

External Corrosion Control of On-Grade Carbon Steel Storage Tank Bottoms

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Foreword

Sustaining long-term leak-free operation of aboveground storage tank (AST) bottoms is an extremely important goal of all AST owners and operators. Mitigation of corrosion on the external side of on-grade carbon steel tank bottoms is a principal element necessary to achieve this goal.

Scope

This standard provides a comprehensive compilation of corrosion mitigation considerations, practices, and procedures for AST bottoms. It is applicable from tank construction through long-term integrity management and maintenance processes. It presents supplements and alternatives to cathodic protection (CP). A broad section on vapor corrosion inhibitor (VCI) practices and procedures for mitigation of external tank bottom corrosion is included.

Rationale

Attainment of low tank bottom maintenance costs and leak-free AST bottom operation over the long term is a function of more than just the implementation of external corrosion control systems. This standard practice provides industry guidance on a variety of important corrosion mitigation practices to consider during AST engineering and construction, as well as during the operational phase.

Referenced Standards and Other Consensus Documents

The latest edition, revision, or amendment of the referenced standards in effect shall govern unless otherwise dated.

AMPP/NACE/SSPC, www.amp.org:

NACE TM0304	Offshore Platform Atmospheric and Splash Zone Maintenance Coating System Evaluation
NACE No. 2/SSPC-SP 10	Near-White Metal Blast Cleaning
NACE SP0193	External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms
NACE SP0775	Preparation, Installation, Analysis, and Interpretation of Corrosion Coupons in Oilfield Operations
SSPC-PA 2	Procedure for Determining Conformance to Dry Coating Thickness Requirements
SSPC-SP 2	Hand Tool Cleaning

American Petroleum Institute (API), www.api.org:

API 650	Welded Tanks for Oil Storage
API 651	Cathodic Protection of Aboveground Petroleum Storage Tanks
API 653	Tank Inspection, Repair, Alteration, and Reconstruction

ASTM International, www.astm.org:

ASTM G95	Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)
ASTM G14	Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
ASTM D4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

ASTM G57	Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
ASTM G51	Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing
ASTM D516	Standard Test Method for Sulfate Ion in Water
ASTM C778	Standard Specification for Standard Sand
ASTM C144	Standard Specification for Aggregate for Masonry Mortar
Environmental Protection Agency (EPA), www.epa.gov:	
EPA 0376.1	Sulfide – Titrimetric, Iodine
International Organization for Standardization (ISO), www.iso.org:	
ISO 31000	Risk Management - Principles and Guidelines

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: General

- 1.1 This standard has been developed to specifically address corrosion monitoring and control beyond CP for the external side of AST bottoms. Guidance is provided for the use of other corrosion control technologies with an emphasis on VCI applications.
- 1.2 The provisions of this standard are intended to be applied under the direction of a competent person who, by reason of knowledge of the physical sciences and principles of engineering and mathematics, acquired by education and related practical experience is qualified to engage in the practice of AST external bottom corrosion control.
- 1.3 Descriptions of many factors that contribute to external corrosion of the tank bottom plates are provided as well as guidance on monitoring of the tank pad electrolyte in contact with the tank bottom.
- 1.4 This standard is applicable to welded, bolted, and riveted carbon steel ASTs that are field or shop-fabricated and constructed on-grade.
- 1.5 Corrosion mitigation guidance is provided relative to the external side of AST bottoms. Internal product-side tank bottom corrosion mitigation is not included in this standard.
- 1.6 Limited CP details and guidance are included in this standard. For additional AST CP guidance, see NACE SP0193.
- 1.7 An important focus of this standard is to welcome and encourage the consideration of new applicable products, technologies, and processes for inclusion during future standard reviews/revisions.

Section 2: Definitions

Aboveground Storage Tank (AST): A stationary container of greater than 500-barrel capacity usually cylindrical in shape, consisting of a metallic roof, shell, bottom, and support structure where more than 90 percent of the tank volume is above surface grade.

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

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

Anodic Polarization: (1) The change of the electrode potential in the noble (positive) direction caused by current across the electrode/electrolyte interface. (2) A forced noble (positive) shift in electrode potential (See *Polarization*).

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

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

Cathodic Protection: A technique to reduce the corrosion 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) A thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.

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

Corrosion Coupon: A weighed sample (coupon) of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The coupon is then cleaned of all corrosion products and is reweighed. The weight loss is converted to a total thickness loss or average corrosion rate.

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

Criterion: Standard for assessment of the effectiveness of a CP system.

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

Electrical Resistance (ER) Probe: A corrosion growth rate/metal loss measurement probe that is based on the principle of increase in resistance of a metal strip or wire as a function of metal loss due to reduction in the cross-sectional area of the probe element. It indicates the cumulative metal loss of the element.

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

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purposes of this standard, electrolyte refers to the soil or liquid adjacent to and in contact with the external side of an AST bottom.

External Side: The external surface of the product containment bottom in contact with the tank pad.

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

Polarization: The change from the corrosion potential because 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) (CP 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.

Secondary Containment: A device or system used to control the accidental escape of a stored product so it may be properly recovered or removed from the environment. For the purpose of this standard, secondary containment refers to an impermeable membrane.

Tank Pad: The material immediately adjacent to the exterior steel bottom of an aboveground storage tank.

Vapor Corrosion Inhibitors (VCI): Sometimes referred to as “Volatile Corrosion Inhibitors.” Substances that slowly release a corrosion-preventative compound into an enclosed air space, effectively protecting exposed metal surfaces.

VCI Specialist: A competent person who, by reason of knowledge of the physical sciences and principles of engineering and mathematics, acquired by education and related practical experience is qualified to engage in the practice of AST corrosion control through the application of VCI products and technologies.

NOTE: Such persons may be but are not limited to, persons acknowledged as VCI Specialists by VCI manufacturers if their professional activities include suitable experience in AST corrosion control through the application of VCI products and technologies.

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

Section 3: External Corrosion of Aboveground Steel Storage Tank Bottoms

3.1 Introduction

- 3.1.1 The external side of aboveground storage tank bottoms is typically bare steel with mill scale. The bare steel surface is in contact with the tank pad materials installed during tank construction. Therefore, the steel is susceptible to corrosion for the life of the bottom.
- 3.1.2 Corrosion of the steel bottom plates results from an electrochemical process. There are certain conditions that need to be present for the electrochemical process to function and for corrosion cells to develop. The elements that are common to all corrosion cells are:
 - 3.1.2.1 An anode where oxidation and metal loss occur.
 - 3.1.2.2 A cathode where reduction and protective effects occur.
 - 3.1.2.3 Metallic and electrolytic paths between the anode and cathode through which the electronic and ionic current flows.
- 3.1.3 External corrosion of AST bottoms occurs in numerous forms. The most common types of corrosion experienced on tank bottoms are generalized surface corrosion and localized (pitting) corrosion.
 - 3.1.3.1 The general surface corrosion of bare steel includes thousands of microscopic corrosion cells occurring on the metal surface. This typically results in relatively uniform metal loss.
 - 3.1.3.2 Pitting corrosion is a localized form of corrosion by which “pits” or “holes” are produced in the tank bottom plates.

3.2 Corrosion Mechanisms

3.2.1 Dissimilar Metal Corrosion

3.2.1.1 This type of corrosion occurs when two dissimilar metals with different electrical potentials are connected in such a way as to be electrically continuous and in contact with a common electrolyte.

3.2.2 The most significant factors impacting corrosion rates are:

3.2.2.1 The current flow between the dissimilar metals when coupled together.

3.2.2.2 The relative surface areas of the cathode and anode.

3.2.2.3 The temperature of products contained in the tank.

3.2.3 Corrosion tends to be more severe when the anodic area is small with respect to the cathode surface area and the two metals have large natural voltage differences as identified in the Galvanic Series of Metals.

3.2.4 As an example, this type of corrosion may occur on carbon steel tank bottom locations connected to underground metals that are cathodic to carbon steel such as stainless steel or copper.

3.2.5 The metal composition is also a factor in determining areas on a metal surface that become anodic. Differences in electrochemical potential between adjacent areas can result from uneven distribution of alloying elements or contaminants within the metal structure. Corrosion may also be caused by differences between weld metal, heat-affected zone, and parent metal.

3.3 Dissimilar Soils Corrosion

3.3.1 Tank bottom corrosion is substantially affected by the electrolyte in contact with the steel surface. Corrosion rates are likely to increase if the electrolyte is not uniformly consistent and is contaminated with various types of soils, micro-organisms, and other debris.

3.3.2 Dissolved salts in the tank pad increase the current carrying capacity of the soil electrolyte and affect reaction rates at the anodic and cathodic areas.

3.3.3 Microbiologically Influenced Corrosion (MIC) is the result of the metabolic activity of micro-organisms contained in the sand electrolyte in contact with the tank bottom. Severe corrosion may occur if conditions support accelerated MIC growth.

3.3.4 Moisture content, pH, oxygen concentration, and other factors also interact in a complex fashion to influence corrosion.

3.4 Differential Oxygen Concentration Corrosion Cells

3.4.1 It is common for tank bottoms to experience differing oxygen concentrations over the large surface areas.

3.4.2 The differential oxygen concentrations between areas on a steel surface may generate differences in potential. Areas with higher oxygen concentrations become cathodic, while areas with lower oxygen concentrations become anodic and corrode.

3.5 Important Engineering Considerations Affecting External Tank Bottom Corrosion

Mitigation of external corrosion on tank bottoms should be included in the engineering process of new tank construction, or as part of a tank bottom repair/replacement plan. Important corrosion mitigation factors include:

- 3.5.1** Tank pad materials.
 - 3.5.1.1** Chemical composition
 - 3.5.1.2** Size of aggregates
 - 3.5.1.3** Electrical resistivity
 - 3.5.1.4** Control of installation practices to prevent contamination of the tank pad.
 - 3.5.1.5** Tank pad compaction to ensure uniform contact between the tank bottom and the tank pad material.
- 3.5.2** Undertank containment liners.
 - 3.5.2.1** Electrical resistivity of the liner materials.
 - 3.5.2.2** Location of the containment liners relative to the tank bottom.
 - 3.5.2.3** Drainage of any accumulated water above the liner.
- 3.5.3** Prevention of water intrusion undertank.
 - 3.5.3.1** Elevation of the underground water table.
 - 3.5.3.2** Tank bottom elevation in relation to surrounding grade.
 - 3.5.3.3** Containment and drainage of rainwater within the tank berm area.
 - 3.5.3.4** Drainage of accumulated water undertank.
- 3.5.4** Type of Service
 - 3.5.4.1** Type of product stored.
 - 3.5.4.2** In-service temperature of tank bottom.
 - 3.5.3.3** Frequency of product fill and discharge.
- 3.5.5** Tank bottom and foundation specifications.
 - 3.5.5.1** Tank bottom material of construction.
 - 3.5.5.2** External tank bottom coating.
 - 3.5.5.3** Type of tank support foundation.

3.6 Increased Rates of Corrosion Due to Elevated Tank Bottom Temperatures

- 3.6.1** Accelerated corrosion can occur on the external side of tank bottoms subjected to elevated temperatures in the presence of moisture.
- 3.6.2** NOTE: The corrosion rate of steel may double with every 18 °F (10 °C) increase in temperature above 77 °F (25 °C).
- 3.6.3** ASTs containing products above ambient temperature may require an increase in CP design current density to achieve adequate corrosion protection on the external surface of the bottom.

- 3.6.4** Corrosion rate probes may assist in the evaluation of corrosion rates within an elevated temperature tank pad electrolyte.
- 3.6.5** Elevated tank bottom temperatures may also dry out tank pad materials, resulting in a significant increase in electrolyte resistivity and a reduction in effectiveness of corrosion mitigation systems such as CP or VCIs.

Section 4: Tank Pad Specifications and Installation Practices

4.1 Introduction

- 4.1.1** Different types of sand pad materials are used for aboveground storage tanks due to a wide variety of surface, subsurface, and climatic conditions.
- 4.1.2** The pad material under the tank bottom has a significant effect on external corrosion of the tank bottom and can influence the effectiveness and applicability of engineered systems for corrosion mitigation.
- 4.1.3** There are a wide variety of tank pad materials available, some of which may impede the beneficial effects of CP or other engineered systems for corrosion mitigation.
- 4.1.4** A competent person should review the tank pad specifications and installation procedures prior to the construction of the respective tank to determine which engineered systems for corrosion mitigation would help preserve the integrity of the tank bottom.

4.2 Tank Pad Option

4.2.1 Sand Tank Pad

- 4.2.1.1** Clean washed and graded sand is one of the most common materials used as a pad beneath aboveground storage tank bottoms.
- 4.2.1.2** The use of clean sand alone normally does not eliminate the need for CP or other engineered systems of corrosion mitigation since corrosion may occur due to intrusion of water and other contaminants from rain, snow, shallow water table, or condensation. Guidelines for the chemical and electrical analysis of the sand for corrosive contaminants are discussed in [Paragraph 4.3](#).
- 4.2.1.3** A clean sand tank pad used in conjunction with engineered corrosion mitigation systems is an effective means of protecting the tank bottom from external corrosion.

4.2.2 Continuous Concrete Tank Pad

- 4.2.2.1** A properly designed concrete tank pad constructed on stable, adequately prepared subsoil may be effective in eliminating intrusion of groundwater and mitigating external tank bottom corrosion.
- 4.2.2.2** The surface of the concrete tank pad and steel bottom plate should be kept free of contaminants during construction.
- 4.2.2.3** Preparation of a stable soil to support the concrete slab is essential to ensure the continued integrity of the pad. Unstable soil may induce cracks in the slab through which water and contaminants may permeate to the steel tank bottom and provide a corrosive environment.

- 4.2.2.4** Although corrosion from the soil may be mitigated by a concrete pad, there may still be a collection of moisture between the tank bottom and the tank pad due to condensation, blowing rain or snow, flooding due to inadequate drainage, or rainwater from the roof of the tank flowing down the tank walls. Corrosion may occur due to this moisture accumulation.
- 4.2.2.5** CP is generally not considered an effective way to combat the external side corrosion mechanisms associated with continuous concrete tank pad foundations. The high resistivity of the concrete severely restricts CP system current flow to the tank bottom.
- 4.2.2.6** A free-draining concrete tank pad and a seal around the periphery of the tank may be effective in eliminating the accumulation of moisture between the pad and the tank bottom where flooding in the dike area above the tank bottom does not occur.
- 4.2.2.7** In situations where water may condense on the tank bottom, or water is retained above the concrete pad, accelerated corrosion may occur.
- 4.2.2.8** Numerous complex factors affect tank bottom underside corrosion in the presence of concrete. Prediction of the propensity of corrosion in this case is difficult. Thus, care should be observed with tanks on concrete pads since CP is likely to be ineffective, although other corrosion mitigation methods such as VCI chemistry may be considered.

4.2.3 Crushed Limestone or Clam Shell Tank Pad

- 4.2.3.1** Layers of crushed limestone or clam shells have been used instead of sand for a tank pad in some locations.
- 4.2.3.2** Such tank pads with and without the use of CP have produced mixed soil-side corrosion mitigation results.
- 4.2.3.3** The tank pad should be fine and uniform, since differential aeration corrosion cells can cause pitting at contact areas between the large particles and the metal.
- 4.2.3.4** The intrusion of water from rain or groundwater makes the environment under the tank alkaline, which may reduce corrosion. However, if contaminants are present in the pad, or with time infiltrate the pad, corrosion may accelerate.
- 4.2.3.5** The use of crushed limestone or clam shells does not eliminate the need for CP or other engineered systems of corrosion mitigation.
- 4.2.3.6** A steel retaining ring is sometimes installed at a sufficient distance from the tank shell to ensure berm stability. The ring shall not impede the drainage of water away from the tank.
- 4.2.3.7** For new tank construction, the use of a crushed limestone or clamshell tank pad is discouraged.

4.2.4 Oiled Sand Tank Pad

- 4.2.4.1** Oil has been mixed with sand during tank pad construction in some locations for various reasons, including compaction and corrosion control. Because severe tank bottom external side corrosion has been routinely experienced with these tank pad materials, tank pads should not be constructed of oiled sand.