Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems

API RECOMMENDED PRACTICE 1632
THIRD EDITION, MAY 1996

American Petroleum Institute

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Manufacturing, Distribution and Marketing Department

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FOREWORD

This recommended practice describes the corrosion problems characteristic in underground steel storage tanks and piping systems and provides a general description of the two methods currently used to provide cathodic protection against corrosion.

Persons planning to construct an underground storage facility, replace existing underground storage tanks and piping systems, or cathodically protect existing underground storage tanks and piping should refer to applicable local, state, and federal fire, safety, and environmental regulations as well as the following publications:

a. API RP 1615.
b. API RP 1621.
c. NACE RP-01-69.
d. NACE RP-02-85.
e. NFPA 30.
f. NFPA 70.
g. PEI RP100-87.

At the time this recommended practice was written, legislation and regulations related to the design, installation, operation, and maintenance of cathodic protection systems for underground petroleum storage systems were under development at the federal, state, and municipal levels. Therefore, the appropriate government agencies should be consulted for regulations that apply to the area of installation prior to taking any action suggested in this recommended practice.

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Suggested revisions are invited and should be submitted to the director of the Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems

SECTION 1—GENERAL

1.1 Scope

This recommended practice covers two methods of providing cathodic protection for buried steel petroleum storage and dispensing systems. Its intent is to provide information specific to buried steel structures such as motor fuel storage tanks and delivery piping, waste oil tanks, heating-oil tanks, and automobile lifts installed at service stations. Information presented for service stations is not necessarily applicable to buried tanks and piping used for other purposes. This recommended practice is intended to serve only as a general guide to marketers, architects, and engineers interested in cathodic protection of underground petroleum storage and dispensing systems. Specific cathodic protection designs are not provided. Such designs should be developed or adapted by a qualified corrosion engineer or a person thoroughly familiar with cathodic protection practices.

1.2 Referenced Publications

The editions of the following documents that are in effect at the time of publication of this recommended practice are cited herein:

API

RP 1615	*Installation of Underground Petroleum Storage Systems*
RP 1621	*Bulk Liquid Stock Control at Retail Outlets*

NACE[1]

RP-01-69	*Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
RP-02-85	*Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems*

NFPA[2]

30	*Flammable and Combustible Liquids Code*
70	*National Electrical Code*

PEI[3]

RP100-87	*Recommended Practices for the Installation of Underground Liquid Storage Systems*

SECTION 2—CORROSION OF BURIED STEEL STRUCTURES

2.1 Introduction

Corrosion may be defined as the deterioration of metal due to a reaction with its environment. External corrosion of buried steel structures is an electrochemical process. For the process to occur, areas with different electrical potentials must exist on the metal surface. These areas must be electrically connected and in contact with an electrolyte. There are, therefore, four components in each electrochemical corrosion cell: an anode, a cathode, a metallic path connecting the anode and cathode, and an electrolyte (see Figure 1). The role of each component in the corrosion process is as follows:

a. At the anode, the base metal goes into solution (corrodes) by releasing electrons and forming positive metal ions.
b. No metal loss occurs at the cathode. However, other chemical reactions occur that consume the electrons released at the anode.
c. Positive current flows through the metal path connecting the cathode and anode. Electrons generated by the chemical corrosion reactions at the anode are conducted through the metal to the cathode where they are consumed.
d. Positive current flows through the electrolyte from the anode to the cathode to complete the electrical circuit. In the case of buried structures, the electrolyte is moist soil.

2.2 Corrosion Processes

2.2.1 GALVANIC CORROSION

2.2.1.1 Corrosion is usually not limited to a single point, as shown in Figure 1. In the case of general corrosion, thousands of microscopic corrosion cells occur randomly over the metal surface, resulting in relatively uniform metal loss. In the case of pitting, the individual corrosion cells tend to be larger, and distinct anode and cathode areas can often be identified. Metal loss may be concentrated within relatively small areas, and substantial areas of the surface may be unaffected by corrosion.

[1]National Association of Corrosion Engineers International, P.O. Box 218340, Houston, TX 77218.
[2]National Fire Protection Association, Batterymarch Park, Quincy, MA 02269-9990.
[3]Petroleum Equipment Institute, P.O. Box 2380, Tulsa, OK 74101.

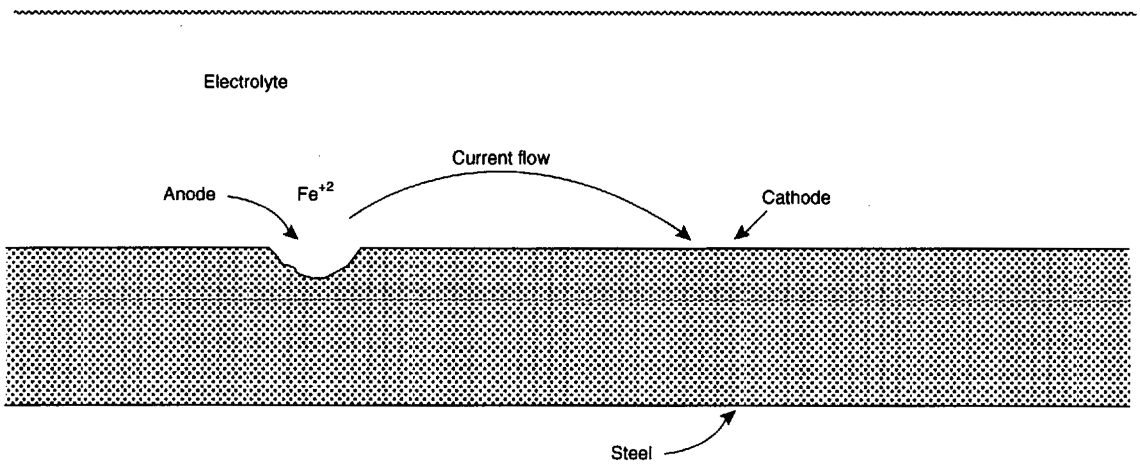

Figure 1—Electrochemical Corrosion Cell

2.2.1.2 Both metal composition and environmental factors may determine which areas on a metal surface become anodes or cathodes. Steel is an inherently nonhomogeneous material, and for a particular environment, potential differences between adjacent areas can result from uneven distribution of alloying elements or contaminants within the metal structure. Differences between the weld material and the steel plate can also cause corrosion cells in welded structures.

2.2.1.3 Physical and chemical properties of the soil (electrolyte) may also influence the location of anodic and cathodic areas on the metal surface. For example, differing oxygen concentrations at different areas on a buried steel structure may generate potential differences. Areas with lower oxygen concentrations become anodic areas, and areas with higher oxygen concentrations become cathodic areas. This may result in more severe corrosion attack at the bottom of a buried tank than at the top of the tank since oxygen concentration in soil is primarily dependent on diffusion from the soil surface (see Figure 2). The same mechanism can also contribute to corrosion in areas where clay or debris contact a steel tank buried in a sand backfill, or where a tank is buried in two different types of soil (see Figure 3).

2.2.1.4 Soil characteristics substantially affect the type and rate of corrosion occurring on buried structures. For example, dissolved salts influence the current-carrying capacity of the soil electrolyte and help determine reaction rates at anode and cathode areas. Soil moisture content, pH (a measure of acidity), and the presence of sulfides also influence corrosion. These factors, and perhaps others, interact in a complex fashion to influence corrosion at each location.

2.2.2 STRAY CURRENT AND BIMETALLIC CORROSION

2.2.2.1 In addition to galvanic corrosion, stray current corrosion and bimetallic corrosion may also be encountered on buried steel structures. Like galvanic corrosion, these corrosion processes also involve electrochemical reactions.

2.2.2.2 Stray currents are electric currents that travel through the soil electrolyte. The most common and potentially the most damaging stray currents are direct currents. These currents are generated from grounded DC electric power operations including electric railroads, subways, welding machines, and impressed-current cathodic protection systems (described in Section 4). Stray currents may enter a buried metal structure and travel through the low-resistance path of the metal to an area on the structure closer to the current source. Current leaves the structure at that point to return to the source through the soil electrolyte. Corrosion occurs at the area where current leaves the structure (see Figure 4).

2.2.2.3 Bimetallic corrosion occurs when two metals with different compositions are connected in a soil electrolyte. For example, bimetallic corrosion can occur where a bronze check valve is joined to steel piping or where galvanized pipe is connected to a steel tank. In the bronze check valve and steel pipe example, the steel pipe becomes the anode, and the bronze check valve is the cathode. Since current takes the path of least resistance, the most severe corrosion attack on the steel pipe often occurs in the area immediately adjacent to the check valve (see Figure 5).

2.3 Corrosion Control

2.3.1 INTRODUCTION

Corrosion of buried steel structures may be eliminated by proper application of cathodic protection. Cathodic protection is a technique for preventing corrosion by making the entire surface of the metal to be protected act as the cathode of an electrochemical cell. Corrosion is not eliminated. It is simply transferred from the metal surface to an external

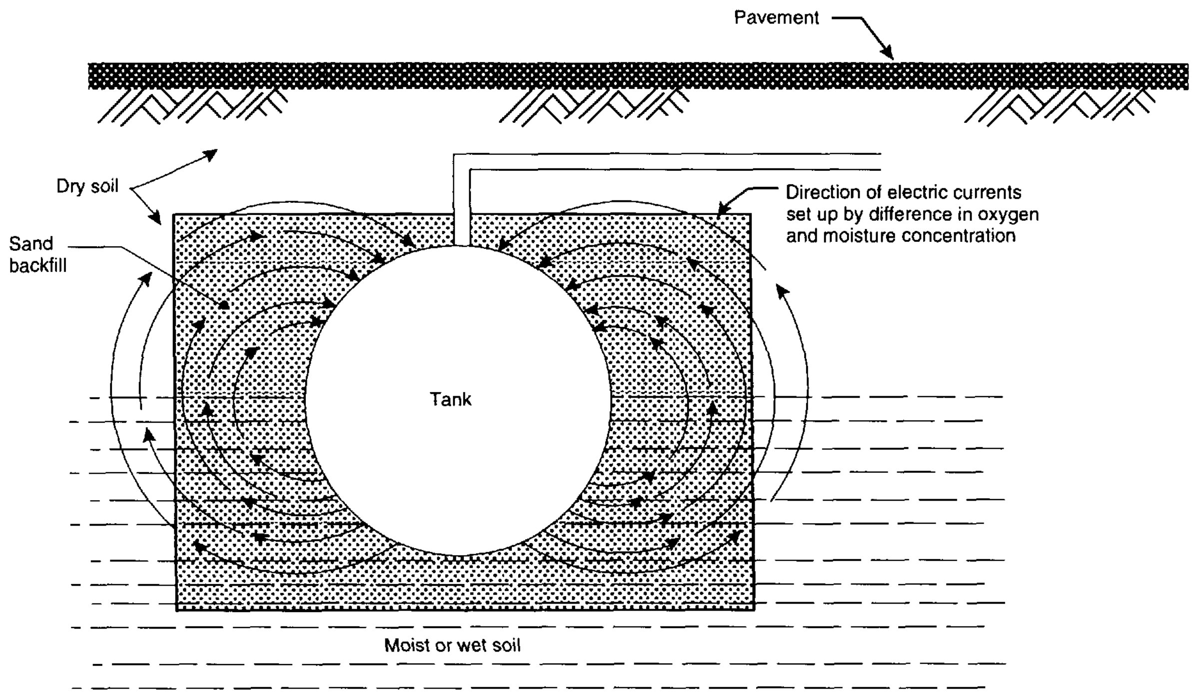

Figure 2—Corrosion Caused by Differences in Oxygen and Moisture Content of Soils

anode. There are two methods of applying cathodic protection to underground metal structures:

a. Sacrificial or galvanic anodes.
b. Impressed current.

2.3.2 SACRIFICIAL OR GALVANIC ANODES

2.3.2.1 Sacrificial or galvanic anode systems employ a metal anode more negative in the galvanic series than the metal to be protected (see Table 1 for a partial galvanic series). The anode is electrically connected to the structure to be protected and buried in the soil. A galvanic corrosion cell develops, and the active metal anode corrodes (is sacrificed) while the metal structure cathode is protected. As the protective current enters the structure, it opposes, overcomes, and prevents the flow of any corrosion current from the metal structure. The protective current then returns to the sacrificial anode through a metallic conductor (see Figure 6).

2.3.2.2 Advantages of sacrificial anode cathodic protection systems include the following:

a. No external power supply is necessary.
b. Installation is relatively easy.
c. Costs are low for low-current requirement situations.
d. Maintenance costs are minimal after installation.
e. Interference problems (stray currents) on structures other than the one being protected are rare.
f. Sacrificial anodes may be attached directly to new coated tanks by tank manufacturers.
g. The method is effective for protection of small electrically isolated structures.

2.3.2.3 Disadvantages of sacrificial anode cathodic protection systems include the following:

a. Driving potential is limited, and current output is low.
b. The method may not be practical for use in soils with very high or very low resistivity.
c. The method is not applicable for protection of large bare-steel structures.
d. Anode life may be short when protecting large surface areas of bare steel.

2.3.3 IMPRESSED CURRENT

2.3.3.1 The second method of applying cathodic protection to a buried metal structure is to use impressed current from an external source. Figure 7 illustrates a typical installation of this type using an AC power supply with a rectifier. The DC current from the rectifier flows through the soil to the structure from a buried electrode. Impressed-current anodes are made of relatively inert materials, such as carbon or graphite, and therefore have a very low rate of corrosion.

2.3.3.2 Advantages of impressed-current cathodic protection systems are as follows:

a. Availability of large driving potential.
b. High-current output capable of protecting other underground steel structures with a low operating cost.
c. Possibility of flexible current output control.

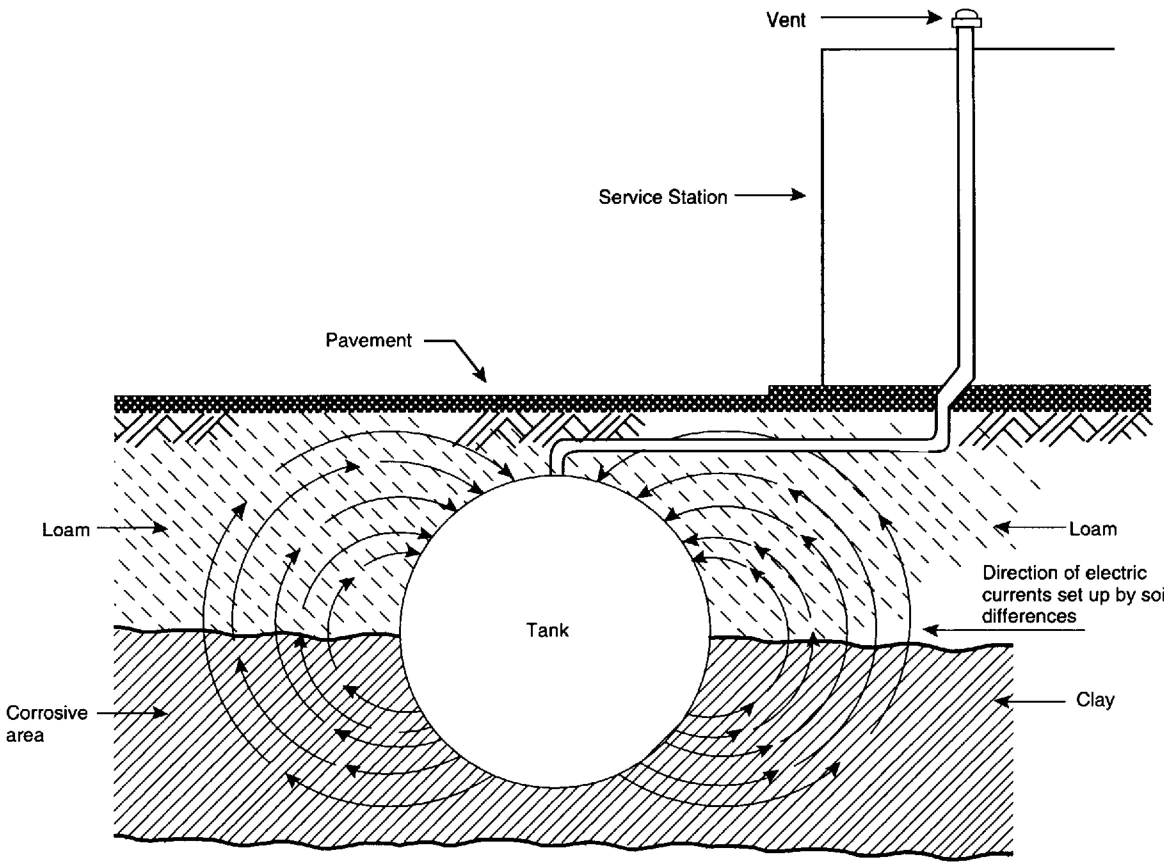

Figure 3—Corrosion Caused by Dissimilar Soils

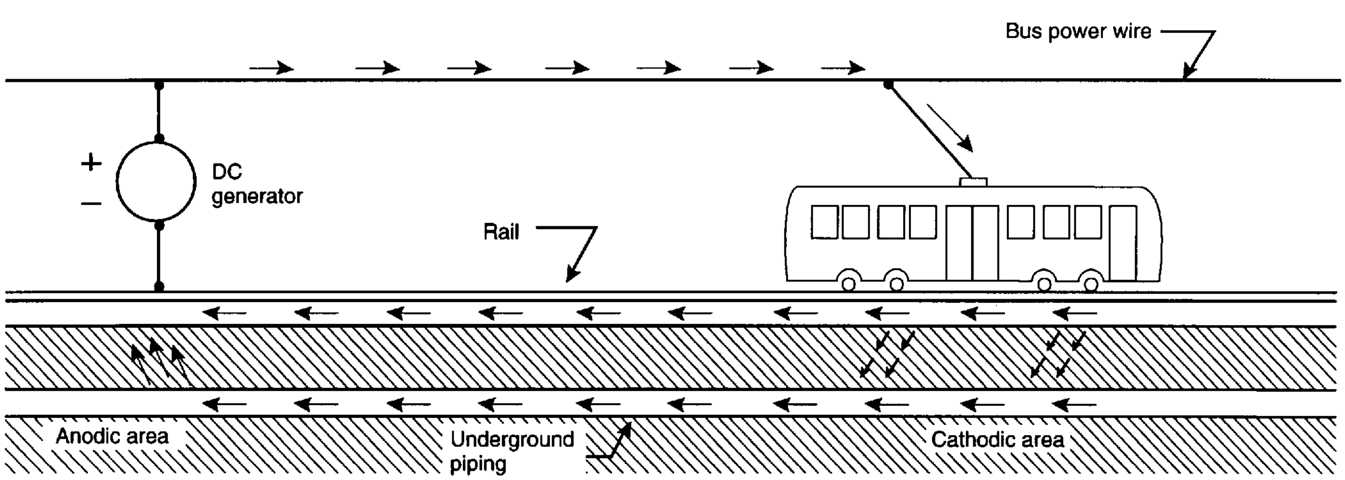

Figure 4—Stray Current Corrosion

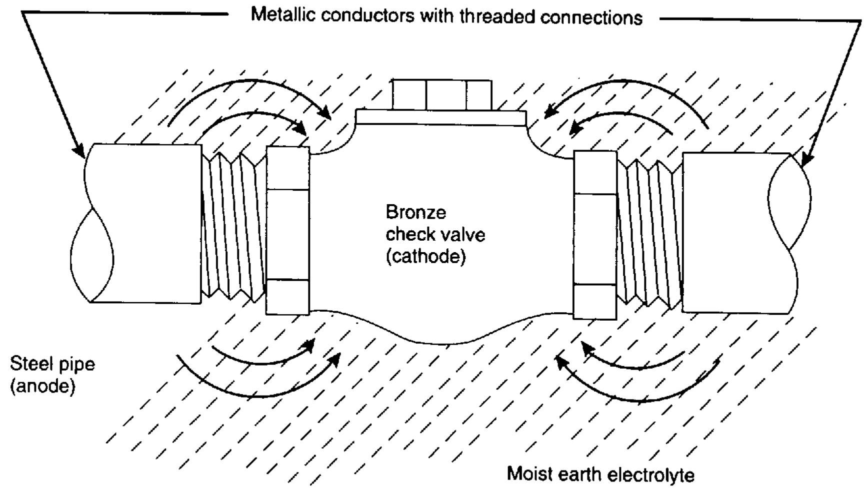

Figure 5—Bimetallic Corrosion

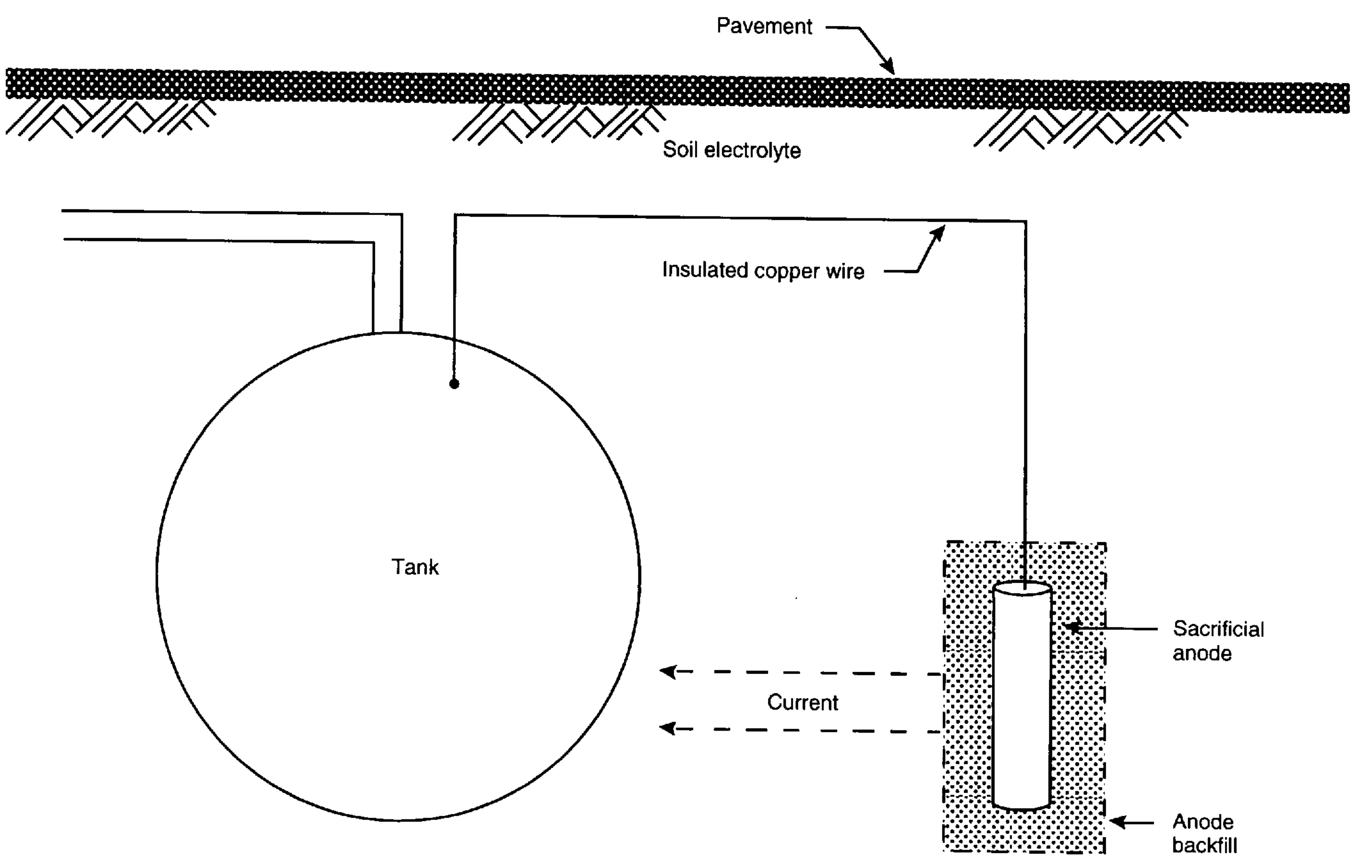

Figure 6—Sacrificial Anode Cathodic Protection

Table 1—Practical Galvanic Series

Metal	Volts[a]
Commercially pure magnesium	-1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% Zn)	-1.0
Commercially pure aluminum	-0.8
Mild steel (clean and shiny)	-0.5 to -0.8
Mild steel (rusted)	-0.2 to -0.5
Cast iron	-0.5
Lead	-0.5
Mild steel in concrete	-0.2
Copper, brass, bronze	-0.2
High-silicon cast iron	-0.2
Mill scale on steel	-0.2
Carbon, graphite, coke	+0.3

Note: Data applies in environments consisting of neutral soils and water.
[a]Voltages are referenced to copper/copper sulfate.

d. Applicability to almost any soil resistivity.
e. Capability of protecting large bare-steel structures.

2.3.3.3 Impressed-current cathodic protection systems have the following disadvantages:

a. They may cause interference problems (stray currents) on foreign structures.
b. The current may be deliberately or unintentionally switched off and protection eliminated.
c. Systems must be monitored and maintained on a regular schedule.
d. Systems may damage coatings if the level of current output is too high.
e. Compared to sacrificial anode systems, the maintenance and operating costs are higher.

2.3.4 SELECTION CRITERIA

2.3.4.1 As indicated by the advantages and disadvantages of sacrificial and impressed-current systems listed in 2.3.2 and 2.3.3, the type of system selected for a particular location may depend upon a number of factors. In general, systems and designs selected should provide adequate corrosion protection while minimizing installation, maintenance, and operation costs. New coated tanks and piping may be protected by either system; whereas, existing installations will normally require impressed-current systems. Since complete corrosion protection of buried structures

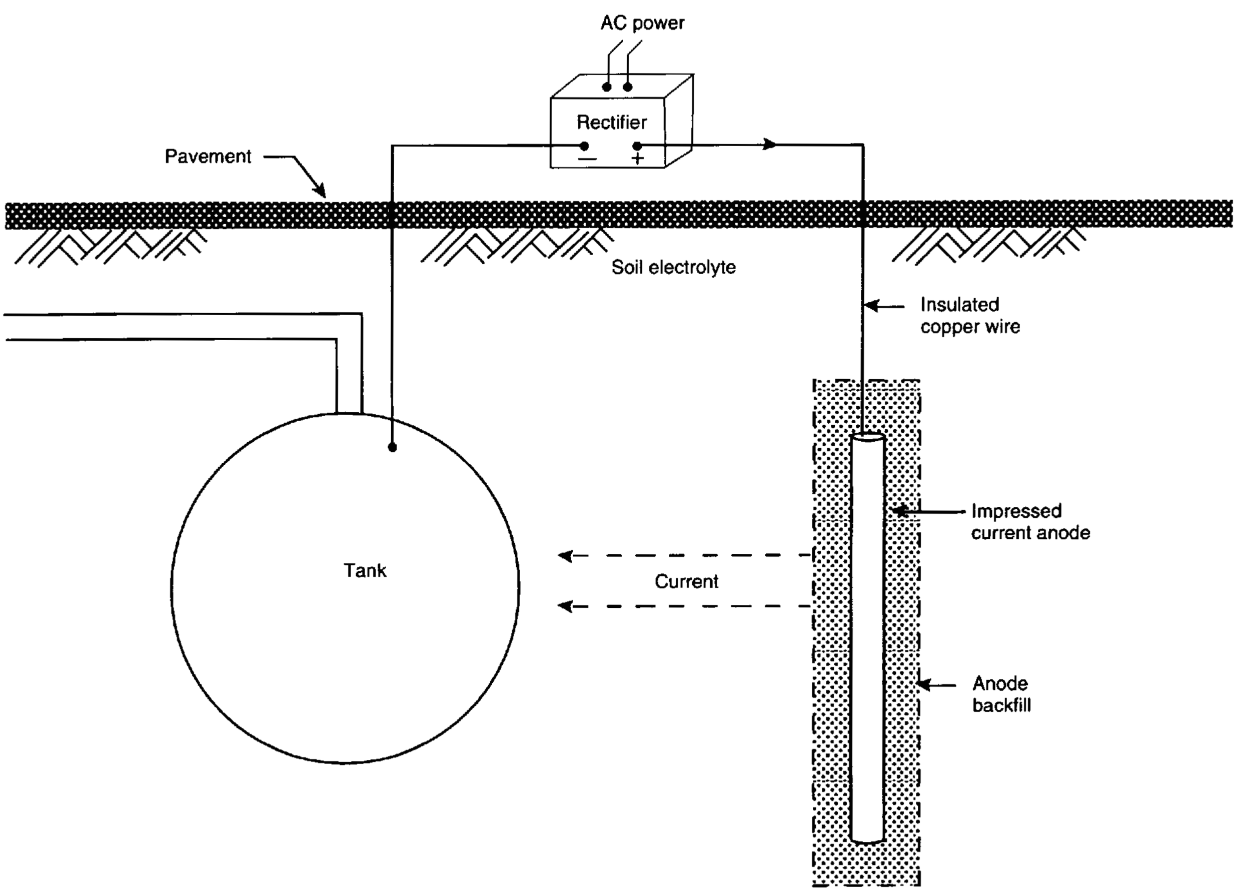

Figure 7—Impressed-Current Cathodic Protection

under cathodic protection depends upon proper system design, it is recommended that cathodic protection systems should be designed by qualified corrosion engineers or other persons thoroughly familiar with cathodic protection.

2.3.4.2 Consideration should be given to the following factors in developing cathodic protection designs for buried structures:

a. Soil resistivity.
b. Present and future current requirements.
c. Life of the cathodic protection system in relation to the intended life of the structures to be protected.
d. Presence of stray currents from other sources.
e. Anode placement to provide uniform protective current.
f. Condition of the structures to be protected (new or old, coated or bare).
g. Capability to minimize excessive current output that can harm structure coatings or produce interferences with nearby buried structures.
h. Reliability of cathodic protection system components.

2.3.4.3 In some instances, on-site surveys may be required to obtain information necessary for specific designs. In other cases, designs may be sufficiently versatile to cover the wide range of conditions normally encountered.

2.3.5 INSTALLATION

The installation of cathodic protection systems involves the use of wire conductors connecting anodes and structures, anodes and test stations, and anodes and rectifiers. The exact location of such wiring and anodes should be carefully identified on a plot plan of the facility, and a copy of this plan should be maintained by the owner.

SECTION 3—SACRIFICIAL ANODE PROTECTION

3.1 Description

3.1.1 Corrosion protection with sacrificial anodes may be used in preference to an impressed-current system where current requirements are low. Sacrificial anodes are usually constructed of zinc or magnesium metal, packaged in a low-resistivity backfill. Zinc anodes are best utilized in low-resistivity soils where their lower current output will result in longer anode life. Magnesium anodes, because of their higher driving potential (–1.6 volts compared to –1.1 volts for zinc), are frequently used in higher resistivity soils or soils with high concentrations of carbonates, bicarbonates, or phosphates.

3.1.2 Low driving voltages and low-current outputs (usually less than 0.10 amperes per anode) generally limit sacrificial anodes to cathodic protection of well-coated structures. Sacrificial anode corrosion protection systems are particularly suited to new installations involving coated tanks and/or distribution piping.

3.2 Factory-Installed Anodes

3.2.1 Underground storage tanks are available from tank manufacturers with sacrificial anode cathodic protection systems already attached. Current requirements are minimized by factory application of long-lasting corrosion resistant coatings. Sacrificial anodes are attached at the plant, with anode weight and size determined by the tank surface area. Nonconductive bushings and flanges are provided with each tank to isolate the tank from any extra current demand resulting from electrical contact between the tank and associated metal piping. These bushings and flanges must be used to protect the tank and maintain the supplier's warranty. These tanks may also be obtained with factory-installed test leads which facilitate field monitoring of anode current output and tank-to-soil potential.

Note: Steel product piping isolated from the tank by nonconductive bushings and flanges will require its own cathodic protection system.

3.2.2 Factory-installed cathodic protection systems for new tanks are designed to satisfy requirements for most soil situations. The purchaser should compare conditions present at the proposed installation sites with the conditions under which long-term corrosion protection is provided by the factory-installed system.

3.2.3 Tanks with factory-installed cathodic protection systems must be handled carefully during transportation and installation to protect against coating damage or rupture of anode packages. Anode wires, test leads, tank coating, and tank isolation bushings should be inspected for obvious damage prior to final installation. As with any cathodic protection system, a regular postinstallation monitoring program is necessary to determine that corrosion protection is being maintained.

3.3 Field-Installed Anodes

3.3.1 Field-installed, sacrificial-anode cathodic protection systems may also be used to protect new or existing well-coated tanks and piping. A coal tar coating routinely applied to steel petroleum storage tanks should not be considered an adequate coating for cathodic protection purposes. Many of the corrosion resistant coatings used on cathodically protected petroleum pipelines (see NACE RP-01-69) may also be used as coatings for buried petroleum-storage tanks and dispensing piping. Effective coatings reduce current requirements of these structures to levels that can be supplied over a long term by sacrificial anodes.

3.3.2 Current requirements for new or existing buried structures may be calculated if the soil resistivity, total surface area to be protected, and coating quality are known. For existing structures, it is also possible to quantitatively determine current requirements by electrically connecting buried structures to a variable DC power source and measuring structure-to-soil potentials versus a copper-copper sulfate electrode. The observed current output needed to achieve a desired cathodic protection potential may then be used for designing a cathodic protection system for the structures.

3.4 Anode Types and Placement

3.4.1 Three sacrificial anode materials are commonly used for soil installations:

a. High-potential magnesium alloy.
b. Standard magnesium alloy.
c. Zinc.

3.4.2 Magnesium and zinc anodes prepackaged in chemical backfill are readily available in a number of size and weight configurations to meet various current output and anode-life design requirements. The use of a chemical backfill with anodes is necessary for reliable operation in soil environments. Chemical backfill promotes anode efficiency, lengthens anode life, and keeps the anode environment moist.

3.4.3 The number of sacrificial anodes required to provide cathodic protection to buried structures depends primarily upon total current requirements; however, current distribution factors should also be considered. Where several anodes are needed for a structure, better current distribution (more uniform polarization) may be achieved by distributing the anodes uniformly around the structure. In the case of new tank installations, sacrificial anodes are often placed parallel to the tank walls, at or near the level of the tank bottom. For petroleum distribution systems, anodes are typically installed below the piping at a depth of about five feet. Installation of anodes at these locations for tanks and piping serves two purposes:

a. It helps assure anodes remain in a moist environment.
b. It provides better current distribution to the lower portion of the buried structures where corrosion is typically most severe.

3.5 Electrical Connections and Isolation

3.5.1 A low-resistance electrical connection must be made between the structure to be protected and the wire lead for the sacrificial anodes. For new installations and where safety factors permit, powder weld connections, such as Cadweld or Thermit type, should be used. In some situations, safety factors may dictate the use of mechanical connections. Mechanical connections should be made carefully because poor electrical contact will increase the effective wire resistance in the circuit and limit the amount of useful current available from the anode. All exposed metal at structure-lead wire connections should be waterproofed and coated with electrical insulating material. This will prevent bimetallic corrosion between the copper wire and the steel tank if the sacrificial anode should fail at some time in the future.

3.5.2 Current output of sacrificial anodes is limited, and cathodic protection designs typically do not provide sufficient current for protecting adjacent buried structures. Therefore, the structure to be protected should be electrically isolated from other buried metal structures, including piping and electrical conduit. Properly installed insulating unions and bushings provide effective electrical isolation. Location of these insulating fittings will depend upon the cathodic protection design and the extent of the structure to be cathodically protected. These insulating fittings should be inspected after installation to insure no damage has occurred. Particular care should be taken to assure that the structure to be protected is isolated from any buried metallic power conduit. For example, petroleum distribution piping protected by sacrificial anodes should have an isolating union at each dispensing unit, and underground storage tanks with submersible pumps should have isolating bushings between the pump riser pipe and the tank.

3.6 Evaluating Corrosion Protection

3.6.1 There are several criteria for determining if adequate cathodic protection has been achieved on buried structures (see 4.4.1) The most common criterion for ensuring adequate sacrificial anode protection for underground petroleum-storage tanks and piping is the measurement of a negative potential of at least 0.85 volts between the tank (or piping) and the surrounding soil (the electrolyte) when using a copper-copper sulfate reference electrode in contact with the soil electrolyte. During the testing, the sacrificial anodes remain attached to the structure, and all measurements must consider all voltage drops other than those across the structure/electrolyte boundary for valid interpretation of the data.

3.6.2 Routine measurements of structure-to-soil potential for evaluating the extent of corrosion protection are often difficult to obtain at petroleum storage and distribution sites because the buried structures are covered by asphalt or concrete pavement. While valid potential measurements are possible through asphalt or concrete, special equipment and trained personnel may be required to obtain and interpret these results. More reliable results can be obtained by installing permanent access manholes through the pavement to the soil at the time cathodic protection is installed. The soil access manholes should be positioned to enable measurement of potentials over the structure at points farthest from the sacrificial anodes or in shielded areas.

3.6.3 As an alternative to making structure-to-soil potential measurements as described in 3.6.1, long-life reference cells may be permanently installed in the soil near protected structures. Specially designed copper-copper sulfate or packaged zinc reference cells are commercially available for this purpose. These reference cells are typically located within several inches of the structure in areas where current distribution may be poor, at points farthest from attached anodes, or under the tank. Acceptable potential readings at such locations, according to the criterion in 3.6.1, are a good indication that adequate corrosion protection has been achieved on the entire external structure surface.

3.6.4 Lead wires attached to the buried reference cells should be run to a permanent test station at the site to allow easy attachment to the instruments used for testing. It may also be convenient or necessary to attach a test lead to the buried structure and run it to the test station to facilitate periodic potential monitoring.

3.6.5 Structure-to-soil potential measurements are made by electrically connecting the buried structure to the negative terminal of a suitable high-resistance voltmeter (50,000 ohms internal resistance or higher). The positive terminal of the voltmeter is connected to a properly placed reference cell. When a buried zinc reference cell is used, –1.1 volts must be added to the observed voltmeter reading to calculate the potential reading that would result from using a copper-copper sulfate reference cell.

3.6.6 Where sacrificial anodes have been installed, their proper operation should be confirmed by a qualified person 6 to 12 weeks after installation and 1 year thereafter. If these tests confirm proper operation, subsequent inspection intervals can be extended to 5 years. However, if underground work is performed at the protected site, cathodic protection should be remonitored 6 to 12 weeks after work completion and 1 year thereafter before again extending the inspection interval. Procedures used and data obtained should be clearly recorded and included in permanent cathodic protection records for the location, along with the name of the person making the measurements and the date measurements were made.

SECTION 4—IMPRESSED-CURRENT PROTECTION

4.1 Description

4.1.1 Impressed-current cathodic protection is often the most economical means of controlling corrosion in existing underground bare steel petroleum storage tanks and distribution piping systems. It may also be used to provide corrosion protection for other buried structures at the same site, such as used oil tanks, heating oil tanks, and automobile lifts. The additional cost for protecting other structures is often minimal.

4.1.2 Cathodic protection requires a source of direct current. For impressed-current systems, direct current is typically provided by a rectifier attached to a conventional AC power source. The rectifier converts alternating current to direct current. DC output from the rectifier flows to the buried impressed-current anode, through the soil electrolyte and onto the surface of the structure as shown in Figure 6.

4.2 Rectifier Selection and Operation

4.2.1 A typical cathodic protection rectifier has two major components: (a) a step-down transformer to reduce the AC supply voltage, and (b) rectifying elements to provide DC output. Units may be obtained with either selenium or silicon rectifier elements. Both types of elements are widely used and provide dependable service. Either may show cost or performance advantages for a particular application. Small selenium units are often less expensive than similar silicon units, but silicon rectifiers are generally more efficient. Silicon units are particularly susceptible to damage from power surges; therefore, protective devices should be included in these units to prevent lightning damage. Selenium rectifiers are not recommended if ambient temperatures are expected to exceed 130°F (55°C).

4.2.2 The rectifier output capacity selected will depend upon (a) estimated or measured current requirements of the structure to be protected and (b) the voltage needed to cause current to flow from the anodes to the buried structure. Rectifiers with a moderate excess capacity should be selected to allow for adjustments during the life of the cathodic protection system and to prevent damage due to voltage overloads.

4.2.3 Rectifiers may be damaged by voltage overloads. Excess rectifier voltage outputs of 15 to 30 percent above expected needs are suggested to allow for possible line voltage fluctuations. Some excess rectifier-current output capacity is suggested, particularly for coated structures. Coatings may degrade with time and increase the current requirements of a structure.

4.2.4 Careful consideration should be given to selecting installation locations for rectifiers. Efforts should be made to place the units in areas not susceptible to accidental or malicious damage, since no corrosion protection is provided by an impressed-current system if the rectifier is inoperative. Whenever possible, rectifiers should be mounted within a secure building in a location that allows regular and convenient monitoring. All wiring to rectifiers must comply with local and national electrical codes.

4.2.5 Rectifiers are available with optional equipment that facilitates periodic monitoring and provides an indication that power is available to impressed-current anodes. It is suggested that the equipment listed in the following should be mounted on the front panel of each rectifier cabinet:

a. Green and red signal lights to indicate proper/improper rectifier operation.
b. A volt-ammeter for measuring rectifier voltage and current output.
c. A non-resettable elapsed time meter with a minimum hour capacity of 99,999 hours.
d. A warning sign stating that the cabinet contains a cathodic protection rectifier and that corrosion of underground structures can result if power to the unit is shut off.
e. Optional audio alarm signals which sound if a rectifier is not operating properly may be useful in some situations.

4.2.6 The AC power source for each rectifier should be an isolated circuit with an individual circuit breaker on the main electrical panel. This breaker switch should have a tab-lockout bracket installed, if permitted by local code, to prevent inadvertent switching-off of power to the rectifier. Rectifier cabinets should be sealed or padlocked to prevent unauthorized entry to the on-off AC circuit breaker and exposed high-voltage contacts within the cabinet.

4.3 Anode Installation and Connections

4.3.1 Several materials are used as impressed-current anodes. The most common are these:

a. Graphite.
b. High-silicon cast iron.
c. Platinized niobium, tantalum, or titanium.
d. Mixed metal oxide.

4.3.2 Each anode material has an optimum current density that provides maximum anode service life. Anodes may be located in remote ground beds, or deep wells or distributed closely about the structure to be protected. The latter two designs may be required to achieve the following:

a. Avoid physical interference with existing facilities.
b. Provide better current distribution.
c. Avoid stray current interference with off-site structures.

4.3.3 The number of anodes used in a particular remote groundbed or deep-well cathodic protection design will be determined primarily by total current requirements of the structure(s) to be protected and the optimum current density of the anode material selected. For a distributed anode design, additional anodes may be installed to provide more uniform current distribution.

4.3.4 Impressed-current anodes are typically installed in carbonaceous backfill. If the backfill is installed properly, much of the current reaching the anode is conducted to the backfill by electrical contact. This promotes consumption of the backfill instead of the anode and substantially lengthens the effective anode life. Carbonaceous backfill also tends to reduce total circuit resistance by lowering anode-to-soil resistance.

CAUTION: The negative lead of the rectifier must be attached to the structure to be protected. If the structure is mistakenly attached to the positive lead, the structure will serve as an anode and rapid corrosion failure of the structure can result.

4.3.5 A weld connection powder (for example, Cadweld or Thermit type) is the preferred means for connecting the negative rectifier lead wire to the underground structure; however, good mechanical connections may be substituted if necessary. All connections and wire splices should be carefully waterproofed and covered with electrical insulating material.

4.3.6 All underground wire attached to the positive rectifier terminal is at a positive potential with respect to ground. If not completely insulated, the wire may discharge current (act as an anode), which will result in corrosion of the wire and eventual failure of the cathodic protection installation. Therefore, all anode lead wires, header cables, and any wire splices should be carefully inspected prior to backfilling. Backfill should be free of sharp stones or other material that could damage wire insulation.

4.4 Evaluating Corrosion Protection

4.4.1 Three voltage measurement criteria are applicable for determining if effective cathodic protection has been achieved on the underground petroleum storage tanks and distribution piping:

a. A negative potential of at least 0.85 volts with the cathodic protection applied (rectifier turned on). This potential is measured with respect to a saturated copper-copper sulfate reference electrode contacting the soil electrolyte. Voltage drops other than those across the structure/electrolyte boundary must be considered for valid interpretation of this voltage measurement.
b. A negative polarized potential of at least 0.85 volts relative to a saturated copper-copper sulfate reference electrode contacting the soil electrolyte. This measurement is made with the cathodic protection system turned off. It is typically done shortly after the system is turned off—within a couple of seconds.
c. A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a stable reference electrode contacting the electro-

lyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading after the immediate shift shall be used as the base reading from which to measure polarization decay.

4.4.2 Considerations for measuring structure-to-soil electrolyte potentials discussed in Section 3 are also applicable to structures protected by impressed-current systems. Permanent soil access manholes over underground structures or buried long-life reference electrodes should be included as part of each impressed-current cathodic protection installation. Constant potential rectifiers are available that use buried reference electrodes to automatically control rectifier current output to the anodes, and thereby maintain a constant preset potential on a structure. These rectifiers are particularly useful for installations subject to periodic stray currents, or in areas where there are wide variations in soil resistivity due to soil moisture changes.

4.4.3 When an impressed-current system is energized, a qualified person familiar with cathodic protection equipment and theory should measure structure-to-soil potentials according to one or more of the appropriate criteria described in 4.4.1. Structure-to-structure potentials between protected structures and other buried structures at the site (including all underground utility systems) should be measured to verify that bonding or insulation provisions included in the cathodic protection design have been met. Necessary adjustments of rectifier output should be made based on these results and the structure-to-soil potential readings. Procedures used and data obtained during this initial survey should be recorded in permanent cathodic protection records for the location. The name of the person making the measurements and the date measurements were made should also be noted on the record sheet. An insulation checker can be a method to verify the effectiveness of insulating flanges.

4.4.4 Metallic bonds between cathodically protected structures and adjacent buried structures belonging to a different owner may occasionally be necessary to satisfy interference problems. Such bonds should be made only after obtaining permission from the owner of the foreign structure, and usually requires a mutual testing program witnessed by representatives of both structure owners.

4.4.5 Monthly checks of rectifiers are necessary to verify that the units are operational. Annual surveys of structure-to-soil potentials and structure-to-structure potentials of an impressed-current system are also necessary to ensure continued satisfactory operations. Surveys should be conducted using procedures outlined in this section for the initial startup survey. Results obtained should be added to the permanent cathodic protection records for the location. Any adjustments or other maintenance should be performed promptly.

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