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Standard
Recommended Practice

External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms

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NACE International
P.O. Box 218340
Houston, Texas 77218-8340
+1 713/492-0535

Foreword

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

The purpose of this recommended practice is to outline practices and procedures for providing cathodic protection to the steel bottoms of on-grade storage tanks that are in contact with the electrolyte. Recommendations are included for both galvanic anode systems and impressed current systems. Design criteria are included for the upgrade of existing tanks as well as for newly constructed tanks. This standard should be used by people planning to install new on-grade metallic storage tanks, upgrade cathodic protection on existing tanks, or install new cathodic protection on existing tanks.

This NACE International standard recommended practice was prepared by NACE Task Group T-10A-20, a component of NACE Unit Committee T-10A on Cathodic Protection, and is issued under the auspices of NACE Group Committee T-10 on Underground Corrosion Control. The task group was composed of corrosion engineers, technicians, and other people experienced in the design, installation, and maintenance of cathodic protection systems for on-grade metallic storage tank bottoms.

NACE International Standard Recommended Practice

External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms

Contents

Section 1: General

1.1 This recommended practice presents guidelines for the design, installation, and maintenance of cathodic protection for the exterior bottoms of on-grade metallic storage tanks. Cathodic protection can be installed to protect new or existing tanks, but cannot protect metallic surfaces that are not in contact with the electrolyte.

1.2 Tanks considered in this recommended practice can be welded, bolted, or riveted. For the purpose of this recommended practice, field- and shop-fabricated tanks are discussed together.

1.3 It is understood in this document that cathodic protection may be used alone or in conjunction with protective coatings.

1.4 All cathodic protection systems should be installed with the intent of conducting uninterrupted, safe operations. When cathodic protection is applied, it should be operated continuously to maintain polarization.

1.5 The criteria for cathodic protection are based upon current industry standards.

1.6 Corrosion control must be a consideration during the design of on-grade metallic storage tanks.

Section 2: Definitions

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

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

Backfill: Material placed in a hole to fill the space around anodes, vent pipe, and buried components of a cathodic protection system. Anodes can be prepackaged with backfill material for ease of installation.

Breakout Piping: All piping associated with the transfer of products in and out of storage tanks.

Cathode: The electrode of an electrolytic cell at which reduction is the principal reaction.

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

Cell: Electrochemical system consisting of an anode and a cathode immersed in an electrolyte. The anode and cathode may be separate metals or dissimilar areas on the same metal. The cell includes the external circuit which permits the flow of electrons from the anode toward the cathode.

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

Deep Groundbed: One or more anodes installed at a nominal depth of 15 m (50 ft) or more below the earth's surface for the purpose of supplying cathodic protection.

Differential Aeration Cell: An electrolytic cell, the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.

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

Electrolyte: A chemical substance or mixture, usually liquid, containing ions which 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 the test cell. It is this portion of the cell through which electrons travel.

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

Galvanic Anode: A metal which, because of its relative position in the galvanic series, provides sacrificial protection to metals that are more noble in the series, when coupled in an electrolyte.

Groundbed: The anode(s) of a cathodic protection system that provides cathodic protection current to structures in contact with the electrolyte.

Impressed Current: Direct current supplied by a device employing a power source external to the electrode system of a cathodic protection installation.

Oxidation: Loss of electrons by a constituent of a chemical reaction.

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

Reference Electrode: A reversible electrode used for measuring the potentials of other electrodes.

Stray Current Corrosion: Corrosion resulting from direct current flow through paths other than the intended circuit. For example, by any extraneous current in the earth.

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

3.1 Introduction

3.1.1 This section outlines the information that should be considered prior to designing a cathodic protection system to protect on-grade metallic storage tank bottoms in contact with an electrolyte.

3.2 Site Assessment Information

3.2.1 Prior to designing a cathodic protection system, the following information is valuable to obtain:

(a) Tank, piping, and grounding construction drawings, including dimensions, etc.,

(b) Site plan and layout,

(c) Date of construction,

(d) Material specifications and manufacturer,

(e) Joint construction (i.e., welded, riveted, etc.),

(f) Coating specifications,

(g) Existing or proposed cathodic protection systems,

(h) Location of electric power sources,

(i) Electrochemical properties of the tank bedding or padding material,

(j) History of the tank foundation (i.e., has the tank been jacked up?, leveled?, etc.),

(k) Unusual environmental conditions,

(l) Operating history, including leak information (internal and external),

(m) Maintenance history,

(n) Containment membranes/impervious linings,

(o) Secondary bottoms,

(p) Water table and site drainage information,

(q) Liquid levels maintained in the tank,

(r) Nearby foreign structures, and

(s) Type of liquid stored.

3.3 Predesign Site Appraisal

3.3.1 Determining the Extent of Corrosion on Existing Systems

3.3.1.1 Information regarding the degree of tank bottom corrosion is useful since considerable bottom damage may require extensive bottom repairs or replacement prior to the installation of cathodic protection.

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

(a) Visual inspection,

(b) Tank bottom plate thickness measurements (ultrasonic testing, coupon analysis, etc.),

(c) Estimation of general corrosion rates through the use of electrochemical procedures,

(d) Determining the magnitude and direction of galvanic or stray current transferred to or from the tank through piping and other interconnections, and

(e) Determining soil and foundation characteristics including resistivity, pH, chloride ion content, and moisture content, and estimating the degree of corrosion deterioration based on comparison with data from similar facilities subjected to similar conditions.

3.3.1.3 Data pertaining to existing corrosion conditions should be obtained in sufficient quantity to permit reasonable engineering judgments. Statistical procedures should be used in the analysis where appropriate.

3.3.2 Electrical Isolation

3.3.2.1 Electrical isolation facilities must be compatible with electrical grounding requirements conforming to applicable codes and safety requirements.

3.3.2.2 The design of a cathodic protection system should consider the possible need for electrical isolation of the tank from breakout piping and other interconnecting structures. Isolation may be necessary for effective cathodic protection or safety considerations.

3.3.2.3 Electrical isolation of interconnecting piping can be accomplished through the use of 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 shall be compatible with the products being transported through the line.

3.3.2.4 Polarization cells, lightning arresters, and grounding cells can be useful in some situations for maintaining isolation under normal operating conditions and providing protection for an 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 tests,

(b) Tank-to-grounding system resistance and potential tests,

(c) Tank-to-electrolyte potential tests,

(d) Electrical continuity tests for mechanical joints in interconnecting piping systems, and

(e) Electrical leakage tests for isolating fittings installed in interconnecting piping and between the tanks and safety ground conductors.

3.3.3 Cathodic Protection Type, Current Requirements, and Anode Configuration

3.3.3.1 Soil resistivity tests should be performed in sufficient quantity to aid in determining the type of cathodic protection (galvanic or impressed current) required and the configuration for the anode system.

3.3.3.1.1 Resistivities can be determined using the four-pin method described in ASTM[1] Standard G 57,[2] with pin spacings corresponding to depths of at least that expected for the anode system, or by using an equivalent testing method. (In very dry environments, electromagnetic conductivity testing may be used to measure resistivities.)[3] 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.

3.3.3.1.2 Where deep groundbeds are considered, resistivities should be analyzed using procedures described by Barnes[4] to determine conditions on a layer-by-layer basis. On-site resistivity data can be supplemented with geological data including subsurface stratigraphy, hydrology, and lithology. Sources for geological information include water well drillers, oil and gas production companies, the U.S. Geological Survey Office,[5] and other state and federal agencies.

3.3.3.1.3 Cathodic protection current requirements can be estimated using test anode arrays simulating the type of groundbed planned. Test currents can be applied using suitable sources of direct current. Test groundbeds can include driven rods, anode systems for adjacent cathodic protection installations, or other temporary structures that are electrically separated from the tank being tested. Small diameter anode test wells may be appropriate and should be considered when extensive use of deep anode groundbeds is contemplated.

3.3.3.1.4 Applied test current levels should result in compliance with the selected criterion for cathodic protection.

3.3.4 Stray Currents

3.3.4.1 The presence of stray earth currents may result in cathodic protection current requirements that are greater than if natural conditions were to be considered. Possible sources of stray current include DC-operated rail systems and mining operations, cathodic protection systems, welding equipment, and high-voltage direct-current (HVDC) transmission systems.

3.3.4.1.1 Field tests to determine if stray currents are a concern include tank-to-electrolyte potentials and structure-to-electrolyte potentials on adjacent structures, earth gradient measurements, and current flow measurements on tank breakout piping and safety grounding conductors.

3.3.4.1.2 Possible interference effects caused by adjacent cathodic protection systems should be determined by interrupting the current output using a known timing cycle. Structure-to-electrolyte potentials and other parameters should be monitored over a minimum 24-hour period in areas where dynamic stray currents or transient effects are expected to be a concern. Recording instruments can be used for this purpose.

3.3.4.1.3 Cathodic protection designs should incorporate every practical effort to minimize electrical interference on structures not included in the protection system. Predesign test results can be analyzed to determine the possible need for stray current control provisions in the actual cathodic protection system.

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(1) American Society for Testing and Materials, 1916 Race St., Philadelphia, Pennsylvania 19103.
(2) ASTM Standard G 57 (latest revision), "Standard Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method" (Philadelphia, PA: ASTM).
(3) F.W. Hewes, "Prediction of Shallow and Deep Groundbed Resistance Using Electromagnetic Conductivity Measurement Techniques," CORROSION/87, paper no. 130 (Houston, TX: NACE International, 1987).
(4) H.E. Barnes, "Electrical Survey Detects Underground Rock," Pipeline Industry, April 1959.
(5) U.S. Geological Survey Office, P.O. Box 25046, Federal Center, Denver, CO 80225.

Section 4: Criteria for Cathodic Protection

4.1 Introduction

4.1.1 This section lists criteria for cathodic protection that, when complied with either separately or collectively, will indicate that adequate cathodic protection of an on-grade metallic storage tank bottom has been achieved.

4.2 General

4.2.1 The objective of using cathodic protection is to control the corrosion of an on-grade metallic storage tank bottom in contact with an electrolyte.

4.2.2 The selection of a particular criterion for achieving the objective in Paragraph 4.2.1 depends, in part, on prior experience with similar tank bottoms and environments wherein the criterion has been used successfully.

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

4.2.4 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-electrolyte boundary, to the presence of dissimilar metals, and to 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 may be in error.

4.3 Criteria for Steel Tank Bottoms

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

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

NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

4.3.1.1.1 Measuring or calculating the voltage drop(s),

4.3.1.1.2 Reviewing the historical performance of the cathodic protection system,

4.3.1.1.3 Evaluating the physical and electrical characteristics of the tank bottom and its environment, and

4.3.1.1.4 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 tank bottom metallic surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.

4.4 Alternative Reference Electrodes

4.4.1 Other standard reference electrodes may be substituted for the CSE's. Two commonly used reference electrodes are listed below. The voltages given are equivalent (at 25°C [77°F]) to a negative 850 mV potential referred to a CSE:

4.4.1.1 Saturated silver/silver chloride reference electrode: a negative 780 mV potential

4.4.1.2 High-purity zinc (99.99%): a positive 250 mV potential (see Paragraph 7.3.4)

4.4.2 Permanent electrodes must be encapsulated in an appropriate backfill material.

4.5 Special Considerations

4.5.1 Special cases such as stray currents and stray electrical gradients may exist that require the use of criteria different from those listed above.

4.5.2 Abnormal conditions sometimes exist in which protection is ineffective or only partially effective. Such conditions may include elevated temperatures, disbonded coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte.

4.5.3 Rocks, clay deposits, or clumps under tank bottom plates can promote the formation of localized corrosion activity, which is difficult to monitor or evaluate.

Section 5: General Considerations for Cathodic Protection Design

5.1 Introduction

5.1.1 This section recommends procedures and considerations that apply to the design of cathodic protection systems for on-grade metallic storage tank bottoms.

5.2 Cathodic Protection Objectives and System Characteristics

5.2.1 The major objectives in designing the cathodic protection system are:

(a) To protect the tank bottom,

(b) To provide sufficient and uniformly distributed 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 interference currents,

(e) To provide adequate allowance for anticipated changes in current requirement for protection,

(f) To locate and install system components where the possibility of damage is minimal, and

(g) To provide adequate monitoring facilities to permit a determination of the system's performance (see Section 11.2).

5.2.2 General characteristics of impressed current and galvanic current cathodic protection systems are listed in Table 1. Impressed current systems are usually used for large diameter tanks or where conditions require more current than is available from galvanic anodes.

5.2.3 An impressed current cathodic protection 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 groundbeds around or under the tank and/or deep anode groundbeds.

5.2.3.1 Satisfactory anode materials include mixed-metal oxides, polymer carbon, graphite, high-silicon chromium-bearing cast iron, platinized niobium and titanium, scrap metal, or below-grade structures that have been removed from service and cleaned of contaminants.

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

5.3 In the design of the cathodic protection system, the following shall be considered:

5.3.1 Recognition of hazardous conditions prevailing at the site and the selection and specification of materials and installation practices that will ensure safe installation and operation,

5.3.2 Compliance with all applicable federal, state, and local codes, and owner requirements,

5.3.3 Selection and specification of materials and installation practices that will ensure dependable and economic operation of the system throughout its intended operating life,

5.3.4 Design of proposed installation to minimize stray currents,

5.3.5 Avoiding excessive levels of cathodic protection, which can cause coating disbondment and possible damage to high-strength and special alloy steels,

5.3.6 Where amphoteric metals are involved (i.e., lead, tin, aluminum), care should be taken so that high pH conditions are not established that could cause corrosion of the metal, and

5.3.7 Presence of secondary containment systems.

5.4 Current Requirement

TABLE 1
Cathodic Protection System Characteristics

GALVANIC CURRENT	IMPRESSED CURRENT
No external power required	External power required
Fixed, limited driving voltage	Driving voltage can be varied
Limited current	Current can be varied
Satisfies small current requirements	Satisfies high current requirements
Used in lower resistivity environments	Used in higher resistivity environments
Usually no stray current interference	Must consider interference with other structures

5.4.1 Current requirement for achieving a given protective level should be determined by preliminary testing on existing tank bottoms through the use of temporary cathodic protection systems.

5.4.2 Current requirement on new or proposed tank bottoms should be established by calculating surface areas and applying a protective current density based on the size of the tank, the electrochemical characteristics of the environment, and the parameters of the groundbed utilized.

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

5.4.4 Liquid levels within tanks must be sufficient to ensure that the entire tank bottom is in intimate contact with the electrolyte when establishing current requirements and testing applied protection levels. Constant, adequate liquid levels are important to maintain polarization.

5.4.4.1 As the liquid level increases (and more of the tank bottom touches the ground), the protective current requirement will increase and the potential measured may decrease due to the increased surface area of steel contacting the electrolyte.

5.5 Tank System Configuration

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

5.5.2 Non-welded metallic joints may not be electrically continuous. Electrical continuity can be ensured by bonding existing joints.

5.5.3 Where isolation is required, care must be taken to assure that the isolation is not shorted, by-passed, etc.

5.6 Special consideration should be given to the presence of sulfides, bacteria, coatings, elevated temperatures, shielding, pH conditions, treated tank padding material, soil/groundwater contamination, dissimilar metals, and backfill/concrete/metal interface at the ring wall and heating or refrigeration coils under tank bottoms.

5.7 On-grade tanks that are set on solid concrete or asphalt pad foundations generally require specialized measures for corrosion protection. In this circumstance 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 pad.

5.8 Design Drawings and Specifications

5.8.1 Suitable drawings should be prepared to show the overall layout of the tank bottoms to be protected and the cathodic protection system and associated appurtenances.

5.8.2 Specifications should be prepared for all materials and installation procedures that are used during construction of the cathodic protection system.

Section 6: Design Considerations for Impressed Current Cathodic Protection

6.1 Introduction

6.1.1 This section recommends procedures and considerations that specifically apply to the design of impressed current cathodic protection systems for on-grade metallic 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.

6.2.2 Anode groundbed configurations can be vertical, horizontal, or diagonal. Anodes can be installed in a distributed fashion under tank bottoms. The selection of anode configuration is dependent on environmental factors, current requirement, and the size and type of tank bottom to be protected.

6.2.3 When selecting deep anode systems, consideration must be given to sealing the deep anode column to prevent the migration of contaminants down the anode column (see NACE Standard RP0572,[6] "Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds").

6.2.4 Various anode materials have different rates of deterioration when discharging current. Therefore, for a given output, the anode life will depend on the environment, anode material, anode weight, and the number of anodes in the cathodic protection system. Established anode performance data should be used to calculate the probable life of the system.

NOTE: Platinized niobium anodes should not be used in hydrocarbon-contaminated environments.

6.2.5 The useful life of impressed current anodes can be lengthened by the use of special backfill around the anodes. The most commonly used backfill materials are metallurgical coal coke and calcined petroleum coke.

[6] NACE Standard RP0572 (latest revision), "Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds" (Houston, TX: NACE International).

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

6.2.7 Suitable provisions for venting the anodes should be made in situations where it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current groundbed to deliver the required current. Venting systems must be designed to prevent contaminants from getting into the venting system.

6.3 Safety

6.3.1 All impressed current 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 Rectifiers and junction boxes must meet regulatory requirements for the specific location and environment in which they are installed. Such locations shall be determined by reviewing local, state, federal, and prevailing industrial codes.

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

6.3.3 In order to prevent arcing, care must be exercised when working on breakout piping attached to tanks with cathodic protection applied. When cathodic protection systems are turned off, sufficient time must be allowed for depolarization before opening connections. Bonding cables must be used when parting breakout piping joints.

Section 7: Design Considerations for Galvanic Anode Cathodic Protection

7.1 Introduction

7.1.1 This section describes the factors that should be considered in the design of external corrosion protection of on-grade storage tank bottoms utilizing galvanic anode cathodic protection.

7.2 Galvanic protection systems can be applied to tank bottoms where the metallic surface area exposed to the electrolyte can be minimized through the application of a dielectric coating or the area is small due to the tank size or configuration. For more information regarding the selection and application of coatings, refer to NACE Standard RP0285,[7] "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems."

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

7.2.2 In applications where either the tank bottom is uncoated or is large due to the tank size or configuration, the use of impressed current cathodic protection should be considered to minimize the cost of the protection system. See Section 6 for more information regarding the design considerations for impressed current protection systems.

7.3 Galvanic Anode Selection

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

7.3.2 The selection and use of these anodes should be based upon the current requirements of the tank bottom, the soil conditions, the temperature of the tank bottom, and the cost associated with the materials.

7.3.3 The current available from each type of anode depends greatly upon the soil conditions, the anode shape, and the driving potential of the anode.

7.3.4 When high-purity zinc anodes are employed, care should be exercised to ensure the anodes meet the requirements of ASTM B 418,[8] Type II anode material. The purity of the zinc can greatly affect the performance of the material as a galvanic anode for soil applications.

7.3.5 Zinc anodes should not be used when the temperature of the anode environment is above 49°C (120°F). Higher temperature can cause passivation of the anode. The presence of some salts, such as carbonates, bicarbonates, and nitrates, in the electrolyte may also affect the performance of zinc as an anode material.

7.3.6 Galvanic anode performance may be enhanced in most soils by using special backfill material. Mixtures of gypsum, bentonite, and sodium sulfate are most often used.

7.3.7 The anodes should be supplied with adequate lead wire attached by the anode supplier.

7.3.7.1 Lead wire should be at least 2 mm diameter (#12 AWG) with oil and water-resistant insulation.

[7] NACE Standard RP0285 (latest revision), "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems" (Houston, TX: NACE International).
[8] ASTM Standard B 418 (latest revision), "Standard Specification for Cast and Wrought Galvanic Zinc Anodes" (Philadelphia, PA: ASTM).

Section 8: Design Considerations — Cathodic Protection with Secondary Containment and Replacement Bottoms

8.1 Introduction

8.1.1 Impervious membranes and replacement tank bottoms are used together or separately.

8.1.2 Secondary containment membranes and secondary metallic tank bottoms can shield the metallic surface of the primary tank bottom from the flow of cathodic protection current, resulting in a lack of adequate cathodic protection.

8.1.3 Sand or other fill material used between the liner and the tank bottom, or between two bottoms, should be tested for resistivity.

8.2 Membranes and Liners

8.2.1 Impervious membranes or liners used for secondary containment may act as a barrier to the flow of cathodic protection current from anodes located outside the containment envelope. Anodes must be placed between the membrane and the metallic tank bottom so that current will flow to the metallic surfaces requiring protection.

8.2.2 Permanent reference electrodes or reference cell insertion tubes must be located between the metallic tank bottom and the membrane to obtain accurate tank bottom-to-electrolyte data.

8.3 Replacement Tank Bottoms

8.3.1 When a replacement metallic tank bottom is installed in an existing tank over the original bottom with an electrolyte between the two bottoms, galvanic corrosion activity can develop on the new bottom, which may result in premature failure of the new bottom.

8.3.2 Cathodic protection should be considered for the primary (new) bottom. The anodes and reference electrodes or nonconductive reference cell insertion tubes must be placed in the electrolyte between the two bottoms.

8.3.3 The installation of a nonconductive, impervious membrane or liner above the original bottom will reduce galvanic corrosion activity on the replacement bottom and will reduce the current required for cathodic protection.

8.4 Cathodic Protection Anodes

8.4.1 Impressed current or galvanic anode-type cathodic protection may be used.

8.4.1.1 Galvanic anodes may be magnesium or zinc.

8.4.1.2 Anode materials that can be used for impressed current systems can include high-silicon chromium-bearing cast iron, mixed-metal oxide, graphite, conductive polymer cable, etc.

8.4.1.3 The current requirement for protection with impressed current systems may be higher than for galvanic systems, due to the depolarizing effect of oxidation by-products from the anodes (typically chlorine, oxygen, or carbon dioxide).

8.4.2 Adequate space must be provided between the two tank bottoms to allow for installation of a cathodic protection system with uniform current distribution from the anodes.

8.4.3 Impressed current anodes must not contact the metallic 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 Considerations

9.1 Introduction

9.1.1 This section recommends elements to consider during the installation of cathodic protection systems for on-grade metallic storage tank bottoms.

9.2 Preparation

9.2.1 Materials should be inspected prior to installation or use in order to ensure that specifications have been met.

9.2.2 Installation practices shall conform to all applicable local and national codes and requirements.

9.3 Anode Installation

9.3.1 Anodes should be installed with sufficient distance between the anode and the tank bottom. The anodes can be installed either vertically, horizontally, or diagonally.

9.3.2 The anode lead wires should be extended to the side of the tank away from the construction to minimize possible damage. After the tank foundation has been prepared and the tank set in place, the wires should be terminated in a test station or bond box.

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

9.4 Reference Electrodes

9.4.1 When measuring the tank bottom-to-electrolyte potential, the portable reference cell should be placed at intervals around the perimeter of the tank and under the tank. The potentials measured at these locations should be representative of the entire tank bottom due to the anode installation under and/or around the tank. For large diameter tanks, the potential measured at the perimeter of the tank will not represent the potential at the center of the tank.

9.4.2 Permanent reference cells or nonconductive tubes for installation of a portable reference electrode should be installed under all tanks regardless of the groundbed type that is installed.

9.4.3 For new and existing tanks, consideration should be given to the use of a perforated or slotted nonmetallic pipe installed horizontally under the tank bottom from outside the ring wall. This procedure can be accomplished by boring or water jetting holes from the ring wall to the center of the tank. With the access pipe in place, a portable reference electrode can be passed through the pipe to obtain potential measurements under the tank. Consideration must be given to the structural aspects of the tank, padding, and foundation to ensure that support capabilities will not be adversely affected.

NOTES: (1) Extreme caution must be exercised when boring or water jetting under tanks. (2) Special attention must be given during the design and installation of access pipes to assure that any tank containment system is not breached by their installation.

9.4.3.1 A constant distance should be maintained from the tank bottom to the reference electrode. Increasing space between tank bottom and reference electrode will increase the voltage drop.

9.4.3.2 The reference electrode shall be inserted with a nonmetallic material, such as a small PVC pipe. Metallic tapes, bare wires, etc., can directly induce interference and adversely affect the potential readings.

9.5 Test Stations and Bond Boxes

9.5.1 Test stations or bond boxes for potential and current measurements should be provided at sufficient locations to facilitate cathodic protection testing.

9.5.2 The test station or bond box should be mounted on or near the side of the tank in an area that is protected from vehicular traffic.

9.5.3 The test station or bond box should allow for disconnection of the anodes to facilitate current measurements and potential measurements for voltage drop as required to evaluate the protection level. Where desired, test leads from buried reference electrodes can be terminated in the same test box as tank bottom test wires.

9.5.4 Bond boxes can be utilized to connect continuity bonds or protective devices.

9.5.5 The test station or bond box can be equipped with calibrated resistors (shunts) in connections between the anodes and the tank for use in measuring the anode current output and thus the estimated anode life. Shunts are typically rated between 0.001 and 0.1 ohm.

9.5.6 The test station or bond box should be clearly marked and accessible for future monitoring of the tank bottom and if possible should be attached to the tank.

9.5.7 All lead wires to the test station or bond box should be protected from damage by a minimum 46-cm (18-in.) burial and/or placing them within a conduit. Warning tape can be installed over direct buried cables to prevent the possibility of damage during excavation.

9.6 Safety Considerations

9.6.1 All people to be involved in the installation of the cathodic protection system should participate in a thorough safety training program.

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

9.6.3 All utility companies and other companies with facilities crossing the work areas should 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 should be located and noted prior to any construction.

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

Section 10: Energizing and Testing

10.1 Introduction

10.1.1 This section discusses factors that should be considered when energizing and testing a cathodic protection system for on-grade metallic storage tank bottoms.

10.2 Design Parameters

10.2.1 Knowledge of the performance criteria considered during design for cathodic protection and the operational limits of cathodic protection devices and hardware should be available to set operating levels for the cathodic protection system.

10.3 Initial Data

10.3.1 Prior to the energizing of cathodic protection systems, data and information should be collected to provide an initial base line of information, such as:

(a) Tank bottom-to-electrolyte potentials,

(b) Pipe-to-electrolyte potentials on connected piping,

(c) Dielectric isolation,

(d) Foreign structure-to-electrolyte potentials,

(e) Test coupons,

(f) Permanent reference electrodes, and

(g) Fluid level in tank during testing. The level of fluid must be sufficient to ensure that the entire tank bottom is contacting the electrolyte during testing (0.9 m to 4.6 m [3 to 15 ft], depending upon the tank diameter).

10.3.2 Verification of cathodic protection 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, and

(e) Location of cathodic protection system cables.

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

10.4 Current Adjustment

10.4.1 The exact operating level of cathodic protection systems must often be determined by a series of trial tests at various operating levels. The specific operating level will depend upon the criterion for cathodic protection used for the on-grade tank(s). Section 4 of this document defines the various criteria for achieving cathodic protection of on-grade metallic storage tank bottoms. Time required to achieve polarization on a bare tank bottom will be different from tank to tank.

10.4.2 When adjusting the operating levels of cathodic protection systems, consideration must be given to the effect of stray current on adjacent structures.

10.4.2.1 Among the structures that should be considered as possibly affected by stray current are:

(a) Piping separated from the tank(s) by high-resistance fittings,

(b) Buried electric facilities,

(c) Buried fire protection piping,

(d) Buried water piping,

(e) Adjacent tankage,

(f) Transmission or distribution piping serving the tank(s),

(g) Municipal or public utility structures serving the facility in which the tank(s) is located, and

(h) Fencing.

10.4.2.2 Structures that may contain discontinuous fittings or joints, such as cast iron systems, ductile iron piping systems, or piping with mechanically connected fittings, require special attention to ensure that stray current effects are detected and mitigated.

10.5 Testing

10.5.1 The final operating levels of cathodic protection systems should be established to achieve the cathodic protection criterion established by the design documents, as set forth in Section 4 of this document, or by the operating policies of the owner of the facility.

10.5.2 Documentation of all operating parameters should be done after the system is energized. Those parameters should include:

(a) Initial base line data,

(b) As-built drawings,

(c) Operating currents,

(d) Locations of test facilities,

(e) Key monitoring locations,

(f) Equipment manuals, and

(g) Tank fluid level.

10.5.3 Electrical potential and current readings should be recorded and documented for future reference.

Section 11: Operation and Maintenance of Cathodic Protection Systems

11.1 Introduction

11.1.1 This section recommends procedures and practices for maintaining the effective and efficient operation of cathodic protection systems for on-grade metallic storage tank bottoms.

11.2 Monitoring Cathodic Protection Systems

11.2.1 The protection systems should be monitored to ensure adequate cathodic protection of the tank bottoms in accordance with the criteria set forth in Section 4.

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

11.2.3 Rectifiers or other current sources should be monitored at regular intervals to ensure continuous current output.

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

11.2.4.1 Experience has indicated that on 12-m (40-ft) diameter or larger tanks, measurements obtained at the perimeter of the tank may not reflect the actual conditions of the entire tank bottom.

11.2.5 Voltage drop in potential measurements taken under a tank bottom will be affected by liquid level changes inside the tank.

11.2.6 As with any monitoring and maintenance program, the tank cathodic protection system should be monitored for the existence of any stray current interference from adjacent structures or protection systems. This is especially important with galvanic anode systems when impressed current protection systems are being employed nearby. (Because the tank protected with galvanic anodes is usually isolated from all adjacent structures, it could become an intermediate anode.)

11.3 Routine inspections and tests of impressed current cathodic protection components that should be made to ensure proper operation and maintenance of the system are as follows:

11.3.1 All sources of impressed current should be checked at bi-monthly intervals to ensure effective operation of the system. Evidence of proper functioning can be current and voltage outputs consistent with previous readings, or a satisfactory polarized potential state of the protected tank bottom surface.

11.3.2 All cathodic protection 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. Annual 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.

11.4 Test equipment used for obtaining cathodic protection data should be checked periodically for accuracy and maintained in operating condition.

11.5 Corrective action should be taken when surveys and inspections indicate that protection is no longer effective. These measures include the following:

11.5.1 Repair, replace, or adjust components of the cathodic protection system,

11.5.2 Provide supplementary cathodic protection where additional protection is necessary, or

11.5.3 Repair, replace, or adjust continuity bonds and continuity devices.

11.6 Care shall be exercised to ensure that remedial measures intended to restore or enhance protection do not compromise the integrity of liners or membranes.

Section 12: Record-Keeping

12.1 Introduction

12.1.1 This section recommends pertinent information that should be recorded and filed for future information and reference.

12.2 Tank Information

12.2.1 Tank information should include but not be limited to the information outlined in Section 3.2.

12.3 Cathodic Protection Systems

12.3.1 Information about the design and installation of impressed current protection systems should include:

(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 permanent reference electrodes,

(g) Soil resistivity,

(h) Date of energizing and initial current and voltage settings,

(i) Cost of system,

(j) Fluid level in the tank during survey, and

(k) As-built drawings of the installation.

12.3.2 Information about the design and installation of galvanic anode protection systems should include:

(a) Design calculations and considerations,

(b) Anode material and expected life,

(c) Number of anodes and distribution plot,

(d) Date of activation,

(e) Initial current output and tank bottom potentials,

(f) Cost of system,

(g) Fluid level in the tank during survey, and

(h) As-built drawings of the installation.

12.4 Maintenance Records

12.4.1 Maintenance records should be kept that include:

(a) Tabulations of bi-monthly readings of impressed current power source,

(b) Reports of periodic or annual inspections,

(c) All repairs and additions, and

(d) Costs of maintenance.

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