Jeremy Hailey

Northwest Corrosion Engineering

360.826.4570

nwcorrosion.com

Introduction

Jeremy Hailey, P.E.

- Corrosion Engineer with 16 years experience
- Started NW Corrosion Engineering 10 years ago
- Focus on corrosion control system designs, troubleshooting, and some installation work
- Conduct training seminars and classes for Steel Tank Institute, National Association of Corrosion Engineers, and the American Water Works Ass’n.
- NACE Certified Corrosion Specialist, Cathodic Protection Specialist, and Certified Coating Inspector

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Northwest Corrosion Engineering

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Topics of Discussion

1. Corrosion Theory
2. Methods of Corrosion Control
3. Corrosion Protection Criteria
4. Considerations for Design of Corrosion Control Systems

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Corrosion Theory

- All materials have various physical properties
  - Color, hardness, ductility, shear strength, ability to conduct heat, melting point, electrical potential…..
- Corrosion in metal occurs because of an electrical imbalance, or electrical potential difference.
- Much like when two beakers of water, each at a different temperature, are poured together the resulting temperature will be somewhere between the two starting temperatures.

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Requirements of a Corrosion Cell

- For corrosion to occur, four individual items must be present:
  1. Anode – The place where corrosion occurs; the more electronegative site
  2. Cathode – Location being protected from corrosion; the more electropositive site
  3. Electrolyte – Medium supporting ionic current flow, generally water or soil
  4. Metallic Path – Material that allows for the transfer of electrons.

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Demonstration

- Measure the electrical difference between various materials and a stable reference electrode
- Arrange materials according the their relative electrical potential (galvanic series)
- Conclusion:
  - Materials that are more electronegative will corrode to protect those that are more electropositive.

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Galvanic Series

Material	Potential (mV)
Magnesium	-1750
Zinc	-1100
Aluminum	-1050
New Carbon Steel	-500 to –800
Stainless Steel	-300
Rusted Carbon Steel	-200 to –500
Copper	-200

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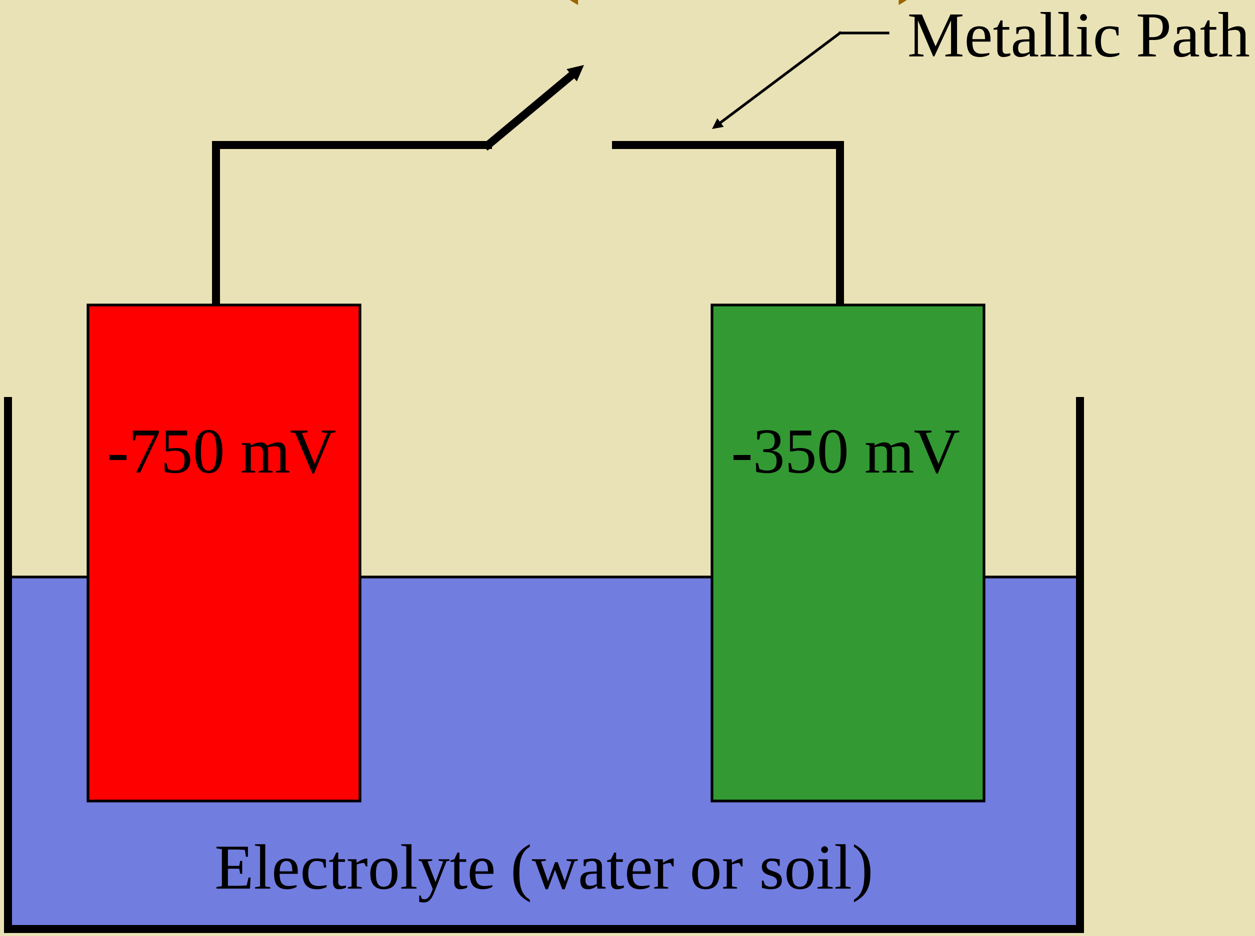
Corrosion Cell (almost)



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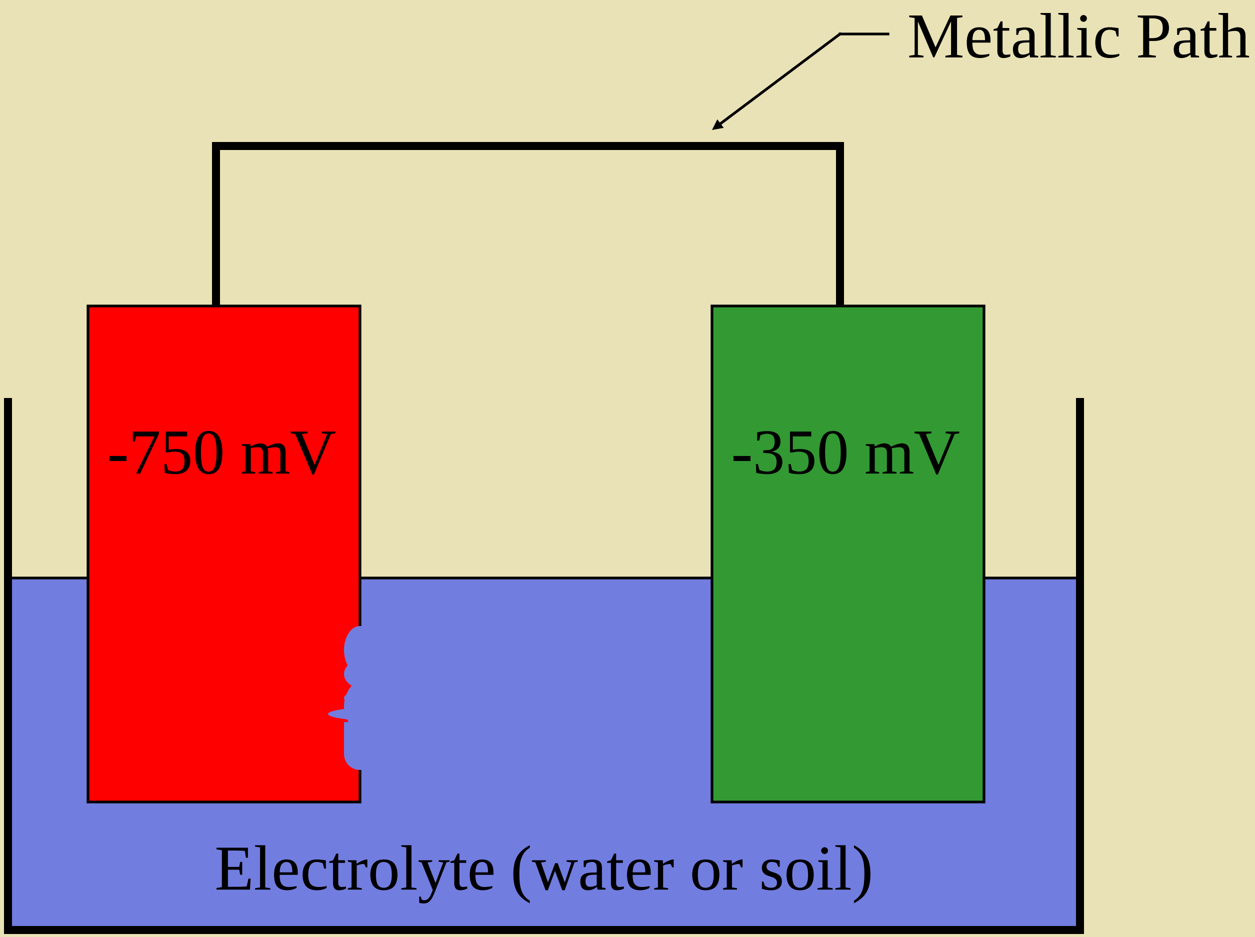
Corrosion Cell



Mixed potential will be between –750 and –350 mV

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Corrosion Cell

- Because there is now a metallic path between the two metals to support electron (current) flow, corrosion will be occurring at the anodic, or more negative, material.
- The amount of corrosion is a function of the materials consumption rate. For example, 1 ampere of current flowing off a ductile iron pipe for one year will result in 20 pounds of metal loss.

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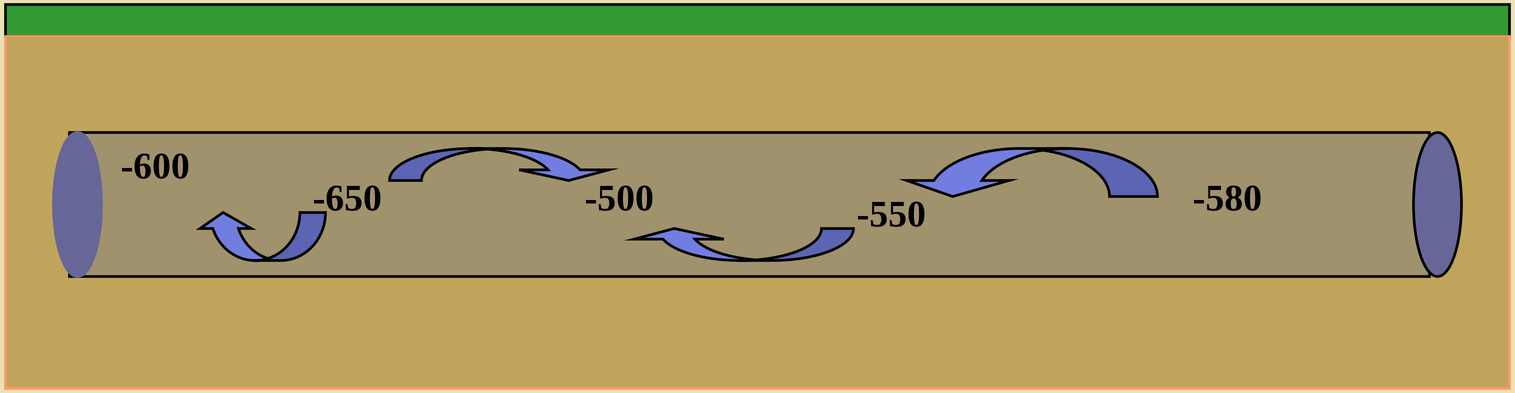
Unfortunately…………..



Potential differences can exist within the same structure, resulting in current flow and subsequent corrosion.

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What is Corrosion Why Does Corrosion Occur?

- Corrosion is the deterioration of a material, usually a metal, resulting from a reaction with its environment.
  - Metals tend to want to revert back to their ores.

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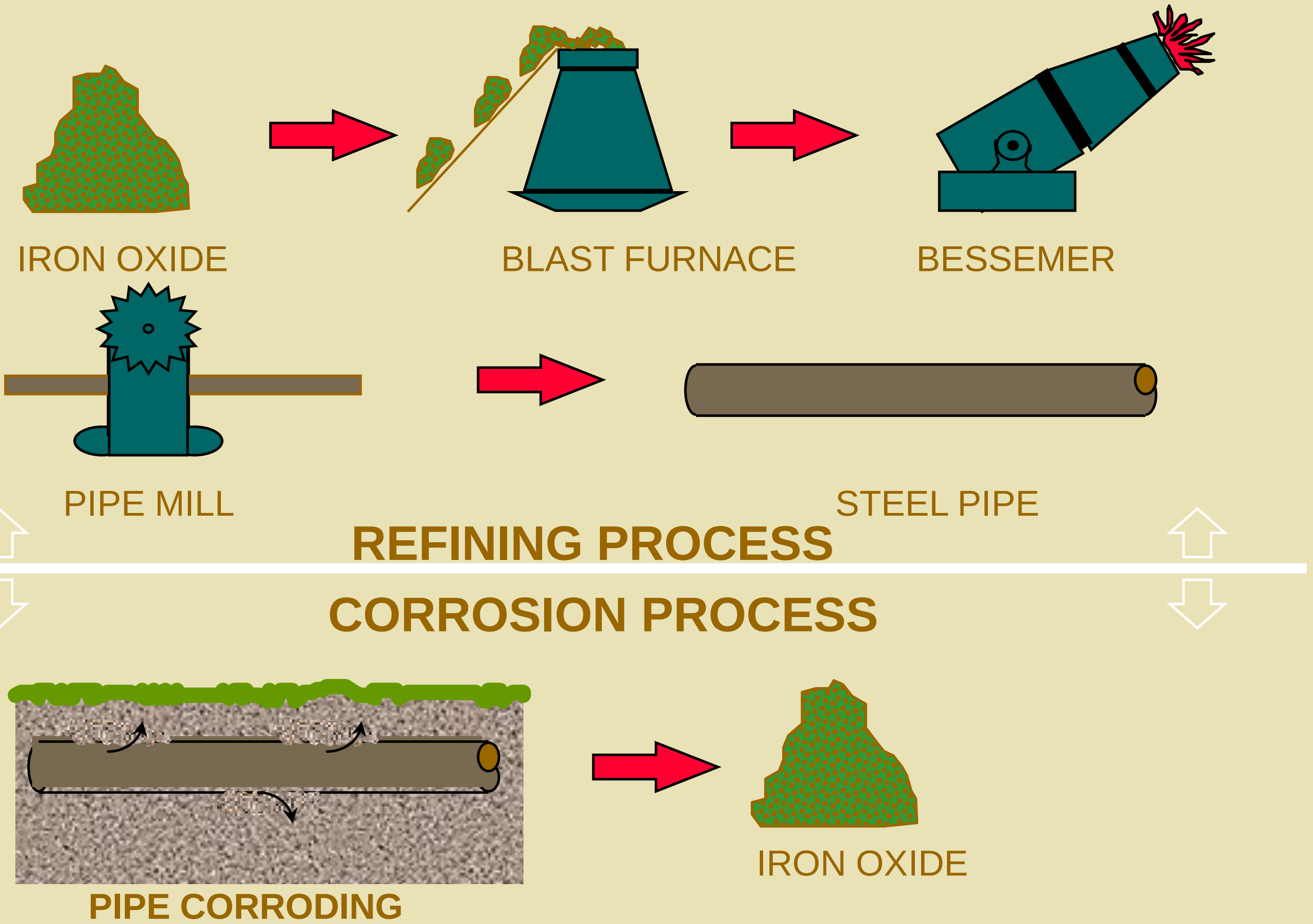
For Example:



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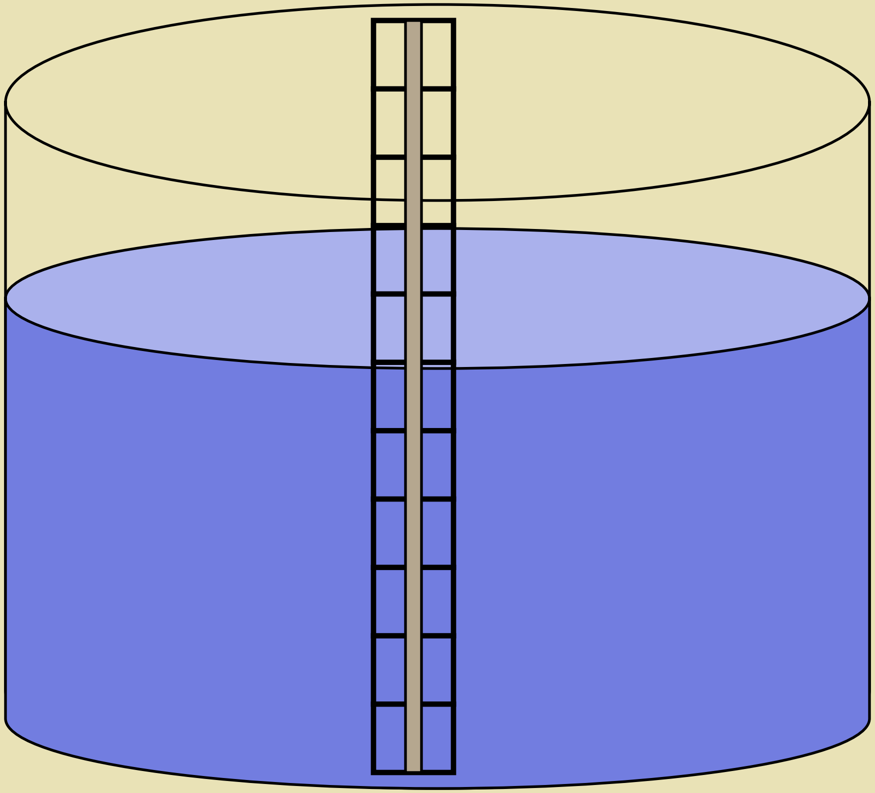
A Carbon Steel Tank and Internal Ladder Connected to a Galvanized (Zinc-Coated) Steel Safety Rail



What will happen to the safety rail?

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Methods of Corrosion Control

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What Can We Do About It?

- Now that we are familiar with how and why corrosion occurs, what techniques are available to slow or stop the process?
  - Material Selection
  - Environment Alteration
  - Coatings
  - Cathodic Protection

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Material Selection

- Titanium – Resistant to most corrosive environments.
- Fiberglass, HDPE, Polyethylene, etc.
  - Will not conduct current.

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Material Selection

- The major drawback of using exotic metals for corrosion control is cost.
- Non-metallic piping is used for a majority of new installations and facility upgrades.

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Alter Environment

- A closed-loop hot water circulation system is an ideal location for corrosion to occur.
- Differences in temperature will promote corrosion cells.
- Example: Cooling system of a engine has temperature differentials and dissimilar metals.
- Fortunately, antifreeze is manufactured with corrosion inhibitors that absorb the free oxygen and leave a thin surface film that significantly slows the corrosion process.

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Coatings

- Coatings are the first line of defense against corrosion.
- Good coatings provide a barrier between the substrate and electrolyte.
- Coatings must be properly specified for service conditions.

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Cathodic Protection

- Cathodic Protection uses the principals of current flow to force a material to consume in preference of another material.
  - In other words, we decide what will corrode.
- Cathodic Protection is generally provided in two forms:
  - Galvanic Anode
  - Impressed Current

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Galvanic Anode Cathodic Protection

- Galvanic anode cathodic protection relies upon the potential difference between to materials to provide protective current.
  - Galvanic Chart
- Common galvanic anode materials include:
  - Magnesium
  - Zinc

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Magnesium Anodes

- Used where higher current outputs are required.
- Used in higher resistivity soils and waters.
- Common applications include:
  - Hot water heaters
  - Well coated tanks
  - Well coated pipelines

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Magnesium Anode Installation

Drill holes to required depth

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Magnesium Anode Installation

Prepare anodes for installation

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Zinc Anodes

- Have a lower driving potential than magnesium – they can't provide as much protective current.
- Are used in soils and waters.
- Commonly used on seawater vessels.

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Steel Tank With Three Zinc Anodes on Each Side

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Galvanic Anode Cathodic Protection

- Advantages Include:
  - Easy to install
  - Generally trouble-free operation
  - Does not require an external power source
  - Require very little maintenance
  - Little chance to cause stray current interference

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Galvanic Anode Cathodic Protection

- Disadvantages:
  - Limited “throwing” capacity.
  - May not provide adequate corrosion control for bare or poorly coated structures.
  - Generally have a shorter design life than impressed current systems.

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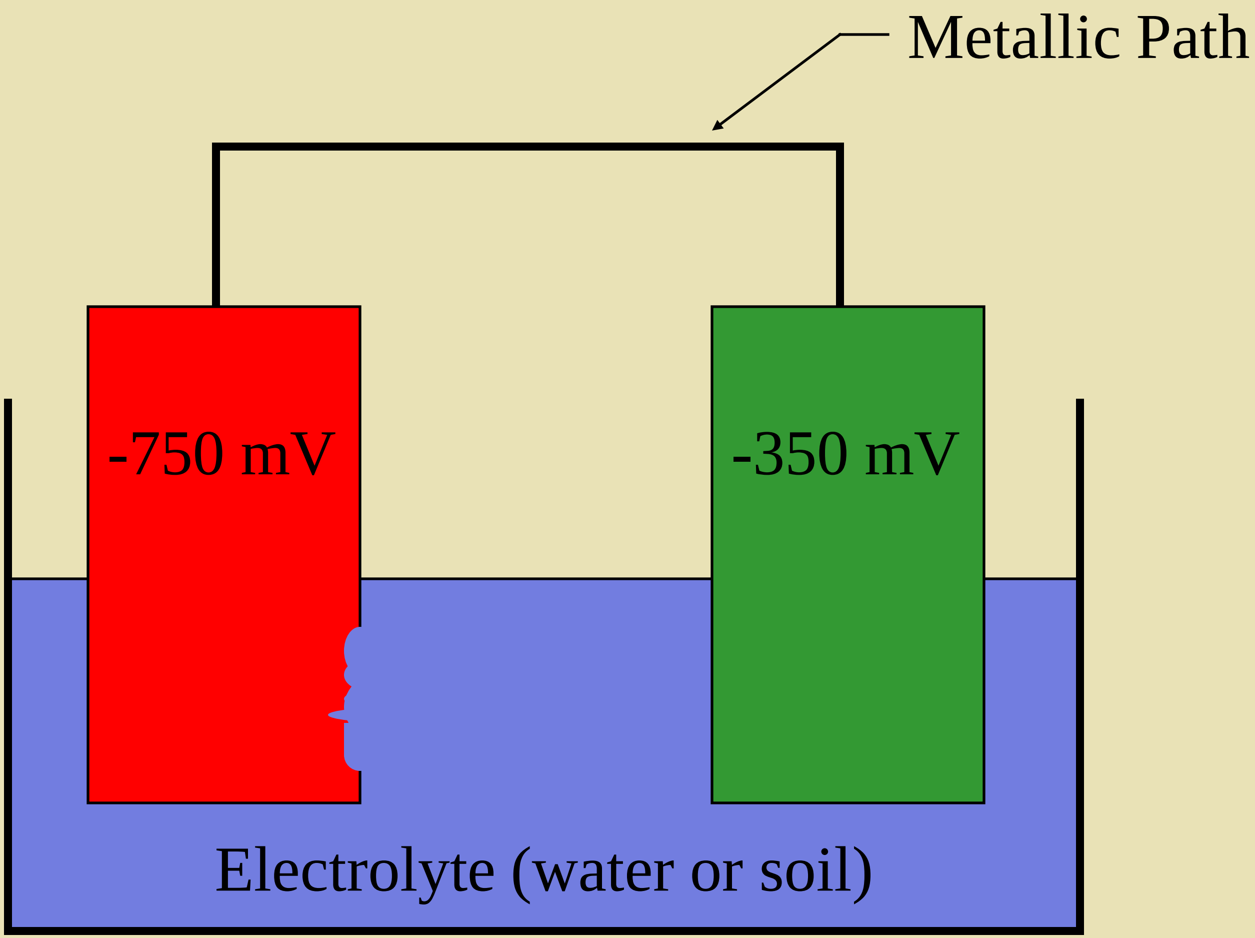
Galvanic Anode CP Systems



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Impressed Current Cathodic Protection (ICCP)

- ICCP relies upon a transformer rectifier to supply the driving voltage to the anodes.
- ICCP anodes are generally inert materials with very low consumption rates (typically 1-2 pounds per amp-year as opposed to upwards of 17 pounds per amp-year for some galvanic anodes).

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Northwest Corrosion Engineering

360.826.4570

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Transformer Rectifier

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Impressed Current Cathodic Protection (ICCP)

- ICCP systems are used where a large amount of current is required, such as bare or poorly coated pipelines and electrically shorted UST systems.
- Advantages of ICCP:
  - Can be used to provide current a significant distance.
  - Typical system design life is a minimum of 20 years.
  - Generally operate trouble-free.

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Impressed Current CP Systems

Disadvantages:

- Higher initial cost.
- Requires an AC power source
- Higher maintenance requirements.
- Must monitor rectifier output bi-monthly.
- Higher probability of stray current interference.

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Common ICCP Anode Materials

- High Silicon Cast Iron
- Graphite
- Mixed Metal Oxide
- Platinum Wire/Mesh
- Scrap Iron

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Northwest Corrosion Engineering

360.826.4570

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Vertical Anode Installation For An Impressed Current Cathodic Protection System to Provide Corrosion Control To An Underground Storage Tank

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Auger Truck and Drilling Bit

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Canister Anode

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Trenching Cables

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Impressed Current CP Systems

Impressed current systems utilize a power source to force current from one structure to another.

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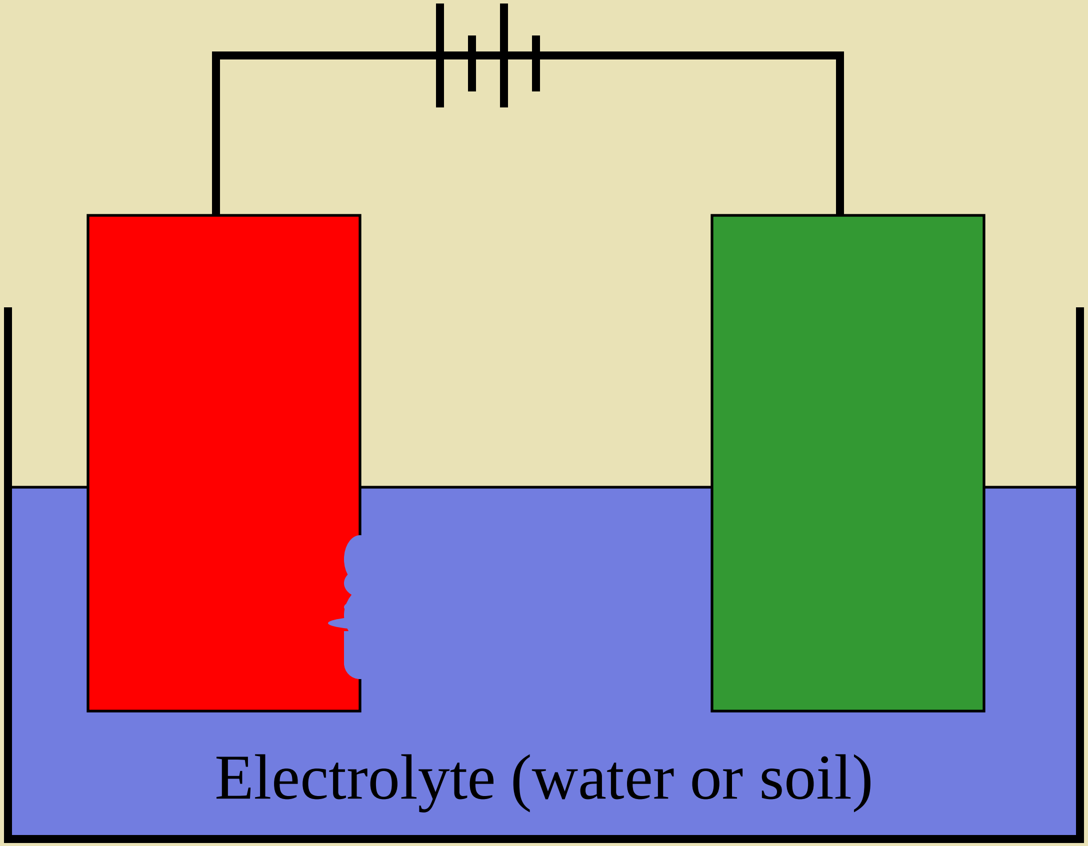
Impressed Current CP Systems



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Corrosion Control Protection Criteria

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Regulatory Requirement of UST Operation – Corrosion Control

- 40 CFR Protection of Environment Subchapter I, Part 280 outlines the requirements for owners and operators of UST's.
- Corrosion control must be maintained to continuously provide corrosion protection to all metallic components of the portions of the system that routinely contain regulated substances and are in contact with the ground.
- As of December 22, 1998, all underground steel tanks containing hazardous materials were required to maintain effective corrosion control.

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Northwest Corrosion Engineering

360.826.4570

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Regulatory Requirement of UST Operation – Corrosion Control

- Exceptions to this regulation include:
  - All tanks under 110 gallons
  - Farm or residential fuel tanks of 1,100 gallons or less capacity used for storing motor fuel for noncommercial purposes
  - Home heating oil fuel tanks

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Regulatory Requirement of UST Operation – Corrosion Control

- Acceptable corrosion control criteria is outlined in NACE RP0285 - Corrosion Control of Underground Storage Tank Systems by Cathodic Protection.
- API Publication 1632 Cathodic Protection of underground Petroleum Storage Tanks and Piping Systems.
- ISO Standard 15589-1

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360.826.4570

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Regulatory Requirement of UST Operation – Corrosion Control

- Corrosion Control Criteria:
  - Polarized potential of at least –850 millivolts (Cu-$CuSO_4$).
  - Minimum 100 millivolts of polarization, taking into account all IR drops except those across the structure to electrolyte boundary.
  - ON potential of at least -850 millivolts (Cu-$CuSO_4$).

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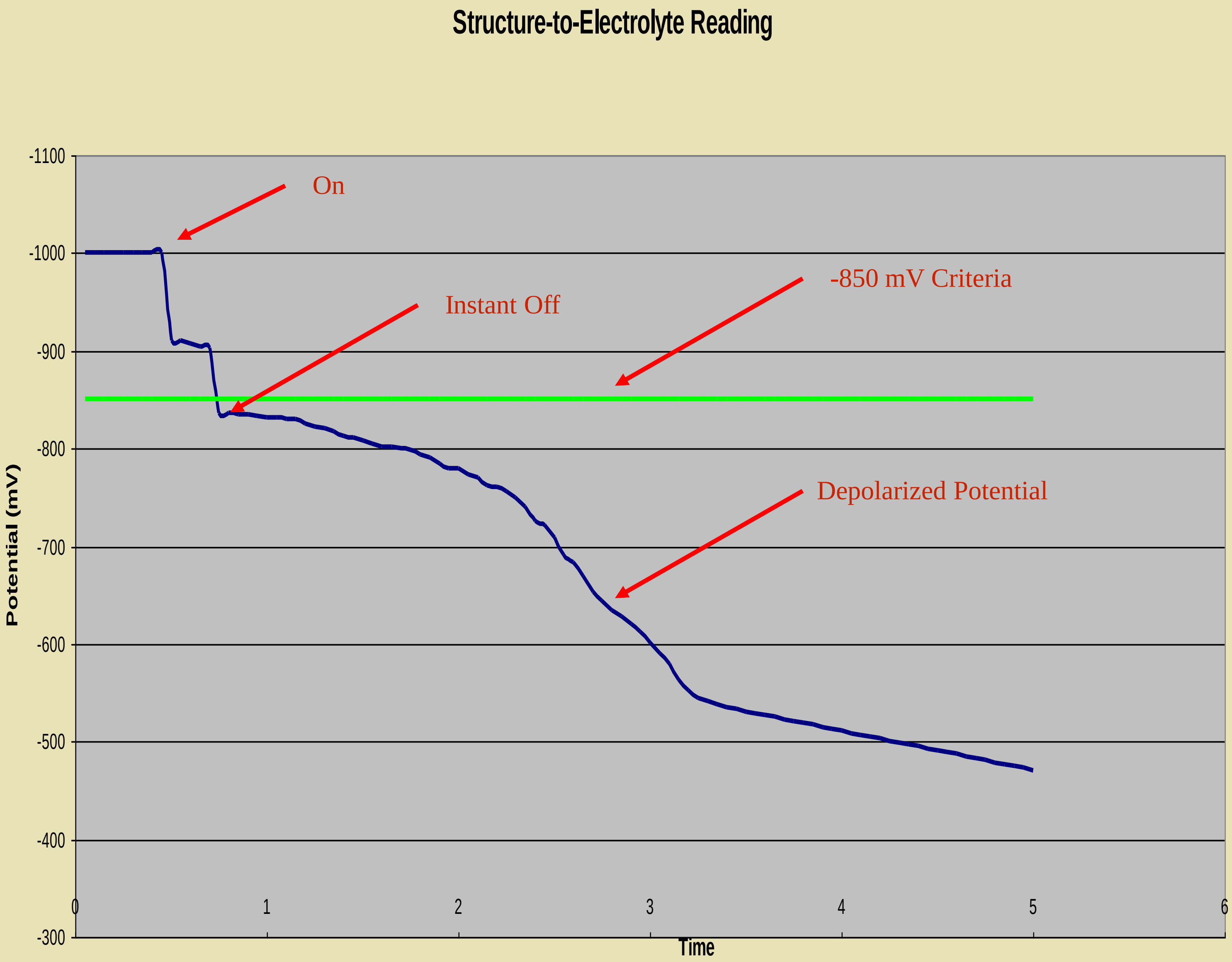

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Testing Requirements: Galvanic Anode CP Systems

1. All galvanic anode systems must be inspected at the time of installation and within 6 months of installation or system repair/upgrade.
2. Adequate corrosion control criteria must be verified every three years.
3. Records of the previous two potential surveys must be maintained.

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Testing Requirements: Impressed Current CP Systems

1. All impressed current systems must be inspected after installation and within 6 months of installation or system repair/upgrade.
2. Proper operation of the rectifier must be verified bi-monthly. Inspection includes documentation of rectifier output.
3. Adequate corrosion control criteria must be verified every three years.
4. Records of the previous three months of rectifier inspections must be kept on site as well as records of the previous two potential surveys.

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Northwest Corrosion Engineering

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Design Considerations

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General Information

- Each site is specific unto itself. Because of this, each facility should have a corrosion control system design that its tailored for its requirements.
- Some companies use a canned design for all sites. These designs are based upon a worse case scenario and generally result in a system that is more than what is required.
- The result is additional cost to the site owner.

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Components of a Steel UST

- Fuel station underground storage tanks incorporate several components for their operation:

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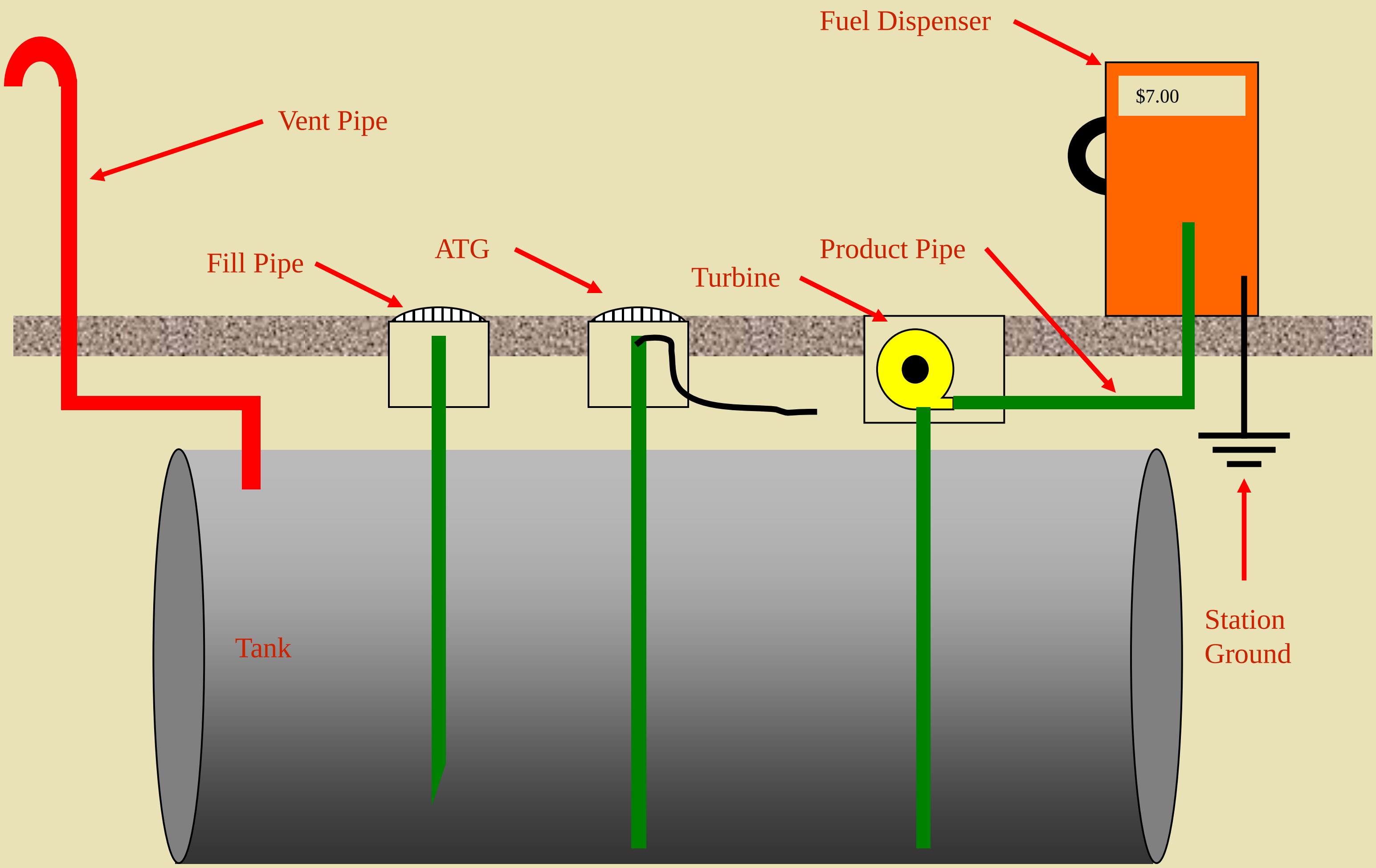
UST Components



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Field Tests – For Starters

Site layout

- A site layout provides important information concerning the location of the UST’s, product piping, vent pipes, electrical conduits, and other buried utilities.
- Yeah right – best of luck getting an accurate site drawings.

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Field Tests

1. Electrical continuity testing

- After you have established that you won't be getting your hands on a site map, it is important that you establish what components of the UST system are electrically continuous. These components include:
  - Tanks
  - Product piping
  - Vent piping
  - Dispenser piping
  - Electrical conduits
  - Electrical grounds
  - Other facilities (water pipe, sewer pipe, gas lines…..)

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Field Tests

1. Electrical Continuity Testing

- Electrical continuity testing establishes what structures are going to be included within the cathodic protection system design.
- Oftentimes, a short to the electrical conduit or AC grounding system will not allow for the use of galvanic anodes to provide adequate protection to the required structures.
- Methods of continuity testing include:
  - Point-to-point
  - Fixed cell moving ground
  - Current response

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Field Tests

2. Current Requirement Determination

- Current requirement testing involves connecting a temporary anode to the structure. Then apply cathodic protection current, and determine the change in electrical potential due to the application of that current.
- Adjustment of the current is made until corrosion control criteria is met or judgment can be made as to how much current will be required.
- This testing takes a bit of practice and a good eye for potential temporary anodes.

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Field Tests

1. Soil Resistance Testing

- Once the amount of protective current that will be required is arrived at, the condition of the ground surrounding the tanks and where the anodes are to be installed must be determined.
- Determine soil resistivity in accordance with ASTM Test Method G57 – Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

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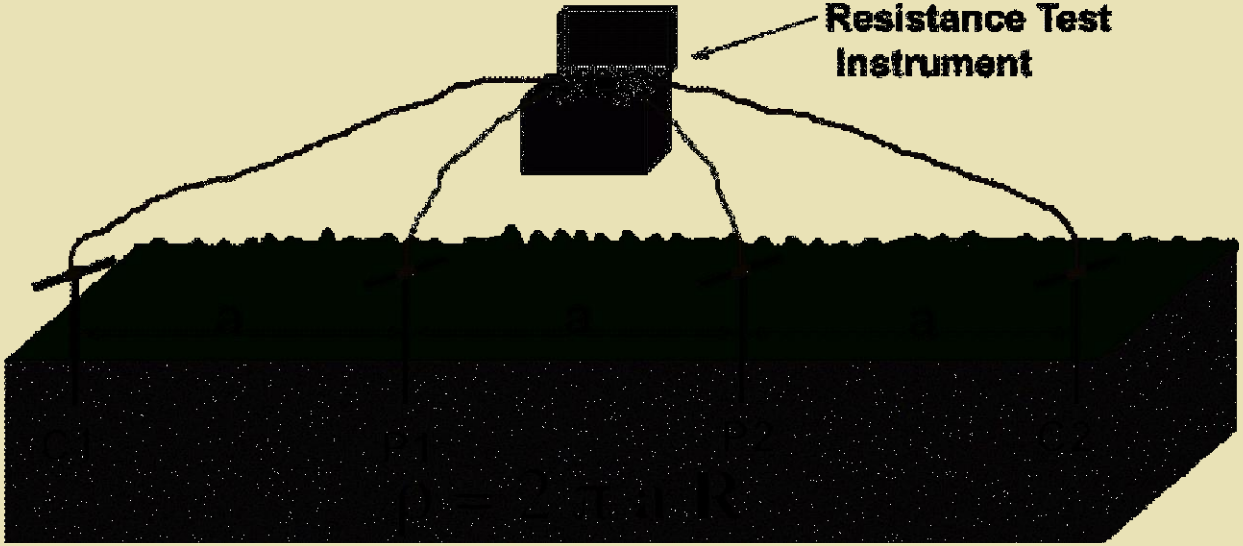
Field Tests



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Field Tests

- Once the soil resistance is known, the soil resistivity can be calculated.
- Now comes the fun part (actually its all fun) – figuring out what type of system will be required
  - Galvanic anode or
  - Impressed current

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Design Calculations

- Ohms law states that circuit resistance multiplied by current is equivalent to voltage. In other words:

  Volts = Current * Resistance (or V = I * R)

- We already know how much current (I) we need from out current requirement tests.
- The trick becomes figuring out what our circuit resistance is. To do this we use Dwight's equation, plugging in our value for soil resistivity, and run different anode scenarios (both quantity and size of anode) to determine our total resistance.

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Design Calculations

- Using a form of Dwight's Equation, we can calculate the resistance to earth of various anode configurations:

$RGB = (.00521 * \rho)/(N*L) * [(\ln (8L/d) – 1) + (2*L/S) * \ln (0.656 * N)]$

- If we are interested in using a galvanic system, then we already have two of the variables of Ohms law figures out: $V = I * R$
- We know I from field tests
- We know V (just the electrical difference between the anode material and the structure
- We just need to find the right combination of anode quantity and size to ensure that our Resistance value is less than V/I

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Design Summary

- If our circuit resistance is too high to overcome using galvanic anodes, we then have to look at using an impressed current system.
- An IC system allows us flexibility in design because we can control the voltage.
- Again IC systems are most common when we have facilities where all the buried structures are electrically continuous or where the tanks have a poor coating.
- Galvanic systems work best where the current requirements are low (i.e. an electrically isolated, well coated tank).