A review of state of the art for Corrosion under insulation (CUI) testing of coatings

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Group Oil & Gas segment manager
Hempel A/S
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• Potential damage mechanisms
• ISO DIS 19277
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  • Testing
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• Other CUI test methods
  • Future industry work (JIP)
  • Small scale test
• Summary
Why the fixation with CUI testing?

- High detection cost
- High correction cost
- High “Consequence of failure” associated with CUI
- Increased industry awareness (recent years)
- CUI reduction initiatives
- Part of a wider objective
Potential damage mechanisms
- Successful corrosion protection of process pipework under all conditions

- Wear due to insulation
  - E.g. Foamglas
- Fabrication damage
- Installation damage

- Atmospheric corrosion resistance
- Thermal cycling
- UV degradation / chalking

- Minimum
- Maximum
- Cycling

- Insufficient cross linking (immersion resistance)
- Thermal cycling

A review of state of the art in Corrosion under insulation (CUI) testing of coatings: Aberdeen: May 2017
Brief history of testing

Focus on temperature resistance. Lead to acceptance of conventional high heat systems such as zinc silicate systems and thin film silicones.

Concerns over performance beneath insulation lead to prevalence of “immersion” type tests as proof of performance and increased specification of linings for CUI situations.

Realisation a wider scope was required. Inclusion of thermal cycling as well as heat and immersion testing. Corresponded to emergence of Inert Multi-Polymeric Matrix (IMPM) type materials.

A review of state of the art in Corrosion under insulation (CUI) testing of coatings : Aberdeen : May 2017
Expected performance

Above: Exposure of 85% zinc silicate to Houston pipe test (Mineral wool) shows extensive corrosion.

Below: Different types of IMPM types following CUI testing (Houston pipe test)

Micro-cracking in Epoxy novolac “lining” following heat exposure to 250°C
IOGP Draft ISO/CD 19277:2016(E)

• Spray applied coatings (extend to thermal spray)
• Does not address tapes or sacrificial coatings
• -45 °C to + 200 °C (extend to cryogenic conditions)
• Impact of heat conditioning
• Principle performance measures
  • Adhesion
  • Atmospheric corrosion
  • Thermal cycling
  • CUI resistance
    • Multi-phase CUI cyclic corrosion test (mandatory)
    • Houston Pipe test (optional)
IOGP Draft ISO/CD 19277:2016(E)
- CUI categories

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum temperature</th>
<th>Peak temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-1</td>
<td>−45 °C</td>
<td>to 60 °C</td>
</tr>
<tr>
<td>CUI-2</td>
<td>−45 °C</td>
<td>60 °C to 150 °C</td>
</tr>
<tr>
<td>CUI-3</td>
<td>−45 °C</td>
<td>150 °C to 204 °C</td>
</tr>
</tbody>
</table>

- Higher temperatures may be subject of future standard
- Option to use -196°C as minimum for cryogenic pre-qualification
- Peak temperature under normal operating conditions
- Thermal conditioning used to simulate additional thermal events
- Qualify for categories individually
Conditioning - Normal and additional thermal

- All coatings conditioned for 23 °C ± 2 °C with 50 % ± 5 %
- Additional thermal conditioning may be requested
  - Maximum category temperature
  - Other significant temperature
  - Total 100 hours in 5 cycles
- Reflects progressive nature of CUI conditions

Different properties come with different conditioning temperatures
But heating improves products right?

- Novolac Epoxy (2x 100 µm)
- Thin film silicone
- IMPM #1 (MIO) 2 x 150 µ
- IMPM # 2 (MIO) 2 x 150 µ
- IMPM # 3 (ALU) 2 x 150 µ

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Influence of micro-cracking

- Novolac Epoxy (2x 100 µm)
- IMPM #1 (MIO) 1 x 150 µ
- IMPM #2 (MIO) 1 x 150 µ
- IMPM #3 (ALU) 1 x 150 µ

- 250°C
- 650°C
- 300°C
- 300°C

Heating as per ASTM D2485 from 200°C to 650°C (250°C for Novolac epoxy, 450°C for #3 Alu) in 50°C increments every 24 hours. Visual and microscopic inspections between each interval.

<table>
<thead>
<tr>
<th>Coating</th>
<th>Minimum crack width</th>
<th>Maximum crack length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novolac Epoxy (2x 100 µm)</td>
<td>Extensive macro cracking</td>
<td></td>
</tr>
<tr>
<td>High build silicone #1 (MIO) (1 x 150 µ)</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>High build silicone #2 (MIO) (1 x 150 µ)</td>
<td>600</td>
<td>2500</td>
</tr>
<tr>
<td>High build silicone #3 (ALU) (1 x 150 µ)</td>
<td>200</td>
<td>2000</td>
</tr>
</tbody>
</table>

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Temperature as a category definer

- Industry has a long way to go on standardisation of temperature
- IOGP initiative recently interviewed 11 operators + NORSOK
- Essentially no correlation of temperature categories
- Possible future recommendations under discussion

-35 C to 120° C
120 C to 200° C
200 C to 450° C
Adhesion

• Two types stipulated
  • Cross cut ISO 2409
    • Coatings < 250 microns
    • Criteria 0-2
  • ISO 4624
    • Pull off adhesion test
    • > 5 Mpa
    • No adhesive break to substrate

• Exposure time
  • Pre-testing
  • Post exposure evaluation

A review of state of the art in Corrosion under insulation (CUI) testing of coatings : Aberdeen : May 2017
Atmospheric corrosion

<table>
<thead>
<tr>
<th>Classification</th>
<th>ISO 9227 (neutral salt spray)</th>
<th>ISO 2812-2 (water immersion)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration</td>
<td>Duration</td>
</tr>
<tr>
<td></td>
<td>Carbon steel</td>
<td>Carbon steel</td>
</tr>
<tr>
<td></td>
<td>Scribed</td>
<td>Scribed</td>
</tr>
<tr>
<td>Applied and</td>
<td>Applied and conditioned</td>
<td>Heat conditioned</td>
</tr>
<tr>
<td>conditioned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>Heat conditioned</td>
<td></td>
</tr>
<tr>
<td>conditioned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUI-1</td>
<td>720 hours</td>
<td>3 000 hours</td>
</tr>
<tr>
<td></td>
<td>480 hours</td>
<td>2 000 hours</td>
</tr>
<tr>
<td>CUI-2</td>
<td>720 hours</td>
<td>3 000 hours</td>
</tr>
<tr>
<td></td>
<td>480 hours</td>
<td>2 000 hours</td>
</tr>
<tr>
<td>CUI-3</td>
<td>720 hours</td>
<td>3 000 hours</td>
</tr>
<tr>
<td></td>
<td>480 hours</td>
<td>2 000 hours</td>
</tr>
</tbody>
</table>

- **Pre - service**
  - Applied and conditioned column

- **In service shutdown**
  - Heat conditioned column

Test method | Classifications | ISO 4628-2 | ISO 4628-3 | ISO 4628-4 | ISO 4628-5 | ISO 4628-8 |
---|---|---|---|---|---|---|
ISO 9227  | CUI-1 CUI-2 CUI-3 | 0 (S0) | Ri 0 | 0 (S0) | 0 (S0) | 2/3 |
ISO 2812-2 | CUI-1 CUI-2 CUI-3 | 0 (S0) | Ri 0 | 0 (S0) | 0 (S0) | 2/3 |

Time of assessment (after end of test) | Immediately | < 8 h |
Thermal cycling

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum temperature</th>
<th>Maximum temperature</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-1</td>
<td>5 °C</td>
<td>60 °C</td>
<td>20</td>
</tr>
<tr>
<td>CUI-2</td>
<td>5 °C</td>
<td>150 °C</td>
<td>20</td>
</tr>
<tr>
<td>CUI-3</td>
<td>5 °C</td>
<td>204 °C</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Classifications</th>
<th>ISO 4628-2</th>
<th>ISO 4628-3</th>
<th>ISO 4628-4</th>
<th>ISO 4628-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-1</td>
<td>0 (S0)</td>
<td>Ri 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
</tr>
<tr>
<td>CUI-2</td>
<td>0 (S0)</td>
<td>Ri 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
</tr>
<tr>
<td>CUI-3</td>
<td>0 (S0)</td>
<td>Ri 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
</tr>
</tbody>
</table>

Above: Test set-up for thermal cycling.

Left: IMPM coating after thermal cycling test

A review of state of the art in Corrosion under insulation (CUI) testing of coatings: Aberdeen: May 2017
The controversial bit......CUI testing - Multiphase CUI cyclic corrosion test (mandatory)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Multi-phase cyclic CUI test temperature</th>
<th>ISO 4628-2</th>
<th>ISO 4628-3</th>
<th>ISO 4628-4</th>
<th>ISO 4628-5</th>
<th>ISO 4628-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-2</td>
<td>150 °C</td>
<td>0 (S0)</td>
<td>Ri 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
<td>2/2</td>
</tr>
<tr>
<td>CUI-3</td>
<td>175 °C</td>
<td>0 (S0)</td>
<td>Ri 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
<td>2/2</td>
</tr>
</tbody>
</table>

Multi-phase cyclic CUI

<table>
<thead>
<tr>
<th>Classification</th>
<th>Duration</th>
<th>Temperature</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-2</td>
<td>1008 hours</td>
<td>150 °C</td>
<td>15 cycles consisting of 4 hours hot dry environment, 4 hour hot and wet environment, followed by 48 hours ambient environment, with entire cycle repeated a total of 6 times</td>
</tr>
<tr>
<td>CUI-3</td>
<td>1008 hours</td>
<td>175 °C</td>
<td>15 cycles consisting of 4 hours hot dry environment, 4 hour hot and wet environment, followed by 48 hours ambient environment, with entire cycle repeated a total of 6 times</td>
</tr>
</tbody>
</table>
The controversial bit......CUI testing
- Optional Houston pipe test (HPT)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Optional vertical pipe insulation test cycles and settings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon steel pipe or tube</td>
</tr>
<tr>
<td></td>
<td>As applied and conditioned</td>
</tr>
<tr>
<td></td>
<td>Cycles</td>
</tr>
<tr>
<td>CUI-2</td>
<td>30</td>
</tr>
<tr>
<td>CUI-3</td>
<td>30</td>
</tr>
<tr>
<td>CUI-4</td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Classification</th>
<th>ISO 4628-2</th>
<th>ISO 4628-3</th>
<th>ISO 4628-4</th>
<th>ISO 4628-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI-2</td>
<td>0 (S0)</td>
<td>R1 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
</tr>
<tr>
<td>CUI-3</td>
<td>0 (S0)</td>
<td>R1 0</td>
<td>0 (S0)</td>
<td>0 (S0)</td>
</tr>
</tbody>
</table>
The controversial bit......CUI testing
Pros and cons

**Multiphase CUI cyclic corrosion test**
- Heated test panels
- **No insulation**
- Wet/dry, hot/cold cycles
- 42 day exposure
- 5% NaCl solution
- **No field validation**

Cost: $$
Complexity: medium/high
CUI relevance: medium

**Heated insulated pipe (vertical arrangement)**
- Wet/dry and hot/cold cycling
- Temperature gradient
- Temperature changes with saturation
- 30 days
- Solution saturated insulation
- **No field validation**
- Solution composition may differ along pipe

Cost: $$
Complexity: medium/high
CUI relevance: medium
IOGP Draft ISO/CD 19277:2016(E)

**Status**

- Currently ISO Step 20 (Under preparation)
- Country comments incorporated TC67 / WG 11 meeting Doha, February
- Submitted for formatting
- Expected to ballot Q3/Q4 2017

- Only a roadmap – a degree of customisation to obtain relevant results for your equipment may be required
Joint Industry Project into CUI (SWRi)

- Extensive test-work carried out on various coating types including TSA
- Currently soliciting for JIP
- Better understand insulation and coating combinations and develop predictive models
- Electrochemical techniques for corrosion and coating performance measurements

Above: Test set-up for CUI testing
Left: Higher temperature cells
Understand coating insulation combined performance

Above: Post test evaluation using various methods (organic and metallic coatings)
Four phase program

Task 1 : Determine initial thermal and mechanical properties of coatings (input for selection of coatings in Task 2 )
Task 2 : Selection of coating materials for Task 3
Task 3 : Testing of Coatings/Insulations using the Refined Test Protocol
Task 4 : Determination of Coating/Insulation Durability under Wet Insulation

Cost: $$$$$
Complexity: High
CUI relevance: High
Small scale test method

- Challenge with HPT is its non isothermal nature
- Original Houston work also included non-pipe work
- Development of similar currently undertaken by Hempel
- Facilitates rapid screening on multiple systems in low laboratory footprint
- Currently evaluating corrosion rate versus cycle duration versus cycle frequency
On line application and temperature resistance

- ISO standard does not really address maintenance
- Application temperature (substrate) can significantly impact corrosion performance
- Manufacturers claims vary

720 hours salt spray testing
Summary

• More knowledge of coatings performance beneath insulation than ever
• Coating manufacturers have contributed significantly
• Disparate test methods hinder true comparison
• ISO 19277 first effort to consolidate
• Further programs to better correlate with field experience
• Need to better understand coating / insulation combinations
Hempel and CUI

• Coating solutions for CUI of epoxy, novolac epoxy and IMPM types
• Extensive CUI test facilities in Copenhagen, Denmark
• Access to analysis and tribology services via adjacent Danish technical university
• Represented on
  • ISO 19277 via TC 67 WG 11
  • NACE TG 516 working group
  • IOGP initiative “Generic coating standard definitions & terms” (temperature standardisation)
CUI test capabilities

- Houston pipe test (HPT)
- Multiphase CUI cyclic corrosion test
- Cyclic immersion testing
- High heat testing to ASTM D2485
- Elevated temperature application “bench”
- Physical property testing (flexibility, hardness, impact etc.)
- Atmospheric exposure ISO 20340 : 12944 : 9227 : 2812
- Used by several recognised operators for qualification under auditing

- Small scale CUI test chamber (under development)
- For client CUI programs contact SIDA@hempel.com

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