CORROSION

AND

CATHODIC PROTECTION

Prepared by:
GENERAL CORROSION CORPORATION
MINNEAPOLIS, MN

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Section One: Corrosion Related Definitions

Anode - The electrode of an electrochemical cell at which oxidation or corrosion occurs.

Cathode - The electrode of an electrochemical cell at which reduction or practically no corrosion occurs.

Cathodic Protection - A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Coating – A dielectric material applied to a pipe to separate it from the environment.

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

Corrosion Cell – A circuit consisting of an anode and a cathode in electrical contact in an electrolyte. Corrosion generally occurs only at the anodic areas. (Also: electrochemical cell, galvanic cell).

Corrosion Potential – The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions. (Also: open-circuit potential).

Criterion – A standard for assessment of the effectiveness of a cathodic protection system.

Depolarization – The elimination or reduction of polarization by physical or chemical means. This results in increased corrosion.

Direct Current – DC electricity is of prime importance in the corrosion (and the corrosion control) process.

Electrode – A conductor in contact with an electrolyte in which current is transferred to or from the electrolyte.

Electrolyte – An ionic conductor. Usually soil or liquid next to and in contact with buried or submerged metallic structures.

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

Ground Bed – The portion of the cathodic protection system consisting of the anode and back-fill material.

Holiday – A discontinuity in a protective coating that exposes the underlying metal surface to the environment.

Impressed Current Cathodic Protection – A DC current supplied by a rectifier to protect large, and usually bare, structures from external corrosion.

Instant-Off Potential – The measurement of the structure-to-soil potential made immediately following the interruption of the cathodic protection rectifier.

Interference – Any electrical disturbance on a metallic structure as a result of stray current.

Corrosion Related Definitions (continued)

I/R Drop – The voltage drop across a resistance according to Ohm's Law. (Also: I/R Error, Voltage Drop).

Isolation – The condition of being electrically separated from other metallic structures or the environment. (Also: electrical isolation).

NACE – National Association of Corrosion Engineers.

Ohms Law – The relation between the voltage, the current and the resistance of a circuit.
(Examples: volts = amperes x ohms; amperes = volts / ohms; ohms = volts / amperes).

Pipe to Electrolyte Potential – The potential difference between the pipe metallic surface and the electrolyte that is measured with reference to a reference electrode in contact with the electrolyte. (Also: structure-to-soil potential).

Polarization – The change from the open-circuit potential (more active or negative) as a result of current across the electrode-electrolyte interface.

Potential – The measurement of the structure under test expressed in volts.

Protection Potential – A measured potential meeting the requirements of a cathodic protection criterion.

Protective Potential – The minimum potential required to suppress corrosion.

Rectifier – The DC power supply, external to the cathodic protection system, needed to deliver adequate current demands to the system to be protected.

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. Usually constructed of Copper/Copper Sulfate. (Also: Reference Cell, Half Cell).

Sacrificial Cathodic Protection – The reduction or prevention of corrosion of a metal in an electrolyte by coupling it to a more anodic metal. (Also: Galvanic cathodic protection).

Stray Current Corrosion – Corrosion that is caused by currents impressed onto a structure by some external source.

Voltage Drop – The voltage drop across a resistance according to Ohm's Law. (Also: I/R Error, I/R Drop).

Section Two: Corrosion Theory

Everything corrodes. Period. Everything from humans to plastics, but especially metals must corrode. When two metals having different potentials are coupled together and contained in a conductive electrolyte, current will flow and corrosion will commence. Current will flow from the metal with the more negative potential through the electrolyte to a metal that is more positive. Corrosion will occur at the point where the current leaves the metal surface.

In order for corrosion to occur, four components must be present. They are:

- **Anode** – The point at which the structure corrodes.
- **Cathode** – The point at which the structure is protected from corrosion.
- **Electrolyte** – The soil or water adjacent to the structure with a resistivity low enough to allow current flow from the anode to the cathode.
- **Metallic Path** – The direct metallic couple between the anode and the cathode that allows for the completion of the DC electrical circuit.

If one of the components of the basic corrosion cell is removed, corrosion will cease to exist. A dry cell battery is a good example of a basic corrosion cell. Current will flow from the zinc outer casing (anode) through the inner electrolyte (usually a conductive paste) to the center carbon rod (cathode) then back to the outer case by way of a metallic path to complete the circuit. When batteries become old and "leaky", the outer zinc anode has actually corroded away to expose the inner electrolyte. Corrosion.

Why metals corrode:

- **Dissimilar Metals** – When two metals with different natural potentials are coupled together, the more active or anodic metal will corrode with respect to the more passive or cathodic metal. This was described above with the dry cell battery and outlined in Table 1.
- **New vs. Old Steel** – When new shiny steel is coupled to old steel of equal native potentials, the new steel will corrode with respect to the old steel.
- **Soil Resistivity** – A corrosion cell can develop at the juncture of a pronounced change in soil resistivity. The anodic area of the structure will occur in the regions of lower soil resistivities.
- **Soil pH** – Changes in soil pH will contribute to corrosion. The area of a structure exposed to a lower soil pH will become more anodic to that of an area with a higher pH.
- **Chlorides** – Higher chlorides found in the electrolyte will be more anodic than electrolytes with a lower chloride count.
- **Oxygen Concentration** – Oxygen starved regions of the metallic structure will be more anodic than oxygen rich regions of the same structure. A good example is when a pipeline travels under an earth only back-fill then passes under a road or driveway. The electrolyte under the concrete or asphalt is oxygen starved and thusly more anodic.

Corrosion may be caused by other factors including (but not limited to): Moisture content of the electrolyte, ion concentrations, metal grain composition, milling imperfections, scratches on the structure and sharp edges or threads.

As mentioned, corrosion can and will be caused by a difference in the potentials of metals contained within a conductive electrolyte. The potential differences can be caused by coupling dissimilar metals together, variations within the same structure, variations in the electrolyte, or a combination of any or all of these.

Corrosion Theory (continued)

Table 1
Galvanic Energy Series
(Active)
Magnesium   -1.70 volts
Aluminum   -1.20 volts
Zinc   -1.10 volts
New Steel   -0.65 volts
Old Steel   -0.50 volts
Copper   -0.20 volts
Carbon   +0.40 volts
Silver   +0.50 volts
Platinum   +0.90 volts
Gold   +1.20 volts
(Passive)

Any two of the above listed metals, when coupled together and submerged in a conductive electrolyte, will create a basic corrosion cell. The metal located more towards the active end of the table will be anodic with respect to the more passive metal.

You can see why magnesium, zinc, and under certain conditions, aluminum are used for anode material for sacrificial anode cathodic protection systems.

Section Three: Cathodic Protection

Just as the basic corrosion cell requires the four components to survive (anode, cathode, electrolyte & metallic path), so does cathodic protection. It has been established that DC electricity will generate corrosion, and corrosion, in turn will generate DC electricity. Therefore, it is possible to prevent corrosion by the use of DC electricity. This, then, is the basis for cathodic protection.

The application of cathodic protection does not *stop* the corrosion process, but rather transfers the corrosion to a desired location. Actually, in some cases, more corrosion will take place after a properly designed cathodic protection system has been installed. The ultimate goal is to transfer all corrosion from the structure to be protected to the anode ground bed(s).

Cathodic protection is the electrical method of preventing corrosion on metallic structures (usually iron or steel) situated in a conductive electrolyte (usually soil or water) by coupling the structure through the cathodic protection system to the anode ground bed. Once the cathodic area of the structure to be protected has polarized to the open circuit potential of the anodic area, all corrosion is arrested (or transferred).

Impressed Current Cathodic Protection

Impressed current cathodic protection systems are primarily used where current requirements are high due to large structure surface areas that are exposed to a conductive electrolyte. Typical applications are for the protection of poorly coated structures, holidays in well-coated structures, structures situated in highly resistive electrolytes and for structures not electrically isolated from its surroundings. Steel structures require from 1.5 – 2.0 milli-amperes of current per square foot of exposed surface area to meet cathodic protection criteria. Therefore, the cathodic protection system must be designed and installed with a good understanding of the condition of the structure and its environment.

Major design considerations for an impressed current cathodic protection system:

- **Structure to be Protected** – The size and condition of the structure must be known to adequately determine its current requirement.
- **Soil Resistivity** – The resistivity of the soil must be known to properly size the ground bed for optimum current flow from the anode to the electrolyte – and from the electrolyte to the cathode.
- **Electrical Isolation** – The cathodic protection system must be sized based on the amount of exposed steel to be protected. If the structure to be protected is not electrically isolated from its surroundings, it must be known that additional cathodic protection current will be needed. In most cases, electrical isolation is not desired due to the possibility of accelerated corrosion caused by interference from the cathodic protection system.

The amount of DC current available from an impressed current cathodic protection system can be designed from a few amperes to hundreds of amperes. The impressed current cathodic protection system should be sized to allow for output adjustments if needed due to changes in circuit or electrolyte resistance or structure current demands. Any portion of the structure that does not receive adequate current flow will continue to corrode. If any cathodic protection current picked up by the structure flows back into the electrolyte, corrosion will be accelerated at the location on the structure where the current is discharged. Therefore, it is extremely important to properly design, install, maintain and survey the system to ensure proper levels of cathodic protection exist.

Section Three: Cathodic Protection (continued)

Sacrificial Anode Cathodic Protection

Sacrificial anode cathodic protection systems are primarily used where current requirements are minimal due to the fixed driving voltage (about 1.7 volts) and limited current output (from 10-50 milli-amperes) per anode. Typical applications are for the protection of holidays in well-coated structures and for small electrically isolated structures. As mentioned, steel structures require 1.5 – 2.0 milli-amperes of current per square foot of exposed surface area to meet cathodic protection criteria. Therefore, the ability to achieve total electrical isolation is, without a doubt, the most important factor when considering a sacrificial anode cathodic protection system.

Major design considerations for a sacrificial anode cathodic protection system:

Structure to be Protected – The structure must be very small in size or extremely well coated. Large exposed surface areas require current demands that exceed the capabilities of a sacrificial anode.
Soil Resistivity – The resistivity of the soil must be low enough to allow adequate current flow from the anode to the electrolyte – and from the electrolyte to the cathode. High soil resistivities will impede current flow from the anode.
Electrical Isolation – The structure to be protected must be isolated from other foreign structures to minimize current demands

As mentioned, total electrical isolation must be achieved by installing dielectric unions and/or flanges at the submersible pumps, dispensers, service risers or building entrances. All points of contact between the structure to be protected and foreign structures must be located and made discontinuous. The soil resistivity must be low and uniform enough to allow the current to uniformly flow from all points on the anode. Any portion of the structure that does not receive adequate current flow due to high soil resistivity will continue to corrode. Finally, the structure to be protected must be either very well coated or very small in size due to limited current available with the sacrificial anode cathodic protection system. If any of these conditions cannot be met, an impressed current cathodic protection system must be considered.

When all design criteria has been reviewed, tested and met, the proper cathodic protection system can then be applied to the structure to be protected. With the aid of numerous design calculations based on conditions observed on-site, the proper material, number, size, weight, spacing and life expectancy of the anode groundbed can be determined.

Section Four: Cathodic Protection Testing Procedures

Once your corrosion concerns have been identified and a cathodic protection system has been designed and installed, periodic testing of the system must be implemented. As usual, there are many testing procedures available to meet cathodic protection criteria.

With most impressed current cathodic protection systems, the NACE Standard TM0497-97, Test Method-2, *Negative 850 mV Polarized Pipe-to-Electrolyte Potential of Steel and Cast Iron Piping with Cathodic Protection Applied* is used. NACE has determined that the structure to be protected, when adequately protected, be at least or more negative than –850 mV with cathodic protection currents removed when measured with appropriate testing equipment. That is, the basic corrosion cell created by the addition of the cathodic protection system has a *polarized potential* not less (or more positive) than –850 mV.

With most sacrificial anode cathodic protection systems, the NACE Standard TM0497-97, Test Method-1, *Negative 850 mV Pipe-to-Electrolyte Potential of Steel and Cast Iron Piping with Cathodic Protection Applied* is used. NACE has determined that the structure to be protected, when coupled with an anode or anodes, be at least or more negative than –850 mV when measured with appropriate testing equipment. That is, the basic corrosion cell created by the addition of the cathodic protection system has a *potential* not less (or more positive) than –850 mV.

Impressed Current CP Testing

Equipment Required

- **Voltmeter** – The meter must have a nominal input resistance of 10 megohms to reduce measurement errors.
- **Reference Electrode** – The reference electrode must be clean, stable and repeatable. Most reference cells used for cathodic protection testing are Copper/Copper Sulfate.
- **Test Leads** – Two color-coded leads for proper connection polarity.
- **Current Interrupter** – The device used to cycle the rectifier so that *instant-off* potentials of the structure may be observed and recorded.

Cathodic Protection Testing Procedure

1. Determine the location of the pipeline or structure to be tested. In most cases, test stations, pavement test ports and pipeline risers are adequate testing locations.
2. Install and cycle the current interrupter(s) at all rectifiers within the area to be surveyed.
3. Set the voltmeter to the DC Volt scale.
4. Connect the negative (common) lead from the voltmeter to the reference electrode.
5. Connect the positive lead from the voltmeter to the structure to be tested.
6. Place the reference cell in direct contact with the electrolyte and as close to the structure to be tested as possible.
7. Read and record the pipe-to-electrolyte potential at the precise moment the rectifier is cycled off.
8. Repeat this procedure at all adequate testing locations available.
9. Measure and record the ON/OFF potential shift of all foreign structures in the vicinity.
10. Repeat this procedure annually.

<u>Section Four: Cathodic Protection Testing Procedures (continued)</u>

<u>Sacrificial Anode CP Testing</u>

<u>Equipment Required</u>

- **Voltmeter** – The meter must have a nominal input resistance of 10 megohms to reduce measurement errors.
- **Reference Electrode** – The reference electrode must be clean, stable and repeatable. Most reference cells used for cathodic protection testing of sacrificial anode systems are Copper/Copper Sulfate.
- **Test Leads** – Two color-coded leads for proper connection polarity.

<u>Cathodic Protection Testing Procedure</u>

1. Determine the location of the pipeline or structure to be tested. In most cases, test stations, pavement test ports and pipeline risers are adequate testing locations.
2. Set the voltmeter to the DC Volt scale.
3. Connect the negative (common) lead from the voltmeter to the reference electrode.
4. Connect the positive lead from the voltmeter to the structure to be tested.
5. Place the reference cell in direct contact with the electrolyte and as close to the structure to be tested as possible.
6. Read and record the pipe-to-electrolyte potential.
7. Repeat this procedure at all adequate testing locations available.
8. Repeat this procedure annually.

Note: When implementing either cathodic protection test method, consideration must be made for voltage drops (I/R error) that might be encountered that will artificially enhance the testing results. Voltage drops may occur in the following:
- Electrolyte – The resistance found in the electrolyte between the reference electrode and the structure to be tested.
- Reference Electrode – A poorly charged or contaminated reference electrode.
- Test Leads – High resistive test leads.
- Reference Electrode or Structure Connection – Poor contact at the connections.
- Reference Electrode to Electrolyte – Poor contact between the reference electrode and the electrolyte.
- Structure Coating – Current flow through the coating.

Cathodic protection criteria have been met when the structure-to electrolyte potential measurement is at least or more negative than –850 mV and consideration has been made for <u>ALL</u> sources of I/R Error.

Section Five: Cathodic Protection Testing Errors

 While either NACE Standard Test Method is relatively quick and easy to use, some unforeseen measurement errors may be encountered. However, errors can be kept to a minimum by simply taking care of your test equipment and following proper cathodic protection testing procedures.

Some Common Testing Errors

- Defective voltmeter.
- Incorrect voltmeter voltage range selected.
- Broken or frayed test wires.
- Damaged or broken test wire insulation that allows the conductor to contact the electrolyte.
- Polarity of the test wires reversed.
- Loose or faulty voltmeter connections.
- Dirty or corroded structure connection points.
- Contaminated reference electrode.
- Dry reference electrode porous plug.
- High-resistance contact between the reference electrode and the electrolyte.
- Test personnel contacting the reference cell terminal and/or the structure connection while potential measurements are being made.
- Soil too dry to allow electrical contact between the reference electrode and the electrolyte. The soil around the reference electrode may be moistened with tap water.
- Soils that are frozen will not allow electrical contact between the reference electrode and the electrolyte. Cathodic protection testing should be done during the Spring-Fall months.
- Concrete or asphalt paved areas will not allow sufficient electrical contact between the reference electrode and the electrolyte. Potential measurements should be taken directly adjacent to these areas or at available pavement test ports.

Most measurement errors can be remedied on-site by personnel familiar with proper cathodic protection testing procedures. Or, you can call a qualified corrosion expert (say, General Corrosion Corporation for example) who will be more than happy to answer any or all questions that you may have.

Section Six: Cathodic Protection System Maintenance

Impressed Current CP System Maintenance

The impressed current cathodic protection system requires a fair amount of regular maintenance to ensure proper operation. It is required that the rectifier DC voltage and amperage be read and recorded every 60 days. This will not prove that the cathodic protection system is operating properly, but rather that the system has not been inadvertently turned off or has failed due to component breakdown. The impressed current system must be left on at all times to ensure proper corrosion control. (The only exception is when maintenance is being performed on the piping/tank system. Then it is a good idea to turn the rectifier off to prevent accidental arching incase the CP wires are severed).

The data gathered every 60 days can be helpful to determine groundbed efficiency or even to predict groundbed failure. For example, an abrupt and then constant increase in groundbed resistance indicates probable groundbed failure. The ground bed resistance can be calculated by simply using Ohm's Law. *Note: Some fluctuations in the rectifier output can be anticipated with changes in the electrolyte (i.e. moisture, temperature).*

Although regulations call for the complete survey of the CP system every three years by someone certified by NACE as a "Corrosion Expert", the system being protected by an impressed current cathodic protection system *should* be surveyed annually to verify proper levels of cathodic protection. The system should be surveyed as outlined in Section Four: Cathodic Protection Testing Procedures. At the same time, each individual anode should be surveyed to determine individual anode life. If a single anode from an impressed current system fails, that portion of the structure being protected may not have proper levels of cathodic protection. Also, during the survey, the rectifier should be cleaned and the efficiency measured and recorded. The rectifier efficiency can be calculated by using the following formula:

Percent Efficiency = DC Power / AC Power x 100
Where DC Power = DC Volts x DC Amps
And AC Power = AC Volts x DC Amps

As the rectifier efficiency decreases, the cost of operation increases as well as the probability of component failure.

As with any electrical device, down time will occur due to unplanned component failure. A good maintenance program will ward off some component failures, and basic troubleshooting skills will bring the equipment back on line.

Most common failures encountered are due to blown fuses, loose or dirty terminals, open external circuits and lightning damage. These are usually found by a simple visual inspection of the cathodic protection system. Many problems are obvious to the experienced technician. Signs of arcing, strange odors and/or discoloration indicate problem areas.

Note: If proper (expected) DC VOLTAGE is present at the output terminals, it is unlikely that the problem lies within the rectifier itself.

Section Six: Cathodic Protection System Maintenance (continued)

Sacrificial Anode CP System Maintenance

The sacrificial anode cathodic protection system is relatively maintenance free. Keeping the anode-to-structure connections located in the test stations clean and free from corrosion product is all that is required. This can be accomplished during the annual cathodic protection survey as outline in Section Four: Cathodic Protection Testing Procedures.

One bit of additional maintenance that can be performed (but is not required) is to periodically check the anode output current to determine the effectiveness and the life expectancy of the anode. This also can be done at the time of the annual cathodic protection survey.

The anode life expectancy can be calculated by using the following formula:

$$\frac{Th \times A \times E \times UF}{I}$$

Where:
Th = Theoretical amp-hours/lb. (0.114 for magnesium *or* 0.0424 for zinc)
A = Anode weight. (Typically 17 or 32 pounds)
E = Current efficiency. (50% for magnesium *or* 90% for zinc)
UF = Utilization factor. (Typically 85% for both magnesium and zinc)
I = Current measured at the anode. (Measured in amps)

The result will be Anode Life in years.