Corrosion & Cathodic Protection

Presented by Marty Iozzo
Cost of Corrosion

NACE International & U.S. Federal Highway Administration - 2002

- $17.6 billion
  PRODUCTION & MANUFACTURING
  12.8%

- $47.9 billion
  UTILITIES
  34.7%

- $20.1 billion
  GOVERNMENT
  14.6%

- $22.6 billion
  INFRASTRUCTURE
  16.4%

- $29.7 billion
  TRANSPORTATION
  21.5%
Cost of Corrosion

$276,000,000,000,000!

Each Year!!
.....So What is Corrosion?
.....So What is Corrosion?

2Fe + O₂ + 2H₂O → 2Fe⁺⁺ + 4OH⁻

What??????
- OR -

• An Electro-Chemical Reaction of a Metal With Its Environment

• The Tendency of a Metal to Return to Its Origin
Corrosion = Rust!
Corrosion

Four parts needed for a corrosion cell to exist

1. **Anode** – Where corrosion occurs
2. **Cathode** – Protected from corrosion
3. **Electrolyte** - Soil or water (any conductive environment) adjacent to – and containing both the anode and the cathode
4. **Metallic Path** - Physically connects the anode to the cathode

*Remove any one part, and the corrosion cell cannot exist*
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Typical Corrosion Cell

- Anode: Corroding Area
- Electrolyte: Soil
- Cathode: Protected Area
- Metallic Connection: Structure

Practical Case Showing Conventional Current Flow

Electron Flow →
Corrosion Cell - Battery
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Metal Higher (more negative) on the scale is the Anode.
Corrosion Cell - Galvanic Anode
### Galvanic Series

Metal Higher is Anode

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New Pipe/Old Pipe

Old Pipe (Cathode)  New Pipe (Anode)  Old Pipe
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Galvanic Series

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**Galvanic Series**

Metal Higher is Anode
Dissimilar Metals

Steel Pipe (Cathode)

Galvanized Fitting Anode (Corroding Area)

Electrolyte (soil)

Steel Pipe (Cathode)

Dissimilar Metal Corrosion
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**Galvanic Series**

Metal Higher is Anode
Bright Metal

Pipe (Cathode)

Threads Bright Metal (Anode)

Scratches Caused by Pipe Wrench (Anode)
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Galvanic Series

Metal Higher is Anode
Dissimilar Soils

(Cathode)  (Anode)  (Cathode)
Sandy Loam  Clay  Sandy Loam

Corrosion Caused by Dissimilar Soil
Dissimilar Soils

- Pipeline in Clay is Anodic

- Adjacent Pipeline in Sand is Cathodic
Differential Oxygen

CORROSION CAUSED BY DIFFERENTIAL AERATION OF THE SOIL

Aerated Soil
Oxygen is Available (Cathode)

Pipe

Poor or No Aeration (Anode)
Differential Oxygen

- Pipeline Under a Roadway
- Pipeline Under a Railroad
- Pipeline Under a Water Crossing
Stress Corrosion

Diagram showing stress corrosion on a pipe coupling with lower stressed areas labeled as (Cathode) and higher stressed area (Anode) connected by arrows.
Stress Corrosion

- Stress Concentration on Bolts
- Bolts in Tension
CP Interference Corrosion

Current picked up by foreign line

Anodes

Protected line

Interference current flowing in earth, returning to protected line.

Foreign line or affected line

Protective current
AC Induction
Corrosion Prevention & Corrosion Control (Cathodic Protection)
How Cathodic Protection Works

- As previously mentioned, corrosion occurs where DC current discharges from the structure to the electrolyte at the anode.

- The objective is to allow the entire structure to be cathodic.
How Cathodic Protection Works

- As the potential of the cathode sites polarize towards the potential of the anode sites, corrosion is reduced.

- When the potential of all cathode sites reach the open circuit potential of the most active anode site, corrosion is eliminated.
Polarization Reduces the ΔV Along the Structure

1: Static Potentials

2: Most positive sites polarize first

3: Next most positive sites polarize

4: Last most positive sites polarize

5: All sites polarized
Corrosion

Four parts needed for a corrosion cell to exist

1. Anode – Where corrosion occurs
2. Cathode – Protected from corrosion
3. Electrolyte – Soil or water (any conductive environment) adjacent to – and containing both the anode and the cathode
4. Metallic Path – Physically connects the anode to the cathode

*Remove any one part, and the corrosion cell cannot exist
Cathodic Protection

Four parts needed for a CP cell to exist

1. Anode — Where corrosion occurs
2. Cathode — Protected from corrosion
3. Electrolyte - Soil or water (any conductive environment) adjacent to – and containing both the anode and the cathode
4. Metallic Path - Physically connects the anode to the cathode

*Remove any one part, and Cathodic Protection cannot exist
CP Cell - Battery

Diagram showing the components of a battery, including cathode, anode, zinc anode, conductive paste electrolyte, carbon cathode, and metallic path.
Cathodic Protection

• Galvanic Anode

• Impressed Current
Galvanic Anode

- Requires No External Power
- Smaller Diameter Pipe
- Coated Structure
- Isolated Structure
- Lesser Current Requirements
- Lesser Concern For Interference
Coatings

- Fusion Bonded Epoxy (FBE)
- Two Part Liquid Epoxy
- Polyethylene & Polypropylene
- Coal Tar Enamel
- Wax
- Mastic
- Shrink Sleeve
- Tape (Hot & Cold Applied)
Galvanic Anode
### Galvanic Series

- **Mg (Magnesium)**: -1.70 volts
- **Al (Aluminum)**: -1.20 volts
- **Zn (Zinc)**: -1.10 volts
- **New Steel**: -0.65 volts
- **Old Steel**: -0.50 volts
- **Cu (Copper)**: -0.20 volts
- **C (Carbon)**: +0.40 volts
- **Ag (Silver)**: +0.50 volts
- **Pt (Platinum)**: +0.90 volts
- **Au (Gold)**: +1.20 volts

Metal Higher is Anode
## Galvanic CP Design

<table>
<thead>
<tr>
<th></th>
<th>1K</th>
<th>2K</th>
<th>3K</th>
<th>4K</th>
<th>5K</th>
<th>6K</th>
<th>7K</th>
<th>8K</th>
<th>9K</th>
<th>10K</th>
<th>15K</th>
<th>20K</th>
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<tbody>
<tr>
<td>Soil Resistivity in Ohm-cm</td>
<td>155</td>
<td>77</td>
<td>52</td>
<td>39</td>
<td>31</td>
<td>26</td>
<td>22</td>
<td>19</td>
<td>17</td>
<td>16</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Nominal Output in Milliamperes</td>
<td>5</td>
<td>11</td>
<td>16</td>
<td>21</td>
<td>27</td>
<td>34</td>
<td>37</td>
<td>43</td>
<td>48</td>
<td>53</td>
<td>80</td>
<td>106</td>
</tr>
<tr>
<td>Nominal Life in Years</td>
<td>2,950</td>
<td>1,475</td>
<td>990</td>
<td>740</td>
<td>590</td>
<td>495</td>
<td>423</td>
<td>370</td>
<td>330</td>
<td>295</td>
<td>197</td>
<td>148</td>
</tr>
<tr>
<td>Nominal Anode Spacing in Feet</td>
<td>2,950</td>
<td>1,475</td>
<td>990</td>
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Impressed Current

- Requires External Power
- Lots of Current Needed
- Poorly Coated or Bare
- Electrical Isolation Not Possible
- Larger Diameter Pipe
- Buried Tanks & Tank Bottoms
- Long Lines
- More Chance For Interference
Impressed Current

Diagram showing the flow of protective current through a protected structure connected to an anode bed.
Impressed Current

Set up shown is typical for Transmission Lines

AC power

Rectifier

Buried Header Cable

Anodes
Usually Graphite, High Silicon, Cast Iron, or Mixed Metal Oxide. Bottom of anodes usually 12 feet below Grade.

Pipe or Structure

100 feet to 600 feet Typical

Protective Current
Impressed Current Cathodic Protection

- Schematic of Impressed Current Cathodic Protection
- Power Source Typically a Transformer / Rectifier
- Grade
- (+) to (-)
- Protected Structures
- Protective Current
- Impressed Current Cathodic Protection Using Deep Anode Groundbed
- Anode Groundbed
- AC power
- 50 feet to 300 feet or more
Interference Bond
When Is Cathodic Protection Achieved?

*When we can compare our measured cathodic protection potentials against, and satisfy a recognized Standard Recommended Practice - while making considerations for ‘IR Drop / Error’*
C.P. TEST EQUIPMENT

HIGH INPUT IMPEDANCE DIGITAL VOLT METER
- 10 MΩ OR GREATER

COPPER/COPPER SULFATE REFERENCE CELL
- CLEAN, FULLY CHARGED & CALIBRATED

TEST WIRES WITH ALLIGATOR CLIPS
- SELECTION OF SHORT & LONG WITH NO SPLICES

CLEAN WATER
- TO SATURATE THE TEST LOCATION

MISC. HAND TOOLS
- TO MAKE MINOR REPAIRS ON-SITE
The ‘Weakest Link’
IR Drop / Error - Defined

- IR Drop is primarily caused by CP current flowing through some resistance
- IR Drop is higher when current is large
- IR Drop is higher when Resistance is large
- IR Drop is higher on well-coated structures when the distance to the nearest coating holiday is greater (longer DC path)
Structure-to-Soil Potential Measurement

Reference Electrode Placed into Soil Directly Above Pipe

Electrical Contact to Pipe

Area of Pipe “Measured”
-0.85V Current Applied Criterion w/IR Drop Considered

- The reference cell is placed as close as possible to the structure under test (near structure)
- A structure-to-soil potential is read and recorded
- The reference cell is placed at ‘remote earth’ from the structure
- A structure -to-soil potential is read and recorded
- Subtract the difference in potential readings from the ‘near structure’ potential to obtain ‘IR Drop Free’ potential
- This potential must be at least -0.85V to meet criterion
-0.85V Polarized Criterion (No DC Current Flow)

- Interrupt ALL sources of DC current flow
  - All influencing rectifiers
  - Bonds to foreign structures
  - Sacrificial anodes may not be practical
- Interruption must be done quickly and simultaneously
- The reference cell is placed as close as possible to the structure under test
- Read and record the ‘OFF Cycle’ potential (Instant Off)
- The ‘OFF Cycle’ potential must be at least -0.85V to meet criteria
100mV Polarization (Decay) Criterion

- Interrupt ALL sources of DC current flow
  - All influencing rectifiers
  - Bonds to foreign structures
  - Sacrificial anodes may not be practical
- Interruption must be done quickly and simultaneously
- Record ‘ON Cycle’ potential
- Record ‘OFF Cycle’ potential
- Turn off all sources of DC current flow
- Allow the Structure to ‘Depolarize’
- There must be at least 100mV potential decay from the ‘OFF Cycle’ potential to the ‘Depolarized’ potential to meet criteria
100mV Polarization (Formation) Criterion

- Remove ALL sources of DC current flow and allow the structure to completely depolarize
- Record the depolarized baseline
- Energize the structure and record the ON potential
- Interrupt ALL sources of DC current and record the OFF potential (Instant Off)
- Allow the structure to polarize
- There must be at least 100mV of potential formation from the depolarized baseline to the OFF potential to meet criteria
Baseline (Off) Corrosion Potential

CP Applied

Instant-Off Potentials

Polarization w/Current Flow (Is this >100 mV?)

On Potentials

Normal Operation

Structure Potential (mV)

time (increasing)
Common C.P. Measurement Errors

Faulty Test Equipment
   All test equipment should be in proper working condition. The voltmeter should be calibrated or “known” to be accurate. All test leads and jumper wires should be checked for continuity before each use.

Reference Cell Condition
   The reference cell should be clean, fully charged and calibrated.

Poor Structure Connection
   Make sure contact is being made with the structure under test.

Reference Cell Placement
   The reference cell should be placed as near as possible (without touching) the structure under test. The reference cell should be positioned over native soil only. Never attempt to measure through concrete, asphalt, etc.

Soil Condition
   Saturate the soil around the test location with clean water if dry conditions are encountered. Avoid Contaminated soil.

IR (Voltage) Drop (Error)
   See all conditions listed above.

Outside Air Temperature
   The reference cell is stable and calibrated at an ambient temperature of 70 degrees F. The reference cell will have a potential difference of 0.5mV per 1 degree F from ambient temperature.

Inclement Weather
   Never conduct potential measurements during severe weather conditions. Also, saturated/conductive equipment and personnel will lead to erroneous potential readings.

Experience
So....... To Summarize

- Corrosion is the degradation of steel due to a reaction with its environment
- Cathodic Protection is achieved when the cathodic sites of a structure are polarized in the direction to the potential of the most anodic sites on the same structure
- Cathodic Protection can be ‘proved’ by following recommended practices to meet criteria