

Cathodic Protection of Aboveground Petroleum Storage Tanks

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Introduction

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

- API Standard 650;
- API Recommended Practice 652;
- API Standard 653;
- API Specification 12B;
- API Specification 12D;
- API Specification 12F;
- API Standard 2610;
- AMPP SP0193;
- AMPP SP0285;
- NFPA¹ 30;
- NFPA 70; and,
- PEI² RP200.

The appropriate government authority having jurisdiction should be consulted for regulations that apply to the area of installation prior to taking any action suggested in this recommended practice (RP).

¹ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

² Petroleum Equipment Institute, P.O. Box 2380, Tulsa, Oklahoma 74101-2380. www.pei.org.

Cathodic Protection of Aboveground Petroleum Storage Tanks

1 Scope

1.1 The purpose of this RP is to present procedures and practices for achieving effective corrosion control on aboveground storage tank carbon steel bottoms using cathodic protection. This RP contains provisions for the application of cathodic protection to existing and new aboveground storage tanks. Corrosion control methods based on chemical control of the environment, or the use of protective coatings are not covered in detail.

1.2 When cathodic protection is used for aboveground storage tank applications, it is the intent of this RP to provide information and guidance specific to aboveground metallic storage tanks in hydrocarbon service. Certain practices recommended herein may also be applicable to tanks in other services. It is intended to serve only as a guide to people interested in cathodic protection. Specific cathodic protection designs are not provided. Such designs should be developed by a person thoroughly familiar with cathodic protection practices for aboveground petroleum storage tanks.

1.3 This RP does not designate specific practices for every situation because the varied conditions in which tank bottoms are installed preclude standardization of cathodic protection practices.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 575, *Inspection of Atmospheric and Low-Pressure Storage Tanks*

API Recommended Practice 652, *Lining of Aboveground Petroleum Storage Tank Bottoms*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Technical Report 655, *Vapor Corrosion Inhibitors for Storage Tanks*

API Recommended Practice 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*

API Standard 2610, *Design, Construction, Operation, Maintenance and Inspection of Terminal and Tank Facilities*

ASTM C144,³ *Standard Specification for Aggregate for Masonry Mortar*

ASTM C778, *Standard Specification for Standard Sand*

ASTM D512, *Standard Test Methods for Chloride Ion in Water*

ASTM D516, *Standard Test Method for Sulfate Ion in Water*

ASTM D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2700 kN-m/m³))*

ASTM G51, *Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing*

ASTM G57-06, *Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method*

³ ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org

EPA 0376.1, ⁴ *Test Method for Sulfide—Titrimetric Iodine*

AMPP, ⁵ *Peabody's Control of Pipeline Corrosion*, ISBN 1-57590-114-5

AMPP TM0497, *Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems*

AMPP SP0177-2007, *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems*

AMPP SP0193-2016, *External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms*

AMPP SP0285-2011, *Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*

AMPP SP0388-2007, *Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks*

AMPP SP0572-2007, *Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds*

AMPP SP0575-2007, *Internal Cathodic Protection Systems in Oil Treating Vessels*

AMPP TPC 11, *A Guide to the Organization of Underground Corrosion Control Coordinating Committees*

3 Terms and Definitions

Definitions in this section reflect the common usage among practicing corrosion control personnel. In many cases, in the interests of brevity and practicality, the strict scientific definitions have been abbreviated or paraphrased. For the purposes of this document, the following terms and definitions apply.

3.1

aboveground storage tank (AST)

An on-grade, stationary, uniformly supported container, cylindrical in shape, usually consisting of a fixed or floating roof, shell, bottom, and support structure.

3.2

anode

The electrode of an electrochemical cell at which oxidation (corrosion) occurs. Antonym: cathode.

3.3

anode bed

Consists of one or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.

3.4

backfill

Commercial, uniformly conductive material placed in a hole to fill the space around anodes, vent pipe, and buried components of a cathodic protection system.

NOTE Anodes can be prepackaged with backfill material for ease of installation.

⁴ U.S. Environmental Protection Agency, Ariel Rios Building, 1200 Pennsylvania Avenue, N.W., Washington, D.C. 20460, www.epa.gov.

⁵ AMPP International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas, 77084-4906, www.ampp.org.

3.5**bottom edge projection (bottom extension)**

The portion of the tank bottom steel plate that extends horizontally past the outside vertical surface of the shell (i.e. the external lip formed at the base of the tank where the bottom steel plate protrudes and is welded to the bottom of the shell, around the entire tank perimeter). Also referred to as bottom extension.

3.6**breakout piping/tanks**

Piping/tanks used to relieve surges in a hazardous liquid pipeline system or piping/tanks used to receive and store hazardous liquid transported by a pipeline for re-injection and continued transportation by pipeline.

3.7**cathode**

The electrode of an electrochemical cell at which a reduction reaction occurs. Antonym: anode.

3.8**cathodic protection**

A technique to reduce corrosion of a metal surface by making the entire surface the cathode of an electrochemical cell.

3.9**coke breeze**

A commercial carbonaceous backfill material.

3.10**continuity bond**

A metallic connection that provides electrical continuity.

3.11**corrosion**

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

3.12**corrosion protection**

The minimization of corrosion using protective linings/coatings for exposed steel surfaces, and cathodic protection for soil-side tank bottom steel plate surfaces.

3.13**current density**

The current per unit area flowing to or from a metallic surface.

3.14**current requirement test**

A test where the use of direct current flow from a temporary anode bed to the structure to be protected is used to determine the amount of current necessary to protect the structure.

3.15**deep anode bed**

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

3.16**differential aeration cell**

An electrochemical cell, the electromotive force of which is due to a difference in oxygen concentration at one part of the tank bottom as compared with that at another part of the tank bottom of the same material.

3.17**electrical isolation**

The condition of being electrically separated from other metallic structures.

3.18**electrochemical cell**

An electrochemical system consisting of an anode and a cathode immersed in an electrolyte to create an electrical circuit. The anode and cathode may be separate metals or dissimilar areas on the same metal. The cell includes an external circuit, which permits the flow of electrons from the anode toward the cathode.

3.19**electrode potential**

The potential of an electrode as measured against a standard reference electrode. The electrode potential does not include any voltage measurement errors due to the passage of current through the resistance of the metallic or electrolytic paths.

3.20**electro-osmosis**

Drying of the tank pad directly adjacent to the anode surface thereby increasing the anode-to-electrolyte resistivity and overall anode bed resistance.

3.21**electrolyte**

A chemical substance containing ions that migrate in an electric field. For the purposes of this RP, electrolyte refers to the soil or water adjacent to and in contact with the bottom of an aboveground petroleum storage tank, including the contaminants and chemicals contained therein.

3.22**external circuit**

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

3.23**external liner**

A system or device, such as a non-conductive membrane, installed beneath an aboveground storage tank, in or on the tank dike, to contain any accidentally escaped product.

3.24**foreign structure**

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

3.25**galvanic anode**

A metal that, because of its relative position in the galvanic series, provides sacrificial protection to another metal that is more noble, when electrically coupled in an electrolyte. These anodes are the source of current in galvanic or sacrificial cathodic protection.

3.26**galvanic cathodic protection**

The reduction or prevention of corrosion of a metal in an electrolyte by electrically connecting it to a more anodic metal.

3.27**galvanic series**

A list of metals and alloys arranged according to their relative potentials in a given environment.

3.28**holiday**

A discontinuity in a protective coating that exposes the underlying substrate to the environment.

3.29**impressed current**

An electric current supplied by a device employing a power source that is external to the electrode system. (An example is the direct current output of a cathodic protection rectifier.)

3.30**interference bond**

A metallic connection designed to control stray electrical current discharge from a metallic structure.

3.31**IR drop**

The voltage generated across a resistance by an electrical current in accordance with Ohm's Law: $E = I \times R$. For this RP, the most significant IR drop is the portion of a structure-to-soil potential caused by current flow through a resistive electrolyte from the anode to the structure.

3.32**isolation**

See electrical isolation.

3.33**membrane**

A thin, continuous sheet of nonconductive synthetic material used to contain and/or separate two different environments.

3.34**oxidation**

The loss of electrons by a constituent of a chemical reaction.

3.35**oxygen concentration cell**

A corrosion cell that occurs at areas of the tank bottom that are diffused of oxygen, which are directly adjacent to oxygenated areas of the tank bottom. Corrosion will occur at the de-aerated locations on the tank bottom. Areas of the tank bottom that are not in contact with the tank pad are not oxygen concentration cells.

3.36**polarization**

The change from the open-circuit potential of an electrode because of current across the electrode/electrolyte interface.

3.37**rectifier**

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

3.38**reduction**

The gain of electrons by a constituent of a chemical reaction.

3.39**reference electrode**

An electrode whose open-circuit potential is constant under similar conditions of measurement.

3.40**release prevention barrier (RPB)**

Includes steel bottoms (when used in a double bottom or secondary containment system), synthetic materials, clay liners, and all other barriers or combination of barriers placed in the bottom of, or under an aboveground storage tank, which have the following functions: a) preventing the escape of stored product, and b) containing or channeling released material for leak detection.

3.41**resistor**

A device used within an electrical circuit to control current flow.

3.42**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.

3.43**shallow anode bed**

A group of cathodic protection anodes installed individually, spaced uniformly, and typically buried less than 6 m (20 ft) below grade.

3.45**shunt**

A conductor of a known electrical resistance through which current flow may be determined by measurement of the voltage across the conductor and calculation using Ohm's Law.

3.46**stray current**

Current flowing through paths other than the intended circuit.

3.47**stray current corrosion**

Corrosion resulting from direct current flow through paths other than the intended circuit.

3.48**structure-to-electrolyte voltage (also structure-to-soil potential or pipe-to-soil potential)**

The voltage difference between a metallic structure and the electrolyte which is measured with a reference electrode in contact with the electrolyte.

3.49**structure-to-structure voltage (also structure-to structure potential difference)**

The difference in voltage between metallic structures in a common electrolyte.

3.50**tank bottom flexing**

The physical movement of the tank bottom during filling and emptying of the tank causes air, oxygen, and water moisture to freely flow out from under the tank, and air, oxygen, and water moisture to flow back under the tank.

3.51**tank pad**

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

3.52**test lead**

An electrically conductive wire or cable attached to a structure and terminated in a test station. It is used for the measurement of structure-to-electrolyte potentials and other measurements.

3.53**test station**

A small enclosure or housing that is the termination point of one or more test leads.

3.54**voltage**

An electromotive force, or a difference in electrode potentials expressed in volts. Also known as “potential”.

3.55**water bottom**

A water layer in the bottom of a tank caused by separation of water and product due to differences in solubility and specific gravity.

3.56**standard fixed high input resistance voltmeter**

Voltmeter with fixed input resistance up to 20 Mega-ohms.

3.57**variable input resistance voltmeter**

Voltmeter with input resistance between 10 Mega-ohms to greater than 2 Giga-ohms.

4 Corrosion of Aboveground Steel Storage Tanks

4.1 Introduction

4.1.1 Corrosion may be defined as the deterioration of a metal resulting from a reaction with its environment. Corrosion of steel structures is an electrochemical process. For the corrosion process to occur, areas with different electrical potentials must exist on the metal surface. These areas must be electrically connected and in contact with an electrolyte.

There are four components required for a corrosion cell: an anode, a cathode, a metallic path connecting the anode and cathode, and an electrolyte (see [Figure 1](#)). The role of each component in the corrosion cell is as follows:

- At the anode, the base metal goes into solution (corrodes) by releasing electrons and forming positive metal ions. For steel, the anodic reaction is: $Fe \rightarrow Fe^{+2} + 2e^{-}$
- At the cathode, chemical reactions take place using electrons released at the anode. No corrosion takes place at the cathode. One common cathodic reaction is: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$
- The metallic path provides a way for electrons released at the anode to flow to the cathode.
- The electrolyte contains ions and conducts current from the anode to the cathode by ionic movement. The electrolyte contains both negatively charged ions called anions and positively charged ions called cations that are attracted to the anode and cathode, respectively. Moist soil is the most common electrolyte for external surfaces of the tank bottom, while water and sludge generally are the electrolytes for the internal surfaces.

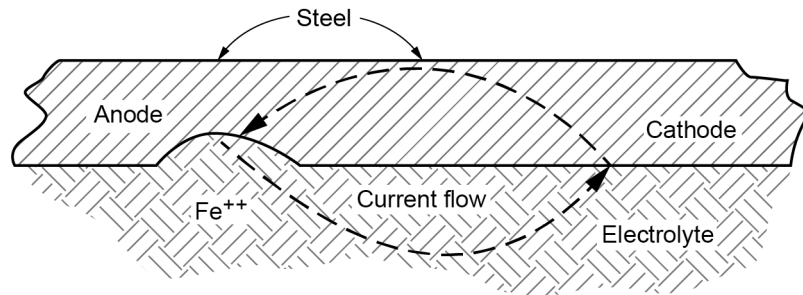


Figure 1—Electrochemical Corrosion Cell

4.1.2 There are many forms of corrosion. The two most common types relative to tank bottoms are general and localized (pitting) corrosion. In general corrosion, thousands of microscopic corrosion cells occur on an area of the metal surface resulting in relatively uniform metal loss. In localized (pitting) corrosion, the individual corrosion cells are larger and distinct anodic and cathodic areas can be identified. Metal loss in this case may be concentrated within relatively small areas with substantial areas of the surface unaffected by corrosion.

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

Other factors such as soil type, soil resistivity, grain size and distribution (soil gradation), presence of gravel or rocks in soil, soil layers, mineral constituents (solids and dissolved), underlying bedrock, organic materials, microbial activity, seasonal rainfall, water table level, seasonal runoff/drainage, soil temperature range, frost line, existence or introduction of hydrocarbons, and/or existence or introduction of other chemical components or foreign materials each interact in a complex fashion may increase the corrosion rate.

Introduction of chemical inhibitors such as Portland cement, lime, or biocides, may decrease the corrosion rate.

4.1.4 Physical and chemical properties of the electrolyte also influence the location of cathodic and anodic areas on the metal surface. This phenomenon can cause corrosion of steel tank bottoms on a homogeneous sand pad, and/or when contaminated with clay or other debris or natural soil that does not have a uniform consistency (see [Figure 2a](#)). Differing oxygen concentrations between areas on a steel surface may generate differences in potential. This is especially true on tank bottoms due to tank bottom flexing and is a primary corrosion mechanism on tank bottoms. Areas of the tank bottom that are highly oxygenated become cathodic versus areas directly adjacent to the oxygenated areas become anodic in an oxygen concentration cell (See [Figure 2b](#)). Air spaces/ gaps between the tank bottom and tank pad (such as tank bottom resting on a concrete ringwall), or voids in the tank pad) are not oxygen concentration cells, and typically do not experience high levels of corrosion due to the steel self-passivation.

4.1.5 Soil characteristics substantially affect the type and rate of corrosion on a structure in contact with soil. For example, dissolved salts influence the current carrying capacity of the soil electrolyte and help determine reaction rates at the anodic and cathodic areas. Moisture content, pH, oxygen concentration, and other factors interact in a complex fashion to influence corrosion.

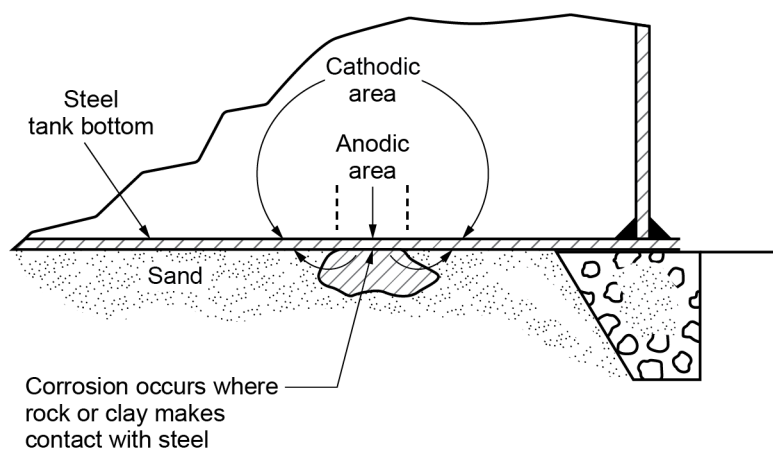


Figure 2a—Corrosion Caused by Rocks or Clay in Tank Pad

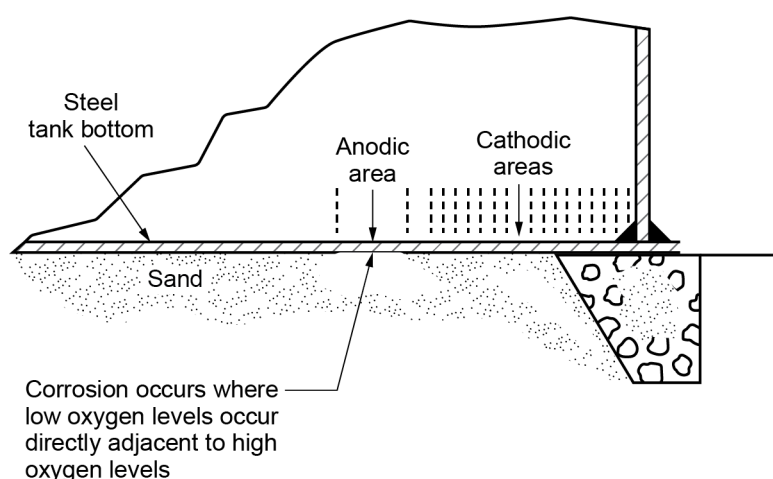


Figure 2b—Oxygen Concentration Cell Caused by Difference in Oxygen Due to Tank Bottom Flexing

4.2 Corrosion Mechanisms

4.2.1 DC Stray Current Corrosion

Stray currents (also known as interference currents) travel through the soil electrolyte and on to structures for which they are not intended. Usually, the affected structure collects the interference currents from the electrolyte; the source of these currents is not electrically connected to the affected structure. As shown in [Figure 3](#), stray current may enter an unprotected or protected tank bottom and travel through the low resistance path of the metal to an area on the tank closer to the protected structure (e.g. pipeline, facility piping or another tank). At this location, the current discharges back into the electrolyte (soil) at point B with resultant metal loss. The most common, and potentially the most damaging, stray currents are direct currents. These currents are generated from grounded DC electric power systems including electric railroads, subways, welding machines, impressed current cathodic protection systems, and thermoelectric generators.

The severity of corrosion (metal loss) resulting from interference currents depends on several factors:

- separation and routing of the interfering and affected structures and location of the interfering current source;
- magnitude and density of the current;
- quality or absence of a coating on the affected structures;
- the presence and location of mechanical joints having high electrical resistance;

- e) temperature:
- f) tank pad or soil resistivity.
- g) the careful placement of distributed anodes is required to prevent stray current corrosion, even on CP protected tanks

Further information related to proper design to avoid stray currents, and detection and control of stray current corrosion, can be found in [Section 7](#) and [Section 10](#).

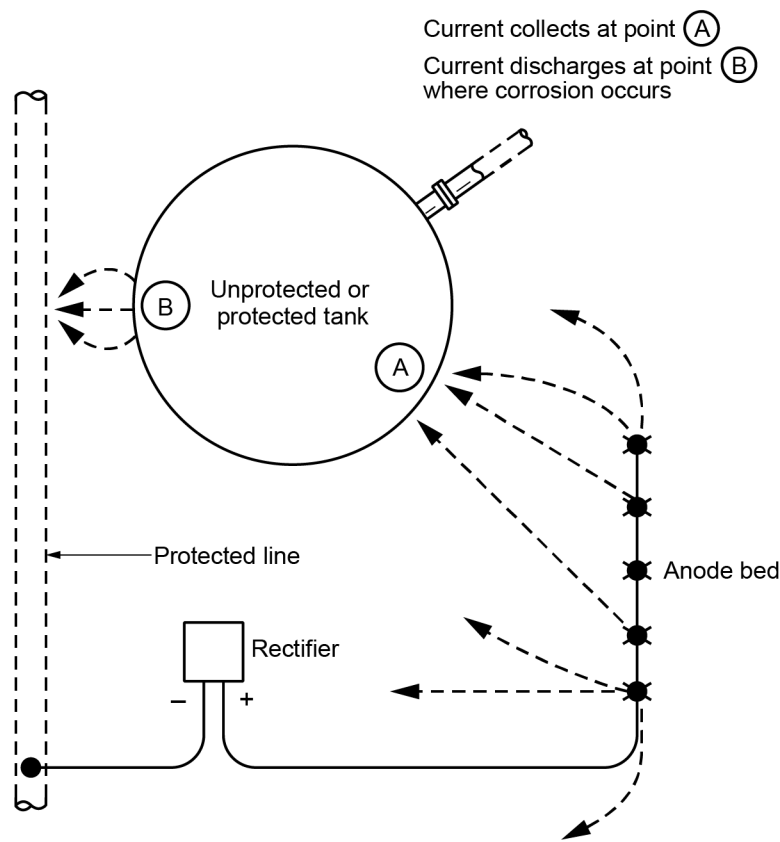


Figure 3—Example of Stray Current Corrosion of an Unprotected Tank Bottom

4.2.2 Galvanic Corrosion

Galvanic corrosion occurs when two metals with different compositions (thus, different electrolytic potentials) are connected in an electrolyte (usually soil). Current will flow from the more active metal (anode) to the less active metal (cathode) with accelerated attack at the anodic metal. For example, galvanic corrosion can occur when a bronze check valve is joined to carbon steel piping or where stainless steel, copper pipe, copper ground rod, or bare copper earthing cables are connected to a carbon steel tank. In the pipe/steel tank example, the stainless steel, copper pipe, or copper ground rod becomes the cathode, and the steel tank is the anode.

The use of alternative grounding and earthing materials may be considered, based upon the specific and prevailing environment. Careful consideration should be given to zinc-based materials, as soil can passivate the zinc or increase the rate of corrosion. ANSI IEEE Std 80 should be used as a guide for selecting approved grounding materials.

Current follows the paths of least resistance, resulting in galvanic corrosion occurring on areas on the steel tank bottom where the electrochemical reactions and current paths satisfy all of the required electrochemical processes. These may occur adjacent to the stainless steel or copper earthing, or groundings as shown in [Figure 4](#). The extent of such a problem is dependent on several factors. The most significant factors are: