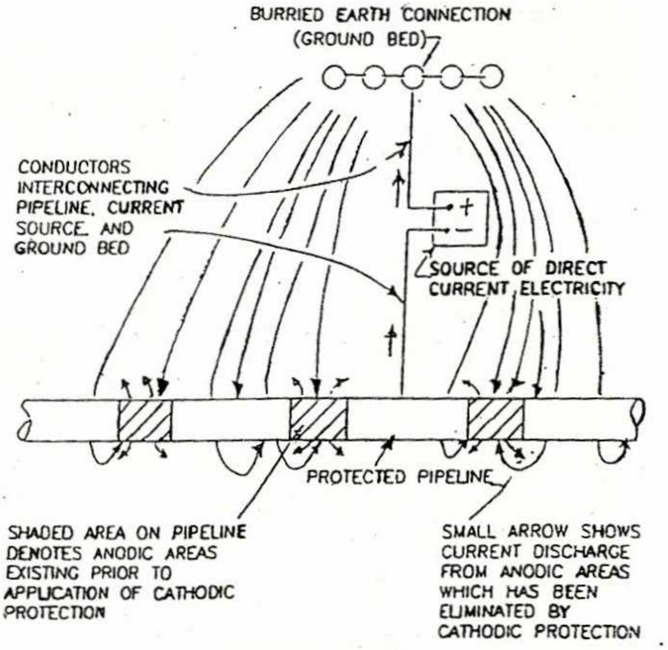

Fig. 6 : Basic cathodic protection installation in bare pipeline portion.

the surrounding electrolyte and the entire exposed surface becomes a single cathodic area, hence the name.

Cathodic Protection — How it Works ?

As shown in Fig. 6 direct current is forced to flow from a source external to the pipeline onto all surfaces of the pipeline. When the amount of current flowing is adjusted properly, it will overpower corrosion current discharging from all anodic areas on the pipeline and there will be a net current flow onto the pipe surface at these points. The entire surface then will be cathodic and the protection complete.

It can be said from the above that cathodic protection does not necessarily eliminate corrosion. It does, however, remove corrosion from the structure being protected and concentrates the corrosion at another known location. At this known location, the current discharging structure (group bed) can be designed for reasonably long life. It is also easily tested and replaced at the end of its useful life without endangering the pipeline system being protected. In discharging current to earth, the ground bed materials are subject to corrosion. Because the sole purpose of this ground bed is to discharge current, it is desirable to use materials which are consumed at much lower rates (pounds per ampere per year) than are the usual pipeline metals.

Practical application of cathodic protection

1. Cathodic protection with Galvanic Anodes (Fig. 7)
2. Cathodic Protection with Impressed Current (Fig. 8)

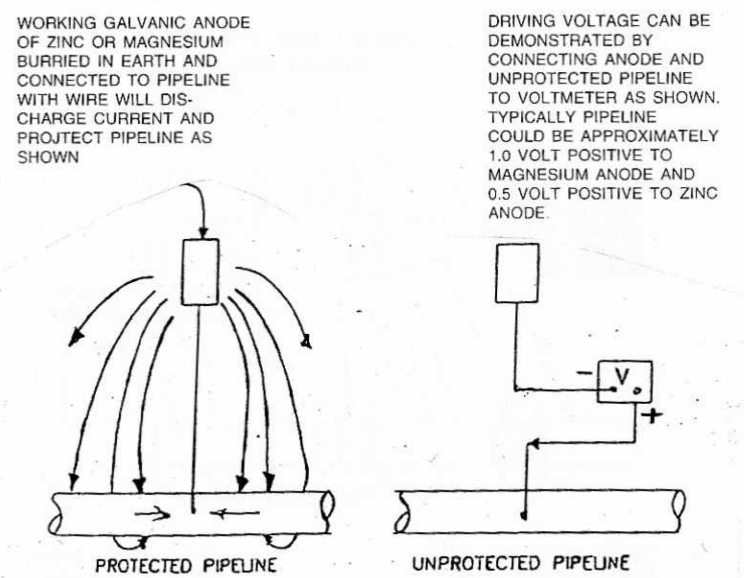

Fig. 7 : Cathodic protection with galvanic anodes.

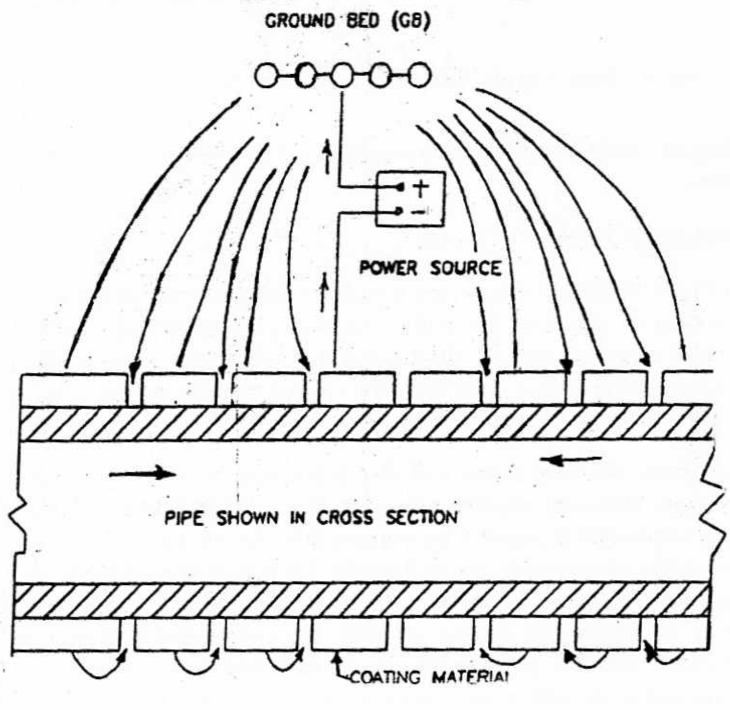

Fig. 8 : Cathodic protection of coated pipeline.

The driving voltage existing between pipe steel and galvanic anode metals is limited to low values, so if the anodes are to discharge a useful amount of current, contact resistance between the anodes and earth must be low.

In order to be free of the limited driving voltage associated with galvanic anodes, voltage from some outside power source may be impressed on the circuit between protected pipeline and ground bed Fig. 8 illustrates this situation.

Presently, the most common power source is the rectifier. This device simply converts alternating current electric power (from the usual electric distribution systems) to low voltage direct current power. Rectifiers usually are provided with means for varying the d-c output voltage, in small increments, over a reasonably wide range. While maximum output voltage may be less than 10 volts or over 100 volts, most pipeline rectifiers are believed to have maximum voltage outputs in the range between 10 and 50. Units can be obtained with maximum current output ranging from less than 10 amperes to several hundred amperes.

Criteria for cathodic protection (CP)

Although the basis theory of CP is simple i.e. making the entire pipeline a cathode - the obvious question that arises is "How do we know when we have attained this condition when working on a buried structure"? This is done by the following criteria

Measurement of potential between the pipeline and earth

The criteria is to measure potential between the pipeline and earth. This is done at the surface above the buried or submerged line and permit a rapid and reliable determination of the degree of protection attained. It has been established by various investigators that the most highly anodic areas to be expected on a steel pipeline in most soils and water will have a potential of around - 0.8 volt as measured with respect to a copper sulfate electrode contacting the environment immediately adjacent to the anodic area. For usual potential measurements, it is not practical to excavate so that the electrode can be placed at pipe depth close to the line. The common closest approach is at the ground surface directly above the pipeline. To allow for potential drop in the soil between this point and the pipe and to allow for some latitude in the potential most highly anodic areas, the practical value of - 0.85 volt has been adopted as an indication of satisfactory protection. Experience has proved the adequacy of this criterion for practical purpose.

Potential Change

We discussed the criterion of - 0.85 volt as indicative of cathodic protection. Some workers, particularly when working on bare pipelines, use a criterion of potential change rather than working to a particular absolute value. In using this system, the intent is to change the pipeline potential by 0.25 or 0.30 volt in the negative direction when the CP current is applied. Although this method may not be as technically sound as working to the - 0.85 volt value (to copper sulfate electrode), good results have been reported from practical stand point. Any stable reference electrode is satisfactory when using this method.

Current Measurement

There are two general way in which current measurement can be used as an indication of CP. When working on bare pipelines, experience has indicated that new bare steel pipe will require approximately. One milliamperes of protective current per square foot of pipe surface. Old bare steel pipe may require up to three milliamperes per square foot. These are general guides only and assume reasonably well distributed current sources. The coated pipe line will require approximately one milliamperes per square foot. Although applying current as indicated by the use of such guides can be expected to give a reasonable degree of CP, potential measurements should be used determine when full cathodic protection has been attained.

Current Potential Curves

Current potential curves are used to determine the amount of current required to attain CP on a section of pipeline. This method can be used on sections of bare pipeline. It has been used advantageously on vertical pipelines (well casings). The current potential curve criterion requires a considerable amount of time and careful test techniques to obtain a determination at a point along a pipeline.

Coupons

Coupons can be a valuable tool in determining the effectiveness of CP. Coupon of pipeline steel are attached to the pipeline by insulated wire at points where test are to be made. The coupon buried at pipeline depth as illustrated in Fig. 10. The figure shows two method of attaching the coupons i.e. completely buried or provides with leads extending above ground to permit current and potential measurements. Positive proof of the adequacy of protection may be obtained after a period of a year or more in operation when the coupon may be removed, examined for pitting attack and weighed to ascertain the amount of weight loss, if any.

RECENT DEVELOPMENTS WITH REGARDS TO MEASUREMENT CRITERIA OF CP FUNCTION

CP reliability on steel pipe microbially active soils[2]

Evaluation of CP reliability on steel pipe in microbially active soil has not yet been performed well. Primarily, this has resulted from lack of understanding of bacterial behaviour under cathodically protected conditions. The reliability of CP of steel pipe in soil in the presence of bacteria, such as iron bacteria (IB) and sulfate reducing bacteria (SRB), was evaluated using steel specimens exposed to bacteria containing soil and polarized in the potential range from -0.65 V with respect to is a copper - copper sulfate (Cu-CuSo4) electrode to -1.3 V. The finding are as follows.

In the case of sandy soil containing IB, when cathodic polarization potentials were applied more negatively than generally accepted protection criteria of - 0.85 V, CP was achieved substantially by the decrease in number of living IB as a result of environmental changes, including a decrease in the redox potential (ER) and an increase in pH caused by cathodic reaction.

In the case of clay containing SRB, when cathodic polarization potential was applied more negatively than the recommended protection criteria for active SRB clay of 0.95 V, CP was achieved.

Stray current mapper for protecting piping system[3]

Most steel natural gas piping networks are equipped with CP system that impress low voltage currents on the pipe to inhibit the formation of corrosion. However, in increasingly complex underground environment, stray currents from other sources (such as parallel or crossing pipelines, industrial plants or electric rail road systems) can come in contact with a pipe and not only reduce the ability to repress corrosion, but in some cases, can reverse the CP process and case the pipe to more quickly experience corrosion problems.

Stray current mapper - an above ground, one person operated system that can detect, identify, and assess stray current interferences. Traditional techniques to identify stray currents rely on time consuming tests, involving connection to the pipeline at test stations, which are done on an as needed basis. The stray current mapper provides a new cost effective method for routine examinations.

Smart test station[4]

Smart test station is a new product which utilizes probe to measure the performance of CP system. The probe element can be used as a CP coupon to measure, instant-off potential, current density and depolarization rate. The Smart test station is available with options for customisation to your special application requirements, such as stray current areas, multiple pipeline right of - way and bond sacrificial anodes.

Coupons[4]

The use of coupons is another state-of-the art technology used in the attempt to eliminate long - long, interference effects. Coupons can be isolated from the pipeline in order to help determine the effectiveness of the CP system.

Induced AC on pipeline[5]

If a high-voltage AC power system is parallel to a cathodically protected pipeline system (induced AC, fault condition, etc.), it can cause safety hazard because of possible shock hazards to employees (working personnel) or to members of the surrounding community. These hazard could be mitigated with the proper use of grounding grids or other such methods. There is no report of any confirmed cases in which induced AC has been proven to cause corrosion. The use of solid state cells and zinc corrosion ribbon should be considered to deal with the problem.

Influence of casing that is shorted to carrier pipe on CP[5]

A shorted casing is not inherently detrimental to the carrier pipe inside of a casing. However, if it does lower the CP criterion, it may affect the carrier pipe outside of the casing as well. Shorted casings can cause corrosion of the carrier piping in areas where the CP current leaves the carrier pipe and goes on to the casing. Pipeline casings are normally made from bare, carbon steel pipe. The current requirements for casings, therefore, are high. This can result in a depression of the "instant-off" potential in the area of casing short. Because the contact area is small, accelerated corrosion can occur. Electrolytic shorts, which are shorts caused by liquid inside the casing, usually result in less severe corrosion, and are often seasonal. Electrolytic shorts can occur over the entire length of the casing distributing the area over which the current is discharged, distributing the corrosion over a wider area.

CONCLUSION

Although there are many corrosion control methods available but CP is found to be the most reliable corrosion control methods for buried structure & pipelines. The galvanic and impressed current are the two proven methods implied in CP system. However, this process do lack certain amount of uncertainty due to vagaries in working condition especially the soil characteristics and other environmental conditions. Further the present system needs constant vigilance and data collection is required at frequent interval of time for such critical application. The recent trend however, is to use surveillance system based on use of SCADA, etc. which implies software based data interpretation system provides exact location of the area which needs immediate attention. We are gradually adopting the above modern systems for monitoring purpose in India.

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