APPALACHIAN UNDERGROUND CORROSION SHORT COURSE

AUCSC

Education and Training for Corrosion Control

Fundamentals Course

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

APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
2011 FUNDAMENTALS COURSE

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April 4, 2011 Revision

To submit comments, corrections, etc. for this text, please email: curriculum@aucsc.com

Fundamentals of Corrosion Mathematics and Electricity

AUCSC – May 2010

UNITS

- Introduce “conversion factors” in order to change from one unit system to another.
- Miles to feet (and back)
- Dollars to nickels (and back)
- Millivolts to volts (and back)
- Amps to milliamps (and back)

First Concept

- ANY number times "1" is always the same number
- EXAMPLE

  5 * 1 = 5

  23 * 1 = 23

  142 * 1 = 142

- You can keep multiplying the number by "one" with no change
- EXAMPLE

  5 * 1 * 1 * 1 = 5

  23 * 1 * 1 * 1 * 1 = 23

Second Concept

- A number divided by itself is equal to "1"
- There are some cases where this is not true, but you don't need to worry about it.

EXAMPLES

$$\frac{5}{5} = 1$$

$$\frac{23}{23} = 1$$

$$\frac{142}{142} = 1$$

Let's Elaborate on the Second Concept

- I introduced the second concept using pure numbers – 5, 23, 142
- Let's use distance instead of pure numbers.

- If I run 5280 feet.
- And "you" run 1 mile.
- Who runs farther?
- Same distance.
- 1 mile = 5280 feet
- Then:

$$\frac{1 mile}{5{,}280\ feet} = 1$$

So what?

- We have all we need to convert units.
- Convert 15000 feet to miles.
- The units must "cancel" – it's your clue

$$15{,}000\ feet * \frac{1 mile}{5{,}280\ feet} = \frac{2.84\ \cancel{feet} - mile}{\cancel{feet}}$$

The wrong conversion factor

- If you use the “inverse” of the conversion factor you get two clues.
- First the units don’t look right. They don’t cancel.
- Second the number can be “way off”

$$15{,}000\, feet * \frac{5{,}280\, feet}{1 mile} = \frac{79{,}200{,}000\, feet - feet}{mile}$$

The other direction

- If we want to convert miles to feet, we flip the “conversion factor”
- Given 8.62 miles, find out how many feet that is.

$$8.62\,\text{miles} * \frac{5280\ \text{feet}}{1\,\text{mile}} = 45{,}513.6\, feet$$

Another simple example

- How many nickels in $39.70?

$$39.70 dollars * \frac{20 nickels}{1 dollar} = 794 nickels$$

- Get the conversion factor upside-down, and you'll see the mistake three ways.

$$39.7 dollars * \frac{1 dollar}{20 nickels} = 1.985 \frac{dollar - dollar}{nickel}$$

Number's too low . Fractional nickel. Goofy unit.

We can string conversion factors together

- I have 6.425 miles of pipeline.
- Convert that distance to "inches".
  (don't need to know how many inches in a mile)

$$6.425 miles * \frac{5280 ft}{1 mile} * \frac{12 in}{1 ft} = 407{,}088 inches$$

The units will keep "cancelling"

- Or even convert to millimeters
  (don't need to know how many mm in a mile)

$$6.425 miles * \frac{5280 ft}{1 mile} * \frac{12 in}{1 ft} * \frac{25.4 mm}{1 in} = 10{,}340{,}035 mm$$

Volts

- Volt – named after Count Alessandro Volta who invented the modern battery and discovered “methane”.
- 1 Volt = 1 kg-m/C-s^2 ^
- Voltage is equivalent to pressure in a fluid system

Voltage Conversion

- There are 1000 mV in 1 Volt. Then:

$$\frac{1000mV}{1Volt} = 1 \qquad \frac{1Volt}{1000mV} = 1$$

- Examples:

$$2.5V * \frac{1000mV}{1V} = 2500mV \qquad 630mV * \frac{1V}{1000mV} = 0.63V$$

$$-1.7V * \frac{1000mV}{1V} = -1700mV \qquad 2300mV * \frac{1V}{1000mV} = 2.3V$$

$$12V * \frac{1000mV}{1V} = 12000mV \qquad 823mV * \frac{1V}{1000mV} = 0.823V$$

Amps

- Named after a French physicist Andre Ampere
- 1 Amp = 1 Coulomb per second
- The fluid equivalent of an amp is volumetric flow – gallons per minute, cubic feet per sec
- There are 1000 milliamps in one amp.
- So the conversion factor are:

$$\frac{1A}{1000mA} = 1 \qquad \frac{1000mA}{1A} = 1$$

Mnemonic Device

- "grandMa is one Absolutely Magnificent Person"
- Grand - 1000
- Ma – milliamp
- Is – equals
- 1 AMP
- 1000 mA = 1 AMP - OR -

$$\frac{1000mA}{1A} = 1 \qquad \frac{1A}{1000mA} = 1$$

Conversion Examples - amps

$$-1.71A*\frac{1000mA}{1A}=-1710mA$$

$$630mA*\frac{1A}{1000mA}=0.63A$$

$$2.5A*\frac{1000mA}{1A}=2500mA$$

$$-823mA*\frac{1A}{1000mA}=-0.823A$$

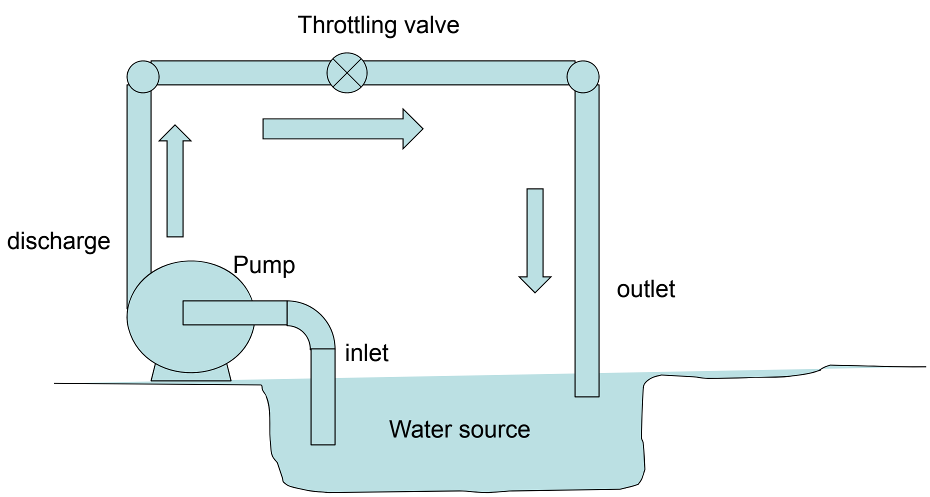
$$-12A*\frac{1000mA}{1A}=-12000mA$$

$$2300mA*\frac{1A}{1000mA}=2.3A$$

$$.74A*\frac{1000mA}{1A}=740mA$$

$$0.45mA*\frac{1A}{1000mA}=0.00045A$$

Let's start with water instead of electricity



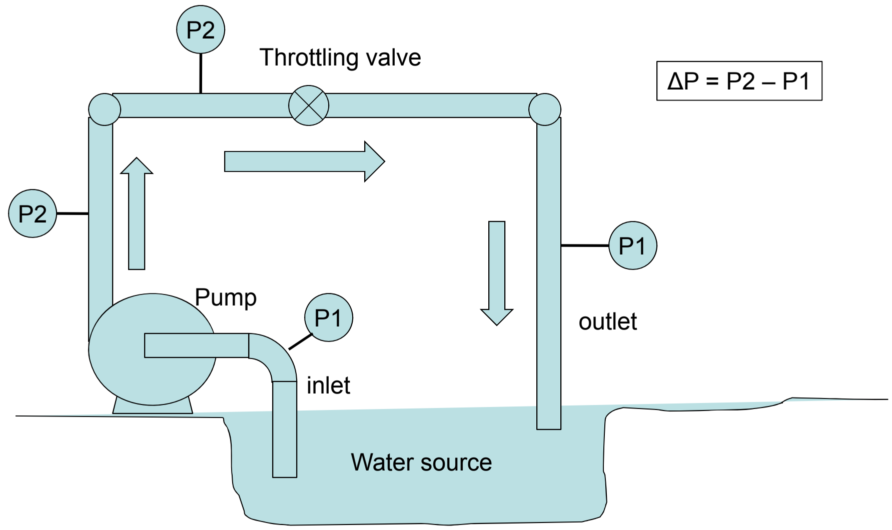
Fluid “circuit”

- External power goes into the pump
- Pump picks up water
- The pump adds pressure (psi) to the water
- The water pressure drops across the valve
- The water is discharged to its source
- The flow rate (gallons per minute) of the water is constant throughout the system.

Pressure

- Pressure can be measured with out disturbing the flow – pressure gauge tap
- Pressure increase across the pump is the same as the pressure drop across the valve.

Pressure

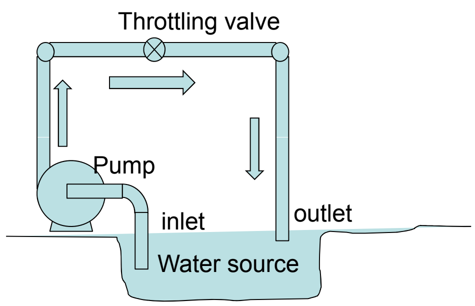


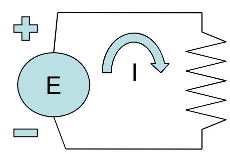
Flow

- Flow is the same rate "volume per unit time" at ALL points in the system
- Typical flow rate is "gallons per minute"
- Flow rate out = flow rate in
- If that was not true, then fluid is accumulating somewhere in the system
- Flow must be measured by redirecting all fluid through a flow meter
- There are "advanced" ways to measure without interrupting flow stream.

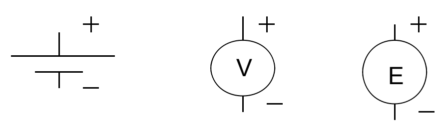
Equivalence to Electricity

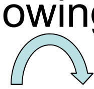
- Pressure = Voltage or Potential (E)
- Flow = Current or Amperage (I)

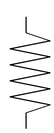




Electricity Symbols

- Voltage source 

- Current flowing – usually represented with an arrow  and an "I"

- Resistor  R

Fluid / Electricity Equivalence

FLUIDS

- Pressure
  - Pounds per square inch
  - Measured without diverting flow
- Flow
  - Gallons per minute
  - Measured by diverting the flow

ELECTRICITY

- Voltage / Potential
  - Volts
  - Measured without diverting current
- Current
  - Amps
  - Measured by diverting the current

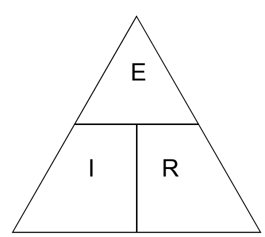
Ohm's Law

A potential of 1 volt across a resistance of 1 ohm causes 1 amp of current to flow

$E = I * R$

$I = E / R$

$R = E / I$



OHM's LAW

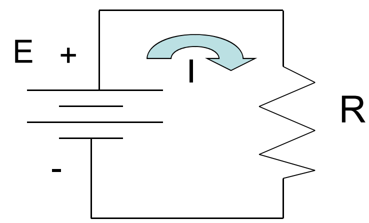
- Using the triangle.
- Cover the variable that you need to find.
- The "known" variables will be in the configuration you need.
- Need to know "I"?
- Cover the I and you're left with $\frac{E}{R}$.
- Therefore I = $\frac{E}{R}$

Units and Ohm's Law

- ALWAYS convert units to Amps, volts, and Ohms.
- Do NOT use milliamps, millivolts, or kilo-ohms.

Ohm's Law Applied

- If the voltage (E) is 1 Volt and the resistance (R) is 1000 ohms, how much current (I) is flowing?

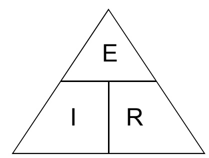


- I = E/R = E ÷ R
- I = 1V/1000ohms
- I = .001 Amps

E = IR

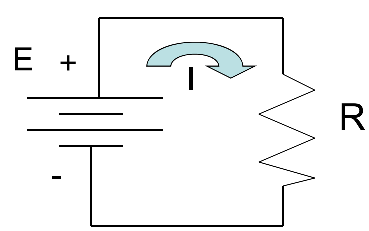
R = E/I

I = E/R



Ohm's Law Example 1

- If the voltage (E) is 10.5 Volts and the resistance (R) is 5 ohms, how much current (I) is flowing?

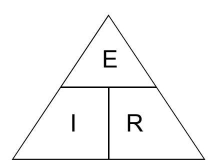


- I = E/R = E ÷ R
- I = 10.5V ÷ 5ohms
- I = 2.1 Amps

E = IR

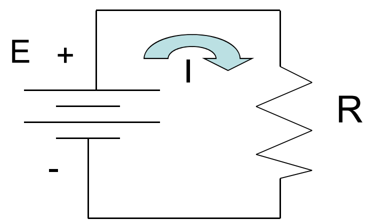
R = E/I

I = E/R



Ohm's Law Example 2

- If the voltage (E) is 1.6 Volts and the current (I) is 2 amps, what is the resistance in the circuit?

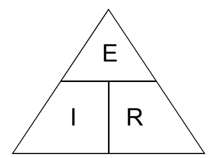


- R = E ÷ I
- R = 1.6V ÷ 2 amps
- R = 0.8 ohms

E = IR

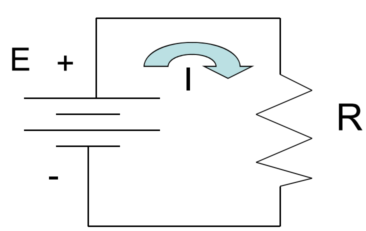
R = E/I

I = E/R



Ohm's Law Example 3

- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?

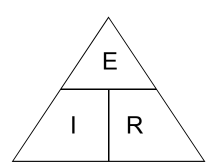


- E = I*R
- I = 100 mA = 0.1A
- R = 1.5 ohms
- E = 0.1 * 1.5
- E = 0.15V

E = I*R

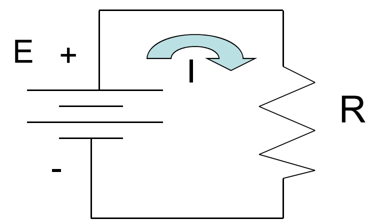
R = E/I

I = E/R

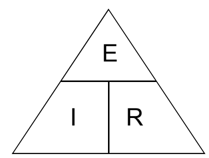


Example 3 – mistake included

- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?
- E = I*R
- I = 100 mA
- R = 1.5 ohms
- E = 100 * 1.5
- E = 150 V (not 0.15V)

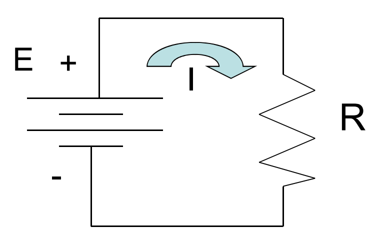


E = I*R
R = E/I
I = E/R

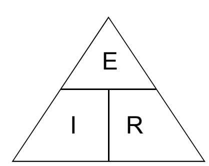


Ohm's Law Example 4

- If the current (I) is 2.5 mA and the voltage (E) is 2.5 volts, what is the resistance of the circuit?
- R = E ÷ I
- I = 2.5 mA = 0.0025A
- E = 2.5 volts
- R = 2.5 ÷ .0025
- R = 1000 ohms

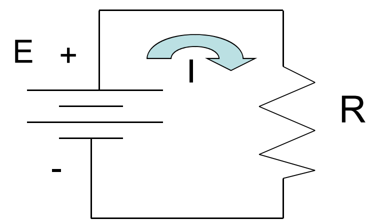


E = I*R
R = E/I
I = E/R

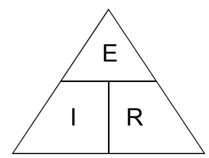


Example 4 – mistake included

- If the current (I) is 2.5 mA and the voltage (E) is 2.5 volts, what is the resistance of the circuit?
- R = E ÷ I
- I = 2.5 mA
- E = 2.5 volts
- R = 2.5 ÷ 2.5
- R = 1 ohm (wrong)

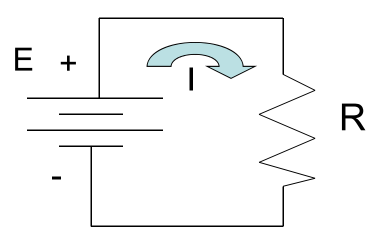


E = I*R
R = E/I
I = E/R

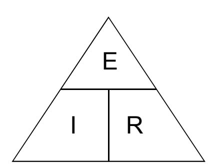


Ohm's Law Example 5

- If the current (I) is 20 A and the resistance (R) is 2 ohms, what is the voltage across the resistor?
- E = I*R
- I = 20 A
- R = 2 ohms
- E = 20 * 2
- E = 40 V

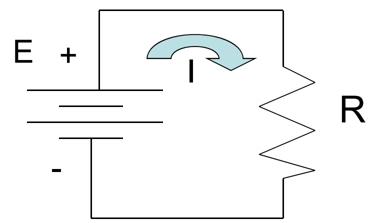


E = I*R
R = E/I
I = E/R



Ohm's Law Example 6

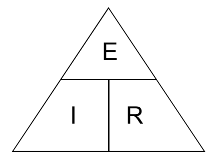
- If the voltage (E) is 12 Volts and the resistance (R) is 4 ohms, how much current (I – in milliamps) is flowing?
- I = E ÷ R
- I = 12V ÷ 4 ohms
- I = 3 Amps
- I = 3 A * (1000mA/1A)
- I = 3000 mA



E = IR

R = E/I

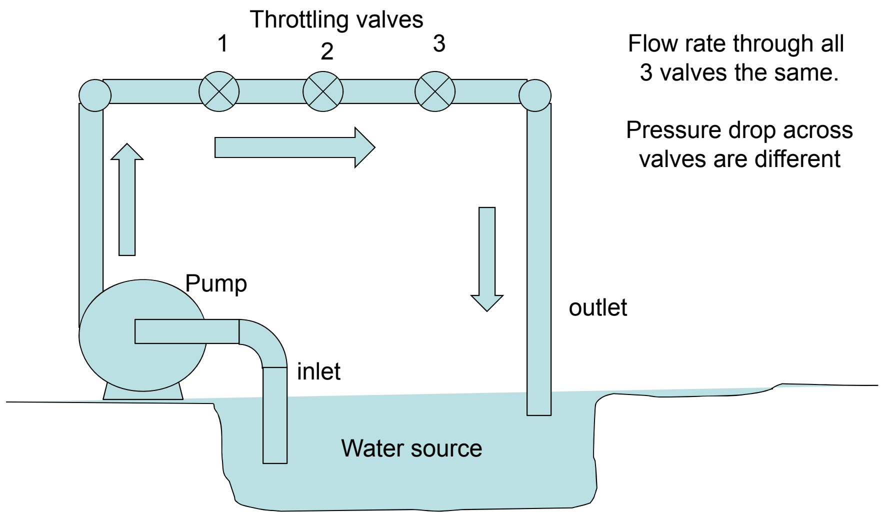
I = E/R



Electric Circuit Analysis

- Resistors in a circuit can be connected in series
  - Current is the same through all resistors
  - Voltage drop across different resistances is different
- Resistors in a circuit can be connected in parallel
  - Current through different resistors is different
  - Voltage drop across all resistors is the same

Series Piping

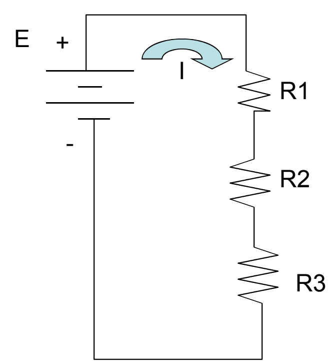


Flow rate through all 3 valves the same.

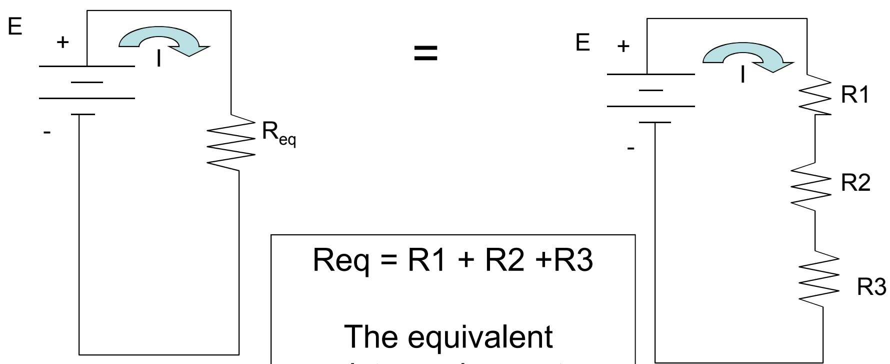
Pressure drop across valves are different

Resistors in Series

- All the current flows through all the resistors
- Depending on the resistance values, the voltage drop across each R is different.
- What is the equiv R?



Resistors in Series
what is the equivalent resistance?



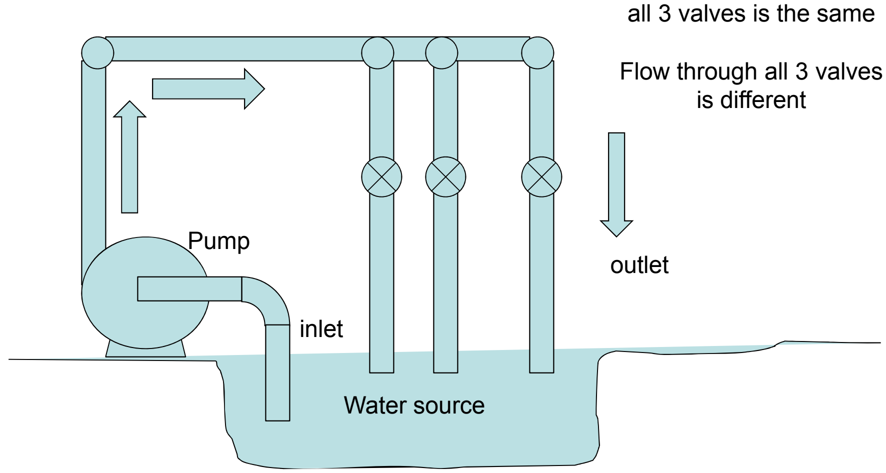
Req = R1 + R2 +R3

The equivalent resistance is greater than the largest resistor.

Parallel Piping

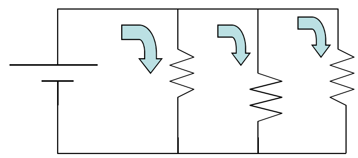
Pressure drop across all 3 valves is the same

Flow through all 3 valves is different

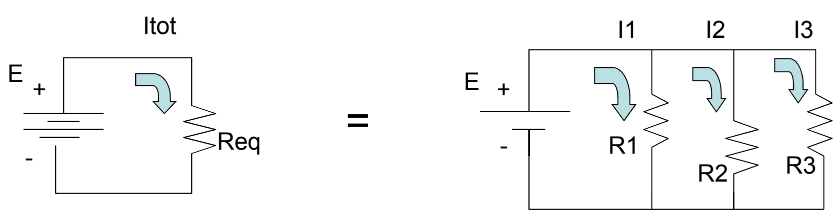


Resistors in Parallel

- Different currents flow through the resistors
- The voltage drop across each R is the same.
- What is the equiv R?



Resistors in Parallel



1/Req = 1/R1 + 1/R2 + 1/R3

The calculated equivalent resistance is less than the smallest resistor

Rectifier Efficiency

- Efficiency = Power Out / Power In
- For a rectifier – output is DC, input is AC
- Power Out
  = DC output voltage * DC output current
- Power In
  = AC input voltage * AC input current

Current out

- DC current out:
  - One way is to measure the voltage across the shunt resistor.
  - You measure 4 Volts DC.
  - The shunt “factor” = 20 mA per Volt
  - Output current = 4 V * (20 mA/Volt) = 80 mA

AC Current is the more difficult variable

- Clamp on ammeter not exactly right
  - Inductance of transformer interferes
  - Snap shot of current flow
- Meters being replaced with digital models
- Good average current comes from billing data (30 day billing cycle).

Example

- AC Input voltage 120V
- AC Input current 2Amps

- DC Output voltage 5 Volts
- DC Output current 15 Amps

- Efficiency = (5 * 15) / (120 * 2) = .3125
- Efficiency = 31.25%

Fundamentals Course

Basic Corrosion

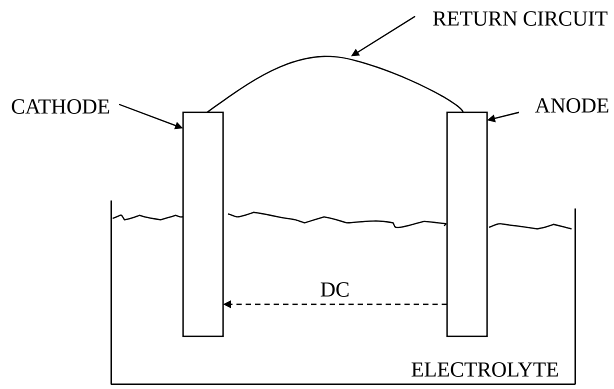
Fundamental introduction and theory behind the corrosion process

CORROSION

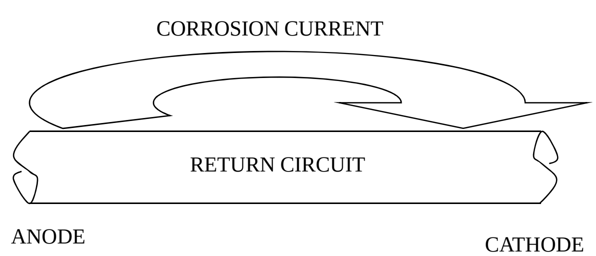
THE DETERIORATION OF A MATERIAL, USUALLY A METAL, DUE TO A REACTION WITH ITS ENVIRONMENT

OR

THE TENDENCY OF A REFINED METAL TO RETURN TO ITS NATURAL STATE AS AN ORE



FUNDAMENTAL CORROSION CELL

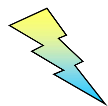


FUNDAMENTAL CORROSION CELL ON PIPE

TYPES OF CORROSION

NATURAL

STRAY

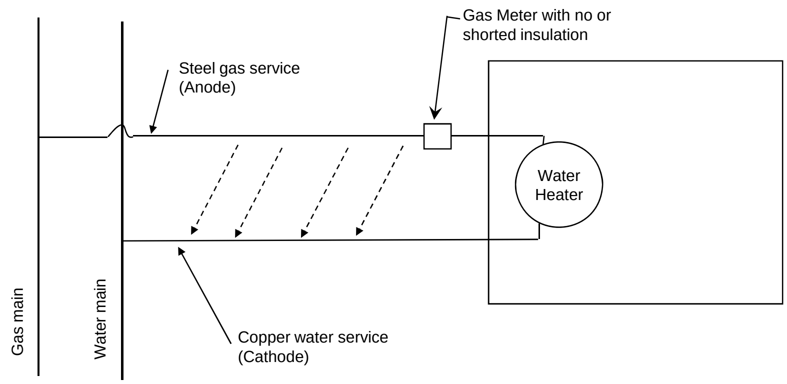


NATURAL CORROSION

- CAUSED BY A NATURAL REACTION BETWEEN A METAL AND ITS ENVIRONMENT
- YOU BURY A PIECE OF METAL AND IT CORRODES
- HERES WHY ☛

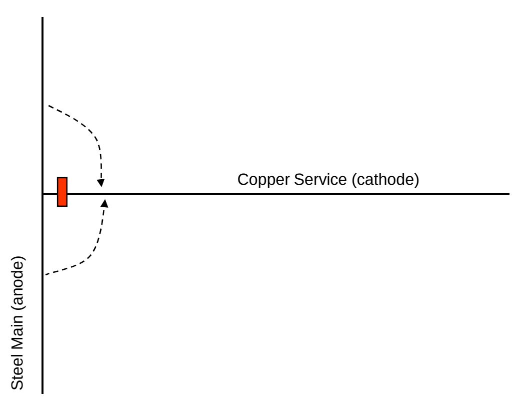
Dissimilar Metal Corrosion

Gas and Water Service Lines



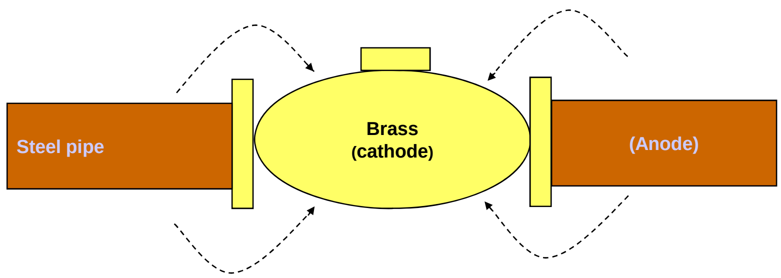
Dissimilar Metal Corrosion

Copper Service on a Steel Main



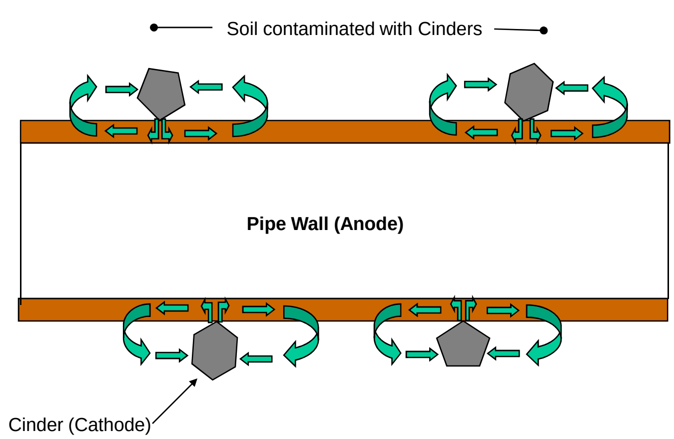
Dissimilar Metal Corrosion

Brass Stop in a Steel Line

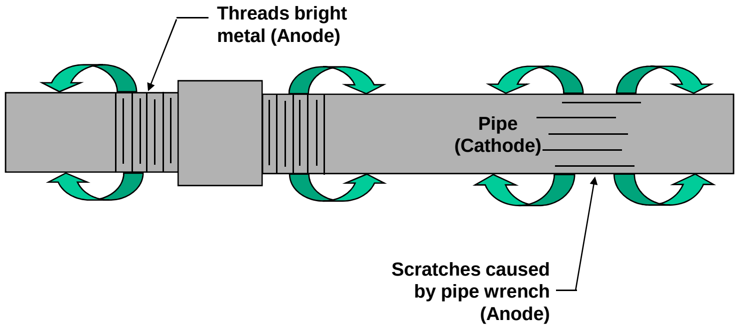


Corrosion due to cinders

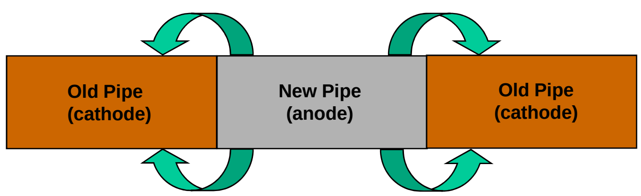
Physical contact between Pipe and Cinders



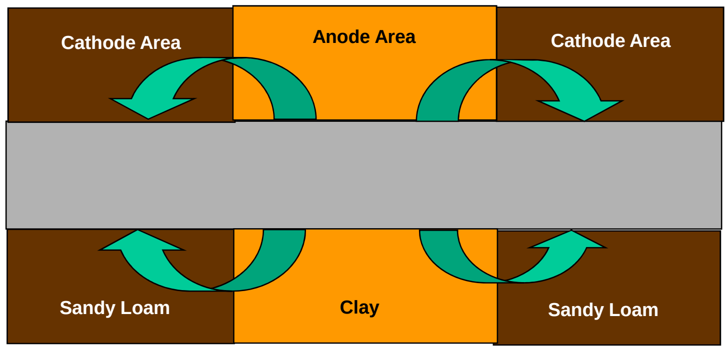
Corrosion caused by Dissimilarity of Surface Conditions



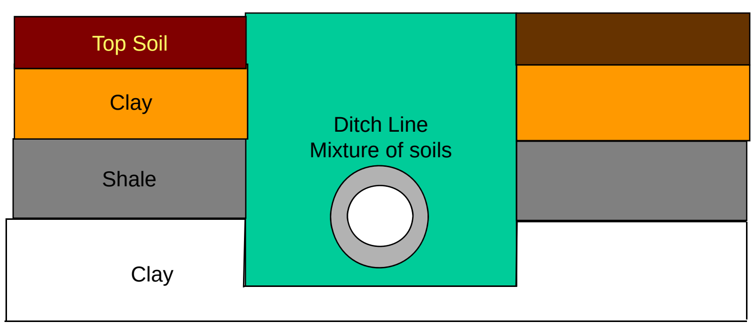
New-Old Pipe Corrosion Cell



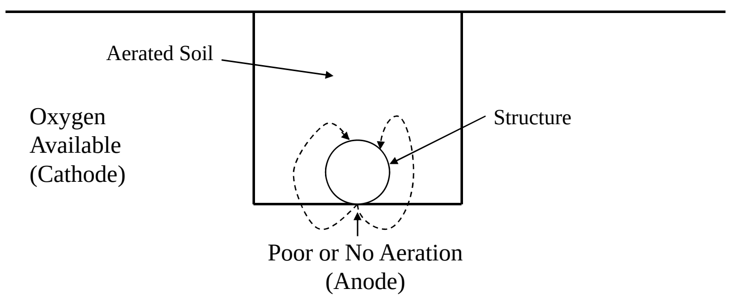
Corrosion caused by Dissimilar Soils



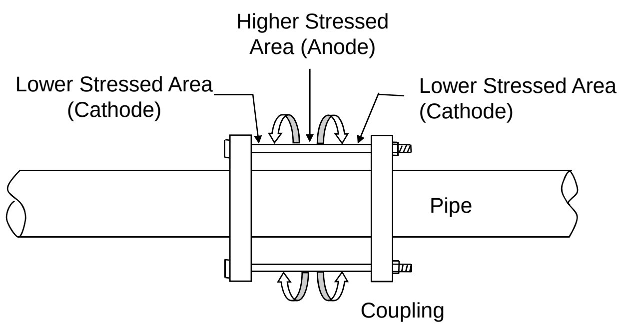
Corrosion caused by Mixture of Different Soils



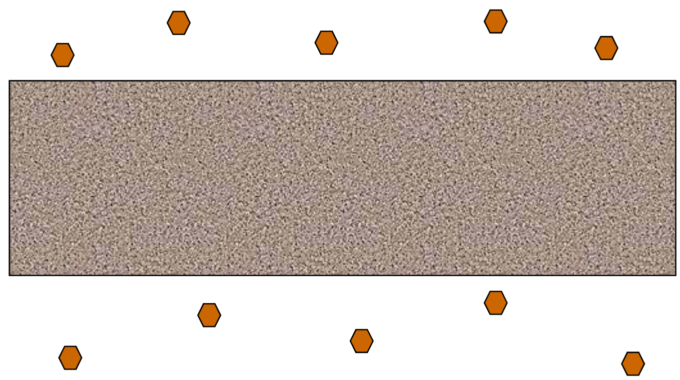
Corrosion caused by Differential Aeration of Soil



Stress Corrosion



Cast Iron Graphitization



Microbiologically Influenced Corrosion (MIC)

Two types:
Acid Producing Bacteria (APB)
Sulfur Reducing Bacteria (SRB)

Unique pitting of metal:
Step wise pitting
Smooth "Thumb print" pitting
Worm hole pitting

The bacteria does not eat the pipe, but rather their waste by products, when mixed with water can create acids. Which dissolve the metal.

Microbiologically Influenced Corrosion (MIC)

Can occur internally and externally.

Can be mitigated internally, by use of chemical inhibitors, added to the gas stream, or by removing the water from the system.

Can be mitigated externally by certain types of coatings, or with enhanced cathodic protection, pipe surface potentials over 1.5 volts.

Review the types of corrosion

Naturally Occurring Corrosion

Dissimilar metals

Dissimilar surface

Dissimilar Soils

Differential Aeration

Cinders

Stress

Graphitization

Microbiological Influenced Corrosion

Stray Current Corrosion

Caused by discharge of man-made current.
DC (direct current)
AC (alternating current)
Telluric Currents

Sometimes called “electrolysis

Stray Current Corrosion

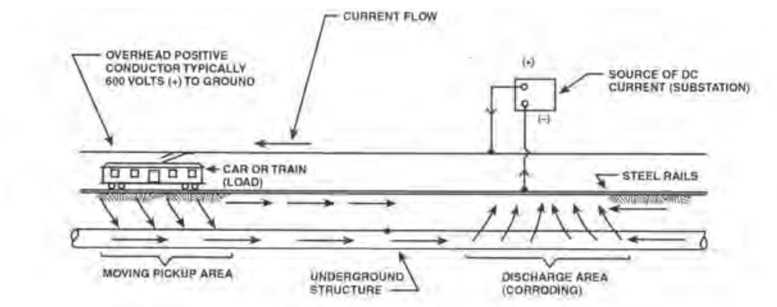
Alternating current, is mainly a safety issue. AC can be induced from overhead high voltage power lines. A measured voltage over 15 volts AC, must be mitigated. Can be measured by setting meter on AC volts, and taking a pipe to soil reading.

Direct current, is a large concern to the corrosion person. Due to the fact that 1 ampere leaving a steel structure, removes 20 pounds of iron per year. DC stray currents can be a rather large amount. There is two types of DC stray current, **static** or steady state and **dynamic** or fluctuating current.

Example:
2 amps per year
2amps X 20 pounds = 40 pounds lost
Times 3 years = 120 pounds of lost iron
6 inch pipe weights 18.974 pounds per foot

Stray Current from DC Transit System

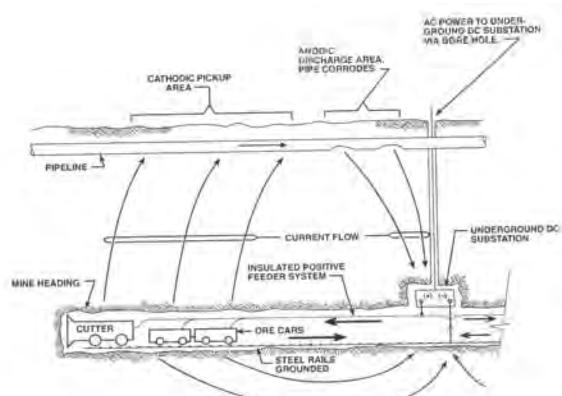
Dynamic Stray Current



DC TRANSIT SYSTEM AS A SOURCE OF STRAY CURRENT CORROSION

Stray Current from Underground Mining Operation

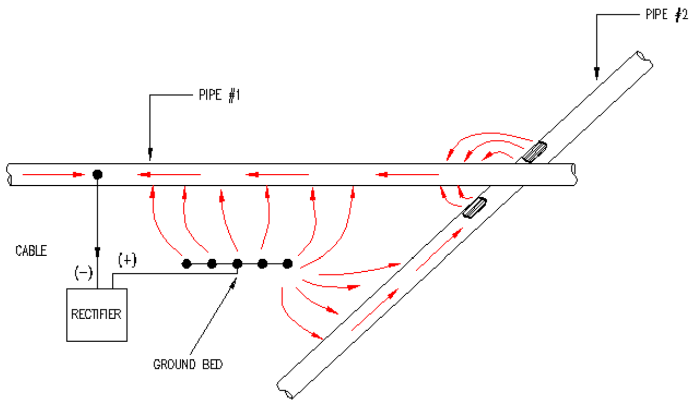
Dynamic Stray Current



CORROSION BY STRAY CURRENT FROM DC MINING OPERATIONS

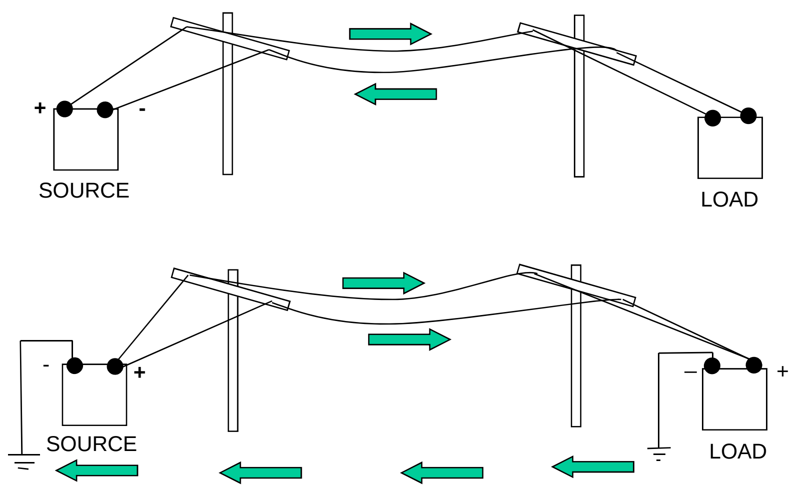
Stray Current from Impressed Current System

Static Stray Current



Stray Current from High Voltage DC Transmission Lines

Static Stray Current



Types of Corrosion

Stray Current Corrosion

Electrified railroads/Transit systems

Underground mine railroads

Impressed Current Cathodic Protection

High Voltage DC Transmission Lines

1 Ampere removes 20 pounds of iron per year, from structure

Factors Affecting the Rate of Corrosion

Soil Resistivity

Anode/Cathode Relationship

Potential Difference between
Anode/Cathode

Polarization

Soil Resistivity

Below 500 ohm-cm	Very Corrosive
500 to 1000 ohm-cm	Corrosive
1000 to 2000 ohm-cm	Moderate Corrosive
2000 to 10,000 ohm-cm	Mildly corrosive
10,000 ohm-cm and above	Progressively less Corrosive

Anode to Cathode Ratio

Large anode to small cathode, the rate of corrosion at the anode is must less severe. Because there is a larger surface area from which the current will discharge.

Large cathode to small anode, the rate of corrosion at the Anode is much more severe. Because the area at which to Discharge current is concentrated, to a smaller area.

Potential Difference between the Anode and Cathode

Practical Galvanic Series

Active End

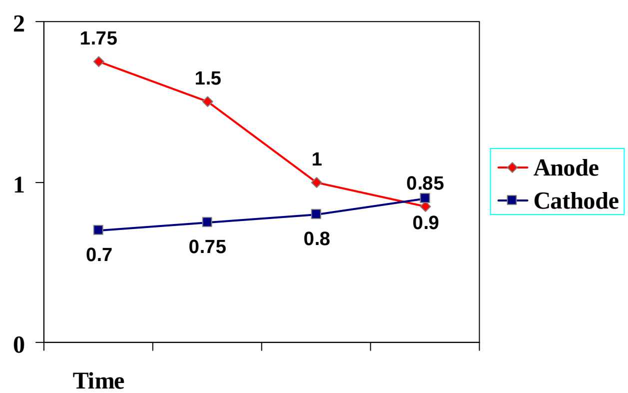
Material	Potential*
High Potential Magnesium	-1.75
Magnesium Alloy	-1.50
Zinc	-1.10
Aluminum Alloy	-1.05
Clean Carbon Steel	-0.50 to –0.80
Rusted Carbon Steel	-0.20 to –0.50
Cast/Ductile Steel	-0.50
Lead	-0.50
Steel in Concrete	-0.20
Copper	-0.20
High Silicon Iron	-0.20
Carbon, Graphite	+0.30

Passive or Noble End

* Potentials with respect to saturated Cu-$CuSO_4$ Electrode

Polarization

High Potential Magnesium	P/S	-1.75 Volts
Clean Carbon Steel	P/S	-0.50 to –0.80 Volts



The End

Have a great week at Appalachian Underground Corrosion Short Course

John Otto
Equitable Gas Company
4 South 9Th Street
Pittsburgh, PA 15203-1118

E-mail: jotto@eqt.com
Phone: 412-395-3584

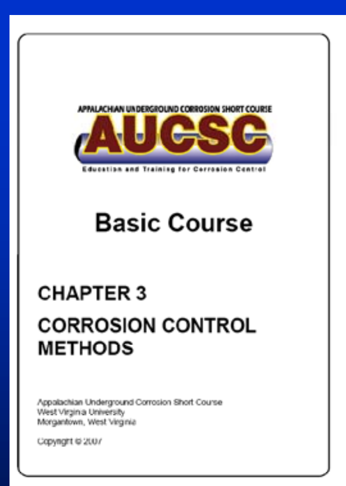
9 Rules to remember in corrosion work:

1. **The hardest problem to solve is the one that doesn't exist.**
2. **Don't take for granted the work done before you, was correct.**
3. **Never criticize the work done before you came aboard. (They had a reason, right or wrong.)**
4. **Always start with the simplest fix.**
5. **If one thing doesn't work try something else.**
6. **Don't assume the way you were taught is the right way.**
7. **Whatever works for you is the way you should work. (Note: I didn't say it's the best way.)**
8. **Don't dismiss a fresh idea.**
9. **Use common sense.**

N.A.C.E. Certified Corrosion Technician
Bertman J. Smith

Introduction to Cathodic Protection

Thomas B. Williams, Jr.
New England CP, Inc.
tom@newenglandcpinc.com



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

Introduction to Cathodic Protection

- A review of the fundamental corrosion cell
- Coatings and cathodic protection
- Isolating joints and cathodic protection
- The theory of cathodic protection
- When have we achieved cathodic protection?
- Cathodic protection current requirements
- Galvanic anode cathodic protection
- Impressed current cathodic protection

Corrosion Control Methods

For Natural or Galvanic Corrosion Control:

- Coatings
- Cathodic Protection
- Isolating Joints

For Stray Current Corrosion Control:

- Coatings
- Cathodic Protection
- Isolating Joints
- Drainage Bonds

The 4 Parts of a Corrosion Cell

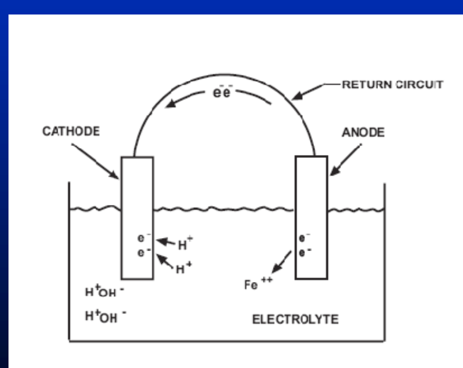
- Anode
- Cathode
- Electrolyte
- Return Circuit

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.

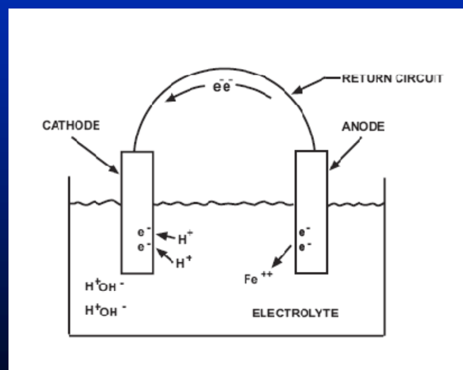
The Fundamental Corrosion Cell

- There are 4 parts to a corrosion cell:



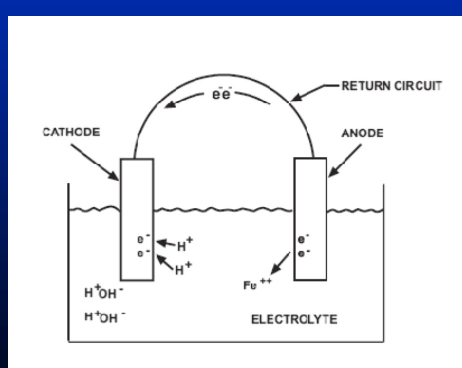
The Fundamental Corrosion Cell

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



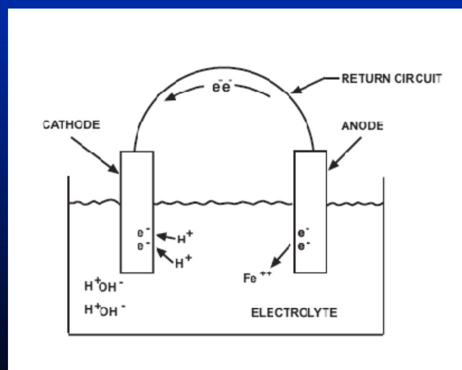
The Fundamental Corrosion Cell

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



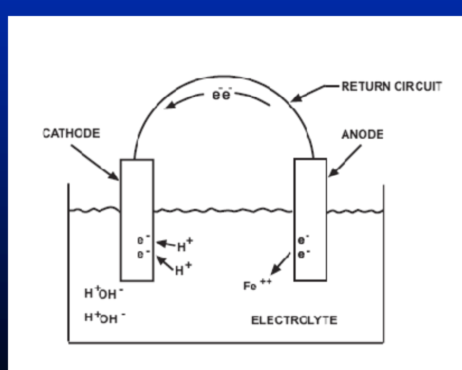
The Fundamental Corrosion Cell

- 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 hydrogen film builds up at the cathode. The hydrogen film 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 soil (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 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.
- 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.

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.
- Unfortunately, there is no such thing as a perfect coating.
- The better the coating, the less cathodic protection we need. We only need to protect the bare areas.

Factors that prevent applying and keeping a perfect coating:

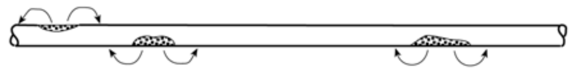
- Undetected handling damage during construction.
- Detected handling damage during construction that nobody bothered to repair.
- Stones or debris in backfill that force their way through the coating.
- Soil movement or structure movement with pressure changes (pipelines).
- Tree roots working through coating.
- Excavations by others which expose the structure and damage the coating with excavation equipment. Aka Third Party Damage

Isolating Fittings and Cathodic Protection

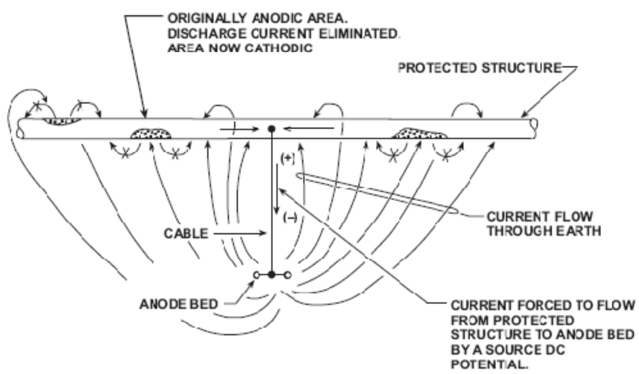
- Isolating fittings are used to confine cathodic protection current to a structure (or portion of a structure) to be cathodically protected.
- We only want to protect the bare areas of our structure. Not the bare areas of other underground structures.
- Isolating fittings are also used to separate cathodic protection systems from each other.

Theory of Cathodic Protection

- Anodes Corrode
- Cathodes do not corrode.
- If we make the entire surface of our pipe 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 the areas.



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

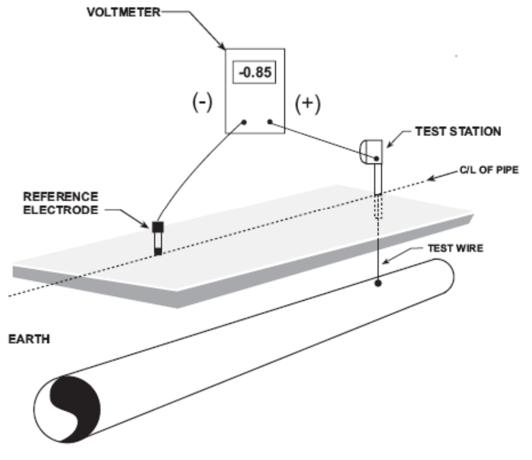


HOW CATHODIC PROTECTION WORKS

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).



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.
- Isolating fittings keep the current on the intended structure.

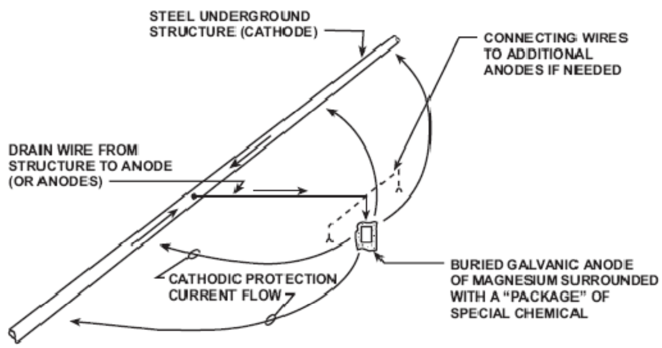
Two methods of cathodic protection:

- 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
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

↓ Progressively more cathodic (noble) and less corrosive

(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 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):

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

- 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:

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

Driving Voltage Effect on Current Output for Galvanic Anodes

- For a magnesium anode:

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

- For a zinc anode:

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

- For an aluminum anode:

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

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):

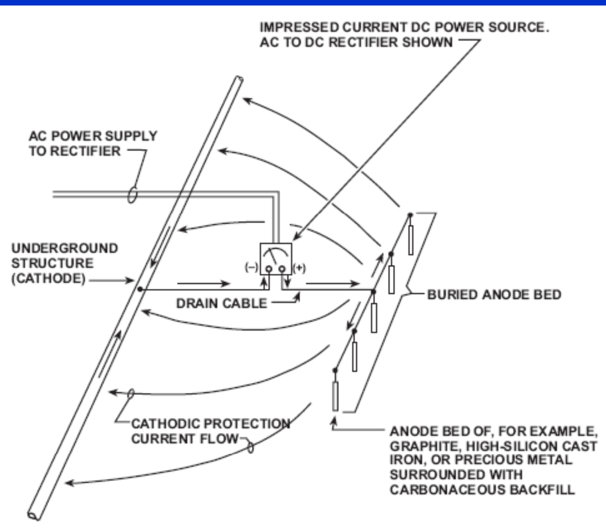
- They work better.
- They work better because they put out more current and last longer if installed in prepared backfill.

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.

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

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.

ELECTRICAL ISOLATION

CLASS PERIOD 5

Art Birx

ISOLATORS

- Isolators electrically isolate undesirable metal structures from the pipeline that is cathodically protected. Isolators work by eliminating the metallic path from the corrosion cell.

ISOLATORS (cont)

Isolators are used but not limited to the following uses:

- Separate foreign metal structures from protected pipelines
- Separates different types metals from each other
- Separates coated lines from bare lines
- Separates C/P lines from unprotected lines
- Electrically isolates pipes into manageable sections

DIELECTRICAL ISOLATION Primary Function (WHY?)

- Method of Corrosion Control
  - To stop the flow of CP current.
  - To limit the amount of current needed.
  - to prevent a corrosion cell.
- Inserted in pipelines and structures to **BLOCK** the flow of electrical current.

Failure to Provide Dielectric Isolation

- Severe corrosion can take place.
- New pipelines would become anodic in connection to the existing bare or poorly coated pipelines.
- Nonisolated sections of coated and bare piping would allow the potentials to fall below cathodic protection criteria.

Failure to Provide Dielectric Isolation (Cont.)

- Current requirements would increase in order to protect the poorly coated or bare pipe not isolated from the coated piping.
- Cost of cathodic protection will increase.
- Corrosive environments can impact the pipeline above (Atmospheric Corrosion) and pipe below ground.

Dielectric Isolation Materials

- Weld-in isolator
- Isolating compression couplings
- Isolating bolted couplings
- Fiber board gaskets
- Isolating unions
- Plastic Pipe
- Isolating meter swivels
- Dielectric Coatings
- Isolation flanges

Dielectric Isolation Types

- Coatings isolate the surrounding environment from the structure, this prevents the electrolyte from coming in contact with the pipeline above and below ground.

  - Coatings are our number one defense against corrosion on pipelines.

Dielectric Isolation Types (Cont)

- Coatings can vary on dielectric strengths, in most cases based on mil thickness and type of materials.

- Coatings keep the current on the pipeline. Current leaving the pipeline results in corrosion

- Coatings reduce the amount of holidays on a pipeline, and lessen the amount of protective current required. This lowers the cost of materials.

Dielectric Isolation – Coating Materials

- Types of coatings used –

  - Liquid Epoxy – two part/applied resin and harder, one coat estimate of 20 mils.

  - Extruded Coatings – high density polyethylene with an under coat of mastic approx. 60 mils thickness.

  - Asphalt Based Mastics – cold applied with brush to desired thickness

Dielectric Isolation – Coating Materials (Cont.)

- Fusion Bonded Epoxy – thin film coating, preheated to 400 to 500 F, with applied resin 10 to 18 mils pending customer's design requirements

- Cold Applied Tapes – plastic film with butyl rubber backing 15 to 35 mils.

- Cold Applied Waxes – grease type materials, blend of petroleum wax 20 to 30 mils.

Dielectric Isolation Devises

- **Meter Isolation & Above Ground Installations**

Meter Swivels

- Installed at meter, isolates customer from pipeline
- Should be installed on outlet of meter

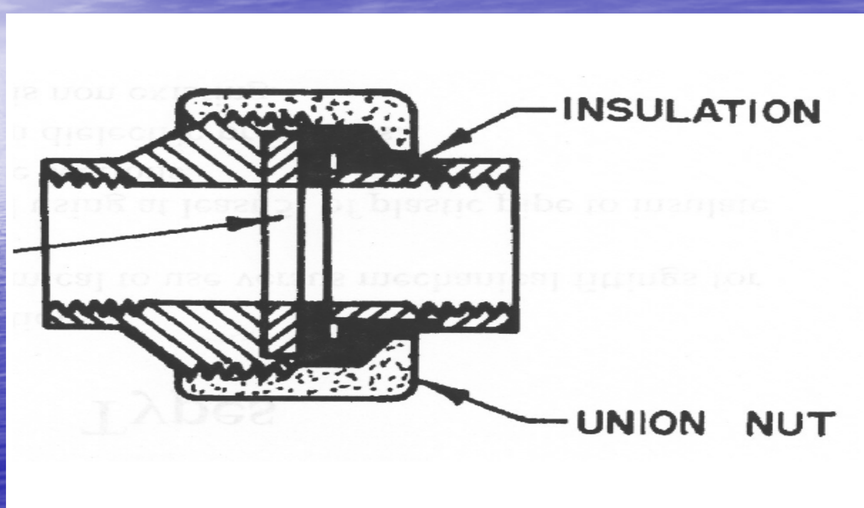
Dielectric Isolation Devises

- **Meter Isolation & Above Ground Installations (Cont)**

Isolating Unions

- Used on above ground metering & regulation stations to isolate piping
- Usually installed on threaded pipe
- Not recommended for below ground installation

Isolating Union



Dielectric Isolation Devises

- Plastic Pipe
  - More economical to use versus weld-end fittings or flanges
  - Recommended installing a minimum of 5 ft. of plastic pipe when isolating from steel pipe
  - Very high dielectric properties
  - No chance of failure do to shorting

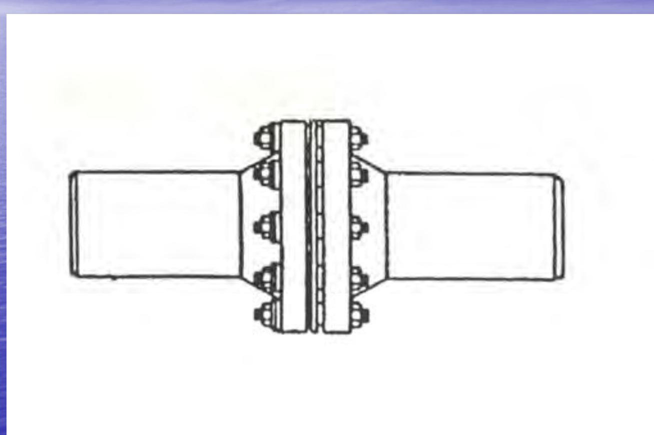
Dielectric Isolation Devises

- Weld-end Isolator
  - Can only be installed by qualified welder
  - Not most economical isolation device to install
  - Can fail due to soil stress or shifting

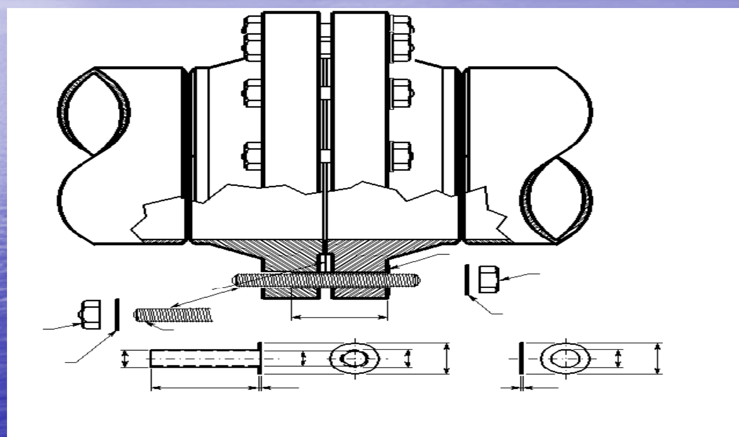
Dielectric Isolation Devises

- Isolating Flange Kit
  - Components are non-conductive and provide isolation of pipes and fittings connected by flanges
  - Flange kits consist of:
    - Nonconductive gasket
    - Isolation sleeves
    - Nonconductive washers

Weld-End Flange Isolator



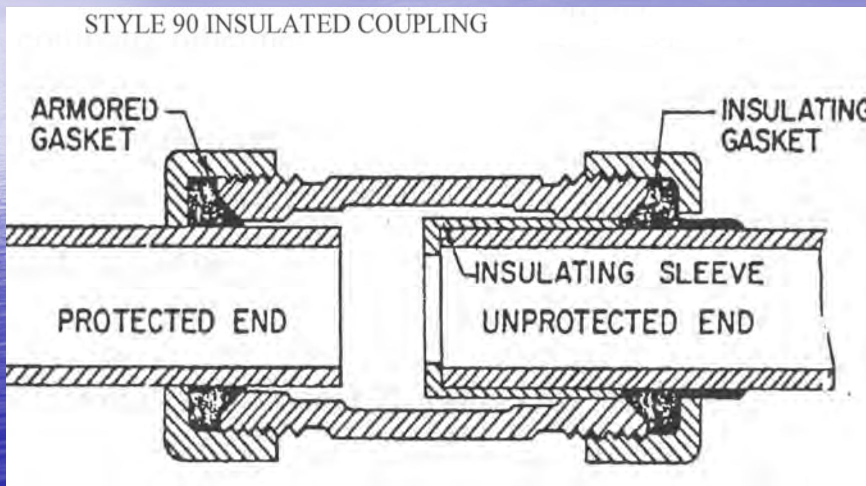
Weld-End Flange Isolator Side-View



Dielectric Isolation Devises

- Isolation Compression Couplings
  - For low to medium pressure pipelines
  - For pipe up to 2” in diameter
  - Non-conductive interior components
  - Some devises prone to leakage
  - Can fail due to soil stress or movement
  - Less expensive than other alternatives

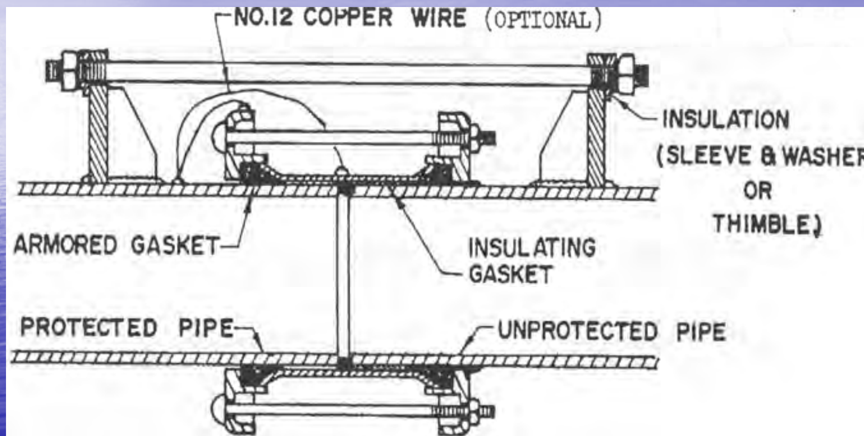
Isolating Compression Coupling



Dielectric Isolation Devises

- Isolating Bolted Couplings
  - For pipelines 2” & larger in diameter
  - Non-conductive interior components
  - Can fail due to soil stress or movement
  - Less expensive than other alternatives

Isolating Bolted Coupler



Testing Isolators

- Before installation check all isolators for electrical leakage. The resistance should be OL (over limit) on the meter.
- Test all isolators after installation **before** backfilling **do not** use a ohm meter after the isolator has been installed.
- Take pipe/soil potential reading on both sides of the isolator keeping the half cell in the same place. If the two readings are not different then the isolator may be shorted.

Gas Electronics

Model 601

Isolation Checker

Dielectric Isolation Precautions

- If the isolator is installed near high voltage AC lines or is in close proximity to electrical towers, precautions should be taken to prevent risks to personnel and damage from lightning strikes and stray AC currents.

  - Methods commonly used:

    Zinc ribbon

    Magnesium anodes

    :To provide a low resistance grounding system

Dielectric Isolation Precautions

- DOT subpart I, 192.467:

  If installation of the isolator is inside of a building that may have a combustible atmosphere, precautions must be taken to prevent arcing across the isolator.

  - Methods commonly used:

    A zinc grounding cell

Dielectric Isolation Protection

- DOT Subpart I, 192.455:
  - All isolated metallic fittings shall be coated and cathodically protected.
- Improper installation and application practices are the primary reasons for failure of isolators!

Pipeline Coatings

2005 AUCSC

Fundamentals Session

Jeff Didas – Colonial Pipeline Company – Richmond, VA

Remember This!

- Coatings are the #1 defense against corrosion.
- This is true for underground, transition and above ground service.

Coating Types

- Underground – buried or immersion service
- Transition area coatings
- Atmospheric coatings

Underground Pipeline Coatings

- Mill or Plant Applied
- Field Applied
- Line Coatings
- Repair Coatings
- Coating Discussion
- Coating Cost
- Coating Quality

Mill or Plant Applied

- Most economical method to apply coatings
- Highest level of quality and quality control
- Plant/Mill conditions allow use of higher performing coatings
- Normally, high quality storage, handling and shipping
- Normally allows for some coated pipe storage

Field Applied

- Costly method either over the ditch or in the ditch
- Hard to manage quality control due to environmental conditions
- Normally lower performing coatings
- Newer field coatings do allow higher productivity

Line Coatings

- Coal Tar Enamel
- Asphalt Enamel
- Extruded Polyethylene
- Fusion Bonded Epoxy
- Somastic
- Pritec
- Liquid Epoxy
- 3 Layer

Repair Coatings

- Tapes
- Wax
- Shrink Sleeves
- Two - Part Epoxy
- Mastic
- Misc.

Coatings Discussion

- Most important component of a pipeline
- High quality holiday free coating requires almost no cathodic protection current
- Coatings need to be specified
- Coatings need to be tested
- Every coating has a use, but most coatings are used improperly – follow procedures

Coating Cost

- Cost of material
- Cost of application
- Cost to repair
- Handling
- Expected life
- Dielectric strength

Coating Quality

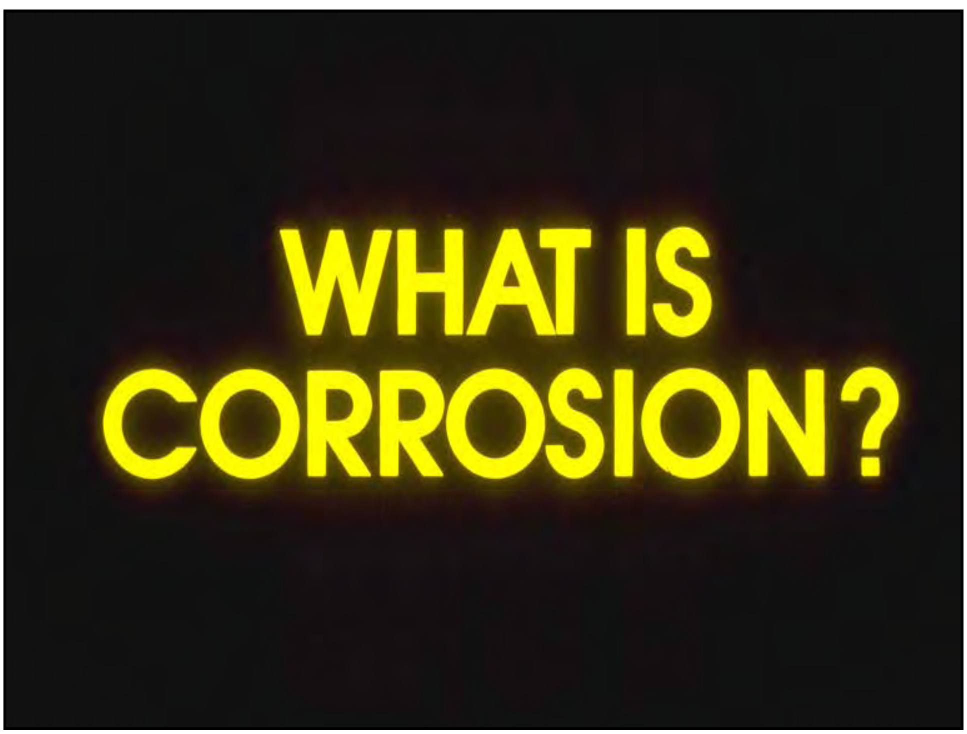
- Quality determines price
- Quality is normally dependent upon surface preparation & application methods
- Quality is assured with competent inspection
- Quality is determined by good procedures and good specifications

Transition Area Coatings

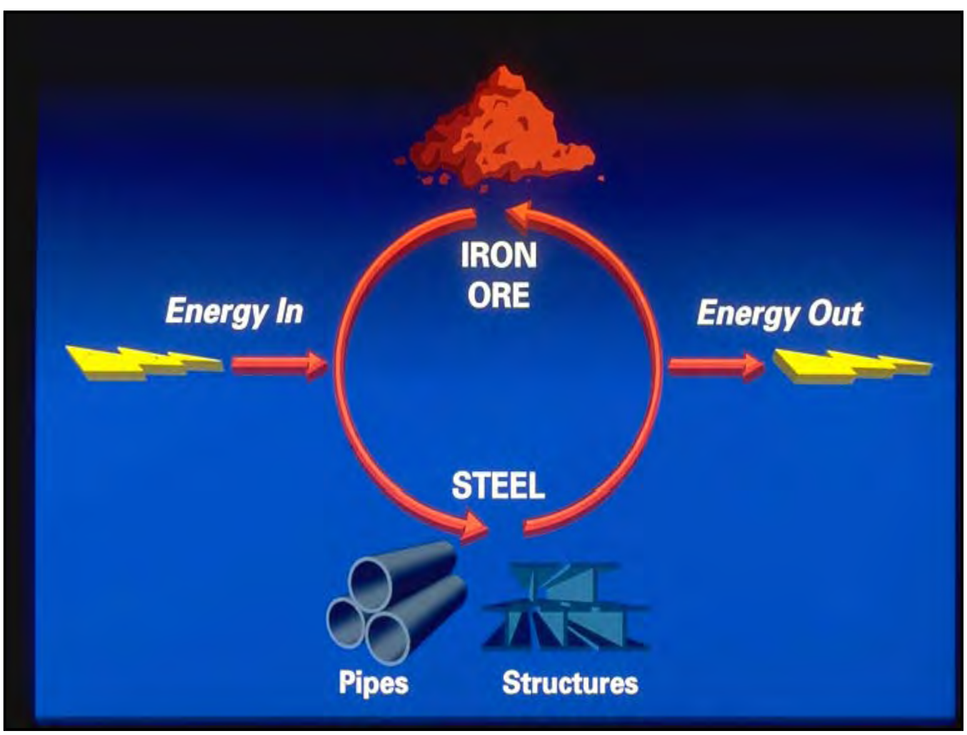
- Used where piping transitions from buried service to atmospheric service
- Used to protect from mechanical damage – freeze/thaw cycle, weed whackers, gravel, etc.
- Used to protect buried service coatings from Ultraviolet light when used above ground

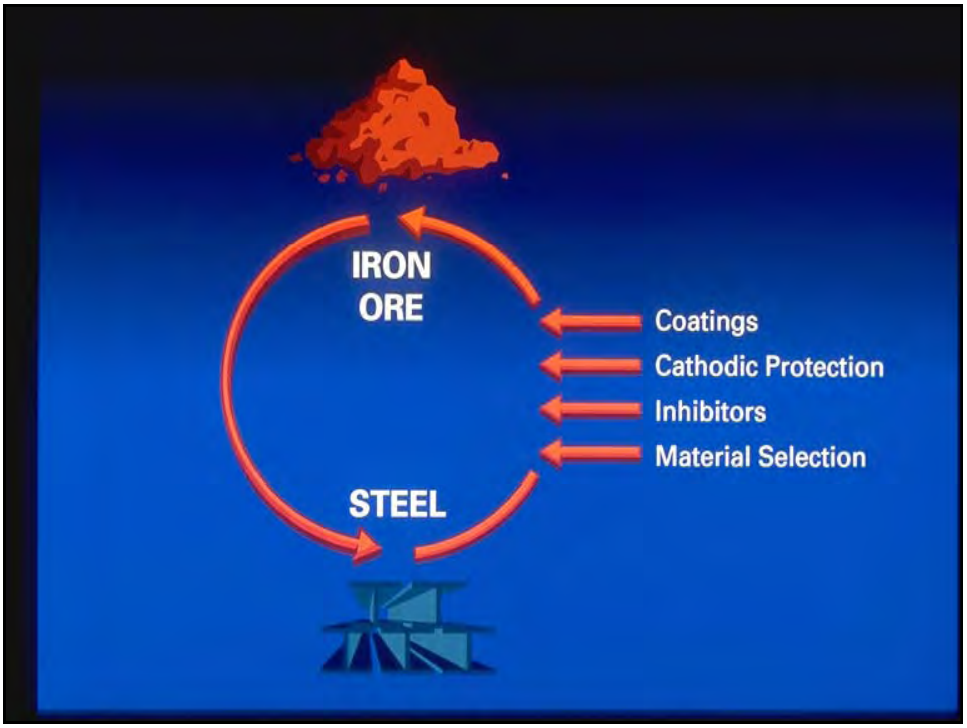
Atmospheric Coatings

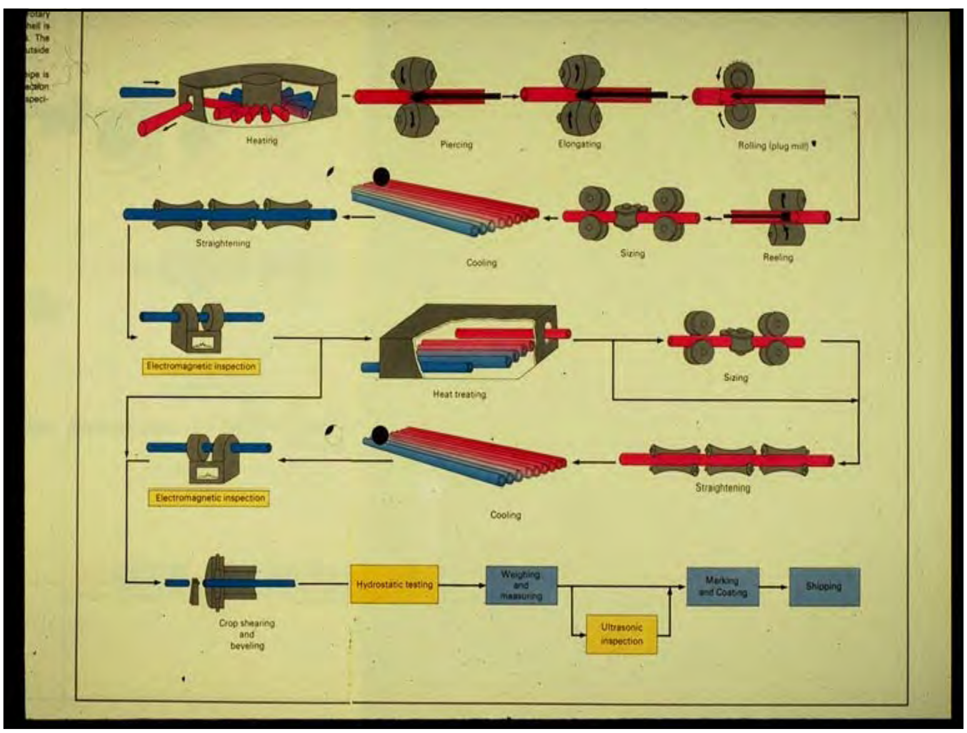
- Various types, quality and expected life
- Primary purpose is corrosion prevention, secondary purpose is appearance
- Problem areas, flanges, nuts, bolts, hold down clamps, high temperature service, beneath insulation, through walls/foundations, etc.

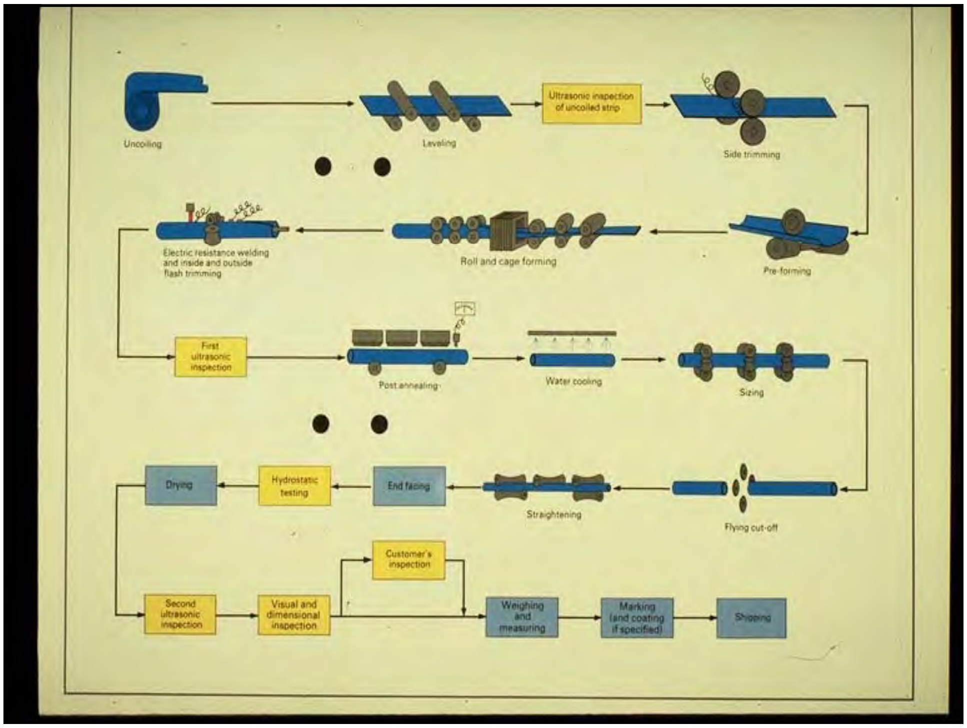


CORROSION IS THE DESTRUCTION OF A SUBSTANCE, USUALLY A METAL, OR ITS PROPERTIES BECAUSE OF A REACTION WITH ITS ENVIRONMENT.

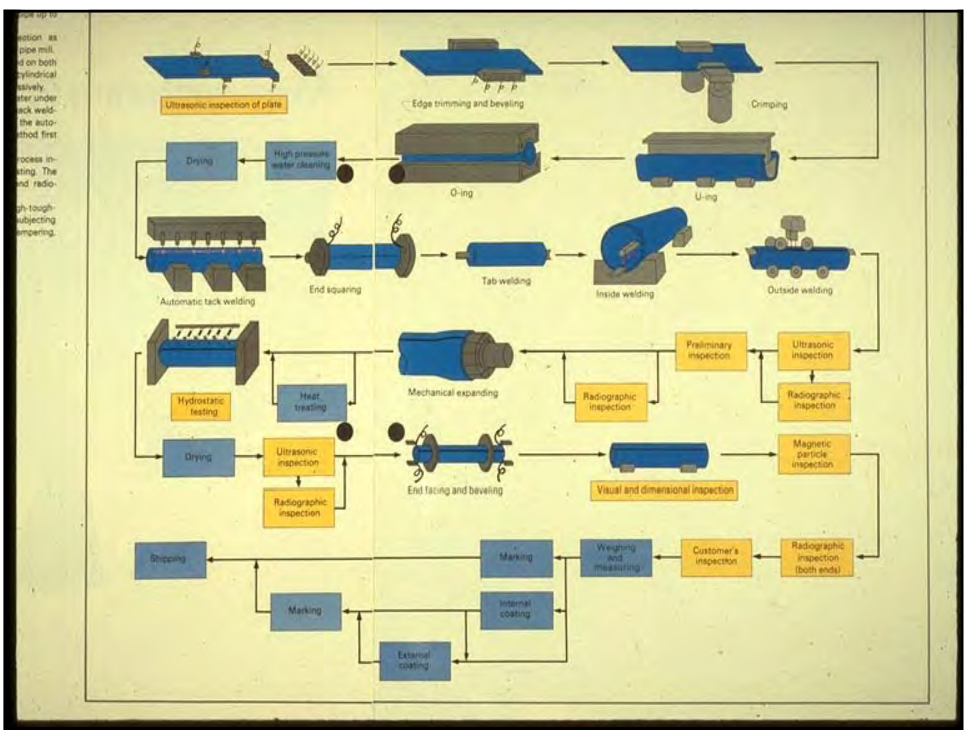



IRON
ORE
Coatings
Cathodic Protection
Inhibitors
Material Selection
STEEL

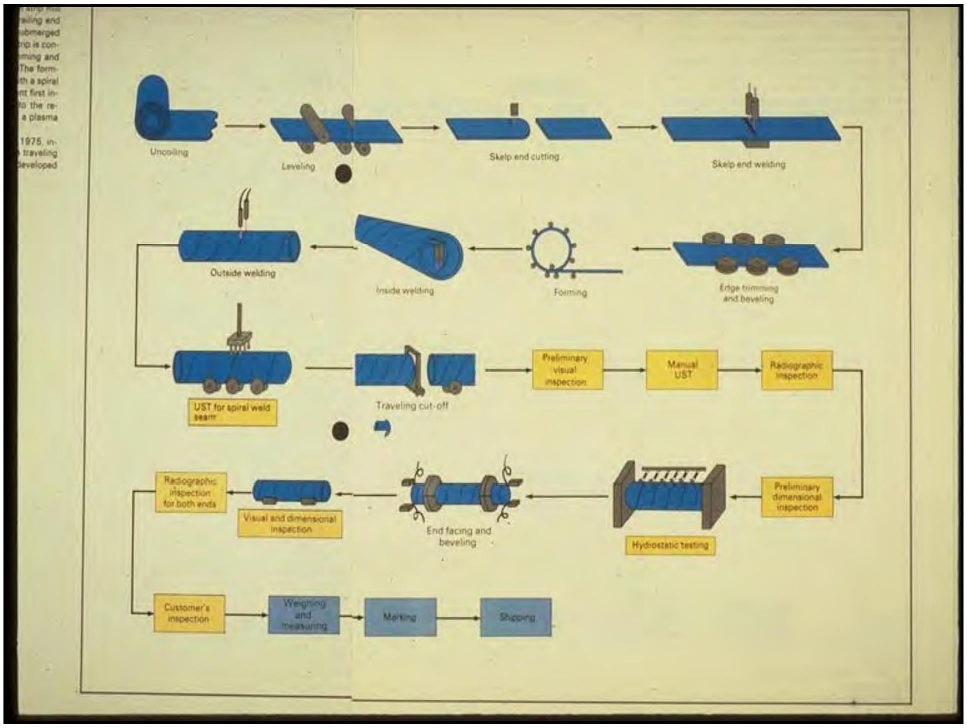

Heating
Piercing
Elongating
Rolling (plug mill)
Straightening
Cooling
Sizing
Reeling
Electromagnetic inspection
Heat treating
Sizing
Electromagnetic inspection
Cooling
Straightening
Crop shearing and beveling
Hydrostatic testing
Weighing and measuring
Ultrasonic inspection
Marking and Coating
Shipping

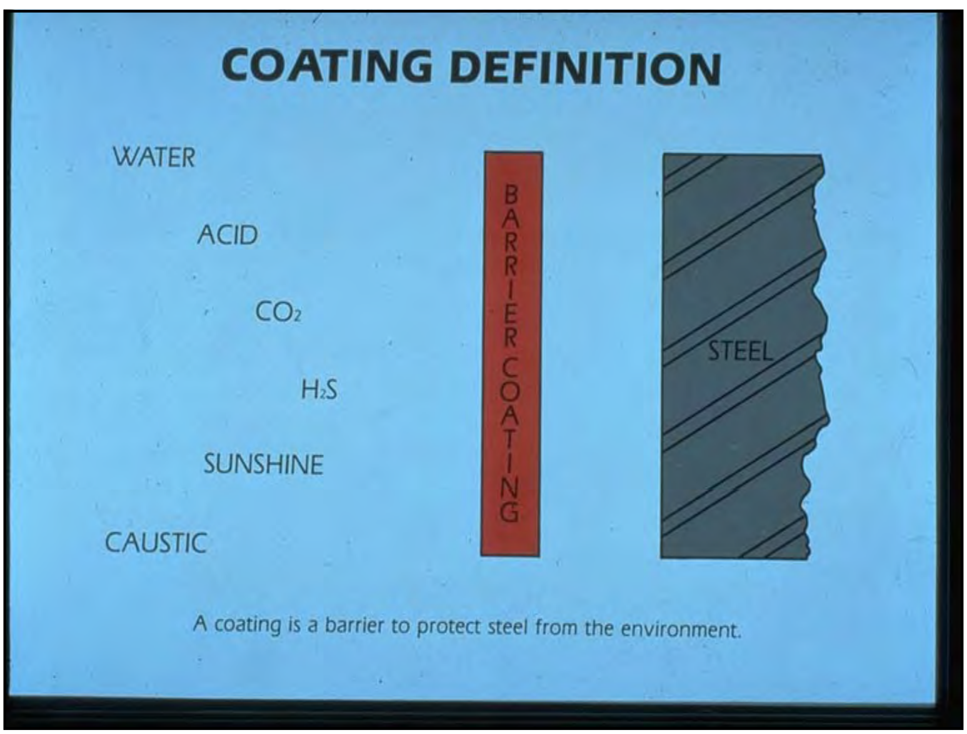


Uncoiling
Leveling
Ultrasonic inspection of uncoiled strip
Side trimming
Electric resistance welding and inside and outside flash trimming
Roll and cage forming
Pre-forming
First ultrasonic inspection
Post annealing
Water cooling
Sizing
Drying
Hydrostatic testing
End facing
Straightening
Flying cut-off
Customer's inspection
Second ultrasonic inspection
Visual and dimensional inspection
Weighing and measuring
Marking (and coating if specified)
Shipping



Ultrasonic inspection of plate
Edge trimming and beveling
Crimping
Drying
High pressure water cleaning
O-ing
U-ing
Automatic tack welding
End squaring
Tab welding
Inside welding
Outside welding
Mechanical expanding
Preliminary inspection
Ultrasonic inspection
Hydrostatic testing
Heat treating
Radiographic inspection
Radiographic inspection
Drying
Ultrasonic inspection
End facing and beveling
Visual and dimensional inspection
Magnetic particle inspection
Radiographic inspection
Shipping
Marking
Weighing and measuring
Customer's inspection
Radiographic inspection (both ends)
Marking
Internal coating
External coating


Uncoiling
Leveling
Skelp end cutting
Skelp end welding
Edge trimming and beveling
Forming
Inside welding
Outside welding
UST for spiral weld seam
Traveling cut-off
Preliminary visual inspection
Manual UST
Radiographic inspection
Preliminary dimensional inspection
Hydrostatic testing
End facing and beveling
Visual and dimensional inspection
Radiographic inspection for both ends
Customer's inspection
Weighing and measuring
Marking
Shipping


COATING DEFINITION
WATER
ACID
CO_2
H_2S
SUNSHINE
CAUSTIC
BARRIER COATING
STEEL
A coating is a barrier to protect steel from the environment.

Perfect Coating

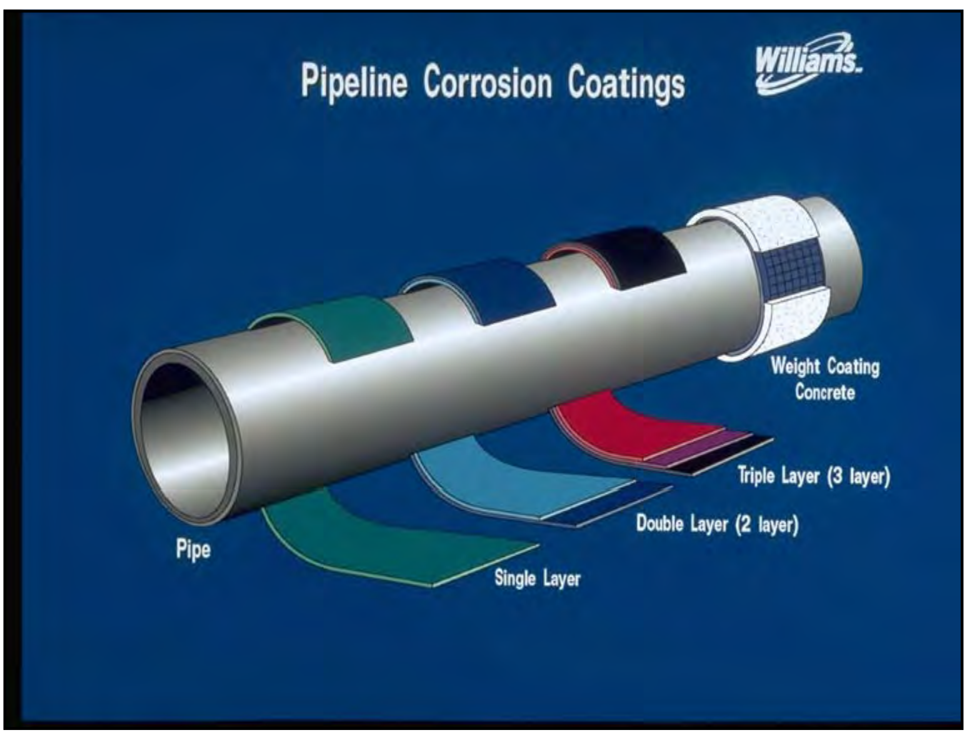
- Ease of Application - A monkey can put it on with a mop on any surface or from above ground.
- Cost Effective - Cost $1.00/Gallon or less!
- Environmentally Safe and Friendly – OK to Drink it.
- Performance - Lasts forever.

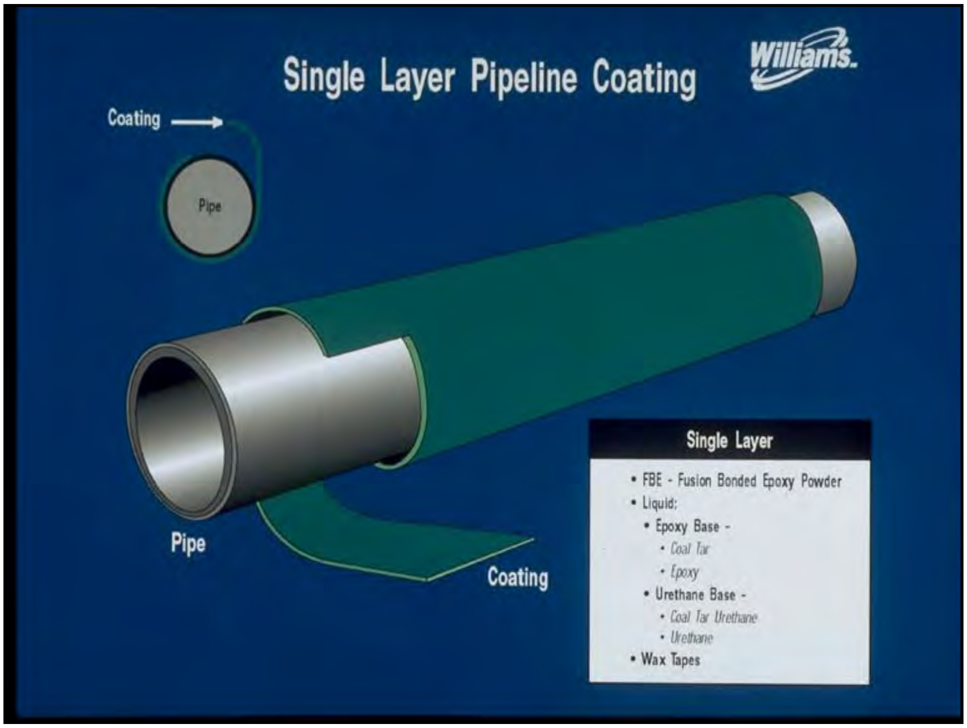
In Reality a Perfect Coating

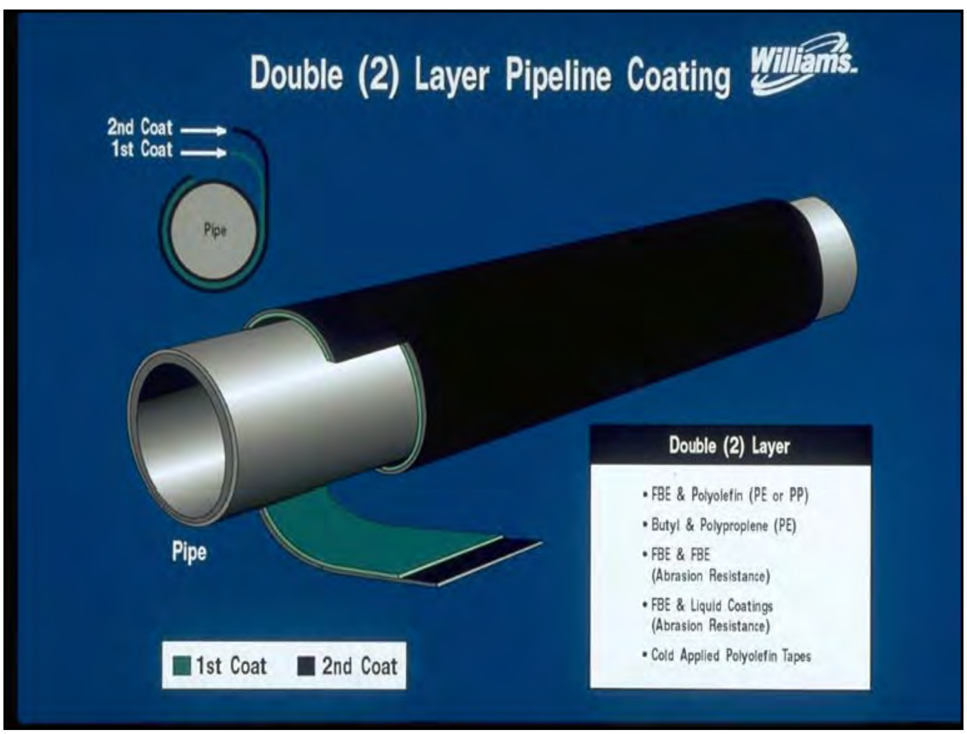
- Requires a quality standard
- Requires a quality specification
- Requires a quality coating mill
- Requires a quality material or materials
- Requires a quality inspector or inspectors

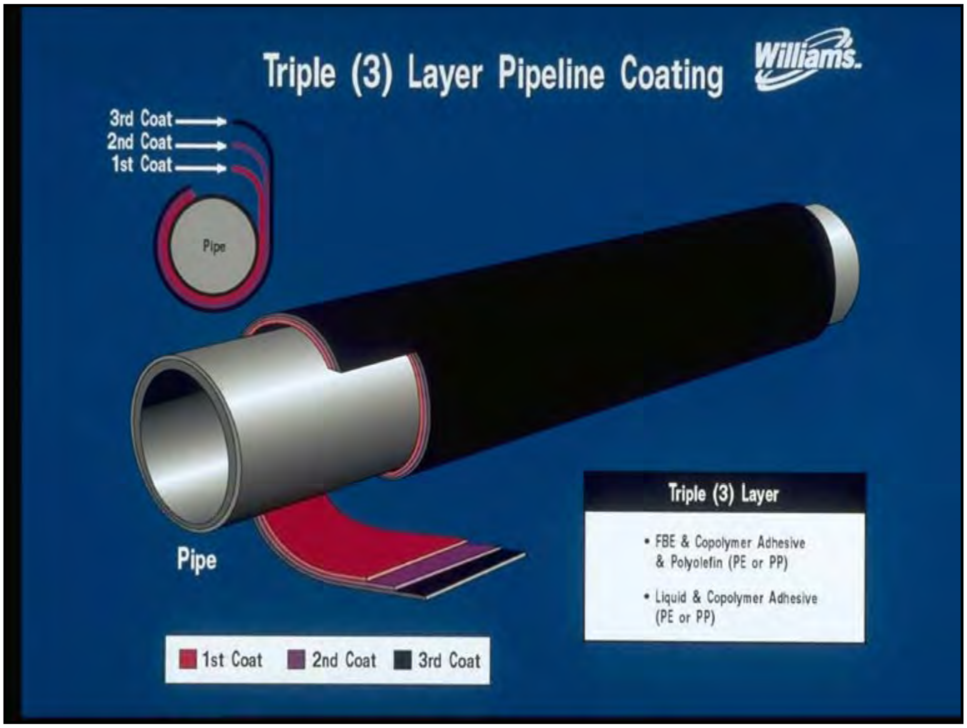
General Requirements of a Pipeline Coating

- Ease of Application
- Good Adhesion to Pipe
- Good Resistance to Impact
- Flexibility
- Resistance to Flow
- Water Resistance
- Electrical Resistance
- Chemical and Physical Stability
- Resistance to Soil Bacteria
- Resistance to Marine Organisms
- Resistance to Cathodic Disbondment
- Resistance to Soil Stress

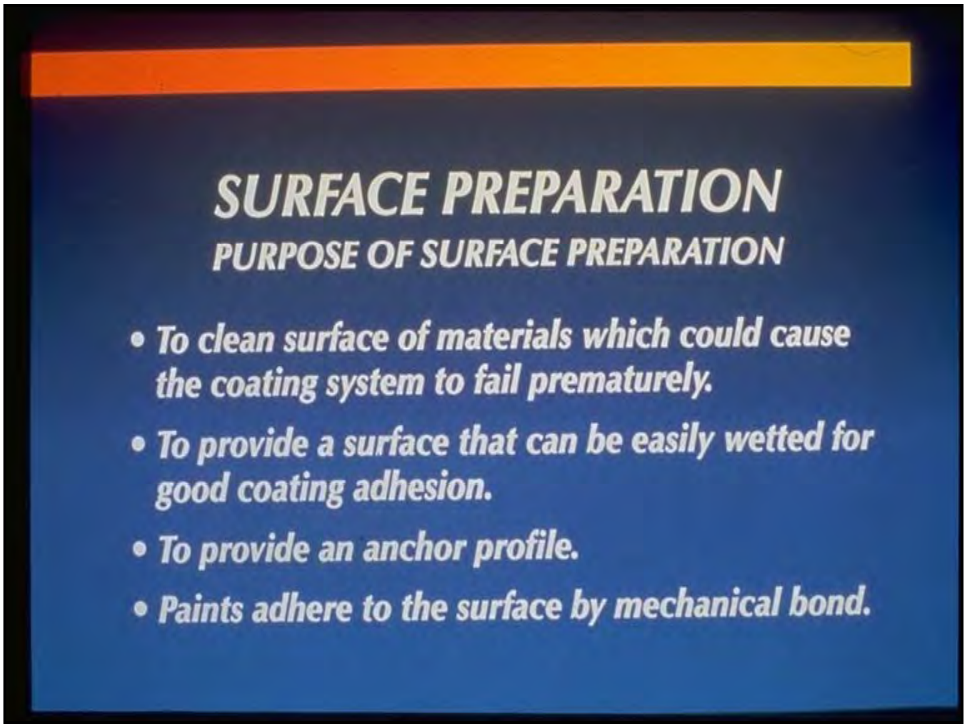


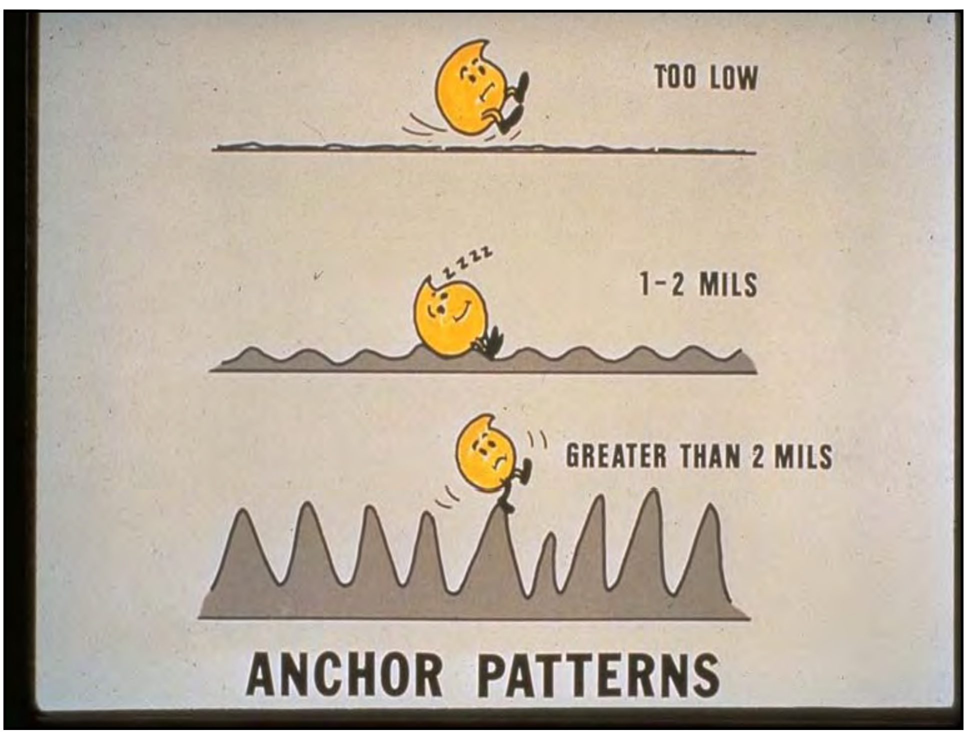

Single Layer Pipeline Coating
Williams.
Coating
Pipe
Pipe
Coating
Single Layer
• FBE - Fusion Bonded Epoxy Powder
• Liquid:
• Epoxy Base -
• Coal Tar
• Epoxy
• Urethane Base -
• Coal Tar Urethane
• Urethane
• Wax Tapes

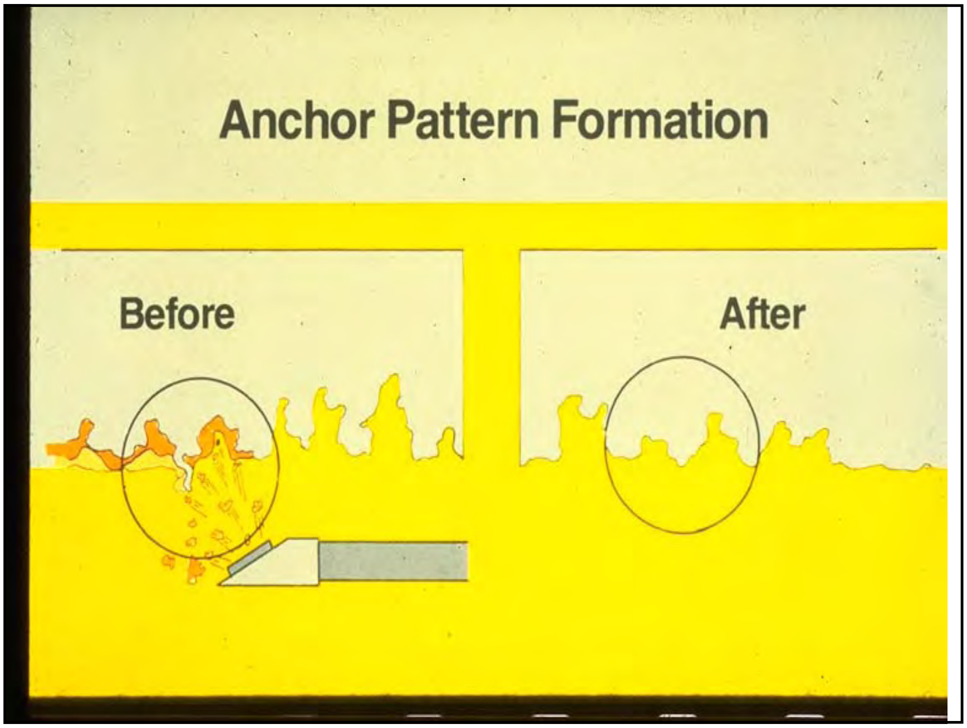

Double (2) Layer Pipeline Coating
Williams.
2nd Coat
1st Coat
Pipe
Pipe
Double (2) Layer
• FBE & Polyolefin (PE or PP)
• Butyl & Polypropylene (PE)
• FBE & FBE
(Abrasion Resistance)
• FBE & Liquid Coatings
(Abrasion Resistance)
• Cold Applied Polyolefin Tapes
1st Coat
2nd Coat


Triple (3) Layer Pipeline Coating
Williams.
3rd Coat
2nd Coat
1st Coat
Pipe
Pipe
Triple (3) Layer
• FBE & Copolymer Adhesive & Polyolefin (PE or PP)
• Liquid & Copolymer Adhesive (PE or PP)
1st Coat
2nd Coat
3rd Coat


SURFACE PREPARATION

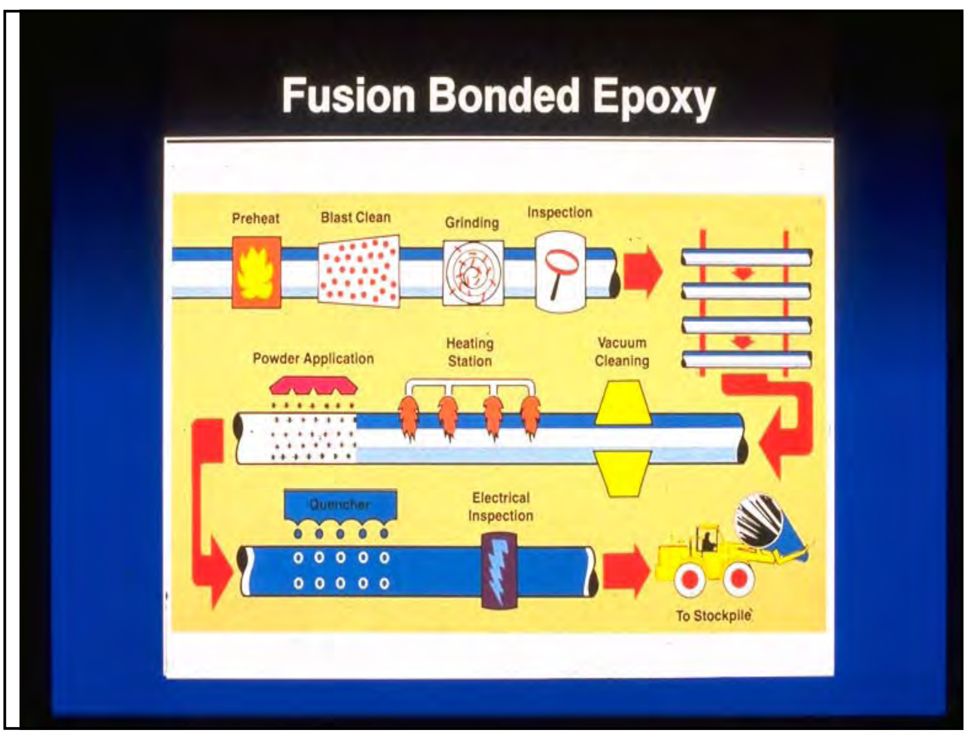

SURFACE PREPARATION
PURPOSE OF SURFACE PREPARATION
• To clean surface of materials which could cause the coating system to fail prematurely.
• To provide a surface that can be easily wetted for good coating adhesion.
• To provide an anchor profile.
• Paints adhere to the surface by mechanical bond.

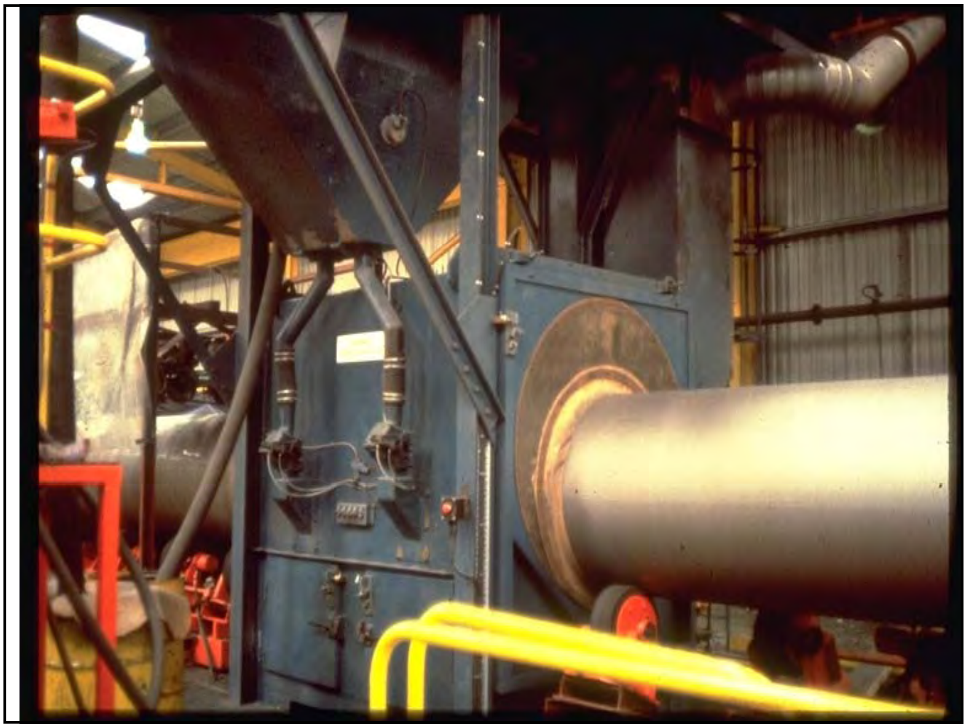

TOO LOW
1-2 MILS
GREATER THAN 2 MILS
ANCHOR PATTERNS

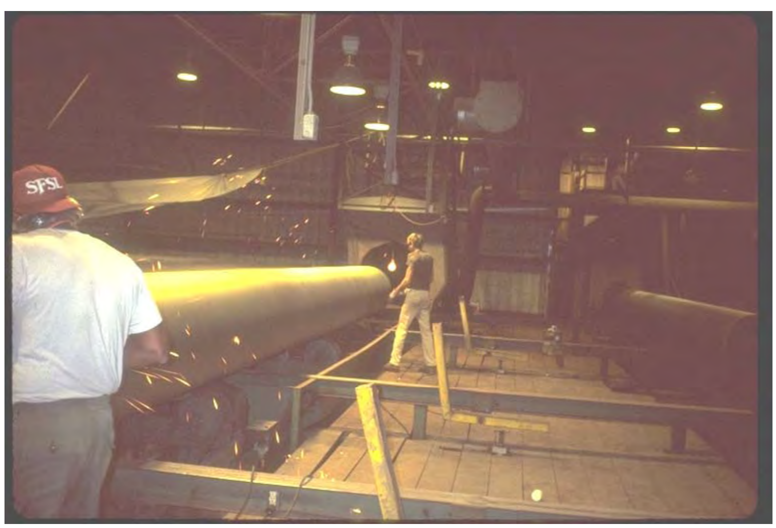

Anchor Pattern Formation
Before
After

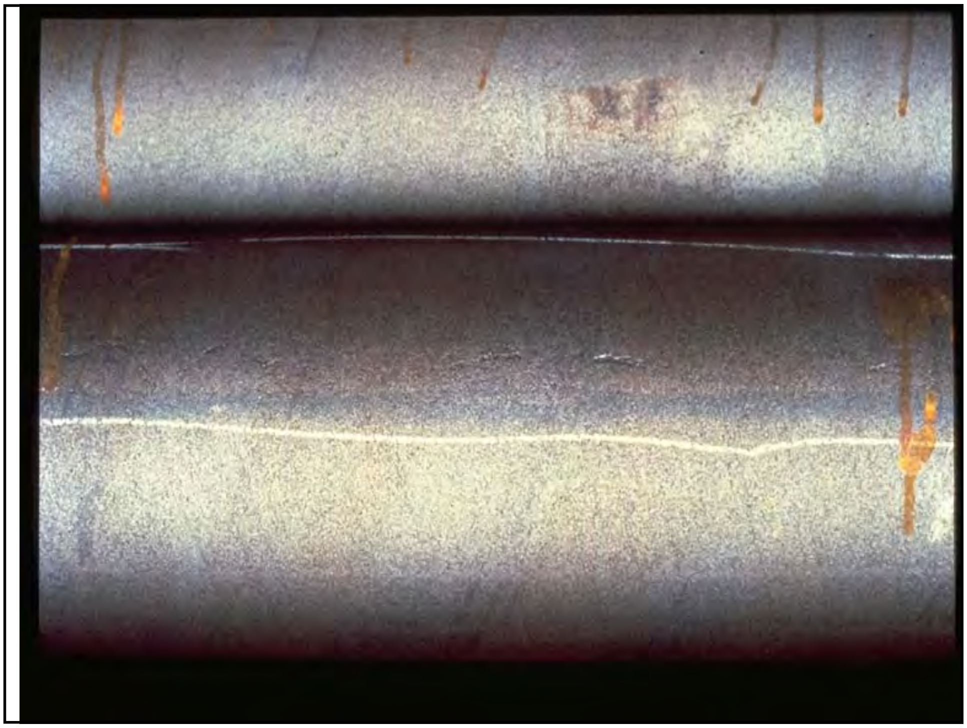

FUSION BONDED
COATINGS

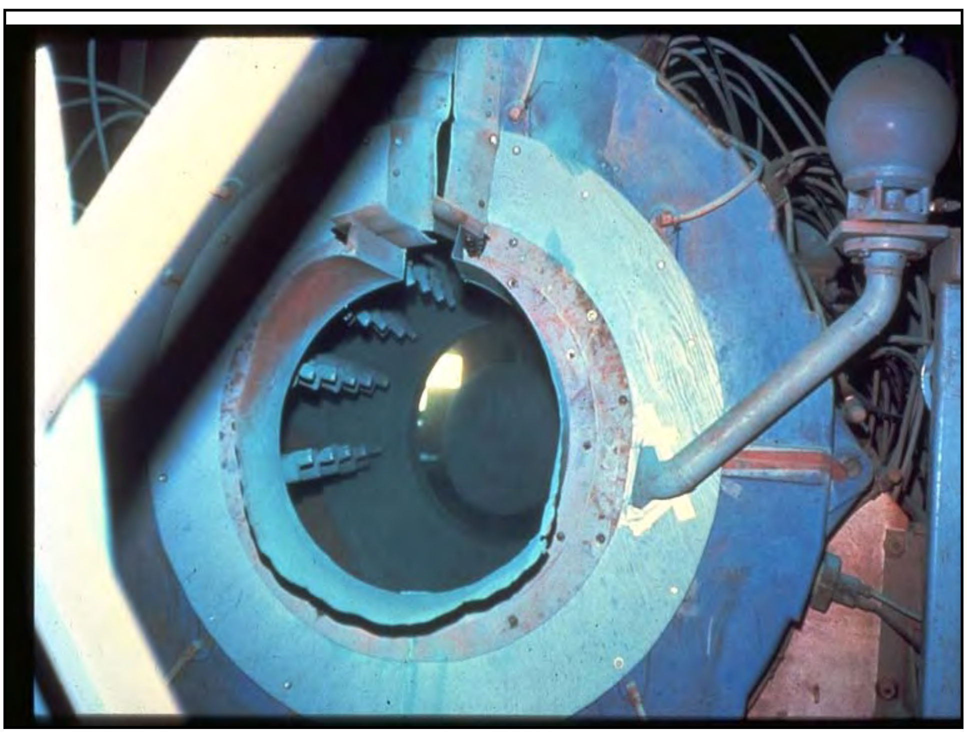

APPLICATION
PROCEDURE
1. CLEAN
2. HEAT
3. APPLY
4. CURE
5. INSPECT
6. REPAIR

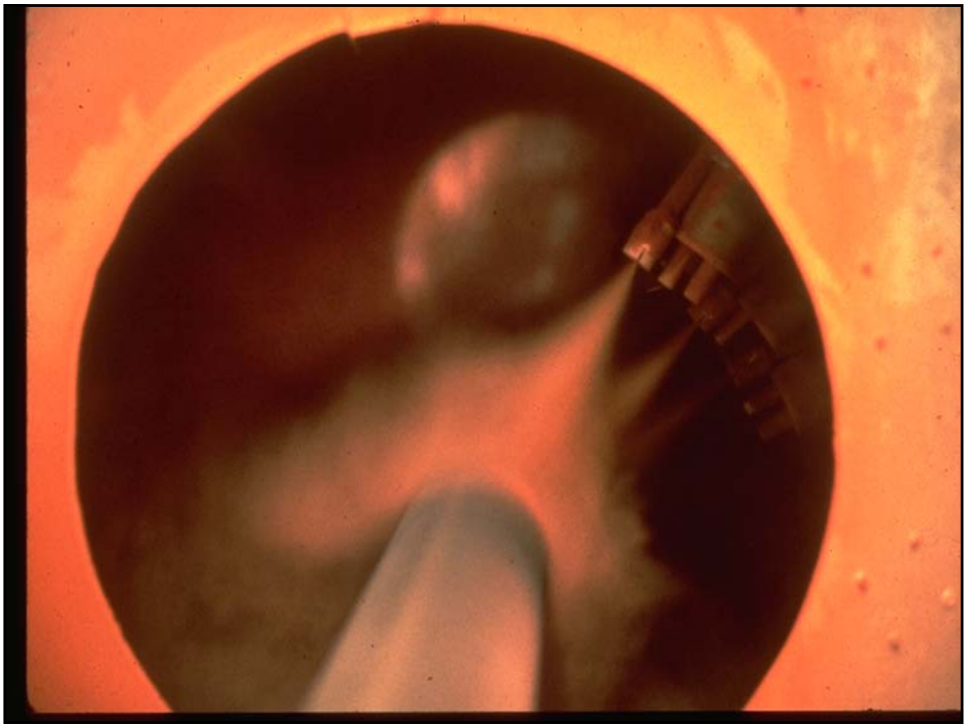

Fusion Bonded Epoxy
Preheat
Blast Clean
Grinding
Inspection
Powder Application
Heating Station
Vacuum Cleaning
Quencher
Electrical Inspection
To Stockpile

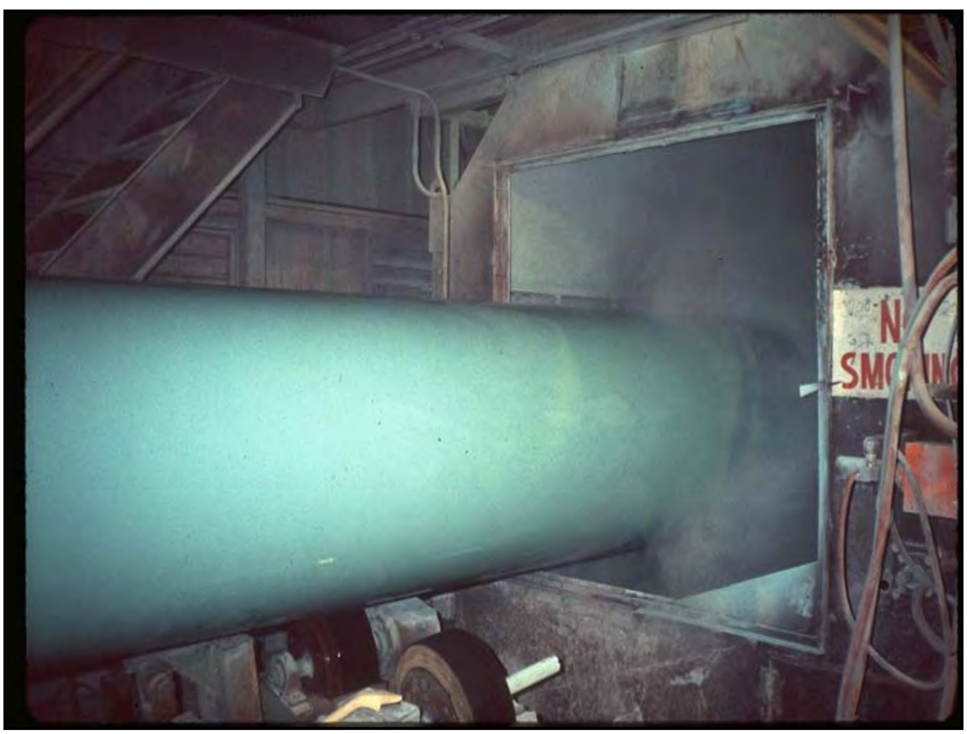


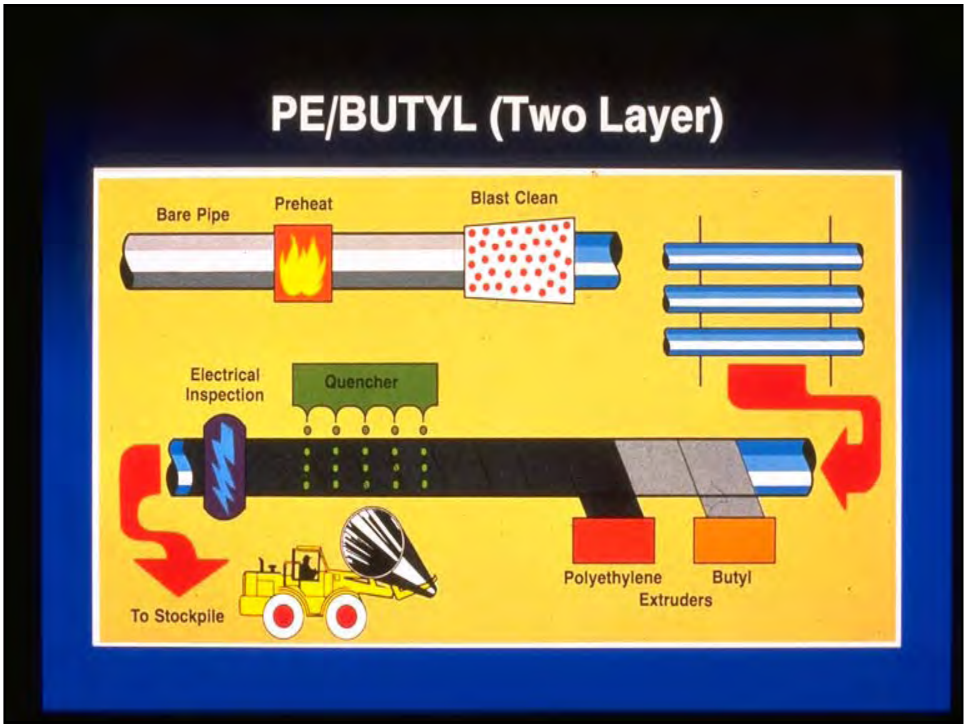

SFSL

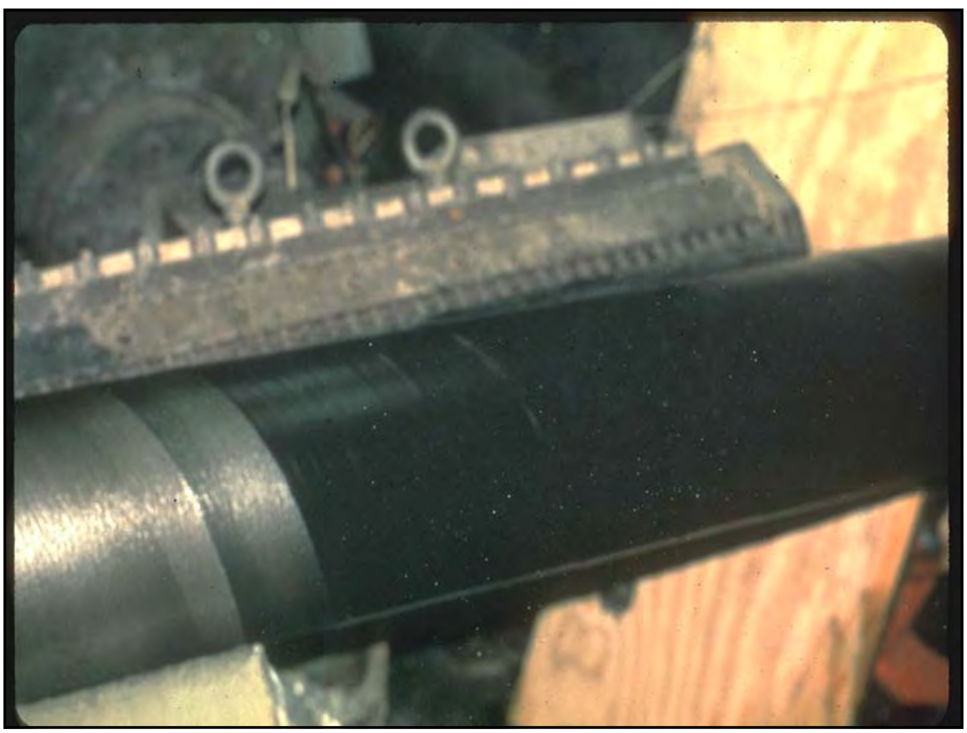


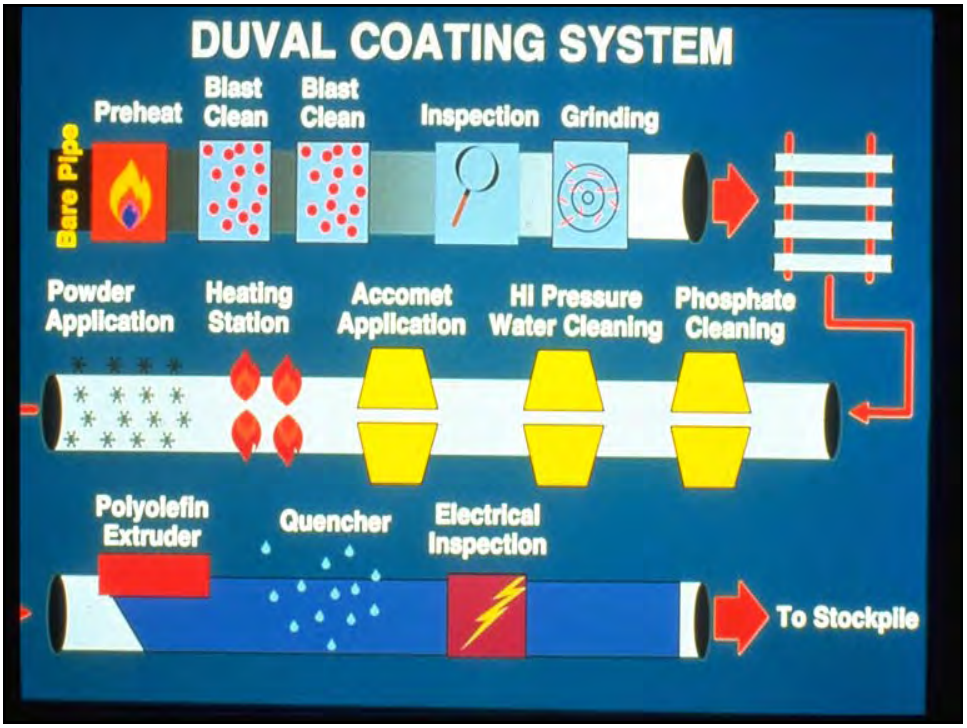


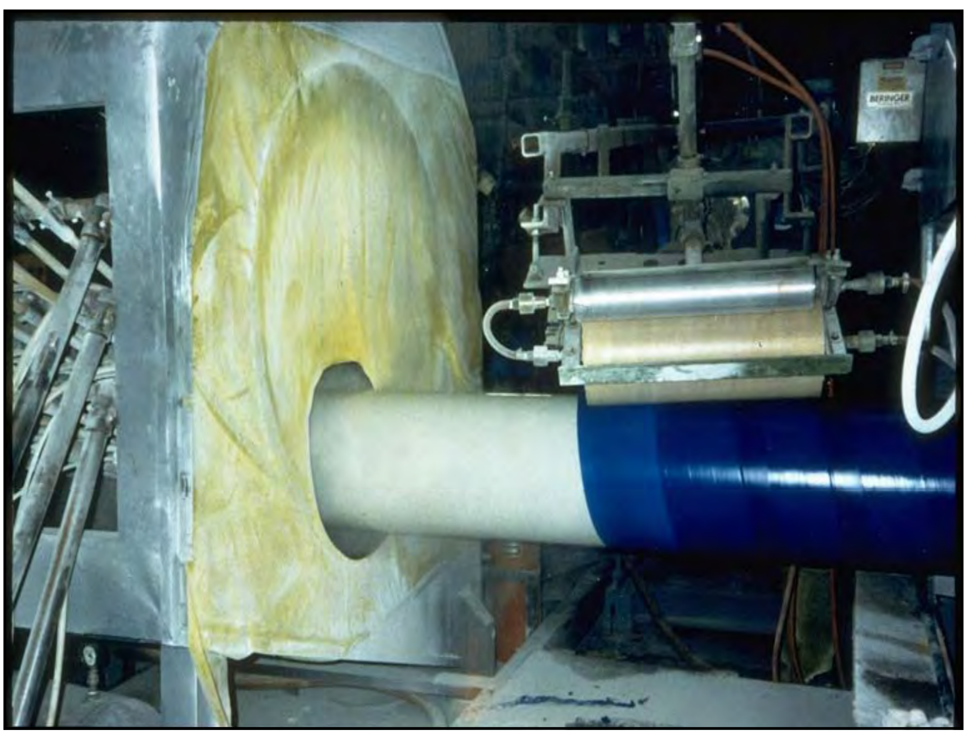


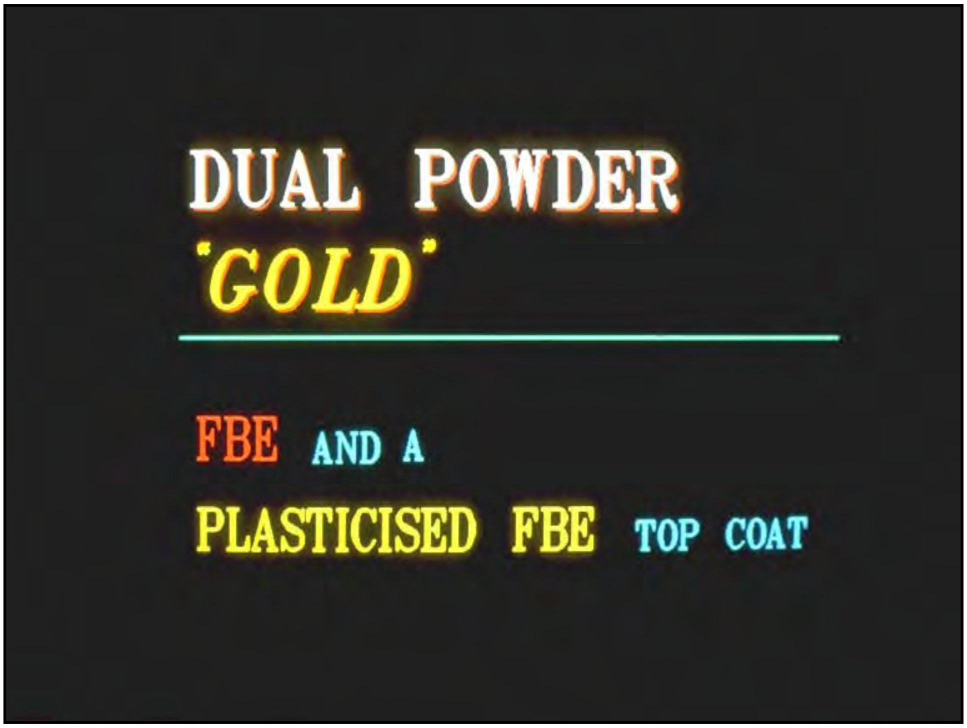


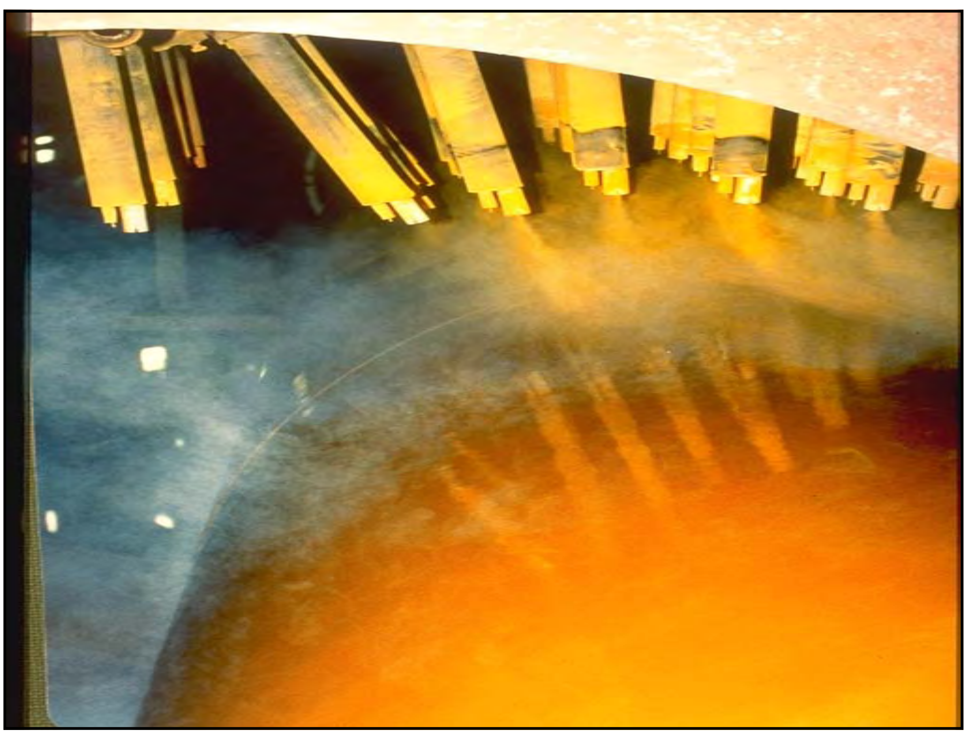

PE/BUTYL (Two Layer)
Bare Pipe
Preheat
Blast Clean
Electrical Inspection
Quencher
To Stockpile
Polyethylene
Butyl
Extruders

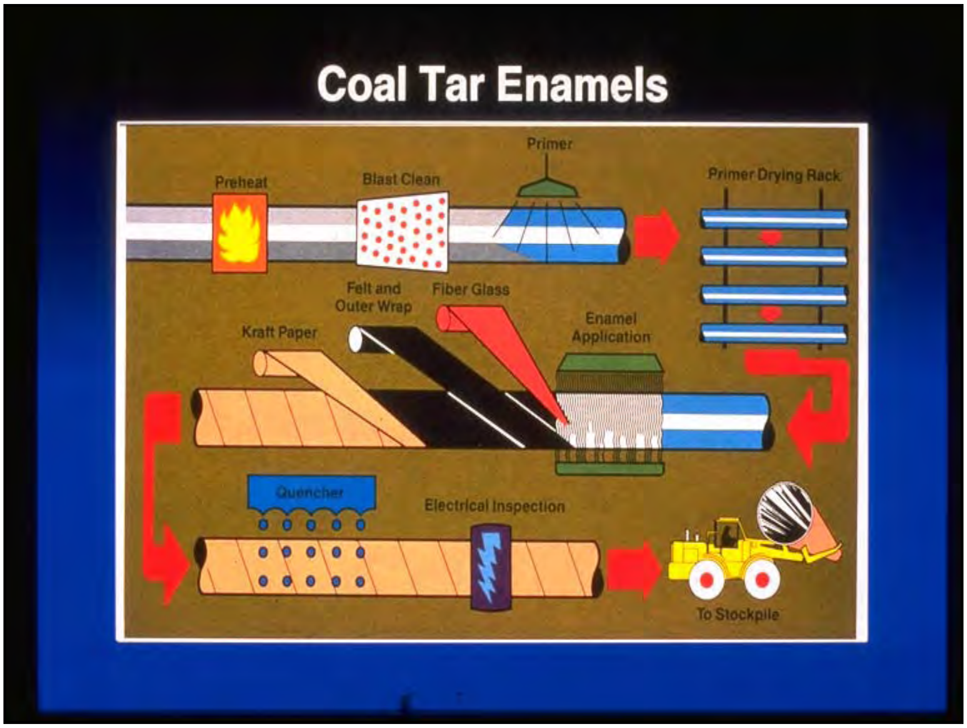


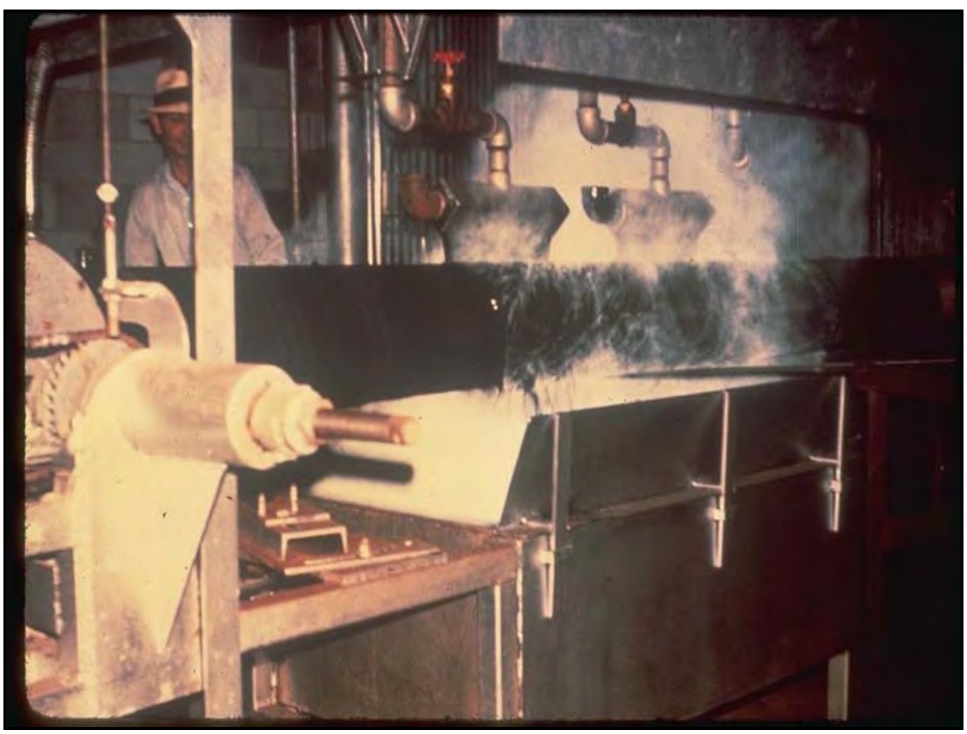

DUVAL COATING SYSTEM
Bare Pipe
Preheat
Blast Clean
Blast Clean
Inspection
Grinding
Powder Application
Heating Station
Accomet Application
Hi Pressure Water Cleaning
Phosphate Cleaning
Polyolefin Extruder
Quencher
Electrical Inspection
To Stockpile

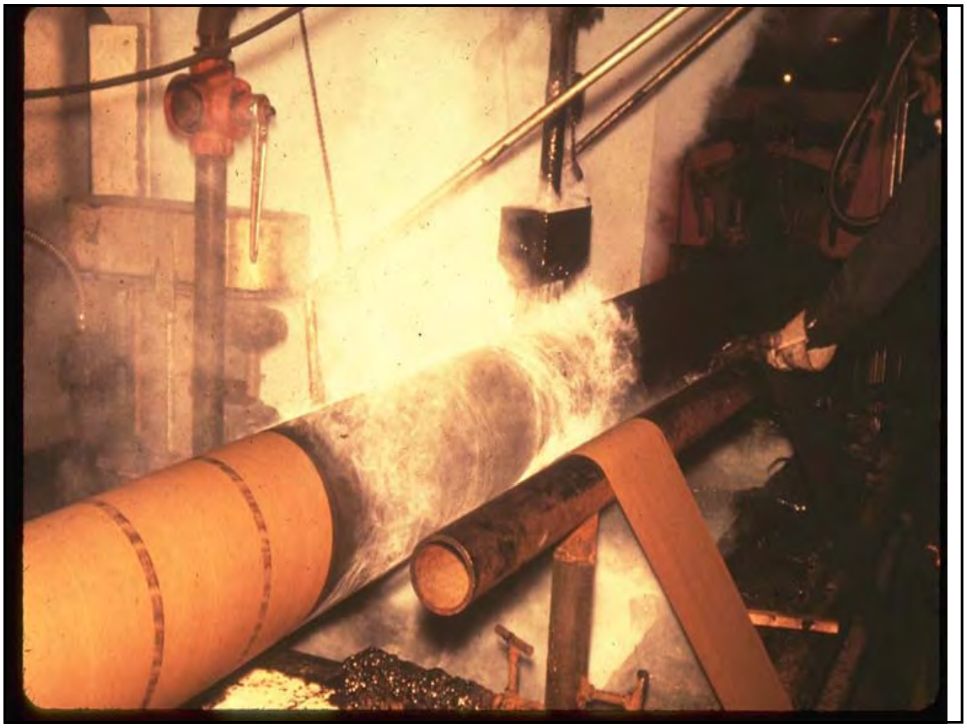


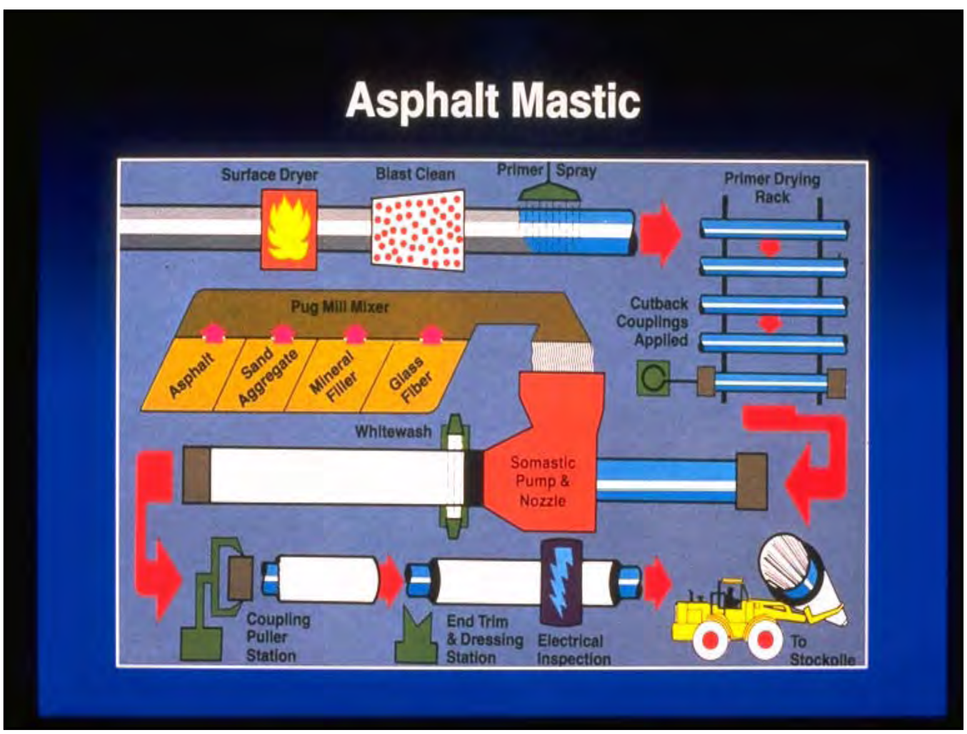

DUAL POWDER
"GOLD"
FBE AND A
PLASTICISED FBE TOP COAT



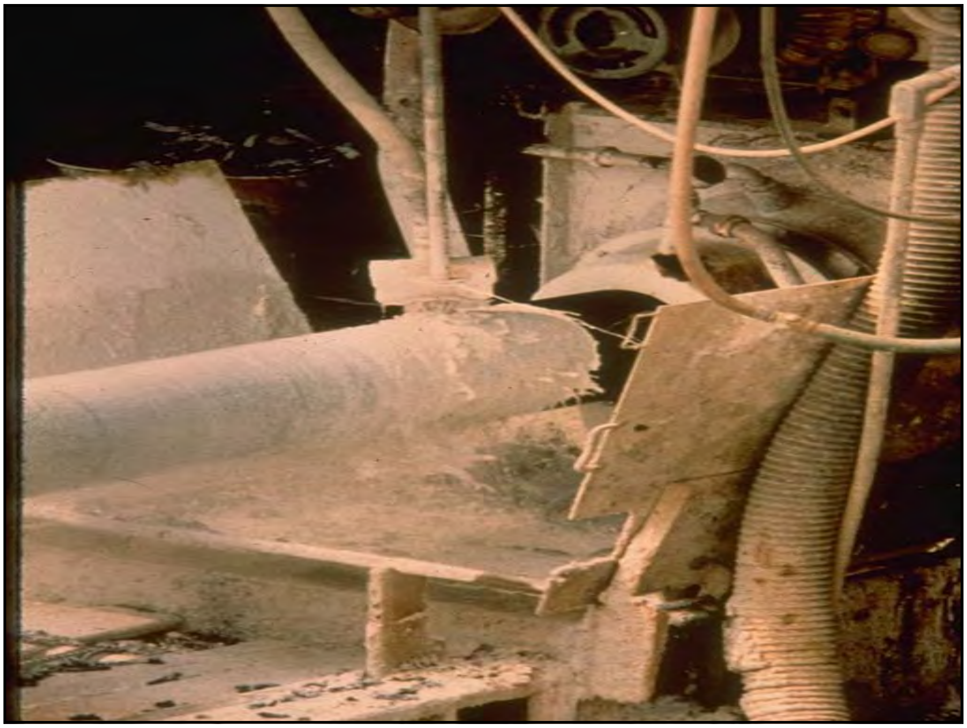

Coal Tar Enamels
Primer
Preheat
Blast Clean
Primer Drying Rack
Felt and
Outer Wrap
Fiber Glass
Kraft Paper
Enamel
Application
Quencher
Electrical Inspection
To Stockpile







Asphalt Mastic
Surface Dryer
Blast Clean
Primer
Spray
Primer Drying Rack
Pug Mill Mixer
Asphalt
Sand Aggregate
Mineral Filler
Glass Fiber
Cutback Couplings Applied
Whitewash
Somastic Pump & Nozzle
Coupling Puller Station
End Trim & Dressing Station
Electrical Inspection
To Stockpile



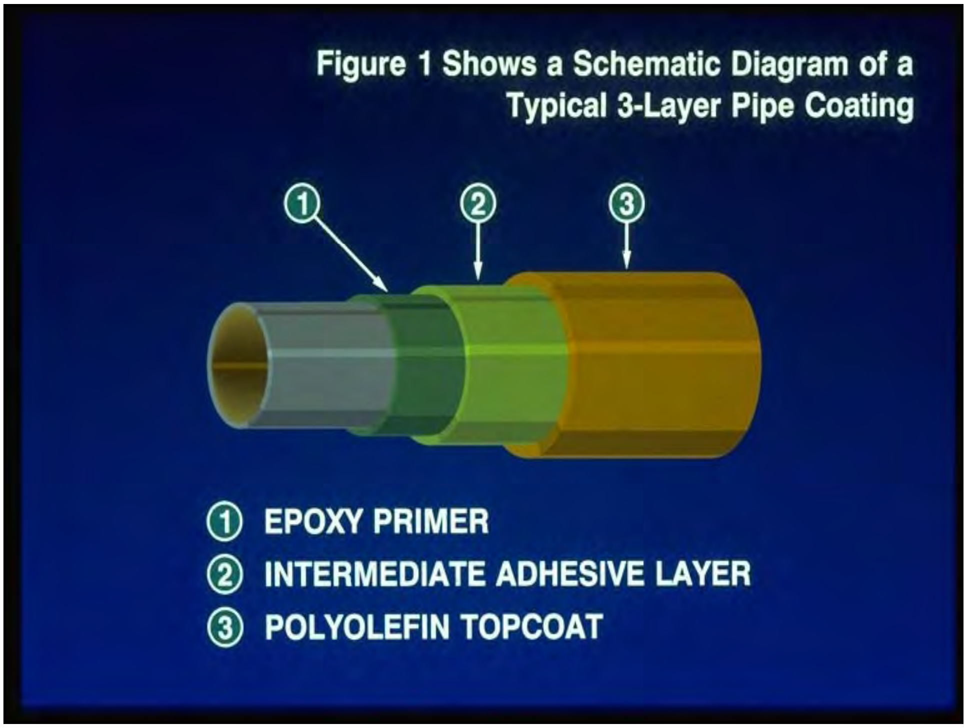
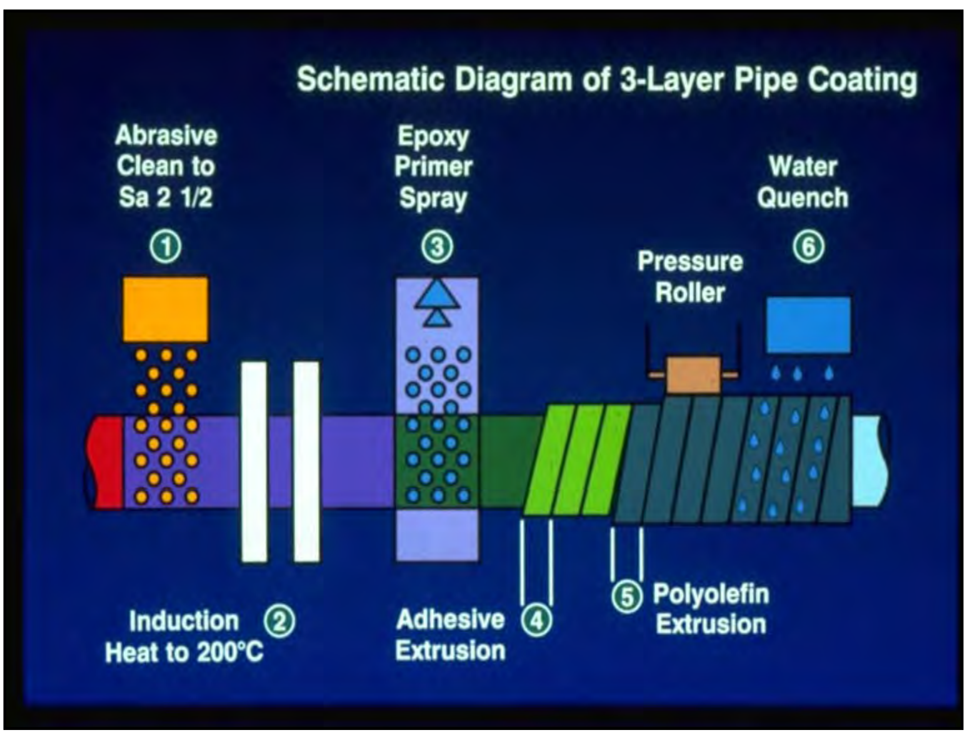
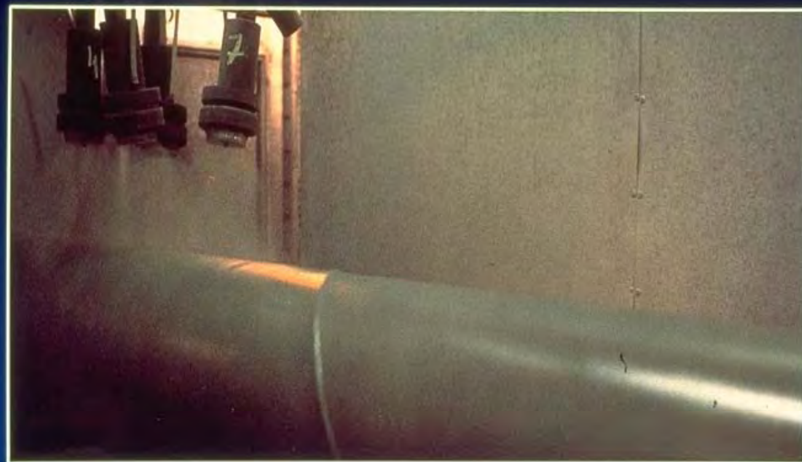


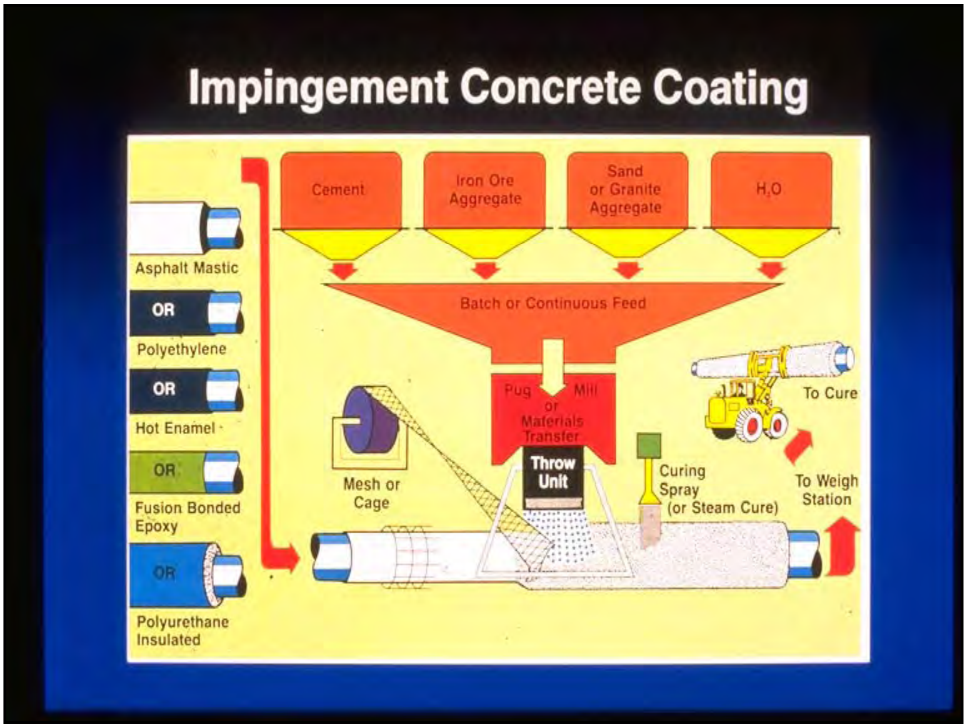
Figure 1 Shows a Schematic Diagram of a Typical 3-Layer Pipe Coating
1
2
3
1 EPOXY PRIMER
2 INTERMEDIATE ADHESIVE LAYER
3 POLYOLEFIN TOPCOAT

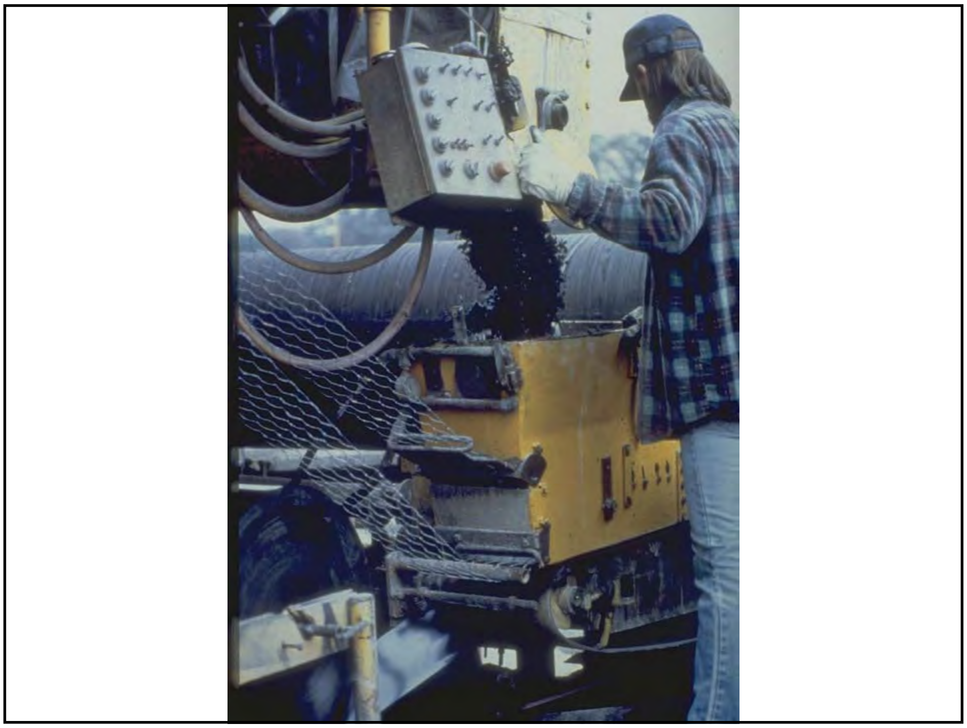

Schematic Diagram of 3-Layer Pipe Coating
Abrasive Clean to Sa 2 1/2
1
Epoxy Primer Spray
3
Water Quench
6
Pressure Roller
Induction Heat to 200°C
2
Adhesive Extrusion
4
5
Polyolefin Extrusion

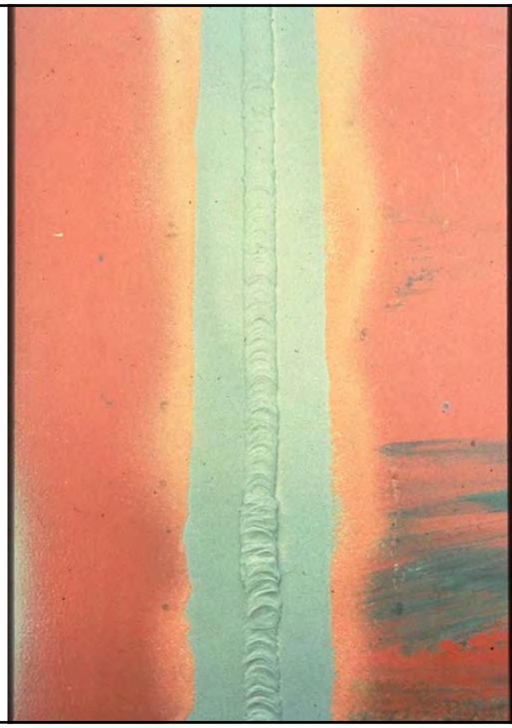


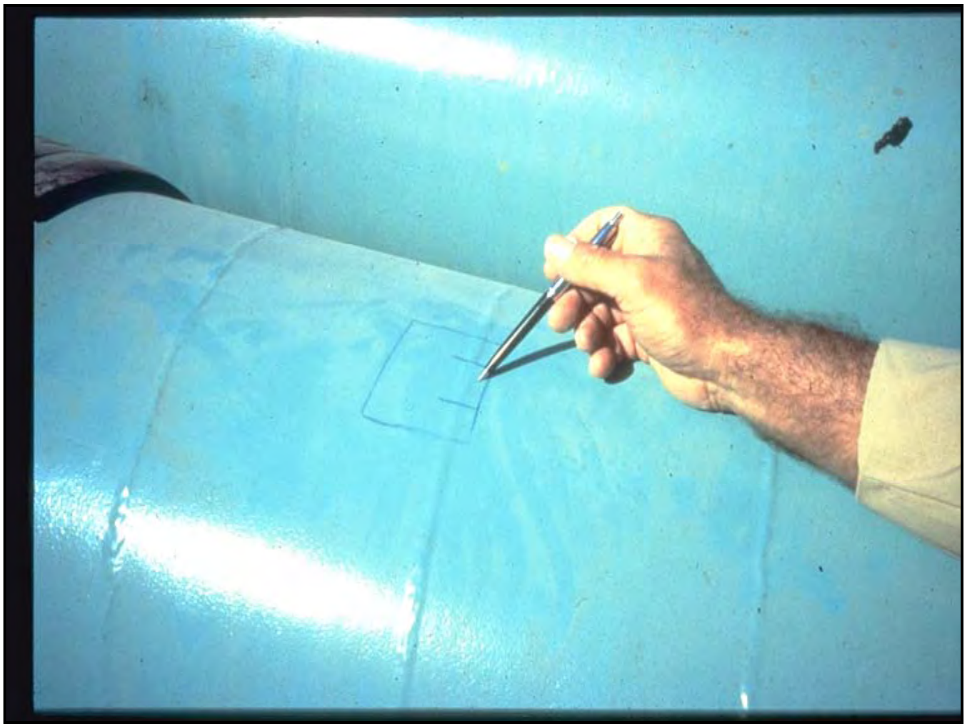
Application of EUROKOTE Epoxy Powder Primer Layer

Extrusion of Adhesive and Low Density
Polyethylene Over the Epoxy Primer Layer


Impingement Concrete Coating
Cement
Iron Ore Aggregate
Sand or Granite Aggregate
H_2O
Asphalt Mastic
OR
Polyethylene
OR
Hot Enamel
OR
Fusion Bonded Epoxy
OR
Polyurethane Insulated
Batch or Continuous Feed
Pug Mill or Materials Transfer
Throw Unit
Mesh or Cage
Curing Spray (or Steam Cure)
To Cure
To Weigh Station







Line Pipe Coating Process

INTRODUCTION

This slideshow steps you through the process of Mill-Applied external thin film (FBE) coating. The guideline for this process is set forth in NACE Specification RP0394-94.

The pipe enters the mill and is ready for the abrasive blasting procedure.

The pipe enters the pre-heat oven where its temperature is raised to approximately 130 degrees. It then enters the abrasive blasting booth.

The pipe exits the blasting booth with a near-white surface finish and the required anchor profile.

At this stage, the blasted pipe surface is checked for raised slivers, scabs, laminations, or bristles which are removed by file or abrasive sanders. A coupler is then inserted into the end of each joint of pipe.

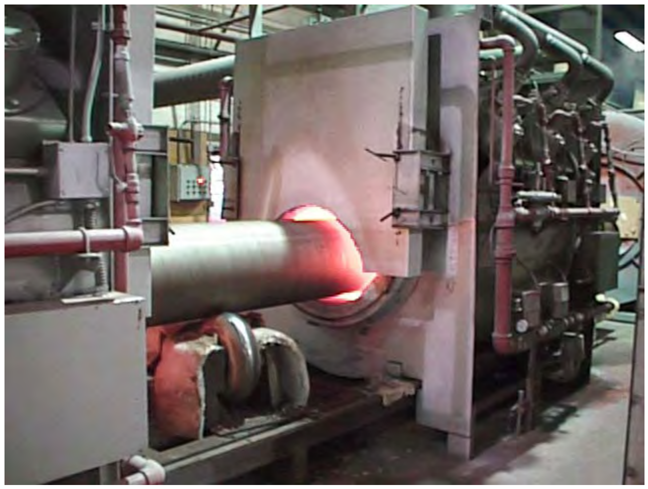
The coupler is used to connect and seal two joints of pipe together, so one pushes the other through the rest of the process.

Two pipe joints joined with coupler.

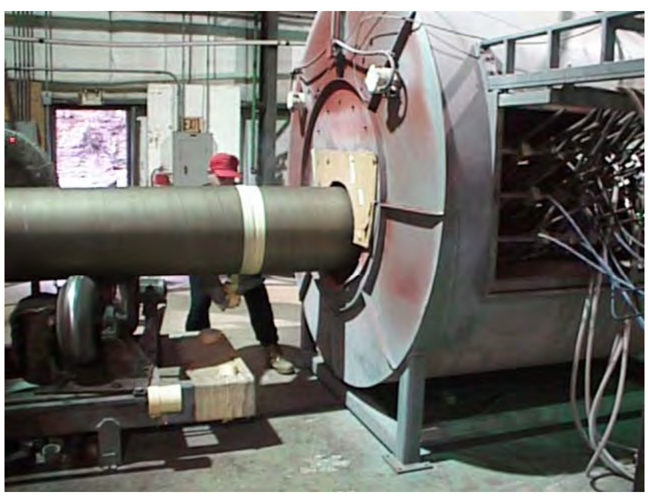
The pipe then enters an acid bath to remove surface contaminants.

After the acid bath and rinse, the pipe enters a series of ovens that raise the temperature of the pipe to approximately 475 degrees before application of the coating.

Pipe entering last oven before coating.



The joint between pipes is covered, so that the ends of each joint are left free of coating. This is done to allow welding in the field.



The pipe exits the coating booth where jets have applied a coating to the hot pipe with an average coating thickness of 15 mils.

The tape around the joint is now removed and pipe continues to the quenching chamber.

In the next step of this process, the pipe enters a quenching chamber and is water cooled to around 250 degrees.

Pipe coming out of quenching chamber.

Stencil being added to pipe stating the company name, API information and size and wall thickness of pipe.

Company Inspector verifying that the coating thickness is acceptable.

Ropes are put around pipe to keep joints of pipe separated and to prevent coating damage.

A 2,000 volt , nonpulsating, low ripple DC dry-type holiday detector is then used to detect any holidays that may exist in the coating.

Repair of a pinhole size holiday in the coating. Patching with these touch up sticks is only allowed in the mill while the pipe is still hot. Preheating the pipe properly is the limiting factor for field application.

Holiday repair using touch-up sticks.

Each pipe is measured and given a number.

The pipe is then carried into the yard. The forklift has protective padding on the jaws.

The pipe is stacked with padded boards between them to prevent damage to the coating.

The joints of pipe are unloaded on to the padded boards and the ropes separate the joints and protect them from damage when striking other pipes.

The End!

- Questions?

Morgantown – Rectifier Fundamentals

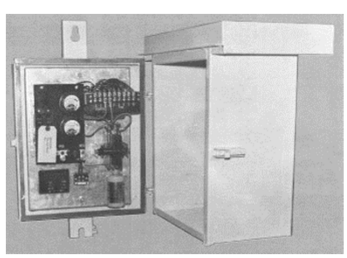
Introduction

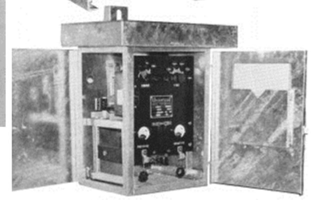
- What is a Rectifier
- Safety
- Rectifier Components
- Inspection Procedures
- Current Flow Measurements
  - Shunts
- Records

What is a Rectifier

- Rectifier converts or rectifies alternating current (AC) to direct current (DC)
- DC current then flows to groundbed - then to structure needing cathodic protection

Examples of Rectifiers





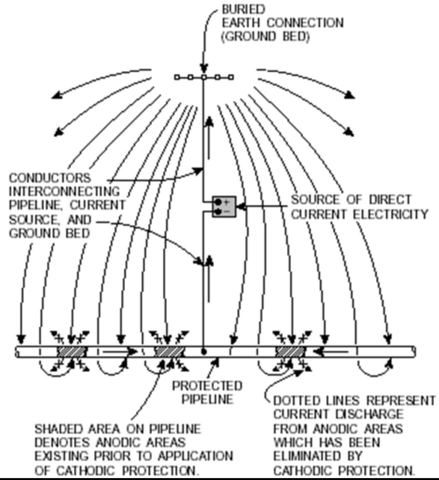
Safety (continued on next slide)

- Electrical
  - Rectifiers can present a shock hazard
  - Never just grab the handle; you may not be able to let go
  - Test the case before touching, use a tester for AC or Volt Meter
- Before reaching into the case
  - turn off the AC power at the external switch or panel breaker
  - Simply turning the rectifier switch off still leave live AC terminals and connections inside the case

Safety

- Bees and Bugs
  - Bees, wasps and other creatures like the warmth inside a rectifier case
  - Knock on the door to see if anyone's home
  - Crack open the door and spray in a voluptuous quantity of insecticide (non-conductive)
  - Sweep out the debris and go to work

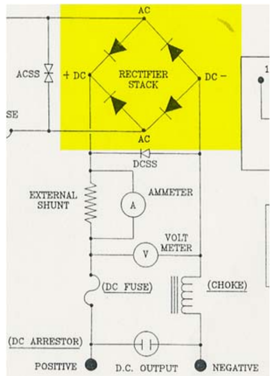
Rectifier – Part of the Impressed Current System



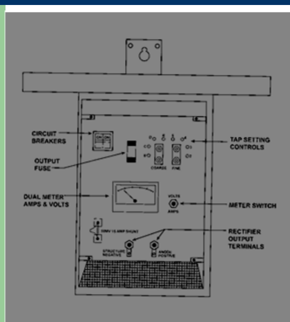
Basic Components of a Rectifier

- Header Cables
- Circuit Breaker
- Transformer
- Rectifying Elements (Stack)
- Accessory Equipment

Header Cables – Negative to Structure, Positive to Groundbed



Typical Rectifier



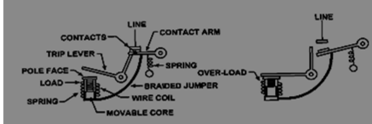
TYPICAL AIR COOLED RECTIFIER

FIGURE 7-17

- Standard Rectifier
  - Circuit Breaker
  - Output Fuse
  - Tap Setting Controls
  - Dual Meter - Amps and Volts
  - Meter Switch
  - Rectifier Output Terminals

Circuit Breaker

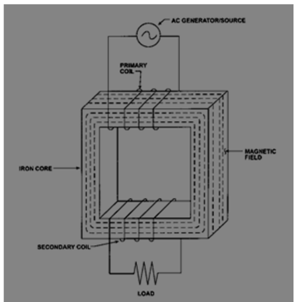
- **Primary Function**
  - provide overload protection for the circuit in which it's installed
  - serves as an on-off switch for the rectifier



FULLY MAGNETIC CIRCUIT BREAKER

FIGURE 7-13

Transformer



TYPICAL TRANSFORMER DIAGRAM

FIGURE 7-14A

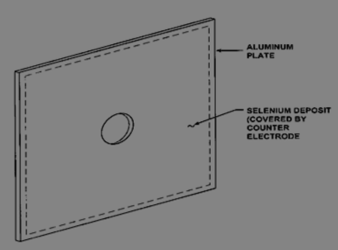
- **Primary Function**
  - used to "step up" or "step down" voltage
  - isolate voltage from source

Rectifier Element

- Allows current to flow in only ONE direction
- Two Types of Rectifying Elements
  - Selenium Cell
  - Silicon Diode

Selenium Cell

- **Primary Function**
  - barrier layer on selenium side of plate prevents current from passing from the selenium side to the aluminum side

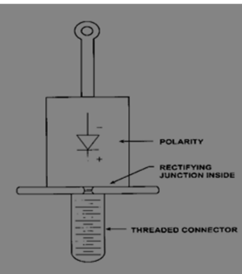


TYPICAL SELENIUM CELL DIAGRAM

FIGURE 7-15

Silicon Diode

- **Primary Function**
  - permits current to flow in only one direction
  - provides high current and voltage outputs



TYPICAL SILICON DIODE DIAGRAM

FIGURE 7-16

Accessory Equipment

- Amp/Volt meters
- Lightning Arresters
- Filters
- Shunts

Accessory Equipment

- **Amp and Volt meters**
  - installed to measure and monitor amp and voltage output of rectifier
- **Lightning Arrestors**
  - installed on AC input and DC output circuits of rectifier
  - prevent damage to rectifier unit during lightning surges

Accessory Equipment

- **Efficiency Filters**
  - improve the efficiency of the rectifier
  - eliminate electronic noise /interference on electronic circuits
  - can also provide lightning protection to the DC side of circuit
- **Shunts**
  - provide a way of measuring the output current of the rectifier

Physical Inspection

- Inspect for physical damage
- Record amperage and voltage output
- Adjust outputs as necessary
- Turn rectifier and incoming AC off
- Check rectifier plates for excessive heat
- Check all connections for tightness and evidence of arcing or overheating
- Clean interior of unit
- Check oil level if applicable
- Clean ventilating screens if required
- Restore power to rectifier
- Recheck and confirm output
- Clean exterior of unit
- Close and lock rectifier

Rectifier Readings

- **AC Input Voltage**
- **AC Input Current**
- **Output Voltage**
- **Output Current**
- **Records**

AC Input Voltage

- Can be read at either the electrical disconnect or behind the main breaker on the front panel of the unit
- Access to the rear of the breaker may be difficult so extreme caution should be exercised
- These readings are being taken in front of any protective devices

AC Input Current

- The AC current measured by using a clamp-on ammeter scaled down enough to read the expected current
- Could be difficult on small output units with high input voltages because most clamp on ammeters cannot read down below 5 amperes

Output Voltage

- Read the output on the rectifier meter(s)
  - Some rectifiers have separate meters for voltage and current (amperage) outputs
  - Some have a single meter called a unimeter
    - The unimeter has scales for both voltage and current and a selector switch under the meter
    - **BE SURE TO READ THE RIGHT SCALE. DON'T MIX UP THE VOLTAGE AND AMPERAGE READINGS!**
- Using a portable voltmeter, read and record the voltage across the output terminals
  - Should be within 10% of the rectifier meter reading
    - If not, make a note that the rectifier meter(s) may need replacement

Output Current

- Read the output on the rectifier meter(s)
  - As previously noted, some rectifiers have separate meters for voltage and current (amperage) outputs, and some have a single meter called a unimeter
- Read the current with a portable meter across the rectifier shunt
  - shunts are explained later under **CURRENT FLOW MEASUREMENTS**

CURRENT FLOW MEASUREMENTS

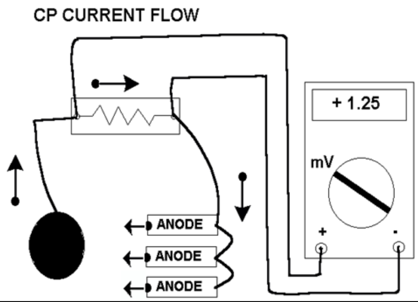
- Measuring current with an ammeter in series with the circuit
  - Requires opening the circuit, connecting the meter, taking the reading, and putting everything back when you're done
  - Time consuming, and in low current circuits (galvanic anode outputs, for example) the resistance of the ammeter itself may be sufficient to reduce the apparent current flow
- Most current flow measurements in corrosion work are taken by reading the voltage drop across a shunt of known resistance
- Also permits reading currents that are too large for your ammeter

Ammeter Readings

- Works by taking a voltage drop across a calibrated resistance
  - Displayed in amperes (A) or mill amperes (mA)
  - Note the following about ammeter readings:
    - Inconvenient
    - Slow
    - Can be dangerous when dealing with large currents
    - Meter is placed in series with the circuit
    - Obtaining a reading may require leaving the current off too long
    - Ammeter resistance may skew the readings
- Most digital multimeters have a maximum current capacity of 10.0 amps
  - Larger currents will blow the meter fuse
  - Fuses are usually difficult to reach, and if you don’t have a spare, you will not be able to continue with your work

Shunt Measurements

- Made by reading the voltage (IR) drop across the shunt terminals
- Data can be obtained quickly, safely and accurately



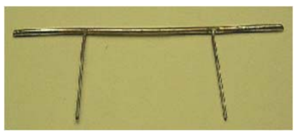
Calculate Current - Shunts

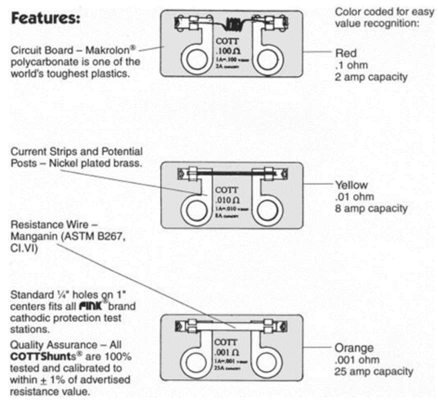
- Current can be calculated from Ohm’s Law:
- I-E/R or:
- current = voltage divided by resistance.

	Shunt Ratings		Shunt Value	Shunt Factor
	AMPS	**mV**	**OHMS**	**A/mV**
Hollaway Type				
RS	5	50	0.01	0.1
SS	25	25	0.001	1
SO	50	50	0.001	1
SW or CP	1	50	0.05	0.02
SW or CP	2	50	0.025	0.04
SW or CP	3	50	0.017	0.06
SW or CP	4	50	0.0125	0.08
SW or CP	5	50	0.01	0.1
SW or CP	10	50	0.005	0.2
SW	15	50	0.0033	0.3
SW	20	50	0.0025	0.4
SW	25	50	0.002	0.5
SW	30	50	0.0017	0.6
SW	50	50	0.001	1
SW	60	50	0.0008	1.2
SW	75	50	0.0067	1.5
SW	100	50	0.0005	2

J.B. Type				
Agra-Mesa	5	50	0.01	0.1
Cott or MCM				
Red (MCM)	0.1	100	0.1	0.01
Red (Cott)	0.5	50	0.1	0.01
Yellow	5	50	0.01	0.1
Orange	25	25	0.001	1

Common Shunts





Records

- Good records are essential to document the corrosion control work being done
  - Required by federal and state laws
  - Turn in complete rectifier operating date each time you inspect a rectifier
  - This is the only way to develop an operating record of each rectifier
  - Operating records are essential to determine if rectifiers are operating properly

Summary

- What is a Rectifier
- Safety
- Rectifier Components
- Inspection Procedures
- Current Flow Measurements
  - Shunts
- Records

Questions??

Appalachian Underground Corrosion Short Course

Fundamentals

Of

Pipe & Cable Locating

George S. Lomax

Heath Consultants Inc.

Pipe and Cable Locator

- A device that is usually made up of two components, a transmitter and a receiver, that is used to transmit an electro magnetic signal onto an intended target (conductor).

How does a Pipe or Cable Locator work?

- The transmitter generates a signal on a specific frequency to energize the target.
- The receiver is tuned to the same frequency as the transmitter.
- The target (conductor) is “energized” by the signal from the transmitter.

Transmitter Frequencies

- Low Frequency 800Hz to 20Khz
  - Advantages: Distance & Adherence
  - Disadvantage: Poor Penetration
- High Frequency 250Khz to 480Khz
  - Advantages: Good Penetration
  - Disadvantages: Distance & Adherence
- Medium Frequency:20Khz to 250Khz
  - Best frequency for general locating

Modes of Operation

- Inductive (indirect)
  - Easy to setup, least accurate way to locate
- Conductive (direct hook up)
  - Often hard to find contact point, better accuracy
- Inductive Clamp
  - Better accuracy than inductive
- Passive
  - Detects 60Hz AC "ripple" on conductor

Choosing the Right Tool

- Simple Split Box vs. Electronic Locator
  - Split Box Locator should be used for short incidental locates, C&M crew, leak repair, etc.
  - Single Frequency Electronic Locator is recommended for more accurate locates where depth measurements are needed.
  - Multi-Frequency Electronic Locators are recommended for Damage Prevention and trouble shooting Cathodic Protection Systems.

Other Types of Locators

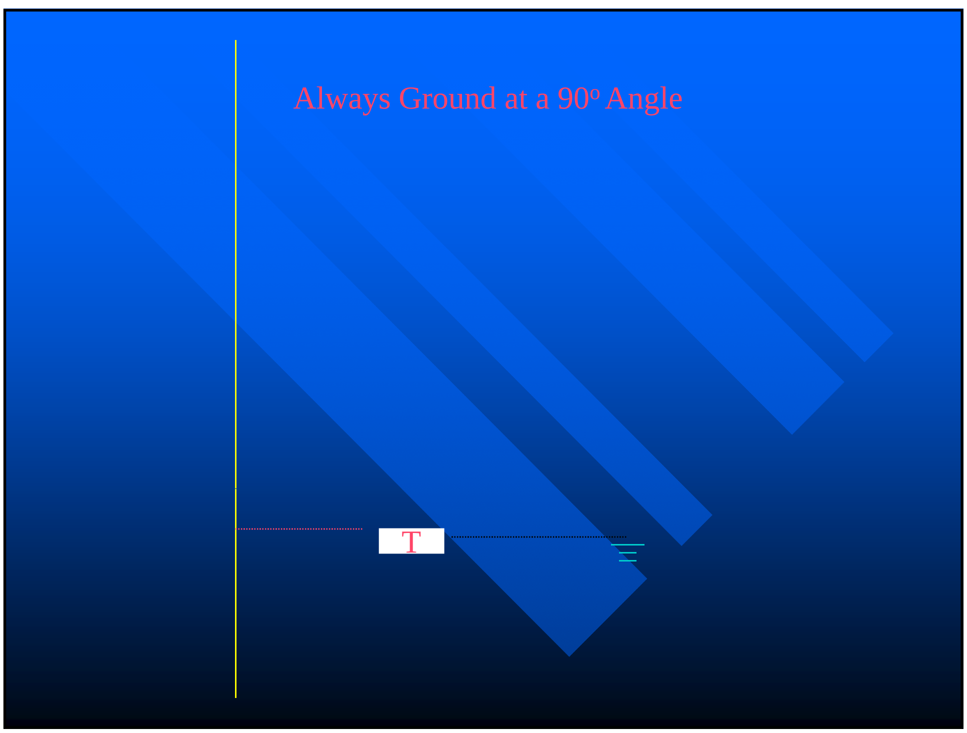
- Valve Box Locator
  - Treasure finder type instrument
- Ferromagnetic Locator
  - Locates iron based objects only
- Ground Penetrating Radar
  - Must interpret readings

Keys to Accurate Locating

- Always read instruction manual provided with instrument.
- Request on-site training by qualified person.
- Become familiar with operation of instrument on “known” locates.
- Research conductor to be located:
  - Maps, Service Records, Inspection Reports

Keys to Accurate Locating

- Read the Street before locating:
  - Look for visual indicators, valves, hydrants, pedestals, test stations, etc.
- For best accuracy, always use the Conductive Mode .
- When grounding the transmitter, try to run ground cable at a 90^{o} angle to the conductor.



Keys to Accurate Locating

- Always connect cable assembly from transmitter to “clean shiny metal”.
- Never run ground wire over or near other conductors.
- When locating in the inductive mode, make sure transmitter is aligned properly with the intended conductor.

Keys to Accurate Locating

- Depth measurements using a “split box” type locator are most inaccurate.
- Depth measurements using an Electronic Locator are only accurate when used in Conductive Mode.
- Depth measurements are for your information only.

Keys to Accurate Locating

- If in doubt, hand dig to confirm location of conductor.
- If still in doubt, don't mark it out.
- A guess is the shortest distance between an accurate locate and a reportable incident.

The End

Cathodic Protection Measurement Basics

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Colonel
AFCESA
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CP Measurements

- Pipe-To-Soil Potentials
- CP Current Flow
- Resistance
- Rectifier Readings

Pipe-To-Soil Potentials

- Voltmeter
  - Digital, Analog, Computerized
  - High Input Impedance
  - Rugged
- Lead Wires
  - Tight Connections
  - Secure To Structure
  - Low Resistance As Possible

Pipe-To-Soil Potentials

- Reference Electrode Types
  - Copper-Copper Sulfate (Most Common)
  - Silver-Silver Chloride (Offshore – Salt Water)
  - Zinc Metal (Rough Conditions)
  - Lead-Lead Chloride (Lead Sheathed Cables)
  - Calomel (Hg-$HgCl_2$) (Laboratory Use)
  - Hydrogen Cell (Laboratory Use)

Pipe-To-Soil Potentials

- To Maintain Criteria of SP-0169
  - $Cu\text{-}CuSO_4$ (-) 0.850 V
  - Ag-AgCl (Sat KCl) {4.6M} (-) 0.733 V
  - Ag-AgCl (KCl @ 3.5M) (-) 0.739 V
  - Ag-AgCl (KCl @ 1.0M) (-) 0.756 V
  - Ag-AgCl (Seawater) (-) 0.784 V
  - Zinc Metal (+) 0.228 V
- Be Very Careful With Ag-AgCl References. The KCl Concentrations Shift the Potential

Pipe-To-Soil Potentials

- $Cu\text{-}CuSO_4$ Reference Electrode
  - Temperature Sensitive
    - Copper-Copper Sulfate Ref: 0.5 mV per ^{o}F
    - Shift Positive When Colder
  - Contaminant Free
    - Clean Bar and Tip
    - Clear Solution
  - Saturated Solution
    - Distilled Water with Blue Crystals Left Over

Pipe-To-Soil Potentials

- Position
  - Directly Over Structure
  - Closer The Better But Don't Touch Structure
- Good Electrolyte Contact
  - Tip Contact to Ground
  - Thick Layers of Crushed Rock
  - Watch out for Unknowns like:
    - Geoplastic sheets under stone
    - Asphalt layers under concrete pavement (old roads)
    - Paved Over Trolley Tracks (Old Cities)

Pipe-To-Soil Potentials

- Sign Convention

Voltmeter (-) Lug	Voltmeter (+) Lug	Sign Convention
Structure	Half Cell	0.850
Half Cell	Structure	(-) 0.850

CP Current Flow

- Direct Readings
  - Inconvenient
    - Slow
    - Dangerous
  - Meter in Series with Circuit
    - Off Too Long
    - Sway Readings
- Shunt Readings
  - Accurate and Faster
  - Voltmeter Across Known Resistance

CP Current Flow

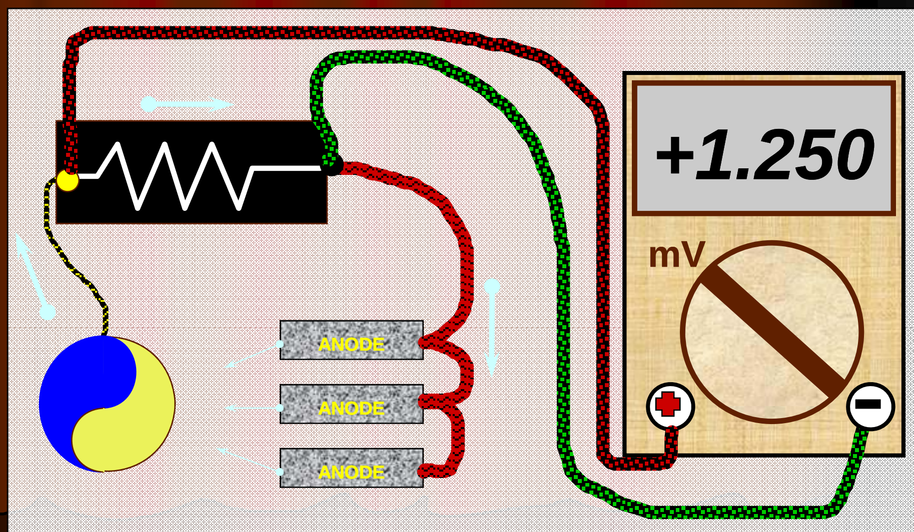
- Shunt Readings Rated in Ohms

0.001 Ohm:	**1 mV = 1 Amp**	**25 Amp Max**
0.01 Ohm:	**1 mV = 0.1 Amp**	**8 Amp Max**
0.1 Ohm:	**1 mV = 0.01 Amp**	**2 Amp Max**

- Shunt Readings By Proportion

50 mV = 50 Amps	**1 mV = 1 Amp**
50 mV = 100 Amps	**1 mV = 2 Amps**
100 mV = 100 Amps	**1 mV = 1 Amp**
50 mV = 60 Amp	**1 mV = 1.2 Amps**

CP Current Flow



Resistance

- Direct Readings
  - Isolate Circuit
  - Turn Off Power
- Calculated
  - Known V & Known I
  - Calculate: $R = V / I$
- Other Method
  - B3 Series Meter

Rectifier Readings

- AC Input
  - Voltage at Disconnect or Behind Breaker
  - Current by Clamp-On Ammeter
  - Power = (3600 x Kh x N) / T
- AC Throughput
  - Voltage Across Main Lugs of Taps
- DC Output
  - Voltage Across the Output Lugs
  - Current: Voltage Across the Shunt
- Efficiency
  - Power Out / Power In