Corrosion Mitigation Strategies - an Introduction

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Joe Curran
**Corrosion Mitigation Strategies - an Introduction**

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**ABSTRACT**

**SUBJECT TERMS**

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**LIMITATION OF ABSTRACT**

Same as Report (SAR)

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71

**NAME OF RESPONSIBLE PERSON**
Where Are We?

Army Corrosion Summit
Clearwater Beach, Florida
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

Leaders in Corrosion Control Technology
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, fatigue
**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 Considerations

• 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
  • Corrosion fatigue

Leaders in Corrosion Control Technology
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 damage
  - 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

Leaders in Corrosion Control Technology
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

Leaders in Corrosion Control Technology
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

- AC Power Input
- AC Breaker Switch
- Housing
- Rectifying Stacks
- Current Shunt
- Output Voltmeter
- Output Ammeter
- Grounding
- To Structure
- To Anodes
- Step-Down Transformer
- Adjusting Taps On Secondary Winding

Leaders in Corrosion Control Technology
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

Oxidizing Power

Corrosion Rate

Transpassive

Passive

Active

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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)

More Positive
(+)

More Negative
(–)

Anode Polarization

Corrosion Current With Inhibitor

Initial Corrosion Current

Log i
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)

More Positive (+)  More Negative (-)

Cathodic Polarization

Initial Corrosion Current with Inhibitor

Corrosion Current

Log i

Leaders in Corrosion Control Technology
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 (−)
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

Leaders in Corrosion Control Technology
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
  - Hydrogen ions
  - Temperature
  - Sulfate
  - Metal cations
  - Hydroxyl ions
  - Chloride
  - Bicarbonate

Leaders in Corrosion Control Technology
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