△NACE ®
INTERNATIONAL
THE CORROSION SOCIETY

Standard
Recommended Practice

Internal Cathodic Protection Systems
in Oil-Treating Vessels

This NACE International standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this NACE International standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE International assumes no responsibility for the interpretation or use of this standard by other parties and accepts responsibility for only those official NACE International interpretations issued by NACE International in accordance with its governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

Users of this NACE International standard are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This NACE International standard may not necessarily address all potential health and safety problems or environmental hazards associated with the use of materials, equipment, and/or operations detailed or referred to within this standard. Users of this NACE International standard are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this standard.

CAUTIONARY NOTICE: NACE International standards are subject to periodic review, and may be revised or withdrawn at any time without prior notice. NACE International requires that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication. The user is cautioned to obtain the latest edition. Purchasers of NACE International standards may receive current information on all standards and other NACE International publications by contacting the NACE International Membership Services Department, 1440 South Creek Drive, Houston, Texas 77080-4906 (telephone +1 281/228-6200).

Foreword

This standard recommended practice is a general guide for the application of effective cathodic protection to all oil-treating vessels. This standard covers design criteria, the selection and installation of applicable systems, and the operation, monitoring, and maintenance of installed systems. There are many design variations in existing oil-treating vessels, with new designs being introduced continually. The preparation of a recommended practice for the cathodic protection of each individual vessel design is not practical. Therefore, this standard is not specific with respect to one or more vessel designs. It is intended for use by corrosion engineers involved in oil and gas production, especially those concerned with surface facilities. Nothing contained in this standard is intended to conflict with applicable codes, including OSHA[1] regulations.

This standard was originally prepared in 1975 by Task Group T-1E-6, a component of Unit Committee T-1E on Cathodic Protection of Oilfield Equipment, and revised in 1995 by Task Group T-1E-11. It was reaffirmed in 2001 by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings. This STG is composed of corrosion consultants, corrosion engineers from oil- and gas-producing companies, representatives from manufacturers, and others concerned with internal corrosion control in oil-treating vessels.

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*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state something considered good and is recommended but is not mandatory. *May* is used to state something considered optional.

_____

[1] Occupational Safety and Health Administration (OSHA), 200 Constitution Ave. NW, Washington, DC 20210.

_____

NACE International
Standard
Recommended Practice

Internal Cathodic Protection Systems
in Oil-Treating Vessels

Contents

_____

Section 1: General

1.1 This standard presents recommended practices for the cathodic protection of internal surfaces of oil-treating vessels, heat exchangers, or the water side of process vessels.

1.2 The provisions of this standard should be applied under the direction of a 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, acquired by professional education and related practical experience, is qualified to engage in the practice of corrosion control in oil-treating vessels.

1.3 Effective performance of the cathodic protection system requires operation within the limits of the design, monitoring of the system, and maintenance to replace damaged and consumed parts.

1.4 Cathodic protection is not effective when applied to steel surfaces in the oil or gas phase because of the absence of an electrolyte. Coatings and/or chemical inhibitors should be used to control corrosion on the steel surfaces in the oil and gas phase.

Section 2: Definitions

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 the solution at the anode.

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 of a metal surface by making that surface the cathode of an electrochemical cell.

Coating: A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film.

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

Corrosion Engineer: A person, who by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, is qualified to engage in the practice of corrosion control.

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

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

Electrode: A conductor 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 purpose of this standard,

electrolyte refers to the water, including the chemicals contained therein, adjacent to and in contact with a submerged metal surface.

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.)

Passivation: A reduction of the anodic reaction rate of an electrode involved in corrosion.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Salt Bridge: A salt solution used with a reference electrode to bridge a gap in an electrical circuit to obtain potential data with a reference electrode.

Steel-to-Water Potential: The potential difference between a steel vessel surface and a reference electrode immersed in the water with which the steel vessel surface is in contact (sometimes referred to as cathodic solution potential).

Section 3: Determination of Need for Cathodic Protection

3.1 General

3.1.1 Experience reveals that corrosion and metal loss is to be expected in any oil-treating vessel where any portion of the internal steel surface is exposed to oilfield brines because of their aggressive corrosive nature. The need for cathodic protection is contingent on the severity of existing or anticipated corrosion and the extent to which it affects equipment operation. Consistent with the latter, cathodic protection should be installed when it will accomplish one or more of the following: remove or minimize unsafe conditions caused by failure, provide economical control over equipment failures and losses, and remove or minimize the possibility of vessel content loss because of leaks or vessel collapse.

3.1.2 Internal coatings may be used in conjunction with cathodic protection to protect oil-treating vessels. Internal coating reduces the surface area of steel to be protected.

3.2 Corrosion Rates

3.2.1 The corrosiveness of a fluid stream is a function of the following:

3.2.1.1 Corrosion usually becomes more severe as the conductivity (dissolved solids content) of water (electrolyte) increases, but low-conductivity water can be corrosive.

3.2.1.2 Corrosion in produced oilfield brines usually increases as the partial pressure of acid-forming components, such as carbon dioxide (CO_2) or hydrogen sulfide (H_2S), increases.

3.2.1.3 Corrosion is accelerated by even trace amounts of oxygen.

3.2.1.4 Corrosion usually increases with increasing temperature unless scaling is increased.

3.2.1.5 Corrosion usually increases with increasing flow velocity and turbulence.

Section 4: Design and Selection of Cathodic Protection System

4.1 Basic Design Criteria

4.1.1 The design of a vessel's cathodic protection system depends on the internal configuration of the vessel. Selection of the appropriate system depends on factors such as initial cost, maintenance, type and condition of coatings (if any), power availability and cost, and system life.

4.1.2 Vertical cylindrical vessels containing no baffles, compartments, firetubes, etc., are usually protected with anodes or strings of anodes suspended from the deck (roof) of the vessel. This design method offers two advantages over other designs: (1) better current distribution because anodes are parallel to the vessel walls, and (2) deteriorated or depleted anodes can be replaced without lowering the water level or draining the vessel.

4.1.3 Compartmented vessels or those containing baffles, firetubes, spreaders, etc., should have at least one anode installed in each compartment exposed to the corrosive fluid. If a vessel is not designed to accommodate a cathodic protection system that will provide effective protection throughout, it may be necessary to make modifications or redesign the vessel interior to provide access to areas needing cathodic protection by installing fittings in the vessel for inserting anodes through the walls. An example of such modification is positioning of a spreader in a heater treater below the firetubes so there is sufficient clearance to install an anode between the firetube and spreader.

4.1.4 Correct location and position of anodes in vessels are essential for proper current distribution. Cathodic protection anodes should be placed such that their protective current can be distributed to all surfaces exposed to the corrosive electrolyte. Each anode should be located as near to the center of the compartment or center of the electrolyte as practical.

4.1.5 Factors determining the number, weight, and shape of anodes required for cathodic protection of vessels are:

(a)   area of bare water-immersed steel to be protected;

(b)   current density required;

(c)   anticipated current output of the anodes;

(d)   vessel configuration; and

(e)   desired life of the cathodic protection system.

4.1.6 Current density requirements can range from 50 to 400 mA/m2 (5 to 40 mA/ft2) of bare water-immersed steel. In the absence of specific current density data, 100 mA/m2 (10 mA/ft2) is commonly used for design. However, vessels handling water containing depolarizers, such as H2S and oxygen, or operating at high temperatures and/or high flow rates, could require higher current densities to maintain protective potentials. Internal coating of vessels decreases the area of bare steel in contact with water and reduces the amount of current required for corrosion protection.

4.2 System Selection

4.2.1 Cathodic protection can be provided by impressed current systems or galvanic anode systems. Typical performance data for commonly used impressed current and galvanic anodes are shown in Table 1. Prior to the application of either impressed current or galvanic anodes, it must be ensured that treated electrolytes are chemically compatible with the anode.

Table 1—Typical Performance Data for Commonly Used Impressed Current and Galvanic Anodes

Type of Anode	A-h/kg[A]	A-h/lb[A]
Impressed Current Anodes		
Linseed oil-impregnated graphite	13,000 to 15,000 (14,000)	6,000 to 7,000 (6,500)
High-silicon cast iron with chromium	18,000 to 24,000 (19,000)	8,000 to 11,000 (8,500)
Galvanic Anodes		
Magnesium	1,000 to 1,100 (1,000)	450 to 500 (450)
Aluminum[B]	400 to 2,000 (1,300)	200 to 950 (600)
Zinc	700 to 800 (800)	300 to 350 (350)

[A] Values in parentheses are commonly used in design calculations.
[B] Caution: The performance and efficiency of aluminum anodes vary with the alloy, and with certain alloys they vary with the heat treatment.

Note: Anode efficiencies vary widely, particularly for galvanic anodes. Factors influencing this include anode locations, position and surface area, water composition and temperature, and selective electrochemical attack.

4.2.2 Impressed current systems have greater flexibility if high current demand is anticipated.

4.2.2.1 Impressed current systems can be used in any water, but are usually the most practical in high-resistivity waters where an appreciable amount of current is required to achieve protection.

4.2.2.2 Impressed current systems typically require more monitoring and maintenance than galvanic anodes.

4.2.2.3 Automatic potential rectifier systems decrease the likelihood of underprotection or the excessive use of power and coating disbondment resulting from overprotection (see Paragraph 4.3.2).

4.2.2.4 Impressed current anodes should be provided with individual lead wires to the rectifier for control and measurement of current output from each individual anode.

4.2.3 Galvanic anodes are commonly used when electrical power is not feasible to use or is not available and may be preferred for low-current-requirement installations, even if electrical power is available. The effects of the produced fluid chemistry on the performance of a galvanic anode should be considered. The pH of produced fluids containing dissolved CO_2 and/or H_2S can be lowered to acidic levels that can attack zinc, aluminum, or magnesium. Large concentrations of H_2S may also react with the anode to alter its performance. The possibility of the presence of other impurities, such as amines, emulsions, or even small quantities of mercury, should be considered. Consideration should be given to effects of the various oilfield treating chemicals and workover fluids that may flow through the vessel being protected. Residual acids from stimulation treatments may cause severe attack on all galvanic anodes. The potential effects of demulsifiers, scale and corrosion inhibitors, drilling mud, and other material that might be added to production should be considered.

4.2.4 Galvanic anode materials most commonly used are aluminum, magnesium, and zinc alloys. The

composition, resistivity, and temperature of the electrolyte largely dictate which material is most suitable.

4.2.4.1 Aluminum alloys are commonly used in brines with resistivities below 100 ohm-cm. Aluminum's lower driving potential, compared with that of magnesium, leads to lower current output and longer life. Generally, more than one aluminum anode is required to provide current output equivalent to that of magnesium.

4.2.4.1.1 Consideration must be given to selection of the proper aluminum alloy (pure aluminum should not be used as an anode) to ensure adequate protection at optimum economy. The electrochemical properties (potential and current capacity) of aluminum anodes are dependent on the alloy, the electrolyte composition, and the electrolyte temperature. Temperatures above 49°C (120°F) can reduce the current capacity of aluminum anodes.

4.2.4.2 Magnesium alloys are commonly used in brines with resistivities above 100 ohm-cm. Magnesium's higher driving potential, compared with that of aluminum, leads to higher current output and shorter life. If magnesium anodes are used in low-resistivity electrolytes, current output should be controlled by resistors in the external circuits.

4.2.4.3 Zinc alloys are not commonly used in vessels because they may show a decrease in potential with increase in electrolyte temperature and may possibly become cathodic to steel at temperatures in the range of 54°C (130°F).

4.3 Internally Coated Vessels

4.3.1 Cathodic protection mitigates corrosion at coating holidays.

4.3.2 Excessive cathodic protection potentials may cause coating damage. Generally, at polarized potentials more negative than -1.05 to -1.10 V (copper/copper sulfate reference electrode [CSE]), excessive hydrogen can be formed and cause coating damage.

Section 5: Anode Installation

5.1 Vertical Suspension

5.1.1 Anodes must be spaced to distribute current uniformly to the vessel walls and bottom, and at a depth that assures that some anodes are submerged regardless of water level. Either type of anode (galvanic or impressed current) can be installed in this manner.

5.1.2 Impressed current anodes must be suspended from a suitable hanger (deck mount), properly isolated to prevent grounding of the lead wire to the vessel.

5.1.3 Galvanic anodes should be electrically isolated where current monitoring is contemplated.

5.2 Internally Supported

5.2.1 Galvanic anodes may be placed on supports on the vessel floor and isolated from the vessel. Anode leads can be brought out through watertight connections welded in the clean-out plate and connected back to the vessel wall. Shunts and resistors may then be installed in the external anode leads to monitor or regulate anode performance.

5.2.2 Alternatively, galvanic anodes may be bolted or welded to brackets permanently affixed to the vessel surface. However, this type of installation does not allow any method for monitoring the anode output or knowledge of anode consumption other than by visual inspection.

5.3 Vessel Wall Placement

5.3.1 Galvanic or impressed current anodes can be installed horizontally in compartmented vessels through mountings welded into the side of the vessel.

5.3.2 Anode heads for installation in nipples are most commonly made of a nonmetallic material designed to withstand the temperature and pressure within the vessel. The shield portion of the head must be of sufficient length to prevent anode grounding to the vessel or excessive current discharge close to the anode entrance port. In all cases, actual lengths of the nipple and the anode head, as well as the positioning of the nipple on the curved surfaces, must be related in design in order to prevent this undesired current discharge. Anode entrance ports should be installed during fabrication of vessels. Materials and welding procedures should be consistent with primary vessel design.

5.3.3 When steel anode mounting heads are considered, they must be properly designed to provide isolation between the anode mounting head and the vessel.

Section 6: Reference Electrode Entrance

6.1 Methods

6.1.1 Entrance ports for insertion of reference electrodes should be installed in the vessel at the same time as the anode entrance ports.

6.1.2 In compartmented vessels, reference electrode ports must be installed as far from the anodes as possible in order to obtain potentials representative of the steel surface. These ports are usually 2.5-cm (1-in.) diameter connections welded into the vessel wall in each compartment and equipped with a 2.5-cm (1-in.) full-opening valve so that the reference electrode may be inserted into the vessel.

6.1.3 In vertical cylindrical vessels equipped with roof-type hatches, the reference electrode may be inserted through the hatches. If this is anticipated, the anodes should be installed at the maximum distance from the hatch.

Section 7: Criteria for Protection

7.1 Steel-to-Water Potential

7.1.1 The presence of a protective potential should be verified after the vessel is polarized. Polarization normally occurs within two weeks in bare vessels and within a few minutes in coated vessels.

7.1.2 The steel surface is protected if the surface is more negative than -0.85 V vs a CSE (-0.80 V vs a Ag/AgCl electrode). However, if the fluid contains sulfides/H_2S, a protection potential of -0.95 V vs a CSE (-0.90 V vs a Ag/AgCl electrode) is required to achieve protection. Polarization and protection of the vessel are generally assured if the potential immediately after switching the cathodic protection current off is equal to or more negative than these values.

7.2 Coupon Tests

7.2.1 Coupons may be installed to monitor the effectiveness of cathodic protection. Coupons must be electrically connected to the vessel wall. Coupon weight-loss measurements are used to determine the effectiveness of protection.

Section 8: Monitoring, Records, and Maintenance

8.1 Monitoring

8.1.1 Operating personnel should visually inspect surfaces under cathodic protection whenever vessels are opened. In addition, thickness measurements of vessel walls should be taken to determine cathodic protection effectiveness.

8.1.2 Potential and/or anode current output surveys should be made monthly after initial installation of cathodic protection equipment until current requirements are established. After current requirements are established, quarterly surveys are usually adequate.

8.1.2.1 Care must be taken in placing the reference electrode into the treating vessel. For potential measurements, the electrode must be as far from the anodes as possible. In pressure vessels, the electrode is "inserted" (introduced into the vessel against existing vessel pressure) through a full-opening valve installed in the vessel for that purpose (see Paragraph 6.1.2). Reference electrodes manufactured to withstand pressure and temperature can also be permanently installed.

8.1.2.2 Contamination of the reference electrode with oil or sediments such as iron sulfide must be avoided. A salt bridge may be used to prevent contamination of the reference electrode.[1]

8.1.2.3 Location of the reference cell near an anode may indicate a higher potential than elsewhere in the vessel.

8.1.2.4 Water levels lower than normal may result in higher potentials because of increased current density.

8.1.3 Galvanic anodes are sometimes installed without shunts. However, if the cathodic protection system cannot be monitored by potential measurements, shunts of known resistance (normally 0.01 ohm) should be installed. Current measurements can be obtained by measurement of the potential across the shunt of known resistance.

8.2 Records

8.2.1 Record keeping is vital to effective maintenance of cathodic protection systems (and thus continued protection of the vessels).

8.2.2 Monthly records should be kept for all impressed current anode installations. The records should show DC voltage and amperage readings for each anode.

8.2.3 Quarterly records should be kept for galvanic anode installations. The records should show current readings on galvanic anodes.

8.3 Maintenance

8.3.1 Malfunctions should be repaired promptly to ensure desired performance. Corrosion damage can occur whenever the potentials are less negative than the values indicated in Paragraph 7.1.2.

8.3.2 Anodes must be replaced periodically as they are consumed. Zero current readings usually indicate deteriorated anodes, broken anode cables, malfunctioning rheostats, or loose connections in the circuit. Low current readings in galvanic systems may indicate similar problems.

8.3.3 Zero reported voltage or current readings may occur because of various malfunctions. A rectifier troubleshooting guide should be consulted when such malfunctions occur.

8.3.4 During maintenance of the vessel, visual examination of the vessel surfaces should be conducted to verify the effectiveness of the cathodic protection system. Deterioration of the surface of the vessel and/or interior welds indicates the need for relocation of the anodes, increasing quantity of anodes, or an appraisal of the cathodic protection system.

Section 9: Safety

9.1 Precautions must be taken to avoid sparks in the presence of flammable substances and explosive gas mixtures that may be present around oil-treating vessels.

9.2 The cable-to-anode connections in impressed current systems shall never be disconnected, nor shall the anode be removed, while the rectifier is in operation.

9.3 Usual precautions to prevent fire or explosion must be taken before a cathodic protection system can be installed or repaired in a vessel handling water mixed with oil or gas.

9.4 CAUTION: Usual precautions must be taken when monitoring or performing maintenance on cathodic protection systems in vessels containing H_2S. If the anodes in such vessels are to be removed for replacement or inspection, a mask approved for use in H_2S environments must be worn. Additional information on the toxicity of H_2S can be obtained from the Manufacturing Chemists' Association's[(2)] "Chemical Safety Data Sheet SD-36,"[2] and from *Dangerous Properties of Industrial Materials*.[3]

9.5 The rectifier case, external AC disconnect switch box, and any related metallic equipment must be grounded.

9.6 Depending on the area classification, explosion-proof rectifiers and electrical devices may be required.

9.7 Special gaskets capable of withstanding high temperatures should be used to mount anodes in fired vessels, particularly if the gaskets are located near the fire tubes.

9.8 Equipment, wiring, enclosures, and installation of cathodic protection systems must comply with all applicable codes, including OSHA regulations.

References

1. NACE Publication 35201 (latest revision), "Report on the Application and Interpretation of Data from External Coupons Used in the Evaluation of Cathodically Protected Metallic Structures" (Houston, TX: NACE).

2. "Chemical Data Safety Sheet SD-36" (latest revision) (Washington, DC: Manufacturing Chemists' Association).

3. N. Irving Sax, Dangerous Properties of Industrial Materials (New York, NY: Reinhold Book Corp., 1984).

[(2)] Manufacturing Chemists' Association, 1825 Connecticut Ave. NW, Washington, DC 20009.