Introduction to Cathodic Protection

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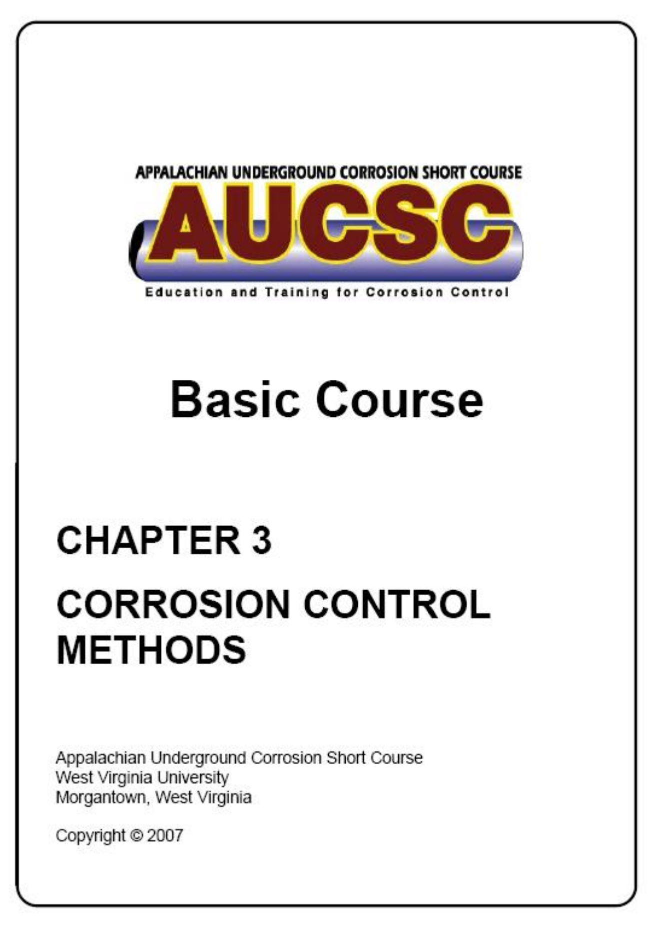
- This is “Fundamentals” so I will keep it simple.
- I am going to show you some formulas to help illustrate some “concepts” of cathodic protection.
- At the end of the class I will finish with a cathodic protection joke that you will be forced to awkwardly laugh at.
- After going through the class you should get the joke or I have failed you.
- You might not think it’s funny but you should at least get it.



APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
AUCSC
Education and Training for Corrosion Control

Basic Course

CHAPTER 3

CORROSION CONTROL METHODS

Appalachian Underground Corrosion Short Course
West Virginia University
Morgantown, West Virginia

Much of the material in this class comes from the Basic Course Chapter 3 – Corrosion Control Methods

What is Cathodic Protection?

NACE Definition

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

Introduction to Cathodic Protection

- A review of the fundamental corrosion cell
- Coatings and cathodic protection
- Electrical isolation fittings and cathodic protection
- When have we achieved cathodic protection?
- Cathodic protection current requirements
- Galvanic anode cathodic protection
- Impressed current cathodic protection

What structures can be cathodically protected?

- Any metallic structure that is buried or submerged

EXAMPLES -

- Pipelines
- Underground storage tanks
- The bottom of aboveground storage tanks
- The internal surface of water storage tanks
- The internal surface of household water heaters
- Lead sheath electric and telephone cables
- Waterfront structures such as docks and piers
- Power plant structures such as waterboxes and traveling screens
- Steel building piles
- Cars – if they are buried or submerged

Corrosion Control Methods

- Cathodic Protection
- Coatings
- Electrical Isolation

The 4 Parts of a Corrosion Cell

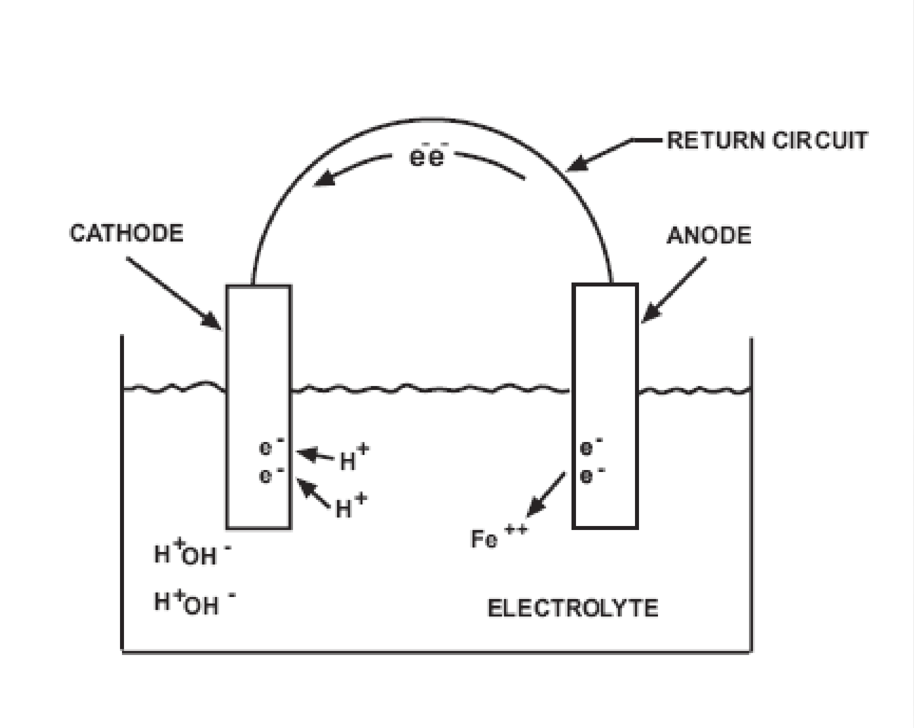
- Anode
- Cathode
- Electrolyte
- Return Circuit

If we are missing any one of these four things we will not have a corrosion cell.

Keep this in mind because we can use this to our advantage.

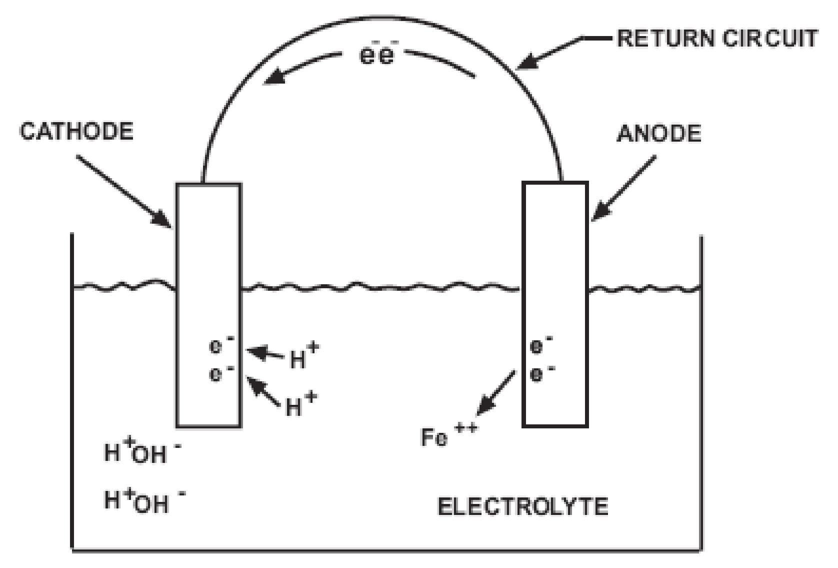
The Fundamental Corrosion Cell

- There are 4 parts to a corrosion cell:



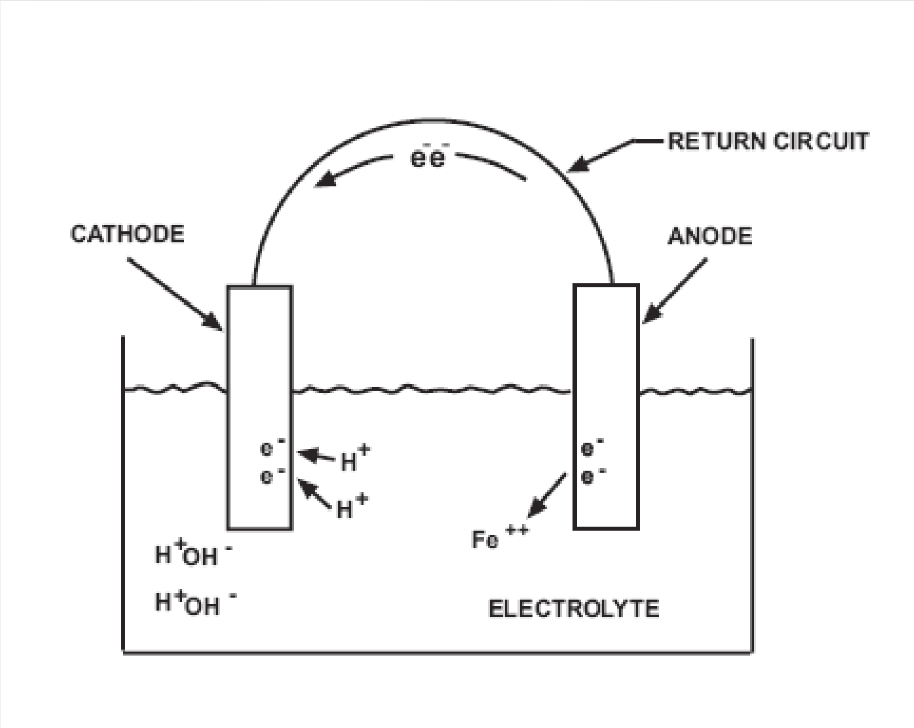
The Fundamental Corrosion Cell

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.



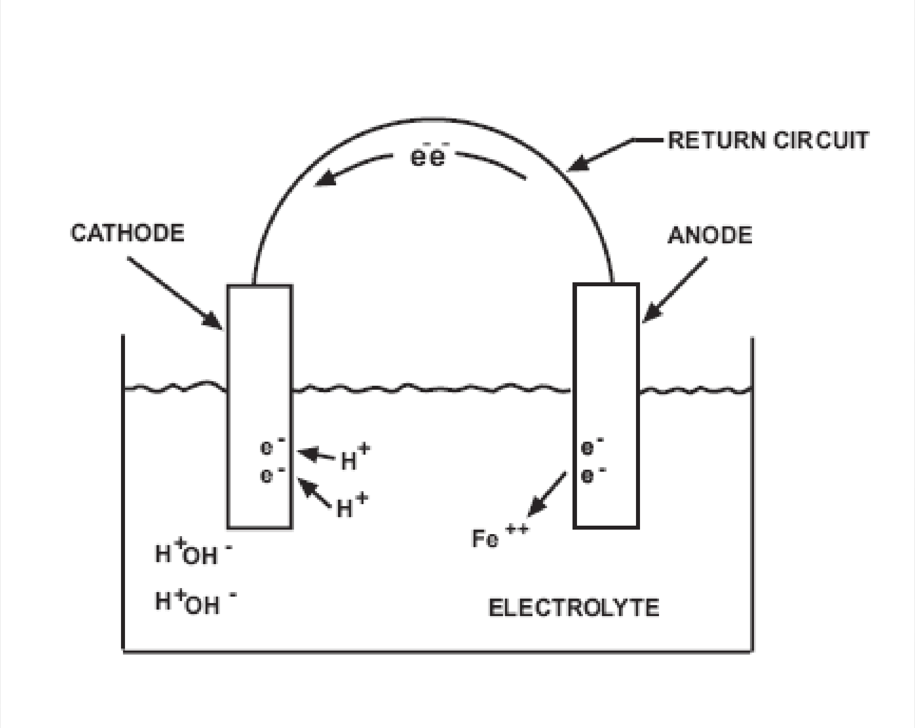
The Fundamental Corrosion Cell

- Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves the metal is called the anode. Corrosion occurs at the anode.



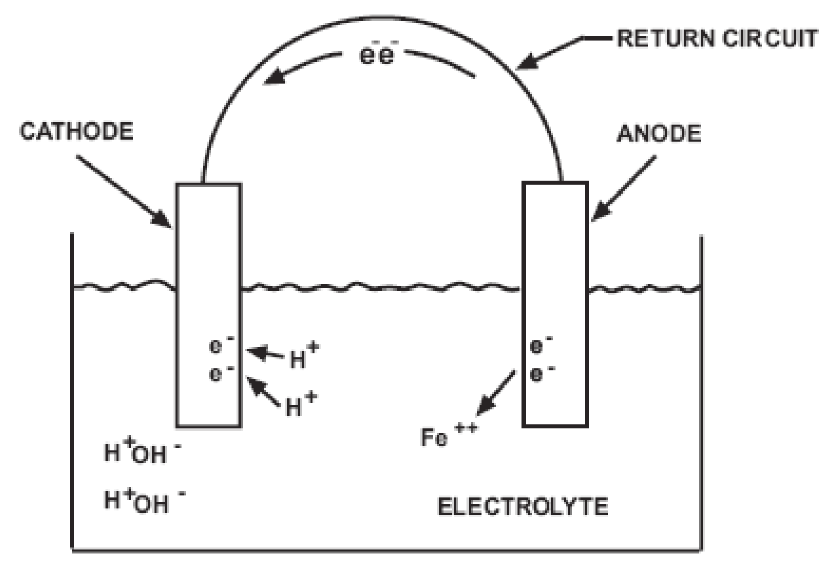
The Fundamental Corrosion Cell

- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A cathodic reaction occurs at the cathode. Most often this is the build up of a hydrogen film. This cathodic reaction is referred to as “polarization.”



The Fundamental Corrosion Cell

- The flow of current is caused by a potential (voltage) difference between the anode and the cathode.



The Fundamental Corrosion Cell and Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
- Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves the metal is called the anode. Corrosion occurs at the anode.
- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A cathodic reaction occurs at the cathode. Most often this is the build up of a hydrogen film. This cathodic reaction is referred to as “polarization.”
- The flow of current is caused by a potential (voltage) difference between the anode and the cathode.
- If we do not have any one of these four things we will not have a corrosion cell. We can use this to our advantage.

What is Cathodic Protection?

NACE Definition

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

Coatings and Cathodic Protection

- Coatings are the first line of defense in corrosion control.
- We don’t need cathodic protection if the metal is not in contact with the electrolyte. We have eliminated one part of the corrosion cell, the electrolyte.
- If we had a perfect coating, we would not need cathodic protection.
- Unfortunately, there is no such thing as a perfect coating. But very fortunate for corrosion technicians.
- The better the coating, the less cathodic protection we need. We only need to protect the bare areas.

Electrical Isolation and Cathodic Protection

- Electrical isolation fittings are used to confine cathodic protection current to a structure (or portion of a structure) to be cathodically protected.

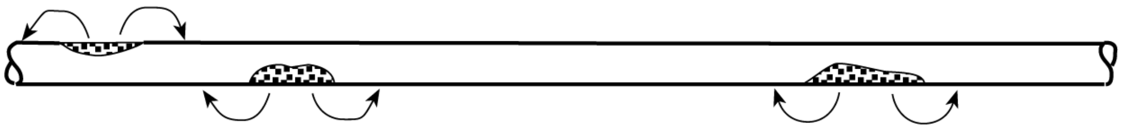
- Electrical isolation fittings eliminate the return circuit.

- We only want to protect the bare areas of our structure. Not the bare areas of other underground structures.

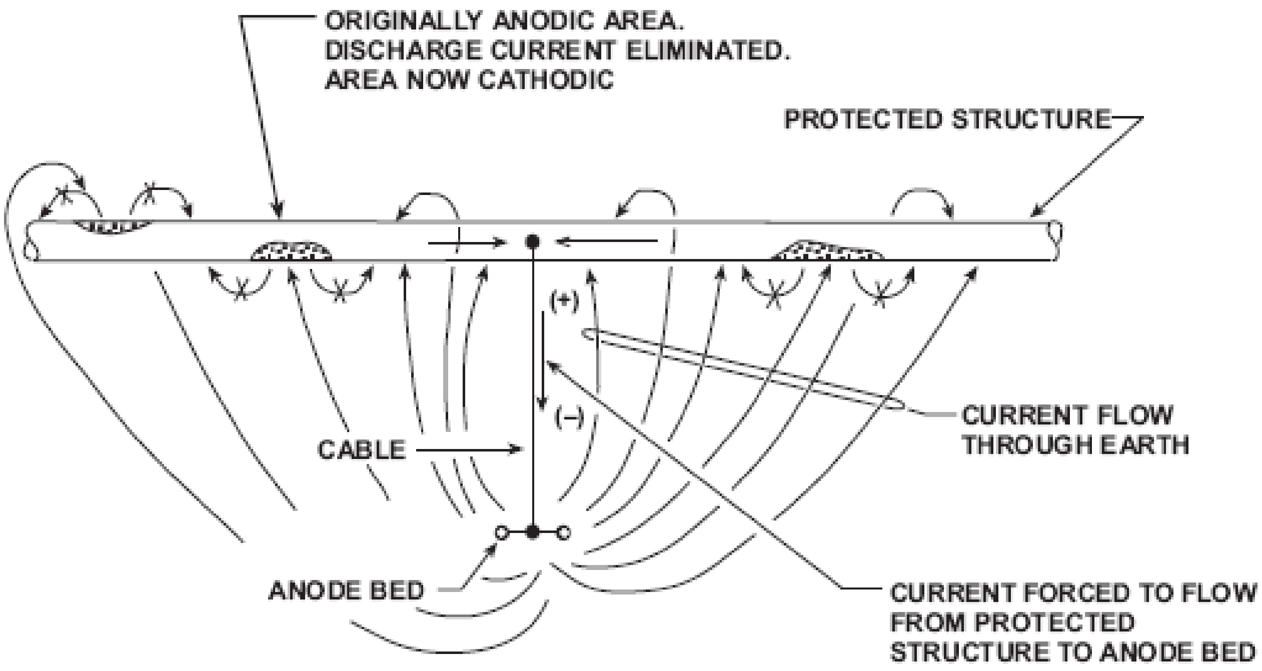
- Electrical isolation fittings are also used to separate cathodic protection systems from each other.

Theory of Cathodic Protection

- Anodes Corrode.
- Cathodes do not corrode.
- If we make the entire surface of our structure a cathode there will be no corrosion. Hence the name “cathodic protection” for this method of corrosion control.
- Direct current is forced to flow into the earth through a ground connection outside the structure (anode bed) and then through the earth to the structure to be protected.
- The amount of current forced to flow onto the structure is adjusted to a level which will nullify current discharge in anodic areas and result in net current collection in those areas.



Anodic areas on a pipeline.
Arrows indicate current leaving the metal and causing corrosion.

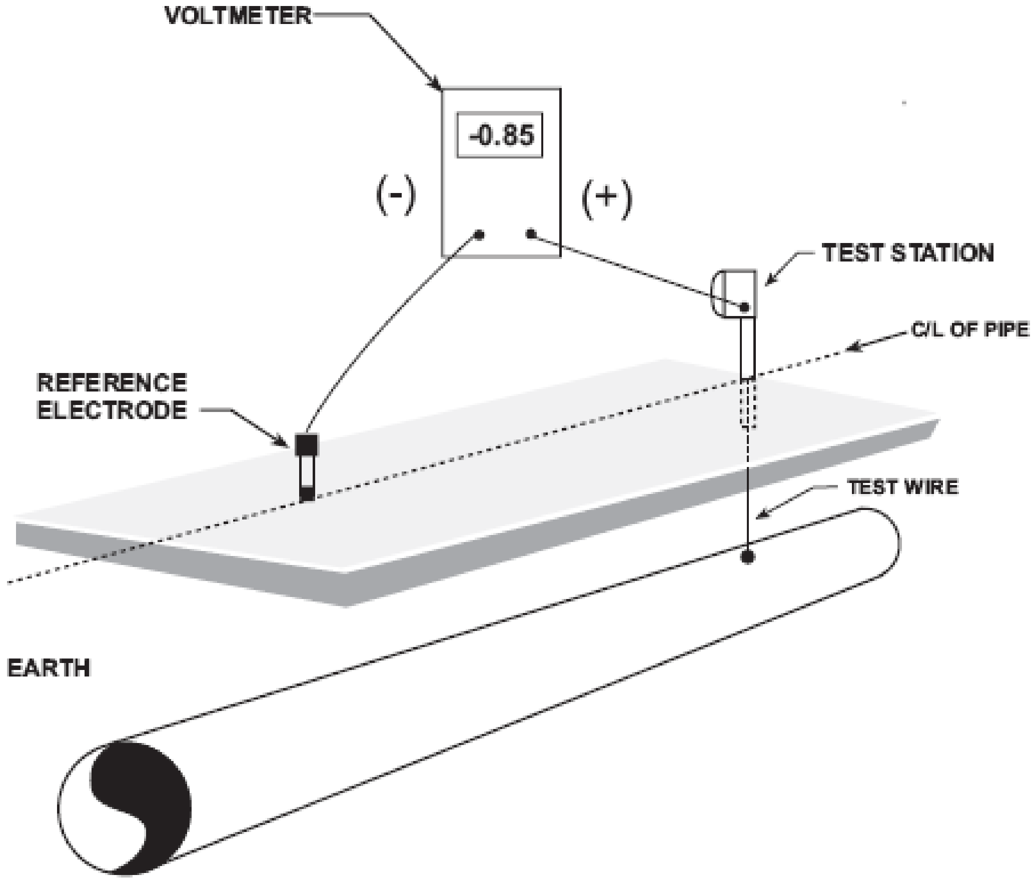


HOW CATHODIC PROTECTION WORKS

FIGURE 3-2

We have achieved cathodic protection when:

- We have net current flow onto our structure and we have caused a cathodic reaction to occur.
- In soil this cathodic reaction is typically the formation of a hydrogen film also know as polarization.
- We can determine if we have achieved cathodic protection by measuring the structure-to-electrolyte voltage.
- If the structure-to-electrolyte voltage meets a criterion we have achieved cathodic protection. The most common criterion for steel is -0.85 volts to a saturated copper/copper sulfate reference electrode (CSE) with IR considered.



PIPE-TO-SOIL POTENTIAL MEASUREMENT

Cathodic Protection Current Requirement

- The total amount of current needed to cathodically protect a structure.
- Primarily related to the amount of bare metal that our structure has in contact with the electrolyte.
- Short, well coated structures have a low current requirement.
- Long, poorly coated structures have a high current requirement.
- Electrical isolation fittings keep the current on the intended structure.

Two methods of cathodic protection:

- Galvanic anode or sacrificial anode cathodic protection. Sometimes referred to as a “passive” system.
- Impressed current cathodic protection. Sometimes referred to as an “active” system.

Both of these methods are ways to create a corrosion cell in which our structure is a cathode.

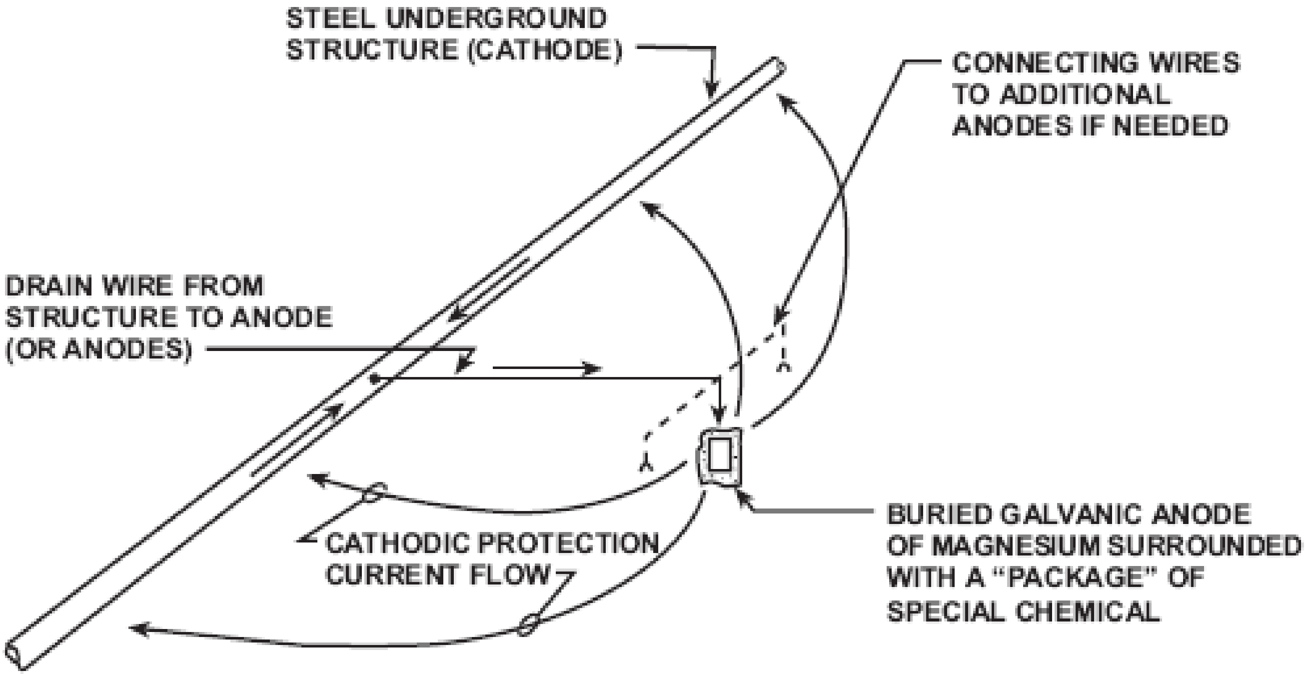
The Fundamental Corrosion Cell and Galvanic Anode Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit. The anode must be connected to the structure!

- Corrosion occurs wherever current leaves the metal and enters the soil (electrolyte). The point where current leaves the metal is called the anode. Corrosion occurs at the anode. The anode is "consumed" as it corrodes and will eventually need to be replaced.

- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A hydrogen film builds up at the cathode. The hydrogen film is referred to as "polarization."

- The flow of current is caused by a potential (voltage) difference between the anode and the cathode. This is the "driving voltage" and in galvanic anode cathodic protection is caused by the natural potential difference between the protected structure and the galvanic anode.



GALVANIC ANODE CATHODIC PROTECTION

FIGURE 3-3

TABLE 2-1

PRACTICAL GALVANIC SERIES

Progressively more anodic ↑ (less noble) and more corrosive	Metal	Volts[1]
	Commercially pure magnesium	-1.75
	Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
	Zinc	-1.1
	Aluminum alloy (5% Zn)	-1.05
	Commercially pure aluminum	-0.8
	Mild steel (Clean and shiny)	-0.5 to -0.8
	Mild steel (rusted)	-0.2 to -0.5
	Cast iron (not graphitized)	-0.5
	Lead	-0.5
↓Progressively more cathodic (noble) and less corrosive	Mild steel in concrete	-0.2
	Copper, brass, bronze	-0.2
	High silicon cast iron	-0.2
	Mill scale on steel	-0.2
	Carbon, graphite, coke	+0.3

(1) Typical potentials measured between metal (when immersed in neutral soils or waters) and a copper-copper sulfate reference cell contacting the adjacent soil or water.

Common Galvanic Anode Materials

- Magnesium. High potential magnesium anodes have a potential of -1.75 volts to CSE. Other alloys are around -1.50 volts to CSE. Most common anode for use in soil.
- Zinc. Typically -1.1 volts to CSE. Significantly less “driving voltage” than magnesium. Used in low resistivity soil and sea water. Also used for AC mitigation.
- Aluminum. Typically -1.05 to -1.15 volts to CSE. Most commonly used in sea water.

Advantages of Galvanic Anode Cathodic Protection

- They are self-powered. No dependence on outside sources of power.
- Low maintenance requirements.
- Minimum probability of stray current interference on other underground structures.

Disadvantages of Galvanic Anode Cathodic Protection

- Low, fixed driving voltage.
- Relatively high consumption rate which means a relatively low life expectancy.

Ohm’s Law

$$E = IR$$

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

Driving Voltage

- The difference in voltage between the anode and the protected structure (the cathode):

$$\text{Driving Voltage} = E_{\text{Anode}} - E_{\text{Cathode}}$$

- The voltage that causes current to flow in a corrosion cell, or a cathodic protection system.

- If R remains the same, the current will increase in proportion to the driving voltage:

$$I = \frac{E_{\text{Anode}} - E_{\text{Cathode}}}{R}$$

Driving Voltage Effect on Current Output for Galvanic Anodes

- For a magnesium anode:

$$I = \frac{1.75\,V - 0.85\,V}{R} = \frac{0.90\,V}{R}$$

- For a zinc anode:

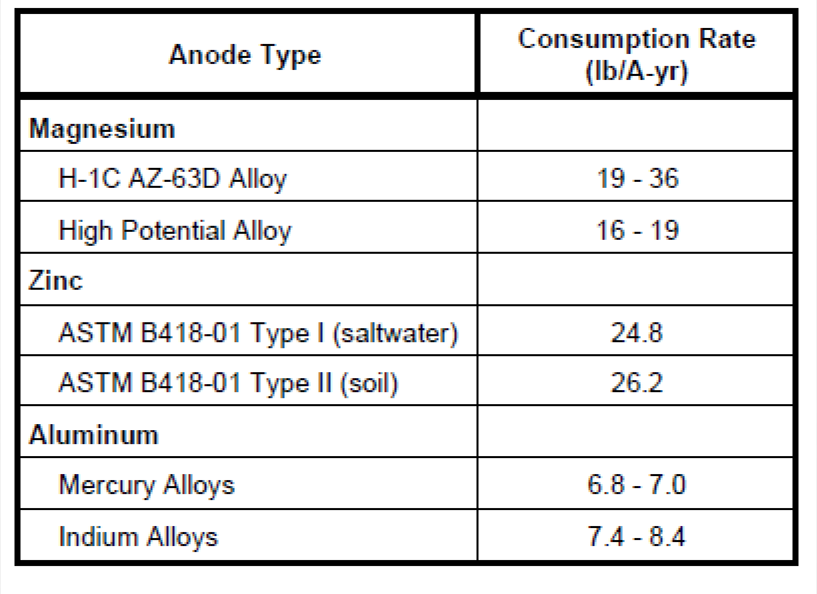
$$I = \frac{1.10\,V - 0.85\,V}{R} = \frac{0.25\,V}{R}$$

- For an aluminum anode:

$$I = \frac{1.05\,V - 0.85\,V}{R} = \frac{0.20\,V}{R}$$

Consumption of Galvanic Anode Materials

- As current flows, the anode material is corroded or “consumed”.
- After it has been consumed, the anode will need to be replaced.
- Different anode materials have different consumption rates:



Anode Type	Consumption Rate (lb/A-yr)
Magnesium	
H-1C AZ-63D Alloy	19 - 36
High Potential Alloy	16 - 19
Zinc	
ASTM B418-01 Type I (saltwater)	24.8
ASTM B418-01 Type II (soil)	26.2
Aluminum	
Mercury Alloys	6.8 - 7.0
Indium Alloys	7.4 - 8.4

- The lower the consumption rate the longer the anode will last.

Magnesium and zinc anodes for use in soil are commonly packaged with a prepared backfill consisting of:

- 75% Hydrated Gypsum ($CaSO_4 \cdot 2H_20$)
- 20% Bentonite Clay
- 5% Sodium Sulfate

The purpose of the prepared backfill is (the short answer):

- They work better.

The purpose of the prepared backfill is (the long answer):

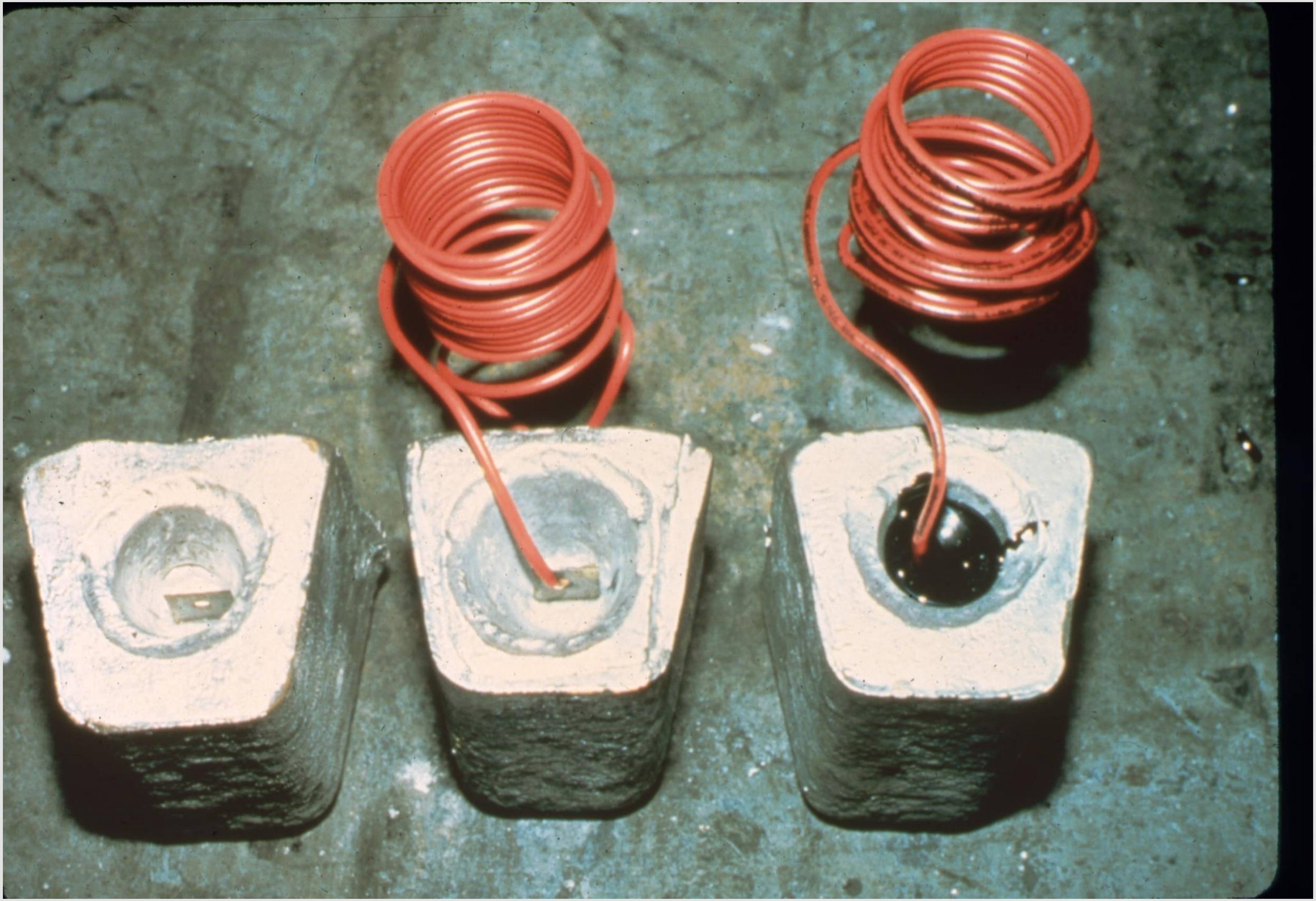
- It increases the effective surface area which lowers the anode to earth contact resistance.
- The bentonite clay absorbs and retains moisture.
- The gypsum provides a uniform, low resistance environment.
- The sodium sulfate (a depolarizing agent) minimizes pitting attack and oxide film formation on the anode.
- It provides uniform environment directly in contact with anode to assure even consumption.

GALVANIC ANODE CASTINGS

aluminum

magnesium

zinc




GALVOMAG
GALVOPAX
GALVOMAG
HIGH POTENTIAL
2 UNITS TYPE 17D3
MAGNESIUM
ANODE
WITH BACKFILL
PACKAGED BY
CATHODIC PROTECTION SERVICE
HOUSTON
TULSA - FARMINGTON - LOS ANGELES - MIDLAND
CORPUS CHRISTI - NEW ORLEANS - DENVER
TRADEMARKS OF THE DOW CHEMICAL COMPANY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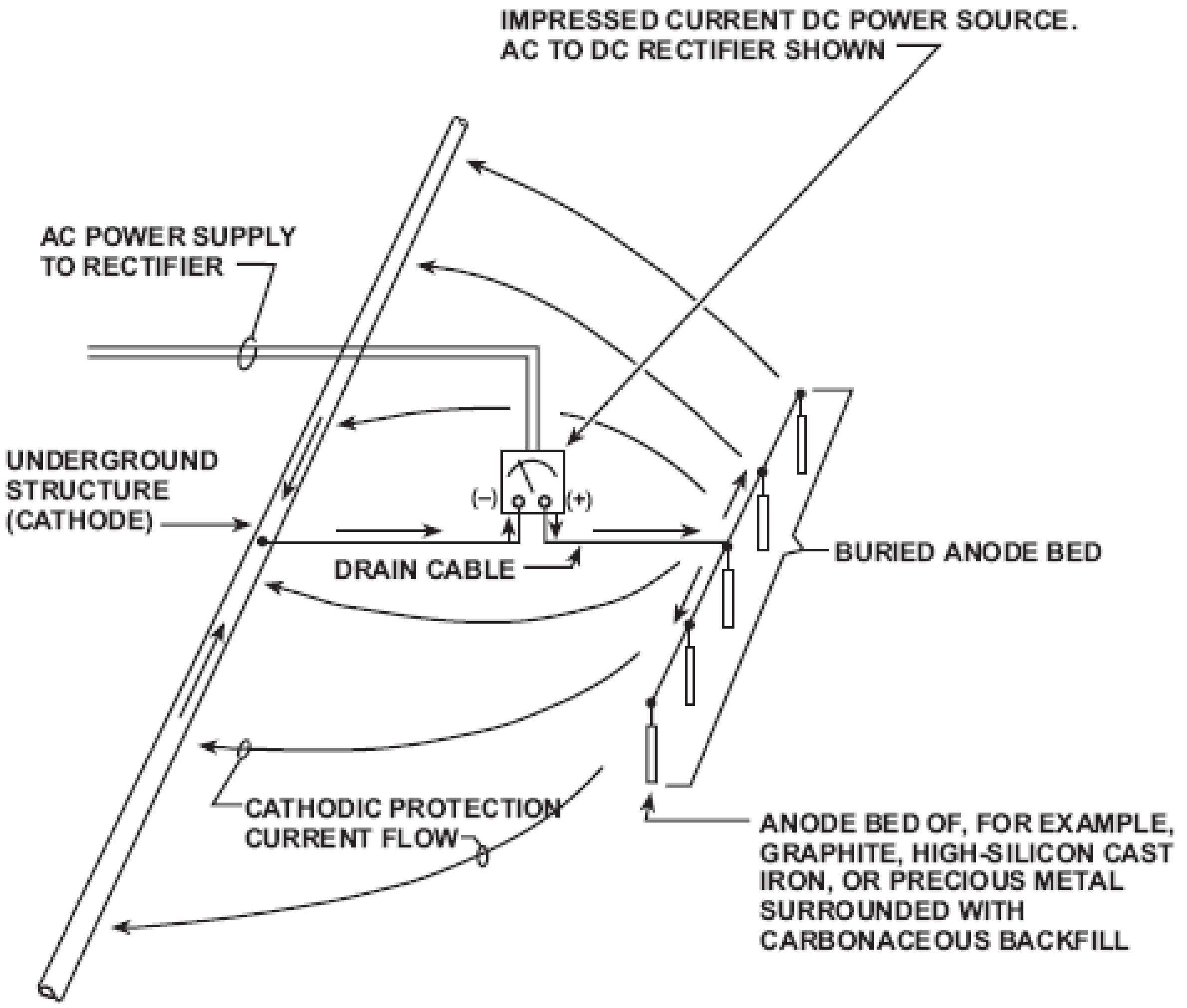
The Fundamental Corrosion Cell and Impressed Current Cathodic Protection

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.

- Corrosion occurs wherever current leaves the metal and enters the soil (electrolyte). The point where current leaves the metal is called the anode. Corrosion occurs at the anode. The anode is "consumed" as it corrodes and will eventually need to be replaced.

- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. This is the basis of cathodic protection. A hydrogen film builds up at the cathode. The hydrogen film is referred to as "polarization."

- The flow of current is caused by a potential (voltage) difference between the anode and the cathode. This is the "driving voltage" and in impressed current cathodic protection is caused by the DC source (usually a rectifier) which creates a potential difference between the protected structure and the impressed current anode.



IMPRESSED CURRENT CATHODIC PROTECTION

FIGURE 3-4

Sources of DC for Impressed Current Cathodic Protection

- Transformer - Rectifier Units or simply “Rectifiers”
- Solar Photovoltaic Cells
- Thermoelectric Generators
- Turbine Generator Units
- Engine Generator Units
- Wind Powered Generators

Common Impressed Current Anode Materials

- High silicon cast iron
- Graphite
- Mixed metal oxide (MMO)
- Platinum
- Scrap steel – abandoned structures

Other Impressed Current Anode Materials

- Aluminum
- Lead Silver
- Magnetite
- Polymer conductive

Advantages of Impressed Current Cathodic Protection

- A wide range of DC voltage and current output capacities. This provides great flexibility in system design.

- Higher “driving voltage” than galvanic anode systems.

- Single installations which will protect much larger structures (or portions of structures) than is usually possible with single galvanic anode installations.

- Impressed current anodes typically have lower consumption rates than galvanic anodes which means a longer life expectancy.

Disadvantages of Impressed Current Cathodic Protection

- Greater maintenance requirements than for galvanic anode installations.

- Dependence on availability of a dependable power supply or fuel supply.

- Continuing cost of energy where AC power or a fuel supply is required.

- Greater possibility of stray current interference on other underground structures than is the case with galvanic anode installations.

Driving Voltage Effect on Current Output for Impressed Current Anodes

- For a magnesium anode:

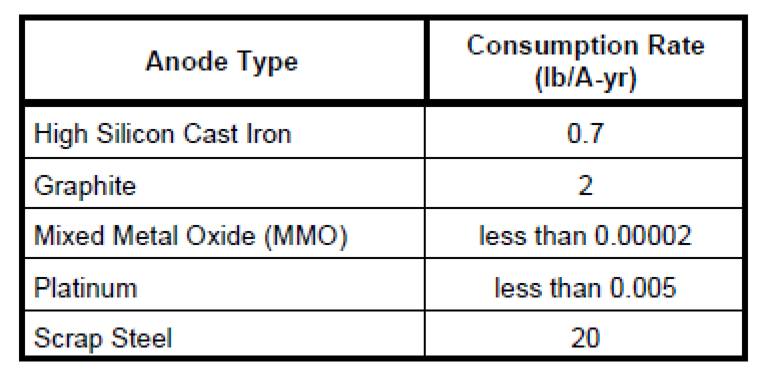
$$I = \frac{1.75\,V - 0.85\,V}{R} = \frac{0.90\,V}{R}$$

- For an impressed current anode, whatever you set the DC source (rectifier) at. For example:

$$I = \frac{80.0\,V - 0.85\,V}{R} = \frac{79.15\,V}{R}$$

Consumption of Impressed Current Anode Materials

- As current flows, the anode material is corroded or “consumed”.
- After it has been consumed, the anode will need to be replaced.
- Different anode materials have different consumption rates:



Anode Type	Consumption Rate (lb/A-yr)
High Silicon Cast Iron	0.7
Graphite	2
Mixed Metal Oxide (MMO)	less than 0.00002
Platinum	less than 0.005
Scrap Steel	20

- The lower the consumption rate the longer the anode will last.
- Most impressed current anode materials have a much lower consumption rate than galvanic anode materials.

Factors is Choosing Common Impressed Current Anode Materials

- Cost
- Life
- Size
- Ease of construction
- Compatibility with environmental conditions
- Historical performance – what you have used in the past that works for you

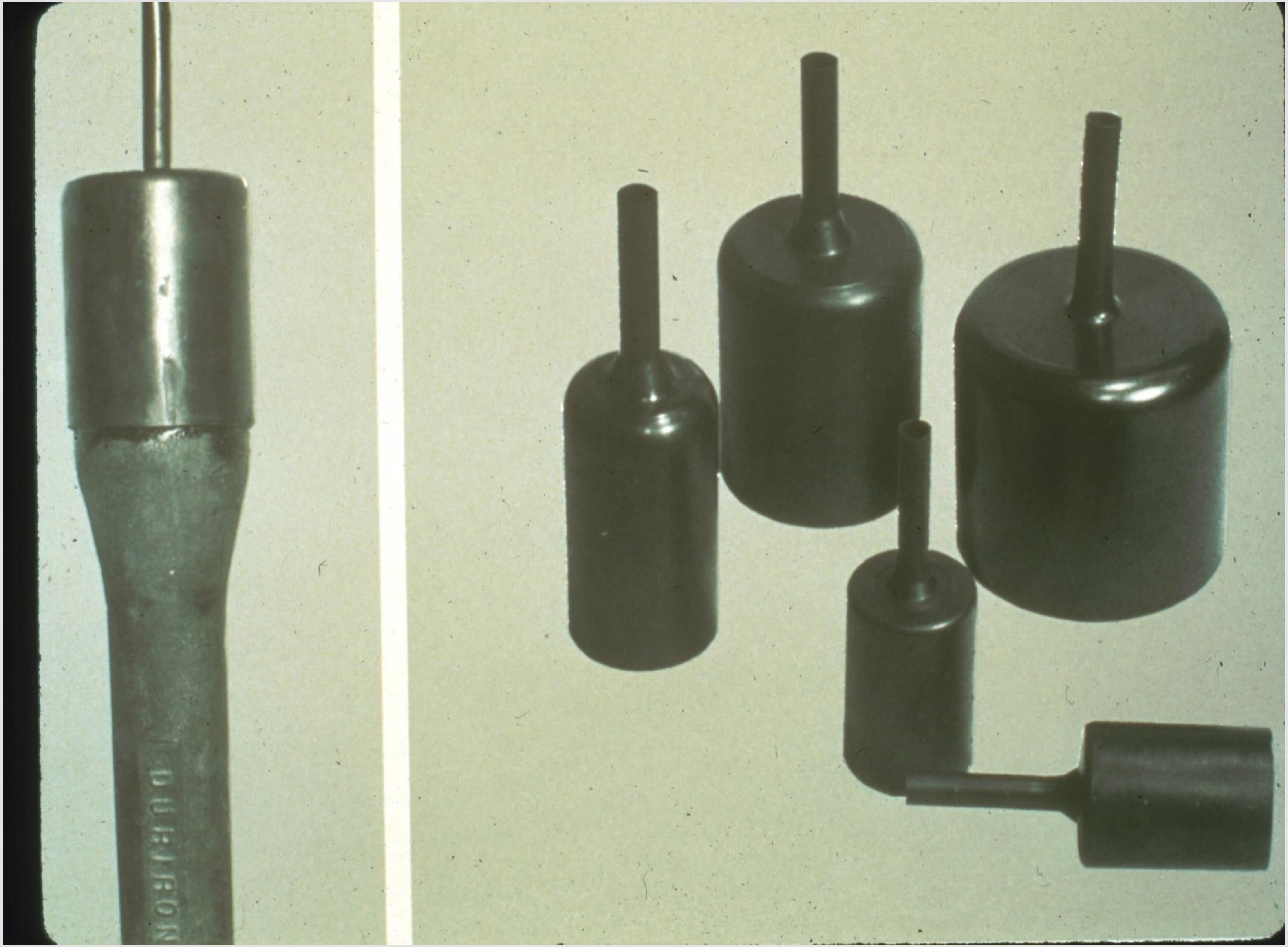
Impressed current anodes for use in soil are commonly placed in a prepared backfill.

- Carbonaceous backfill aka coke breeze.

- Impressed current anodes can be purchased prepackaged with prepared backfill or it can be placed around anode during construction.

- The backfill lowers the effective resistance to earth of the anode by increasing its size.

- The backfill also increase the life of the anodes.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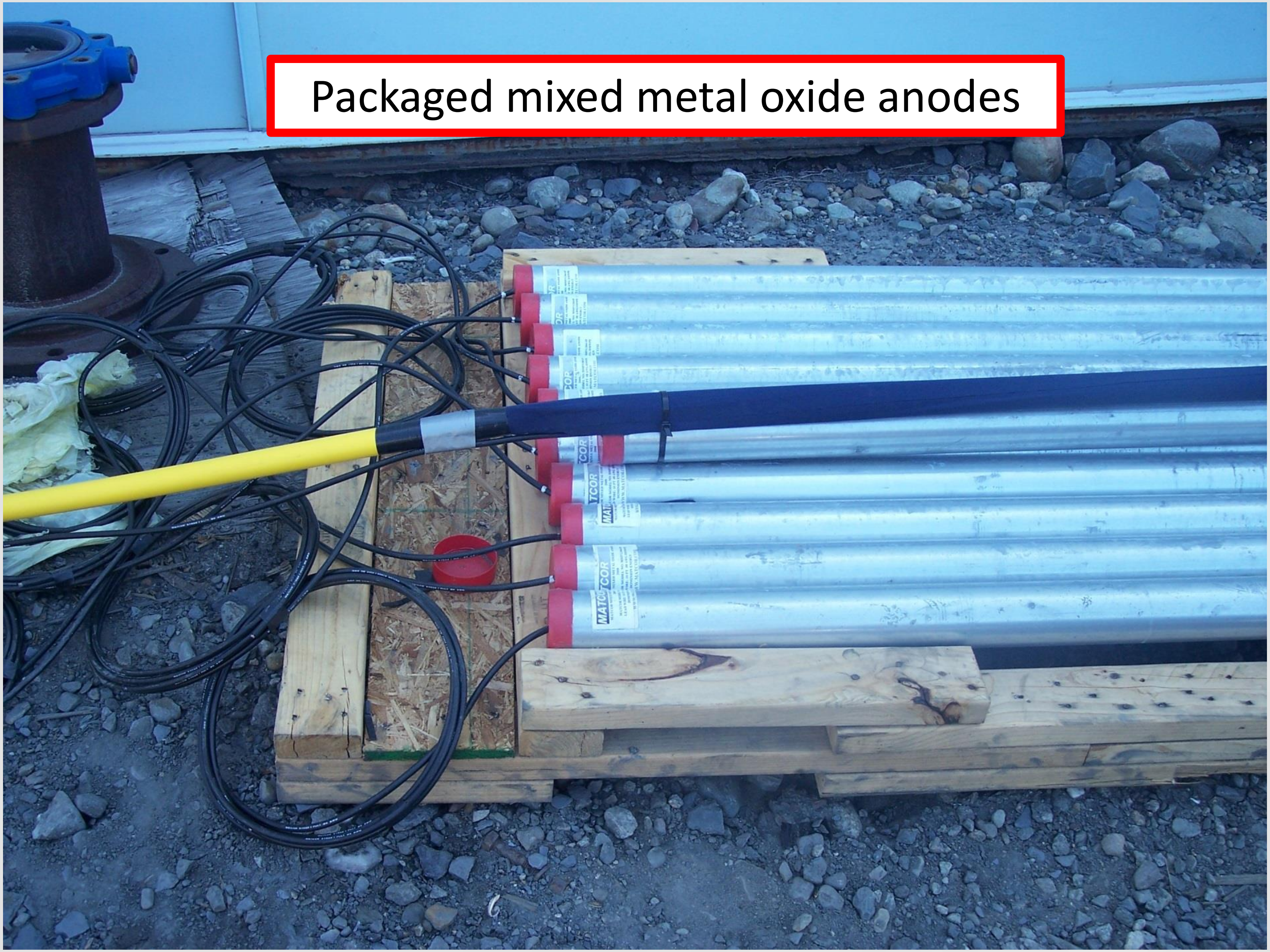
Packaged mixed metal oxide anodes



Packaged mixed metal oxide anodes

Drill rig installing packaged mixed metal oxide anodes


MATTUCHIO

Impressed Current Cables and Splices

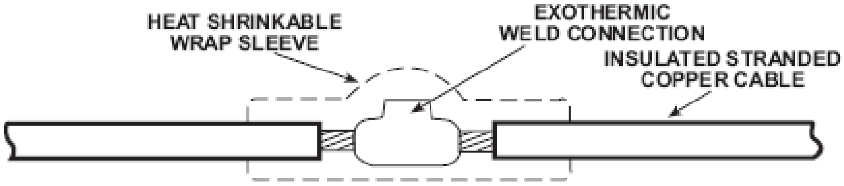
- Since the cable on the positive side of the rectifier becomes an anode, it is critical that there be no exposed conductor in the electrolyte or it will corrode quickly and the system will fail.
- There must be a high quality connection between the anode lead wire and the anode.
- High quality cable insulation must be used for the anode lead wires and anode header cables. Most commonly this is HMWPE insulation.
- The anode lead wires are typically spliced to the anode header cable with split-bolt connectors, crimp connectors or exothermic welds.
- The splices are typically covered with taping systems, epoxy kits or shrink sleeves.

Impressed Current Cables and Splices (cont)

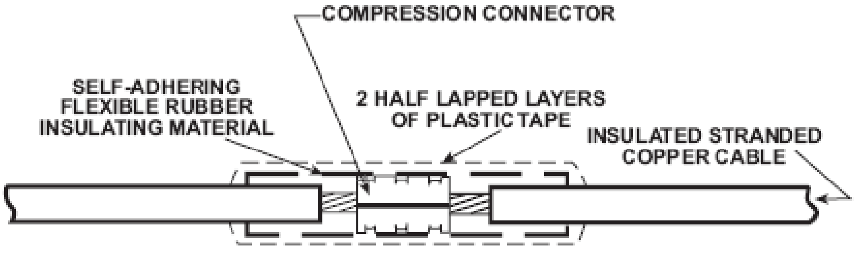
- The cable on the negative side of the rectifier is cathodically protected so the cable integrity is less important.

- Galvanic anode cables get protected by the anode.

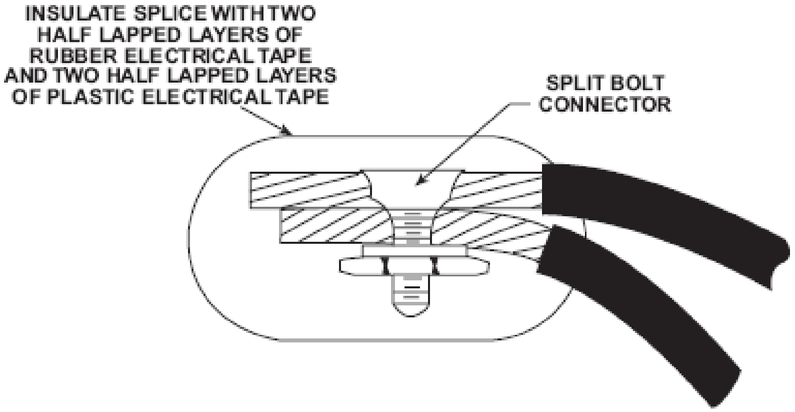
Anode junction box



EXOTHERMICALLY WELDED SPLICE



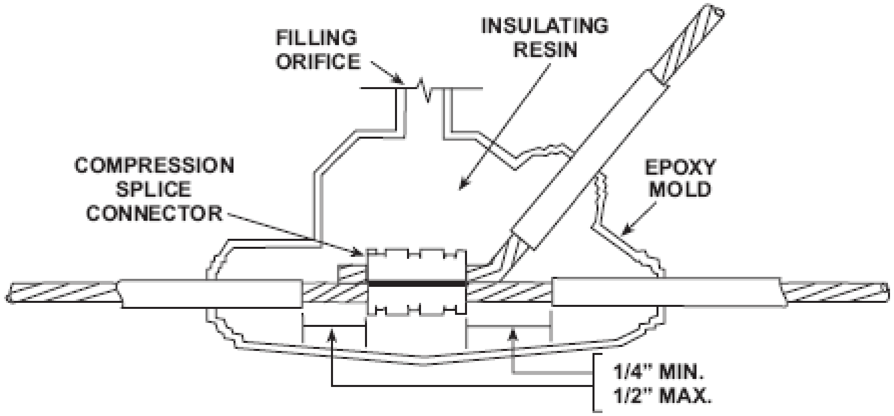
COMPRESSION CONNECTION



SPLIT BOLT SPLICE CONNECTION

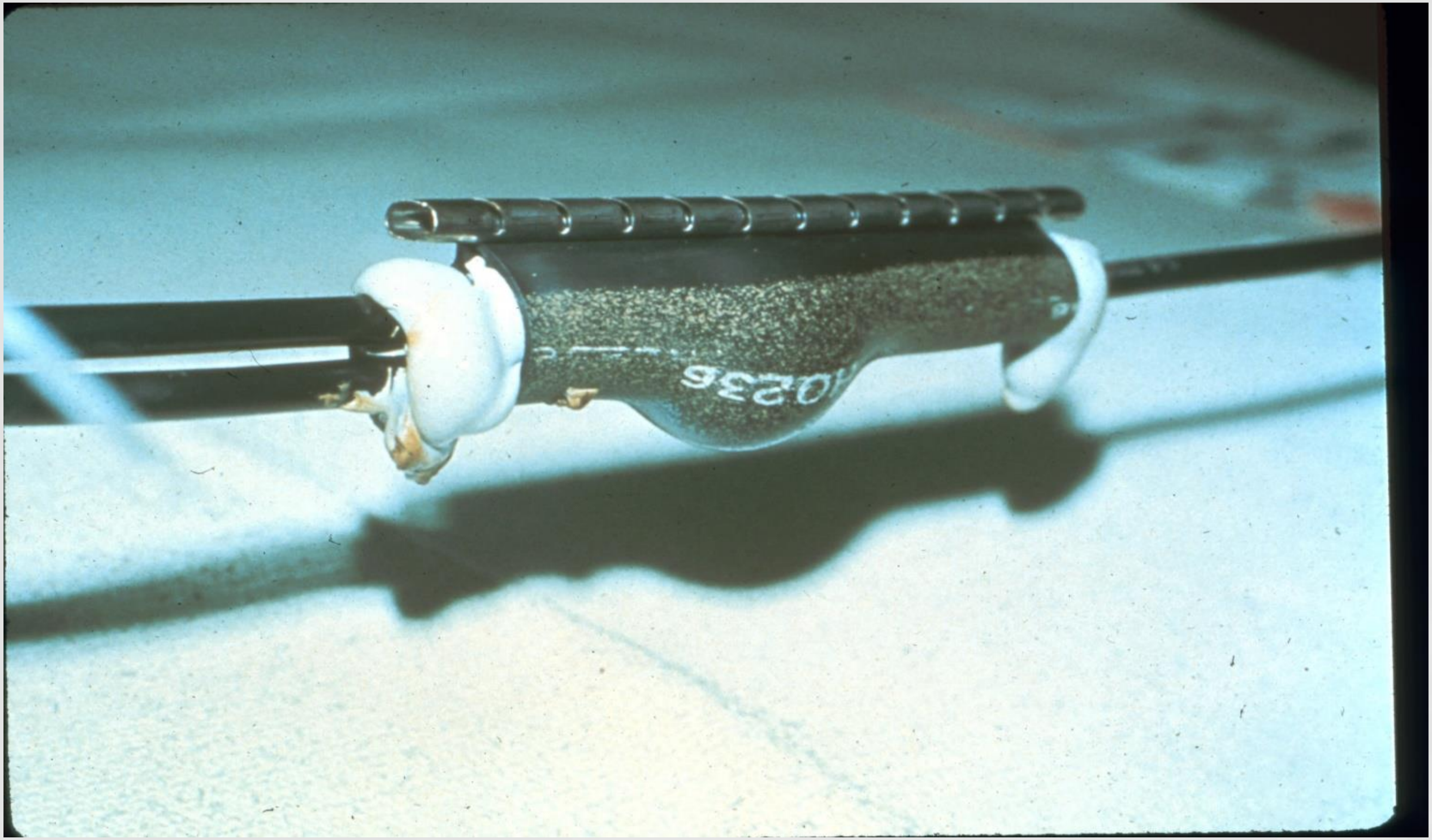
CABLE SPLICE CONNECTIONS

FIGURE 3-13



EPOXY ENCAPSULATED SPLICE

FIGURE 3-14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What structures can be cathodically protected?

- Any metallic structure that is buried or submerged
- Pipelines
- Underground storage tanks
- The bottom of aboveground storage tanks
- The internal surface of water storage tanks
- The internal surface of household water heaters
- Lead sheath electric and telephone cables
- Waterfront structures such as docks and piers
- Power plant structures such as waterboxes and traveling screens
- Steel building piles
- Cars – if they are buried or submerged

An Anode Joke

- A magnesium anode walks into a bar.
- He walks up to a cast iron anode sitting at the bar and says “Hey, I’m galvanic.”
- The cast iron anode responds “I’m impressed.”