NACE SP0186-2007
(formerly RP0186-2001)
Item No. 21031

Standard Practice

Application of Cathodic Protection for External Surfaces of Steel Well Casings

Reaffirmed 2007-03-10
Reaffirmed 2001-09-20
Reaffirmed September 1984
Approved March 1986
NACE International
1440 South Creek Drive
Houston, TX 77084-4906
+1 281/228-6200

ISBN:1-57590-134-X

Foreword

Oil and gas wells represent a large capital investment. It is imperative that corrosion of well casings be controlled to prevent loss of oil and gas, environmental damage, and personnel hazards, and in order to ensure economical depletion of oil and gas reserves.

This NACE International standard practice identifies procedures to determine the need for cathodic protection (CP) and the current requirements to achieve CP of well casings associated with oil and gas production and gas storage. It also outlines practices for the design and installation of CP systems and for their operation and maintenance. The purpose of this standard is to ensure more effective prevention of corrosion of well casings by making available reliable information about CP as it relates to well casings. This standard is intended for use by corrosion engineers in oil and gas production, especially those concerned with the CP of steel well casings.

This standard was originally prepared in 1986 by Unit Committee T-1E on Cathodic Protection and Task Group (TG) T-1J-2, a component of Unit Committee T-1J on Storage Wells. It was reaffirmed in 1994 by Unit Committee T-1E, and in 2001 and 2007 by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings. The STG membership consists of representatives from oil and gas producing and storage companies, equipment manufacturers, consulting firms, and CP service companies. Included in the membership are persons involved in design, consulting, research, construction, maintenance, and manufacturing and supply of materials, all of whom are concerned with the establishment and maintenance of cathodic protection systems used with well casings. This standard is issued by NACE under the auspices of STG 35.

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. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

NACE International

Standard Practice

Application of Cathodic Protection for External Surfaces of Steel Well Casings

Contents

Section 1: General

1.1 This standard presents acknowledged procedures for the control of external corrosion of steel well casings by applying CP. This standard is intended to be a guide for establishing minimum requirements for corrosion control when CP is practical and cost-effective.

1.2 This standard does not designate practices for specific situations. The complexity of some casing spacing, subsurface proximity to other casings, and environmental conditions preclude standardizing the application of CP. Deviation from this standard may be warranted in specific situations, provided those in responsible charge can demonstrate that the objectives expressed in this standard have been achieved.

1.3 This standard does not include corrosion control methods based on chemical control of the environment.

1.4 This standard applies only to well casing exteriors and not to internal corrosion, or to corrosion of other surface or downhole equipment.

1.5 The provisions of this standard should be applied under the direction of competent persons knowledgeable in the physical sciences, principles of engineering, and mathematics. They may have acquired knowledge by professional education and related practical experience and should be qualified to practice corrosion control for well casings by the use of CP. Such persons may be registered professional engineers recognized as being qualified as corrosion specialists in the appropriate fields of corrosion control by NACE International. Their professional activities should include suitable experience in well casing corrosion control practices.

Section 2: Definitions[1]

Alternating Current (AC): Current whose direction changes with time.

Ampere: Unit of current that is one coulomb per second.

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.

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Casing Potential Profile: Voltage (IR) drop and current direction versus casing depth is plotted. Amount of current is determined from the IR drop and casing resistance. (See nonmandatory Appendix A.)

Casing-to-Electrolyte: See *Structure-to-Electrolyte Potential.*

Casing-to-Reference Electrode: See *Structure-to-Electrolyte Potential.*

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.

Cement: Cement slurry fills the space between the casing and the sides of the wellbore to a predetermined height above the bottom of the well.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

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

Counterpoise: A conductor or system of conductors arranged beneath a power line, located on, above, or most frequently, below the surface of the earth and connected to the footings of the towers or poles supporting the power line.

Coupling (or Collar): Well casing joint connector.

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

---

[1] Definitions in this section are those presented in the *NACE Glossary of Corrosion-Related Terms* and those that reflect the common usage among practicing corrosion control personnel. In many cases, in the interest of brevity and practicality, the strict scientific definitions are abbreviated or paraphrased.

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

Dielectric Coating: A coating that does not conduct electricity.

Direct Current (DC): Current whose direction does not change with time.

Drainage: Conduction of electric current from an underground or submerged metallic structure by means of a metallic conductor.

E-log-I: A test that indicates the cathodic protection current required by a slope change on the cathodic polarization diagram. (Refer to nonmandatory Appendix B.)

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

Electric Log: A survey taken in the open borehole of a well to determine the lateral formation resistivity.

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 a buried or submerged metallic structure, including the moisture and other chemicals contained therein.

Electroosmotic Effect: The effects of the movements in an electric field of liquid with respect to colloidal particles immobilized in a porous diaphragm or a single capillary tube.

Fault Current: A current that flows from one conductor to ground or to another conductor due to an abnormal connection (including an arc) between the two. A fault current flowing to the ground may be called a ground fault current.

Field: A group of wells in close physical proximity, usually considered a unit when applying cathodic protection. It may be an oil or natural gas production field or a natural gas storage field.

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

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.

Gamma Ray Neutron Log: Gamma ray is a measurement of the natural radioactivity of a formation. Neutron log is used for delineation of porous formations. Data are used to identify the formations in the earth.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.

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.)

Instant-Off Potential: The polarized half-cell potential of an electrode taken immediately after the cathodic protection current is stopped, which closely approximates the potential without IR drop (i.e., the polarized potential) when the current was on.

Interference Bond: An intentional metallic connection, between metallic systems in contact with a common electrolyte, designed to control electrical current interchange between the systems.

Intermediate Casing: A string of casing set to protect a section of hole and to allow drilling to continue to a greater depth. Also called protection casing string.

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

Isolation: See *Electrical Isolation*.

Lithology: Rock formations traversed by well casing.

Long-Line Current: Current through the earth between an anodic and a cathodic area that returns along an underground metallic structure.

Mutual Interference: An electrical DC interference on a well originating from within the cathodic protection system of several wells and structures, such as several DC power sources for a group of wells.

Native State Potential: The potential with zero groundbed current.

Negative Return: A point of connection between the cathodic protection negative cable and the protected structure.

Ohm: A resistance that passes one ampere of current when a one-volt potential is applied.

Packaged Anode: An anode that, when supplied, is already surrounded by a selected conductive backfill material.

Photovoltaic: Generation of an electromotive force when radiant energy falls on the boundary between two dissimilar materials.

Pipe-to-Soil Potential: See *Structure-to-Electrolyte Potential*.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface. In this standard, polarization is considered to be the change of potential of a metal surface resulting from current to or from an electrolyte.

Potential Profile Log: See *Casing Potential Profile*.

Production Casing: Casing that extends through the surface and intermediate casings, sometimes only to the tip of the zone but almost always through the producing or storing zone.

Rectifier: A device to convert AC power to DC power.

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.

Resistivity: (1) The resistance per unit length of a substance with uniform cross section. (2) A measure of the ability of an electrolyte (e.g., soil) to resist the flow of electric charge (e.g., cathodic protection current). Resistivity data are used to design a groundbed for a cathodic protection system.

Right-of-Way: Right of passage, as over another's property.

Self-Interference: See *Mutual Interference*.

Shunt: A precise resistor with known resistance in an electrical circuit used to measure a voltage (IR) drop, which is used to calculate the amount of current in amperes.

Soil Resistivity: A measure of the ability of a soil or formation to conduct electricity expressed in units of ohm-centimeters or ohm-meters. Data are used to design a groundbed for a cathodic protection system.

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and the electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Structure-to-Structure Potential: The potential difference between metallic structures, or sections of the same structure, in a common electrolyte.

Surface Casing: A casing string extending from the surface to a depth great enough to keep surface waters and loose earth from entering the well.

Surface Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection less than 15 m (50 ft) in depth for the anodes.

Tafel Plot, Tafel Diagram, Tafel Line: A plot of the relationship between the change in potential (E) and the logarithm of the current density (log *i*) of an electrode when it is polarized in both the anodic and cathodic directions from its open-circuit potential.

Tafel Segment: That portion of the Tafel plot that appears as a straight line when current is plotted on the logarithmic scale and potential change is plotted on the linear scale. The beginning of the Tafel segment is that point on the curve at which the current-potential relationship follows the straight line with increasing current increments and deviates from the straight line with decreasing current increments.

Tafel Slope: The slope of the straight-line portion of the E log *i* curve on a Tafel plot. (The straight-line portion usually occurs at more than 50 mV from the open-circuit potential.)

Test Wire: An insulated wire attached to a structure (usually buried) such as a pipeline and brought to a terminal convenient for making electrical tests to evaluate cathodic protection.

Tubing: A pipe inside the production casing through which oil is pumped, or liquid is removed from the natural gas storage zone.

Union (Isolating): See *Electrical Isolation*.

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

Well: A steel-cased hole associated with the production and storage of oil or gas.

Wellbore *(also called bore hole)*: A hole drilled into the earth for the installation of a deep groundbed system.

Wellhead: Valves and other aboveground fittings electrically connected to the production, surface, and intermediate casings. May be called a "christmas tree" when referring to oil and natural gas production and storage wells.

Well Casing: See *Production Casing*, *Intermediate Casing*, and *Surface Casing*.

Section 3: Determination of Need for CP

3.1 Introduction

3.1.1 The purpose of this section is to indicate those factors that should be considered in determining whether a well casing requires CP.

3.1.2 Metallic structures in contact with soil or submerged under water are subject to corrosion. Adequate procedures should be adopted to ensure that corrosion is not affecting safe and economical operation of well casings.

3.2 The decisions governing the need for CP of well casings shall be based on data obtained from corrosion surveys, operating records, prior tests with similar systems in similar environments, and on a study of design specifications and engineering, operating, and economic requirements.

3.2.1 The usual procedures for predicting the probability and rate of corrosion of a particular metallic casing system are as follows:

(a) The corrosion history of the well casing in question or of other systems of the same material in the same general area or in similar environments should be studied. The history should include cumulative leak frequency and downhole data obtained from workover (reconditioning) records.

(b) The environment surrounding a well casing should be studied. Once the nature of the environment has been determined, the probable corrosiveness can be estimated by referring to actual corrosion experience on similar well casings in similar environmental conditions. It should be remembered that formation water changes caused by production or injection methods may be contributing factors. One source of environmental data is the formation resistivity logs run on wells being investigated and on surrounding wells.

(c) The casing should be mechanically or electrically inspected for evidence of corrosion. The condition of the casing system should be carefully determined and recorded. (See nonmandatory Appendix C.)

(d) The casing should be inspected to determine whether there are any anodic areas. A well casing potential profile tool is commonly used for these investigations. (See nonmandatory Appendix A.)

(e) Maintenance records detailing leak locations and wall thickness surveys, which can be used as a guide for locating areas of maximum corrosion, should be reviewed.

(f) Statistical treatments of available leak data should be considered.

(g) The results of pressure testing should be reviewed; under certain conditions, this may help determine whether corrosion has occurred.

(h) When the well casing is pulled, it should be visually inspected.

(i) Close communication should be maintained with those responsible for the workover of a well.

3.2.2 Environmental and physical factors governing the need for CP are as follows:

3.2.2.1 The nature or constituents of the product being produced or stored.

3.2.2.2 Location of the well casing system in a sparsely or densely populated area and the frequency of visits by personnel.

3.2.2.3 Location of the well casing system as related to other facilities.

3.2.2.4 Influence of DC sources foreign to the system.

3.2.2.5 The introduction of secondary or tertiary recovery systems, which can sometimes increase corrosion rates on the backside of a well casing.

3.2.3 Economic factors

3.2.3.1 Costs of maintaining the well casing in service for its expected life may include repairing corrosion leaks, reconditioning, or replacing all or portions of the system.

3.2.3.2 In addition to the direct costs that result from corrosion, contingent costs may be incurred. The more common types of contingent costs are:

(a) Public liability claims.

(b) Property damage claims.

(c) Damage to natural facilities, such as municipal or irrigation water supplies, forests, parks, and scenic areas.

(d) Cost of cleanup of product lost to surroundings.

(e) Cost of individual casing workover(s) as related to corrosion leak(s).

(f) Plant shutdown and start-up costs.

(g) Loss of deliverability because of possible permanent formation damage caused by casing leak(s).

(h) Cost of lost product.

(i) Loss of revenue through interruption of service.

(j) Loss of contracts or good will through interruption of service.

(k) Loss of reclamation or salvage value of well casing.

(l) Loss of well casing, rendering well unusable for production or injection purposes.

3.2.3.3 The usual costs for protecting well casings are the costs of installing and operating CP. Other corrosion control costs may include:

(a) Inhibitors and bactericides used in drilling fluids.

(b) Corrosion-resistant materials.

(c) Cement for zones known to be corrosive.

(d) Electrical isolation to limit possible foreign current discharge from casings and to ensure that CP currents are applied to the well casing.

(e) Dielectric coating on the outer surface of casing.

Section 4: Criterion for CP and Current Requirements

4.1 Introduction

4.1.1 The determination of design current requirements depends, in part, on prior experience with similar structures or environments in which the method has been used successfully. The first-time user is strongly urged to consult a person experienced in well casing CP before finalizing a design.

4.1.2 Certain methods have been developed through laboratory experiment, or have been derived empirically by evaluating data from successful CP systems. These methods are presented in Paragraph 4.3 and can be used to assist with the design process; they are not intended to be a comprehensive or limiting list.

4.2 Criterion for CP

4.2.1 The CP current applied to the well casing shall be considered adequate when measurements indicate that a net flow of current to the casing has eliminated all anodic areas.

4.3 Methods of Determining Design Current Requirements

4.3.1 A profile tool is a device used to measure a voltage (IR) drop across a portion of well casing in service by electrically isolating two sets of contacts from each other. The voltage readings are used to indicate the magnitude and direction of the current flow in the casing. Details of the test method and interpretation of the data are given in Appendix A.

4.3.2 Average current density (mA/m^2) may be used to calculate the quantity of CP current required to prevent external corrosion. The current density used should be dictated by the downhole completion practice and formations (e.g., cementing practices, formation resistivities, water salinity, etc.) encountered in a given well. Current densities usually vary from 10 to 200 mA/m^2.

4.3.3 Mathematical modeling may also be used to determine design current requirements. The effect of applied CP current downhole can be calculated from electrical measurements at the wellhead. The applied voltage and current distribution can be calculated as a function of well depth. Usually, a downhole potential criterion is established as the accepted indication of protection. Several calculation methods are available, and others are being developed.

4.3.3.1 One method of mathematical modeling uses a modified attenuation equation. The native state potential is measured and recorded. It also requires well casing data and current drain measurements made after polarization of the well.

4.3.3.2 Another method uses formation resistivity data to establish a potential attenuation curve for a casing to which CP has been applied.

4.3.3.3 A third method models the well casing by a computerized equivalent electrical circuit incorporating resistivity profiles, nonlinear polarization characteristics, and the well casing data.

4.3.4 E-log-I method

4.3.4.1 The principle behind the E-log-I method is that when current is impressed through the earth onto a metallic well casing, the potential between the well casing and reference electrode is shifted.

The potential shift for a given current level depends on the following factors:

(a) The length of time the current is applied.

(b) Current density, which is affected by factors such as well depth, casing sizes, and cement.

(c) Properties of the electrolyte.

4.3.4.2 As increasing levels of current are impressed, polarization begins on the surface of the casing. The E-log-I data are plotted to enable selection of a current level at which polarization begins. (Details of the test method and interpretation of the data are given in Appendix B.)

4.4 Methods of Evaluating Effectiveness

4.4.1 A combination of procedures is always advised for evaluating the effectiveness of CP.

Bibliography for Section 4

Ballou, J.K., F.W. Schremp. "Cathodic Protection of Oil Well Casings at Kettleman Hills, California." Corrosion 13, 8 (1957): pp. 507-514.

Bates, R.D., B.W. Bradley. "Cathodic Protection of Oil Well Casings." Materials Protection 5, 7 (1966): pp. 33-35.

Battle, J.L. "Corrosion of Casing in Oil and Gas Wells." Corrosion 9, 9 (1953): pp. 313-320.

Blount, F.E., P.W. Bolmer. "Feasibility Studies of Cathodic Protection of Deep Well External Casing Surfaces." Materials Protection 1, 8 (1962): pp. 10-23.

Dabkowski, J. "Assessing the Cathodic Protection Levels of Well Casings." Final Report PRCI Project, 1983, pp. 106-151.

Dabkowski, J. "Monitoring Cathodic Protection of Well Casings." American Gas Association Conference Proceedings, Operating Section, held May 5-7, 1980. Salt Lake City, UT: AGA, 1980, p. T-411.

Doremus, E.P., F.B. Thorn. "Cathodic Protection Stops Casing Corrosion in Fullerton Field." Oil & Gas Journal 67, 31 (1969): pp. 123-124, 127-128.

Hamlin, A.W. "Cathodic Protection of Gas Storage Wells." West Virginia University Technical Bulletin No. 11-1, 1979, pp. 157-161.

Haycock, E.W. "Current Requirement for Cathodic Protection of Well Casing." Corrosion 13, 11 (1957): pp. 767-773.

Heinrichs, H.J., W.O. Ingram, B.G. Schellenberger. "Cathodic Protection Requirements for Well Casings." Journal of Canadian Petroleum Technology 17, 3 (1978): pp. 54-61.

Hodge, R.E. "Cathodic Protection of Natural Gas Storage Wells." Gas 44, 3 (1968): pp. 63-66.

Husock, B. "Methods for Determining Current Requirements for Cathodic Protection of Well Casings—A Review." Materials Performance 23, 1 (1984): pp. 39-44.

Ingram W.O., B.G. Schellenberger. "Deep Well Casing Cathodic Protection Requirements." Journal of Canadian Petroleum Technology 18, 2 (1979): pp. 39-43.

Kirklen, C.A. "Effectiveness of Well Casing Cathodic Protection." Journal of Petroleum Technology 28 (1974): pp. 724-730.

Pace, F.A., S.E. Krupick. "Reduction of Leaks by Using Cathodic Protection—East Texas Field." Journal of Petroleum Technology 34, 7 (1982): pp. 1437-1442.

Paver, E.C. "Cathodic Protection of Storage Well Casings." Gas Age 32, 12 (1965): pp. 22-27.

Phillips, C.S. "External Protection of Well Casings." West Virginia University Technical Bulletin No. 113, 1974, pp. 581-588.

Riordan, M.A., R.P. Steck. "Well Casing as an Electrochemical Network in Cathodic Protection Design." Materials Protection 2, 7 (1963): p. 58.

Roberson, G.R., F.W. Schremp. "Optimizing the Distribution of Cathodic Protection Current." Journal of Petroleum Technology 22, 7 (1970): pp. 812-816.

Schremp, F.W. "Cathodic Protection of Well Casings Offshore." Journal of Petroleum Technology 34, 8 (1982): p. 1863.

Schremp, F.W., L.E. Newton. "Use of Wellhead Electrical Measurements to Calculate Bottomhole Cathodic Protection of Well Casings." CORROSION/79, paper No. 63. Houston, TX: NACE International, 1979.

Titterington, Y.W. "Cathodic Protection of Well Casing." West Virginia University Technical Bulletin No. 48, 1957, pp. 302-312.

Toncre, A.C. "Cathodic Protection of Well Casings in Saudi Arabia." Metallic Corrosion 7 (1981): pp. 6-11.

Unz, M. "Cathodic Protection of Borehole Casing." Materials Performance 14, 10 (1975): pp. 40-47.

Section 5: Design of CP Systems for Well Casings

5.1 Introduction

5.1.1 This section presents recommended procedures for designing CP systems that effectively control corrosion of well casings in contact with the earth. The design should satisfy the criterion in Section 4 and be reliable for the intended operating life of the system.

5.1.2 CP for pipelines is considered separately from well protection when applicable.

5.2 Objectives of CP System Design

5.2.1 Enable application of sufficient protective current to the well casings to meet the criterion for CP.

5.2.2 Minimize the stray current to foreign underground structures. (See Section 7.)

5.2.3 Design a groundbed with a lifetime that is commensurate with the required life of the protected structure.

5.2.4 Provide for periodic maintenance of the groundbed.

5.2.5 Provide a power source and groundbed with sufficient capacity to include connecting pipelines and other structures as required.

5.3 Considerations in the Design of CP Systems

5.3.1 CP applied to the well casings and the connecting pipelines and structures may be a source of mutual interference. (Refer to Section 7.)

5.3.2 Electrical grounding procedure requirements should be considered in the CP design.

5.3.3 In designing a CP system for well casings, the following should be considered:

5.3.3.1 Availability of AC power should be determined.

5.3.3.2 The proposed installation site should be investigated for any hazardous conditions.

5.3.3.3 The AC power source for the CP rectifier should be a suitable distance from the well structure to ensure a safe working area.

5.3.3.4 Materials and installation practices that conform to applicable codes (e.g., National Electrical Manufacturers Association [NEMA][(2)] Standards, National Electrical Code [NEC],[(3)] and practices of NACE International) should be specified.

5.3.3.5 The CP system should be selected and designed for optimum economies of installation, maintenance, and operation.

5.3.3.6 Materials and installation practices that ensure safe and dependable operation throughout the intended service life of the CP system should be specified.

5.3.3.7 A system for optimum currents should be selected. Excessive current can be detrimental to buried or submerged metallic structures.

5.3.3.8 The current requirement data for pipelines connected to wells should be studied so that the groundbeds may be placed in the proper locations. This allows appropriate distribution of current to wells and pipelines.

5.3.3.9 Electrical interference from foreign sources should be investigated and the results included as a design consideration. (See Section 7.)

5.4 Considerations Influencing Location of Anodes

5.4.1 The anode that will be closest to a well should be placed at a distance determined by testing or accepted empirical means.

5.4.2 Plans for long- and short-term additions or changes in buried physical structures.

5.4.3 Location of pipelines connected to wells.

(2) National Electrical Manufacturers Association (NEMA), 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209.
(3) National Electrical Code (NEC), National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

5.4.4 Pipelines used as a negative return and those electrically isolated.

5.4.5 Soil resistivity.

5.4.6 Use of surface or deep vertical type of groundbed.

5.4.7 Location of foreign structures.

5.4.8 Placement where likelihood of physical disturbance or damage is minimal.

5.5 Types of CP Systems for Well Casings

5.5.1 Impressed current system

5.5.1.1 Surface groundbed

5.5.1.2 Deep groundbed

5.5.2 Galvanic anode system

5.6 Considerations in the Selection of the Type of CP System

5.6.1 Current requirements

5.6.1.1 The total casing surface area to receive CP, including surface casings and that portion of intermediate and production casing that is to receive protection.

5.6.2 Soil resistivity

5.6.2.1 Resistivity and installation space availability influence the choice of a surface or deep groundbed installation. High-resistivity formations that restrict the flow of current to the casing may necessitate placement of anodes below such formations.

5.6.2.1.1 Resistivity to a 15-m (50-ft) depth for a surface groundbed may be determined by surface measurements or experience.

5.6.2.1.2 Resistivity for depths greater than 15 m (50 ft) for a deep groundbed may be determined by surface measurement, formation resistivity log, or experience.

5.6.3 Future drilling of wells in the area of CP influence.

5.6.4 Future development of the right-of-way area and extensions to the pipeline system connected to wells jointly protected by the same power source and groundbed.

5.6.5 The cost of installation, operation, and maintenance.

5.6.6 Physical space available and condition of land surface for ease of facility installation, ingress, and egress.

5.6.7 Proximity of foreign structures.

5.6.8 Ability to procure easement.

5.6.9 Interference effect.

5.6.10 Power source availability.

5.7 Factors Determining Anode Current Output, Operating Life, and Efficiency

5.7.1 Various anode materials have different rates of deterioration when discharging a given current density from the anode surface in a specific environment. For a given current output, the anode life depends on the anode and backfill materials and the number of anodes in the CP system. Anode performance data may be used to calculate the probable deterioration rate.

5.7.2 The resistance to electrolyte of the anode system may be calculated from available data. Formulas and graphs relating to these factors are available.

5.7.3 The use of a special backfill material with impressed current anodes lengthens their useful life and reduces the effective anode-to-earth electrical resistance. The most common backfill materials are metallurgical coke, calcined petroleum coke, and natural or manufactured graphite.

5.7.4 Entrapment of gas generated by the anodic reaction can impair the ability of the impressed current groundbed to deliver the required current. Suitable provision should be made for venting the anodes, particularly in a deep groundbed. Increasing the number of anodes may reduce gas blockage by reducing current discharge from each anode.

5.7.5 Electroosmotic effects could impair the ability of the impressed current groundbed to deliver the required current. Suitable provisions should be made to ensure adequate moisture around the anodes. Increasing the number of impressed current anodes may reduce electroosmotic effects.

5.7.6 Special applications such as deep groundbeds require careful selection of cables and wires. Refer to NACE SP0572.[1]

5.8 Impressed Current System Design Considerations

5.8.1 Groundbed location and total current required should be determined.

5.8.2 A deep groundbed may be used when lithology prevents equitable distribution of current to the total depth of the well casing. Placing anodes in relatively low-resistivity shallow formations compared with deeper formations may concentrate excessive current on upper portions of the well casing and deprive the deeper portions of sufficient current. Refer to NACE SP0572.

5.8.3 Placement of groundbeds too close to a well casing may prevent flow of sufficient current to a lower depth. Increasing total current may create interference with other wells and structures.

5.8.4 The performance of vertically or horizontally placed anodes can be affected by their spacing. In a soil of a given resistivity, the output of an impressed current groundbed may be improved by increasing the space between anodes, assuming the additional cable resistance is considered.

5.8.5 DC power sources that can be used:

5.8.5.1 Rectifier units to convert AC to DC power.

5.8.5.2 Thermoelectric generators.

5.8.5.3 Photovoltaic power systems.

5.8.5.4 Wind- or power-driven generators or alternators with rectification.

5.9 Galvanic Anode System Design Considerations

5.9.1 Galvanic anodes have limited use for CP of well casings.

5.10 Design Factors in Applying CP to More than One Well

5.10.1 Several wells may be cathodically protected as a group. When applying CP, the wells should be treated as a unit, along with associated pipelines or structures, using one or more power sources and groundbeds. Care must be taken to ensure adequate current distribution throughout the length of each well.

5.10.1.1 Well casings in a group may vary in length.

5.10.1.2 Well spacing may vary.

5.10.1.3 Intermediate casings may vary in length.

5.10.1.4 Wells with identical completion procedures and equal lengths of casing may have different current requirements.

5.10.2 The current requirements and electrical resistances of any connecting pipeline, when used as a negative return to a rectifier, can limit the amount of current reaching the well casings.

5.10.3 If detrimental electrical interference is encountered, each CP system must be designed to counteract the effects.

5.10.4 CP design varies regarding the physical field parameters. The most effective design considers:

5.10.4.1 Total amount of current required for casings and other structures.

5.10.4.2 Soil resistivity for installation of anodes.

5.10.4.3 Location of well casing with respect to pipelines and other structures.

5.10.4.4 The individual current demand of each well.

5.10.5 Typical CP design options

5.10.5.1 One DC power source and one groundbed for one or several wells.

5.10.5.2 One DC power source and more than one groundbed for several wells.

5.10.5.3 More than one DC power source and one groundbed for several wells.

5.10.6 Perimeter or isolated wells may require a separate CP system.

Bibliography for Section 5

Diffenderfer, R.B. "Cathodic Protection System Design." West Virginia University Technical Bulletin No. 4-1, 1976, pp. 593-603.

Doniquian, T.M. "Pulse Rectifier." Oil & Gas Journal (July 1982): pp. 221-229.

Dwight, H.B. "Calculations of Resistance to Ground." Electrical Engineering 55 (1936): pp. 1319-1328. Also in Materials Performance 22, 4 (1983): pp. 23-33.

NACE Publication 2B160. "Use of High Silicon Cast Iron for Anodes." Houston, TX: NACE International, 1960.

NACE Publication TPC 5. Corrosion Control in Petroleum Production. Houston, TX: NACE International, 1979, pp. 53-65.

Parker, M.E., E.G. Peatlie. Pipeline Corrosion and Cathodic Protection—A Field Manual. Houston, TX: Gulf Publishing Company, 1984, pp. 59-77.

Peabody, A.W. Control of Pipeline Corrosion. Houston, TX: NACE International, 1967, pp. 94-104, 116-119.

Tefankjian, D.A. "Application of Cathodic Protection." West Virginia University Technical Bulletin No. 6-3, 1975, pp. 131-147.

Section 6: Installation of CP Systems

6.1 Introduction

6.1.1 This section presents recommended procedures for installation of CP systems that achieve protection of the well casing structures when design considerations recommended in Section 5 and Appendix D have been followed.

6.2 Construction Specifications

6.2.1 All construction work performed on CP systems shall be done in accordance with construction drawings and specifications. The construction specifications shall be in accordance with recommended practices in Section 5 and nonmandatory Appendix D.

6.3 Construction Supervision

6.3.1 All construction work performed on CP systems shall be under the supervision of a trained and qualified inspector. It shall be the inspector's function to verify that the installation is made in strict accordance with the drawings and specifications, or that exceptions are made only with the express consent of qualified personnel, when it can be demonstrated that the effectiveness of the system is not impaired. It should also be the inspector's function to verify that construction methods and techniques are in accordance with good practices.

6.3.2 All deviations from construction specifications shall be noted on as-built drawings.

6.4 Galvanic Anodes

6.4.1 Inspection and handling

6.4.1.1 Packaged anodes shall be inspected and steps taken to ensure that the backfill material completely surrounds the anode. The individual container for the backfill material and anode should be intact. If individually packed anodes are supplied in waterproof containers, the containers should be removed before installation. Packaged anodes should be kept dry during storage.

6.4.1.2 The lead wire must be securely connected to the anode. The lead wire should be inspected to ensure that it is not damaged. Care should be taken to avoid damage to insulation and kinking of the lead wire.

6.5 Impressed Current Systems

6.5.1 Inspection and handling

6.5.1.1 The rectifier or other power source shall be inspected to ensure that internal connections are mechanically secure and that no damage is apparent. Rating of the direct current source output should comply with construction specifications. Care should be exercised in handling and installation.

6.5.1.2 Impressed current anodes shall be inspected for conformity to specified anode material and size and length of lead wire, and to ensure that the cap, if used, is secure. Care should be exercised to avoid cracking or damaging anodes during handling and installation.

6.5.1.3 The lead wire shall be inspected carefully for defects in insulation (e.g., cracks, abrasions, or excessive thinning below specified thickness). Care should be taken to avoid damage to insulation in the wire. Defects in the lead wire must be repaired or the anode/wire unit must be rejected.

6.5.1.4 Anode backfill material shall conform to specifications.

6.5.2 Installation provisions

6.5.2.1 The rectifier or other power source should be installed so that the possibility of damage or vandalism is minimized.

6.5.2.2 Wiring to rectifiers shall comply with all local and national electrical codes and requirements of the utility supplying power. An external disconnect switch on AC wiring shall be provided. The rectifier case shall be grounded adequately.

6.5.2.3 Impressed current power supplies should be designed to prevent reverse current flow when the unit is not operational.

6.5.2.4 Impressed current anodes should be installed vertically, horizontally, or in deep holes as indicated in the construction specifications. Backfill material, when specified, should be packed around the anodes, eliminating voids. Care shall be taken to avoid damage to the anode, wire, and wire connection to the anode during installation.

6.5.2.5 The conductor (negative lead wire) to the structure shall be connected as indicated in the specifications. Conductor connections to the power source must be mechanically secure and electrically conductive. Before the power source is energized, it must be verified that the negative conductor is connected to the structure and the positive conductor is connected to the anodes and to the power source output terminals. After the power source is energized, suitable electrical measurements shall be made to verify that these connections are correct.

6.5.2.6 Underground negative lead wire shall be effectively insulated. Bare or ineffectively insulated wire may require a substantial amount of the total protective current.

6.5.2.7 Underground splices on the positive lead cable to anodes shall be kept to a minimum. Connections between cable and conductor from each anode shall be mechanically secure and electrically conductive. If buried or submerged, these connections must be sealed to prevent moisture penetration so that electrical isolation is ensured. If the insulation integrity on the buried or submerged positive lead cable, including splices, is damaged, the cable may corrode and fail prematurely.

6.5.2.8 When specifications call for burial of the anode cable, care must be taken to avoid damage to the insulation. Sufficient slack shall be left in the cable to avoid strain on connections and anode leads caused by settling. Backfill materials used around cables should be free of rocks and foreign materials that might damage the wire insulation when installed in the trench. Cables may be installed by plowing if proper precautions are taken.

6.6 Corrosion Control Test Stations and Bonds

6.6.1 Refer to Section D.5 of Appendix D for design of corrosion control test stations and bonds.

6.7 Isolating the Wellhead from Pipelines and Other Structures

6.7.1 Refer to Section D.2 of Appendix D for design of electrical isolation.

Section 7: Control of Interference Currents

7.1 Introduction

7.1.1 This section presents recommended practices for the detection and mitigation of interference currents.The mechanisms and detrimental effects of interference currents are described.

7.2 Mechanism of Interference Current

7.2.1 Interference current corrosion on a well casing differs from electrochemical corrosion caused by other conditions. The source of the corrosion current is foreign or separate from the affected well. The foreign structure may be electrically bonded to or isolated from the affected well. Interfering currents may enter or leave the casing at several locations along the well casing. The damage from an interference current occurs in the area where the current leaves the well casing and enters the electrolyte.

7.2.2 The severity of interference resulting from stray electrical current depends on several factors:

7.2.2.1 Distance between wells.

7.2.2.2 Location of pipelines with respect to wells.

7.2.2.3 Location of interfering current source.

7.2.2.4 Depth of well casing.

7.2.2.5 Location of highly conductive earth formations.

7.2.2.6 Magnitude of potential gradient in the earth that the affected well penetrates. These gradients are created by current flowing to other structures.

7.2.2.7 Location of electric power line grounding system.

7.2.2.8 Quality and extent of the cementing program on the well casing.

7.2.3 Sources of interference currents:

7.2.3.1 Constant current—Sources that have essentially constant DC output are CP rectifiers, thermoelectric generators, photovoltaic and windmill battery units, etc.

7.2.3.2 Fluctuating current—Typical sources are DC electrified railway systems, mine hauling systems, pumps, welding machines, DC power systems, etc.

7.2.3.3 An interference current may originate in a foreign CP system on nearby wells or pipelines that are electrically isolated from the affected well.

7.2.3.4 Mutual interference current can result from CP applied to other wells in a metallically connected system that includes the affected well.

7.3 Detection of Interference Currents

7.3.1 During well casing CP surveys, personnel should look for electrical changes and facilities that may be a source of interference current.

7.3.1.1 A change in casing-to-electrolyte potential when foreign electrical sources are switched off and on is cause to investigate for downhole well casing interference.

7.3.1.2 Well casing current measurement and downhole well casing potential profiles should be used to assess the presence and magnitude of interference current.

7.3.1.3 The presence of external corrosion and perforation of well casing may be determined by using an electromagnetic thickness measurement tool to find changes in wall thickness.

7.3.2 When interference current is suspected, appropriate tests should be conducted to determine its presence and magnitude. All affected parties shall be notified before tests are performed. (Notification should be channeled through an Underground Corrosion Control Coordinating Committee, where one exists).[(4)] Any one or a combination of the following procedures can be used to determine the existence or extent of interference:

7.3.2.1 Casing potential changes shall, where practical, be measured with respect to a remote reference electrode. The reference electrode shall be placed beyond the earth gradient field of interfering current. The foreign direct current source should be turned on and off during the test.

7.3.2.2 Change in the magnitude of well casing current should be measured, and the direction of flow should be determined while performing a well casing potential profile. The foreign direct current source should be turned off and on during the test.

7.3.2.3 The variation in current output of the suspected source of interference current should be determined and compared with measurements obtained in Paragraphs 7.3.2.1 and 7.3.2.2. This may require correlation of data with time.

7.4 Methods for Resolving Interference Corrosion Problems

7.4.1 Each interference problem is unique and the solution should be mutually satisfactory to all parties involved.

7.4.2 Mutual interference between well casings may be minimized when wellheads within the electrically connected system are adjusted to equal potential with respect to a remote reference electrode.

7.4.3 The interfering current source should be removed or relocated.

7.4.4 The effect of interference current may be counteracted by adding CP to the affected well.

7.4.5 Mutual interference between wells in a common CP system may be reduced by providing an interference bond, with a current drain regulating device, from the wells to the rectifier.

7.4.5.1 An interference bond of proper resistance should be designed and installed.

7.4.5.2 A current regulating device should be installed in the rectifier cable connected to the wellhead.

7.4.5.3 The current discharge from interfering cathodic rectifiers should be adjusted to eliminate or decrease interference.

7.4.6 The CP groundbed should be relocated.

7.4.7 The design of the CP system should be modified when connecting pipelines (used as negative returns) require a high percentage of the total current for protecting the wells.

---

(4) Information on Underground Corrosion Control Coordinating Committees may be available from the Technical Activities Division, 1440 South Creek Drive, Houston, TX 77084-4906 (telephone: +1 281/228-6200). Underground Corrosion Control Coordinating Committees are asked to keep NACE International Headquarters informed of their activities, but records are more current on some of the groups than on others.

7.4.7.1 Rectifiers and groundbed with reduced current output per unit should be added.

7.4.7.2 The dielectric coating of connecting pipelines should be improved to reduce the total required current.

7.5 Methods to Indicate Resolution of Interference

7.5.1 A satisfactory downhole well casing potential profile log indicating current that is adequate to eliminate anodic areas on affected casing should be obtained.

7.5.2 Sufficient CP currents, interpreted from surface test data or empirical calculation, should be applied to affected well casing.

7.5.3 Interference current discharges should be neutralized as determined by applicable criteria.

Bibliography for Section 7

Gast, W.F. “Well Casing Interference and Potential Equalization Investigation.” *Materials Performance* 13, 5 (1974): pp. 31-36.

Kilpatrick, J.M., L.V. Collings. “Use of Casing Potential Profile Test for Well Casing Interference Studies.” API Production Division Southwestern District Spring Meeting, Reprint No. 906-12-L. Washington, DC: American Petroleum Institute (API), March 1967, p. 15.

Roberson, G.R. “Effect of Mutual Interference.” *Materials Protection* 6, 3 (1967): p. 36.

Weeter, R.F., R.J. Chandler. “Mutual Interference Between Well Casings with Cathodic Protection.” *Materials Performance* 13, 1 (1974): pp. 26-30.

Section 8: Operation and Maintenance of CP Systems

8.1 Introduction

8.1.1 The purpose of this section is to designate procedures and practices for energizing and maintaining continuous, effective, and efficient operation of CP systems.

8.1.1.1 Electrical measurements and inspections are necessary to determine that protection has been established according to the applicable criterion and that each part of the CP system is operating properly. Conditions that affect protection may change with time, however, and corresponding changes are required in the CP system to maintain protection. Periodic measurements and inspections shall be made to detect changes in the conditions that affect the CP system. Local conditions may exist in which operating experience indicates that surveys and inspections should be made more frequently than recommended herein.

8.1.1.2 Care should be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of CP.

8.2 Tests shall be conducted after each CP system is energized to determine whether the system is satisfying the applicable criterion and is operating efficiently. Tests shall include one or more of the following types of measurements and must relate to the criterion established by this standard.

8.2.1 Casing-to-reference-electrode potential, as applicable.

8.2.2 Calculation technique to estimate CP effectiveness (refer to Paragraph 4.3.3).

8.2.3 Structure-to-structure potential.

8.2.4 Current flow.

8.2.5 Well casing potential profile (refer to Paragraph 4.3.1 and Appendix A).

8.3 Periodic tests are suggested to ensure the continuity of CP; the electrical measurements used in the tests may include one or more of the measurements listed in Paragraph 8.2.

8.4 Inspection and tests of CP facilities should be conducted as follows to ensure their proper operation and maintenance:

8.4.1 All sources of impressed current shall be checked at intervals not to exceed two months. Evidence of proper functioning may include the current output, normal power consumption, a visual or audible signal indicating normal operation, or the satisfactory electrical state of the protected casing.

8.4.2 All impressed current protective facilities should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Inspections may include a check for electrical shorts, ground connections, meter accuracy, efficiency, and circuit resistance.

8.4.3 Reverse current switches, diodes, and inteference bonds, whose failure would jeopardize structure protection, shall be inspected for proper functioning at intervals not to exceed two months.

8.4.4 The effectiveness of electrical isolation fittings and continuity bonds shall be evaluated during periodic testing. This may be accomplished by on-site inspection or by evaluating corrosion test data.

8.5 The test equipment used for obtaining each electrical value shall be of an appropriate type. Instruments and related equipment shall be maintained in good operating condition and checked annually for accuracy.

8.6 Remedial measures shall be taken when periodic tests and inspections indicate that protection is no longer adequate according to applicable criteria. These measures may include:

8.6.1 Repair, replacement, or adjustment of components of CP systems.

8.6.2 Providing supplementary facilities when additional CP is necessary.

8.6.3 Repair, replacement, or adjustment of continuity and interference bonds.

8.6.4 Removal of accidental metallic contacts.

8.6.5 Repair of defective electrical isolation devices.

Section 9: Corrosion Control Records

9.1 Introduction

9.1.1 The purpose of this section is to describe corrosion control records that document in a clear, concise, workable manner the data pertinent to the design, installation, maintenance, and effectiveness of corrosion control measures for well casings.

9.2 Relative to determination of the need for corrosion control, the following should be recorded when applicable:

9.2.1 Information on corrosion leaks (e.g., date, well identity, location).

9.2.2 Electromagnetic casing thickness measure-ments.

9.2.3 Casing potential profile data.

9.2.4 Coating type applied to external surfaces of casings.

9.3 Relative to structure design, the following should be recorded:

9.3.1 Location and design of wellhead and associated electrical isolation devices.

9.3.2 Design and procedure for isolating or bonding any associated electrical power source grounding system.

9.3.3 Design and location of test leads, bond cables, and other test facilities.

9.3.4 Details of any other corrosion control measures taken.

.

9.4 Relative to the design of corrosion control facilities, the following should be recorded:

9.4.1 Results of current requirement tests and how the tests were performed.

9.4.2 Results of soil resistivity surveys at groundbed locations, and where the surveys were made with respect to other wells, pipelines, and structures.

9.4.3 Interference tests and design of interference bonds and drainage switch installations, including:

9.4.3.1 Location of interference source relative to location of wells and other structures.

9.4.3.2 Scheduling of interference tests, correspondence with coordinating committees, coordinating committee minutes, and direct communication with the concerned companies.

9.4.3.3 Record of interference tests conducted, including location of tests, name of company involved, and results.

9.5 Relative to the installation of corrosion control facilities, the following should be recorded:

9.5.1 Installation of CP facilities

9.5.1.1 Impressed current systems

(a) Location and date placed in service.

(b) Type, size, depth, backfill, and spacing of anodes.

(c) Number of anodes.

(d) Location of groundbed anodes with respect to wells, pipelines, and other structures.

(e) Specifications of rectifier or other energy source.

(f) Type(s) and size(s) of buried cable.

9.5.1.2 Galvanic anode systems

(a) Location and date placed in service.

(b) Type, size, backfill, and spacing of anodes.

(c) Number of anodes.

9.5.2 Installation of interference bonds and drainage switches

9.5.2.1 Details of interference bond installation

(a) Locations and names of companies involved.

(b) Resistance value or other pertinent information.

(c) Magnitude and polarity of drainage current.

9.5.2.2 Details of drainage switch installation

(a) Locations and names of companies involved.

(b) Type of switch or equivalent device.

(c) Data showing effective operating adjustment.

9.5.2.3 Details of other remedial measures

9.6 Records of surveys, inspections, and tests set forth in Sections 4, 5, 7, and 8 should be maintained to demonstrate that applicable criteria for interference control and CP have been satisfied.

9.6.1 Current drained from the well casing should be recorded at intervals consistent with company requirements.

9.6.2 Other electrical measurements should be recorded as required to monitor the CP for each well and to satisfy the criterion for CP of the wells.

9.7 Relative to the maintenance of corrosion control facilities, the following information should be recorded:

9.7.1 Maintenance of CP facilities

9.7.1.1 Repair of rectifiers or other DC energy sources.

9.7.1.2 Repair or replacement of anodes, connections, and cable.

9.7.2 Maintenance of interference bonds and drainage switches

9.7.2.1 Repair of interference bonds.

9.7.2.2 Repair of drainage switches or equivalent devices.

9.7.3 Maintenance, repair, and replacement of electrical isolation devices, test leads, and other test facilities.

9.8 Records sufficient to demonstrate the evaluation of the need for and the effectiveness of corrosion control measures should be retained as long as the facility involved remains in service. Other related corrosion control records should be retained for a period that satisfies individual company needs.

References

1. NACE SP0572 (latest revision), "Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds" (Houston, TX: NACE).

2. F.W. Anney, "Electrical Resistivity of Oil-Country Tubular Steels," U.S. Steel Technical Report, March 31, 1971.

3. NACE SP0177 (latest revision), "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems" (Houston, TX: NACE).

4. ANSI/ASME B31.8 (latest revision), "Gas Transmission and Distribution Piping Systems" (New York, NY: ANSI, and New York, NY: ASME).

5. NACE SP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).

Appendix A—Casing Potential Profile (Nonmandatory)

A.1 Introduction

A.1.1 This appendix describes a typical potential profile tool, its function, and use. Procedures for interpreting data are covered. This appendix supplements Paragraph 4.3.1 of this standard.

A.1.2 The name "casing potential profile" has been widely accepted. The measurement is actually a potential difference, and the plotted data represent a casing potential difference profile. The tool measures a potential difference between two points on the casing as opposed to the potential of a pipe as measured in a pipe-to-soil potential in evaluating pipeline corrosion. The term *potential difference* is used interchangeably with voltage (IR) drop.

A.1.3 A casing potential profile should be performed under the direction of a person qualified by knowledge and experience in this particular endeavor.

A.2 Types of Casing Potential Profile Tools

A.2.1 A typical casing potential profile tool consists of two contacts positioned 3 to 8 m (10 to 26 ft) apart on tubing and separated by an electrical insulator. A wire is attached to each contact and brought to the surface to a voltmeter. The tool is moved along the inside of the casing to take voltage drop measurements as needed. (Refer to Figure A1.)

A.2.2 Some of the contact devices are:

A.2.2.1 Spring-loaded knives that continuously contact the casing while moving up or down. Tension is increased against the casing wall by manipulating the position of knives.

A.2.2.2 "Pipe cutter" wheels permanently tensioned on spreader arms. Wheels continuously ride the casing wall at constant pressure.

A.2.2.3 Spreader arms with contactors that are opened and closed by an electric motor or mechanical means from the ground level. Pressure against the casing wall is adjustable.

A.3 Effect of Electrical Resistance on Data

A.3.1 Variable circuit resistance affects voltage (IR) drop readings. Because the electrical resistance of steel casing is extremely low (in the µ-ohm per m range), the equipment design and procedure used to measure voltage are critical. For example, the voltage measured across approximately 6 m (20 ft) of casing can be in the range of 1 to 5,000 µV. The resistance portion of the electrical circuit consists of the following:

A.3.1.1 The well casing between the profile tool's upper and lower contacts.

A.3.1.2 Other permanent tool fittings and cable and connectors.

A.3.1.3 Contact of the knives to the casing wall at each setting.

A.3.2 Resistance tables for the various casing grades are available.[2] The resistance of the casing for a given API[(5)] grade changes as downhole temperature increases.

[(5)] American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005.

The resistance of the casing can be measured prior to installation.

A.3.3 A voltage (IR) drop measured across a given length of casing and total resistance can be used to calculate the current flow. The resistance value should be corrected for changes caused by temperature and grade of steel.

A.4 Other Influences on the Measured Voltage (IR) Drop

A.4.1 Thermal voltage differences between upper and lower contacts, casing wall, and knives. This is caused by the contacts riding continuously on the casing wall.

A.4.2 Resistance between contacts and casing wall. Foreign material on the casing wall can increase the total resistance and give an erroneous voltage (IR)

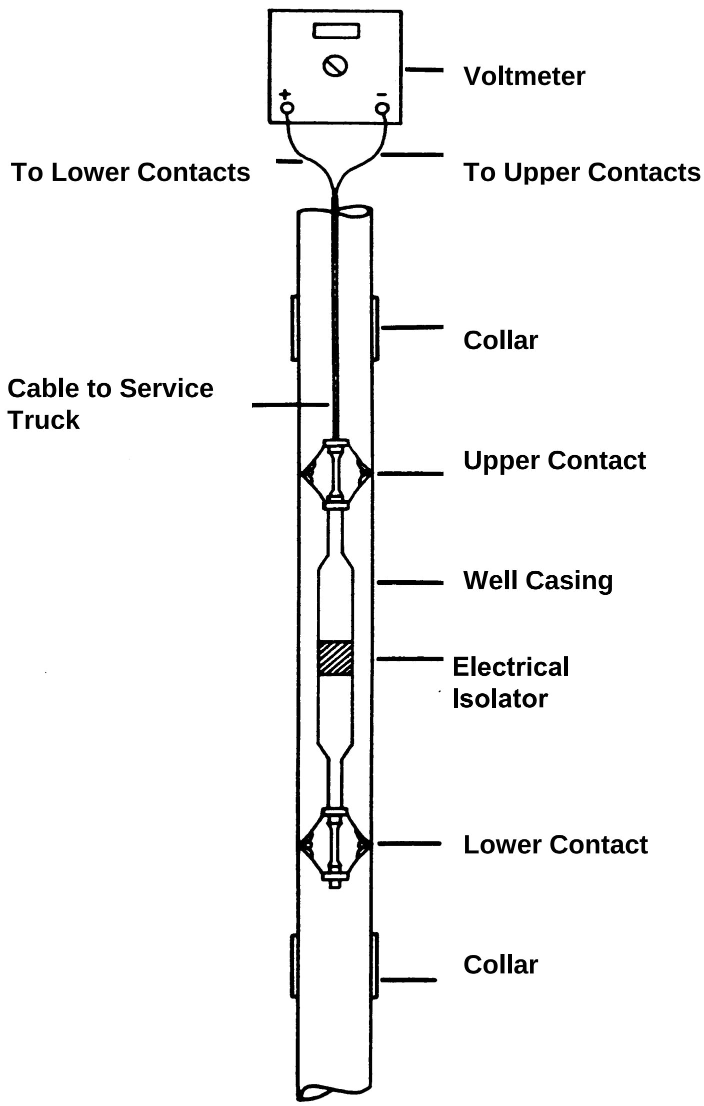

FIGURE A1—Casing Potential Profile Tool

drop reading. Some foreign materials commonly encountered are corrosion products, scale, petroleum deposits, corrosion inhibitors, and moisture.

A.4.3 Ineffective electrical insulation between upper and lower contacts.

A.4.4 Electrically conductive fluid in the casing and in contact with the tool.

A.5 Use of Instruments

A.5.1 Voltmeters with a high impedance and resolution of 1 µV and a short response time are required. They should also have AC rejection and be temperature compensated. Instruments should be calibrated annually.

A.5.2 The accepted procedure is to connect the positive (+) terminal of the voltmeter to the lower contact of the potential tool. A positive reading indicates current flowing up the casing (from positive to negative), and a negative reading indicates current flowing down the casing.

A.5.3 The tool is stopped at a given location in the well casing, and the IR drop readings are repeated, if required, until an acceptable one is obtained. An acceptable reading is one that is consistent with the log and other available data.

A.6 Data Use and Interpretation

A.6.1 A typical example of a casing potential profile plot is shown in Figure A2.

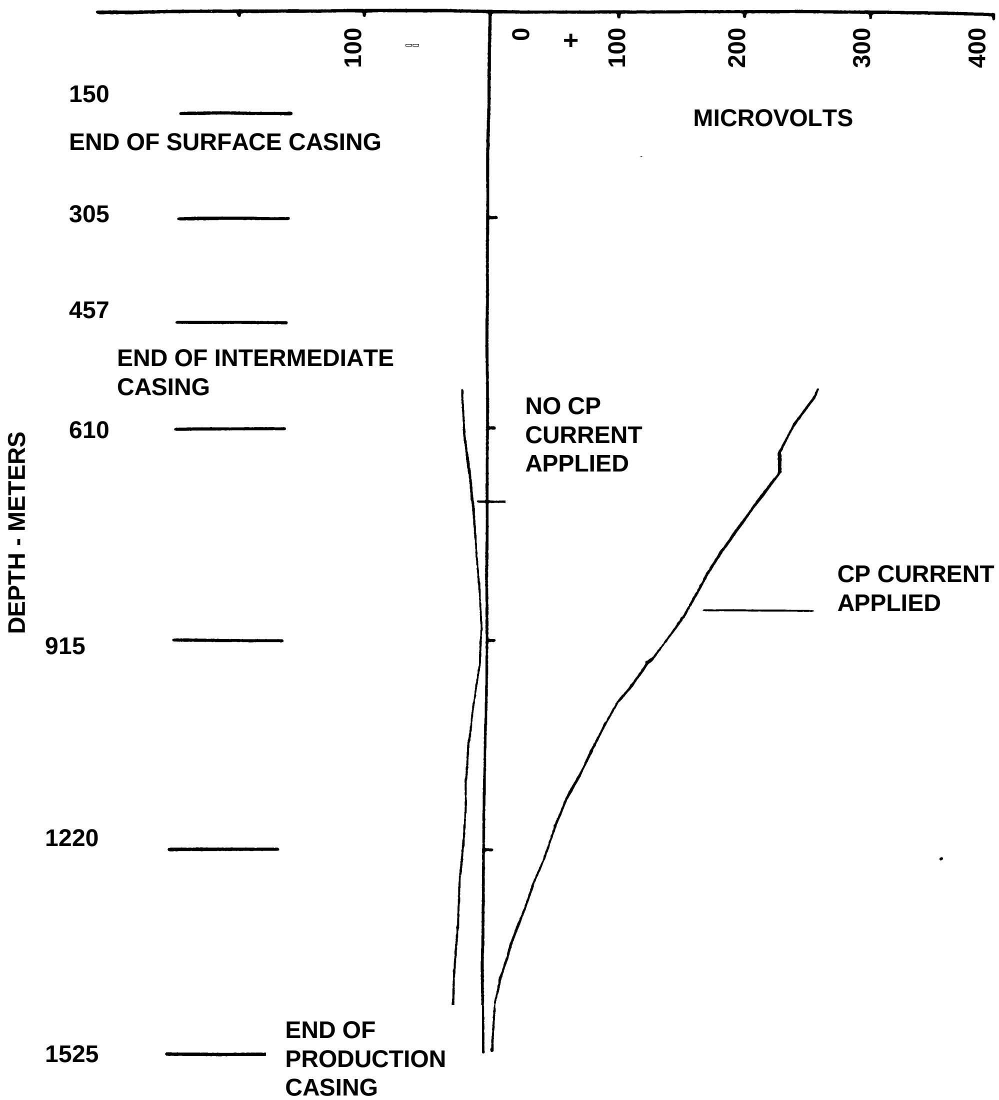

FIGURE A2—Typical Casing Potential Profile Plot

A.6.2 Considerations in interpreting casing potential profile data:

A.6.2.1 Abrupt or inconsistent changes in single readings may indicate poor contact of the tool with the casing wall.

A.6.2.2 Data taken from a production casing shielded by other casing in the well are not necessarily indicative of current gain or discharge from the production casing to the formation.

A.6.2.3 A positive slope of the plotted voltage (IR) drop versus depth normally indicates an increase in the amount of current being picked up by the casing.

A.6.2.4 A negative slope of the voltage (IR) drop normally indicates a discharge of current from the casing.

A.6.2.5 Changes in slope are caused by a change in current or resistance. Resistance changes can be caused by:

(a) Change of wall thickness (e.g., corrosion, manufacturer's tolerance).

(b) Change of API pipe grade.

(c) The bridging of collars by the contacts of the tool.

A.6.2.6 Each voltage (IR) drop reading taken on a section of the casing (typically several meters) measures the long-line current. The local anodic cells are not detectable within the span of the tool. Current pickup is not necessarily uniform along the casing between tool contacts. Therefore, the current density at a given area on the casing may be greater or less than that indicated.

A.6.2.7 Casing potential profile data give a reasonable indication of the amount of current flowing and indicate a direction of current flow. The data cannot be interpreted to determine whether sufficient current is being applied to cancel all corrosion cells.

A.7 Well data for each well can assist in interpreting potential profile readings. These data may include the following:

A.7.1 API grade, diameter, length, and weight of casing joint and its location in the well.

A.7.2 Collar locator, used to facilitate positioning of a casing potential profile tool between collars.

A.7.3 Electromagnetic logs, which help determine changes in wall thickness and grade of casing, and allow evaluation of the inner wall surface condition.

A.7.4 Formation resistivity logs that identify strata that may alter current distribution.

A.7.5 Leak history and repair methods.

A.7.6 Other types of logs for a given well can aid in interpreting casing potential profile data. Refer to Paragraph D.7.4 of Appendix D.

A.8 Interference Testing with the Casing Potential Profile Tool

A.8.1 The casing potential profile tool is valuable when used to determine electrical DC interference. Data obtained pertain only to the conditions prevailing at the time of the test.

Appendix B—E-Log-I Test (Nonmandatory)

B.1 Introduction

B.1.1 The purpose of this appendix is to outline the procedure for performing an E-log-I test and to give guidelines for interpretation of data. This appendix supplements Paragraph 4.3.4 of this standard.

B.2 General

B.2.1 An E-log-I test should be performed under the direction of a person qualified by knowledge of and experience in this particular endeavor.

B.3 Prerequisites to Performing an E-log-I Test

B.3.1 All buried metallic structures must be electrically isolated from the casing.

B.3.2 The temporary groundbed should be located at a sufficient distance from the well to give optimum current distribution along the well casing. When feasible, it should be placed where permanent bed location is anticipated.

B.3.3 Other buried metallic structures should be located.

B.3.4 Foreign rectifiers or other DC sources that could influence the test should be located.

B.3.5 The locations of high-resistivity strata that make it difficult to force current through underlying formations should be determined.

B.3.6 Placement of the reference electrode should be based on well depth, well spacing, and distance to foreign structures, and it should be beyond the influence of the test groundbed.

B.4 Test Procedure

B.4.1 After the equipment is set up (see Figure B1), the test should be conducted according to the following steps.

B.4.1.1 The "native state" potential, i.e., the potential with zero groundbed current, should be measured and recorded.

B.4.1.2 The test should then be begun by impressing current through the groundbed onto the well casing at the predetermined level (typically 0.1 A, as in Figure B2, for the selected time, typically two or three minutes).

B.4.1.3 At the end of the selected time, the current flow should be interrupted and the potential should be observed. Within a fraction of a second, the potential will drop abruptly. It will then begin a gradual "decay." The potential of interest is that just prior to the start of the decay. This is frequently referred to as the instant-off potential.

B.4.1.4 The current interruption should last no more than two seconds. A higher current should then be applied to the casing at the next predetermined current level. Typically, increments from 0.1 to 2.0 A are used.

B.4.1.5 The current increments should be selected to meet the requirements of individual conditions and to ensure the proper interpretation of the E-log-I test.

B.4.1.6 Time intervals should be consistent throughout the test.

B.5 Interpretation of Test Results

B.5.1 Figure B2 is an example of an E-log-I curve. Casing-electrolyte potentials and current applied are plotted on semilogarithmic scales. The interpretation of the curve is dependent on the experience of the operator. The current required is usually taken at the intersection, point A, or the first point lying on the Tafel segment, point B.

B.5.2 If the E-log-I results have not been verified for a given group of wells, additional testing such as the casing potential profile log should be conducted.

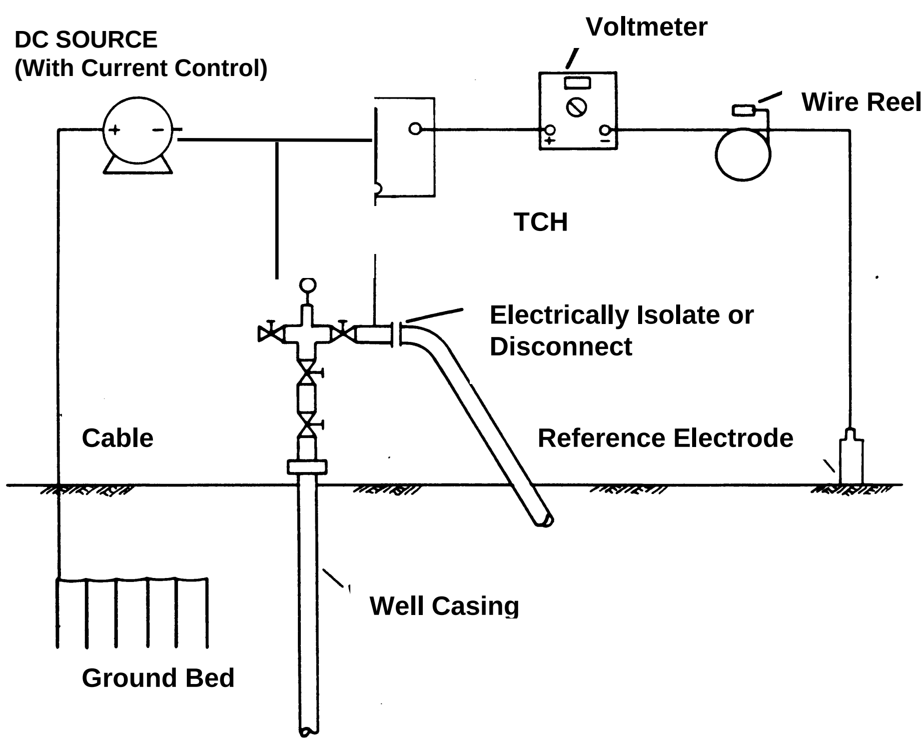

FIGURE B1—Equipment Set-Up for E-Log-I Test

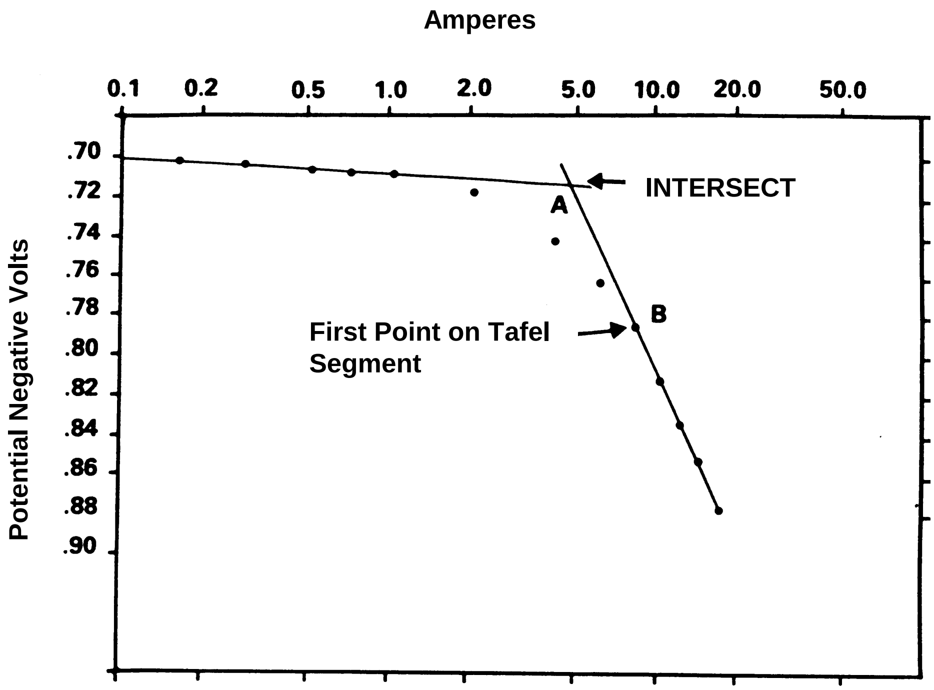

FIGURE B2—Sample E-Log-I Plot

Appendix C—Electromagnetic Casing Inspection Instruments (Nonmandatory)

C.1 Introduction

C.1.1 Subsurface electromagnetic inspection instruments are used to inspect the casing wall for defects. The inspection helps in determining a need to install a CP system or in determining its effectiveness after installation. These instruments fall into two broad categories; one induces an AC electromagnetic field into the casing wall and the other, a DC electromagnetic field into the casing wall. A comparison of these electromagnetic inspection instruments points out the differences in the methods of measurement and the significance of these differences.

C.2 Corrosion Inspection Instruments

C.2.1 The AC inspection instrument derives its signal by detecting the amount of phase shift measured between the low-frequency transmitter coil and the receiver coil. The transmitter coil is energized with a low-frequency AC current, causing an electromagnetic field to be induced into the casing. The field is detected by the receiver coil, usually located 300 to 600 mm (12 to 24 in.) away.

C.2.1.1 The amount of phase shift of the received signal from the transmitter is related to the properties of the casing. These properties are:

(a) Casing weight.

(b) Casing size.

(c) Casing grade, including permeability and conductivity.

(d) Metallic influence outside casing, if inspected casing is inside another casing (e.g., scratchers, centralizers).

C.2.1.2 The predominant response is a result of the change in the casing weight. Because there is an "averaging" effect between the transmitter and receiver coil, there must be significant metal loss (e.g., by corrosion) with respect to normal casing weight to cause a meaningful change in the phase shift.

C.2.1.3 The accuracy is such that a change from one API casing weight to another of the same size casing is detectable. It is responsive to the change in the amount of metal, whether the change is internal or external.

C.2.1.4 Supplementally, a noncontact electronic caliper is usually available for added internal information, and some instruments are also equipped with a set of closely spaced coils to provide uncalibrated indications of small defects.

C.2.2 The DC inspection instrument derives its casing defect signal by detecting a disturbance in an otherwise stable magnetic field within and surrounding the casing wall. The stable magnetic field is induced into the casing wall. A defect such as a corrosion pit causes a field irregularity or "flux leakage" at that point on both sides of the casing wall, whether the defect itself is on the inside or the outside wall of the casing. This disturbance can be created by a single pit, an isolated defect, or by a group of closely located pits, i.e., general corrosion. The instrument sensors detecting the field disturbances are small and are in contact (as close as possible) with the internal circumferential surface of the casing.

C.2.2.1 Signals emitted by these sensors are caused by changes in the field disturbances, which vary because of:

(a) The strength of the induced DC magnetic field.

(b) Defect depth.

(c) Defect shape.

(d) Metallic influence outside casing (e.g., scratchers, centralizers, another casing).

(e) Casing wall thickness.

(f) Casing size.

(g) Casing grade, including permeability and conductivity.

(h) The speed with which the sensor passes the defect.

C.2.2.2 Techniques currently in use utilize the amplitude of the sensor signal. Although casing wall thickness affects the signal amplitude, the sensor does not discern that thickness; the amplitude response is usually calibrated to indicate depth of defect penetration in percent of the total casing wall thickness.

C.2.2.3 Instrument sensitivity is normally limited to defect depths greater than 20% of the casing wall and defect areas greater than 32 mm (1.3 in.) in diameter. Accuracy of the corrosion defect measurement is approximately ±15% of defect depth in ideal single-string conditions when the casing information is known (e.g., weight, grade, etc.)

C.3 The information presented in Table C.1 may be used to determine which instrument is the most effective for certain situations.

C.3.1 Normally, operating conditions for both instruments are for temperatures up to 177°C (351°F), pressures of 100 MPa (14,500 psi), and casing sizes from 110- to 250-mm (4.3- to 9.8-in.) outside diameters. Some instruments can operate in conditions beyond these limits. The performance of either instrument is degraded when run in a multistring casing; however, the DC instrument's operation is less affected.

C.3.2 The running of base logs as soon as possible is recommended for better evaluation of future data.

C.3.3 Clean casing walls result in more reliable inspections.

TABLE C.1—Instrument Effectiveness

Type of Instrument	Detects Casing Collars	Detects Small Defects and Defect Depths	Detects Large Holes in Casing	Detects Casing Weight Change	Detection of Outer Casing String	Detects Parted Casing String	Detects Drill Pipe Wear
AC	Yes	No	Yes	Yes	Yes	Yes	Yes
DC	Yes	Yes	Yes	No	No	Yes	No

Appendix D—Well Completion Design and Other Factors Associated with CP (Nonmandatory)

D.1 Introduction

D.1.1 The purpose of this appendix is to provide accepted corrosion control practices for the design of CP systems for oil production, natural gas production, and natural gas storage wells and associated aboveground facilities. A person qualified to practice corrosion control should be consulted during all phases of well design and installation (see Paragraph 1.5.) These recommendations should not be construed as taking precedence over recognized electrical safety practices. Electrical grounding procedures at the well surface must conform to local, state, and national codes.

D.2 Electrical Isolation

D.2.1 Isolating devices consisting of flange assemblies, prefabricated insulating joints, unions, and couplings should be installed to isolate the well production casing electrically from other wells, associated pipelines, gauge lines, and structures when required to facilitate the application of corrosion control. These devices should be properly rated for temperature, pressure, and dielectric strength. Installation of isolating devices should be avoided in enclosed areas where combustible atmospheres are likely to be present. Typical locations at which electrical insulating devices may be considered are as follows:

D.2.1.1 Where facilities change ownership, e.g., the wellhead.

D.2.1.2 At the junction of bare well casing and associated pipelines and facilities.

D.2.1.3 At the junction of dissimilar metals (to prevent galvanic corrosion).

D.2.2 Isolating devices

D.2.2.1 Inspection and electrical measurements should be performed to ensure that electrical isolation is adequate.

D.2.2.2 Buried isolating devices should be suitably coated or wrapped with insulating material to prevent electrical current transfer through the surrounding soil.

D.2.2.3 Additional or special isolating devices may be needed on pipelines containing conductive fluids.

D.2.3 The need for lightning and fault current protection at isolating devices should be considered. Cable connections from isolating devices to arrestors should be short, direct, and of a size suitable for short-term, high current loading.

D.2.4 When electrical contact would adversely affect CP, well casings should be electrically isolated from supporting pipe stanchions and structures.

D.2.5 When an isolating device is required, proper pressure-rated materials manufactured to perform this function should be used and installed according to manufacturer's recommendations.

D.2.6 As much distance as is practical should separate well casings, associated pipelines, and other facilities from electric transmission tower footings, ground cables, and counterpoise. Regardless of separation, consideration should always be given to lightning and fault current protection of well casings and safety of personnel. (See NACE SP0177.[3])

D.2.7 Plastic fittings used in chemical pump lines must meet electrical and physical requirements.

D.2.8 Isolation of high-temperature natural gas discharge and oil lines requires special design considerations for use of materials.

D.2.9 Nonmetallic isolators should meet specifications for use in buried and aboveground applications, as required.

D.3 Electrical Continuity

D.3.1 Consideration should be given to the electrical properties of screwed casing couplings. To ensure electrical continuity, low-electrical-resistance thread compounds should be used.

D.4 Coatings

D.4.1 A dielectric coating used on a well casing requires a surface that provides a good physical bond between it and the formation or cement to ensure a sealed environment. NOTE: Coatings used on well casings require special dielectric, physical, and chemical qualities, which are beyond the scope of this standard.

D.5 Corrosion Control Test Stations and Bonds

D.5.1 Test stations for potential and current measurements should be provided at the well to facilitate CP testing. Such use may include, but not be limited to, the following:

D.5.1.1 Well production casing.

D.5.1.2 Well surface and intermediate casings.

D.5.1.3 Dehydration, oil pumping, natural gas compressor, and other similar facilities.

D.5.1.4 Foreign metallic pipelines or facilities near the well.

D.5.1.5 Gauge lines.

D.5.2 Test leads should be color coded or otherwise permanently identified. Wire should be installed with slack. Damage to wire insulation should be avoided. Test leads should not be exposed to excessive sunlight. Aboveground test stations are preferred. If test stations are flush with the ground, adequate conductor slack should be provided within the test station to facilitate test connections.

D.5.3 An isolating device can be accommodated by attaching an appropriate test wire and low-resistance current-carrying cable to each side of the device. These cables and wires should be appropriately color coded or labeled and terminated at a convenient location for bonding when needed. Shunts may be used to measure current.

D.5.4 The test station may accommodate current-carrying cable when a pipeline is utilized as the negative return. Current-carrying cable or wire should not be used as a contact for taking casing-to-reference-electrode potentials.

D.5.5 Attachment of test leads and cables to steel well casings and equipment

D.5.5.1 Test leads are usually attached to an aboveground fitting, which is directly connected to the well casing. Soldering or thermit welding may be used to attach wire or cable when heating requirements do not exceed the temperature limit for casing and fittings. NOTE: Care should be taken to ensure that specified temperature limits are not exceeded during thermit welding to prevent damage to the pipe by copper penetration. Consult ANSI(6)/ASME(7) B31.8[4],Paragraph 862.115 on Electrical Connections and Monitoring Points, for additional guidelines on thermit welding. Mechanical connections to flanges and other fittings can be used if they remain secure and maintain low resistance. Refer to NACE SP0169.[5]

D.5.5.2 Attaching test wires directly to the production casing below ground level is beyond the scope of this standard. Special consideration must be given to requirements for cementing and completion procedures.

D.5.6 Coating of test wire attachments

D.5.6.1 All test lead wire and cable should be coated with a direct burial type of electrical isolating material. Attachments to fittings or casings should be coated with a dielectric material. The coating should be compatible with the existing coating on the fitting or casing.

D.6 CP

D.6.1 Refer to Sections 5 and 6 of this standard for the design and installation of CP.

D.7 Information Useful for the Design and Monitoring of a CP System

D.7.1 Well piping system specifications and practices.

D.7.1.1 Total length, size, weight, API grade, and location of each casing string in the well.

D.7.1.2 Electrical resistance of steel casing. Tables are available for various grades and temperatures. (8)

D.7.1.3 Coatings (dielectric)—well casings and connecting pipelines.

D.7.1.4 Cement types and grades, and locations of cemented intervals.

D.7.1.5 Drilling mud—type, inhibitor.

D.7.1.6 Additives to cement or mud.

D.7.1.7 Completion data regarding backfill around casing and the location of cement or other material.

D.7.1.8 Surface well fittings such as valves for access to casing.

D.7.1.9 Locations of metallic scratchers and centralizers.

D.7.1.10 Locations of metallic stress rings.

(6) American National Standards Institute (ANSI), 1819 L St., NW, Washington, DC 20036.
(7) ASME International (ASME), Three Park Avenue, New York, NY 10016-5990.
(8) Casing resistance data tables available from Manager, Casing Inspection Services, Dresser Atlas, Box 1407, Houston, TX 77251. Tables were based in part on data found in a U.S. Steel Technical Report.[2]

D.7.1.11 Acidizing procedures.

D.7.2 Well and associated pipeline site environments

D.7.2.1 Existing and proposed CP systems.

D.7.2.2 Possible interference sources (see Section 7 of this standard).

D.7.2.3 Surface environmental conditions.

D.7.2.4 Foreign buried metallic structures (including location, ownership, and corrosion control practices).

D.7.2.5 Site accessibility.

D.7.2.6 AC power availability.

D.7.2.7 Status of well's electrical isolation from foreign structures.

D.7.3 Field survey, corrosion test data, and operating experience

D.7.3.1 Electrical resistivity of the electrolyte (soil).

D.7.3.2 Electrical continuity (low resistance is required across well casing threaded couplings).

D.7.3.3 Cumulative leak history.

D.7.3.4 Interference current data.

D.7.4 Well logs used to supplement other test data utilized for design

D.7.4.1 Electromagnetic alternating current and direct current logs (thickness gauge).

D.7.4.2 Electric log—formation resistivity normally available from well completion data.

D.7.4.3 Gamma ray neutron log—determines relative lithology for location of high-resistivity formations.

D.7.4.4 Collar locator log—facilitates other logs such as casing potential profile.

D.7.4.5 Cement bond log or temperature log—indicates where cement is located between well casing and formation.

D.7.4.6 Optical inspection inside casing.

D.7.4.7 Caliper log (mechanical feelers) to determine internal wall thickness change or defects such as corrosion pits.

D.7.4.8 Dual induction resistivity log.