

Standard Practice

Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks

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Foreword

The purpose of this standard is to present the standard practices used in providing galvanic anode cathodic protection (CP) to the normally submerged steel surfaces inside steel water storage tanks. This standard provides owners, engineers, and contractors with guidelines for the application of CP to the submerged surfaces of steel water storage tanks; for determining the effectiveness of these CP systems; and for the operation and maintenance of these CP systems.

This standard is applicable to steel water storage tanks of various sizes used in municipal water supply and fire protection, including elevated tanks and flat-bottom tanks at ground level. Although the practices presented in this standard generally are applicable to all such tanks, the galvanic anode CP system described in this standard may not be practical for relatively large tanks.

This standard was originally prepared in 1996 by NACE Task Group (TG) T-7L-1, a component of Unit Committee T-7L, "Cathodic Protection." It was revised in 2004, 2011, and 2015 by TG 284, "Cathodic Protection, Galvanic Anode for Internal Submerged Surfaces of Steel Water Storage Tanks—Review of NACE SP0196." TG 284 is administered by Specific Technology Group (STG) 05, "Cathodic/Anodic Protection." It is sponsored by STG 11, "Water Treatment," and STG 35, "Pipelines, Tanks, and Well Casings." This standard is issued by NACE under the auspices of STG 05.

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.

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Section 1: General

1.1 This standard presents standard practices for using galvanic anodes to apply CP to the internal submerged surfaces of steel tanks used for the storage of potable and reclaimed water, drinking water, irrigation water, and fire protection water. Appendix A (nonmandatory) provides guidance for the use of CP for the internal surfaces of tanks and vessels containing other waters.

1.2 Impressed current CP systems are used extensively for the internal surfaces of water storage tanks; however, this standard addresses only galvanic anode CP systems. For a description of impressed current CP systems, refer to NACE SP0388.¹

1.3 The ground level and elevated storage tanks considered in this standard are of welded, bolted, or riveted-steel construction, and include many shapes and sizes.

1.4 CP as described in this standard may be used alone to control corrosion of submerged steel surfaces or may be used as a complement to the protection provided by protective coatings or other procedures.² CP cannot protect surfaces that are not submerged; these surfaces are typically protected by coatings alone.

1.5 CP may be installed to control corrosion in both newly constructed and existing tanks. When CP is used on existing tanks, it may be necessary to drain the tank during installation.

1.6 Tanks under consideration for application of CP are often associated with potable water and fire protection systems that may be subject to public health and safety regulations.³ This standard shall not infringe on those regulations. Proper disinfection of the tanks may be required after installation.

1.7 The provisions of this standard should be applied under the direction of a competent corrosion engineer. The term “corrosion engineer,” as used in this standard, refers to a person who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics as acquired by professional education and related practical experience, is qualified to practice corrosion control, including CP, for water storage tanks. Such persons may be Registered Professional Engineers or persons recognized as being qualified or certified as Corrosion Specialists or CP Specialists by NACE, if their professional activities include suitable experience in corrosion control and CP.

1.8 This standard may not be applicable in all situations. The corrosion engineer may consider alternative corrosion control methods.

Section 2: Definitions

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 Circuit: The path from a single anode or multiple anodes connected through a shunt, a resistor, and the connection to the tank.

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

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

Conductivity: (1) a measure of the ability of a material to conduct an electric charge; (2) the current transferred across a material (e.g., coating) per unit area per unit potential gradient. (Conductivity is the reciprocal of resistivity).

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

Corrosion Potential: 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]

CP Coupon: A metal specimen made of similar material as the tank under investigation, which is connected to the external surface of, and immersed in, the electrolyte adjacent to the tank being protected by cathodic protection.

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

Driving Potential: Difference in potential between the anode and the steel structure. For the purposes of this standard, driving potential is understood to be the potential difference between the galvanic anodes and the tank wall when the cathodic protection system is in operation.

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

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.

Electrode Potential: The potential of an electrode in an electrolyte as measured against a reference electrode.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purpose of this standard, electrolyte refers to the water, including the dissolved chemicals, in the tank.

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.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

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.)

Open-Circuit Potential: See *corrosion potential*.

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

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.

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

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

Tank-to-Water Potential: The potential difference between a submerged metallic portion of the tank and the water (electrolyte), which is measured with a reference electrode in contact with the water.

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

Section 3: Determination of Need for Cathodic Protection

3.1 Introduction

3.1.1 Steel tank surfaces submerged in natural waters are subject to corrosion. The methods and procedures used to control corrosion should be governed by the rate of corrosion and the cost of maintaining the tank, including the water quality and planned useful life of the tank.

3.1.2 All coatings are subject to damage and deterioration. Therefore, corrosion control by use of coatings alone on the submerged surfaces of a steel water storage tank is usually not possible.

3.1.3 CP is effective in controlling corrosion only on submerged metal surfaces during submersion. It does not reverse structural damage already caused by corrosion. CP may not be effective under disbonded coating.

3.2 Coated Steel Tanks

3.2.1 CP should be used to reduce corrosion on submerged, coated steel tank surfaces where holidays exist—or are anticipated—and where corrosion would occur as a result of those holidays.

3.2.2 The use of dissimilar metals inside the tank may contribute to the creation of a localized galvanic corrosion cell. Where the use of dissimilar metals cannot be avoided, the dissimilar metals should be electrically isolated from the steel tank shell where possible. The application of a protective coating on the more noble metal components may be used in lieu of electrical isolation, provided that the coating can be properly applied and maintained.

3.2.3 If the water is sufficiently corrosive to justify the use of a coating, then CP is also justified and the combination provides a greater degree of protection than when either method is used alone.

3.2.4 Properly designed and maintained CP systems extend the time between recoating the submerged interior surfaces.

3.2.5 The current required for CP is much lower for coated steel tanks compared with bare or poorly coated steel tanks.

3.3 Uncoated Steel Tanks

3.3.1 It is feasible to design a CP system to provide protection for uncoated submerged surfaces of steel tanks (see Section 4).

3.3.2 It may be more practical to protect a bare or poorly coated steel tank with an impressed current CP system. This method is described in NACE SP0388.¹

3.4 Economic Considerations

3.4.1 For coated steel tanks, the cost of CP should be compared with the cost of recoating and metal loss. In addition to extending the life of existing coatings, CP reduces the need for recoating, repairs, leakage, and replacement caused by metal loss at holidays in the coating.

3.4.2 Metal loss can be reduced by the application of CP, where the submerged surfaces are not coated or where the coating has deteriorated to the point that these surfaces can be considered uncoated. The cost of installing CP, projected maintenance costs, and monitoring costs should be compared with the cost of coating maintenance, metal loss, service disruption, reduction in tank life, and water quality degradation.

3.5 Operational Considerations

3.5.1 Removing the tank from service for coating maintenance or repairing corrosion damage may be eliminated or postponed if the CP system is designed and operated properly.

3.5.2 Benefits of keeping the tank in continuous service include system capacity and water availability.

Section 4: Design of Galvanic Anode Cathodic Protection Systems

4.1 General

4.1.1 The elements that the corrosion engineer must consider when designing galvanic anode CP systems for steel water storage tanks are outlined in this section.

4.1.2 In the design of a galvanic anode CP system, the following items must be considered:

- (a) Health and safety;
- (b) Compliance with local and national regulations;³

- (c) Tank design characteristics (e.g., accessibility, crevices, shielded areas, baffles, and compartments);
- (d) Presence of interior tank components constructed of other metals (e.g., stainless steel, copper, galvanized steel);
- (e) Present and future condition of the coating and the generic type of coating used;
- (f) Whether the water is subject to freezing;
- (g) Driving potential of various galvanic anode materials;
- (h) Galvanic anode material, configuration, and anode circuit resistance;
- (i) Galvanic anode life and ease of replacement;
- (j) Ancillary equipment;
- (k) Reference electrode location(s);
- (l) Possibility of vandalism;
- (m) Water chemistry and temperature, and
- (n) Compliance with ANSI⁽¹⁾/NSF⁽²⁾-61³ in the U.S., or other governing standards outside the U.S.

4.1.3 Whenever possible, the CP system design should be based on standard galvanic anode shapes and sizes.

4.1.4 Selection of materials and CP system design shall strive to provide the best economic balance between the installation cost and the maintenance cost over the design life of the system.

4.2 Design Information

4.2.1 Before a galvanic anode CP system is designed, the following information should be obtained:

- (a) Dimensions of the tank, including all submerged surfaces (e.g., wet risers on elevated tanks);
- (b) Area of submerged steel surfaces (e.g., support columns, ladders, baffles, braces, struts);
- (c) Submerged metallic components or accessories constructed of other than carbon steel (e.g., stainless steel, copper, and galvanized steel);
- (d) Galvanic anode attachment configuration (i.e. protruding through walls, mounted internally, or suspended from roof);
- (e) Chemical analysis of the water;
- (f) Water conductivity;
- (g) Seasonal variation in water composition;
- (h) Frequency and rate of emptying and filling the tank;
- (i) Minimum, maximum, and normal fluid levels anticipated during tank operation; and the duration of exposure at each of these levels;
- (j) Type, specification, and condition of internal coating system;
- (k) Condition of internal steel surfaces exposed to the water;
- (l) Whether or not the water is subject to freezing;

⁽¹⁾ American National Standards Institute (ANSI), 25 West 43rd St., 4th floor, New York, NY 10036.

⁽²⁾ NSF International (NSF), P.O. Box 130140, 789 Dixboro Rd., Ann Arbor, MI 48113-0140.

- (m) Average and extreme water temperature;
- (n) Flow patterns, recirculation, aerators, heaters, riser pipes, velocity; and
- (o) Other pertinent information, including age and history of the tank, and whether the tank is of welded, bolted, or riveted construction.

4.2.2 In most cases, an on-site corrosion evaluation and preliminary design survey is useful.

4.3 Design Considerations

4.3.1 Current Output

4.3.1.1 The galvanic anode CP system must be capable of providing sufficient current to protect the tank to the minimum criterion for the full design life of the system, including any anticipated coating deterioration.

4.3.1.2 Calculated current output should be based on the current requirement for CP. This current requirement is expressed in terms of current per unit area of total submerged bare surface area, and depends on the corrosiveness of the water. In fresh waters, the current requirement is usually between 5 and 27 mA/m² (0.5 and 2.5 mA/ft²) of submerged bare surface area. Installations involving high corrosion rates, nonpotable water, and galvanic metal couples may require considerably higher current densities.

4.3.1.3 The driving potential used with the anode circuit resistance to calculate the galvanic anode current output shall be the difference between the closed-circuit potential of the anode and the minimum polarized potential of the tank.

4.3.1.4 For anode circuit resistance calculations, refer to *Anode Resistance Fundamentals and Applications—Classic Papers and Reviews*.⁴

4.3.1.5 Anode circuit resistance variation as a result of temperature and water conductivity changes must be considered. Maximum anode circuit resistance shall be calculated based on the physical shape of the galvanic anode when it is 85% consumed in a uniform manner.

4.3.2 Galvanic Anode Selection

4.3.2.1 Galvanic anodes shall be manufactured from magnesium (Mg) or zinc (Zn) alloys that are formulated specifically for this use. Table 1 lists typical galvanic anode materials and characteristics. For tanks addressed in this standard, aluminum (Al) anodes are not normally used.

4.3.2.2 Galvanic anode materials shall be chosen to be compatible with the water composition and intended use.

4.3.2.3 All galvanic anodes shall have a steel core that extends throughout their full length and is centered within the galvanic anode, and on which the galvanic anode can be supported either vertically or horizontally.

Table 1
Typical Galvanic Anode Materials and Characteristics

Type	Alloy	Nominal Electrode Potential, ^(A) mV vs. CSE ^(B)	Nominal Consumption Rate, ^(C) kg/A·y
Magnesium	ASTM⁽³⁾ B843⁵		
Mg/Mn	M1C	–1,750	8
Mg/Al/Zn	AZ31B	–1,550	8
Mg/Al/Zn	AZ63B	–1,550	8
Zinc^(D)	ASTM B418⁶		
Low Fe	Type II	–1,100	12

^(A) Electrode potential varies with water chemistry.

^(B) CSE = Saturated copper/copper sulfate reference electrode.

^(C) Consumption rate is dependent on water chemistry, temperature, and anode current density.

^(D) **Cautionary Note:** With increasing service temperature the effectiveness of some zinc galvanic anodes may significantly diminish. Depending on the water composition, zinc may completely reverse its polarity in the temperature range between 60 and 82 °C (140 and 180 °F). Caution is required when selecting zinc anodes for elevated temperature immersion service. Consult the anode manufacturer for such usages.

4.3.3 Galvanic Anode Arrangement

4.3.3.1 Galvanic anodes shall be arranged to provide as close to uniform current density as is practical. When uniform current density on the submerged tank surface cannot be achieved, the total CP system current output must be increased to compensate by adding anodes or adjusting the CP system current output through the test box described in Paragraph 4.3.4.1.

4.3.3.2 Anodes with lead wires should have a separate structural support.

4.3.3.3 Galvanic anodes shall be suspended or mounted in such a way as to minimize damage to the system when ice conditions are anticipated, or measures must be taken to prevent ice formation.

4.3.3.4 Galvanic anodes shall be installed and supported to prevent damage during high flow rates and when the tank is drained for inspection and cleaning.

4.3.3.5 Some coatings have been damaged by excessive current density at coating holidays and excessive potential gradients across the coating. The coating selected shall be compatible with CP. Coating failures have been observed at polarized potentials more negative than –1,100 mV vs. saturated copper/copper sulfate reference electrode (CSE).

4.3.4 Installation, Monitoring, and Testing

4.3.4.1 The method of galvanic anode installation should ensure that the anodes are electrically isolated from the tank, except through an accessible electrical connection that can be disconnected for testing the system. Galvanic anodes with lead wires that connect to a collector (header) cable terminating in a test box with a tank connection cable, a tank test lead, a shunt, and a reference electrode lead should be used. The use of a calibrated shunt between the anode collector cable and the tank connection cable facilitates measuring the current output of the CP system. The test box allows for interrupting and adjusting the current and obtaining a polarized potential vs. the reference electrode, free of voltage drop. Although other reference electrodes are sometimes used, CSE is most commonly used.

4.3.4.2 If the galvanic anodes are directly connected to the tank, a CP coupon and reference electrode shall be configured to evaluate the voltage drop and approximate the polarized potential of the tank.⁷

4.3.5 Galvanic Anode Life

⁽³⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

4.3.5.1 Galvanic anode life shall be calculated using the mean operating current density.

4.3.5.2 Galvanic anode nominal consumption rates used in CP system life calculations shall not exceed the values given in Table 1.

4.3.5.3 The anode life should be calculated as the life at 85% or less consumption by anode mass. As used in this context, utilization factor is the percent of total anode mass consumed when the anode must be replaced.

4.3.6 Other

4.3.6.1 The method of cable connection to the tank should be by welding or thermite welding. If other connection methods such as bolting or clamping are used, they must be secure. All electrical connections must be protected against corrosion.

4.3.6.2 All cable connections to the galvanic anodes shall be made to the core material by silver solder and subsequently coated.

4.3.6.3 All immersed cable-to-cable connections shall be made by high-strength compression connector or welding.

4.3.6.4 All cables located inside the tank shall be rated for use in submerged conditions.

4.3.6.5 For bolted and riveted tanks, electrical continuity of all joining components must be achieved, if these components are to receive CP.

Section 5: Installation of Galvanic Anode Cathodic Protection Systems

5.1 Introduction

This section outlines installation techniques for galvanic anode CP systems that protect water storage tanks, when design considerations presented in Section 4 have been followed.

5.2 Construction Specifications

All construction work on galvanic anode CP systems should be in accordance with project construction drawings and specifications.

5.3 Construction Supervision

5.3.1 All construction work should be performed by, or under the direction of, a person who is qualified by experience in the installation of galvanic anode CP systems in water storage tanks, and who should verify that the installation is made in accordance with the project construction drawings and specifications.

5.3.2 Deviations from construction documents and specifications shall be noted on as-built drawings and specifications.

5.4 Inspection and Handling

5.4.1 Galvanic anodes shall be inspected for conformance to specifications for correct galvanic anode material and size, length of lead wire, and method of wire connection. All wire and connections shall be carefully inspected for integrity. Damage to galvanic anode assemblies during handling and installation shall be avoided. If defects are not repaired, the anode must be rejected.

5.4.2 Stationary reference electrodes installed as part of the galvanic anode CP system shall be inspected and tested for conformance to the specifications. The stationary reference electrode shall be tested with reference to an accurate calibrated reference electrode in the electrolyte in which the stationary reference electrode is placed. If a difference in potential exists between the stationary and test reference electrode, the stationary electrode shall be replaced with one that matches the calibrated portable electrode to within ± 10 mV.

5.5 Installation

5.5.1 Construction practices shall conform to all applicable local and national codes.

5.5.2 Test boxes shall be installed at a location for safe and convenient ground access.

5.5.3 All cables shall be protected from abrasion and sharp objects.

5.5.4 Short circuits shall not exist between the cables and the tank structure or conduit.

Section 6: Criteria for Cathodic Protection

6.1 Introduction

The purpose of this section is to list the criteria for CP, which, when complied with, either separately or collectively, indicate that adequate CP of submerged portions of steel water tank interiors has been achieved.

6.2 General

6.2.1 The objective of using galvanic anode CP is to control the corrosion of submerged portions of steel water tank interiors.

6.2.2 The selection of a particular criterion for achieving the objective in Paragraph 6.2.1 depends, in part, on prior experience with similar structures and environments wherein the criterion has been used successfully.

6.2.3 The criteria in Paragraph 6.3 were developed through laboratory experiment or were determined empirically by evaluating data obtained from successfully operated CP systems. It is not intended that persons 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.

6.2.4 Extended periods of time may be required to achieve polarization of uncoated or poorly coated tanks.

6.3 Criteria for Cathodic Protection of Steel Water Tanks

6.3.1 A negative polarized tank-to-water potential of at least 850 mV relative to a CSE; or

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

CAUTIONARY NOTE: This criterion is only applicable to steel water tanks not having corrosion cells caused by connection to more noble metals such as copper, brass, or passive stainless steel (e.g., heated water tanks wherein the submerged heater tube is of copper or brass materials and is electrically continuous with the submerged metal of the tank).

6.4 Measurement Procedures

6.4.1 Potential measurements on water tank interiors should be made with the reference electrode located in the water (electrolyte) as close as possible to the tank steel surface. Consideration shall be given to voltage drops other than those across the tank/water boundary, the presence of dissimilar metals, structural components, and other conditions that may interfere with valid interpretation of potential measurements.

6.4.2 To observe the polarized tank-to-water potential, the voltage drop shall be eliminated from the measurement. Among the methods used to eliminate voltage drop are (1) measuring the tank-to-water potential with the protective current instantaneously interrupted and (2) interrupting the electrical connection between the tank and a submerged CP coupon(s) and immediately measuring the tank-to-water potential of the CP coupon.

6.4.3 A sufficient number of potential measurements shall be taken to determine that adequate CP is being achieved throughout the steel tank, especially at the most difficult-to-protect locations. In practice, potential profiles of the submerged steel at intervals along the wall and floor during initial adjustment shall be taken.

6.5 Reference Electrodes

6.5.1 All reference electrodes utilized in water tanks shall be suitable for immersion service.

6.5.2 CSE is the standard reference electrode for use in water tanks.

6.5.3 Other reference electrodes may be substituted for CSE, but they must be stable in the environment and provide reproducible measurements.

6.6 Special Considerations

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

6.6.2 Significant temperature variations can occur within a tank because of radiant heating. The potentials relative to a CSE indicated in Paragraph 6.3 are applicable at 25 °C (77 °F) and should be adjusted for actual water temperature using Equation (1):

$$\text{Potential } E \text{ [mV] at temperature } T \text{ [}^{\circ}\text{C]} = E \text{ at } 25 \text{ }^{\circ}\text{C} + k (T - 25) \quad (1)$$

where $k = 0.9 \text{ mV}/^{\circ}\text{C}$. ($k = 0.55 \text{ mV}/^{\circ}\text{F}$)

6.6.3 CP for well-coated tanks should only be designed, installed, and energized under the direction of a corrosion engineer with coating and CP experience. The coating system must be compatible with CP and must demonstrate resistance to cathodic disbondment. It has been observed that some coatings may not be compatible with CP and may be damaged by excessive currents. While there is currently no agreement regarding the tank-to-water potential at which damage occurs, coating failures have been observed at polarized potentials more negative than -1.1 V to a CSE.

6.6.4 The CP system should be energized as soon as possible after the tank is filled with water. Waiting until the coating warranty period has expired only subjects the tank to additional deterioration from corrosion and may lead to severe pitting attack at holidays in the coating.

Section 7: Operation and Maintenance

7.1 This section presents the standard practices for the operation and maintenance of an effective galvanic anode CP system.

7.2 Operation

7.2.1 After the CP system has been allowed to reach a stable polarization level, the CP system shall be tested and adjusted to obtain the potentials indicated in Paragraph 6.3.

7.2.2 The CP system must be kept in continuous operation and it must provide the desired tank-to-water potential for effective corrosion control.

7.3 Maintenance

7.3.1 Maintenance should be performed under the direction of qualified personnel as described in Paragraph 1.7.

7.3.2 Annual Testing

7.3.2.1 Under normal conditions, testing of galvanic anode CP systems shall be performed annually. This frequency may vary depending on changes in parameters listed in Paragraph 4.2.1.

7.3.2.2 Tests shall be performed to determine whether the criteria set forth in Paragraph 6.3 are being achieved. The potential and current output shall be monitored and the anode circuit resistance adjusted so that the criteria in Paragraph 6.3 are achieved.

7.3.2.3 Reference Electrodes

7.3.2.3.1 With current off, stationary reference electrodes installed in the tank should be compared with a recently calibrated portable electrode of identical composition to ensure proper levels of CP. If it is not possible to interrupt the current, the stationary reference electrode shall be removed from the tank and tested in a nonmetallic container. The two reference electrodes should have a potential difference of less than $\pm 10 \text{ mV}$. When the potential difference exceeds $\pm 10 \text{ mV}$, the stationary reference electrodes should be replaced, and when the potential difference exceeds $\pm 20 \text{ mV}$, the stationary reference electrodes must be replaced.

7.3.2.3.2 Placement of the stationary reference electrode in the tank shall be evaluated to determine whether it corresponds to the most representative of portable reference electrode potentials of the tank. Measurements made with a portable reference electrode moved to several different locations shall be compared with measurements from

the stationary reference electrode to ensure the stationary reference electrode values are representative of the entire tank.

7.3.2.3.3 For installations in which a stationary reference electrode is not installed or is not functioning, a calibrated portable reference electrode shall be used to take measurements at several locations in the tank.

7.3.2.4 Component Inspections

All galvanic anode CP system components should be completely inspected annually. The inspection shall include polarized potential measurements—corrected for voltage drop by either interruption of the anode current or the CP coupon connection to the tank—to ensure that the CP system is operating properly. For tanks with hand-holes in the top, this includes lowering a portable reference electrode into the tank and taking instant-off measurements along the tank wall to evaluate whether all surfaces of the tank are protected. When instant-off measurements are not possible, the CP coupon data or some other method shall be used to correct for voltage drop. The connection to the portable reference electrode and all the metal components on the electrode and the wire shall be completely insulated.

7.4 Anode Replacement

7.4.1 All galvanic anodes that have ceased to function properly should be replaced. Tank-to-water potentials, current output, or visual inspections shall be used to evaluate anode performance.

7.4.2 Damaged or deteriorated cables, anode lead wires, and electrical connections shall be replaced or repaired using specific CP system components compatible with the original design.

7.4.3 In tanks subject to icing conditions, galvanic anodes shall be inspected or tested after the probability for freezing has passed.

7.4.4 When the water storage tank is taken out of service, the galvanic anodes should be examined, and broken or damaged anodes shall be replaced.

7.4.5 Galvanic anodes should also be examined to determine consumption. When galvanic anode remaining life is less than the time to the next inspection, anodes should be scheduled for replacement.

7.5 Records

7.5.1 Tank Information

7.5.1.1 Complete information and the history of the tank itself should be recorded, including:

- (a) Dimensions and capacity;
- (b) Tank erection and CP contractor;
- (c) Date of erection;
- (d) CP coupon type, configuration, and location;
- (e) Original coating, including coating system, surface preparation, and materials;
- (f) Subsequent coatings and dates of coating;
- (g) History of any structural repairs;
- (h) Costs associated with maintenance of the tank;
- (i) Tank location;
- (j) Warranty dates on coatings and CP; and
- (k) Water temperature range.

7.5.2 Water Information

7.5.2.1 Complete information about the water stored in the tank should be recorded. This information includes the chemical, electrical, and temperature characteristics, as well as information about the variations in these characteristics that occur throughout the year. If different sources of water that have substantially different resistivities are used, the frequency of maintenance testing may need to be adjusted so that tests are performed at each time a change in water chemistry occurs. Basic to determining the changes in chemistry would be the resistivity of the water, which can be reflected by the total dissolved solids in the water.

7.5.2.2 Operational information about frequency and duration of draining, cleaning, and filling should be recorded.

7.5.3 CP System

7.5.3.1 Complete information about the installation and design of the galvanic anode CP system should be documented, including:

- (a) The number and configuration of galvanic anodes, preferably on scaled as-built drawings;
- (b) Galvanic anode dimensions, weight and composition;
- (c) Stationary reference electrode type, model number, and manufacturer;
- (d) Wiring and anode suspension;
- (e) Electrical schematic diagrams;
- (f) Individual galvanic anode circuits and shunt resistances;
- (g) Test box with shutoff switch; and
- (h) Date of energizing and initial current and potential measurements.

7.5.3.2 Maintenance records that include the following should be kept:

- (a) Tabulation of annual measurements of galvanic anode output voltage and current and tank-to-water potentials. These measurements should be taken when the tank is relatively full. The water surface elevation should be recorded each time potential measurements are taken. The location of potential measurements should be recorded;
- (b) Reports on annual inspections;
- (c) All repairs and additions to the galvanic anode CP systems; and
- (d) Costs of maintenance—coating, CP inspections, etc.

References

1. NACE SP0388 (latest revision), "Impressed Current Cathodic Protection of Internal Submerged Surfaces of Carbon Steel Water Storage Tanks" (Houston, TX: NACE).
2. J.B. Bushman, D.H. Kroon, "Cathodic Protection of Water Storage Tanks," AWWA⁽¹⁴⁾ Journal 76, 1 (1984).
3. ANSI/NSF 61 (latest revision), "Drinking Water System Components—Health Effects" (New York, NY: ANSI and Ann Arbor, MI: NSF International).
4. R.L. Benedict, ed., *Anode Resistance Fundamentals and Applications—Classic Papers and Reviews* (Houston, TX: NACE, 1986).

⁽⁴⁾ American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235.

5. ASTM B843 (latest revision), "Standard Specification for Magnesium Alloy Anodes for Cathodic Protection" (West Conshohocken, PA: ASTM).
6. ASTM B418 (latest revision), "Standard Specification for Cast and Wrought Galvanic Zinc Anodes" (West Conshohocken, PA: ASTM).
7. NACE Publication 35201 (latest revision), "Technical Report on the Application and Interpretation of Data from External Coupons Used in the Evaluation of Cathodically Protected Metallic Structures" (Houston, TX: NACE).
8. NACE SP0575 (latest revision), "Internal Cathodic Protection Systems in Oil-Treating Vessels" (Houston, TX: NACE).
9. NACE SP0178 (latest revision), "Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to be Lined for Immersion Service" (Houston, TX: NACE).

Appendix A

Tanks and Vessels Containing Other Waters (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

A.1 Introduction

This appendix lists some tanks that contain water that may not be fully covered in Paragraph 1.1 where CP may be considered as a suitable technology in the overall corrosion protection system. CP of oil treating vessels is addressed in NACE SP0575, and reference should be made to that standard for this and similar applications.⁸

A.2 Hazards

It is possible for tanks that contain waters to also contain toxic or explosive gases or other hazards as a portion of their contents. Some conditions may exist where explosive atmospheres may be ignited in the presence of a CP system through sparking that could be caused by sacrificial anodes. All possible hazards should be evaluated before considering CP.

A.3 Considerations

The designer shall evaluate whether the application of CP is suitable to the particular tank and service conditions in question. The designer's considerations should include, but not be limited to:

- Water and other phases
- Chemistry of conductive electrolyte phase
 - Activity, ionic strength
 - Conductivity
 - Total Dissolved Solids (TDS)
 - Suspended Solids
 - pH
 - Temperature
 - Turbulence
 - Langelier Index
 - Dissolved gases
- Microbial activity
- Tank configuration including internal baffles, sumps and pump outs
- Tank operations including cleaning systems, liquid levels and fluctuations, turbulence, rapid filling and discharge
- Impact of tank configuration and operation on the placement and mounting of anodes and reference electrodes
- Settlement of solids or sludges
- Materials of construction
- Protective coatings and linings
 - Type
 - Condition
 - Age

- Frequency of inspection
- Quality

The coating manufacturer should be consulted for the purpose of ensuring that the coating system selected, or in use, has been properly designed for the service conditions and exposure. Compatibility with an installed and operating CP system, as well as the coating's ability to resist cathodic disbondment, must also be considered.

- Icing / freezing
- Availability of alternating current (AC) power
- Areas of tank that cannot be dewatered
- Tank electrical continuity (e.g. bolted tanks, internal appurtenances)

A.4 Applications

The designer may consider any application where a conductive electrolyte is present. Some typical applications may include:

<u>Tank Service</u>	<u>Galvanic CP Applicability</u>
Brine Tanks	Y
Process Water Tanks	Evaluate
Effluent Tank (Treated)	Y
Waste Water Tank	Y
Inlet Diversion Tank	Y
Raw Seawater Surge Tank	Y
Filtered Seawater and Other Natural Water Storage Tanks	Y
Deoxygenated Seawater Tank	Y
Desalinated Water Tank	Evaluate
Seawater Reverse Osmosis (RO) Product Water Tank	Y
Sewage Storage Tank	Y
Turbine Inlet Air Humidifier Water Tank	Y
Demineralized Water	Seldom
Effluent Tank (Raw)	Evaluate
Ultrafiltration (UF) Feed Tank	Evaluate
UF Permeate Tank	Evaluate
Oil & Gas Process Water (Frac Water)	Evaluate
Condensed Water Collection Tank	Evaluate
Filter Vessels	Evaluate
Oil Treating Vessels	Refer to NACE SP0575
Hydrocarbon Production Tanks	Refer to NACE SP0575

A.5 Limitations:

A.5.1 Demineralized waters: CP is rarely specified for demineralized water service. The reason is the conductivity of the water is very low and it is typically considered to be incompatible with CP. Additionally, contamination of the demineralized water by dissolution of the anodes can be detrimental to the specific service process. In the rare instances where CP is applied in demineralized water service, impressed current CP with inert anodes would be the preferred approach, in accordance with NACE SP0388, but it is also limited in practical application.

A.5.2 Waters containing sludges and foreign materials: Some tanks, such as those associated with waste treatment, may contain foreign materials such as rags, rope and other material that may physically damage anode and reference electrode assemblies. Consideration must be given to possible mechanical damage and avoidance of snags.

A.5.3 Anode Fouling: The performance of sacrificial anodes can, at times, be adversely affected by the presence of inorganic or organic chemicals, resulting in either fouling of the anode surface or reduced life. These effects are specific to the anode material and need to be considered during the CP design.

A.5.4 Generation of Gases: Some waters may have chemistries where CP current can cause the evolution of gases such as chlorine or hydrogen. Although this does not preclude the use of CP, the generated gases must be dealt with effectively and safely. The CP design in non-vented tanks must consider whether anticipated gassing would prohibit the use of CP.

A.5.5 Coated (lined) Tanks: The CP design should carefully evaluate the propensity of cathodic disbondment of the tank internal coating (i.e., lining). Verification is required that the coating is compatible with cathodic protection at the expected operating temperatures. The coating must be resistant to attack from the elevated pH at the tank surface caused by the operation of the cathodic protection system. Additionally, the initial coating conditions are often superior with minimal protective current requirements, whereas the cathodic protection design is often dominated by the final coating conditions when more protective current will be required. Overdesigns with an excessive quantity of magnesium anodes (without current output control provisions) can cause overprotection during the initial conditions that can result in cathodic disbondment and blistering of the coating.

A.5.6 Anode Selection: Under certain conditions of water chemistry and/or elevated temperature, the list of anode materials may be expanded to include other anode materials, such as aluminum and zinc alloys other than ASTM B418 Type II.

A.6 Tank Design

A.6.1 The design of a tank can have a significant impact on the application of cathodic protection. Rigid elements such as baffles and sumps can shield CP current, resulting in inadequate levels of polarization. Anode placement must ensure adequate current distribution and in cases may require the installation of dedicated anodes, such as behind baffle plates and in sumps.

A.6.2 Retractable roof supports, floating and telescopic skimmers and other metallic pipe work and appurtenances must be included in CP surface area calculations where they are immersed. Their impact on current distribution must also be considered. The CP system must be compatible and avoid conflicts with tank operations where movement of internal components, including flexible piping, is expected.

A.6.3 The location of stirrers, both blade and jet type, must be considered, as well as their effect on the velocity of the water in proximity to cathodically protected surfaces and the effect on cathodic polarization.

A.6.4 Internally coated tanks should be designed, fabricated and lined in accordance with NACE SP0178.⁹

A.6.5 Holes installed in baffle plates must be of sufficient size and have edges prepared to ensure proper coating application. Coating holidays in shielded areas can receive inadequate current when compared with those on accessible surfaces.

A.7 System Operation & Maintenance

A.7.1 Where considered necessary, galvanic anode cathodic protection systems should be designed with provisions to monitor and adjust the anode current outputs.

A.7.2 Provisions for measuring tank-to-water potentials with respect to a portable or stationary reference electrode are essential for proper monitoring. For those applications where the chloride ion concentrations are >500 ppm, a Ag/AgCl reference electrode should be used; and for those applications where the chloride ion concentrations are <500 ppm, a Cu/CuSO₄ reference electrode should be used. Some in the industry also use zinc reference electrodes in lieu of Cu/CuSO₄.

A.7.3 Where current monitoring and control provisions are provided, the cathodic protection system should be commissioned by adjusting the anode current output required to achieve the selected criterion for cathodic protection. To ensure continued proper system operation, anode current outputs and tank-to-water potentials should be recorded annually as a minimum, and verified to be operating within the ranges established during system commissioning. If any system component is damaged or a malfunction is discovered, the system should be tested and repaired.

A.8 Types of Cathodic Protection Systems

This standard deals only with galvanic anode CP systems (see Paragraph 1.2). Should impressed current systems be considered using these principles, reference should be made to NACE SP0388.

