The Hidden Enemy: Corrosion under Insulation

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Material Selection Resources Inc.

- Material Selection For All Components
- Failure Analysis- Metals and Plastics
- Electrochemical and Immersion Corrosion Testing
- Educational Training
- Inspection Services
A Pipe Dream: A World Without CORROSION

CUI: An In-Depth Analysis

Types of Insulation for Refrigeration Applications
Corrosion Under Insulation

Background

- Affects carbon steel and SS equipment in the operating range of –4°C to 150°C
- Wet insulation is the root cause
- CUI rate depends on temperature and internal/external containment sources.

• Highly unpredictable and difficult to detect
• One of the top causes of equipment leaks and near misses
• Maintenance costs are significant
SHELL DEER PARK REFINING

CUI Near Miss
January 15, 2002

Shell Deer Park Refining

- The fifth largest refinery in the US.
- Processes 340,000 barrels/day of crude oil.
- 1,000 Shell employees and 400+ contractors
- Located in Deer Park, Texas just outside Houston.
- Joint venture between Shell and Pemex – operated by Shell.

CUI Near Miss

- Corrosion Under Insulation (CUI) Inspection revealed thin spots on 240 psig – six-inch propane line in the Sats Gas Plant.
- Some spots down to 0.025 inches of metal from 0.280 inches.
- Line in service for 30 years.

CUI Near Miss – Potential Consequences

- Leak would have depressured the entire light hydrocarbon contents of the Sats Gas Depropanizer column generating a significant propane vapor release through a 1 inch fish-mouth opening.
CUI Near Miss

- Emergency Operations Center activated and staffed for 32 hours until line secured.
- Emergency response equipment staged in case of leak to minimize consequences.
- Hydrocracker and Catalytic Reformer shut down to depressurize system.
- Other units slowed down in anticipation of emergency shutdown.

- Non-essential personnel notified not to report for work in an abundance of caution.
- By-pass line installed to minimize pressure on the line for installation of engineered clamp.
- X-ray examination of line did not indicate any additional corrosion issues.
CUI Leak Data Analysis (Exxon Data)

- 84% of all CUI leaks are in piping
- 81% of piping CUI is on pipe < 4 inches NPS

Pipe wall thickness is key to failure frequency
- The 16-20 year population is mainly < 4” NPS/low WT pipe
- The over 25 year population is mainly > 6’ NPS/heavy WT
Maintenance Costs Today

- Fixed equipment is the largest cost item
- Fixed Equipment issues are longer-term so it is difficult to justify improvements unless the focus includes life cycle costs.
- 35 cents of every maintenance dollar is spent on fixed equipment
Fixed Equipment Maintenance Costs Today

- Piping accounts for 55% of Fixed Equipment maintenance costs or about 20 cents of every maintenance dollar.

- CUI accounts for 40-60% of piping costs or about 10 cents of every maintenance dollar.
CUI of Carbon Steel

- CUI Corrosion of carbon steel is by a non-uniform general corrosion or highly localized pitting mechanism.
- The corrosion of carbon steel is principally controlled by the metal temperature of the steel surface, availability of oxygen and the presence of corrosive contaminant species in the water.
CUI - Where to Inspect

- Areas exposed to mist overspray from cooling towers
- Areas exposed to steam vents.
- Areas exposed to deluge systems
- Areas subject to process spills, ingress of moisture, or acid vapors
- Carbon steel systems, operating between -5°C and 175°C. External corrosion is particularly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture.
- Systems with deteriorated coating and/or wrappings.
- Cold service equipment consistently operating below the atmospheric dew point
Specific Locations

**Penetrations**
- All penetrations or breaches in the insulation jacketing system, such as dead legs, hangers and other supports, valves and fittings, bolted-on-pipe shoes, ladders and platforms.
- Steam tracer-tubing penetrations
- Termination of insulation at flanges and other components.

**Damaged Insulation areas**
- Damaged or missing insulation jacketing
- Termination of insulation in a vertical pipe or piece of equipment
- Caulking that has hardened, has separated, or missing
- Bulges, staining of the jacketing system
- Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs
- Carbon or low alloy steel flanges, bolting and other components under insulation in high alloy piping.
Examples of Severe CUI Corrosion of Carbon Steel In One Refinery
Corrosion Under Insulation of 300 Series Stainless Steel

- CUI of stainless steels is in the form of chloride stress corrosion cracking.
- Requirements are:
  - Presence of residual or applied surface tensile stresses
  - Presence of chlorides, bromides and fluorides ions may also be involved.
  - Metal temperature in the range 50°C to 150°C
  - The presence of an electrolyte (water)
CUI- External Stress Corrosion Cracking

304 SS 4 inch sch. 40 pipe. The piping system was insulated with calcium silicate insulation and operated at temperatures 50 –100 °C.

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Chloride Stress Corrosion Cracking

Section of pipe under insulation

Section of pipe with no insulation
Corrosion Under Insulation

- CUI of stainless steels is possible under all types of insulating materials.

- CUI may be mitigated by careful selection BUT careful design AND inspection AND maintenance is also necessary.
Corrosion Under Insulation

● **Role of Insulation Materials**
  – Provide annular space for retention of water and corrosive species
  – Materials that may wick or absorb water
  – Materials that may contribute corrosive contaminants

● **Design**
  – The more breaks in the insulation the more water will likely infiltrate the insulation.
Corrosion Under Insulation

- Water source:
  - Infiltration from external source e.g. rainfall, steam discharge, process liquid spills, washdowns, etc
  - Condensations – when metal temperature is less than atmospheric dew point
- CUI in stainless steels occurs in the temperature range from 50-150 deg C, but metal temperatures vary.
Corrosion Under Insulation

- Metal temperature has competing effect:
  - Dries out insulation/reduces “wet” time
  - Concentrates contaminants by evaporation
  - Increases corrosion rate and reduces life of coating, mastics, sealers.

- Role of contaminants
  - Increases corrosiveness/conductivity
Chloride Sources

- Insulation Materials
  - Insulation. Mastics, sealant, adhesives etc
  - Leachable chlorides

- External (main source of chlorides)
  - Rainfall
  - Cooling tower drift
  - Process liquid spills
  - Fire and deluge systems
Conventional CUI Prevention

- Completely seal the insulation to prevent moisture ingress. This option is not very practical for many operating plants.
- The use of inhibited insulation. This option has been claimed to have some success, however CISCC can still occur.
- Replacement of piping system with higher alloyed materials such as Duplex 2101. This option is effective, but is very costly.
- Application of physical barrier, such as epoxy or silicone coatings. This is effective if a holiday free surface is obtained, however the application and cost of the coating is expensive.
Inspection Free and Maintenance Free Philosophy

- For an insulation system to be considered reliable the maintenance cost and inspection costs should be eliminated.
- This is done by using life cycle cost analysis and the use of good CUI prevention tools.
New CUI Prevention Strategy

- Thermal Spray Aluminum Coating (TSA) of carbon steel (especially 4 inches and above).
- High performance coating of carbon steel
- Replace personnel protection insulation with wire cages
- Stainless steel for small diameter pipe instead of carbon steel
- Electrochemical protection using aluminum foil as a sacrificial anode in a galvanic reaction. This option is over five times cheaper than the use of high performance coating systems.

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What is Thermal Spray?

- Thermal spray is NOT a welding process
- Thermal spray coatings are a melted, or softened ceramic, metallic, or polymer materials are transported by a gas stream to a properly prepared substrate
How thermally sprayed coatings of Al, and their alloys combat corrosion

- Anodic (TSA) metal coatings applied to steel cathodes (more noble than Al), are referred to as cathodic or sacrificial protection coating systems.

- These thermal spray coatings provide corrosion protection by excluding the environment (or electrolyte) and acting as a barrier coating (like paints, polymers, and epoxies), but unlike typical barrier coatings they also provide sacrificial anodic protection.
# TSA vs Conventional Paint Systems

<table>
<thead>
<tr>
<th>Feature</th>
<th>TSA</th>
<th>Conventional Paint</th>
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</thead>
<tbody>
<tr>
<td>Corrosion Protection</td>
<td>34+ years based on documented tests</td>
<td>5 - 15 years maximum depending on environment</td>
</tr>
<tr>
<td>Upper Continuous Use Temperature Limit</td>
<td>900°F to 1000°F</td>
<td>300°F to 350°F</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Resistant to solvents, but narrow pH range (not resistant to acids)</td>
<td>Wide pH range, but not resistant to solvents</td>
</tr>
<tr>
<td>Cure Time Between Coats</td>
<td>None</td>
<td>Approximately 24 hours</td>
</tr>
<tr>
<td>Mechanical Durability</td>
<td>Excellent, very resistant to mechanical abuse</td>
<td>Very susceptible to mechanical abuse</td>
</tr>
<tr>
<td>Application Method</td>
<td>Arc and flame spray</td>
<td>Spray, brush and roller</td>
</tr>
<tr>
<td>Work Permit Req'd</td>
<td>Hot work</td>
<td>Cold work, but may restrict hot work in area</td>
</tr>
</tbody>
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3. Results are based on proper surface preparation.
4. Assumes no sealer coating applied over the metal coating.
Electrochemical Protection Using Aluminum Foil

- All insulation specification require austenitic stainless steel operating continuously between 60 and 150C be wrapped in 46 swg 0.1 mm aluminum foil.
- 30 years of experience of using this system in UK
- The foil is sacrificial
- The system relies on good weatherproofing and preventing immersion conditions.
- No failures have occurred where there has been proper application of the system.
Practical Application of Aluminum Foil

- **Vessels**
  - Aluminum applied in bands
  - Held by insulation sprags and insulation support rings

- **Pipes**
  - Wrapped with 50 mm overlap, formed to shed water on vertical lines. Hold with Al or SS wire
  - Foil is molded around flanges and fittings
  - Steam traced lines are double wrapped
Types of Insulations - Cellular

- Cellular Glass
- Elastomeric
- Polystyrene - Expanded and Extruded
- Polisocyanurate
- Polyurethane - sprayed and poured
- Phenolic
- Melamine
- Polyethylene and polyolefin
- Polyimide
Types of Insulations- Fibrous

- Fiberglass- Fiberglass wool and Textile Glass
- Mineral Wool
- High- Temperature Fiber
Types of Insulations- Granular

- Calcium Silicate
- Molded Expanded Perlite
- Microporous Insulation
- Silica Aerogels
- Poured-In-Place Insulation
Insulation Properties
Important to reduce CUI

- Low permeability
- Protection against water intrusion and retention
- Thermal expansion properties should be similar to carbon steel and stainless steel to reduce seal breakage.
- Consistent thermal properties- avoid products whose insulation value change with age, this can lead to dew point issues and therefore CUI
- Product should be benign – no acidic species leaching
Water Extract Data for Various Insulations

- Foamed plastics, pH 2-3
- Mineral wool, pH 6-7
- Calcium silicate, pH 9-11
- Cementitious fireproofing, pH 12-12.5
- Cellular Glass, pH 8-10
What We Have Observed

- Cellular glass very popular in the chemical industry and is considered a high performance insulation.
- Expanded perlite is good but not as available.
- Mineral wool and calcium silicate not used very much. Europe uses mineral wool.
NDT Techniques for Detecting CUI

- Visual Inspection
- Dye Penetrant testing
- Ultrasonic Thickness Measurement
- Flash radiography
- Guided wave Ultrasonic
- Profile radiography
- Real-Time Radiography
- Pulsed Eddy Current
- Digital radiography
- Infrared
- Neutron Backscatter
<table>
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<th>NDT TECHNIQUE</th>
<th>LIMITATIONS</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
<td>Require removal of insulation.</td>
<td>It is possible to quantify the areas of corrosion.</td>
<td>It is impossible to measure remaining wall thickness.</td>
</tr>
<tr>
<td>Dye Penetrant Testing</td>
<td>Require removal of insulation.</td>
<td>It gives all indications for pitting or SCC.</td>
<td>Only for SS.</td>
</tr>
<tr>
<td>Ultrasonic Thickness Measurement</td>
<td>Require removal of insulation.</td>
<td>It gives remaining wall thickness.</td>
<td>It needs surface grinding or brushing.</td>
</tr>
<tr>
<td>Flash Radiography</td>
<td>Setup requires at least 1½ days. It is utilized up to 1m in diameter. This technique does not detect SCC in stainless steels.</td>
<td>Film processing generally takes about 15 minutes and do not need to remove insulation.</td>
<td>Contrast and resolution are not as good as that for conventional radiography. It can also be difficult to separate images from multiple exposures.</td>
</tr>
<tr>
<td>Guided Wave Ultrasonic</td>
<td>This system does not detect localised corrosion and it gives percent wall thickness loss. Only for piping systems. This technique does not detect SCC in stainless steels.</td>
<td>The probe ring is applied at large intervals of pipe (about 6m) and the measurement itself is a matter of minutes the total inspection time. Can be applied in operation.</td>
<td>Needs to remove insulation where must be applied the probe ring (about 200 mm.) It is utilized only for pipeline. It is not used for vessel or tanks.</td>
</tr>
<tr>
<td>Profile Radiography</td>
<td>This technique does not detect SCC in stainless steels.</td>
<td>It gives remaining wall thickness without to remove insulation. Can be applied in operation.</td>
<td>Only for pipe wall in small sections. The exposure source is usually Iridium 192. Cobalt 60 is used for pipes of heavier wall, but the weight is about 250kg. Care must be taken for</td>
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<tr>
<td>Method</td>
<td>Limitations</td>
<td>Benefits</td>
<td>Notes</td>
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<tr>
<td>Real-Time Radiography</td>
<td>This technique does not detect SCC in stainless steels.</td>
<td>It is a fast and reliable survey method without removing insulation. Gamma-ray gives remaining wall thickness. Can be applied in operation.</td>
<td>X-ray gives only the profile of outside pipe. The gamma-ray camera needs cautions for radiation safety. It gives only the video images or recorded using a standard VCR for evaluation later.</td>
</tr>
<tr>
<td>Pulsed Eddy Current</td>
<td>This system does not detect localised corrosion. This technique does not detect SCC in stainless steels.</td>
<td>Does not need to make contact with the surface. Scaffolding can be reduced by using rope access or by attaching the measuring sensor to a straight pole. Can be applied in operation.</td>
<td>It is utilised for ferrous pipe, vessel or tanks.</td>
</tr>
<tr>
<td>Digital Radiography</td>
<td>This technique does not detect SCC in stainless steels.</td>
<td>It gives all digital thickness of pipe and scale without requiring insulation removal. Can be used to relate material type with corrosion rate data. Data and reports may be stored in a single place. Can be applied in operation.</td>
<td>Scaffolding needs when is utilized Co 60 for heavy thickness, because has a heavy weight (about 250kg).</td>
</tr>
<tr>
<td>Infrared</td>
<td>This system does not detect CUI.</td>
<td>It provides temperature information to detect the presence of moisture or water in insulation. Can be applied in operation.</td>
<td>Must be utilized another NDT system to verify CUI.</td>
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</tbody>
</table>
PROPOSED REAFFIRMATION OF NACE STANDARD RP0198-98


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Sent to TCC RPC for Review—December 2003

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Mechanical Insulation Design Guide

by the National Mechanical Insulation Committee (NMIC)

Last updated: 12-27-2007

The National Institute of Building Sciences (NIBS) through the National Mechanical Insulation Committee (NMIC) has developed the Mechanical Insulation Design Guide (MIDG) to provide a comprehensive source of information on the performance, use, testing and standardization of mechanical insulation in buildings and industrial facilities.

The MIDG is continually being improved and updated. Any edits, revisions, updates or interest in adding new information should be directed through the 'Comment' link on this page. Disclaimer

Introduction

- Introduction
- Background
  - National Mechanical Insulation Committee
  - National Mechanical Insulation Committee (NMIC) Objective
  - Mechanical Insulation Market Definitions
- Scope of the Design Guide
  - Using the Mechanical Insulation Design Guide
- Example Design Problems
  - Example 1
  - Example 2
Every Corrosion Problem is an Opportunity