Galvanic System Design

2017 Purdue Corrosion Short Course Advanced Section

Period #6

Advanced Corrosion Course 2017
Galvanic System Applications

► AC is not available
► Current requirement and resistivity are low
► Stray current mitigation
► Well coated Structures
► Hot spot protection
► Supplement impressed current systems
► Temporary protection during pipeline installation
► Protection from induced AC during construction
► Some small structures where IC is not practical (inside water heaters, heat exchangers, chillers, etc.)
Anode Selection Considerations

- Current Requirement
- Total weight of each type of anode
- Anode life calculations
- Desired life of installation
- Efficiency of anode materials
- Theoretical consumption rates
- Driving potentials
- Soil or water resistivity
- Cost of anode material and shipping
- Skill required for proper installation
- Electrolyte considerations
  (chemistry, soil, seawater, brackish mud)
Anode Selection Flow Chart

- Electrolyte Considerations
  - Current Requirement
    - Driving Potential
    - Electrolyte Resistivity
  - Desired System Life
    - Consumption Rate
    - Anode Material Efficiency
- Anode Weight
- Skill Level Necessary for Installation
- Cost of Installation (Labor, Equipment, Anodes, and Freight)
Galvanic Series
(Volts with respect to Cu/CuSO4 reference electrode)

- Magnesium (high potential alloy) -1.75
- Magnesium (low potential alloy) -1.55
- Zinc -1.1
- Aluminum -1.1
- Low Carbon Steel/Cast Iron -0.75
- Low Alloy Steel -0.7
- Copper -0.2
- Platinum +0.1

Each metal has a typical potential range. Environmental conditions and metal purity/alloying will dictate the exact potential.
How does it work?

- CP current, through the electrolyte, from the more active metal (anode) polarizes the cathodic locations on the more noble metal to the open circuit potential of the most anodic locations (The galvanic anode protects the more noble structure (cathode))
- Happens for any two dissimilar metals electrically coupled in an electrolyte
- Galvanic anode will corrode through two processes; Protecting the structure and normal galvanic corrosion of its own surface (self corrosion, it effects the anode efficiency)
- Magnesium & Steel
- Steel & Copper
- Zinc & Copper
- Magnesium and Zinc
Cathodic Protection Concept
Microscopic corrosion cells on the buried metal surface.

The concept of cathodic protection involves reducing the potential difference between local anodic and cathodic sites on a metal surface to zero, resulting in zero corrosion current flow.
Galvanic anode systems

▶ Galvanic (or sacrificial) cathodic protection makes practical use of dissimilar metal corrosion.
▶ There must be a substantial potential difference, or driving voltage, between a galvanic anode and the structure to be protected.
▶ The galvanic anode is connected to the structure it is protecting, either directly or through a test station so it can be monitored.
▶ A shunt (calibrated fixed resistance) is connected between the anode’s cable and structure’s cable to help in the current monitoring.
Anode Material Characteristics

► Magnesium
  – Good driving potential (about -1,550 mV for regular Mg anode, and about -1,750 mV for high pot anode)
  – Performs well in low to mid resistivity soil (up to 10,000 ohm*cm)
  – Passivates in presence of carbonates and bicarbonates
  – Chlorides tend to increase the self corrosion of magnesium and reduce its current efficiency
  – High consumption rate
  – Inefficient (particularly at low current density) - <50%

► Zinc
  – Small driving potential (-1,100 mV)
  – Performs well in sea water and very low resistivity soils (up to 1,500 ohm*cm)
  – Tolerant of contaminants
  – Develops passive films and cease to produce useful amount of current, in presence of phosphates, carbonates and bicarbonates.
  – High consumption rate
  – Efficient as anode - 90%

► Aluminum
  – Small driving potential (-1,100 mV)
  – Performs well in sea water
  – Low consumption rate
  – Efficient as anode – 90%
Galvanic Series

- Typical ranges for metals
- Referenced to saturated calomel reference electrode
Driving Voltage and Current Relationship

▶ Ohm’s Law  
\[ E = I \times R \quad \text{or} \quad I = \frac{E}{R} \]

▶ \( E_{\text{driving}} = E_{\text{anode}} - E_{\text{cathode}} \) (for zinc and aluminum anodes)

▶ \( E_{\text{driving}} = E_{\text{anode}} - (-0.1\text{volt}) - E_{\text{cathode}} \) (for magnesium anodes)

▶ Circuit Resistance is a function of soil resistivity and surface area

▶ Variables that corrosion personnel can control include: Anode placement (soil resistivity, easement available), choosing anode material, number of anodes to install, and what type of anode is to be used
Circuit Resistance

- \( R_{\text{circuit}} = R_{\text{groundbed}} + R_{\text{cathode}} + R_{\text{circuit wiring}} \)

- Anode to earth resistance
  - Sunde (multiple vertical anodes in parallel) or Dwight (single vertical or horizontal anode) formulas

- Cable resistance
  - Page 34 (IC Text), table of R values in ohms per 1000’

- Structure to earth resistance
  - Measure with 3 pins method
  - Estimate mathematically from pipe material and shape, and coating characteristics.
  - Calculate using current response data with respect to reference electrode at remote earth
Key Design Parameters

► Anode to remote earth resistance
  – Cable resistance is low and fixed
  – Anode to earth resistance can be changed by:
    ► Resistivity of soil at the site for anode installation selected
    ► Anode shape
    ► Number of anodes installed
    ► Distance between anodes in the groundbed.
    ► Anode backfill

► Anode efficiency
  – Amount of anode material not consumed in “self corrosion”
  – Efficiency is optimal (50%) with magnesium when current density is at least 30 mA/sq ft of anode surface.

► Cathode to remote earth resistance is fixed
**R_{\text{groundbed}} Calculation**

- Assume: 6 each 5”x66” zinc anodes (60lb), 1,500 ohm-cm soil, 15’ anode spacing, in vertical configuration.
- Anodes are at remote earth respect to the protected structure.
- Calculate using Sunde’s equation for multiple vertical anodes

\[
R_{\text{gbed}} = \frac{0.00521 \rho \times [(\ln 8 L + d) - 1 + 2 L (\ln 0.656 N)]}{N L}
\]

Where:
- \(R_{\text{gbed}}\): Resistance of the total number of vertical anodes in parallel (ohms)
- \(\rho\): Electrolyte resistivity (ohm-cm)
- \(L\): Length of the anode (feet) (packaged dimension)
- \(d\): Diameter of anode (feet) (packaged dimension)
- \(N\): Number of anodes in parallel
- \(S\): Center-to-center spacing of anodes (feet)
- \(\ln\): Natural log = 2.3 log₁₀

\[
R_{\text{gbed}} = \frac{0.00521 \times 1500 \times [(\ln 8 \times 5.5) - 1 + 2 \times (5.5) (\ln 0.656 \times 6)]}{6 \times 5.5}
\]

\[
R_{\text{gbed}} = 1.10 \text{ ohms}
\]
Lowering Anode to Earth Resistance

► Site selection
   – Choose an area of low resistivity and chemically compatible to anode material

► Anode shape
   – Longer anodes have more surface area and hence lower resistance to earth

► Number of anodes installed
   – More anodes increase surface area hence decreasing resistance and reducing current density from anode

► Distance between anodes
   – Increasing the distance between anode, the resistance of groundbed is decreased.

► Anode backfill
   – Gypsum, sodium sulfate, & bentonite ensure good contact between the earth and anode material, contribute to anode efficiency and increase the anode size, decreasing anode resistance to remote earth, when anodes are installed in soil having a resistivity higher than that of the backfill.
Why use magnesium?

► Driving voltage

- $I = \frac{E}{R}$
- $E =$ anode potential – desired cathode potential
- If desired cathode potential is -0.900,
  - for zinc $E = -1.10V - (-0.90V) = -0.2V$,
  - for magnesium $E = -1.75V - (-0.1V) - (-0.90V) = -0.75V$
- Magnesium provides 3.75 times as much driving voltage as Zinc (for this example)
Performing design calculations

► Units, units units

– Watch

► Volts – millivolts
► Amps – milliamps
► Log base 10 vs. natural log
► Feet vs. inches
► Resistance - conductance
Design Process

1. **Calculate surface area**
   a. For anode to remote earth resistance calculations use chemical backfill dimensions and for anode current density use anode material dimensions
   b. Dimension data is available from anode supplier

2. **Estimate or measure current requirement**
   a. Several acceptable methods
      i. Minimum On voltage Drop (-300 mV, between structure and a reference electrode at remote earth)
      ii. E log I method
      iii. Assume % bare structure, current density requirement for literature and calculate
      iv. Estimate from personal experience or from other systems with similar environments

3. **Calculate quantity of anode material for desired life**
   a. Use anode life calculations from page 10 in manual

4. **Calculate ground bed resistance**
   a. Dwight’s equation for vertical or horizontal single anodes.
   b. Sunde’s equation for multiple vertical anodes in a groundbed.
Design Process (continued)

5. Measure or estimate cathode resistance
   a. Measure shift w/ applied current (remote half-cell)
   b. Estimate from coating conductance data and structure area in contact with electrolyte.

6. Calculate cable resistance
   a. Use table on page 34, Impressed Current text

7. Calculate total circuit resistance
   a. \( R_{\text{circuit}} = R_{\text{groundbed}} + R_{\text{cathode}} + R_{\text{circuit wiring}} \)

8. Calculate ground bed current output
   a. \( I_{\text{groundbed}} = \frac{E_{\text{driving}}}{R_{\text{circuit}}} \)

9. Compare to required current

10. If the \( I_{\text{groundbed}} \) is less than needed, the circuit resistance should be decreased, increasing the amount of anodes, and/or distance between anodes.
Summary

► Typical galvanic CP system are distribution systems where current requirements are low
► Driving voltage and circuit resistance determine current output
► Anode efficiency impacts life of the anodes
► Rules of thumb save time
► The design process is largely the same for galvanic and impressed current systems