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
2015 FUNDAMENTALS COURSE

April 17, 2015 Revision

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

Fundamentals of Corrosion Mathematics and Electricity

AUCSC – 5/21/2013

Rules

- Set cell phones to silent operation
- If you get a call, feel free to walk out, and walk back in when you're done
- If you have a question, leave your hand up for about 10 seconds, then use your voice

Disclaimer 1

- We will be concentrating on some fundamental mathematical and electrical concepts
- Math is like any other skill – IT REQUIRES PRACTICE
- I can introduce the information, but you "learn" it by attempting the problems (and struggling) all by yourself.

Disclaimer 2

- This is the "fundamental" course.
- If you are familiar with:
  - Ohms Law
  - Resistors in series
  - Resistors in parallel

  You may find yourself uninterested

  I will TRY to make this interesting.

Agenda

- Units
- circuit theory

- Ohms Law
- series and parallel circuit theory

- Evening session (7:00) – do it again

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:

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

Note… the difference is UNITS

$$\frac{1}{5280} = 0.0001894 \qquad \frac{1 mile}{5280\ feet} = 1$$

$$\frac{1}{2000} = 0.0005 \qquad \frac{1 ton}{2000 lbs} = 1$$

$$\frac{1}{24} = 0.0416 \qquad \frac{1 day}{24 hours} = 1$$

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.

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

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:

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

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

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

$$-1.71A * \frac{1000mA}{1A} = -1710mA \qquad 630mA * \frac{1A}{1000mA} = 0.63A$$

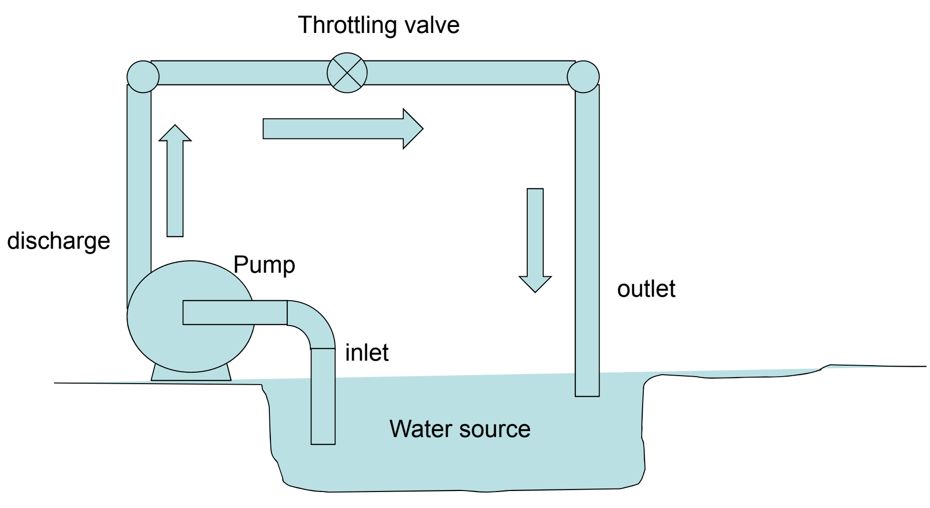
$$2.5A * \frac{1000mA}{1A} = 2500mA \qquad -823mA * \frac{1A}{1000mA} = -0.823A$$

Segue

- So far we've talked about converting units
- Now let's talk about circuits

- We'll start with something more familiar than electricity

Let's start with water instead of electricity



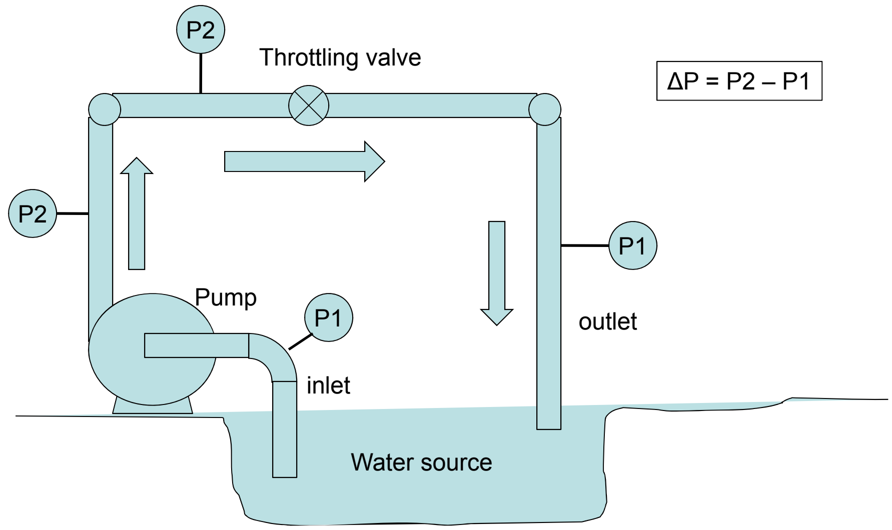
Fluid "circuit"

- 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.

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



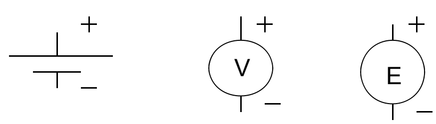
Flow

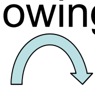
- Measuring flow rate is accomplished by diverting the flow through the meter.
- Flow is the same rate “volume per unit time” at ALL points in the system
- Typical flow rate is “gallons per minute”
- Flow rate out = flow rate in
- If that was not true, then fluid is accumulating somewhere in the system

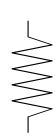
Fluid circuit - continued

- The flow rate (gallons/minute) is the same at all points in the circuit
  - water cannot be compressed
- The pressure increase at the pump is the same as the pressure decrease across the throttling valve
- The flow rate into the pump is the same as the flow rate through the valve is the same as the flow rate back to the reservoir.

Electricity Symbols

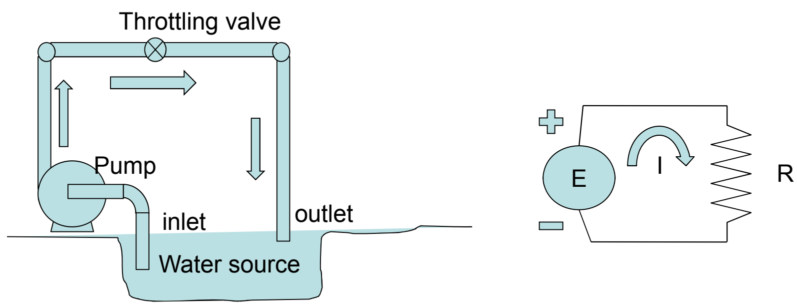
- Voltage source 

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

- Resistor  R

Equivalence to Electricity

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



Equivalence

FLUIDS

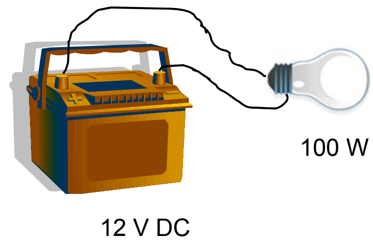
- Pressure
  - Pounds per square inch
  - Measured without diverting flow
- Flow
  - Gallons per minute
  - Measured by diverting the flow

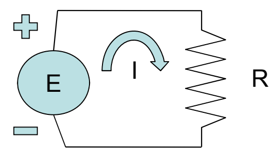
ELECTRICITY

- Voltage / Potential
  - Volts
  - Measured without diverting current
- Current
  - Amps (Coulombs per sec)
  - Measured by diverting the current

A simple circuit

- 12 V DC car battery attached to a light bulb
- Electrical current flows from battery (+) through light bulb filament back to ground (-) on battery

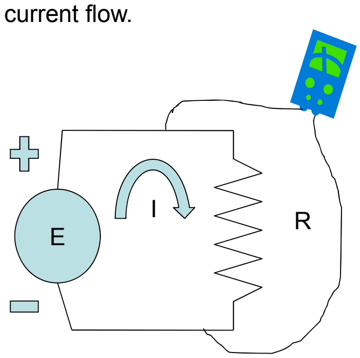


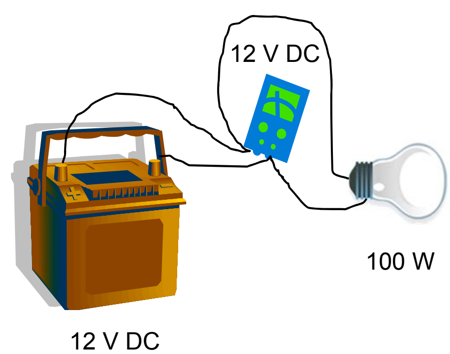


Measuring electrical voltage (potential)

In order to measure voltage, no current goes through the meter

The meter is kept separate from the current flow.

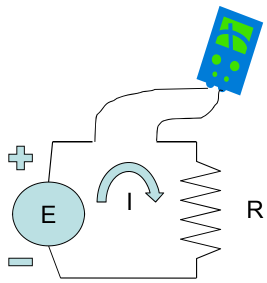


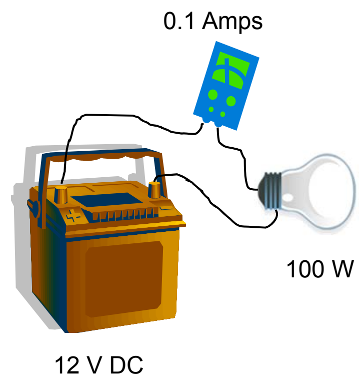


Measuring electrical current

In order to measure current,
all current must go through a meter

The meter is inserted and becomes
part of the circuit.





Of possible future interest…
a 100 Watt light bulb has a
resistance of 121 ohms

Circuits that most people are familiar with

- What is the difference between a “normal” circuit breaker and a “ground fault” circuit interrupter?
- A “normal” circuit breaker opens (breaks) when TOO MUCH current is flowing
- A “ground fault” breaker opens when flow on the “hot” side is DIFFERENT from flow on the “ground” side

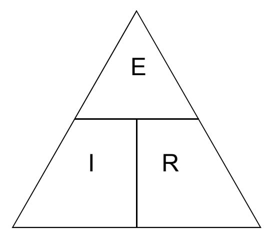
Ohm's Law

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

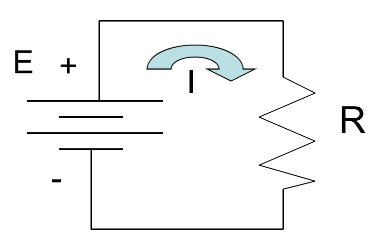
- Using the triangle.
- Cover the variable that you need to find.
- The "known" variables will be in the configuration you need.
- Need to know "I"?
- Cover the I and you're left with $\frac{E}{R}$.
- Therefore I = $\frac{E}{R}$

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?

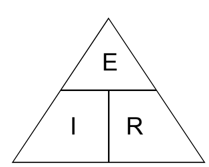


- I = E/R = E ÷ R
- I = 1V/1000ohms
- I = .001 Amps

E = IR

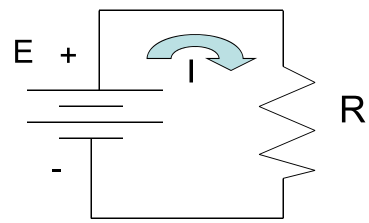
R = E/I

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?

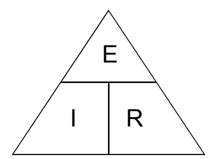


- I = E/R = E ÷ R
- I = 10.5V ÷ 5ohms
- I = 2.1 Amps

E = IR

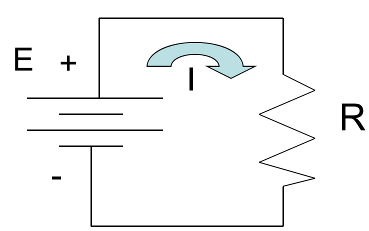
R = E/I

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?

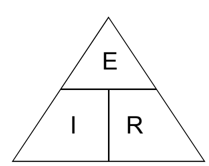


- R = E ÷ I
- R = 1.6V ÷ 2 amps
- R = 0.8 ohms

E = IR

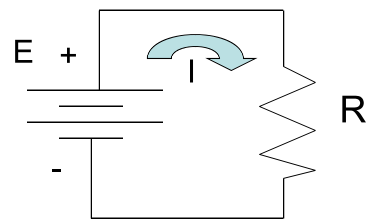
R = E/I

I = E/R



Ohm's Law Example 3

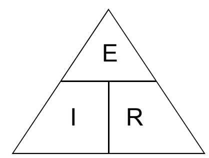
- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?
- E = I*R
- I = 100 mA = 0.1A
- R = 1.5 ohms
- E = 0.1 * 1.5
- E = 0.15V



E = I*R

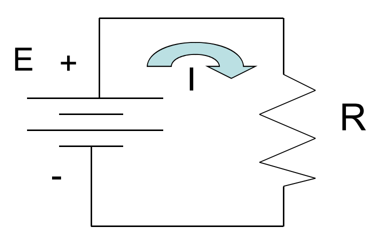
R = E/I

I = E/R



Example 3 – mistake included

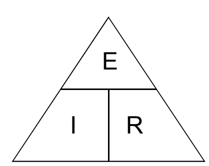
- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?
- E = I*R
- I = 100 mA
- R = 1.5 ohms
- E = 100 * 1.5
- E = 150 V (not 0.15V)



E = I*R

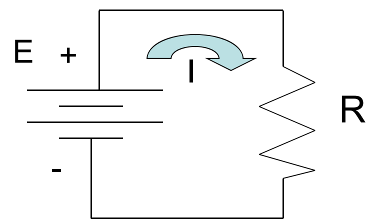
R = E/I

I = E/R

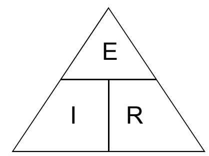


Ohm's Law Example 4

- 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

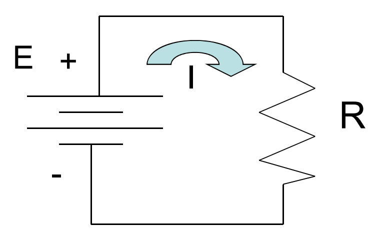


E = I*R
R = E/I
I = E/R

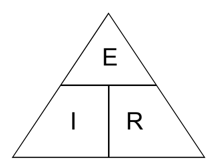


Example 4 – mistake included

- 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)

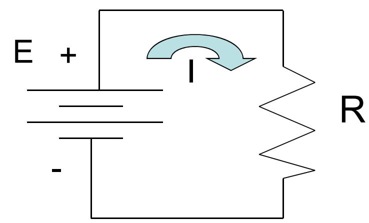


E = I*R
R = E/I
I = E/R



Ohm’s Law Example 5

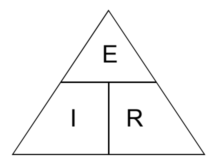
- If the current (I) is 20 A and the resistance (R) is 2 ohms, what is the voltage across the resistor?
- E = I*R
- I = 20 A
- R = 2 ohms
- E = 20 * 2
- E = 40 V



E = I*R

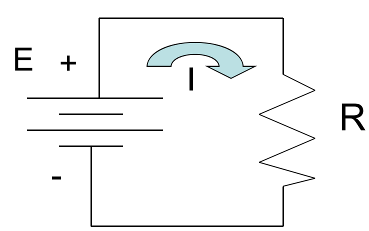
R = E/I

I = E/R



Ohm’s Law Example 6

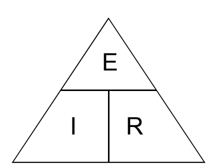
- If the voltage (E) is 12 Volts and the resistance (R) is 4 ohms, how much current (I – in milliamps) is flowing?
- I = E ÷ R
- I = 12V ÷ 4 ohms
- I = 3 Amps
- I = 3 A * (1000mA/1A)
- I = 3000 mA



E = IR

R = E/I

I = E/R



The light bulb example

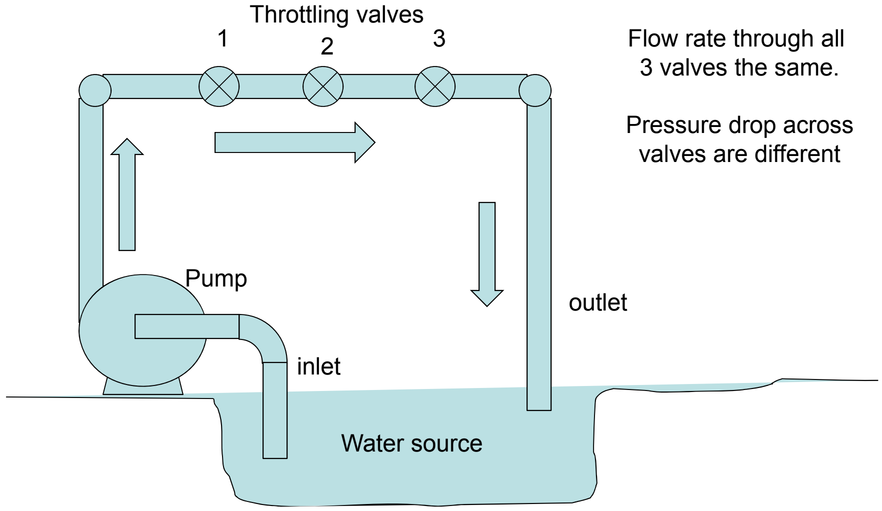
- I really didn’t use a multi-meter to determine the right numbers for my initial example.
- P = V * i → 100W = 110V * i
- i = 100 W / 110 V = 0.91 A

- Now using Ohm’s Law $R = \frac{V}{i}$
- R = 110 V / .91 A = 121 Ω

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

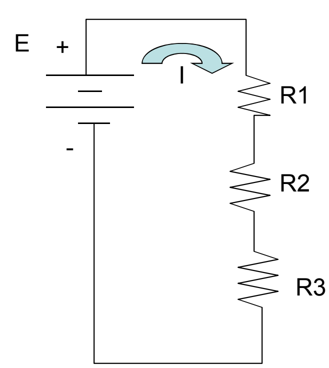


Flow rate through all 3 valves the same.

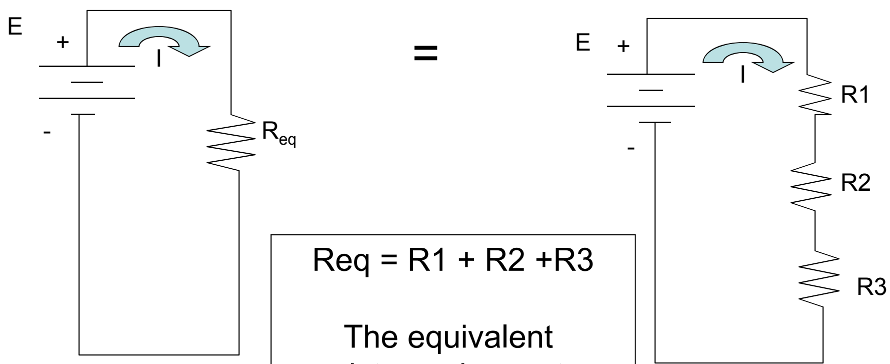
Pressure drop across valves are different

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?



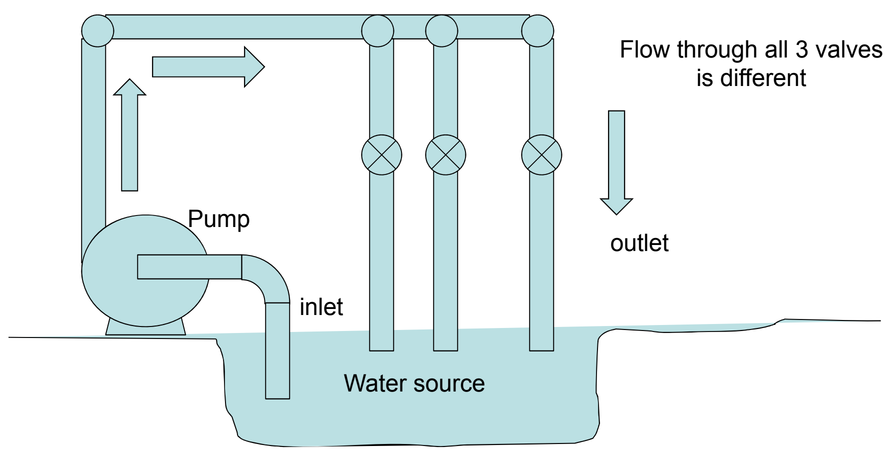
Req = R1 + R2 +R3

The equivalent resistance is greater than the largest resistor.

Parallel Piping

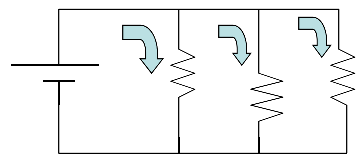
Pressure drop across all 3 valves is the same

Flow through all 3 valves is different

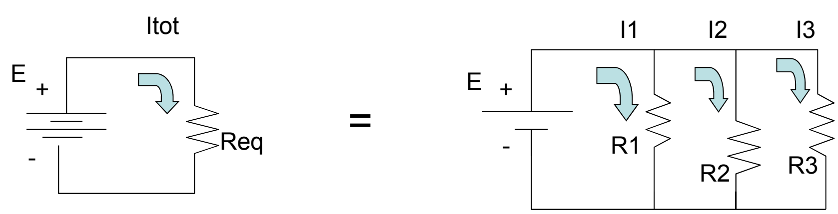


Resistors in Parallel

- 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

END PRESENTATION

- Repeat session at 7 pm

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

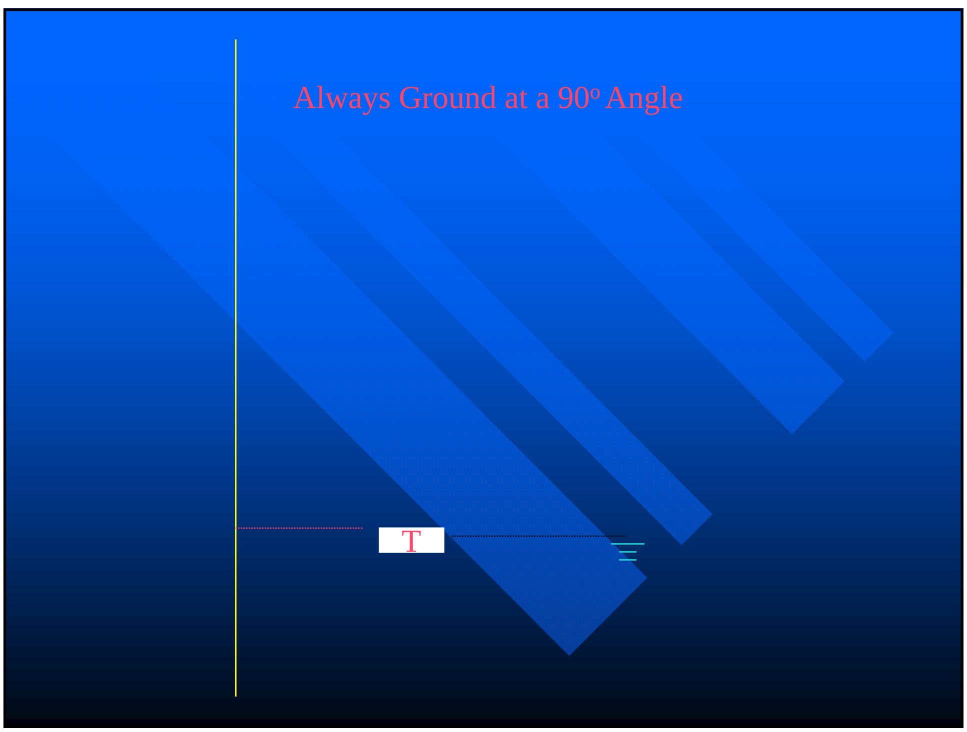
- Valve Box Locator
  - Treasure finder type instrument
- Ferromagnetic Locator
  - Locates iron based objects only
- Ground Penetrating Radar
  - Must interpret readings

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

Fundamentals Course

Basic Corrosion

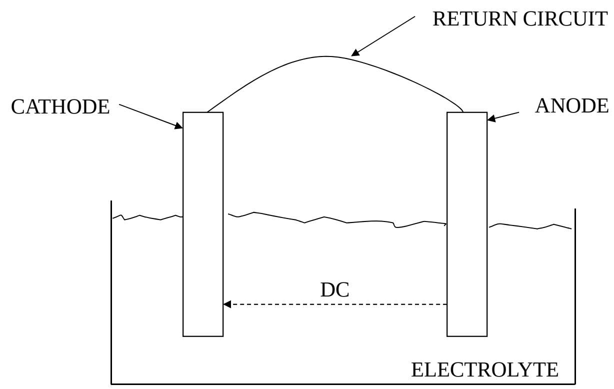
Fundamental introduction and theory behind the corrosion process

CORROSION

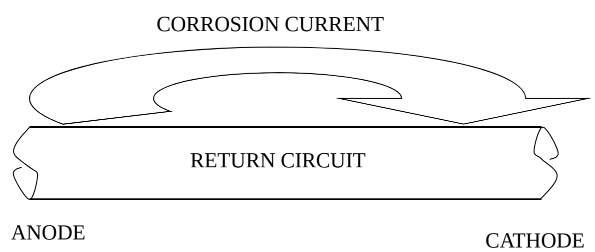
THE DETERIORATION OF A MATERIAL, USUALLY A METAL, DUE TO A REACTION WITH ITS ENVIRONMENT

OR

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



FUNDAMENTAL CORROSION CELL

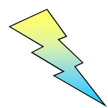


FUNDAMENTAL CORROSION CELL ON PIPE

TYPES OF CORROSION

NATURAL

STRAY

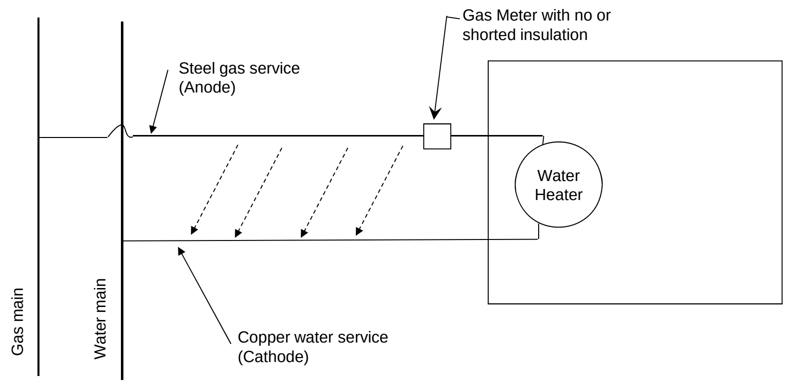


NATURAL CORROSION

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

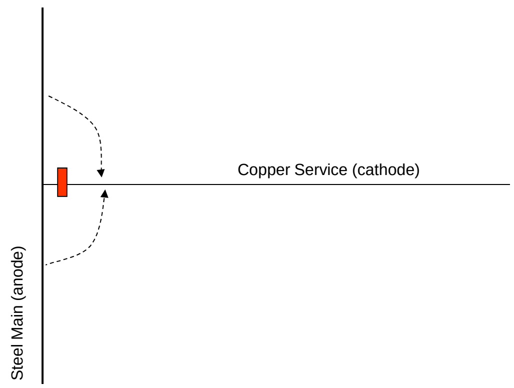
Dissimilar Metal Corrosion

Gas and Water Service Lines



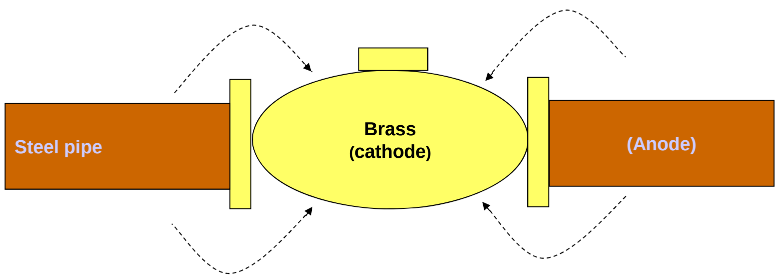
Dissimilar Metal Corrosion

Copper Service on a Steel Main



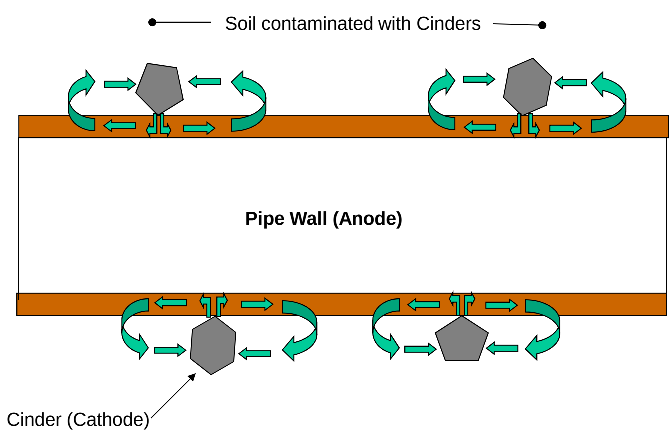
Dissimilar Metal Corrosion

Brass Stop in a Steel Line

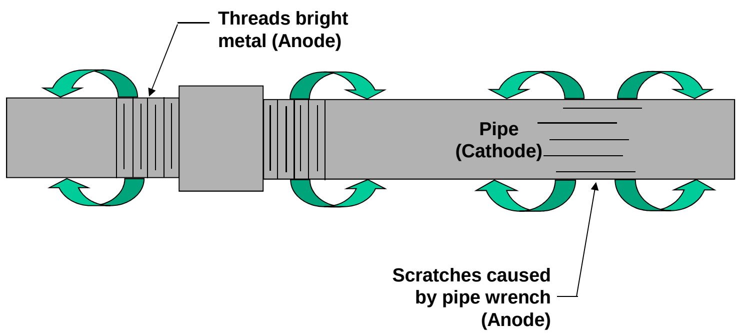


Corrosion due to cinders

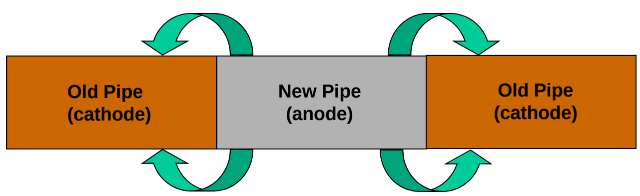
Physical contact between Pipe and Cinders



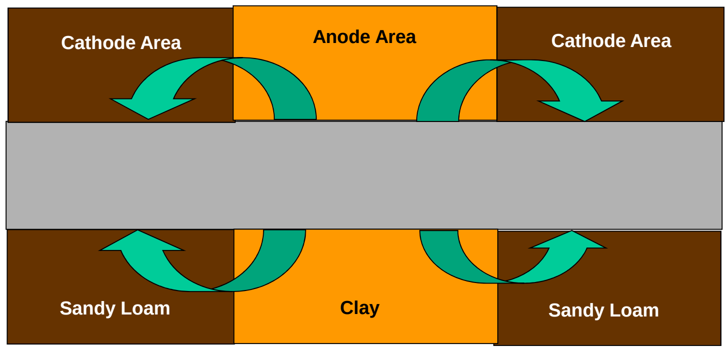
Corrosion caused by Dissimilarity of Surface Conditions



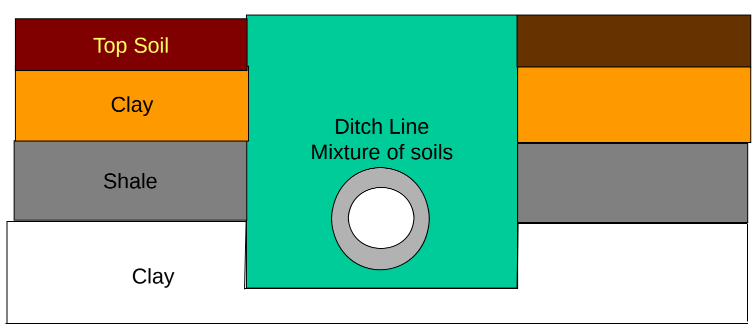
New-Old Pipe Corrosion Cell



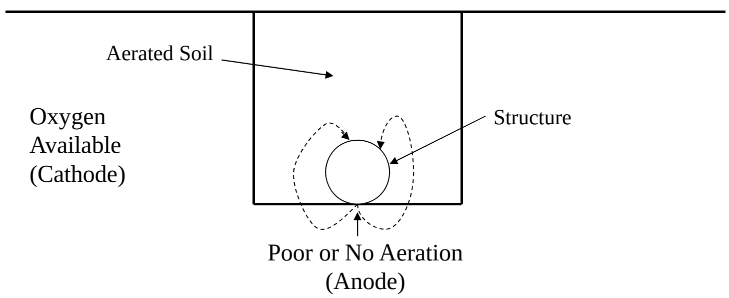
Corrosion caused by Dissimilar Soils



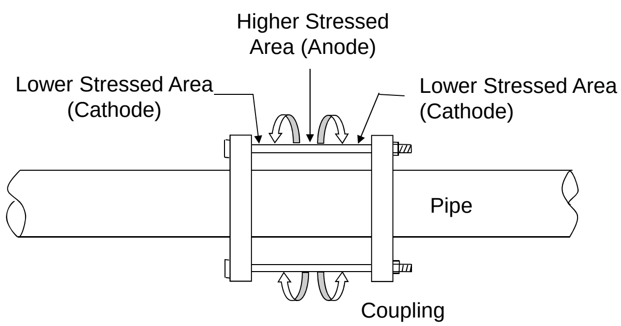
Corrosion caused by Mixture of Different Soils



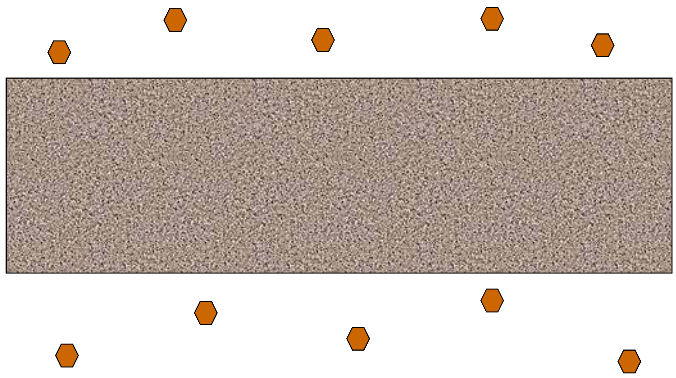
Corrosion caused by Differential Aeration of Soil



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

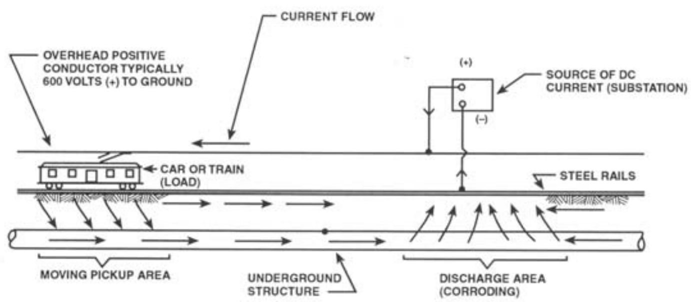
Alternating current, is mainly a safety issue. AC can be induced from overhead high voltage power lines. A measured voltage over 15 volts AC, must be mitigated. Can be measured by setting meter on AC volts, and taking a pipe to soil reading.

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

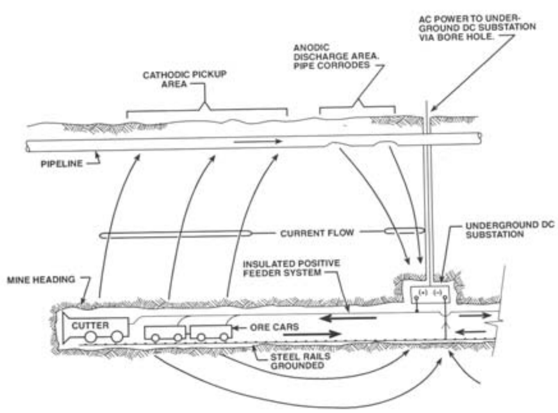
Dynamic Stray Current



DC TRANSIT SYSTEM AS A SOURCE OF
STRAY CURRENT CORROSION

Stray Current from Underground Mining Operation

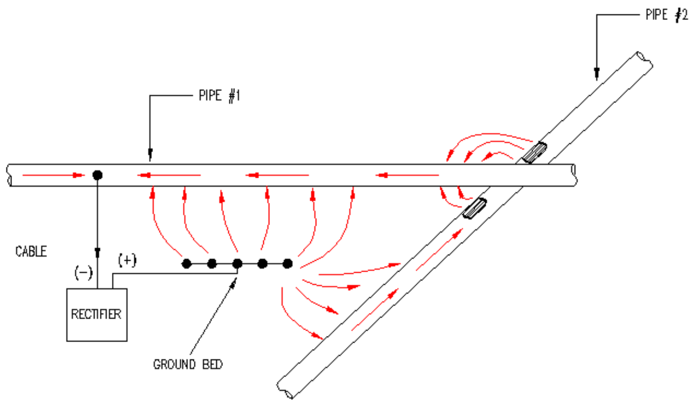
Dynamic Stray Current



CORROSION BY STRAY CURRENT
FROM DC MINING OPERATIONS

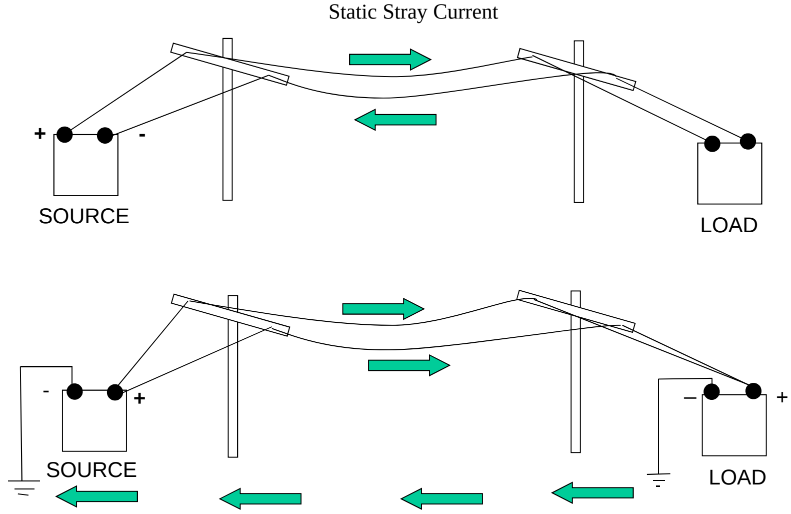
Stray Current from Impressed Current System

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

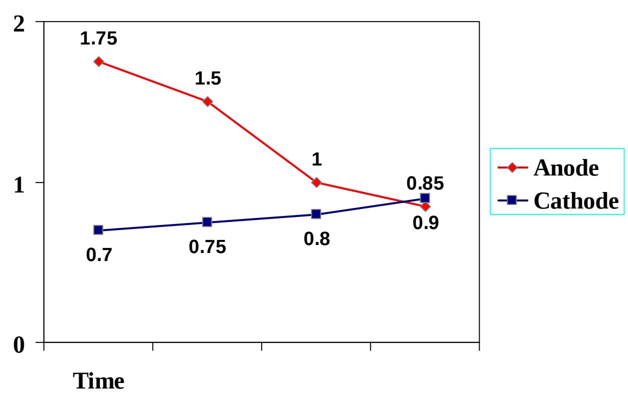
Material	Potential*
High Potential Magnesium	-1.75
Magnesium Alloy	-1.50
Zinc	-1.10
Aluminum Alloy	-1.05
Clean Carbon Steel	-0.50 to –0.80
Rusted Carbon Steel	-0.20 to –0.50
Cast/Ductile Steel	-0.50
Lead	-0.50
Steel in Concrete	-0.20
Copper	-0.20
High Silicon Iron	-0.20
Carbon, Graphite	+0.30

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
Williams - Northeast Gathering & Processing
2620 Memorial Blvd
Connellsville, PA 15425
John.Otto@williams.com

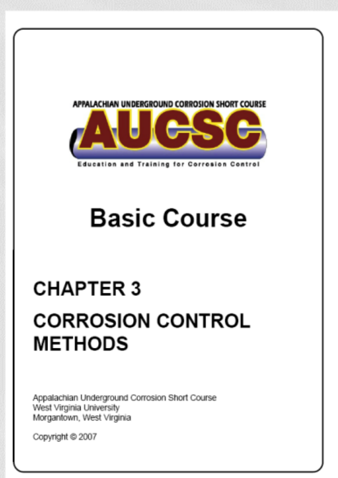
9 Rules to remember in corrosion work:

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. **<u>Never</u> 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 <u>best</u> 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


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

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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
- 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

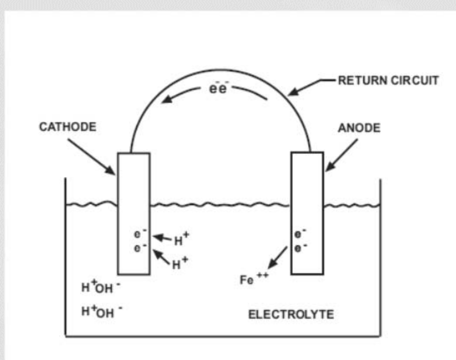
- Anode
- Cathode
- Electrolyte
- Return Circuit

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.

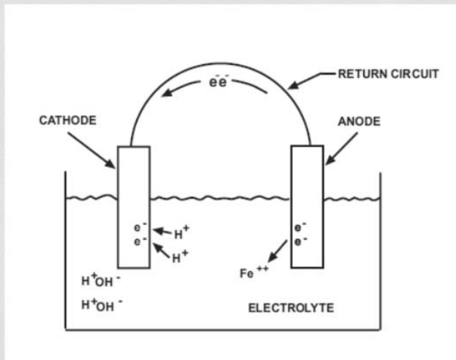
The Fundamental Corrosion Cell

- There are 4 parts to a corrosion cell:



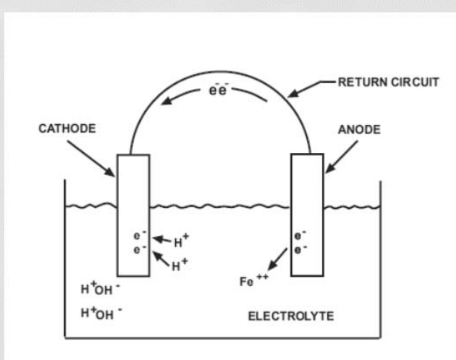
The Fundamental Corrosion Cell

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



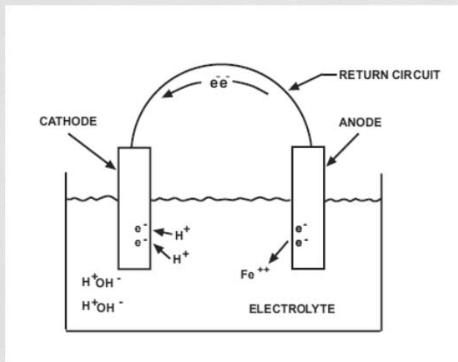
The Fundamental Corrosion Cell

- 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.



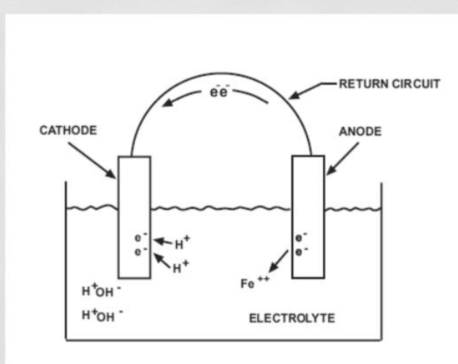
The Fundamental Corrosion Cell

- 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.

Coatings and Cathodic Protection

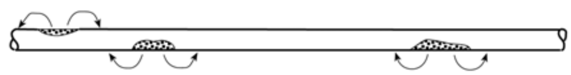
- Coatings are the first line of defense in corrosion control.
- We don't need cathodic protection if the metal is not in contact with the electrolyte. We have eliminated one part of the corrosion cell, the electrolyte.
- If we had a perfect coating, we would not need cathodic protection.
- Unfortunately,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

Electrical Isolation and Cathodic Protection

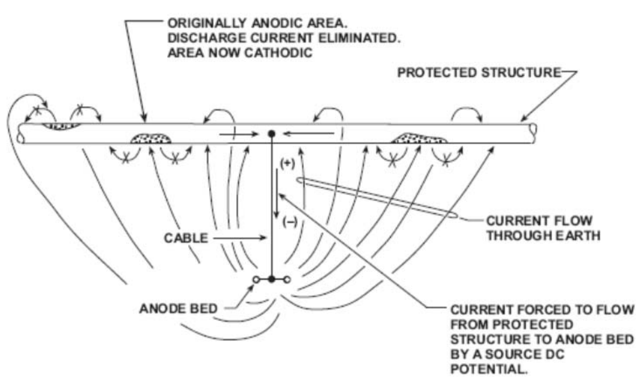
- Electrical isolation fittings are used to confine cathodic protection current to a structure (or portion of a structure) to be cathodically protected.
- We only want to protect the bare areas of our structure. Not the bare areas of other underground structures.
- Electrical isolation fittings are also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

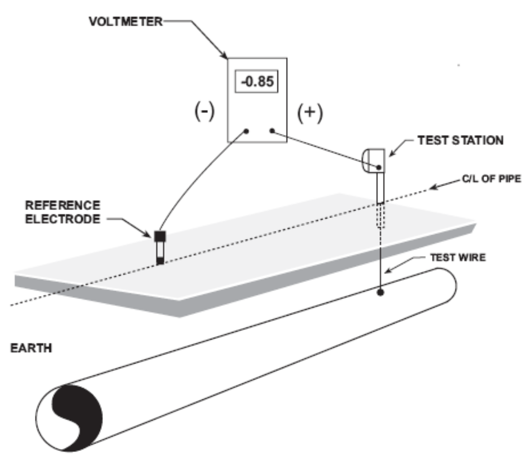


HOW CATHODIC PROTECTION WORKS

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).



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.

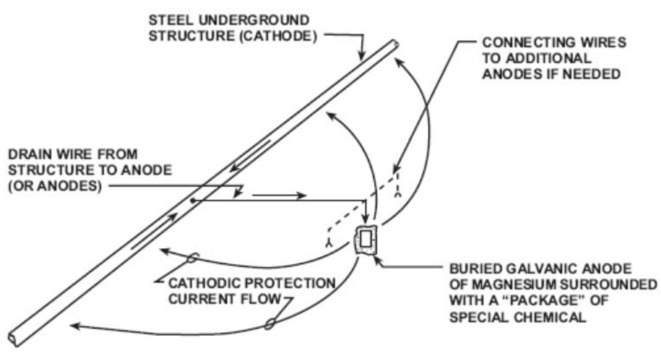
Two methods of cathodic protection:

- 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
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, 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):

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

- 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:

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

- 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:

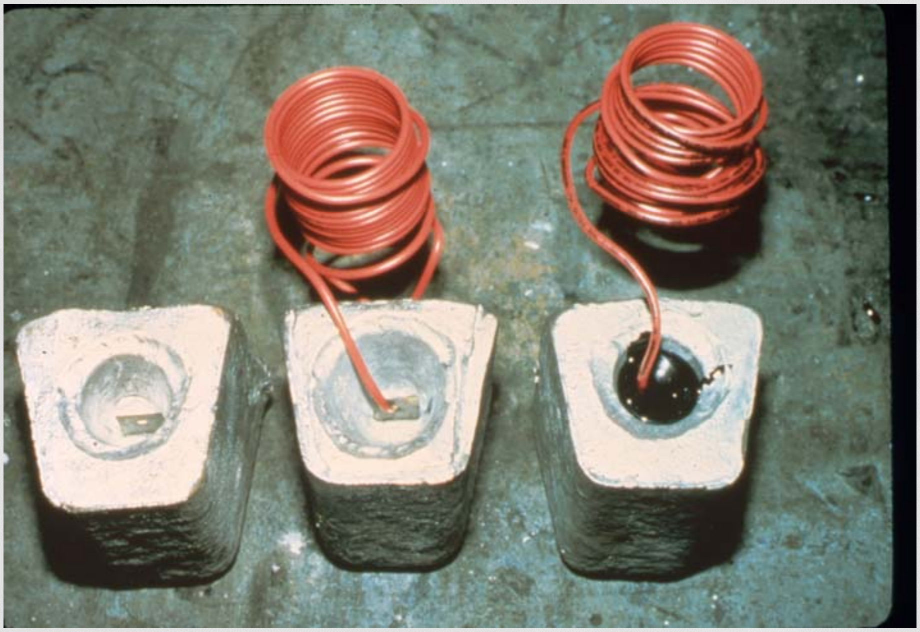
- 75% Hydrated Gypsum ($CaSO_4 \cdot 2H_20$)
- 20% Bentonite Clay
- 5% Sodium Sulfate

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

- They work better.
- 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):

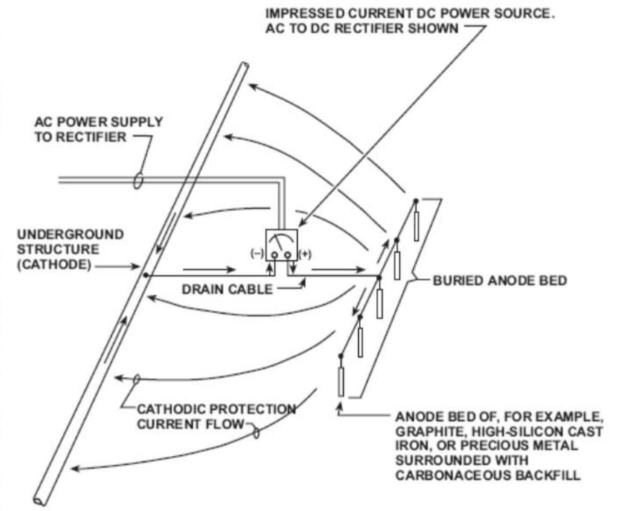
- It increases the effective surface area which lowers the anode to earth contact resistance.
- The bentonite clay absorbs and retains moisture.
- The gypsum provides a uniform, low resistance environment.
- The sodium sulfate (a depolarizing agent) minimizes pitting attack and oxide film formation on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



GALVOMAG
HIGH POTENTIAL
MAGNESIUM
ANODE
WITH BACKFILL
PACKAGED BY
HOUSTON

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

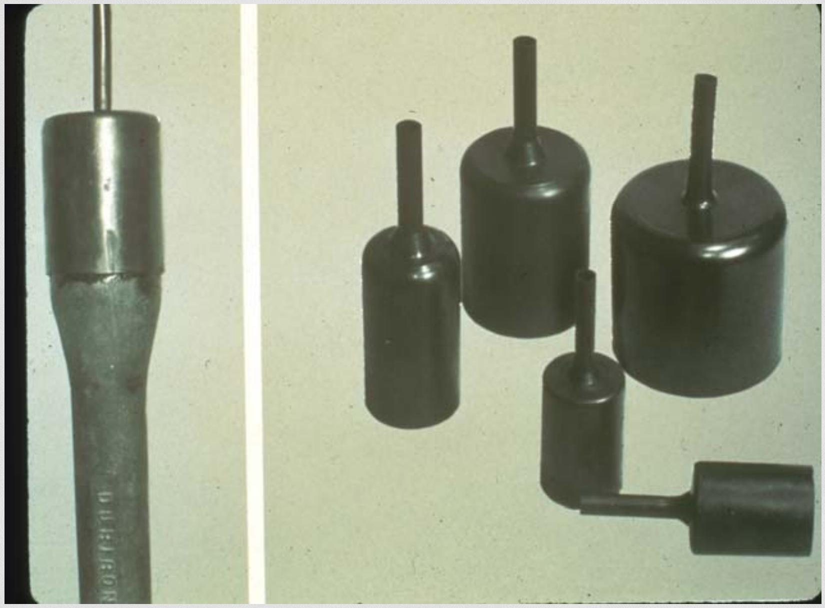
- The lower the consumption rate the longer the anode will last.
- Most impressed current anode materials have a much lower consumption rate than galvanic anode materials.

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.

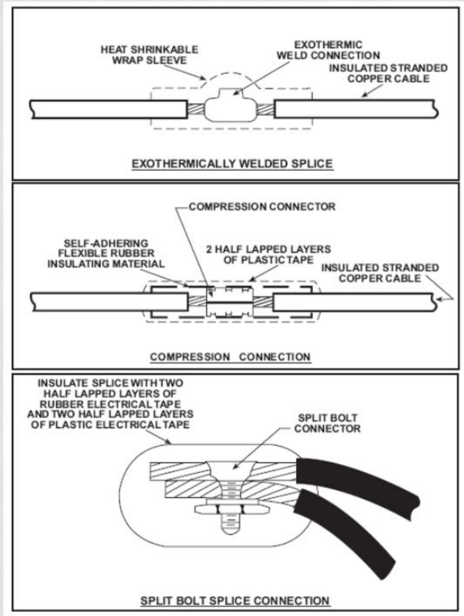


Impressed Current Cables and Splices

- 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.

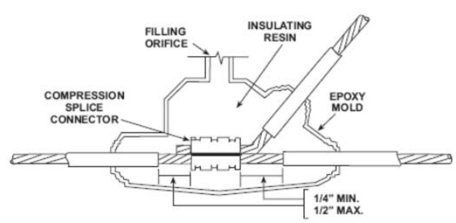
Impressed Current Cables and Splices (cont)

- 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.



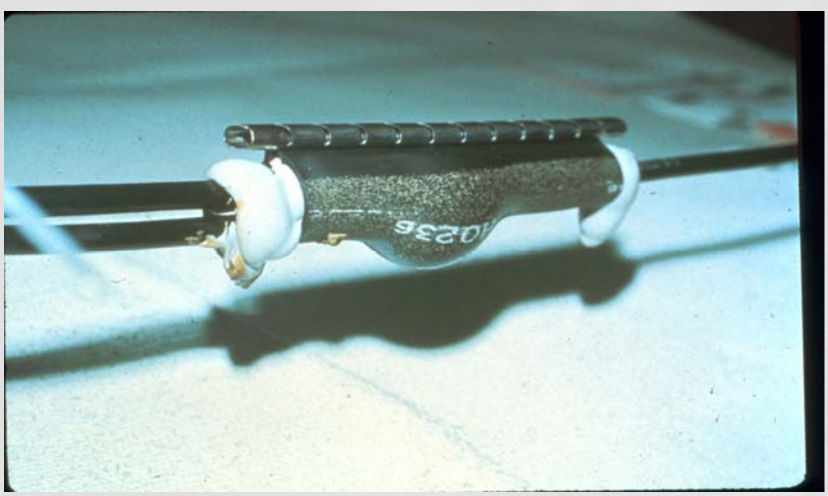
CABLE SPLICE CONNECTIONS

FIGURE 3-13



EPOXY ENCAPSULATED SPLICE

FIGURE 3-14



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

ELECTRICAL ISOLATION

CLASS PERIOD 6

Joel McLawhorn

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.

CODE REQUIREMENTS

§192.467 External corrosion control: Electrical isolation.

- (a) Each buried or submerged pipeline must be electrically isolated from other underground metallic structures, unless the pipeline and the other structures are electrically interconnected and cathodically protected as a single unit.
- (b) One or more insulating devices must be installed where electrical isolation of a portion of a pipeline is necessary to facilitate the application of corrosion control.

CODE REQUIREMENTS

- (c) Except for unprotected copper inserted in a ferrous pipe, each pipeline must be electrically isolated from metallic casings that are a part of the underground system. However, if isolation is not achieved because it is impractical, other measures must be taken to minimize corrosion of the pipeline inside the casing.
- (d) Inspection and electrical tests must be made to assure that electrical isolation is adequate.
- (e) An insulating device may not be in-stalled in an area where a combustible atmosphere is anticipated unless precautions are taken to prevent arcing.

ISOLATORS (cont)

Isolators are used but not limited to the following uses:

- Separate foreign metal structures from protected pipelines (casings and grounded structures).
- Separate different types metals from each other
- Separate coated lines from bare lines
- Separate C/P lines from unprotected lines
- Electrically isolate pipes for troubleshooting purposes

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 may become anodic when connected to bare or poorly coated pipelines.
- Non-isolated 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 insulator
- Compression couplings
- Insulated bolted couplings
- Fiber board gaskets
- Insulated unions
- Plastic Pipe
- Insulated 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.

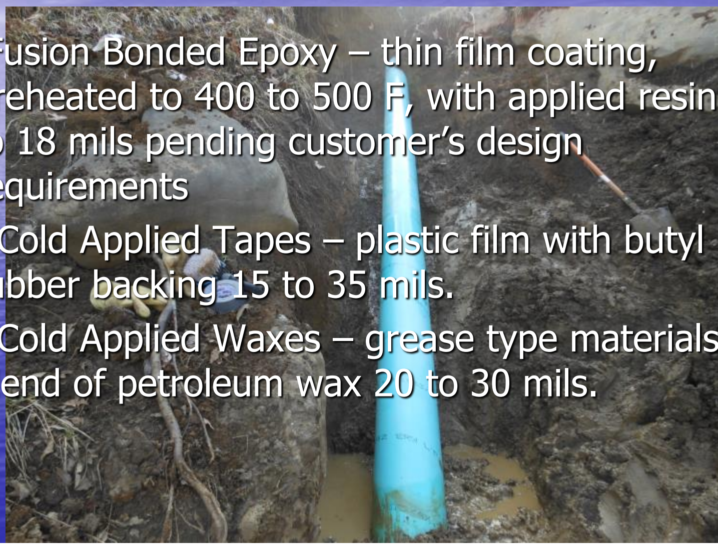
- Coatings keep the current on the pipeline. Current leaving the pipeline results in corrosion

- 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

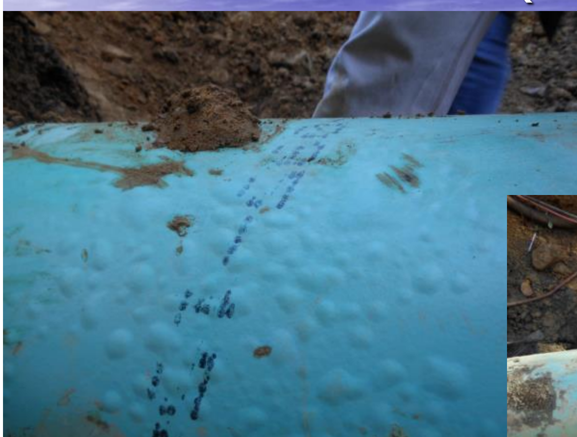
- Types of coatings used –
  - Liquid Epoxy – field applied two part - resin and harder, one coat thickness of 20-50 mils.
  - Extruded Coatings – high density polyethylene with an under coat of mastic approx. 60 mils thickness.
  - Asphalt Based Mastics – cold applied with brush to desired thickness

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 – Coating Materials (Cont.)



Dielectric Isolation Devices

- **Meter Isolation & Above Ground Installations**

Meter Swivels

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

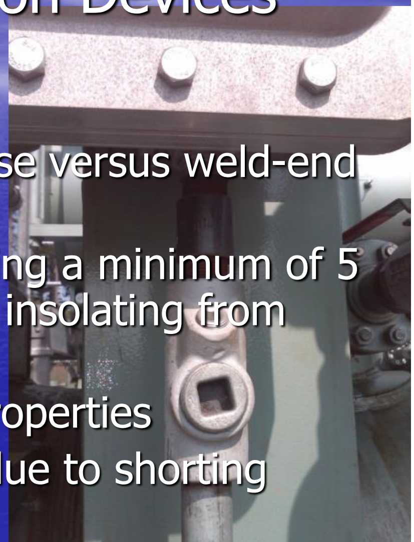
Dielectric Isolation Devices

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

Insulated Unions

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

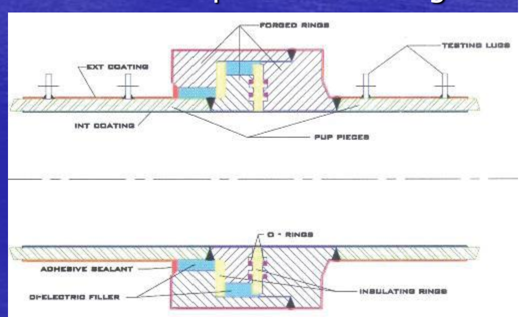
Dielectric Isolation Devices



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

Dielectric Isolation Devices

- Weld-in Isolator
  - Can only be installed by qualified welder (usually require NDE – xray and hydro test)
  - Internal isolator components must be protected during welding process



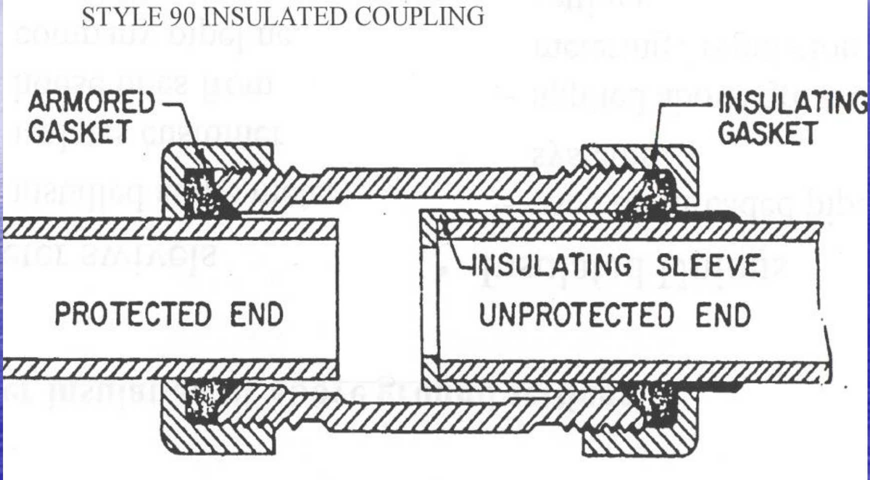
Dielectric Isolation Devises

- Insulated 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

Dielectric Isolation Devices

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

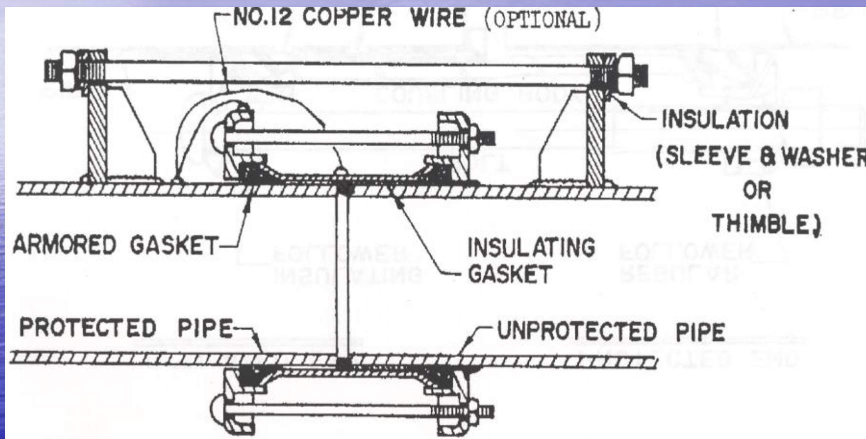
Isolation Compression Coupling



Dielectric Isolation Devises

- Isolation 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

Isolation 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
Insulation 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 resistant grounding system

Dielectric Isolation Precautions

- DOT subpart I, 192.467:

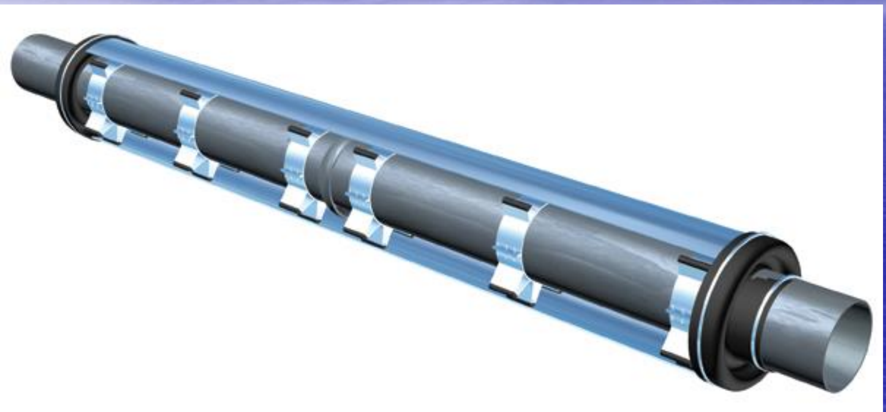
  An insulating device may not be installed in an area where a combustible atmosphere is anticipated unless precautions are taken to prevent arcing.

  - Methods commonly used:

    Solid state device

    Zinc grounding cell

Cased Pipeline Crossing



Cased Pipeline Crossings

Cased Pipeline Crossings

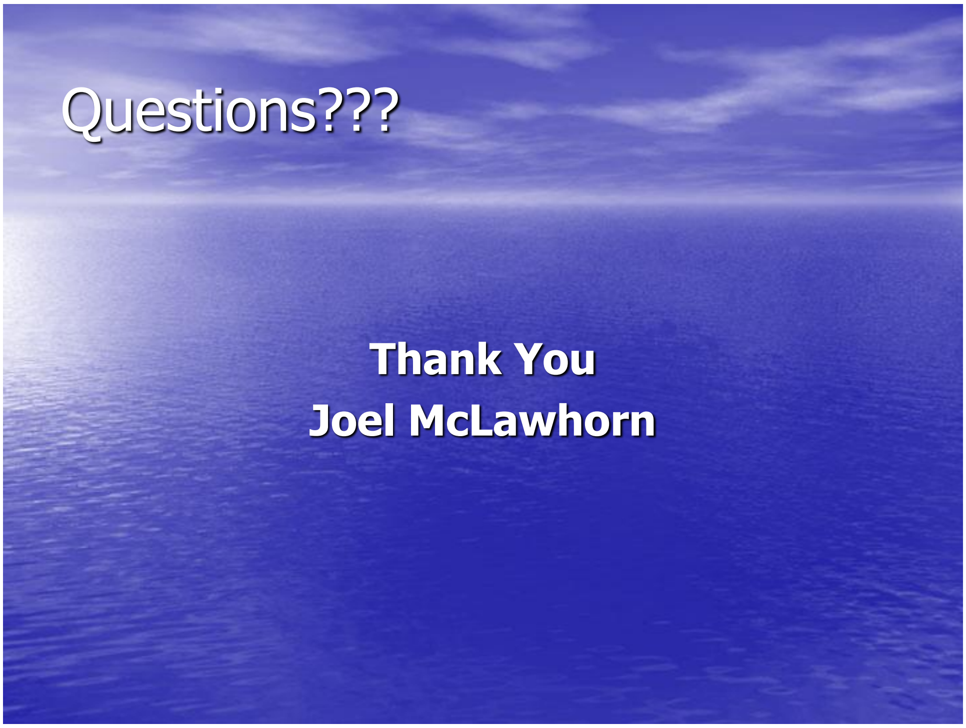
Cased Pipeline Crossing

Cased Pipeline Crossings

Cased Pipeline Crossing

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!


Questions???
Thank You
Joel McLawhorn

Pipeline Coatings

2014 AUCSC

Fundamentals Session

Jeff Didas – Matcor, Inc. – Tucson, AZ

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
- Internal coatings & linings

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

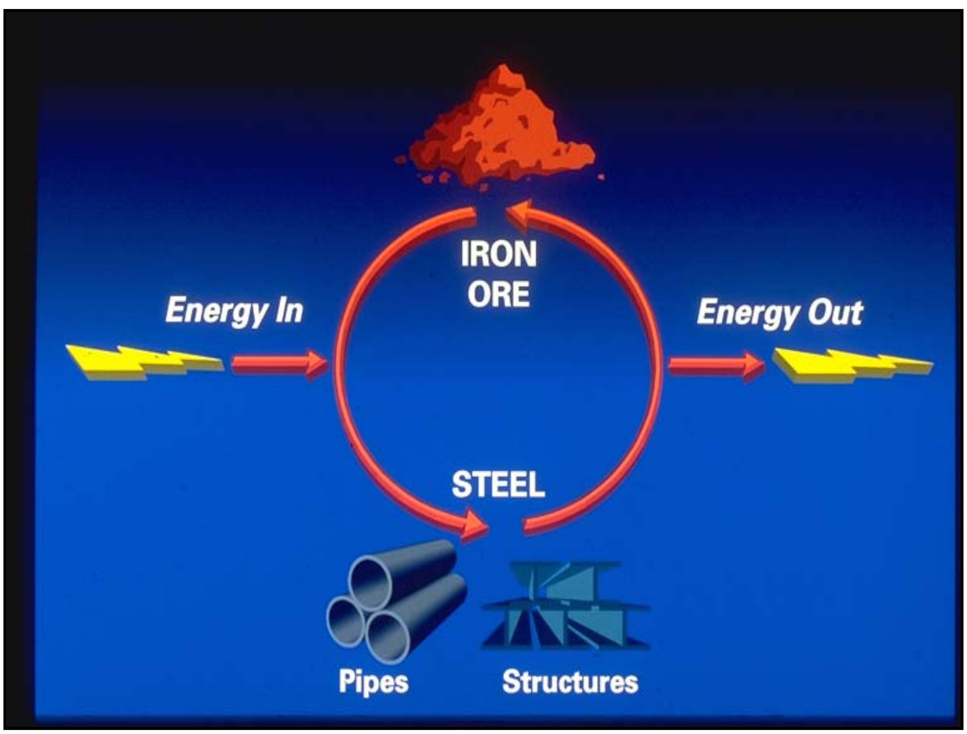
Transition Area Coatings

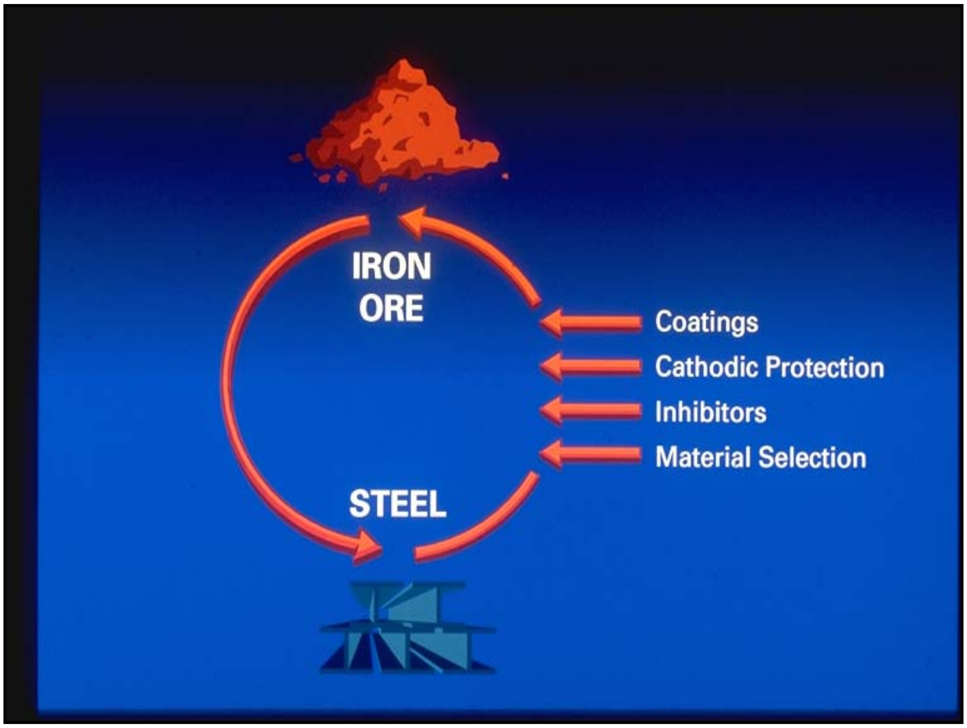
- Used where piping transitions from buried service to atmospheric service
- Used to protect from mechanical damage – freeze/thaw cycle, weed whackers, gravel, etc.
- Used to protect buried service coatings from Ultraviolet light when used above ground

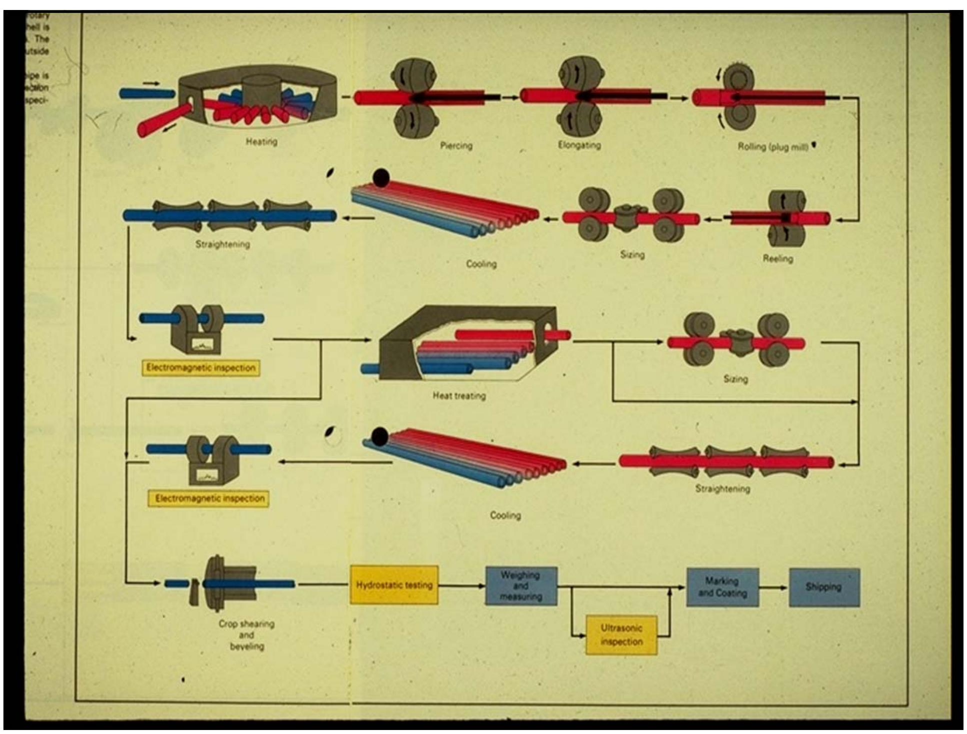
Atmospheric Coatings

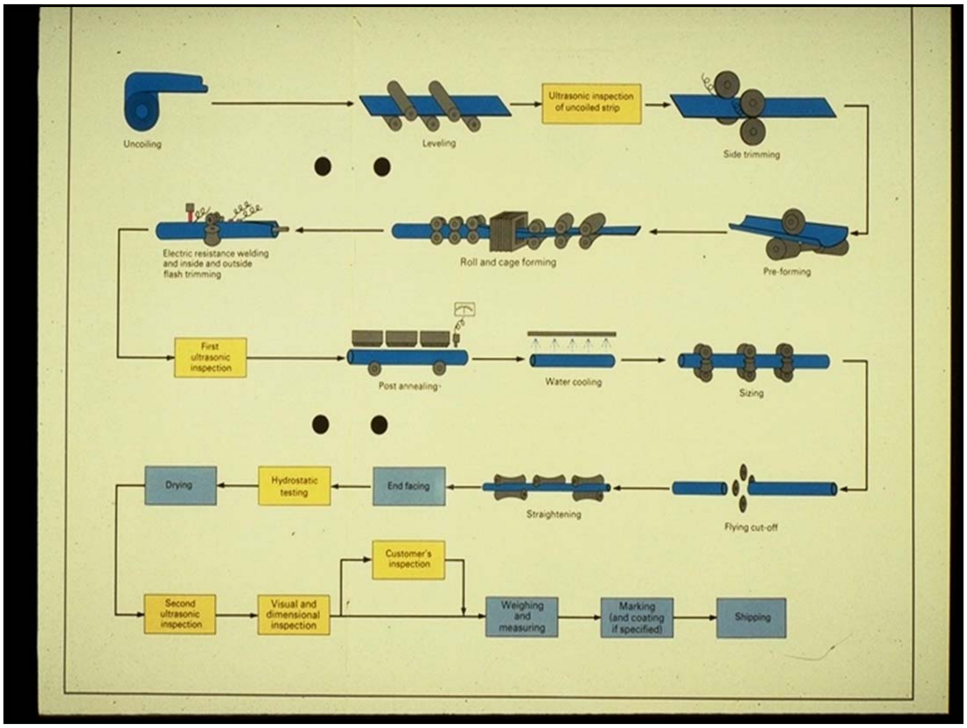
- Various types, quality and expected life
- Primary purpose is corrosion prevention, secondary purpose is appearance
- Problem areas, flanges, nuts, bolts, hold down clamps, high temperature service, beneath insulation, through walls/foundations, etc.

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

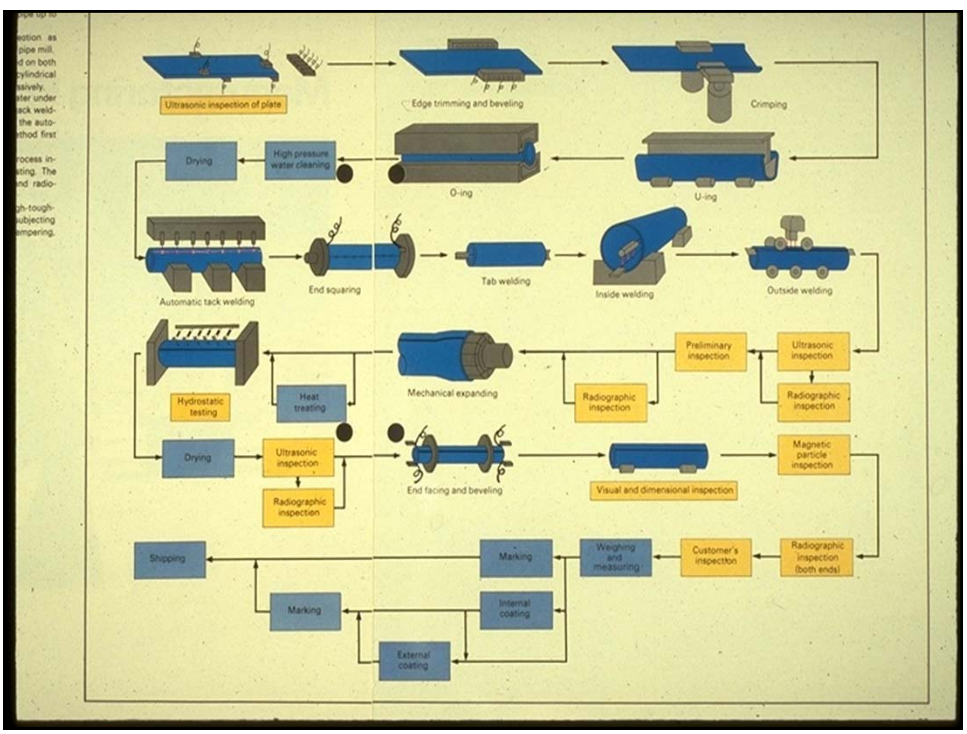



IRON
ORE
STEEL
Coatings
Cathodic Protection
Inhibitors
Material Selection

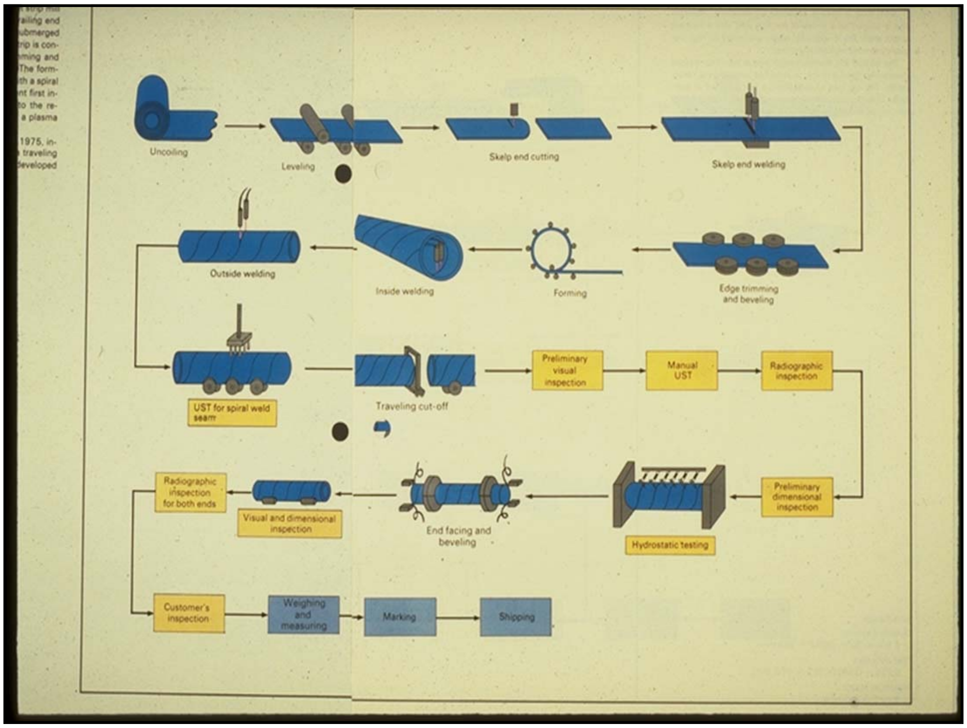

Heating
Piercing
Elongating
Rolling (plug mill)
Straightening
Cooling
Sizing
Reeling
Electromagnetic inspection
Heat treating
Sizing
Straightening
Cooling
Electromagnetic inspection
Crop shearing and beveling
Hydrostatic testing
Weighing and measuring
Ultrasonic inspection
Marking and Coating
Shipping

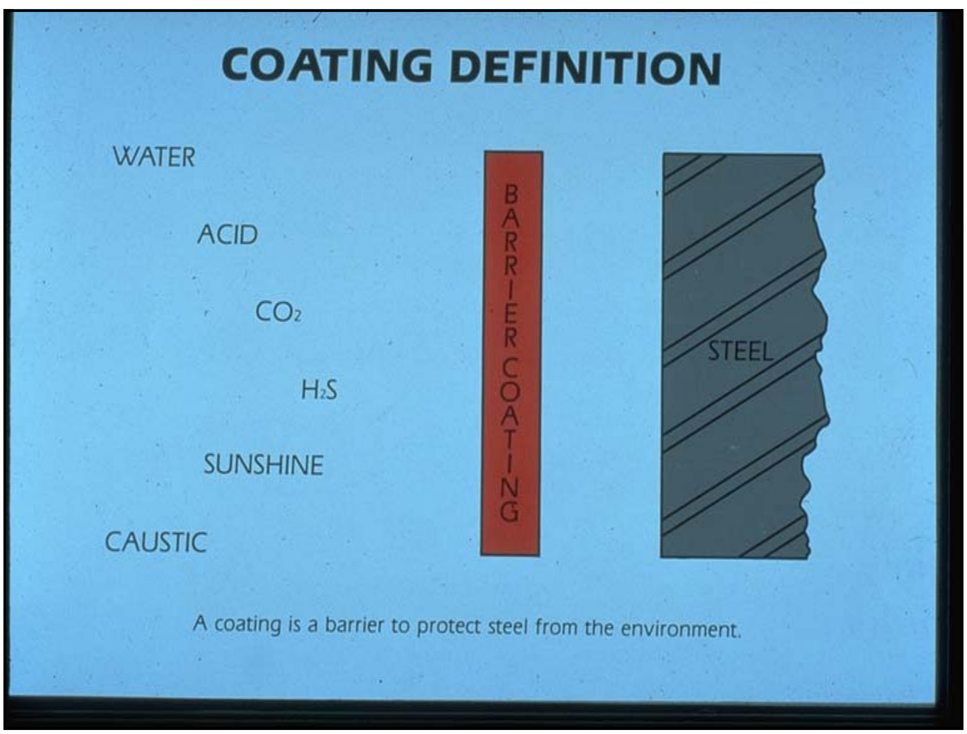


Uncoiling
Leveling
Ultrasonic inspection of uncoiled strip
Side trimming
Electric resistance welding and inside and outside flash trimming
Roll and cage forming
Pre-forming
First ultrasonic inspection
Post annealing
Water cooling
Sizing
Drying
Hydrostatic testing
End facing
Straightening
Flying cut-off
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
Hydrostatic testing
Heat treating
Mechanical expanding
Radiographic inspection
Preliminary inspection
Ultrasonic inspection
Radiographic inspection
Drying
Ultrasonic inspection
Radiographic inspection
End facing and beveling
Visual and dimensional inspection
Magnetic particle 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

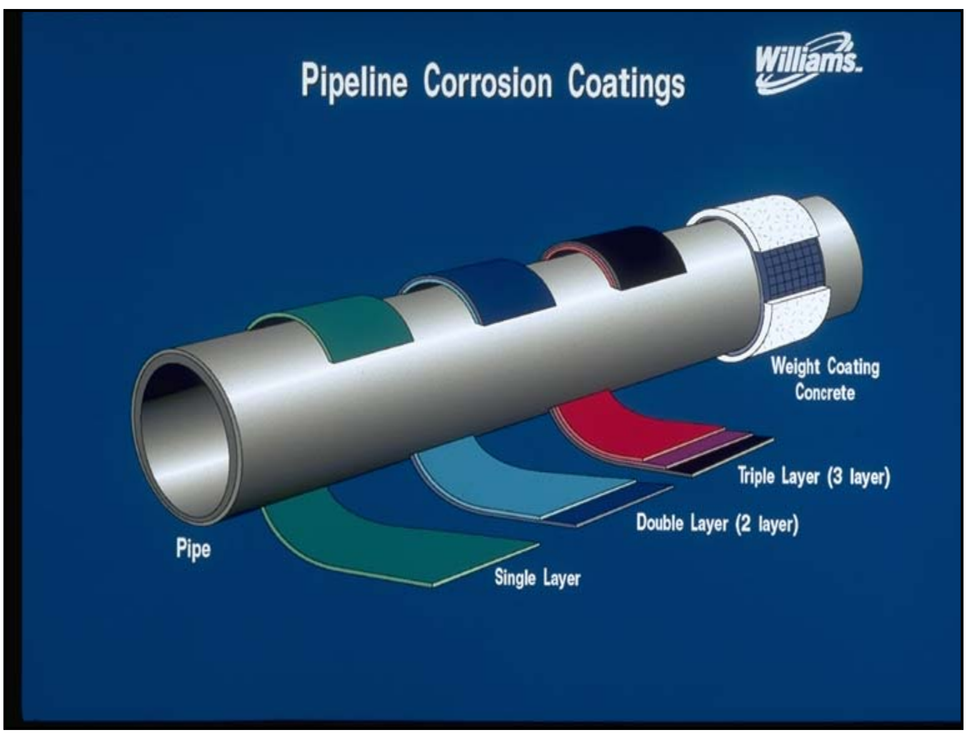
- Ease of Application - It can be applied with a mop on any surface or from above ground.
- Cost Effective - Cost $1.00/Gallon or less!
- Environmentally Safe and Friendly – OK to Drink it.
- Performance - Lasts forever.

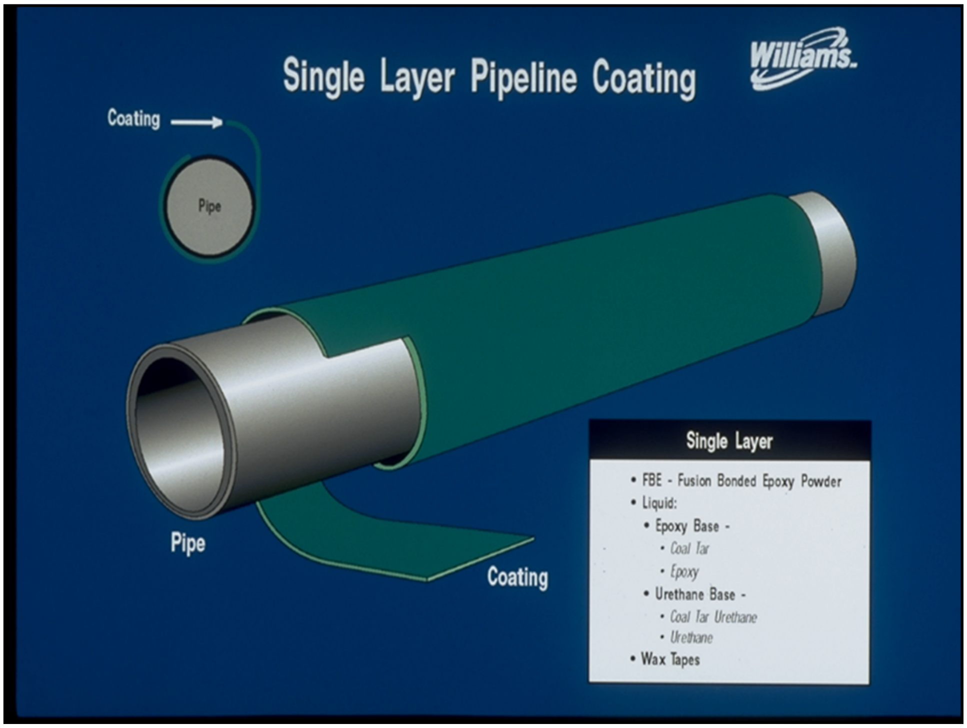
In Reality a Perfect Coating

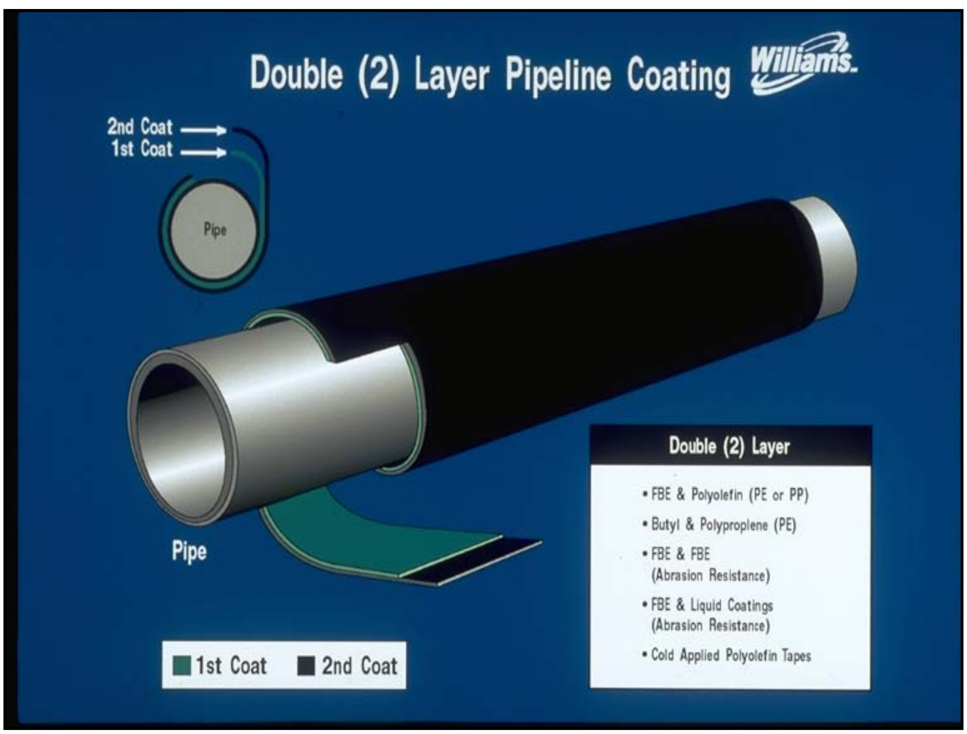
- Requires a quality standard
- Requires a quality specification
- Requires a quality coating mill
- Requires a quality material or materials
- Requires a quality inspector or inspectors

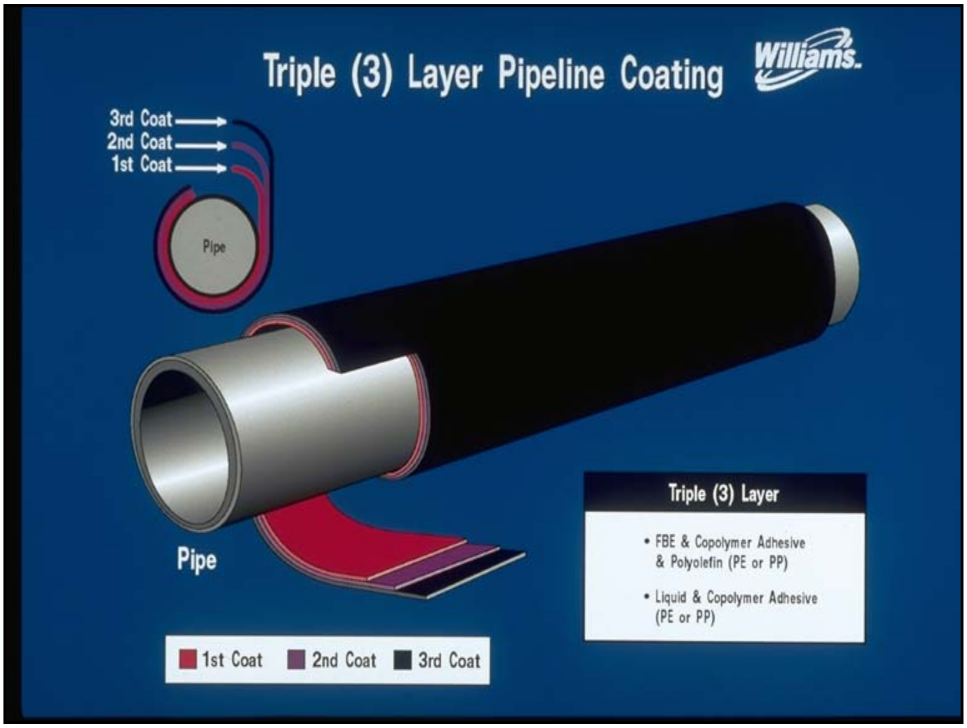
General Requirements of a Pipeline Coating

- 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

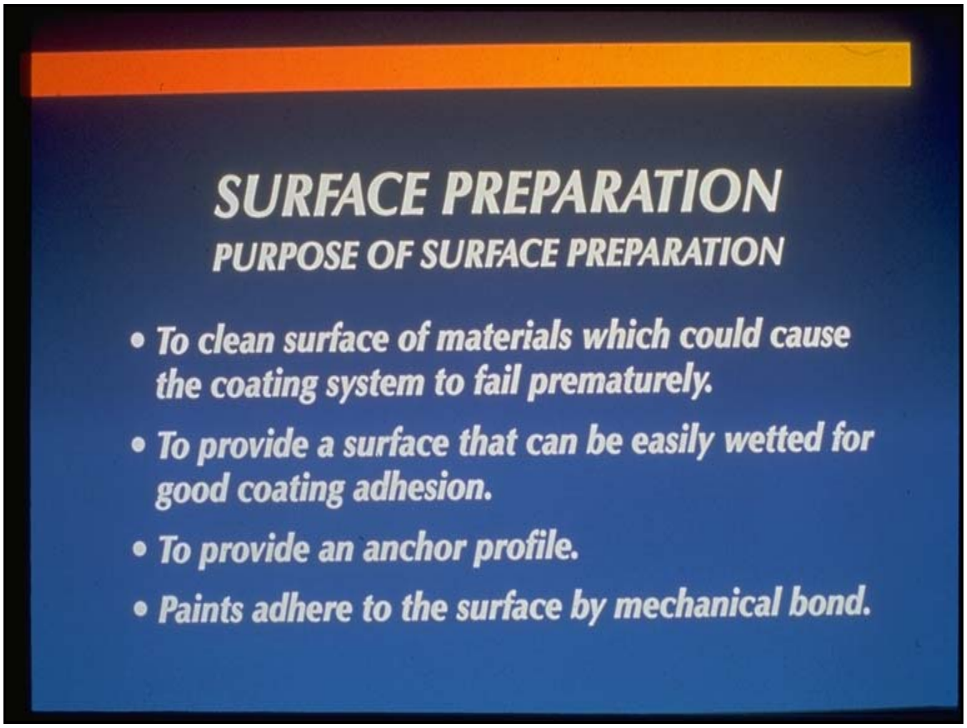


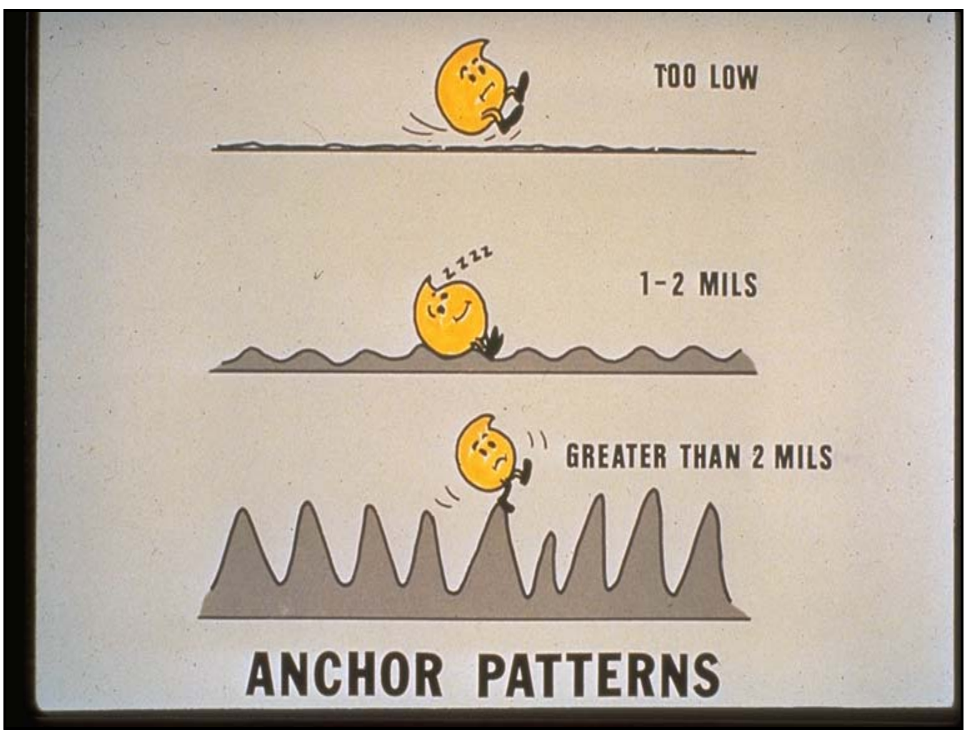

Single Layer Pipeline Coating
Williams.
Coating
Pipe
Pipe
Coating
Single Layer
• FBE - Fusion Bonded Epoxy Powder
• Liquid:
• Epoxy Base -
• Coal Tar
• Epoxy
• Urethane Base -
• Coal Tar Urethane
• Urethane
• Wax Tapes

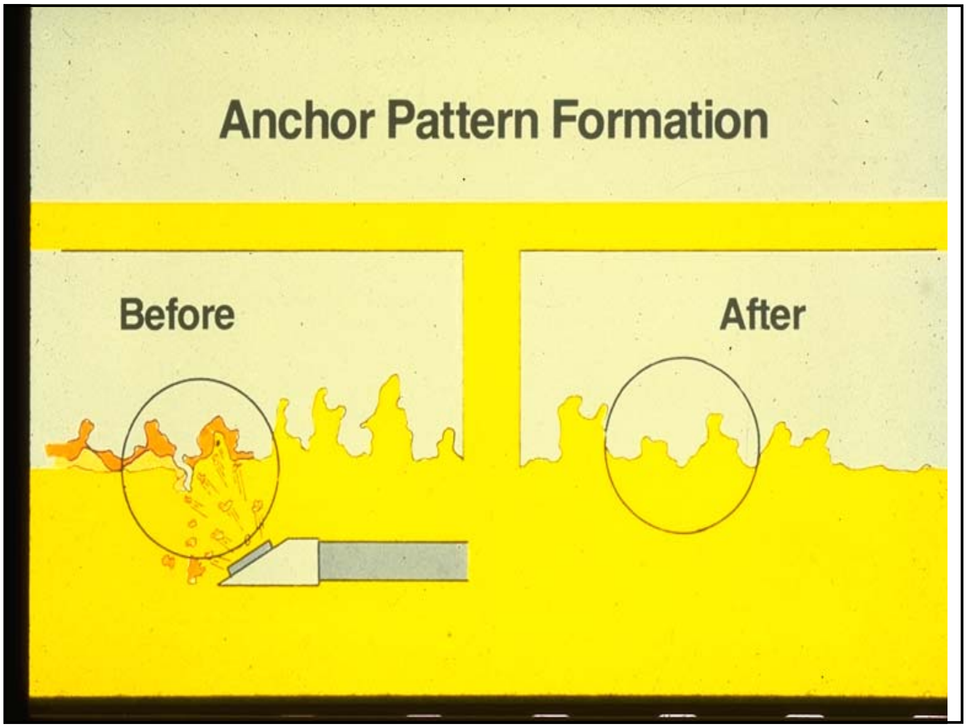

Double (2) Layer Pipeline Coating
Williams.
2nd Coat
1st Coat
Pipe
Pipe
Double (2) Layer
• FBE & Polyolefin (PE or PP)
• Butyl & Polyproplene (PE)
• FBE & FBE (Abrasion Resistance)
• FBE & Liquid Coatings (Abrasion Resistance)
• Cold Applied Polyolefin Tapes
1st Coat
2nd Coat


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

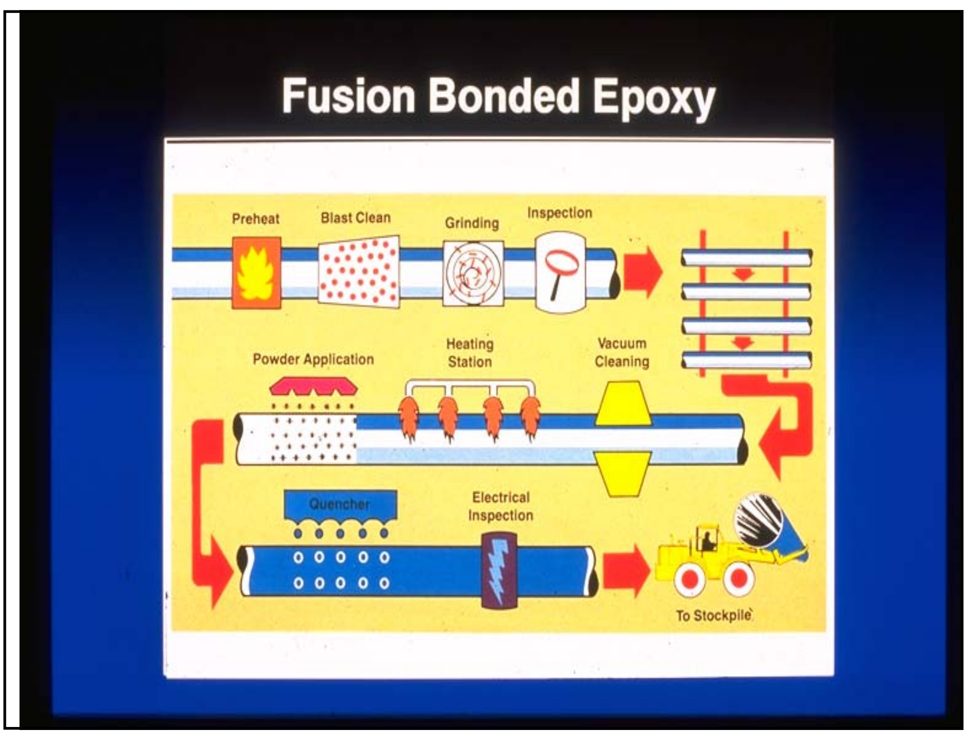

SURFACE PREPARATION
PURPOSE OF SURFACE PREPARATION
• To clean surface of materials which could cause the coating system to fail prematurely.
• To provide a surface that can be easily wetted for good coating adhesion.
• To provide an anchor profile.
• Paints adhere to the surface by mechanical bond.


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

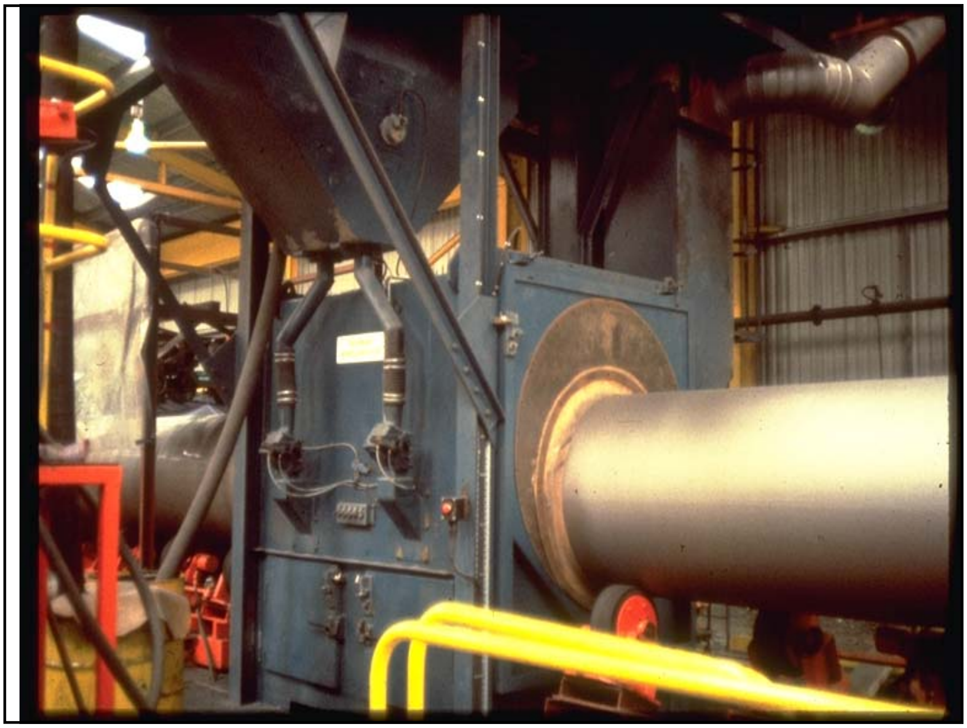

Anchor Pattern Formation
Before
After


FUSION BONDED
COATINGS

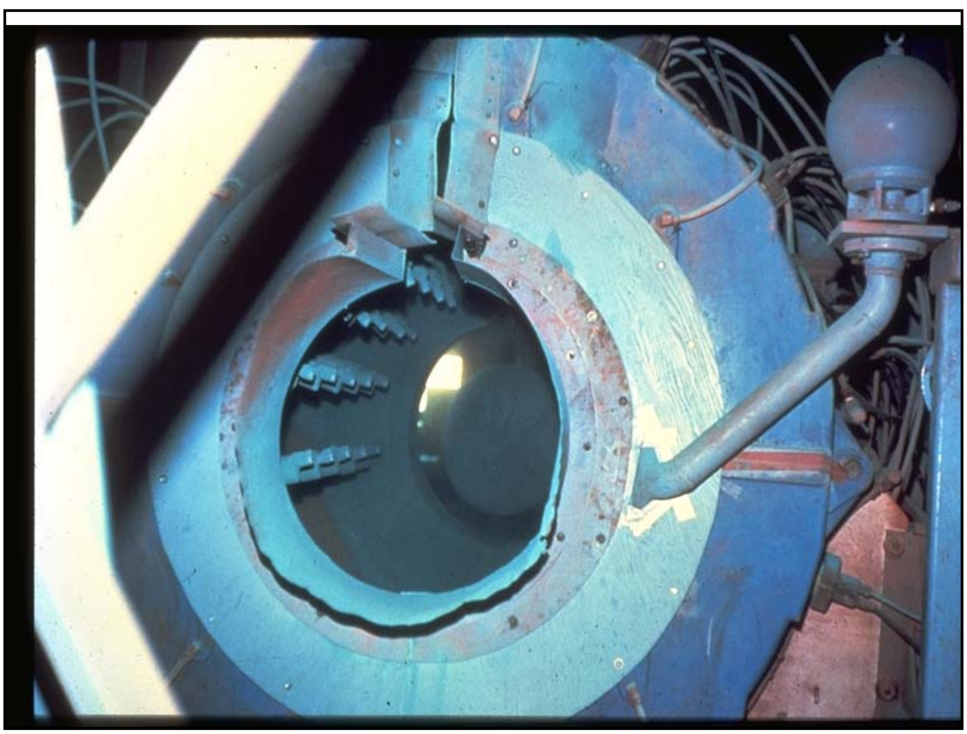
APPLICATION
PROCEDURE
1. CLEAN
2. HEAT
3. APPLY
4. CURE
5. INSPECT
6. REPAIR

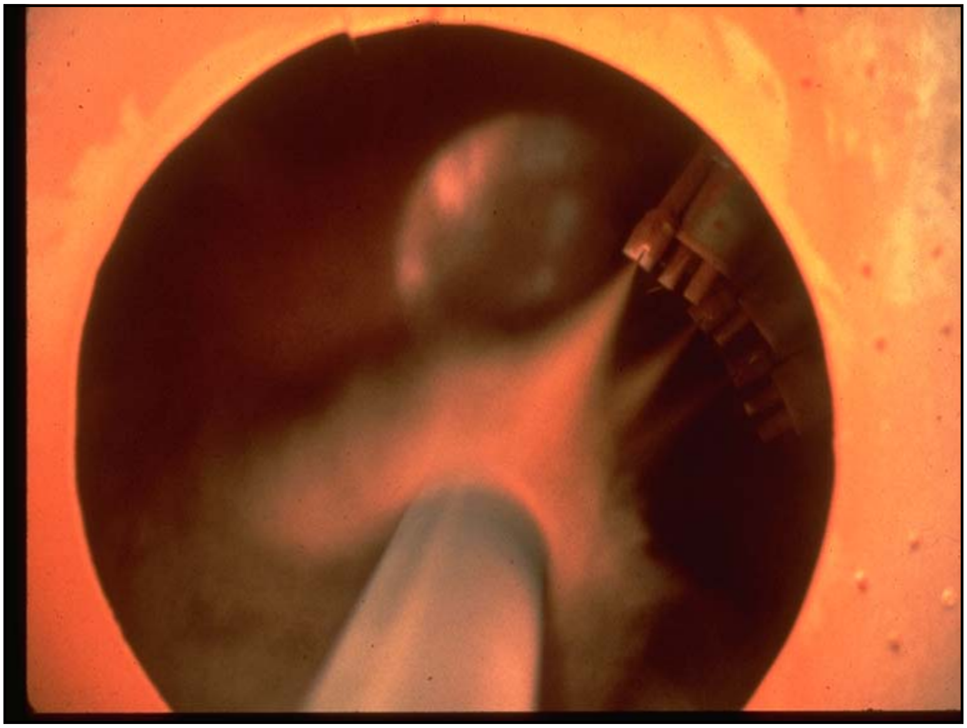


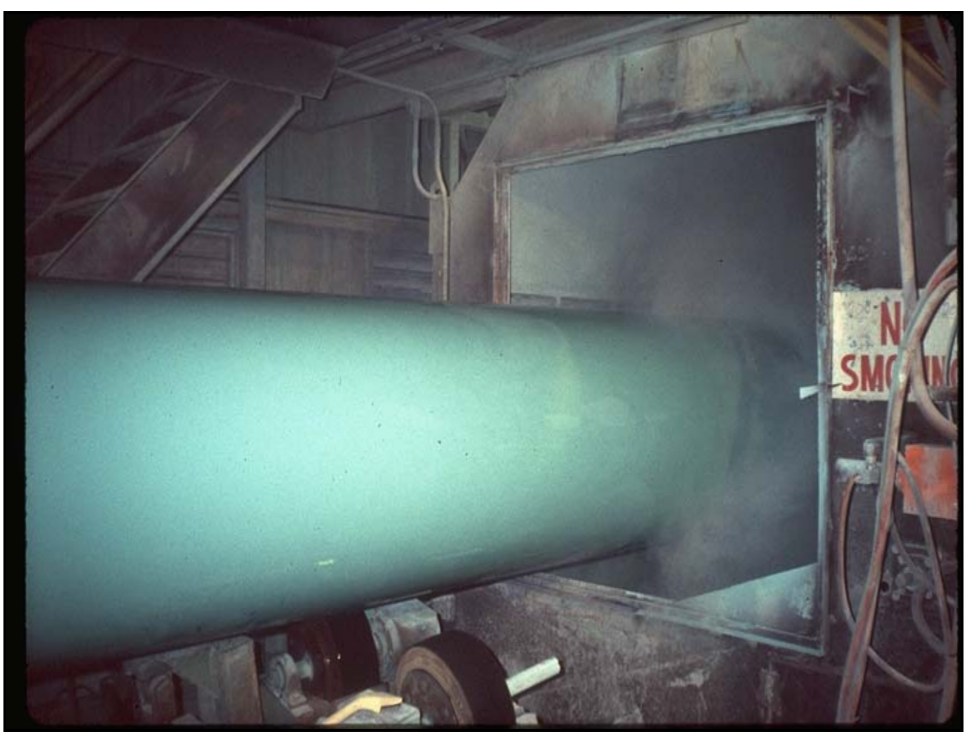
Fusion Bonded Epoxy
Preheat
Blast Clean
Grinding
Inspection
Powder Application
Heating Station
Vacuum Cleaning
Quencher
Electrical Inspection
To Stockpile

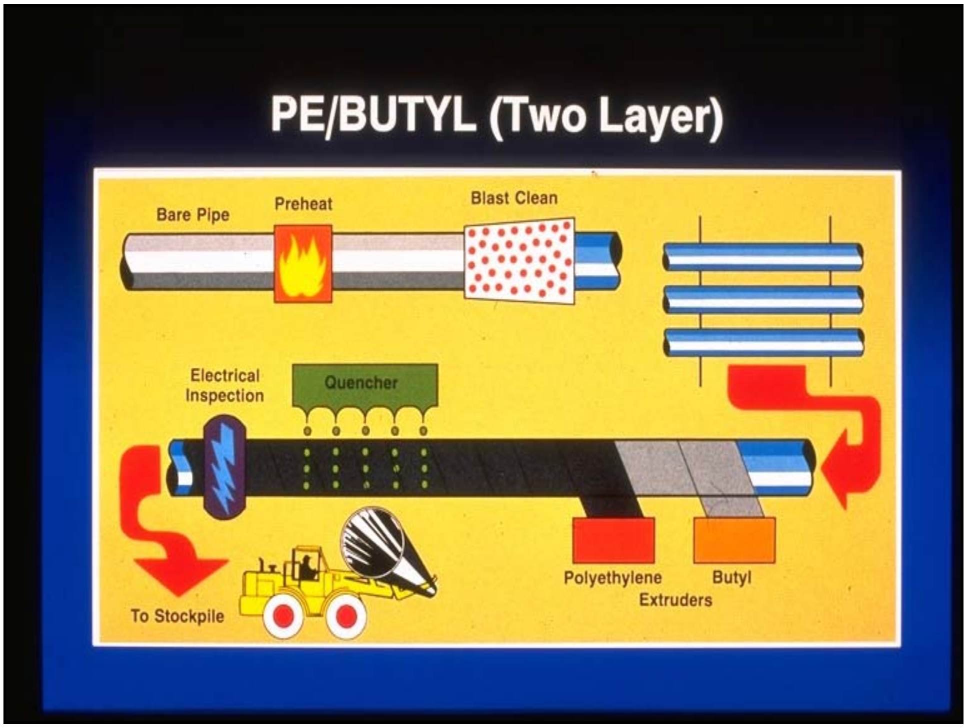


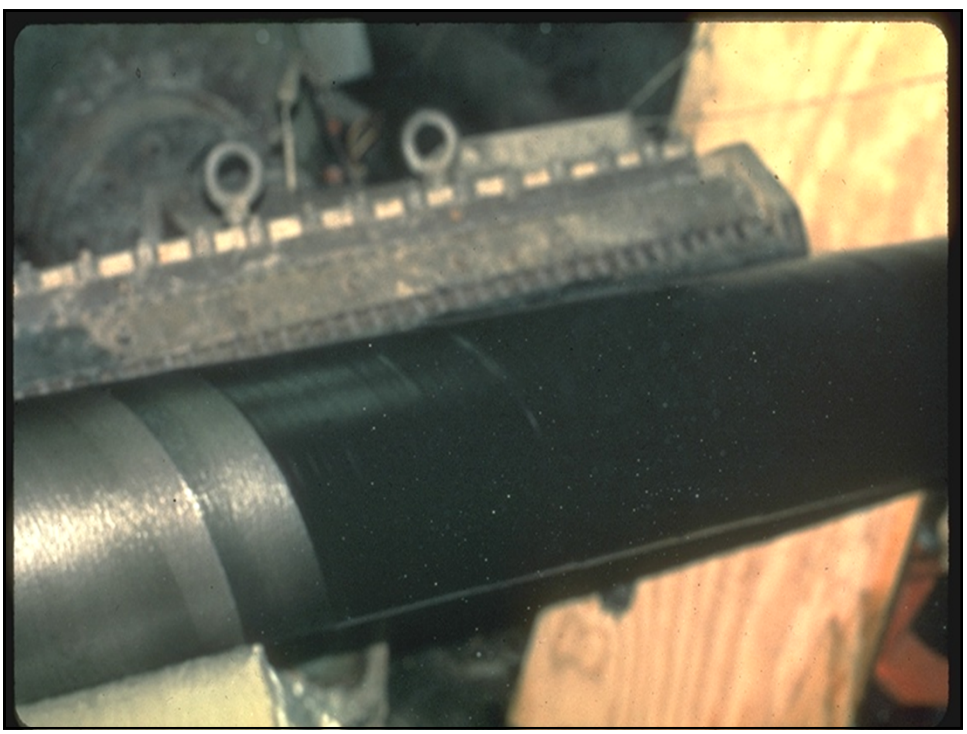

SFSL

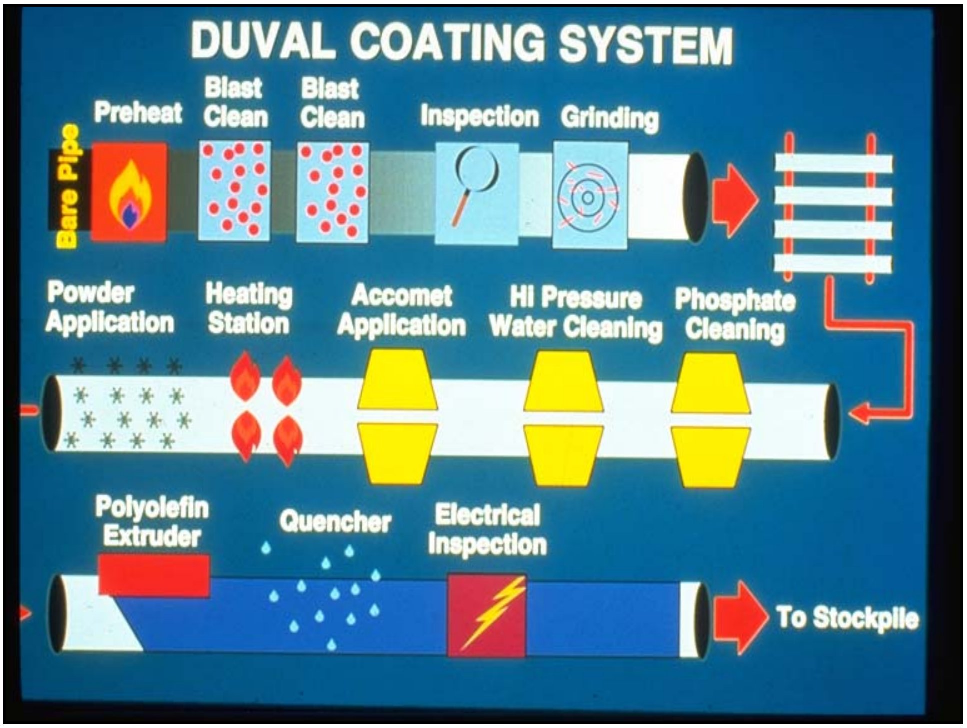


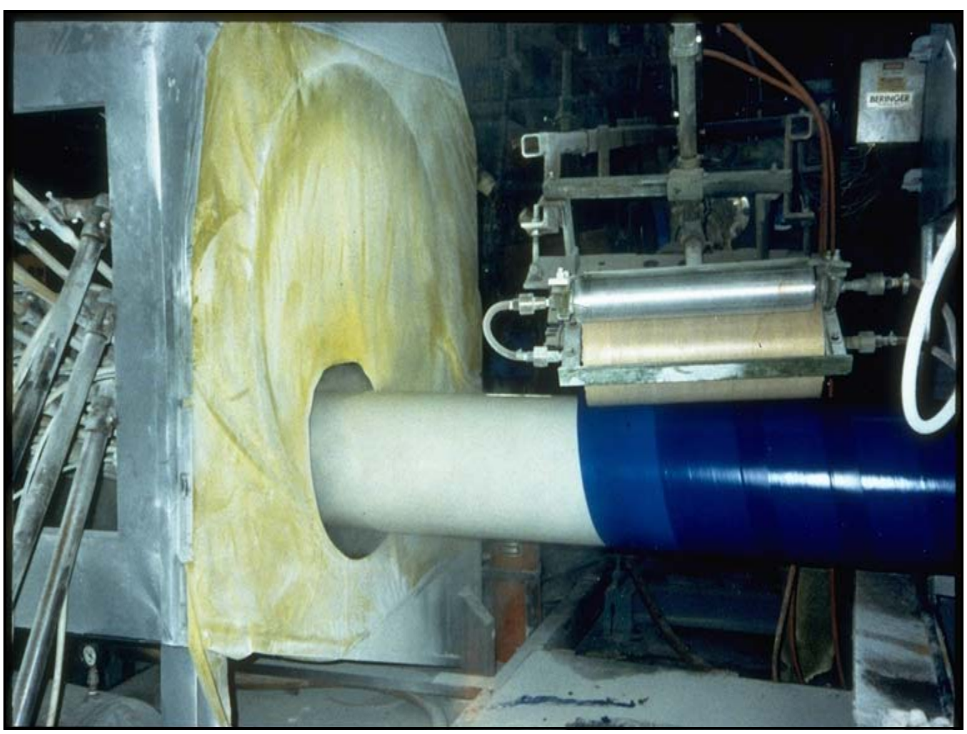




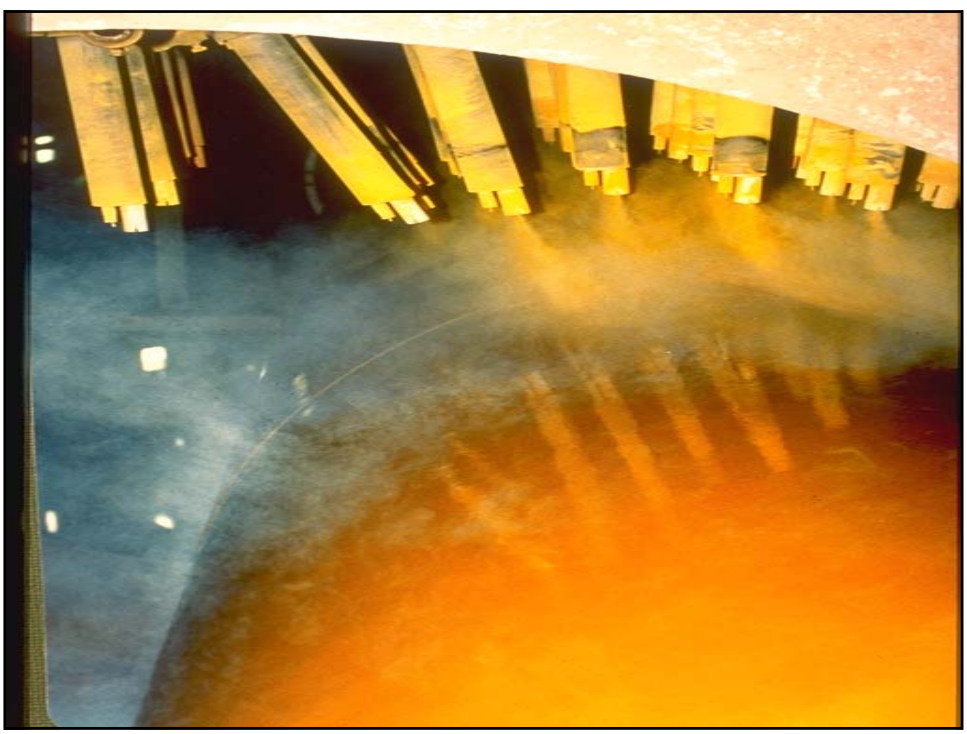

PE/BUTYL (Two Layer)
Bare Pipe
Preheat
Blast Clean
Electrical
Inspection
Quencher
Polyethylene
Butyl
Extruders
To Stockpile

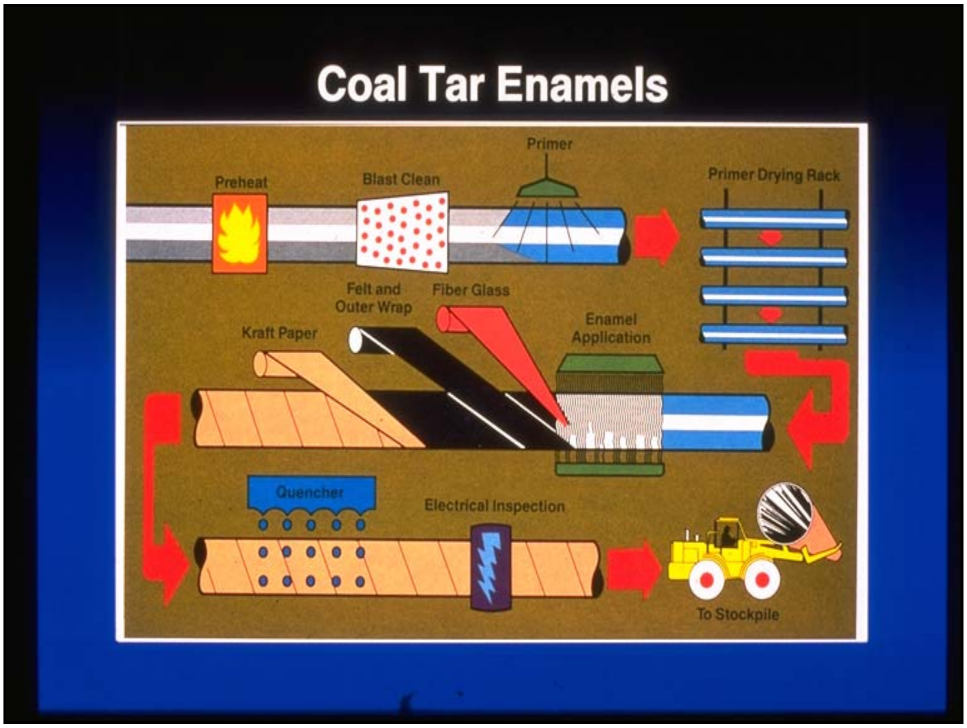


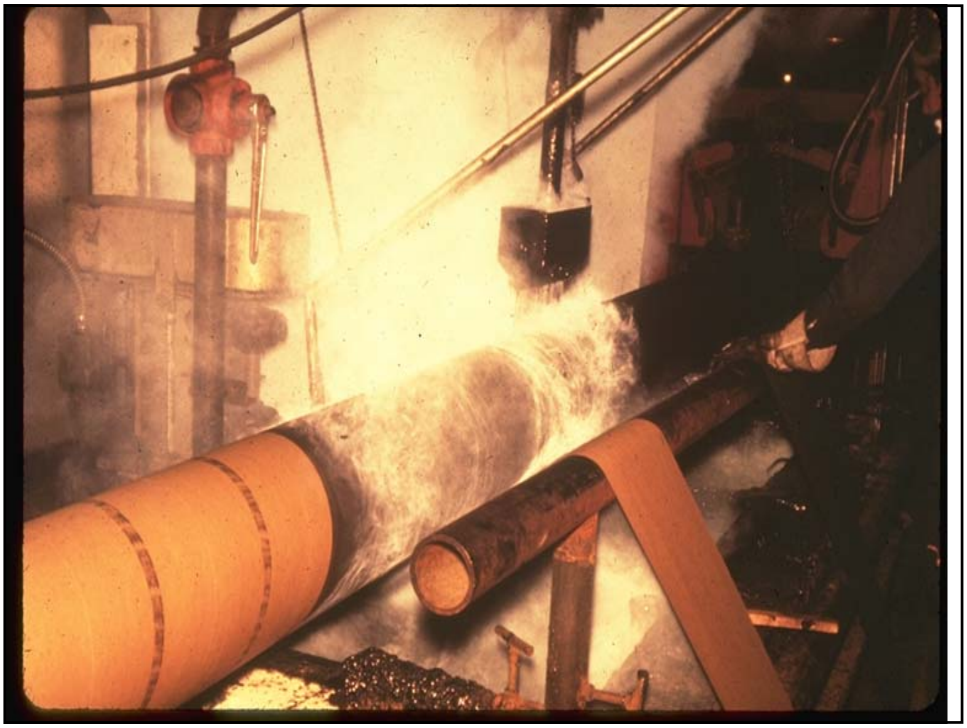

DUVAL COATING SYSTEM
Bare Pipe
Preheat
Blast Clean
Blast Clean
Inspection
Grinding
Powder Application
Heating Station
Accomet Application
Hi Pressure Water Cleaning
Phosphate Cleaning
Polyolefin Extruder
Quencher
Electrical Inspection
To Stockpile

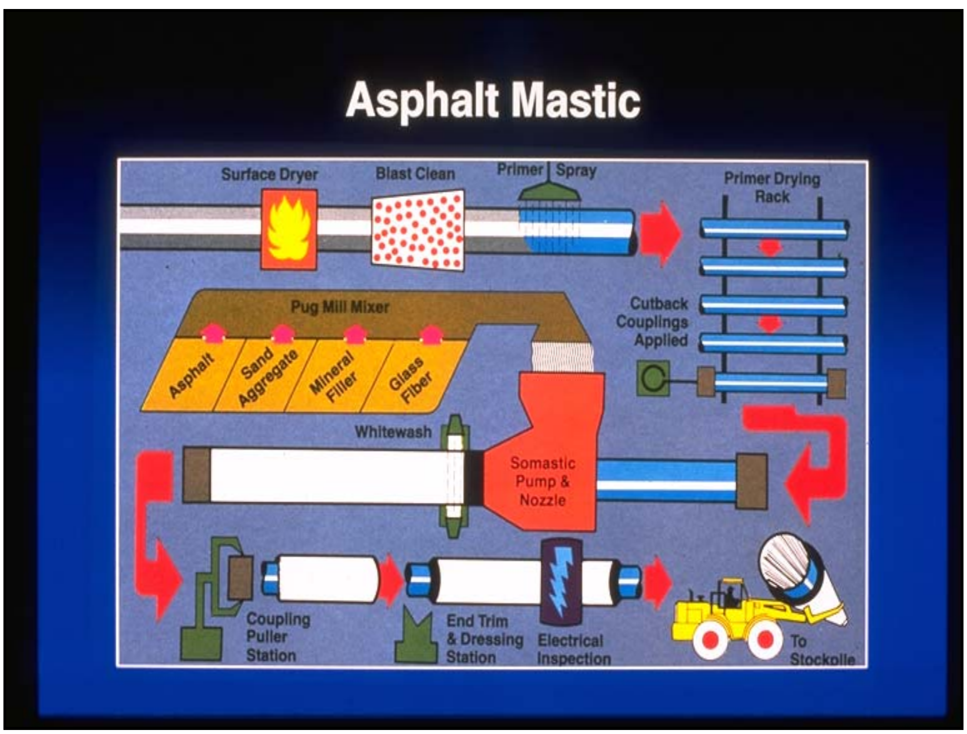



DUAL POWDER
"GOLD"
FBE AND A
PLASTICISED FBE TOP COAT

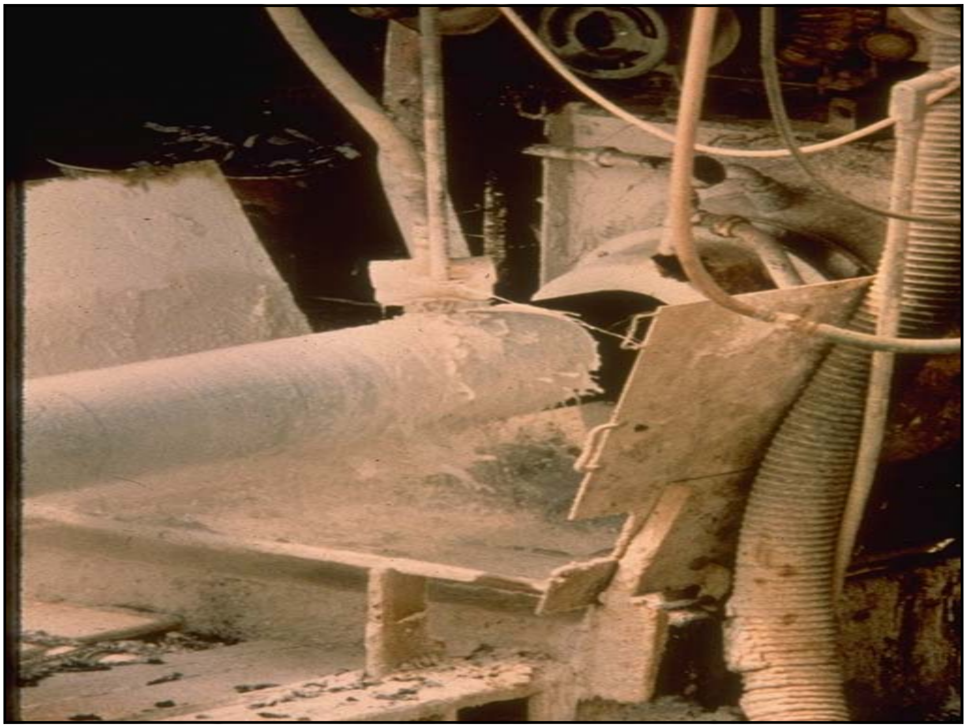


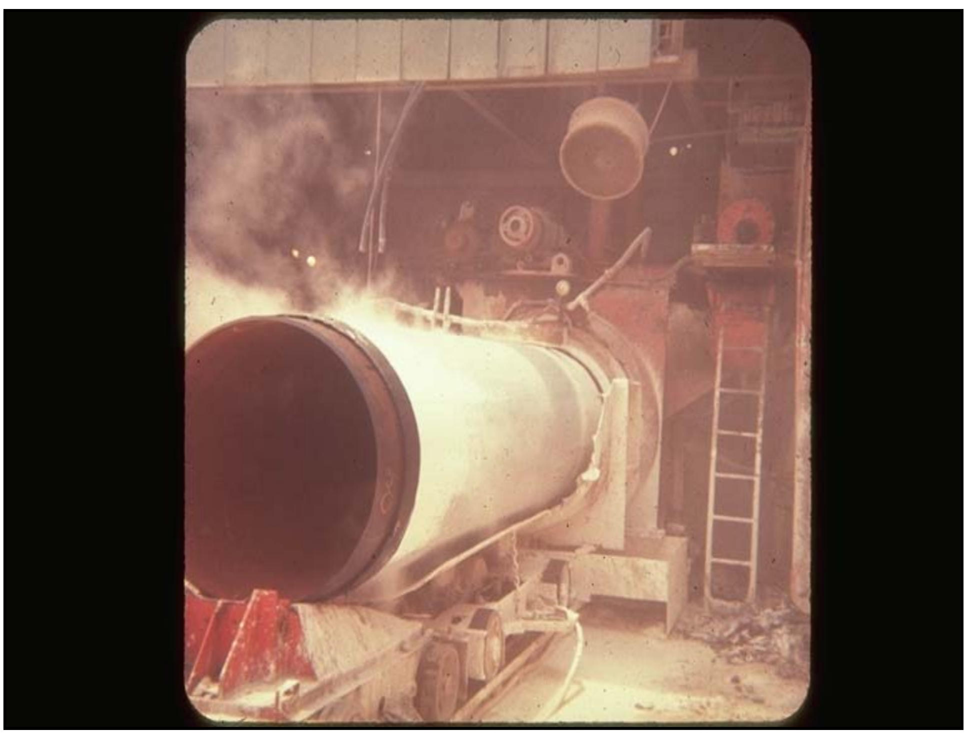

Coal Tar Enamels
Primer
Preheat
Blast Clean
Primer Drying Rack
Felt and
Outer Wrap
Fiber Glass
Enamel
Application
Kraft Paper
Quencher
Electrical Inspection
To Stockpile





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





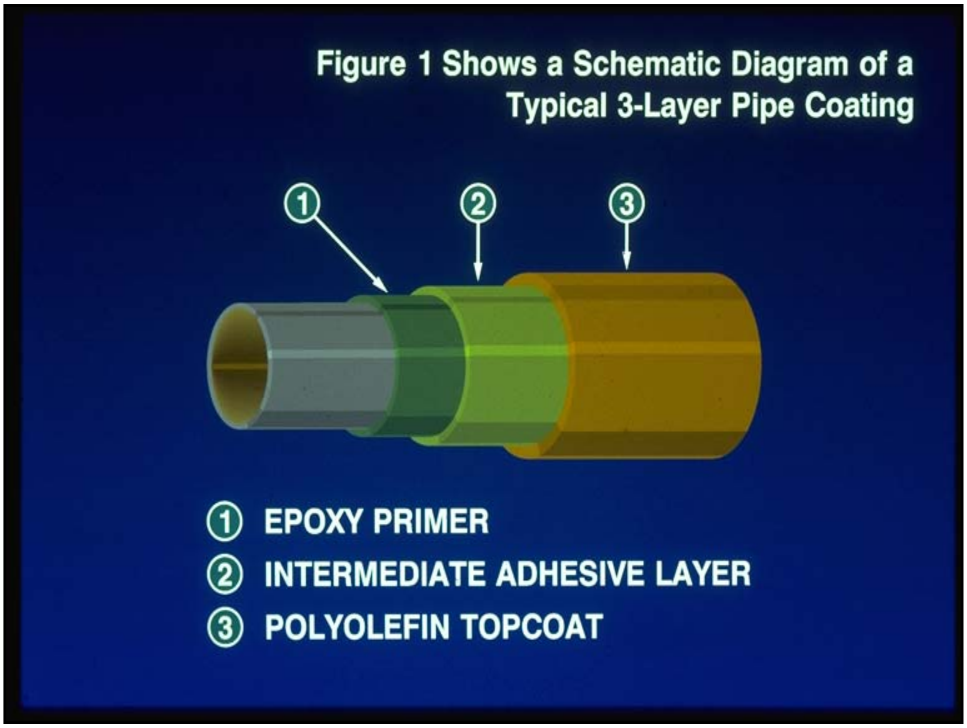
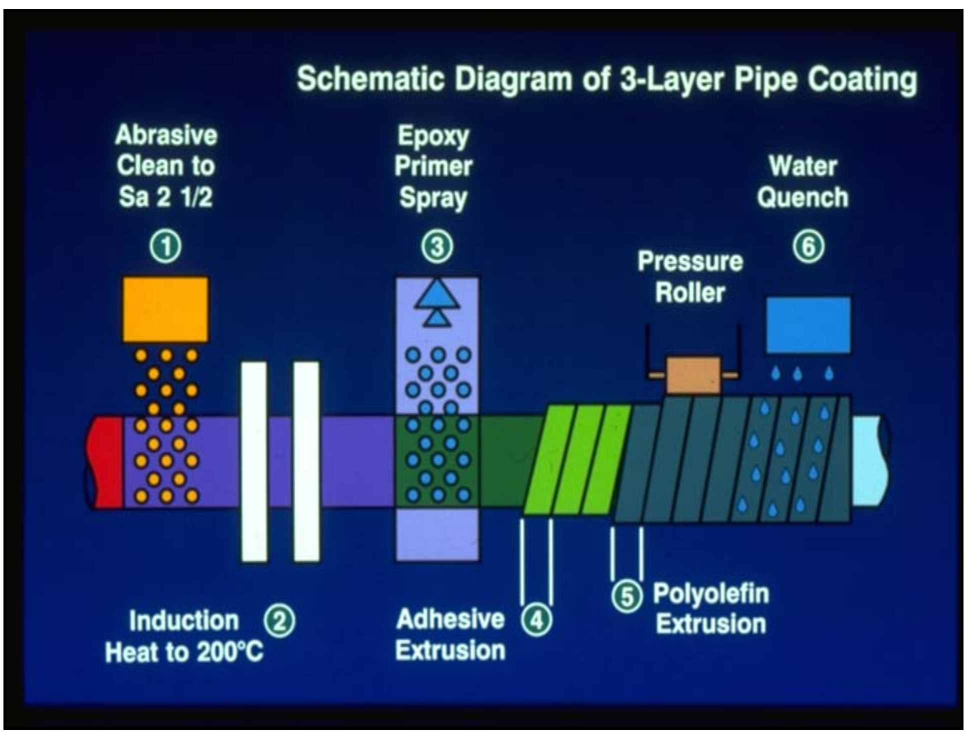
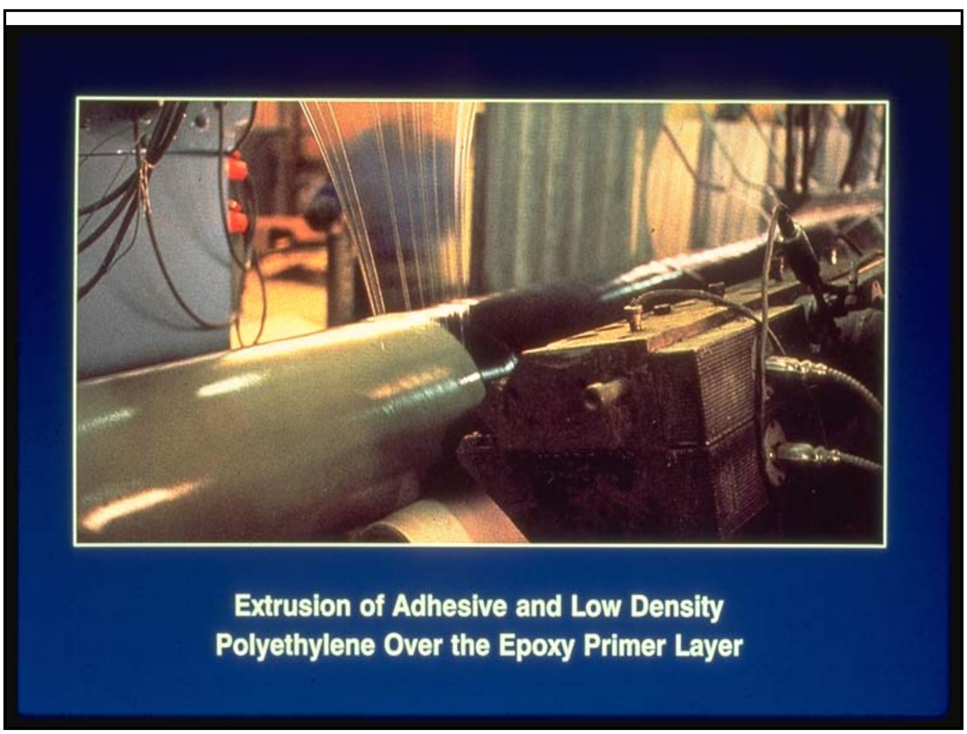
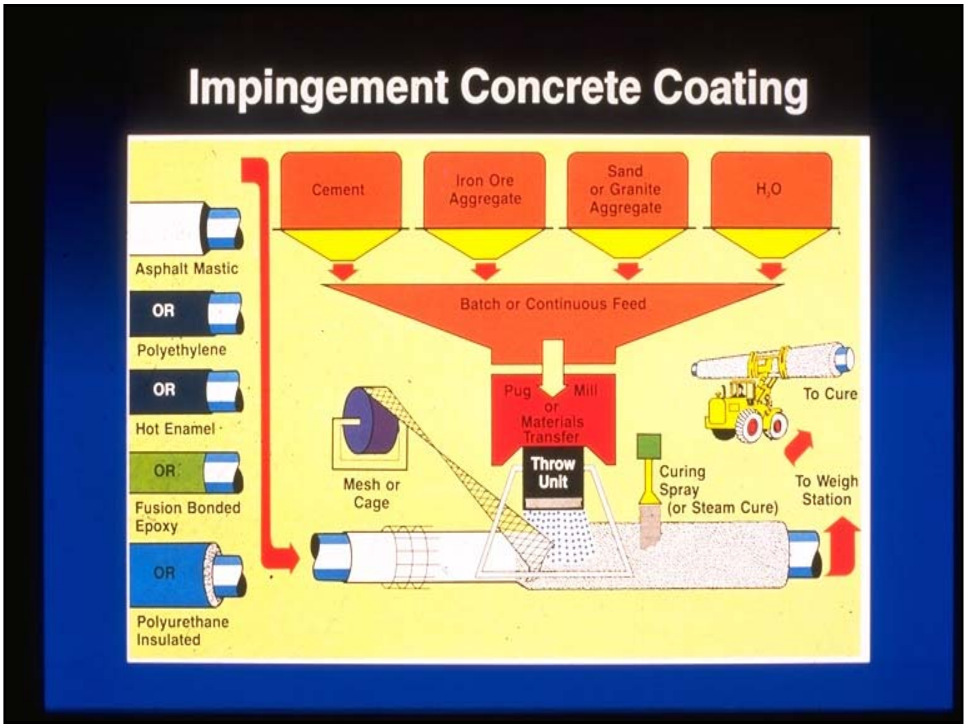


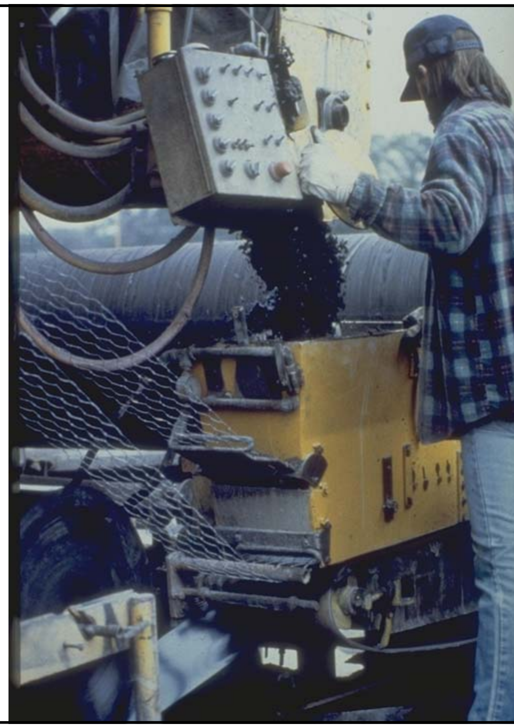
Figure 1 Shows a Schematic Diagram of a
Typical 3-Layer Pipe Coating
1
2
3
1 EPOXY PRIMER
2 INTERMEDIATE ADHESIVE LAYER
3 POLYOLEFIN TOPCOAT


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 2
Heat to 200°C
Adhesive 4
Extrusion
5 Polyolefin
Extrusion

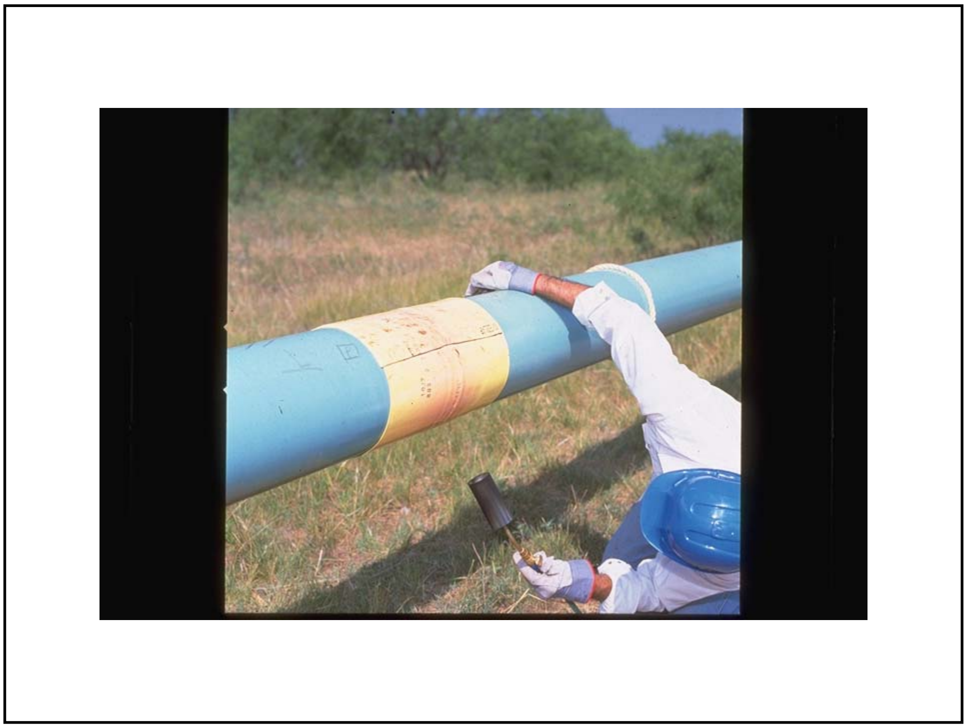

Application of EUROKOTE Epoxy Powder Primer Layer

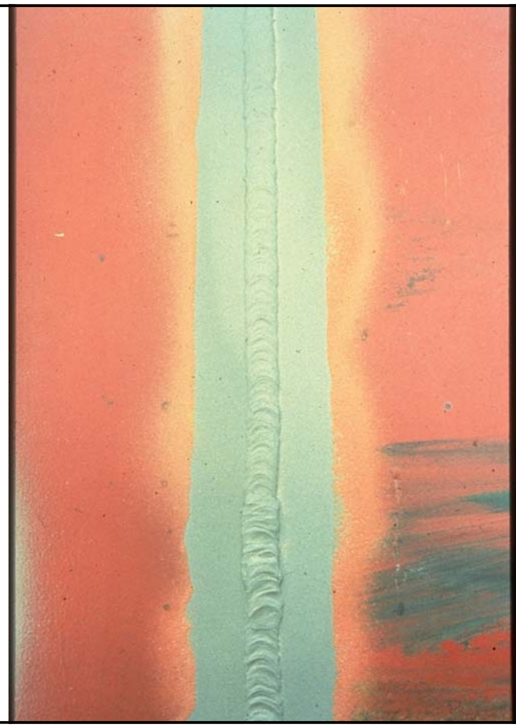

Extrusion of Adhesive and Low Density
Polyethylene Over the Epoxy Primer Layer

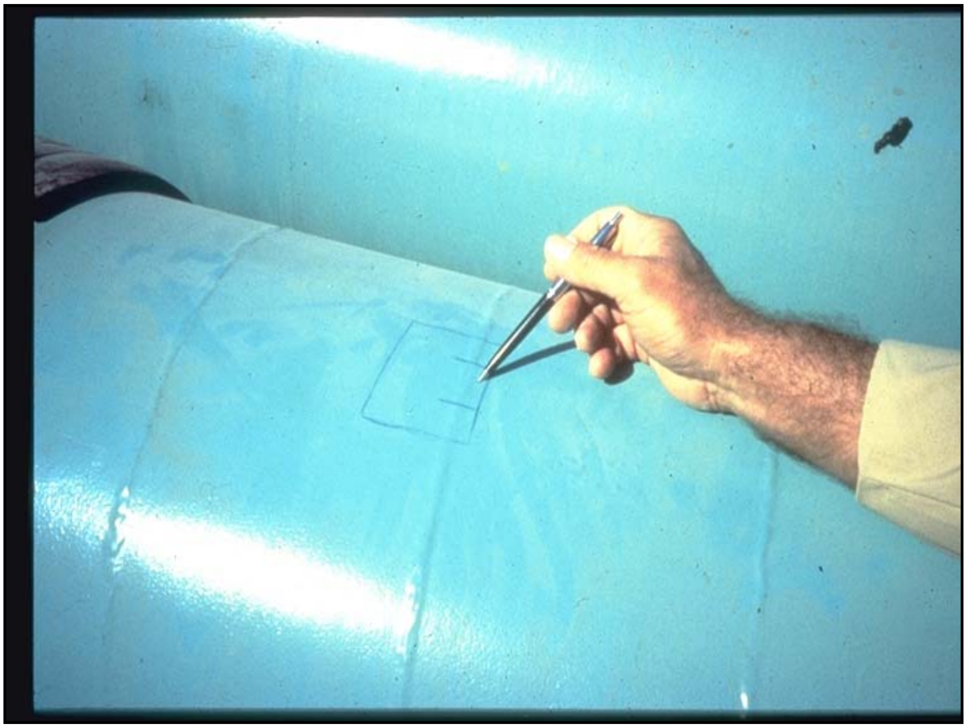

Impingement Concrete Coating
Cement
Iron Ore Aggregate
Sand or Granite Aggregate
H_2O
Batch or Continuous Feed
Asphalt Mastic
OR
Polyethylene
OR
Hot Enamel
OR
Fusion Bonded Epoxy
OR
Polyurethane Insulated
Pug Mill or Materials Transfer
Throw Unit
Mesh or Cage
Curing Spray (or Steam Cure)
To Cure
To Weigh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

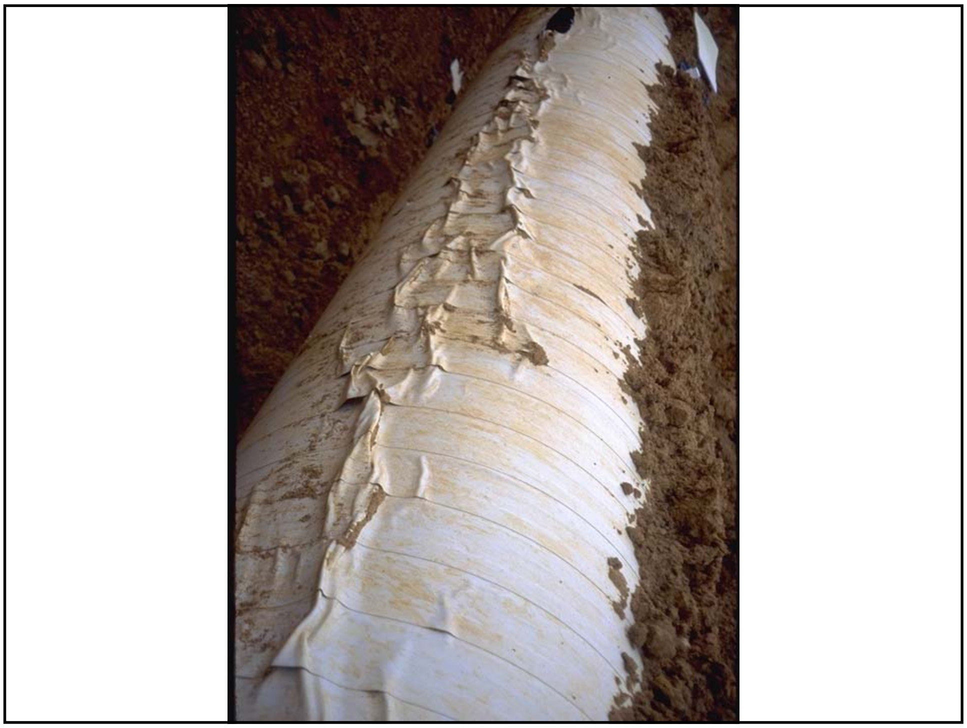



MARTIN DECKER









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.

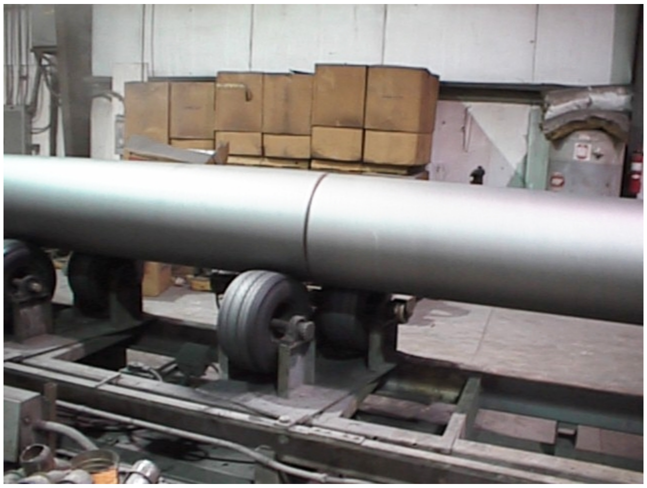
The pipe enters the pre-heat oven where its temperature is raised to approximately 130 degrees. It then enters the abrasive blasting booth.

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

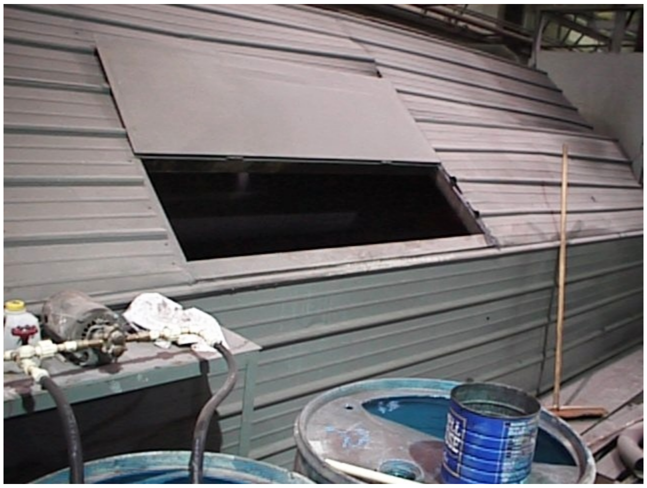
At this stage, the blasted pipe surface is checked for raised slivers, scabs, laminations, or bristles which are removed by file or abrasive sanders. A coupler is then inserted into the end of each joint of pipe.

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.

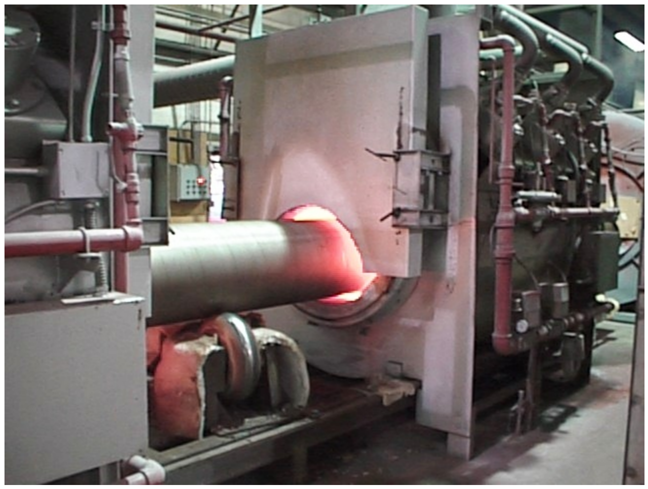


The pipe then enters an acid bath to remove surface contaminants.

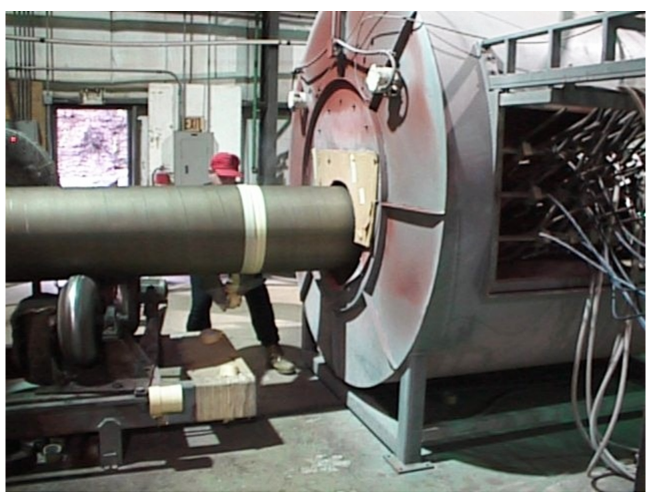


After the acid bath and rinse, the pipe enters a series of ovens that raise the temperature of the pipe to approximately 475 degrees before application of the coating.

Pipe entering last oven before coating.



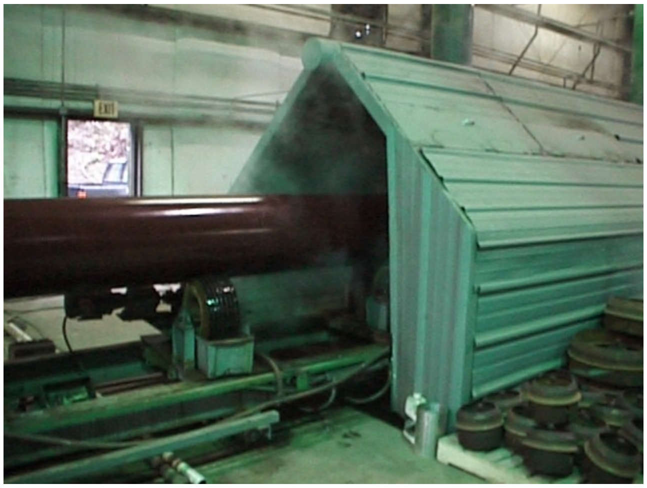
The joint between pipes is covered, so that the ends of each joint are left free of coating. This is done to allow welding in the field.



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

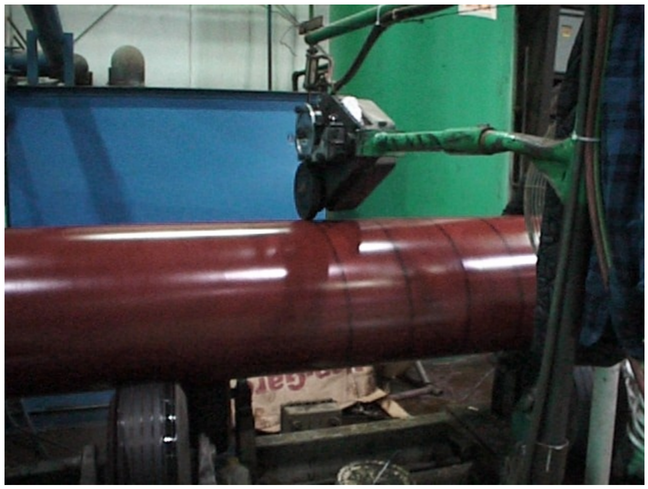
The tape around the joint is now removed and pipe continues to the quenching chamber.

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?

Rectifier Monitoring

Fundamentals Course

Period 7

Instructor: Josh Brewer

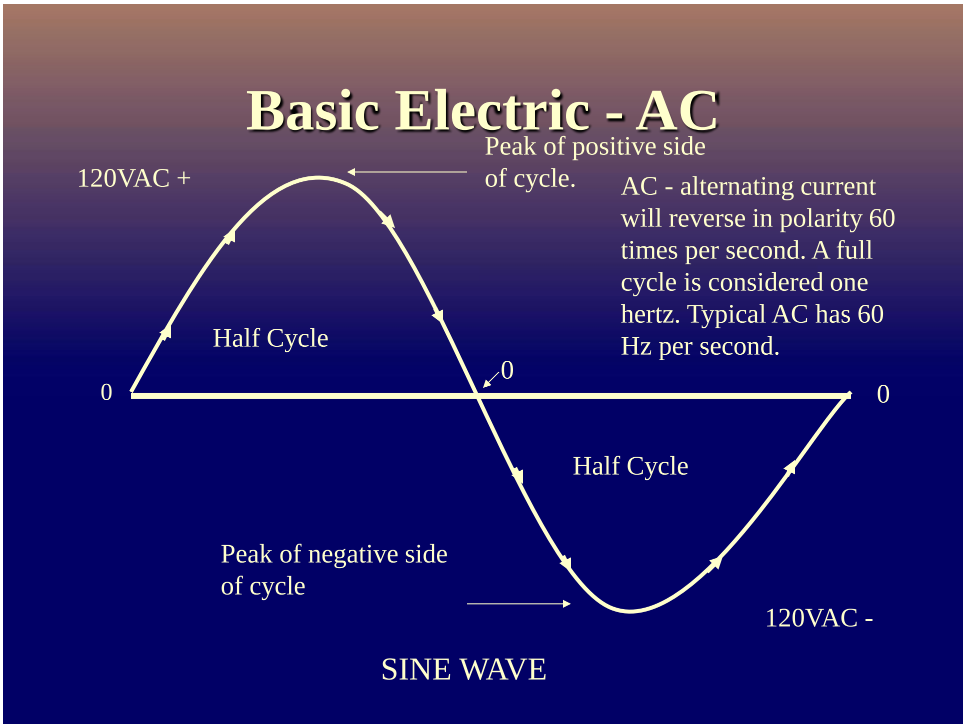
Objective of Presentation

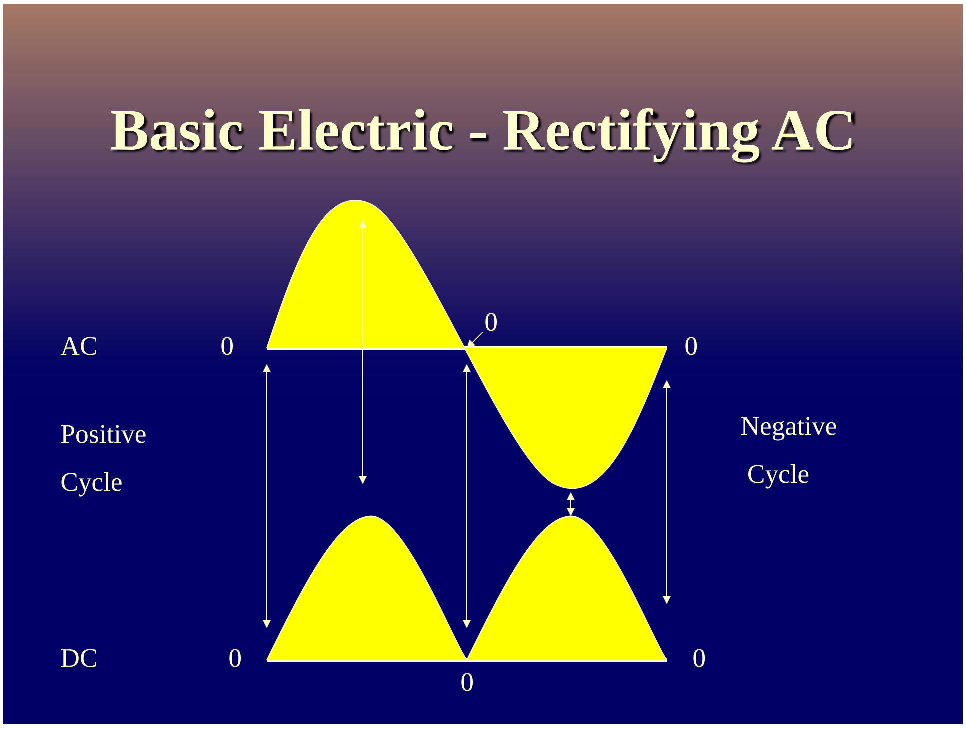
- Familiarize everyone with components of Rectifiers
- Understand workings of components
- Understand the Why, What, How, and When of Rectifier Monitoring

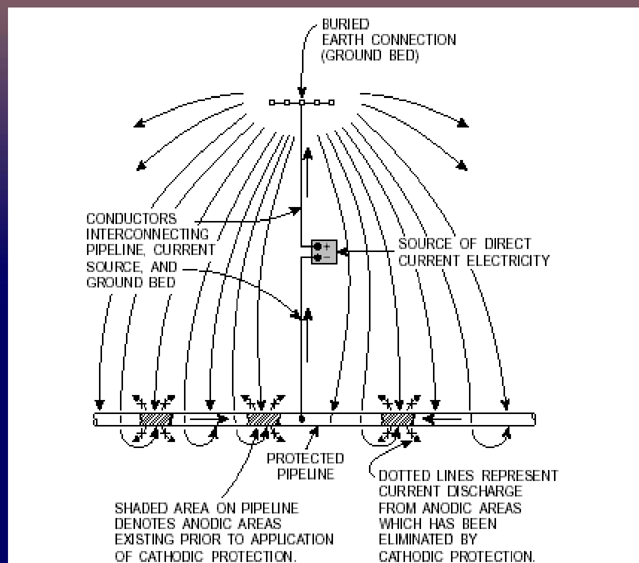
What is a Rectifier ?

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

Samples of Rectifiers

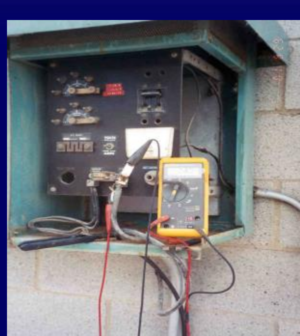

Basic Electric - AC
Peak of positive side
of cycle.
120VAC +
AC - alternating current will reverse in polarity 60 times per second. A full cycle is considered one hertz. Typical AC has 60 Hz per second.
Half Cycle
0
0
0
Half Cycle
Peak of negative side
of cycle
120VAC -
SINE WAVE

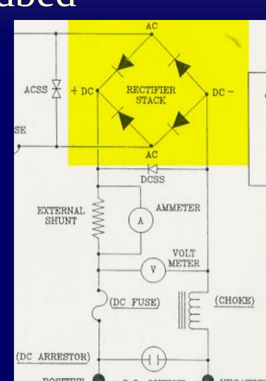

Basic Electric - Rectifying AC
AC
0
0
0
Positive
Cycle
Negative
Cycle
DC
0
0
0



Header Cables

- Negative cable connected to the structure
- Positive cable hooked to the groundbed

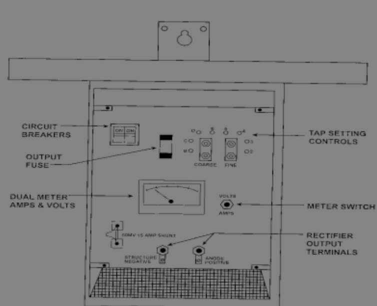




Basic Components of a Rectifier

- Circuit Breaker
- Transformer
- Rectifying Elements
- Accessory Equipment

Standard Rectifier Unit



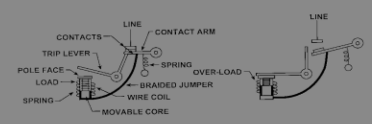
TYPICAL AIR COOLED RECTIFIER

FIGURE 7-17

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

Circuit Breaker

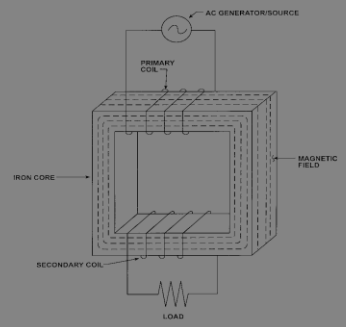
- **Primary Function**
  - provide overload protection for the circuit in which it's installed
  - serves as an on-off switch for the rectifier



FULLY MAGNETIC CIRCUIT BREAKER

FIGURE 7-13

Standard Transformer



TYPICAL TRANSFORMER DIAGRAM

FIGURE 7-14A

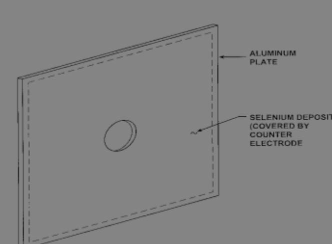
- **Primary Function**
  - used to "step up" or "step down" voltage
  - isolate voltage from source

Rectifying Elements

- Allow 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

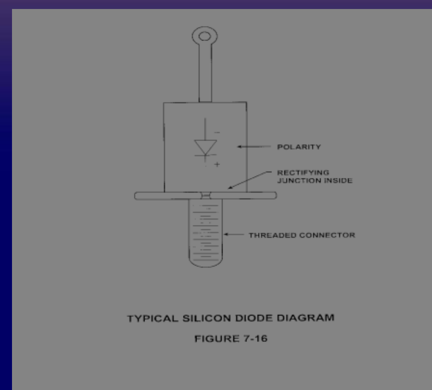


TYPICAL SELENIUM CELL DIAGRAM

FIGURE 7-15

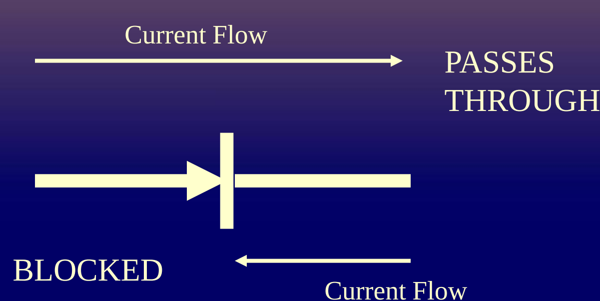
Silicon Diode

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



TYPICAL SILICON DIODE DIAGRAM
FIGURE 7-16

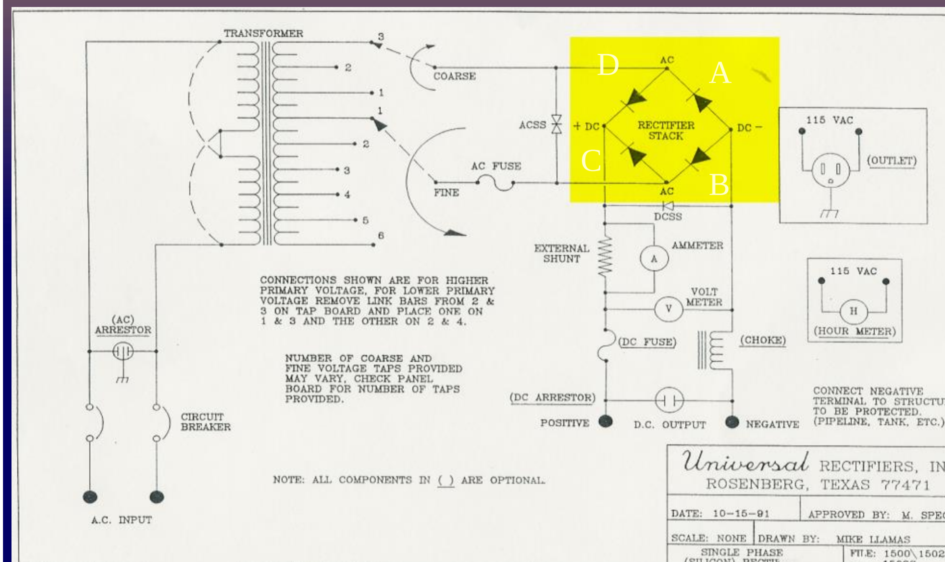
Basic Electric - Diodes



Current Flows one direction.

Used in rectified systems to change AC to DC with a Rectified diode.

Basic Electric - Rectified diode bridge



Basic Electric
Checking the Diode Module

- ➢ **Place your meter on the diode checker**
- ➢ **Disconnect the structure or ground bed cable**
- ➢ **Remove the tabs on the course and fine**
- ➢ **Do the four part test**

Basic Electric Diode Module Check Four Part Test

- Test across the course and the structure terminal
- Test across the fine and the ground bed terminal
- Test across the course and the ground bed terminal
- Test across the fine and the structure terminal
- Reverse all polarities on lead for each test

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

Impressed Current Groundbed

- Cast Iron
- Platinum
- Graphite
- Mixed Metal Oxide
- Coke Breeze

Groundbed Design

- Leave it to the experienced Corrosion Control Engineer
  - Things to consider
    - Right-of-way
    - Soil resistivity
    - Pipe diameter
    - Pipe wall thickness
    - Coating condition and type
    - Proximity to other structures

Review

- What is a rectifier?
- Can you name the major components of a rectifier?
- What are their functions?

Rectifier Monitoring

Department of Transportation
Inspection Requirements

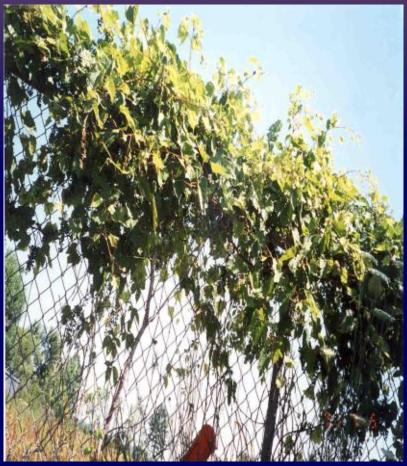
Monitor and Evaluate New and Existing Rectifiers Per CFR-49 Part 192

- Rectifiers inspected 6(six) times per year not to exceed 2.5 months between inspections
- Inspection Includes
  - General Condition of rectifier
  - Recording rectifier DC volts and amps output
- Additional Information
  - readings taken from either rectifier meters OR handheld digital meters
  - record all data and changes made

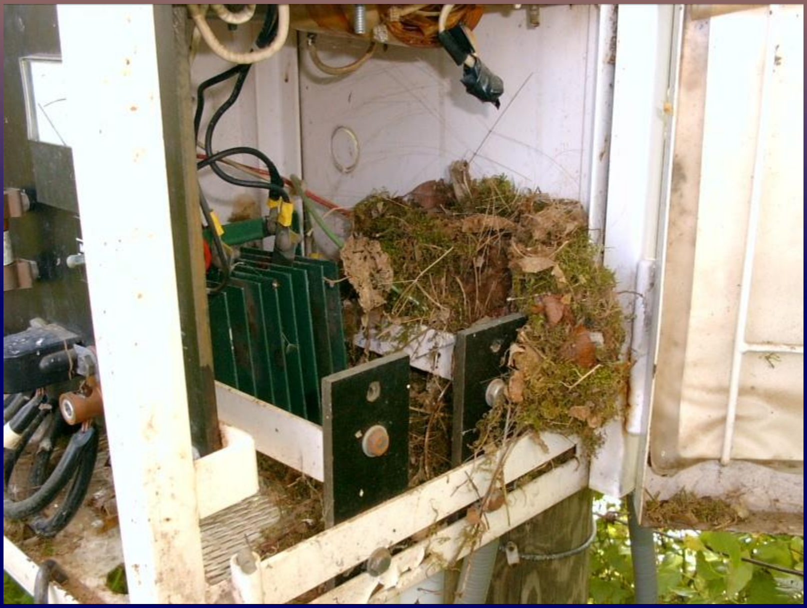
Rectifier Required Inspections

- Importance of Inspections
  - To ensure rectifier unit and ground bed are in good condition

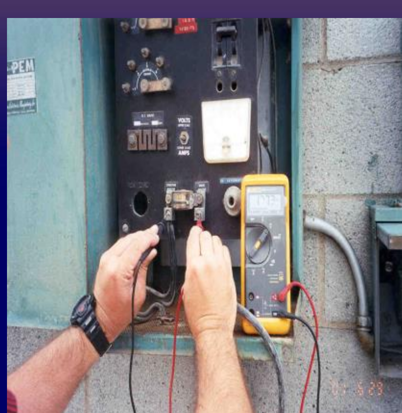
Required Inspections



- Will detect any outside interference problems
- Ensure entire area surrounding rectifier is maintained



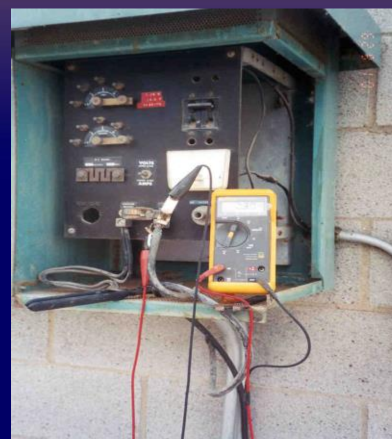
Required Electrical Inspections



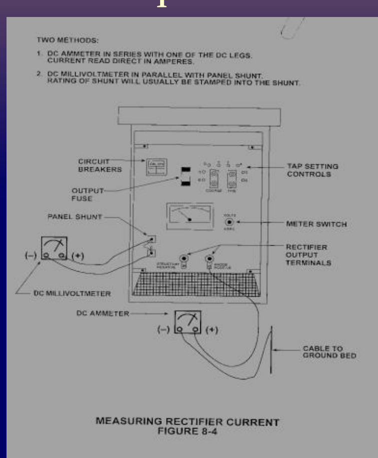
- DC voltage output readings
  - reading DC volts meter on rectifier unit
    - To ensure meter accuracy
  - multimeter is connected in parallel to rectifier output terminals

Required Electrical Inspections

- DC Amperage Output reading obtained by
  - Reading DC amps meter on rectifier unit
  - With mtr. On DC amps setting -connect in series to rectifier output terminals
    - ensure rectifier is turned off then on



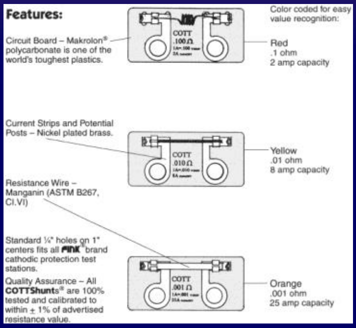
Required Electrical Inspections



MEASURING RECTIFIER CURRENT
FIGURE 8-4

- DC amperage output reading also can be obtained by
  - connecting multimeter in parallel with panel shunt
  - obtain reading and perform calculations

Various types of shunts



Basic Electric - Shunt

- Shunts are resistors; therefore is considered a load.
- Measure voltage across shunt with meter connected in parallel.
- Shunts are used mainly for measuring current flow in a circuit.
  - Rectifiers
  - Bonds

Table 4.2 Shunt Types and Values

	Shunt Rating		Shunt Value	Shunt Factor
	Amps	MV	Ohms	A/mV
Holloway Type				
RS	5	50	.01	.1
SS	25	25	.001	1
SO	50	50	.001	1
SW or CP	1	50	.05	.02
SW or CP	2	50	.025	.04
SW or CP	3	50	.017	.06
SW or CP	4	50	.0125	.08
SW or CP	5	50	.01	.1
SW or CP	10	50	.005	.2
SW	15	50	.0033	.3
SW	20	50	.0025	.4
SW	25	50	.002	.5
SW	30	50	.0017	.6
SW	50	50	.001	1
SW	60	50	.0008	1.2
SW	75	50	.0067	1.5
SW	100	50	.0005	2
J.B. Type				
Agra-Mesa	5	50	.01	.1
Cott or MCM				
Red (MCM)	.1	100	.1	.01
Red (Cott)	.5	50	.1	.01
Yellow	5	50	.01	.1
Orange	25	25	.001	1

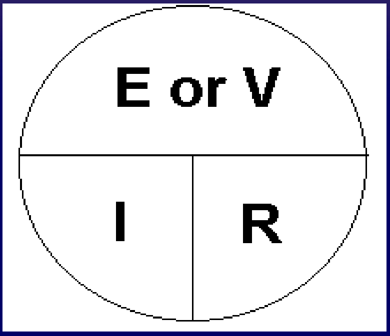
OHM'S Law

- **Mathematically it can be stated three ways:**

(1) I = E/R

(2) R = E/I

(3) E = I x R or E = IR



I = Current in Amperes

E = Voltage in volts

R = Resistance in Ohms

Volt

The volt is the basic unit of electrical pressure which forces an electrical current (electrons) to flow through an electrical circuit.

1000 mV = 1 V

1 mV = 0.001 V

SYMBOL is either V or E

50 mV = 0.05 V	2.5 V = 2,500 mV
250 mV = 0.250 V	10.0 V = 10,000 mV
850 mV = 0.85 V	3.67 V = 3,670 mV

OHM'S Law

- Sample Calculations:

	I	V	R
1.	2	10 V	5 ohms
2.	3A	6	2 ohms
3.	100 mA (.1 A)	10 mV	0.1 ohms
4.	1200 mA	12V	10 ohms

Shunts
Calculation

50 mV - 50 A

Determine Amps/mV

$1 \text{ mV} = \dfrac{50 \text{ A}}{50 \text{ mV}} = \underline{\ 1\ } \text{ A / mV}$

Shunt Resistance $R = \dfrac{E}{I} = \dfrac{0.050 \text{ V}}{50 \text{ A}} = \underline{\ 0.001\ }\ \Omega$

If Measure - 50 mV

$I = \dfrac{V}{R} = \dfrac{50 \text{ mV}}{0.001\ \Omega} = \dfrac{50{,}000 \text{ mV}}{\Omega} = \underline{\ 50\ } \text{ A}$

Additional samples provided at the end of the chapter.

Shunts
Calculation

Determine Shunt Factor (SF)

SF X Measurement (mV) = Amps

50A / 50mV shunt = SF of __1__

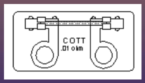
SF __1__ X 4.2 mV = __4.2__ A

50A / 25mV shunt = SF of __0.5__

SF __0.5__ X 4.2 mV = __2.1__ A

Shunts

Calculation



V / R = I

Measurement (V) / R (0.1Ω, 0.01Ω, or 0.001Ω) = I (A)

Measurement of 32.1 mV = .0321 V / 0.1Ω = .321 A

Measurement of 32.1 mV = .0321 V / 0.01Ω = 3.21 A

Measurement of 32.1 mV = .0321 V / 0.001Ω = 32.1 A

Basic Electrical Efficiency Rating Calculation

$$\frac{\text{DC Watts (Output)}}{\text{AC Watts (Input)}} = \text{(answer)} \bullet 100 = \text{Eff. Rating \%}$$

For example,

Measurement of AC current and AC voltage on the inlet of the transformer.

$$\frac{\text{I•E = P (watts) DC Output}}{\text{I•E = P (watts) AC Input}}$$

$$\frac{\text{10amps • 20 Volts = 200 Watts}}{\text{20amps • 30Volts = 600 Watts}} = .33 \bullet 100 = 33\%$$

Review: Rectifier Inspections

- Observe all safety precautions while performing rectifier inspections !
- Check physical condition of rectifier unit and area surrounding rectifier
- Obtain DC voltage reading and record
- Obtain DC amps reading by either method illustrated
- Record accurate readings on appropriate forms

Additional Information - Annual Inspections

- Clean and tighten all connections
- Clean all screens, vents
- Check all meters for accuracy
- Replace damaged wires
- Check all protective devices - fuses, lightning arresters
- Inspect all components for damage
- Clean rectifier unit of dirt, insects,

Questions?

Thanks!

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Cathodic Protection Measurement Basics

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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 ^oF
    - 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

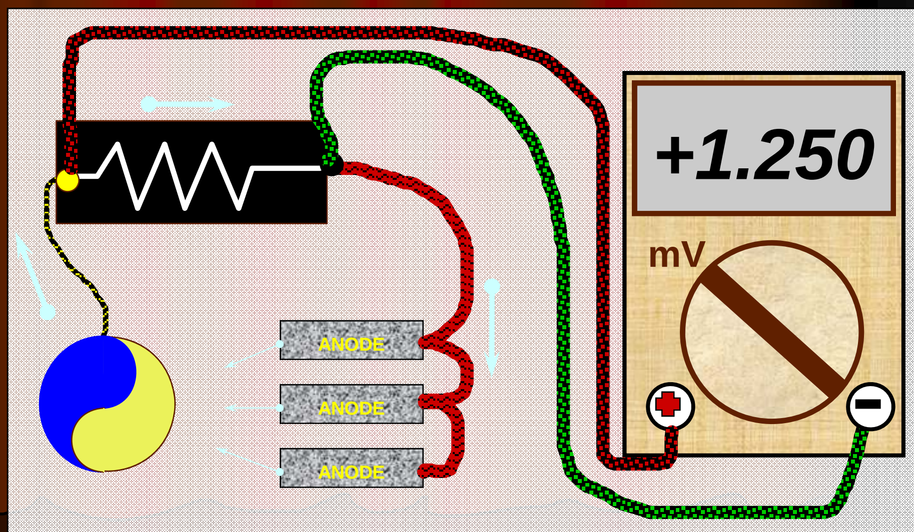
- Shunt Readings Rated in Ohms

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