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Application of Cathodic Protection to Control External Corrosion of Carbon Steel On-Grade Storage Tank Bottoms

ABSTRACT

The purpose of this standard practice is to present practices for application of CP to control external corrosion of carbon steel on-grade storage tank bottoms that are in contact with an electrolyte. Practices for application of both galvanic anode CP systems and impressed current CP systems are included. Design criteria for the upgrade of existing tanks as well as for newly constructed tanks are included. This standard is maintained by Task Group 013.

KEYWORDS

pipelines, tanks, and underground systems, cathodic protection, TG 013, metals, storage tanks

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Foreword

In NACE standards, the terms shall, must, should, and may are used in accordance with the definitions of these terms in the NACE Publications Style Manual. The terms shall and must are used to state a requirement, and are considered mandatory. The term should is used to state something good and is recommended, but is not considered mandatory. The term may is used to state something considered optional.

It is important to maintain the integrity of carbon steel on-grade storage tanks for both economic and environmental reasons. The proper design, installation, and maintenance of cathodic protection (CP) systems can help maintain the integrity and increase the useful service life of carbon steel on-grade storage tanks.

The purpose of this standard practice is to present practices for application of CP to control external corrosion of carbon steel on-grade storage tank bottoms that are in contact with an electrolyte. Practices for application of both galvanic anode CP systems and impressed current CP systems are included. Design criteria for the upgrade of existing tanks as well as for newly constructed tanks are included. This standard is intended for use by personnel planning to install a CP system on new carbon steel on-grade storage tanks, upgrade the CP system on existing carbon steel on-grade storage tanks, or install a new CP system on existing carbon steel on-grade storage tanks.

This NACE standard was originally prepared by Task Group (TG) T-10A-20, a component of NACE Unit Committee T-10A, "Cathodic Protection," and issued in 1993. It was revised by TG 013, "Tanks, Aboveground: External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms," in 2001 and 2015. TG 013 is administered by Specific Technology Group (STG) 35, "Pipelines, Tanks, and Well Casings," and sponsored by STG 05, "Cathodic/Anodic Protection." This standard is issued by NACE International under the auspices of STG 35.

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Figures

Section 1: General

1.1 This standard defines the process necessary to design, install, and operate a thermoplastic-lined oilfield pipeline. The design process includes an assessment of the service conditions, materials, chemical compatibilities of liner materials with any service fluids and additives, pipeline geometry, and risk analysis. The installation process includes site surveys, pipeline preparation, insertion, termination, pressure testing, reburial, and safety. Operation of a lined system must take into consideration the service fluids, materials of construction, safety and environment, commissioning, normal operation, depressuring, and upset conditions, and inspection for liner integrity.

Section 2: Definitions

Amphoteric Metal: A metal that is susceptible to corrosion in both acidic and alkaline environments.

Anode: The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.)

Anode Bed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection current. For the purposes of this standard, an anode bed is defined as a single anode or group of anodes installed in the electrolyte for the purposes of discharging direct current to the protected structure.

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Cable: One conductor or multiple conductors insulated from one another.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.)

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

Cathodic Polarization: (1) The change of electrode potential caused by a cathodic current flowing across the electrode/electrolyte interface. (2) a forced active (negative) shift in electrode potential. [See *Polarization.*]

Cathodic Protection (CP): A technique to reduce the corrosion rate of a metal surface by making that surface the cathode of an electrochemical cell.

Cell: See *Electrochemical Cell.*

Coating: (1) A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. (2) (in a more general sense) A thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.

Concentration Cell: An electrochemical cell, the electromotive force of which is caused by a difference in concentration of some component in the electrolyte. (This difference leads to the formation of discrete cathodic and anodic regions.)

Condensation: The aqueous liquid formed on the external surface of an on-grade storage tank as a result of differences between the temperature of the liquid stored in the tank and the temperature of the environment surrounding the tank.

Conductor: A material suitable for carrying an electric current. It may be bare or insulated.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Corrosion: The deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment.

Corrosion Potential: (represented by the symbol E_{corr}) The potential of a corroding surface in an electrolyte measured under open-circuit conditions relative to a reference electrode. [also known as electrochemical corrosion potential, free corrosion potential, open-circuit potential]

Corrosion Probe: An electrical resistance instrument that determines the corrosion rate on its metal electrode or electrodes by measuring and converting the measurements to metal loss.

Corrosion Rate: The time rate of change of corrosion. (It is typically expressed as mass loss per unit area per unit time, penetration per unit time, etc.)

Current: (1) A flow of electric charge. (2) The amount of electric charge flowing past a specified circuit point per unit time, measured in the direction of net transport of positive charges. (In a metallic conductor, this is the opposite direction of the electron flow.)

Current Density: The electric current flowing to or from a unit area of an electrode surface.

Deep Anode Bed: One or more anodes installed vertically at a nominal depth of 15 m (50 ft) or more below the earth's surface in a drilled hole for the purpose of supplying cathodic protection current.

Differential Aeration Cell: A concentration cell caused by differences in oxygen concentration along the surface of a metal in an electrolyte. [See *concentration cell*]

Diode: A bipolar semiconducting device having a low resistance in one direction and a high resistance in the other.

Direct Current (DC) Decoupling Device: A device used in electrical circuits that allows the flow of alternating current in both directions and stops or substantially reduces the flow of direct current.

Disbondment: The loss of adhesion between a coating and the substrate.

Dissimilar Metals: Different metals that could form an anode-cathode relationship in an electrolyte when connected by an electron-conducting (usually metallic) path.

Distributed-Anode Impressed Current System: An impressed current anode configuration in which the anodes are "distributed" along the structure at relatively close intervals such that the structure is within each anode's voltage gradient. This anode configuration causes the electrolyte around the structure to become positive with respect to remote earth.

Driving Potential: Difference in potential between the anode and the steel structure.

Electrical Interference: Any electrical disturbance on a metallic structure in contact with an electrolyte caused by stray current(s).

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrical Survey: Any technique that involves coordinated electrical measurements taken to provide a basis for deduction concerning a particular electrochemical condition relating to corrosion or corrosion control.

Electrochemical Cell: (1) An electrochemical reaction involving two half reactions, one of which involves oxidation of the reactant (product) and the other of which involves reduction of the product (reactant). (The equilibrium potential of the electrochemical cell can be calculated from the change in free energy for the overall electrochemical reaction. The equilibrium potential of the electrochemical cell can be measured by separating the oxidation and reduction half reactions into individual compartments and measuring the voltage that develops between them under conditions that virtually no charge passes between them.) [thermodynamic use]; (2) an electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte. (The anode and cathode may be different metals or dissimilar areas on the same metal surface.) [common use]

Electrode: A material that conducts electrons, is used to establish contact with an electrolyte, and through which current is transferred to or from an electrolyte.

Electrolyte: A chemical substance containing ions that migrate in an electric field.

External Circuit: The wires, connectors, measuring devices, current sources, etc., that are used to bring about or measure the desired electrical conditions within an electrochemical cell. It is this portion of the cell through which electrons travel.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

Galvanic Corrosion: Accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

Galvanic Couple: A pair of dissimilar conductors, commonly metals, in electrical contact in an electrolyte.

Galvanic Current: The electric current flowing between metals or conductive nonmetals in a galvanic couple.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection current. For the purposes of this standard, a groundbed is defined as a single anode or group of anodes installed in the electrolyte for the purposes of discharging direct current to the protected structure.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system (An example is direct current for cathodic protection.)

Impressed Current Anode: An electrode, suitable for use as an anode when connected to a source of impressed current. (It is often composed of a substantially inert material that conducts by oxidation of the electrolyte and, for this reason, is not corroded appreciably.)

Microbiologically Influenced Corrosion (MIC): Corrosion affected by the presence or activity, or both, of microorganisms.

On-Grade Storage Tank: A storage tank constructed on sand or earthen pads, concrete ringwalls, concrete slabs, or asphalt pads.

Oxidation: (1) Loss of electrons by a constituent of a chemical reaction; (2) corrosion of a material that is exposed to an oxidizing gas at elevated temperatures.

Oxygen Concentration Cell: See *Differential Aeration Cell.*

Polarization: The change from the corrosion potential as a result of current flow across the electrode/electrolyte interface.

Polarization Decay: The change in electrode potential with time resulting from the interruption of applied current.

Polarized Potential: (1) (general use) The potential across the electrode/electrolyte interface that is the sum of the corrosion potential and the applied polarization. (2) (cathodic protection use) The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Rectifier: A device for converting alternating current to direct current. Usually includes a step-down AC transformer, silicon or selenium stack (or other rectifying elements), meters, and other accessories when used for cathodic protection purposes.

Reduction: Gain of electrons by a constituent of a chemical reaction.

Reference Electrode: An electrode having a stable and reproducible potential, which is used in the measurement of other electrode potentials.

Release-Prevention Barrier: A second steel bottom (when used in a double-bottom or secondary containment system), synthetic materials, clay liners, and all other barriers or combination of barriers placed under an on-grade storage tank to prevent the escape of the stored liquid into the environment and to contain or channel released liquid for leak detection.

Resistivity: The electrical resistance between opposite faces of a unit cube of material.

Resistor: An electrical device that limits the quantity of electricity flowing in an electrical circuit by resisting the flow of current through it.

Sacrificial Protection: Reduction of corrosion of a metal in an electrolyte by electrically connecting the metal to a galvanic anode (a form of cathodic protection).

Shallow Groundbed: One or more anodes installed either vertically or horizontally at a nominal depth of less than 15 m (50 ft) for the purpose of supplying cathodic protection current.

Shielding: (1) protecting; protective cover against mechanical damage. (2) Preventing or diverting cathodic protection current from its natural path.

Shunt: A precise resistor with known resistance in an electrical circuit used to measure a voltage drop. The measured voltage drop is used to calculate the amount of current flowing in that electrical circuit.

Sound Engineering Practices: Reasoning exhibited or based on thorough knowledge and experience, logically valid and having technically correct premises that demonstrate good judgment or sense in the application of science.

Stray Current: Current flowing through paths other than the intended circuit.

Stray-Current Corrosion: Corrosion resulting from stray current.

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and the electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Tank Foundation: Material beneath an on-grade storage tank that supports the weight of the tank. This may include concrete slabs, concrete ringwalls, compounded fill (such as sand or earth), and pilings.

Tank Pad: Material immediately adjacent to the underside of the tank bottom of an on-grade storage tank.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Voltage Drop: The voltage across a resistance when current is applied in accordance with Ohm's law.

Wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller-gauge conductors (6 mm^2 [No. 10 AWG[(1)]] or smaller).

Section 3: Preliminary Evaluation and Determination of the Need for Cathodic Protection

3.1 This section presents the information that should be considered prior to the design of a CP system to protect carbon steel on-grade storage tank bottoms in contact with an electrolyte.

3.2 Site Assessment Information

Prior to the design of a CP system, the following information should be obtained:

(a) Tank, piping, and grounding construction drawings, including dimensions.
(b) Type of tank bottom (e.g., coned up, coned down, "W" shape, or level).
(c) Environment at location of tank (e.g., arid, arctic, swamp, coastal region).
(d) Date of tank construction.
(e) Material specifications and manufacturer (e.g., grade of steel).
(f) Site plan and layout.
(g) Joint construction (e.g., welded, riveted).
(h) External coating specifications—coating type (if any) and application.
(i) Existing or proposed CP systems in the area.
(j) Location of electric power sources and electrical area classification.
(k) Materials, sizing, and the electrical and chemical properties of the tank pad material and tank foundation.
(l) History of the tank foundation (e.g., whether the tank has been jacked up/leveled).
(m) Evidence of oxygen concentration cells.
(n) Operating history of the tank, including leak information (internal and external).

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(1) American Wire Gauge.

(o) Maintenance inspection and repair history of the tank.
(p) Release-prevention barriers.
(q) Secondary tank bottoms.
(r) Water table and site drainage information.
(s) Liquid levels maintained in the tank.
(t) Nearby foreign structures.
(u) Type of liquid stored.
(v) Operating temperature (seasonal usage).
(w) Electrical grounding.

3.3 Predesign Site Appraisal

3.3.1 Extent and Magnitude of Corrosion on Existing Tank Bottom(s)

3.3.1.1 Information regarding the extent and magnitude of corrosion on existing tank bottom(s) is useful because considerable tank bottom damage may require extensive repairs or replacement prior to the installation of a CP system.

3.3.1.2 Field procedures for determining the extent and magnitude of existing corrosion may include:

(a) Visual inspection.
(b) Tank bottom plate-thickness measurements (e.g., ultrasonic testing, coupon analysis).
(c) Estimation of general corrosion rates through the use of electrochemical procedures.
(d) Determination of the magnitude and direction of galvanic current or stray current transferred to or from the tank through piping and other interconnections.
(e) Determination of electrolyte (e.g., tank pad and tank foundation) characteristics including resistivity, pH, chloride ion concentration, sulfide ion concentration, and moisture content.
(f) Estimation of the extent and magnitude of corrosion damage based on comparison with data from similar facilities subjected to similar conditions.

3.3.1.3 Tank foundation characteristics are also important factors in the assessment of the extent and magnitude of existing corrosion. The tank pad, material of construction, thickness of ringwalls, and water drainage should all be considered.

3.3.1.4 Data pertaining to existing corrosion conditions should be obtained in sufficient quantity to permit reasonable engineering judgments. Statistical procedures may be used in the analysis, if appropriate.

3.3.2 Electrical Isolation

3.3.2.1 Electrical isolation facilities must be compatible with electrical grounding requirements and conform to applicable codes and safety requirements. If the tank bottom is to be cathodically protected, the use of alternative electrical grounding materials, such as galvanized steel and galvanic anodes, should be considered. This is to eliminate galvanic couples (in which the tank bottom is an anode) and to reduce the amount of cathodic current that is taken by the grounding system.

3.3.2.2 The designer of a CP system should consider the possible need for electrical isolation of the tank from piping, conduits, electrical devices, grounding systems, reinforcing steel encased in a concrete tank pad or tank foundation, and other interconnecting structures. Electrical isolation and DC decoupling devices may be necessary for effective CP or safety considerations.

3.3.2.3 Electrical isolation of piping, conduits, electrical devices, and grounding systems can be accomplished through the use of electrical isolating flanges, dielectric bushings or unions, or other devices specifically designed for this purpose. These devices shall be rated for the proper operating pressure and temperature and be compatible with the liquids being stored in the tank.

3.3.2.4 Polarization cells, lightning arresters, grounding cells, and DC decoupling devices may be useful in some situations for maintaining electrical isolation under normal operating conditions and providing protection for an electrical isolating device during lightning strikes, power surges, and other abnormal situations.

3.3.2.5 Tests to determine tank electrical characteristics include:

(a) Tank-to-earth resistance.
(b) Tank-to-grounding system resistance and potential.
(c) Structure-to-electrolyte potential.
(d) Electrical continuity of mechanical joints in piping.
(e) Leakage current through electrical isolating devices installed in piping and between the tanks and safety ground conductors.
(f) Resistivity of tank pad material.

3.3.3 CP Type, Current Requirements, and Anode Configuration.

3.3.3.1 Tank pad resistivity tests should be performed in sufficient quantity to aid in determining the type of CP (galvanic anode or impressed current) required and the configuration for the anode system. Figure 1 illustrates the four-pin method of soil resistivity testing.

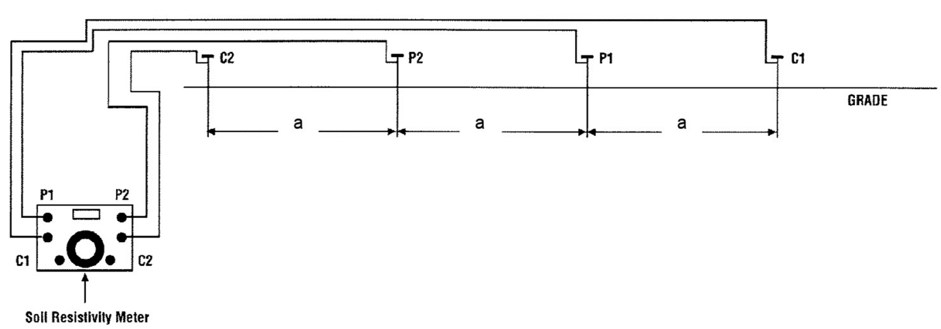

FIGURE 1: Soil Resistivity Testing (Four-Pin Method). NOTE: a = Depth of interest for the soil resistivity measurement.

3.3.3.2 Resistivities may be determined using the four-pin method described in ASTM[(2)] G57,[1] with pin spacings corresponding to depths of at least that expected for the anode system, or by using an equivalent testing method (in high resistivity environments, electromagnetic con-

[(2)] ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

ductivity testing may be used to measure resistivities).[2] The resistivity measurements should be obtained in sufficient detail to identify possible variations with respect to depth and location. As a general guideline, resistivity data should be obtained at a minimum of two locations per tank. Resistivity tests should be performed on the tank pad material where the anodes are placed.

3.3.3.3 Resistivities of some tank pad materials (e.g., soils and waters) normally decrease as their temperatures increase. On heated tanks, the resistivity of the tank pad may be significantly lower than on ambient temperature tanks if their moisture contents are similar. The moisture content of the tank pad sample also affects the resistivity.

3.3.3.4 If deep anode beds (see *groundbed* in Section 2) are considered, resistivities should be analyzed using procedures described by Barnes[3] to determine conditions on a layer-by-layer basis. On-site resistivity data should be supplemented with geological data including subsurface stratigraphy, hydrology, lithology, or previous electrical resistance logs. Sources for geological information include water well drillers, oil and gas production companies, the U.S. Geological Survey,[(3)] and other regulatory agencies. If under the tank anodes are considered, resistivity should be determined by taking samples of the tank pad using a calibrated soil box.

3.3.3.5 CP current requirements should be estimated using test anode arrays simulating the type of anode bed planned where practical. Test currents shall be applied using suitable sources of direct current. Test anode beds may include driven rods, anode systems for adjacent CP installations, or other temporary structures that are electrically isolated from the tank being tested. Small-diameter anode test wells may be appropriate and should be considered if extensive use of deep anode beds is being considered. Figure 2 illustrates a temporary anode bed for current requirement testing. A current requirement test is normally only used for retrofitting existing tanks with a CP system. For new tanks, the required current is covered in Paragraph 5.4.

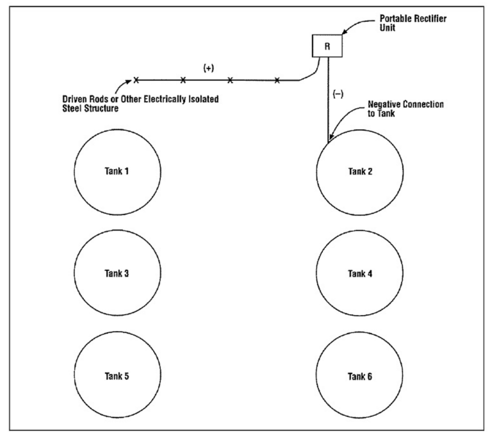

FIGURE 2: Temporary Anode Bed for Current Requirement Testing.

3.3.4 Stray Currents

3.3.4.1 The presence of stray currents may result in CP current requirements that are greater than those required under natural conditions. Possible sources of stray current include DC-operated rail systems and mining operations, other CP systems, welding equipment, high-voltage direct current (HVDC) transmission systems, and high-voltage alternating current (HVAC) transmission systems. Structure-to-electrolyte potentials and other parameters should be monitored over a minimum 24 h period in areas in which dynamic stray currents or transient effects are expected to be a concern. Recording instruments should be used for this purpose. Figure 3 illustrates stray-current corrosion.

3.3.4.1.1 Field tests to determine whether stray currents are a concern include those that provide structure-to-electrolyte potential measurements on the tank and adjacent structures, earth gradient measurements, and current flow measurements on piping and safety grounding conductors.

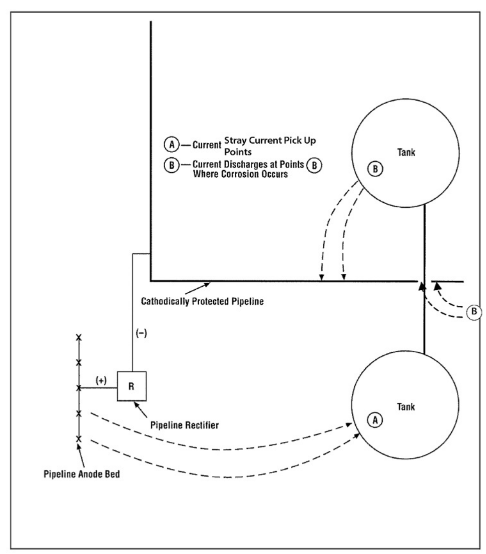

FIGURE 3: Stray-Current Corrosion.

(3) U.S. Geological Survey (USGS), 12201 Sunrise Valley Dr., Reston, VA 20192.

3.3.4.1.2 Possible electrical interference effects caused by adjacent CP systems should be determined by interrupting the current output using a known timing cycle.

3.3.4.1.3 CP designs should incorporate every practical effort to minimize electrical interference on structures not included in the CP system. Design test results should be analyzed to determine the possible need for stray-current control provisions in the CP system.

Section 4: Criteria for Cathodic Protection

4.1 This section presents criteria for CP that, if complied with either separately or collectively, indicate that CP of a carbon steel on-grade storage tank bottom has been achieved.

4.2 General

4.2.1 The objective of using CP is to control external corrosion of a carbon steel on-grade storage tank bottom in contact with an electrolyte. The selection of a particular criterion for achieving this objective depends, in part, on prior experience with similar tank bottoms and environments in which the criterion has been successfully used.

4.2.2 The criteria in Paragraph 4.3 were developed through laboratory experiments or were determined empirically by evaluating data obtained from successfully operated CP systems. It is not intended that personnel responsible for corrosion control be limited to operating under these criteria if it can be demonstrated by other means that the control of corrosion has been achieved.

4.2.3 Potential measurements on storage tanks shall be made with the reference electrode located as close as possible to the tank bottom. On most tanks, measurements should be taken at the perimeter, near the center of the tank bottom, and at various points in between. Consideration must be given to voltage drops other than those across the structure-to-electrolyte boundary, the presence of dissimilar metals, and the influence of other structures. These factors may interfere with valid interpretation of potential measurements. Also, measurements made with a reference electrode located on asphalt pavement or a concrete slab or outside the concrete ringwall may be in error.

4.3 Criteria for Corrosion Control of Carbon Steel Tank Bottoms

4.3.1 Corrosion control can be achieved at various levels of cathodic polarization depending on environmental conditions. However, in the absence of specific data that demonstrate that CP has been achieved, one or more of the following must apply to the CP system:

4.3.1.1 A negative (cathodic) potential of at least 850 mV with the CP current applied. This potential shall be measured relative to a saturated copper/copper sulfate reference electrode (CSE) contacting the electrolyte. Consideration must be given to voltage drops other than those across the structure-to-electrolyte boundary for valid interpretation of this potential measurement.

4.3.1.1.1 Consideration shall be understood to mean the application of sound engineering practices in determining the significance of voltage drops by methods such as:

(a) Measuring or calculating the voltage drop(s).
(b) Reviewing the historical performance of the CP system.
(c) Evaluating the physical and electrical characteristics of the tank bottom and its environment.
(d) Determining whether or not there is physical evidence of corrosion.

4.3.1.2 A negative polarized potential of at least 850 mV relative to a CSE.

4.3.1.3 A minimum of 100 mV of cathodic polarization between the carbon steel surface of the tank bottom and a stable reference electrode contacting the electrolyte. The formation or decay of polarization may be measured to satisfy this criterion.

4.4 Other Reference Electrodes

4.4.1 Other standard reference electrodes may be substituted for the CSE. Two commonly used reference electrodes are listed below, along with their equivalent potential (at 25 °C [77 °F]) to –850 mV potential relative to a CSE.

(a) Saturated silver/silver chloride reference electrode (See Table 2 in NACE SP0169).[4]
(b) High-purity zinc (99.99%) reference electrode (See Table 2 in NACE SP0169).

4.4.2 Stationary (permanently installed) reference electrodes may be used in measuring potentials under the tank. Stationary electrodes may be encapsulated in an appropriate backfill material.

4.4.3 Nonconductive perforated tubes should be included in all new tank installation to allow temporary installation of portable reference electrodes. For existing tanks, reference electrode access piping should be installed under the tank with horizontal drilling equipment capable of providing guidance and directional control to prevent tank bottom damage and to ensure accurate placement of the piping. For additional details, see Paragraph 9.4.

4.5 Special Considerations

4.5.1 Special cases, such as those involving electrical interference, may require the use of criteria different from those listed in Paragraph 4.3.

4.5.2 Coupons and electrical resistance corrosion probes may be useful in evaluating the effectiveness of the corrosion control system.

4.5.3 Conditions in which CP is ineffective or only partially effective sometimes exist. Such conditions may include the following:

(a) Elevated temperatures of the tank bottom (See Paragraph 4.5.4).
(b) Dry tank pad (See Paragraph 4.5.5).
(c) Disbondment of coatings.
(d) Shielding.
(e) Foreign objects in the tank pad (see Paragraph 4.5.6).
(f) Bacteria that can promote MIC (see Paragraph 4.5.7).
(g) Unusual contaminants in the electrolyte.

(h) Areas of the tank bottom that do not come into contact with the electrolyte.
(i) Nonconductive release prevention barrier (RPB) under the tank bottom.
(j) Condensation.

4.5.4 Elevated temperatures of the tank bottom can cause increased corrosion rates. Research has shown that as much as 300 mV of cathodic polarization may be required at 60 °C (140 °F), and must be maintained to achieve effective CP. Corrosion probes may help in the evaluation of corrosion rates at elevated temperatures. In addition, elevated temperatures of the tank bottom can also cause the tank pad to dry out (see Paragraph 4.5.5) as a result of the increased temperature.

4.5.4.1 Corrosion probes may help in the evaluation of corrosion rates at elevated temperatures,

4.5.4.2 Elevated temperatures of the tank bottom can also cause the tank pad to dry out (see Paragraph 4.5.5) as a result of the increased temperature.

CAUTIONARY NOTE: The differential between 250 mV potential relative to a high-purity zinc reference electrode and the –850 mV potential relative to a CSE at 25 °C (77 °F) decreases as the temperature increases.[5,6]

4.5.5 Tank pad materials that have very high resistivity, or that become very high resistivity over time (e.g., that have dried out because of elevated temperatures of the tank bottom) can produce conditions where effective CP is very difficult to achieve.

4.5.6 Rocks, gravel, clay deposits, and organic matter in contact with the underside of the tank bottom plates can promote the formation of localized corrosion, which is difficult to monitor or evaluate.

4.5.7 When active MIC has been identified or is probable, (e.g., caused by acid-producing or sulfate-reducing bacteria), a polarized potential of at least –950 mV, or as much as 300 mV of polarization relative to a CSE must be maintained to achieve effective CP.[7]

4.5.8 When reinforcing steel is embedded in the concrete tank pad and/or tank foundation of an on-grade storage tank and is required to be bonded to the electrical grounding system in accordance with applicable electrical codes or standards, a DC decoupling device may be required to allow CP current to reach the tank bottom.

Section 5: General Considerations for Cathodic Protection Design

5.1 This section presents practices and considerations that apply to the design of CP systems for single- and double-bottom carbon steel on-grade storage tanks.

5.2 CP Objectives and System Characteristics

5.2.1 The major objectives for the design of a CP system are:

(a) To protect the tank bottom from external corrosion.
(b) To provide sufficient and uniformly distributed CP current.
(c) To provide a design life commensurate with the design life of the tank bottom or to provide for periodic anode replacement.
(d) To minimize electrical interference.
(e) To provide adequate allowance for anticipated changes in current requirements for CP.
(f) To locate and install CP system components where the possibility of damage is minimal.
(g) To provide adequate monitoring facilities to permit a determination of the CP system's performance (see Paragraph 11.2).

5.2.2 Impressed current systems are normally used to supply CP for tanks. They are especially beneficial if the service temperature is elevated or if other factors require higher current densities. Impressed current systems are also used if higher driving potentials are required because of the presence of high-resistance electrodes.

5.2.3 An impressed current CP system is powered by an external source of direct current. The positive terminal of the direct current source is connected through insulated conductors to the anode system. The negative terminal of the direct current source is electrically connected to the tank bottom to be protected. Anode systems for on-grade storage tanks can include shallow anode beds, angle-drilled anode beds, and directionally drilled anode beds under the tank, deep anode beds, and close anodes under the tank bottom.

5.2.3.1 Satisfactory impressed current anode materials include mixed-metal oxides, polymer carbon, graphite, high-silicon chromium-bearing cast iron, platinized niobium (columbium), platinized titanium, scrap metal, and below-grade metallic structures that have been removed from service and cleaned of contaminants. Impressed current anode selection should be based on electrolyte chemistry, contaminants, and the compatibility of the anode with the environment.

5.2.4 Galvanic current CP systems operate on the principle of dissimilar metals corrosion. The anode in a galvanic anode CP system must be more electrochemically active than the structure to be protected. CP using a galvanic anode system is afforded by providing an electrical connection between the galvanic anode system and the on-grade storage tank bottom. Typical galvanic anode materials for on-grade storage tank bottom applications include magnesium and zinc.

Table 1
CP System Characteristics

Galvanic Anode CP System	Impressed Current CP System
No external power required	External power required
Fixed, limited driving potential	Driving potential can be varied
Limited current	Current can be varied
Satisfies small current requirements and normally limited to smaller tanks	Satisfies high current requirements and can be used for all sizes of tanks
Used in lower-resistivity environments	Used in lower or higher-resistivity environments
Usually do not cause stray current interference, but can still be interfered with	Must consider interference with other structures

5.3 In the design of a CP system, the following shall be considered:

(a) Recognition of hazardous conditions prevailing at the site and the selection and specification of materials and installation practices that ensure safe installation and operation.
(b) Compliance with all applicable governmental codes and owner requirements.
(c) Selection and specification of materials and installation practices that ensure dependable and economic operation of the CP system throughout its intended operating life.
(d) Design of proposed installation to minimize electrical interference.
(e) Avoiding excessive levels of CP, which may cause coating disbondment and possible damage to high-strength and special alloy steels.
(f) If amphoteric metals are involved (e.g., lead, tin, aluminum), avoiding high or low pH conditions that could cause corrosion.
(g) Presence of secondary containment systems.

5.4 Current Requirement

5.4.1 The preferred method of determining the current requirements for achieving a given level of CP on an existing tank bottom is to test the tank bottom using a temporary CP system. Alternately, a current density may be used for design purposes based on a current density successfully used at the same facility or at a facility with similar characteristics.

5.4.2 For design purposes, current requirements on new or proposed tank bottoms may be established by calculating surface areas and applying a CP current density based on the size of the tank, the electrochemical characteristics of the external environment, the service temperature, and the parameters of the anode beds. Design current densities of 10 to 20 mA/m^2 (1 to 2 mA/ft^2) of bare tank bottom surface are generally sufficient. Where a new tank is built with a nonconductive RPB beneath the tank bottom, or in a double bottom with nonconductive RPB, current densities of 5 mA/m^2 (.5 MA/ft^2) are generally sufficient. Tank bottoms exposed to external environments involving chlorides, sulfides, sulfates, bacteria, low pH, or to elevated service temperatures require more CP current. The history of other tanks with the same external environment should be considered when choosing a design current density.

5.4.3 Care must be exercised to ensure that anode type and placement result in uniform distribution of CP current to the tank bottom surfaces.

5.4.4 Liquid level within an on-grade storage tank must be sufficient to ensure that the entire tank bottom is in intimate contact with an electrolyte while establishing current requirements and testing applied CP levels. Adequate liquid levels are important to maintaining polarization.

5.4.4.1 As the liquid level increases (and more of the tank bottom contacts the electrolyte), the CP current requirement increases and the potential measured may decrease because of the increased surface area of steel contacting the electrolyte.

5.5 Tank System Configuration

5.5.1 Design, materials, and construction procedures that do not create shielding conditions should be used.

5.5.2 Nonwelded mechanical joints might not be electrically continuous. Electrical continuity may be ensured by bonding existing joints.

5.5.3 If electrical isolation is required, care must be taken to assure that the isolation is not shorted, bypassed, etc.

5.6 Special consideration should be given to the presence of sulfides, chlorides, bacteria, coatings, elevated temperatures, shielding, pH conditions, treated tank pad material, electrolyte contamination, dissimilar metals, tank pad/concrete/metal interface at the ringwall, and any heating or refrigeration coils.

5.6.1 Tank pad material

5.6.1.1 The tank pad material shall consist of a uniform homogenous layer of sand or finely crushed stones, which conform to the following sizing, chemical, and electrical properties:

5.6.1.2 The tank pad materials shall conform to ASTM specifications.[8,9]

5.6.1.3 The tank pad material shall be clean, screened, and free of all scrap steel, batten nuts and bolts, washers, metallic debris (e.g., welding rods, tools) and nonmetallic debris (e.g., wood, plastic, sticks, organic matter, vegetation, paper, rocks, gravel, clay, silt, and dissimilar soils).

5.6.1.4 The tank pad material should have the following properties:

Sulfates: < 200 ppm
Chlorides: < 10 ppm
Sulfides: < 0.1 ppm
pH: ≥ 5.0
Resistivity (when saturated with high resistivity water):
> 5,000 Ω·cm

5.6.1.5 The tank pad material should be tested immediately prior to construction of the tank pad to ensure that the properties meet the guidelines in Paragraph 5.6.2.4.

5.6.1.6 If required to conform to the chemical and electrical properties in Paragraph 5.6.1.4, tank pad material washing should be performed at the supply source. Water that does not compromise the resistivity or chemical composition of the tank pad material shall be used for washing. A municipal water supply shall not be used to clean the sand.

5.6.1.7 Oiled tank pad materials shall not be used for new construction.

5.7 On-grade storage tanks that are set on solid concrete or asphalt tank pads generally require specialized measures for external corrosion protection, because CP is generally not effective. In this instance, the external surface of the tank bottom should be coated. In all cases, steps should be taken to ensure that water does not migrate between the tank bottom and the tank pad.

5.7.1 Where a solid concrete slab exists, a tank pad should be installed as specified in Paragraphs 5.6.1, on top of the concrete to provide an improved path for CP current flow to the tank bottom. (See Paragraph 8.1.3).

5.7.2 Providing electrical isolation and DC decoupling devices between the reinforcing steel and the tank bottom should be considered if a concrete ringwall or tank pad is used. On newly constructed tanks in which concrete ringwall foun-

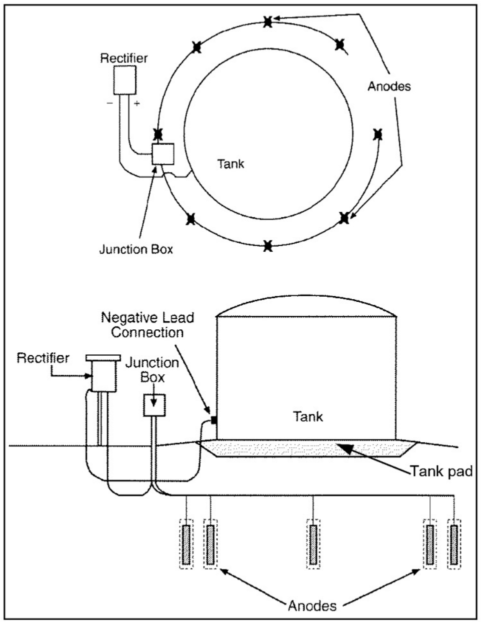

FIGURE 4: Tank CP System with Vertically Drilled Anode Bed.

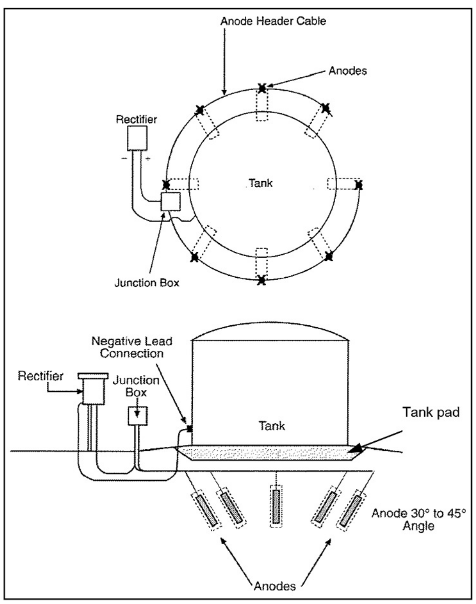

FIGURE 5: Tank CP System with Angle-Drilled Anode Bed.

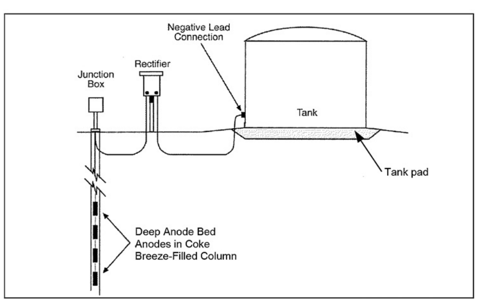

FIGURE 6: Tank CP System with Deep Anode Bed.

dations and footings are used and the reinforcing steel is required to be bonded to the grounding system (in accordance with applicable electrical codes or standards), special design considerations and DC decoupling devices shall be used.

5.8 Design Drawings and Specifications

5.8.1 Specifications should be prepared for all materials and installation procedures that are used during construction of the CP system.

5.8.2 Suitable drawings should be prepared to show the overall layout of the on-grade storage tank bottoms to be protected and the CP system and associated appurtenances.

Section 6: Design Considerations for Impressed Current Cathodic Protection

6.1 This section presents practices and considerations that specifically apply to the design of impressed current CP systems for controlling external corrosion of carbon steel on-grade storage tank bottoms.

6.2 Impressed Current Anode Systems

6.2.1 Impressed current anodes shall be connected with an insulated cable, either singularly or in groups, to the positive terminal of a direct current source such as a rectifier or DC generator. The tank bottom shall be electrically connected to the negative terminal. Cable insulation should be selected based on the anticipated environmental conditions.

6.2.2 Anode bed configurations may be vertical, angled, deep, or horizontal, as illustrated in Figures 4 through 7. Anodes may be installed in a distributed manner under tank bottoms. The selection of anode configuration is dependent on environmental factors, CP current requirements, the size and type of tank bottom to be protected, whether the tank bottom is existing or newly contructed, and whether it is a single- or double-bottom tank. For tanks with double bottoms or release-prevention barriers, refer to Section 8.

6.2.3 Deep anode beds should be designed and installed in accordance with NACE SP0572.[10]

6.2.4 Impressed current anode materials have varying rates of deterioration when discharging current. Therefore, for a given output, the anode life depends on the environment, anode material, anode mass, and the number of anodes in the anode bed. Established anode performance data should be used to calculate the probable life of the anode bed.

6.2.4.1 Anode materials that may be used for impressed current CP systems include mixed-metal oxides, polymer carbon, graphite, high-silicon chromium-bearing cast iron, platinized niobium (columbium), platinized titanium, and scrap metal.

6.2.5 Use of special backfill around the anodes can increase the useful life of impressed current CP anodes. The most commonly used backfill materials are metallurgical coal coke and calcined petroleum coke. Because coke is noble compared to carbon steel, coke should not be allowed to come into contact with the tank bottom.

6.2.6 In the design of an extensive, distributed-anode impressed current system, the voltage and current attenuation along the anode and the anode-connecting (header) cable should be considered. In such cases, the design objective should be to optimize anode system length, anode size and spacing, and cable size to achieve effective corrosion control over the entire external surface of each tank bottom.

6.2.7 As tank pad resistivity and tank diameter increase, anodes distributed around the perimeter of the tank (as shown in Figure 4) may become less effective in supplying sufficient CP current to the center of the tank.

6.2.8 Suitable provisions for venting the anodes shall be made in situations in which it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current anode bed to deliver the required CP current. Venting systems must be designed to prevent contaminants from entering the venting system.

6.2.9 A constant distance should be maintained between the tank bottom and anode column when using horizontally installed anode beds.

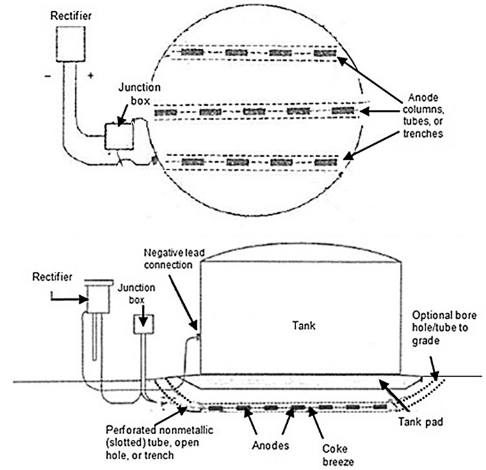

FIGURE 7: Tank CP System with Horizontally Installed Anode Bed. NOTE: Number of columns, tubes, or trenches is based on tank diameter. Special consideration must be given during the design and installation of anode tubes to assure that any RPB is not breached. CAUTION: Extreme caution must be exercised when boring or waterjetting under tanks.

6.3 Safety

6.3.1 All impressed current CP systems must be designed with safety in mind. Care must be taken to ensure that all cables are protected from physical damage and the possibility of arcing.

6.3.2 All components of a CP system must meet regulatory safety requirements and prevailing industrial codes for the specific location and environment in which they are installed. Such locations shall be determined by reviewing regulatory agency and prevailing industrial codes.

Section 7: Design Considerations for Galvanic Anode Cathodic Protection

7.1 This section presents practices and considerations that specifically apply to the design of galvanic anode CP systems for controlling external corrosion of carbon steel on-grade storage tank bottoms without secondary containment.

7.2 Galvanic anode CP systems may be more economical when applied to a tank bottom if the carbon steel surface area exposed to the electrolyte can be minimized through the application of a dielectric coating, the surface area is small as a result of the tank size or configuration, or no power source or impressed current source is available.

7.2.1 Galvanic anodes should be connected to the tank bottom through a test station so that anode performance and voltage drops can be monitored.

7.2.2 For applications in which the tank bottom is either uncoated or large as a result of the tank size or configuration, the use of impressed current CP should be considered to minimize the cost of the CP system. Section 6 provides more information regarding the practices and considerations for the design of impressed current CP systems.

7.3 Galvanic Anode Selection

7.3.1 The three most common types of galvanic anodes effective in soil and tank pad environments are standard-potential magnesium, high-potential magnesium, and high-purity zinc.

7.3.2 The selection and use of these types of galvanic anodes should be based on the CP current requirements of the tank bottom, the soil and tank pad characteristics, the temperature of the tank bottom, and the cost of the materials and installation.

7.3.3 The current available from each type of anode depends greatly on the soil and tank pad characteristics, the anode shape (whether bar, block, or ribbon), and the driving potential of the anode.

7.3.4 If high-purity zinc anodes are used, care should be exercised to ensure that the anodes meet the requirements of ASTM B418[11] Type II anode material. The purity of the zinc can greatly affect the performance of the material as a galvanic anode for soil and tank pad applications.

7.3.5 Zinc anodes shall not be used if the temperature of the anode environment is above 49 °C (120 °F), unless they are tested to perform in that environment. Anode passivation increases with temperature.

7.3.6 The presence of salts such as carbonates, bicarbonates, or nitrates in the electrolyte may also affect the performance of zinc as an anode material.

7.3.7 Galvanic anode performance may be enhanced by using special backfill material. Mixtures of gypsum, bentonite, and sodium sulfate are the most common.

7.3.8 Galvanic anode lead wire should be at least 2 mm (0.08 in) in diameter (#12 AWG [American Wire Gauge]). Cable insulation should be selected based on the anticipated environmental conditions.

Section 8: Cathodic Protection System Design Considerations for Tanks with Release-Prevention Barriers or Replacement Bottoms

8.1 This section presents practices and considerations that specifically apply to the design of CP systems for controlling external corrosion of carbon steel on-grade storage tank bottoms with release-prevention barriers or replacement bottoms.

8.1.1 Release-prevention barriers and replacement bottoms are used together or separately.

8.1.2 Release-prevention barriers and secondary carbon steel tank bottoms may shield the external surface of the primary carbon steel tank bottom from the CP current, resulting in a lack of adequate CP.

8.1.3 Any impact (e.g., corrosiveness) that the fill material used between the release-prevention barrier and the tank bottom or between two tank bottoms could have on the CP system should be considered.

8.2 Release-Prevention Barriers

8.2.1 Impervious membranes or liners constructed of a nonconductive material used as a release-prevention barrier may shield the CP current from anodes located outside the barrier envelope. Anodes must be placed between the barrier and the carbon steel tank bottom so that current flows to the surfaces requiring CP. Figure 8 illustrates a typical CP system (impressed current or galvanic anode) layout for tanks with a release-prevention barrier.

8.2.2 If release-prevention barriers made of conductive material are used with a CP system with anodes outside the space contained by the barrier, the barrier must maintain a resistance low enough for sufficient CP current to flow to the tank bottom.

8.2.3 Stationary reference electrodes or portable reference electrode insertion tubes must be located between the carbon steel tank bottom and the barrier to obtain accurate structure-to-electrolyte data.

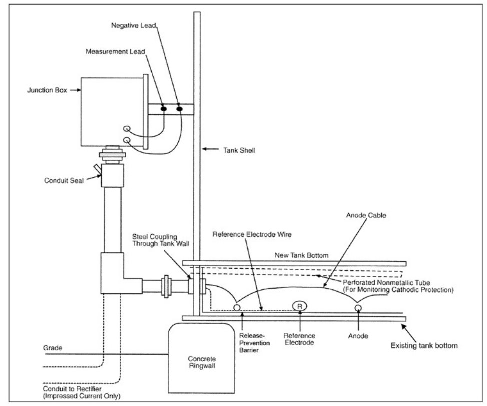

FIGURE 8: Typical CP System (Impressed Current or Galvanic Anode) Layout for Tanks with a Release-Prevention Barrier and/or a Replacement Bottom.

8.3 Replacement Tank Bottoms

8.3.1 If a replacement tank bottom is installed in an existing tank over an original tank bottom in such a manner that there is an electrolyte between the two tank bottoms, galvanic corrosion of the new tank bottom plates may result in premature failure of the replacement tank bottom.

8.3.2 CP should be considered for the primary (new) tank bottom. The anodes and reference electrodes or nonconductive reference electrode insertion tubes must be placed in the electrolyte between the two bottoms. Figure 8 illustrates a typical CP system (impressed current or galvanic anode) layout for tanks with a replacement bottom.

8.3.3 The installation of a nonconductive, membrane or liner above the original tank bottom reduces galvanic corrosion of the replacement tank bottom, reducing the current required for CP. If a nonconductive membrane is not used, the surface area of both tank bottoms must be considered in the CP design.

8.3.4 If the original tank bottom is removed and replaced with a new tank bottom, the CP design shall be that used for a standard, single-bottom tank.

8.3.5 When new patch plates are added to an existing tank bottom in lieu of tank bottom replacement, consideration shall be given to the tank pad and CP of the new steel/old steel galvanic couple area.

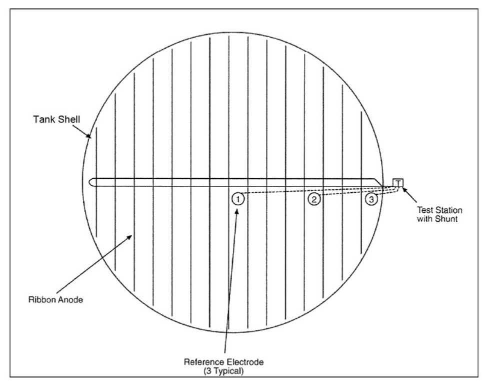

FIGURE 9: Typical Galvanic (Ribbon) Anode CP System Design for a Double-Bottom Tank.

8.4 Cathodic Protection Systems

8.4.1 Either impressed current or galvanic anode CP systems may be used.

8.4.1.1 Figure 9 illustrates a typical galvanic (ribbon) anode CP system design for double-bottom tanks. Galvanic anodes may be magnesium or zinc (see Paragraph 7.3).

8.4.1.2 Figure 10 illustrates a typical impressed current CP system design for a new tank or double-bottom tank. Impressed current anodes may be any of those listed in Paragraph 6.2.4.1.

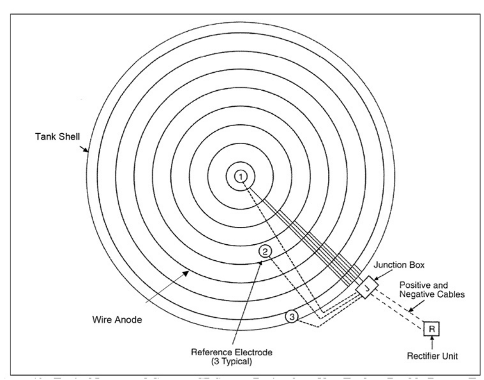

FIGURE 10: Typical Impressed Current CP System Design for a New Tank or Double-Bottom Tank.

8.4.1.3 Because of the depolarizing effect of oxidation by-products (typically chlorine, oxygen, or carbon dioxide) migrating from the anode to the steel cathode, the current density required to achieve protection with an impressed current CP system may be higher than that which is required for a galvanic anode CP system. Generating excessive levels of depolarization should be minimized by operating impressed current CP systems at a minimum level of polarization necessary to meet the CP criterion.

8.4.2 Adequate space must be provided between the two tank bottoms to allow for installation of a CP system with uniform current distribution from the anodes. Because of limited space between the two tank bottoms, close anode spacing may be required to improve current distribution.

NOTE: Impressed current anodes must not contact the carbon steel surfaces of the tank.

8.4.4 Anodes must be installed in a conductive electrolyte. The electrolyte must be sufficiently compacted to prevent settlement of the replacement tank bottom.

Section 9: Installation Practices and Considerations

9.1 This section presents practices and considerations that apply to the installation of CP systems for carbon steel on-grade storage tank bottoms.

9.2 Preparation

9.2.1 Materials should be inspected prior to installation to ensure that specifications have been met.

9.2.2 Installation practices shall conform to all applicable regulatory agency codes and requirements.

9.3 Anode Installation

9.3.1 Anodes should be installed as designed. Care must be taken to ensure that the anodes do not come into electrical contact with any piping, tankage, structures, or sumps during installation.

9.3.2 Slack shall be allowed in the anode lead wires to avoid possible damage caused by settlement of the tank and surrounding soils. Anodes, lead wires, and connections should be handled with care to prevent damage or breakage.

9.3.3 The anode lead wires shall be extended to the side of the tank away from the construction to minimize possible damage. After the tank foundation and tank pad have been prepared and the tank set in place, the anode lead wires should be terminated in a test station or junction box, which may include shunts for measuring anode current outputs.

9.4 Reference Electrodes

9.4.1 Stationary reference electrodes or nonconductive, perforated tubes for temporary installation of a portable reference electrode should be installed under all tanks regardless of the anode bed type and location.

9.4.1.1 Stationary reference electrodes may be prepackaged in a backfill and placed in the tank pad under the tank bottom, or positioned inside the perforated reference electrode access tubes. Reference electrodes placed inside access tubes should be surrounded with a backfill material designed to provide contact between the electrode and the electrolyte outside the tube. If practical, provisions should be made for future verification of all stationary reference electrode potentials with portable reference electrodes.

9.4.1.2 Reference electrode access tubes must have some means of contact with the electrolyte and should have at least one end accessible from outside the tank shell. This contact may be achieved by the use of holes, slits, or not capping the end of the tubes beneath the tank. Perforations and slots should be designed to minimize entry of tank pad material. Portable reference electrodes shall be inserted through the inner bore of the access tube with a nonmetallic material such as small-diameter polyvinyl chloride (PVC) pipe. Inserting a reference electrode with metallic tape, bare wires, etc., may adversely affect potential measurements. If necessary, water should be injected inside the access tube to establish continuity between the electrode and the electrolyte. Deionized water should be used for double-bottom tanks or tanks with a release-prevention barrier.

9.4.2 For existing tanks, reference electrode access tubes should be installed under the tank with horizontal drilling equipment capable of providing guidance and directional control to prevent tank bottom damage and to ensure accurate placement of the tubes. Consideration must be given to the structural aspects of the tank pad and foundation to ensure that support capabilities are not adversely affected. Figure 11 illustrates the placement of a perforated tube for reference electrode access installed under an on-grade storage tank bottom.

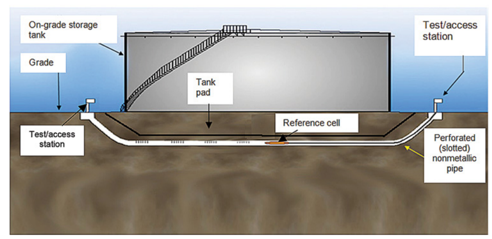

FIGURE 11: Perforated Pipe for Reference Electrode Access Installed Under an On-Grade Storage Tank Bottom.

NOTE: Special consideration must be given during the design and installation of access tubes to assure that any RPB is not breached.

CAUTION: Extreme caution must be exercised when boring or waterjetting under tanks.

9.4.2.1 A constant distance should be maintained from the tank bottom to the reference electrode access tube. Increasing space between the tank bottom and the reference electrode increases the voltage drop.

9.5 Test Stations and Junction Boxes

9.5.1 Test stations or junction boxes for potential and current measurements should be provided at sufficient locations to facilitate CP system testing.

9.5.2 Test stations and junction boxes should be mounted on or near the side of the tank in an area that is protected from vehicular traffic.

9.5.3 Test stations and junction boxes should allow for disconnection of the anodes to facilitate current measurements and potential measurements for voltage drop as required to evaluate the CP level. Test leads from buried reference electrodes should be terminated in the same test station as tank bottom test wires.

9.5.4 Test stations or junction boxes may be used to connect continuity bonds or protective devices. Buried or inaccessible electrical continuity bonds should be connected to a test station or junction box.

9.5.5 Test stations and junction boxes in a galvanic anode CP system may be equipped with shunts in connections between the anodes and the tank to measure the anode current output.

9.5.6 Test stations and junction boxes should be clearly marked and accessible for future monitoring of the tank bottom.

9.5.7 All lead wires to test stations and junction boxes should be protected from damage. Warning tape should be installed over direct-buried cables to prevent the possibility of damage during future excavation.

9.6 Safety Considerations

9.6.1 All personnel to be involved in the installation of the CP system shall participate in an appropriate safety training program.

9.6.2 All underground facilities, including buried electric cables and pipelines in the affected areas, shall be located and marked prior to digging.

9.6.3 All utility companies and other companies with facilities crossing the work areas shall be notified and their affected structures located and marked prior to digging.

9.6.4 All areas with low overhead wires, pipelines, and other structures shall be located and noted prior to any construction.

9.6.5 Operations and maintenance personnel shall be notified of pending construction to coordinate necessary shutdowns or emergency considerations.

9.6.6 Additional safety precautions are required when flammable and/or combustible products are stored.

Section 10: Energizing and Testing

10.1 This section presents practices and considerations that apply when energizing and testing a CP system for carbon steel on-grade storage tank bottoms.

10.2 Knowledge of the performance criteria considered during the design of a CP system as well as the operational limits of CP devices and hardware should be available to the personnel setting operating levels for the CP system.

10.3 Initial Baseline Data

10.3.1 Verification of CP devices and hardware, such as the following, should be done prior to energizing:

(a) Location of anodes.
(b) Ratings of impressed current sources.
(c) Location of reference electrodes.
(d) Location of test facilities.
(e) Location of CP system wires and cables.

10.3.2 Prior to energizing the CP system, the following data and information should be collected:

(a) Structure-to-electrolyte potentials on the tank bottom.
(b) Structure-to-electrolyte potentials on connected piping.
(c) Verification of electric isolation.
(d) Structure-to-electrolyte potentials on foreign structures.

(e) Test coupon data.
(f) Fluid level in the tank during testing.
(g) Corrosion probe data.

10.3.3 All initial baseline data should be documented and the records maintained for the life of the on-grade storage tank. Any deviations from the design or as-built documentation should be noted and included with the initial baseline data.

10.3.4 When measuring the structure-to-electrolyte potentials on the tank with portable reference electrodes, the reference electrodes should be placed at sufficient intervals around the perimeter and under the tank to ensure that the potentials measured are representative of the entire tank bottom. A potential measured at the perimeter of a large-diameter tank does not represent the potential at the center of the tank. For testing with reference electrode access tubes under the tank bottom, see Paragraph 9.4.1.2.

10.4 Current Adjustment

10.4.1 The desired operating level of a CP system must often be determined by a series of trial tests at various operating levels. The specific operating level depends on the criterion for CP used for the on-grade storage tank(s). Section 4 presents the various criteria for achieving CP of external surfaces of carbon steel on-grade storage tank bottoms. Time required to achieve polarization on a bare tank bottom can be different from tank to tank.

10.4.2 When adjusting the operating levels of CP systems, consideration must be given to the effect of electrical interference on adjacent structures. Owners of these structures should be notified of the installation of a new CP system.

10.4.2.1 The structures that should be considered as being possibly affected by electrical interference include, but are not limited to, the following:

(a) On-grade and buried storage tanks.
(b) Piping electrically isolated from the tank(s) by high-resistance fittings.
(c) Buried electric facilities.
(d) Buried fire-protection piping.
(e) Buried water piping.
(f) Transmission or distribution piping serving storage tank(s).
(g) Municipal or public utility structures serving the facility in which a storage tank(s) is located.
(h) Fencing.
(i) Reinforcing steel in concrete foundations for tanks and other structures.

10.4.2.2 Structures that may contain discontinuous fittings or joints, such as cast iron systems, ductile iron systems, or piping with mechanically connected fittings shall be given special attention to ensure that electrical interference is detected and mitigated.

10.4.3 The final operating level of a CP system should be established to achieve the CP criterion established by the design documents as set forth in Section 4, or by the operating policies of the facility owner.

10.5 Documentation

10.5.1 Documentation of all pertinent CP system information and data should be completed after the CP system is energized. Pertinent information and data should include, but are not limited to:

(a) Initial baseline data.
(b) As-built drawings.
(c) Operating currents.
(d) Locations of test facilities.
(e) Key monitoring locations.
(f) Equipment manuals.
(g) Tank fluid level at the time of testing.

10.5.2 All collected data should be recorded and documented for future reference.

10.6 Error Sources: Consideration must be given to sources of error when potentials are measured on carbon steel on-grade storage tank bottoms (refer to NACE Standard TM0101).[12] These error sources include, but are not limited to:

10.6.1 Measurement Circuit Voltage Drop: If a tank pad has a very high resistivity, a voltage drop error occurs in the measuring circuit if a low-input impedance meter is used. This error shall be minimized by using a meter with an impedance greater than 10 megohms. A variable impedance meter should be used to further quantify the error.

10.6.2 Tank Bottom Flexing: When the product level in the tank is low, a portion of the tank bottom may shift upward, affecting the measurement circuit and changing the area of the tank bottom being monitored. This may result in misleading measurements. This error should be minimized by ensuring that there is sufficient product level in the tank during measurements.

10.6.3 Measurements Made from Grade Wall (single-bottom tanks): Potential measurements made from grade are strongly influenced by the potentials at the perimeter of the tank bottom or outside the ringwall (if present). To measure the potentials correctly in the center of the tank bottom, either a stationary reference electrode permanently installed under the tank bottom, or a temporary reference electrode inserted in an access tube located under the tank bottom shall be used.

10.6.4 Alternate tank pad materials (e.g., oiled sand, asphalt, concrete) may cause an error in the potential measurements.

10.6.5 Electrical interference from adjacent CP systems may affect potential measurements on single-bottom tanks.

Section 11: Operation and Maintenance of Cathodic Protection Systems

11.1 This section presents practices for maintaining the effective and efficient operation of CP systems for carbon steel on-grade storage tank bottoms.

11.2 Monitoring Cathodic Protection Systems

11.2.1 CP systems shall be monitored to ensure adequate CP of the tank bottom(s) in accordance with the CP criteria set forth in Section 4.

11.2.2 Annual electrical surveys should be performed to verify that the CP system is meeting the CP criteria. Making more frequent electrical surveys of the CP system may be desirable in critically corrosive environments or where highly variable conditions are present. The accuracy of stationary reference electrodes should be evaluated during these electrical surveys. The effectiveness of electrical isolating fittings and continuity bonds should also be evaluated during the periodic electrical surveys.

11.2.3 All sources of impressed current should be checked at bimonthly intervals to ensure effective operation of the CP system. Current and voltage outputs consistent with previous measurements or a satisfactory polarized potential measured at the protected tank bottom surface may each be considered evidence of proper functioning.

11.2.4 Potential testing should consist of a minimum of four equally spaced potential measurements on the external circumference and at least one potential measurement at the center of the bottom on tanks with a diameter of 18 m (60 ft) or less. On tanks with a diameter greater than 18 m (60 ft), eight equally spaced potential measurements on the external circumference and at least one potential measurement at the center of the tank bottom should be the minimum.

11.2.4.1 Experience has indicated that on large tanks, potential measurements obtained at the perimeter of the tank may not reflect the actual conditions of the entire tank bottom.

11.2.4.2 Potential measurements may be affected by changes of liquid level in the tank.

11.2.4.3 The CP system should be monitored for the existence of any electrical interference from adjacent structures or CP systems.

11.2.5 All CP systems should be inspected as part of a predictive/preventive maintenance program to minimize in-service failure. Inspections should include a check for electrical shorts, ground connections, meter accuracy, rectifier efficiency, and circuit resistance. Scheduled maintenance should include removing debris at the rectifier openings required for cooling and checking to ensure that all connections are secure and unaffected by corrosion. Maintenance should include inspection of junction boxes, test stations, and other equipment.

11.3 Test equipment used for obtaining CP data shall be checked periodically for accuracy and maintained in good operating condition.

11.4 Corrective action shall be taken if electrical surveys and inspections indicate that the CP system is no longer providing adequate CP. These actions include the following:

(a) Repair, replacement, or adjustment of components of the CP system.
(b) Addition of supplementary CP when necessary.
(c) Repair, replacement, or adjustment of continuity bonds and continuity devices.

11.5 Care should be exercised to ensure that remedial measures intended to restore or enhance protection do not compromise the integrity of release-prevention barriers.

11.6 Consideration should be given to locating electrical isolation devices, junction boxes, and rectifiers outside hazardous areas in case sparks or arcs occur during testing.

11.7 Care must be exercised to prevent arcing when working on piping attached to tanks with CP applied. When CP systems are turned off, sufficient time must be allowed for polarization decay before opening connections. Bonding cables must be used when parting piping joints.

11.8 The tank bottom and anodes should be examined for evidence of corrosion whenever access to the tank bottom is possible (especially during internal inspections). Tank bottom thickness inspections and/or coupon cutouts, (which should be removed and examined for external corrosion) and chemical and electrical tests on the exposed tank pad material should be performed.

Section 12: Recordkeeping

12.1 This section presents pertinent information that should be recorded and filed for future information and reference.

12.2 Tank information should include, but not be limited to, the information listed in Paragraph 3.2.

12.3 Design and installation records for CP systems should be kept, including the following information:

(a) Design calculations and considerations.
(b) Power source capacity, circuit breakers, panels, etc.
(c) Number of anodes.
(d) Anode material and expected life.
(e) Anode installation details.
(f) Type, quantity, and location of stationary reference electrodes.
(g) Resistivity of the tank pad material.
(h) Resistivity of the soil.
(i) Date of energizing the CP system and initial current and voltage settings.
(j) Cost of CP system.
(k) Fluid level in the tank(s) during electrical survey.
(l) As-built drawings of the CP system installation.

12.4 Operation and maintenance records for CP systems should be kept, including the following information:

(a) Tabulations of bimonthly measurements of impressed current power source.
(b) Reports of periodic or annual inspections.
(c) All adjustments, repairs, and additions.
(d) Costs of maintenance.
(e) Test equipment calibration records.

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[5] U.S. Department of Commerce, 1401 Constitution Ave. NW, Washington, DC 20230.

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