Corrosion Under Insulation

Understanding Issues Surrounding Corrosion Under Insulation

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Fall Summit
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Corrosion Under Insulation

CUI is a recent branch of corrosion control
Developed in the 1980’s and early 1990’s
Primarily in Petrochemical and Refining
Response to ban of lead, chromium, asbestos
Changes in piping, vessel and tank design
Development of better CUI coatings

Summarized from
Three-day
NACE New Orleans Section
CUI Mitigation Course
Corrosion Under Insulation

What’s Really Under There?
The Challenge:

A typical major refinery or chemical plant may contain a thousand insulated vessels and tanks and a thousand miles of insulated or coated and wrapped pipe.

Current corrosion condition (CUI), inspection intervals, scheduled maintenance and record keeping may vary widely.

Current maintenance budgeting is rarely enough to keep up with corrosion failures, much less to get ahead.

Current specifications and new construction practices do not always provide long-term assurance.
The Reality:

Jacketed and Insulated Equipment in a well-run refinery or chemical plant with an active RBI (Risk Based Inspection) program is inspected once every 3 years or less often, based on the severity rating of the vessel or pipe run.

The 3-year inspection is typically 99% (area) exterior visual and about 1% full removal and observation of the substrate.

CUI Coatings, insulation and jacketing are typically replaced on an 8-15 year cycle for liquid applied coatings and on a 15 to 30 year cycle for Thermal Spray Aluminum (TSA).
This is how Insulated and Jacketed Equipment Should Always Look
Corrosion Under Insulation

And this is what we see in real life.
Corrosion Under Insulation

Major perforations caused by CUI
Like a good sandwich, All the parts of a CUI System Must be compatible and effective

(1.) Red – Stored or Carried Product
(2.) White – Product-Compatible Lining
(3.) Black -- Vessel or Pipe wall
(4.) Gray – CUI Coating
(5.) Yellow – Insulation
(6.) Gray – External jacketing
Corrosion Under Insulation

The CUI Cycle (1.)

Sheet metal Jacketing
Insulation
Pipe or vessel steel wall

Carried or Stored Hot, Cold or Cycling Temperature Product
During rain, dew or fog or whenever water is present, when the stored/carried product temperature is low and rain, dew or fog occur, or water from some other source is on the outside of the jacketing, over extended time periods (years), water may penetrate the jacketing, displace air in the insulation, and may eventually reach the substrate.
Corrosion Under Insulation
The CUI Cycle (3.)

When carried/stored product temperature rises, it heats the vessel or pipe wall and water trapped in the insulation boils, steams away from the hot steel and travels through the insulation toward the jacketing, where it condenses, but is still trapped beneath the jacketing.
When the temperature is lower again, water in the insulation migrates back toward the substrate and corrosion can occur if there is not a good corrosion resistant CUI coating.
Water gets under jacketing

Most water cannot escape

Water accumulates under jacketing

Substrate stays wet
Eventually causing corrosion

The CUI Cycle
Typically 8 to 10 years before Repair/Replacement
Corrosion Under Insulation
The CUI Cycle (5.)

- Stored Product
- Insulation (wet toward bottom)
- Substrate (lining on inside, CUI coating on outside)
- Corrosion Under Insulation
- Internal Corrosion
Both Documents stress a “systems” approach
2.1.3 Relevant guidelines & standards for the industrial/mechanical insulation industry in North America

In North America there are no regulations or codes governing the design and installation of industrial/mechanical insulation. Best practices is generally adopted following a variety of different standards & guidelines published by bodies such as ASTM, NACE, MICA & PIP. Many ownership groups in North America have developed their own internal standards and guidelines which are used throughout various projects. The intention of the PIP guidelines is to consolidate these internal standards from ownership groups to create a uniform approach.

The commonly referred to standards and guidelines in North America include:
- ASTM C1696
- NACE SP0198
- MICA National Commercial & Industrial Insulation Standards

Before Publication of API RP 583
API 583 defines three generic types of insulation most commonly used in oil refineries and petrochemical plants:

- Granular
- Fibrous
- Cellular

Major Generic types of Insulation listed in NACE SP 0198-2010,

<table>
<thead>
<tr>
<th>NACE SP 0198 Listing</th>
<th>Type</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Par. 5.2.1 Pg. 27</td>
<td>Calcium Silicate</td>
<td>ASTM C533</td>
</tr>
<tr>
<td>Par. 5.2.2 Pg. 27</td>
<td>Expanded Perlite</td>
<td>ASTM C510</td>
</tr>
<tr>
<td>Par. 5.2.3 Pg. 28</td>
<td>Mineral Fiber/Wool</td>
<td>Various ASTM</td>
</tr>
<tr>
<td>Par. 5.2.4 Pg. 28</td>
<td>Cellular Glass</td>
<td>ASTM C552</td>
</tr>
<tr>
<td>Par. 5.2.5 Pg. 28-29</td>
<td>Organic Foams</td>
<td>Various ASTM</td>
</tr>
<tr>
<td>Not Listed</td>
<td>Aerogel Blanket</td>
<td></td>
</tr>
<tr>
<td>Not Listed</td>
<td>Spray-On Acrylic</td>
<td></td>
</tr>
<tr>
<td>Not Listed</td>
<td>Epoxy Syntactic Foam</td>
<td></td>
</tr>
</tbody>
</table>
API RP583 chart of insulation types:

**Table 6  Commonly Used Insulation Materials**

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Low Temperature Range</th>
<th>High Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°F</td>
<td>°C</td>
</tr>
<tr>
<td>Calcium silicate</td>
<td>0</td>
<td>-18</td>
</tr>
<tr>
<td>Expanded perlite</td>
<td>600</td>
<td>315</td>
</tr>
<tr>
<td>Cellular glass</td>
<td>-450</td>
<td>-260</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>Fiberglass</td>
<td>-20</td>
<td>-30</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>-350</td>
<td>-210</td>
</tr>
<tr>
<td>Polyisocyanate foam</td>
<td>-290</td>
<td>-180</td>
</tr>
<tr>
<td>Elastomeric foam</td>
<td>-70</td>
<td>-55</td>
</tr>
<tr>
<td>Polystyrene foam</td>
<td>-60</td>
<td>-50</td>
</tr>
<tr>
<td>Phenolic foam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica Aerogel</td>
<td>-460</td>
<td>-270</td>
</tr>
</tbody>
</table>
CALCIUM SILICATE (Granular)

Quoted direct from API RP 583:

Advantages:
- Low thermal conductivity
- Usable to 1000°F (538°C) cont./1200°F (650°C) intm.
- Available in a variety of shapes/sizes/thicknesses

Disadvantages:
- Can absorb and retain water
- Has pH of 9-10 when exposed to water
- Care needed to avoid breakage during installation
EXPANDED PERLITE  (Granular)

Quoted direct from API RP 583:

Advantages:
- Water resistant up to 400°F (205°C)
- Good resistance to mechanical damage
- Available in a variety of shapes/sizes up to NPS 24

Disadvantages:
- More fragile than calcium silicate during installation
- Higher thermal conductivity than calcium silicate
CELLULAR GLASS (cellular)

Quoted direct from API RP 583:

Advantages:
- Does not absorb water
- High resistance to mechanical damage when jacketed
- Thermal conductivity does not deteriorate with aging

Disadvantages
- Fragile as glass
- Thermal shock at temp. gradient $>300^\circ F (>150^\circ C)$
- Abrades in vibrating service, fragile before application

(Not from API RP 583)
- Low permeability and absorption make cellular glass an ideal system for cold and cryogenic service.
MINERAL WOOL (fibrous)

Quoted direct from API RP 583:

Advantages:
- Used in hot applications up to 1200°F (650°C)
- Lower conductivity than calcium silicate and perlite
- Low leachable chloride content (< 5ppm)

Disadvantages:
- Readily permeable to vapors and liquids.
- Subject to mechanical damage
- Low compressive strength and lack of resiliency
MINERAL WOOL (fibrous)

Not from API RP 583:

Most widely used insulation type in Petro CUI (and elsewhere)
Available from multiple manufacturers/vendors
Quality and performance may vary by manufacturer and grade
Binder used can affect performance characteristics
“Water Resistant” grades are available
Specifiers don’t always specify required level of quality
Contractors buy the cheapest generic equal
MINERAL WOOL
DONE WRONG AT AN ASIAN PLASTICS PLANT

Stainless Steel Vessel under insulation with Carbon Steel parts welded directly to it; mineral wool insulation (the only thing done right!) Two-sides galvanized sheet metal jacketing with large cutouts at penetrations allowing water to enter = instant electrolytic cell

Jacketing had been painted Aluminum to hide the rust
SILICA AEROGEL BATTs

Quoted direct from API RP 583:

Silica Aerogel is synthetically produced amorphous silica gel, distinctly different from crystalline silica.

Aerogel is impregnated into a non-woven flexible fabric substrate (batts or blankets) for reinforcement.
Quoted direct from API RP 583:

Advantages
- Highest thermal performance of any insulating material known
- Significantly reduced thickness for equivalent performance
- Wide range of temperature applications

Disadvantages
- Aerogels are typically hygroscopic (absorb water from air)
- Aerogels need chemical treatment to be hydrophobic
- Typically higher material cost
  (easier installation/better performance justify extra cost)
Corrosion Under Insulation

Crushed jacketing =
Crushed Insulation =
Water ingress =
Wet Insulation =
Loss of Efficiency
Wet Insulation
(Regardless of what kind or what original, dry k value)

Doesn’t Insulate.

Wet insulation is also a primary cause of CUI.
The importance of the chart above is that even in a sales presentation, the “best” insulation absorbs almost 100% of its weight in water in only 20 days exposure.
Corrosion Under Insulation
CUI Coatings

API RP 583 Makes no CUI Coating Recommendations
Refers all coatings decisions to NACE SP-0198-2010

NACE SP-0198-2010 rates CUI coatings
(1.) By Temperature Tolerance
(2.) By use on Stainless and/or Carbon Steel

CUI mitigation has emphasized “better” CUI coatings rather than preventing water ingress and wet insulation.
A primary cause of corrosion under insulation is water ingress through the jacketing, into the insulation and to the substrate.

*Note that we used Club Soda, which contains chemicals, just like the water that gets under jacketing.
# Corrosion Under Insulation

NACE SP 0198-2010 Recommended CUI Coating Systems

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Build Epoxy (SS) (CS)</td>
<td>-50 to 140°F</td>
</tr>
<tr>
<td>Fusion Bond Epoxy (CS)</td>
<td>-50 to 140°F</td>
</tr>
<tr>
<td>Phenolic Epoxy (SS) (CS)</td>
<td>-50 to 300°F</td>
</tr>
<tr>
<td>Novolac Epoxy (SS) (CS)</td>
<td>-50 to 400°F</td>
</tr>
<tr>
<td>Silicone Hybrid (CS)</td>
<td>-50 to 400°F</td>
</tr>
<tr>
<td>Thin Film Silicone (SS)</td>
<td>-50 to 1000°F</td>
</tr>
<tr>
<td>Polysiloxane Hybrid (SS) (CS)</td>
<td>-50 to 1200°F</td>
</tr>
<tr>
<td>Thermal Spray Aluminum (SS) (CS)</td>
<td>-50 to 1100°F</td>
</tr>
<tr>
<td>Aluminum Foil Wrap (SS)</td>
<td>-50 to 1000°F</td>
</tr>
<tr>
<td>Wax Tape Wrap (CS)</td>
<td>140°F Maximum</td>
</tr>
</tbody>
</table>
# Corrosion Under Insulation

## Typical Application Times for Liquid Applied Coatings:

<table>
<thead>
<tr>
<th>Coat</th>
<th>Activity</th>
<th>1st Coat</th>
<th>2nd Coat</th>
<th>Spot Repair Low Film Thickness (if needed)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>apply</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>3 days</td>
</tr>
<tr>
<td></td>
<td>drying time</td>
<td>8-12 hours</td>
<td>8-12 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>inspection</td>
<td>1 hour</td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>apply</td>
<td>1 hour</td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>drying time</td>
<td>8-12 hours</td>
<td>8-12 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>inspection</td>
<td>1 hour</td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**2016**
See “Joint Standard, NACE No. 12/AWS C2.23M/SSPC-CS 23.00 Specification for the Application of Thermal Spray Coatings (Metallizing) Of Aluminum, Zinc, and Their Alloys And Composites for the Corrosion Protection of Steel”
Corrosion Under Insulation

Typical Application Time for Thermal Spray Aluminum:

- Single Coat: apply
  - drying time: 1 hour
  - inspection: Near Zero
  - repair any low DFT: 2 hours

Total: Half Day
Time savings versus liquid coatings: 2 ½ days

Thermal Spray Aluminum (TSA) costs more to apply and inspect than liquid coatings but time savings during application and longer service life make TSA extremely competitive for new construction as well as for field maintenance.
The corrosion engineer for the tower on the right estimated every day out of service cost the owner $1,000,000 in lost production. Use of TSA for the CUI coating provided seven-figure cost savings.
Both API RP 583 and NACE SP0198-2010 spend a lot of space discussing jacketing, specifically aluminum or stainless steel sheet metal jacketing. API RP 583 gives new construction structural design recommendations to minimize water ingress. NACE SP0198-2010 includes numerous diagrams of metal jacketing where water ingress is expected.

Both documents assume water ingress is inevitable.
Corrosion Under Insulation Jacketing

Count the seams in the Metal Jacketing.

After 8 to 12 years service with no maintenance and inspection every 3 years
there will be numerous gaps and leaks
Corrosion Under Insulation
Nonmetallic Jacketing

Jacketing doesn’t need to be shiny (or metal) to be good.
NACE SP 0198-201 and API RP 583 both assume metal (Aluminum or Stainless Steel) Jacketing as “standard.” Some overseas facilities use 2 sides galvanized jacketing.

Sheet Metal jacketing is pieced together from hundreds (?) thousands ?) of pieces of sheet metal with joints between each piece.

Joints are supposed to be caulked and leakproof. Sheet metal jacketing is assumed to be damage resistant. It isn’t.
Corrosion Under Insulation

Nonmetallic Jacketing

FRP (Fiberglass Reinforced Plastic) jacketing:

Supplied as a preformed sheet in boxed 1 m x 10 m rolls
Sandwiched between two nonadhesive plastic sheets
Cut and installed at jobsite
Self-curing (sunlight or UV light)
No heat or catalyst is used
Self-adhesive at laps and joints
Forms a monolithic jacket
Cures to 1.5 – 2.0 mm thickness
No caulking of joints required
Can be double-layered at areas of expected damage
Corrosion Under Insulation
Nonmetallic Jacketing

<table>
<thead>
<tr>
<th>Product properties</th>
<th>Performance</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Gray</td>
<td>-</td>
</tr>
<tr>
<td>Handling / Application temperature</td>
<td>min. 5°C - max. 45°C</td>
<td>-</td>
</tr>
<tr>
<td>Service temperature</td>
<td>max. 90°C</td>
<td>-</td>
</tr>
<tr>
<td>Emissions (styrene)</td>
<td>&lt; 20 ppm (MAC-value 25 ppm), safety data sheet upon request</td>
<td>-</td>
</tr>
<tr>
<td>Flashpoint (non-cured)</td>
<td>125°C</td>
<td>-</td>
</tr>
<tr>
<td>Reaction to fire</td>
<td>C-s1, d0 round</td>
<td>EN 13501-1</td>
</tr>
<tr>
<td></td>
<td>C-s2, d0 flat</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>1.8 g/cm³</td>
<td>ISO 1183</td>
</tr>
<tr>
<td>Thickness (after curing)</td>
<td>1.5mm - 2.0 mm</td>
<td>-</td>
</tr>
<tr>
<td>Linear expansion coefficient</td>
<td>$25 \times 10^{-6}$ K$^{-1}$</td>
<td>ISO 11359-2</td>
</tr>
<tr>
<td>Hardness</td>
<td>45 Barcol</td>
<td>ASTM D2583</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>50 MPa</td>
<td>EN ISO 527-4</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>9 GPa</td>
<td>EN ISO 527-4</td>
</tr>
<tr>
<td>Tensile elongation at break</td>
<td>1.0%</td>
<td>EN ISO 527-4</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>150 MPa</td>
<td>EN ISO 14124</td>
</tr>
<tr>
<td>Water vapour permeability</td>
<td>0.001 g/m².h.mmHg</td>
<td>ASTM E96</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>available upon request</td>
<td>-</td>
</tr>
<tr>
<td>Compliance</td>
<td>conforms to CINI 3.2.11 “Weather resistant UV-curing fiberglass reinforced polyester (GRP)”</td>
<td>-</td>
</tr>
</tbody>
</table>

There are few US standards for nonmetallic (FRP) jacketing, since Petrochemical/Industrial CUI jacketing is assumed to be sheet metal.
Major Oil, Chemical and Petrochemical Company coating system specifications currently Rate CUI Liquid Applied Coating Systems as 8 to 15 years Service Life.

The same companies’ specs rate CUI Thermal Spray Aluminum as high as 30 years Service Life.

Several specs require no intermediate inspections for CUI Thermal Spray Aluminum.

Can you trust anything for 30 years without looking at it occasionally?
Corrosion Under Insulation
Risk-Based Inspection Program

Hazard—Something that has potential to cause harm

Risk—Likelihood of a specified undesired event occurring within a specified time period or resulting from specified circumstances

Safety Critical Elements—What needs to be protected

Mitigation—Measures to prevent the hazard occurring

ALARP—As Low As Reasonably Practicable
## Risk Assessment Matrix

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>PEOPLE</th>
<th>ASSETS</th>
<th>ENVIRONMENT</th>
<th>REPUTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No injury or health effect</td>
<td>No damage</td>
<td>No effect</td>
<td>No impact</td>
</tr>
<tr>
<td>1</td>
<td>Slight injury or health effect</td>
<td>Slight damage</td>
<td>Slight effect</td>
<td>Slight impact</td>
</tr>
<tr>
<td>2</td>
<td>Minor injury or health effect</td>
<td>Minor damage</td>
<td>Minor effect</td>
<td>Minor impact</td>
</tr>
<tr>
<td>3</td>
<td>Major injury or health effect</td>
<td>Moderate damage</td>
<td>Moderate effect</td>
<td>Moderate impact</td>
</tr>
<tr>
<td>4</td>
<td>PTD or up to 3 fatalities</td>
<td>Major damage</td>
<td>Major effect</td>
<td>Major impact</td>
</tr>
<tr>
<td>5</td>
<td>More than 3 fatalities</td>
<td>Massive damage</td>
<td>Massive effect</td>
<td>Massive impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INCREASING LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
</tr>
<tr>
<td>Never heard of in the industry</td>
</tr>
</tbody>
</table>

Raising the Standard

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2016
Corrosion Under Insulation
Risk-Based Inspection Program

Plant Survey to evaluate relative risk of units or sections
Units or sections are assigned severity levels
Rating is by management and operators

Regular spot inspections are scheduled
Inspected points are highest-risk units or sections
If problems are found, additional inspection is done
Lower risk areas are surveyed based on condition of high-risk units or sections

Maintenance funding is allocated based on inspection
Maintenance is scheduled to lower event risk
(High risk units with problems receive priority)
Inspection frequency is adjusted based on findings
Corrosion Under Insulation
Risk-Based Inspection Program

Typical Properly Done RBI Inspection Spot.
Spots are designated for severity
Annual inspection rotates severest spots
Each spot is visualized every 3 to 5 years
Or more often if unexpected corrosion is found.
Corrosion Under Insulation
Risk-Based Inspection Program

This is a Good Basic Primer on Risk Based Inspection

JPCL Magazine
August 2013
Available online
Corrosion Under Insulation

Questions?

Please feel free to telephone or e-mail me
With any questions or comments.

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