Corrosion Mitigation Strategies - an Introduction

US Army Corrosion Summit

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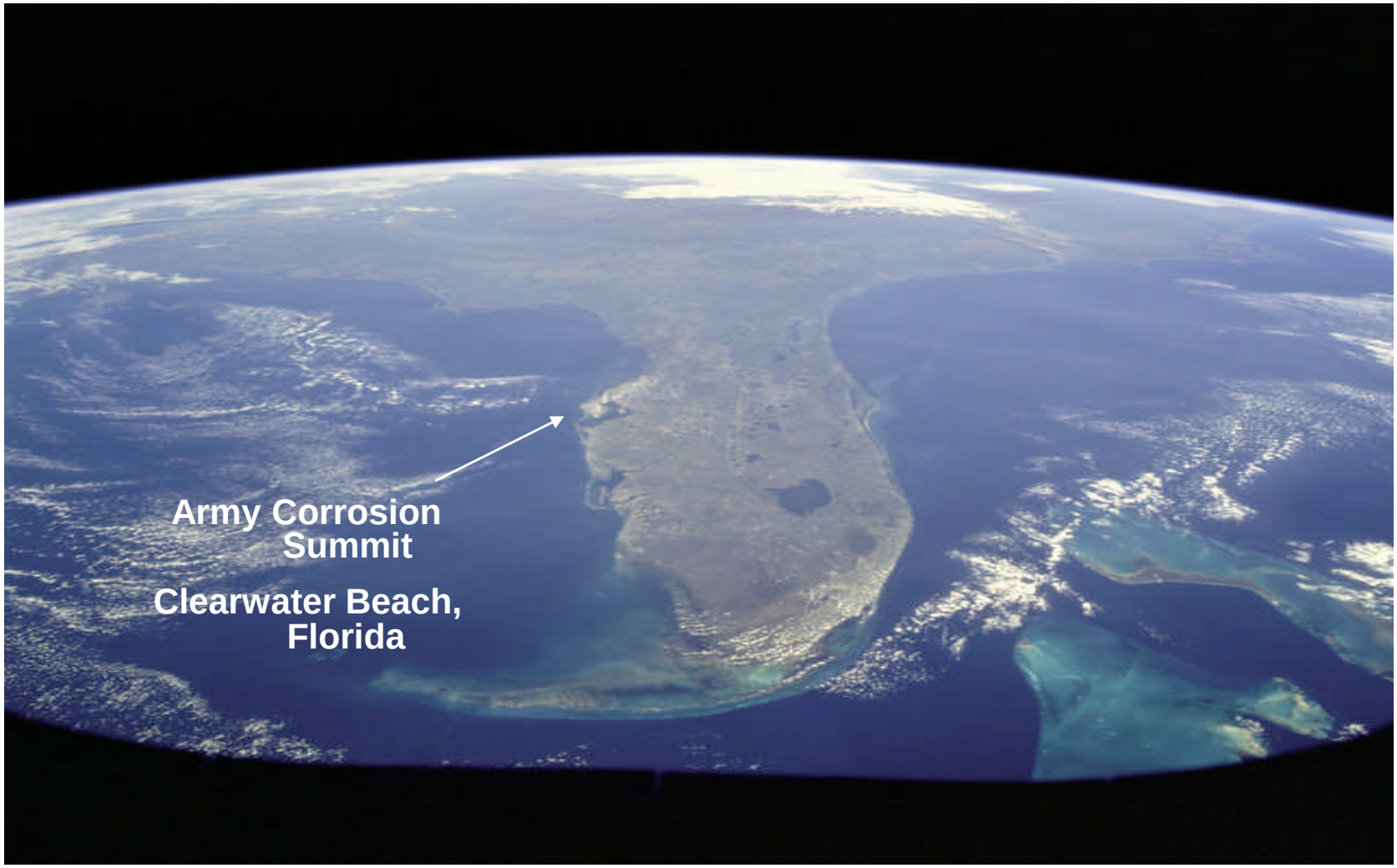
Joe Curran

Where Are We?



Corrosion Mitigation Strategies

- Experience
- Design
- Materials Selection
- Protective Coatings
- Cathodic Protection
- Modification of Environment

Experience

- Similar applications
  - Previous successes
  - Previous failures
- Material performance data
- Selection based on testing
- Corrosion Engineer on the design team

Design

- Materials Selection
- Process Parameters
- Construction Parameters
- Geometry for Drainage
- Dissimilar Metals
- Operating Lifetime
- Maintenance and Inspection
- Crevices
- Corrosion Allowance

Design – Process Parameters

- Temperature
- Velocity
- Pressure
- Chemistry

Design – Temperature

- Direct and indirect effects
  - Rates of diffusion-solubility of gases
  - Affects the surrounding service environment
- Nominal operating
  - Significant effects if varied from normal

Design – Temperature

- Maximum operating/upset
  - Surface deposit formation (heat zones
  - Affects stable protective films
- Minimum operating
  - Condensable gasses deposited on surfaces
- Downtime

Design – Velocity

- Flow rates
  - Fast/slow/stagnant
    - High rates are severe
    - Impingement by entrained solids
    - Availability of corrosion elements
    - Removal of protective films
  - Cavitation

Design – Velocity

- Flow regime
  - System
  - Bi-directional
  - Treatments
  - Methods

Design – Pressure

- Total hydraulic pressure
  - Affects the types of corrosion products formed
  - Stress corrosion cracking
- Overpressure
  - Pressure of a gas over a liquid-solubility of gases in the liquid
- O

Design – Pressure

- Pressure variations
  - Length-pressure drop
  - Reducers
  - Expanders
  - Elbows
  - Power surges
    - Crack protective films, fretting, fatique

Design – Chemistry

- Used to eliminate candidate materials
- pH acidic (H+) basic (OH-) neutral
- Ionic concentrations
  - Major species affect the passive film
  - Minor species in localized attack
- Nature of environment

Design – Construction Parameters

- Shop vs field
- Welding
  - Heat affected zone
- Accommodating for additional corrosion control measures

Methods of Corrosion Control–Design

Dissimilar Metals Considertations

- Potential differences
- Area ratio
- Control by:
  - Compatible materials
  - Area ratio control
  - Insulation
  - Coatings

Methods of Corrosion Control–Design

Corrosion Allowance

- Anticipated lifecycle of asset
- Allow for corrosion to occur
  - Add extra material
  - Uniform attack
  - Linear or decreasing rate

Methods of Corrosion Control–Design

Inspection/Maintenance

- Maintenance manuals
- Ease of access

Methods of Corrosion Control–Materials Selection

- Corrosion resistance in environment
- Availability of data
- Mechanical properties
- Cost
- Availability
- Maintainability
- Compatibility
- Life expectancy
- Reliability
- Appearance

Methods of Corrosion Control–Materials Selection

Environment

- Main constituents
- Impurities
- Temperature
- pH
- Degree of aeration
- Velocity or agitation
- Pressure
- Range of each variable

Methods of Corrosion Control–Materials Selection

Test Data

- Specific service environment
- Actual service - identical service
- Actual service - similar environment
- Laboratory tests
- Published data

Methods of Corrosion Control–Materials Selection

Mechanical Properties

- Strength
- Ductility
- Environmental cracking
  - Hydrogen evolution
  - Stress corrosion cracking
  - Corroson fatigue

Methods of Corrosion Control–Materials Selection

Cost

- Economic analysis
- Fabrication costs
- Other costs
  - Maintenance
  - Repair

Methods of Corrosion Control–Materials Selection

Cost

- Maintenance costs
- Unscheduled shutdowns
- Safety
- Other costs
  - Environmental damagd
  - Product contamination

Methods of Corrosion Control–Materials Selection

Compatibility

- Consider entire system
  - Components can interact
- Galvanic effects
  - Cathodic/anodic ratio
- Metal ion effects
  - Fe/Cu Cu/Al Hg/Al

Methods of Corrosion Control–Materials Selection

Life Expectancy

- Inspection and maintenance guidelines
- Establishing life requirement
- Short life - frequent replacement

Methods of Corrosion Control–Materials Selection

Reliability

- Safety often an issue
  - Accidents, product contamination
  - Corrective corrosion control inappropriate
- Reliability often outweighs cost

Methods of Corrosion Control–Materials Selection

Comparison with Other Methods

- Materials selection important
- Additional methods
  - Coatings
  - Cathodic protection
  - Corrosion inhibitors
  - Combination of methods
- Balance cost and other factors

Methods of Corrosion Control–Materials Selection

Candidate Materials - Metals

- Metallurgy
- Carbon and low-alloy steels
- Stainless steels
- Nickel and nickel-based alloys
- Copper and copper alloys
- Aluminum and aluminum alloys
- Titanium and titanium alloys

Methods of Corrosion Control–Materials Selection

Nonmetals

- Plastics-UV light, heat, solvents
- Composites-environmental attack
- Elastomers-UV, ozone,solvents,oxygen
- Concrete-acids, chlorides, sulfates
- Vitreous Materials-solvents

Methods of Corrosion Control–Protective Coatings

- Corrosion Control
- Waterproofing
- Weather protection
- Biocide
- Fireproofing
- Appearance
- Color coding
- Sanitation/decontamination
- Safety
- Prevent contamination
- Friction reduction
- Wear resistance
- Heat transfer
- Electrical insulation
- Sound deadening

Methods of Corrosion Control –Protective Coatings

- Organic coatings
  - Barrier
  - Inhibitive pigments
  - Cathodic protection

Methods of Corrosion Control –Protective Coatings

- Chemical resistance
- Low permeability
- Easy to apply
- Adhesion
- Cohesive strength
- Tensile strength
- Flexibility/ elongation
- Impact resistance
- Abrasion resistance
- Temperature resistance
  Cold flow resistance
- Dielectric strength
- Cathodic disbondment resistance

Methods of Corrosion Control–Protective Coatings

Selection

- Type of exposure
- Operating/upset conditions
- Substrate
- Application conditions
- Environmental regulations
- Cost
- Application - operation/ shutdown
- Time constraints
- New construction/ maintenance
- Shop/field application
- Design/fabrication

Methods of Corrosion Control –Protective Coatings

Design Defects

- Inaccessible areas
- Fasteners
- Gaps
- Angles
- Threaded areas
- Dissimilar metals

Methods of Corrosion Control –Protective Coatings

Fabrication Defects

- Imperfect welds
- Weld splatter
- Skip welds
- Rough welds
- Laminations
- Gouges
- Sharp corners

Coating Failures

What causes the majority of coating failures?

Poor Surface Preparation

- Rust
- Mill scale
- Anchor pattern
- Residues
  - Oil/grease/soil
  - Chemicals
- Ridges/burrs/sharp edges
- Moisture
- Old Coatings

Surface Preparation – Standards

- NACE
- ISO
- SSPC

Methods of Corrosion Control –Protective Coatings

Coating Application

- Manual
  - Brush
  - Roller
  - Palming
- Spray
  - Conventional air
  - Airless
  - Electrostatic
  - Thermal spray

Methods of Corrosion Control

Coating Application

- Production Techniques
  - Hot dipping
  - Fluidized bed
  - Powder spray

Methods of Corrosion Control

Protective Coating - Inspection

- Surface preparation
  - Cleanliness
  - Anchor profile
- During application
  - Verify conditions
  - Application technique
  - Wet film thickness
- Post application
  - Dry film thickness
  - Adhesion
  - Holidays

Methods of Corrosion Control–Protective Coatings

- Wraps and tapes
- Insulation
- Metallic coatings
  - Coating anodic to base metal
  - Coating cathodic to base metal

Methods of Corrosion Control–Protective Coatings

- External Pipeline Coatings
  - Fusion Bonded Epoxy (FBE)
  - Extruded thermoplastic
  - Coal Tar Enamel
  - Tape
  - Concrete (Weight) Coating

Methods of Corrosion Control – Electrochemical Techniques

- Make metal to be protected act as a cathode
- Application of electrical current
- From corroding anode (galvanic)
- From external power source (impressed)

Methods of Corrosion Control – Cathodic Protection–Galvanic

- Anode requirements
  - Potential
  - Long Life
  - Efficiency
- Aluminum
- Magnesium
- Zinc
  - Fresh water vs salt water

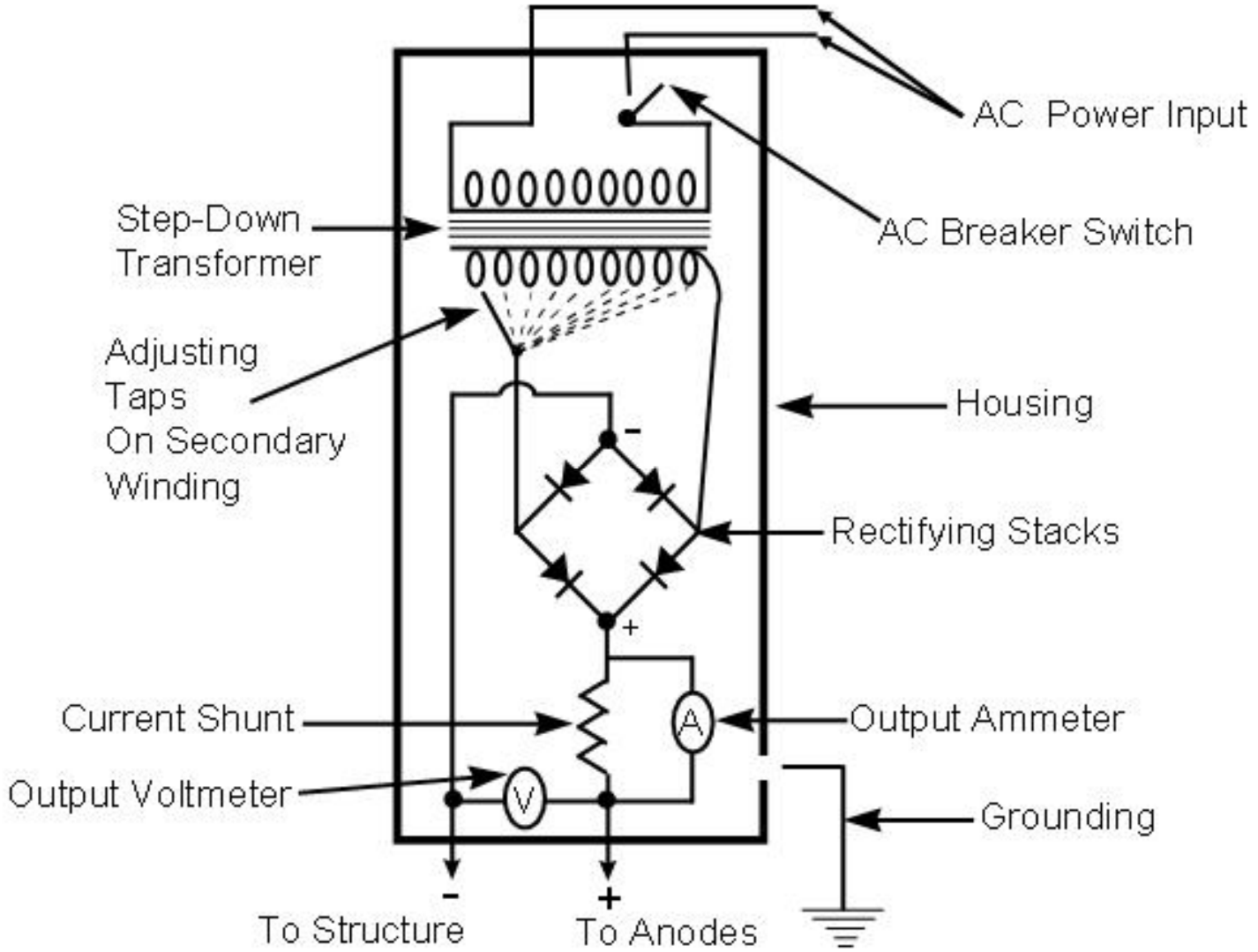
Methods of Corrosion Control – Cathodic Protection–Impressed

- External current source
- Ground bed required
  - Anode consumption not required
  - Inert (low consumption rate) anodes

Methods of Corrosion Control – Cathodic Protection–Impressed

- ***Caution! -*** *Positive terminal of rectifier always connected to ground bed*
- Anodes
  - Scrap iron
  - Silicon cast iron
  - Graphite
  - Magnetite
  - Lead-silver
  - Platinum

Transformer-Rectifier Schematic



Methods of Corrosion Control – Cathodic Protection–Impressed

- ***Caution! -*** *Positive terminal of rectifier always connected to ground bed*
- Power sources
  - Rectifiers
  - Solar cells
  - Generators
  - Wind
  - Thermoelectric

Methods of Corrosion Control – Cathodic Protection–Measurement

- Structure- to-electrolyte potential
  - Reference electrode
- Test coupons
- Potential change

Methods of Corrosion Control – Cathodic Protection–Design

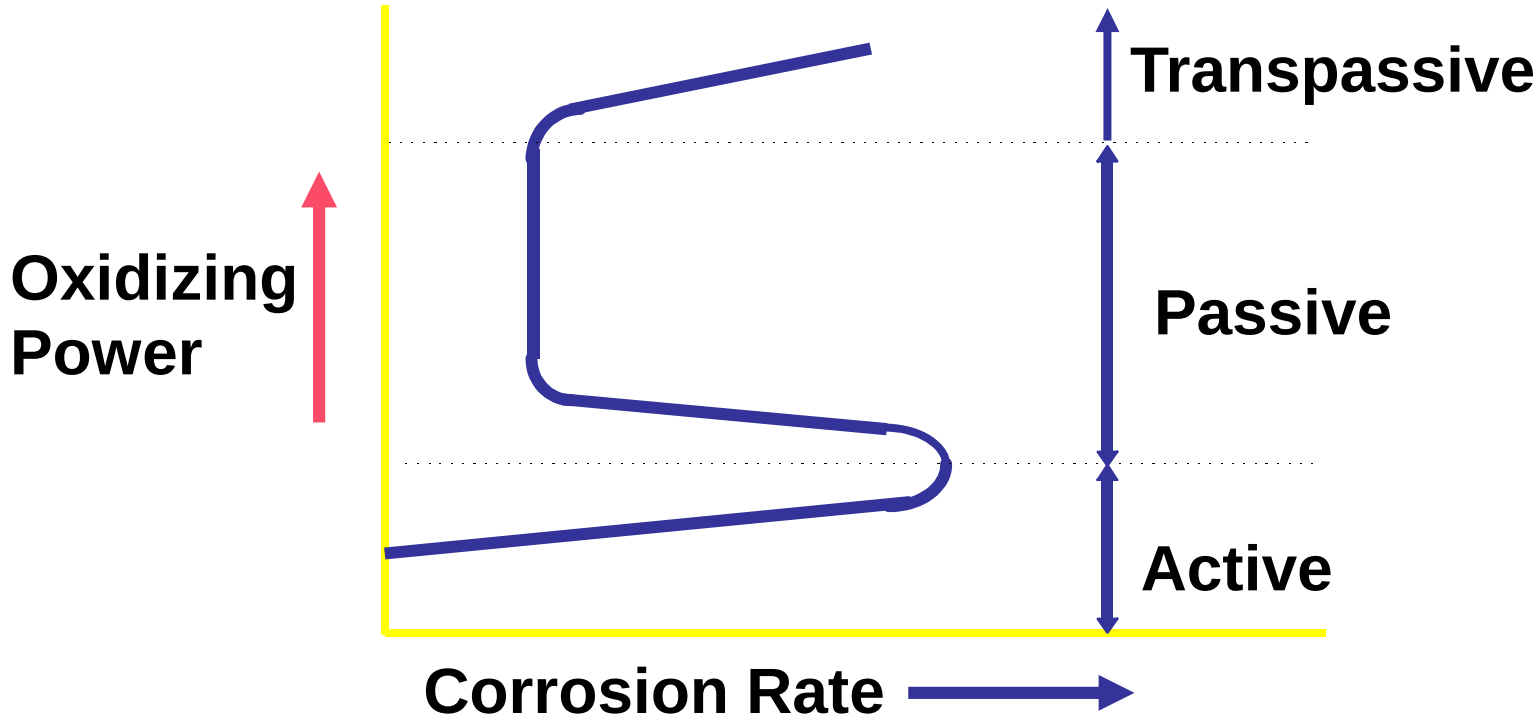
- Regulations
- Anode backfill
- Coatings
- Shielding
- Economics
- Life

Wire & cable
Temperature
Current Environment
Stray currents
Metal

Methods of Corrosion Control – Cathodic Protection–Maintenance

- Galvanic
  - Anode consumption/replacement
  - Wire damage
- Impressed current
  - Power source
  - Ground bed connection

Methods of Corrosion Control – Anodic Protection



Methods of Corrosion Control – Modification of Environment

- Augment inherent corrosion resistance
  - Corrosion inhibitors
  - Deaeration
  - pH control

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors

- Film Formation
  - Adsorption
  - Bulky precipitates
  - Passive films

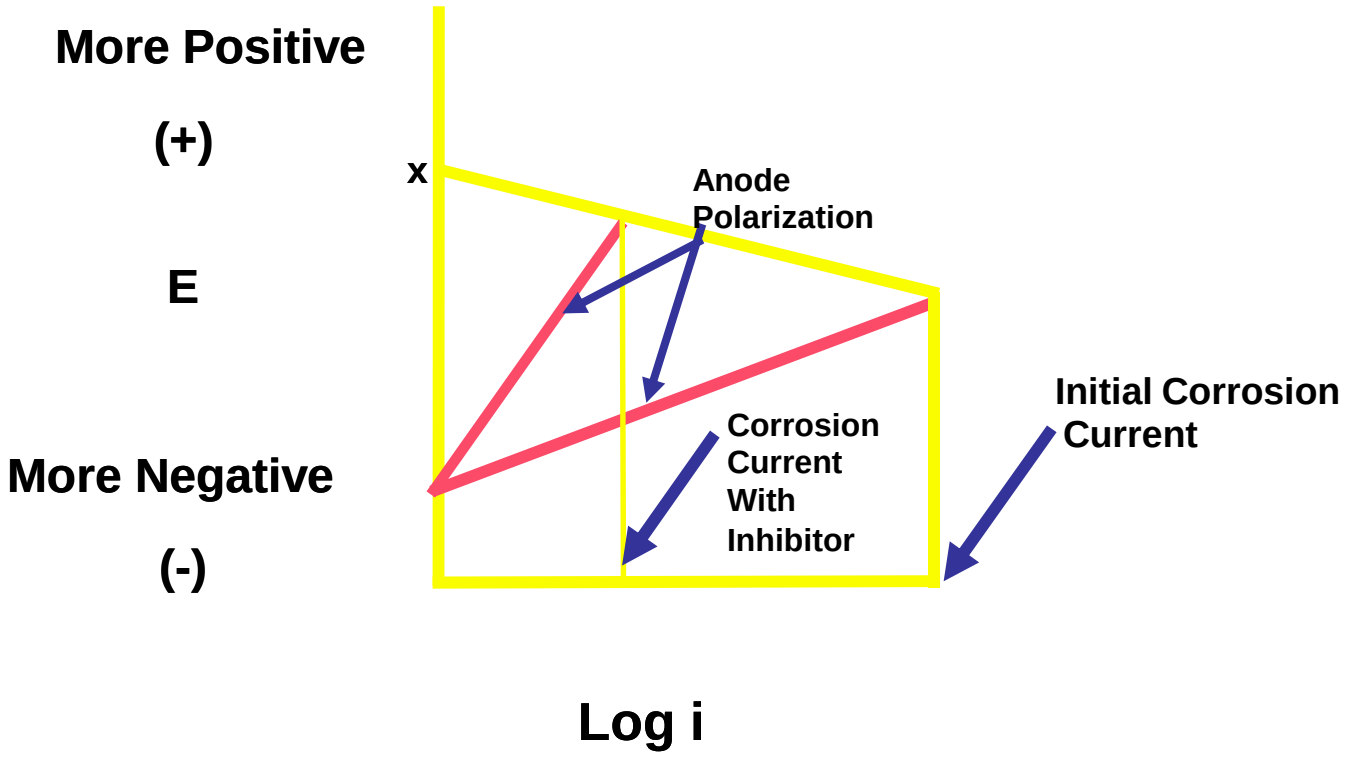
Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors

- Types of Inhibitors
  - Passive (anodic)
  - Cathodic
  - Ohmic
  - Precipitation-inducing
  - Vapor phase

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Anodic)



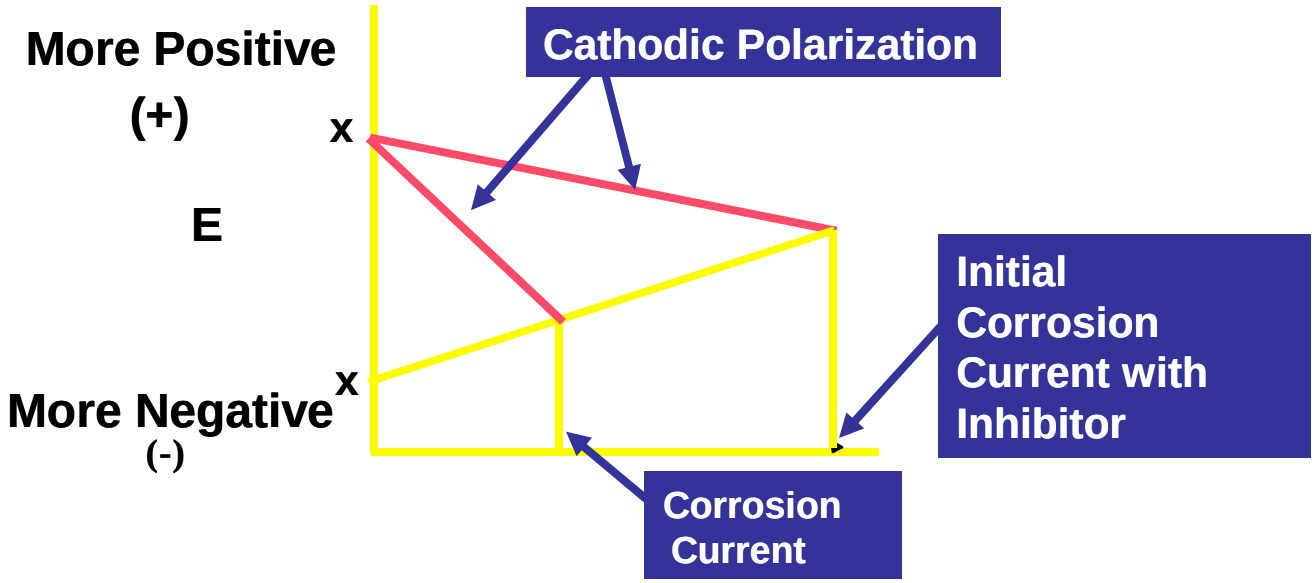
Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Anodic)

- Can cause accelerated local attack if used in insufficient amounts
- Oxidizing
- Non-oxidizing

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Cathodic)



Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Cathodic)

- Cathodic poisons
  - Inhibit cathodic reactions
  - Inhibit hydrogen formation/ evolution
  - Hydrogen damage
- Cathodic precipitates
  - Increased pH at cathode

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Ohmic

- Increase resistance
- Resistive film
  - Anodic areas
  - Cathodic areas
  - Entire surface

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Organic

- Can film entire surface
- Cationic (+)
- Anionic (–)

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Precipitation

- Film-forming compounds
- Can film entire surface
- May act as anodic inhibitors
  - With oxygen
  - Local attack if insufficient amount

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Vapor Phase

- Closed systems
- Volatile solids
- Volatile liquids
- Alkaline films
- Hydrophobic films
- May accelerate attack of some metals

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Aqueous liquid systems
- Affected by environment
  - Oxygen
  - Temperature
  - Sulfate
  - Metal cations
  - Hydroxyl ions
  - Chloride
  - Bicarbonate
  - Hydrogen ions

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Nonaqueous liquid systems
  - Fuels
  - Lubricants
  - Edible oils
- Water content
- Acids

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Gaseous environments
- Open atmosphere
- Vapor phase in tanks
- Natural gas production
- Packaging containers

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application Techniques

- Continuous injection
- Batch treatment
- Squeeze treatment
- Coatings

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Safety

- Handling
- Disposal

Corrosion Inhibitors - Heat Transfer

Methods of Corrosion Control – Modification of Environment

Water Treatment

- Physical
  - Removal of solids
  - Removal of liquids
  - Removal of gasses
- Chemical
  - Softening
  - pH adjustment
  - Demineralization
  - Desalination
  - Oxygen scavenging

Methods of Corrosion Control –Summary

- Design
- Materials Selection
- Protective Coatings
- Cathodic Protection
- Modification of Environment