Improving mineral wool insulation's performance against CUI with next-generation corrosion inhibition

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Abstract

Insulation made from mineral wool has been widely used for decades as the primary thermal insulation on piping and equipment in refineries, petrochemical plants, and other process-intensive facilities. Mineral wool insulation is also favored for being noncombustible, cost-efficient, and easy to install. However, for many of these facilities, corrosion under insulation (CUI) is a critical and costly challenge that can impact any insulation material, and mineral wool is no exception.

CUI occurs when a breakdown in the protective cladding allows water from the surrounding environment to ingress, migrate past the insulation, and come into contact with the metal surface of the pipe or equipment. Left unchecked, this water can bring contaminants that create the ideal conditions for corrosion—leading to leaks that shut down plant processes, raise health and safety risks, and damage a plant's reputation and profitability.

Insulation manufacturers seeking to innovate have made CUI mitigation a key focus for years. This focus has included developing methods and technologies to enhance the insulation's hydrophobicity and water repellency, reduce the content of leachable salts, and improve the insulation's durability and temperature resistance.

This paper discusses ROCKWOOL Technical Insulation's work to upgrade mineral wool performance against CUI by developing an integral corrosion inhibitor that can be activated in case of water ingress. The inhibitors will complement the coating system on the equipment, protecting the steel in areas with imperfections in the coating system that arise from holidays in the application, damage, or initial aging.

This paper will present the development methodology and test results of the optimal corrosion inhibitor for mineral wool, including:

- Discussions on how the corrosion inhibitor embedded in the mineral wool helps mitigate CUI
- Test data showing that the new integral corrosion inhibitor is effective and long-lasting on a pipe or equipment surface.

Introduction

Mineral wool has been widely used for several decades as the primary thermal and acoustical insulation on piping and equipment to save energy, protect personnel, and reduce emissions. Mineral wool products are favored because they are non-combustible; cost-effective; provide excellent (and reliable) thermal and acoustics insulation performance; and are safe, easy, and efficient to install.

Over the years, mineral wool insulation manufacturers have refined and improved the insulation's properties to suit the evolving needs and meet the critical design criteria of insulation installers and plant owners worldwide. One crucial area of refinement has been in the development of mineral wool insulation that can effectively mitigate against corrosion under insulation (CUI).

CUI is widely recognized as a key challenge in various process-intensive industries, including oil and gas refining, petrochemical production, and liquefied natural gas (LNG) facilities, among others. While there are many ways to trigger and aggravate CUI, every scenario shares three common components: unprotected metal, oxygen, and water.

Most CUI mitigation solutions focus on protecting the metal by minimizing or preventing contact with water. Recent improvements to water repellency within insulation have included high-temperature stability. This allows water to be shed away from the insulation, thus reducing the amount of water that the metallic substrate may encounter, even at high temperatures of - 4 °C to 175°C (25°F to 350°F), where CUI has the greatest risk.[1]

A new approach represents the next step in enhancing mineral wool performance for CUI mitigation: the development and incorporation of corrosion inhibitors within the insulation. Such inhibitors are activated upon the ingress of water to provide a thin, protective barrier on exposed/unprotected steel where imperfections in the coating system occur due to holidays from application, damage, and/or initial aging.

These inhibitors, which are applied to the interior insulation layer closest to the pipe or equipment wall, can passivate the steel surface and slow the corrosion process. By keeping corrosion at bay, the likelihood of identifying defects during a scheduled inspection increases, often before significant damage has occurred.

Experimental Methodology

Assessing the inhibitor-treated product's performance in a CUI environment
The actual performance of the insulation with inhibitors was tested following ASTM G189-07 and compared with the standard mineral wool material without inhibitors.[2] ASTM G189-07 was considered the best standardized method available to simulate CUI in a laboratory environment, offering a closed system with the possibility of applying cyclic wet-dry/cold-hot conditions.[3]

The standard mineral wool material was taken from mandrel wound pipe sections. These samples complied with EN 14303 and ASTM C547, with a chloride content of ≤ 10 ppm (EN 13468) and water absorption of ≤ 0.2 kg/m² before and after heat aging at 250 °C (482 °F) for 24 hours (EN 13472/ISO 12623).

A third-party testing company performed the tests following ASTM G189-07, but with the following modifications:

- PTFE spacers between samples were replaced with special silicone O-rings.
- Clamping of the test equipment and coupons was achieved using a spring compression system to counter thermal expansion of the system.
- Ring-formed test coupons were 14.25 mm wide compared to the width in ASTM G189-07 of 6.35 mm.
- The mineral wool pipe section was made to fit the diameter of the assembled pipe, being in direct contact with the test coupons, thus creating a more real-life testing scenario.

None of the modifications was a relaxation compared to the test method and apparatus described in ASTM G189-07.

In the test setup (Figure 1), the insulation material was applied over an assembly of six cylindrical corrosion coupons - carbon steel pipe (DN50/2”-outside diameter 60.3 mm). The coupons were cut precisely and joined mechanically.

The solution, deionized water, entered the test rig through tubing positioned at the 12 o’clock mark. The solution reached the carbon steel coupon surface underneath the insulation material and exited the setup through a drain hole in the cladding at the 6 o’clock position.

The test cycle comprised wet cycles at 60 °C (140°F) for 18 hours and dry cycles at 150 °C (302°F) for 4 hours. During the wet cycle, 42.5 mL of water was added over a period of 10 minutes, followed by a rate of 4.25 mL/hr. The solution was not recirculated.

Two additional 6-mm holes were drilled in the upper part of the cladding to allow water vapor egress during the hot dry stage. A total of 21 cycles were conducted over 21 days, utilizing a total volume of 2.5 liters of water.

Figure 1. Schematic of the modified ASTM G189-07 test setup,

Results and Discussion

Results on corrosion testing.
As final laboratory validation of the produced insulation with corrosion inhibitors, the manufactured insulation (mandrel wound pipe section) was tested according to ASTM G189. A

standard pipe section made in the same material but without inhibitors was used as a reference (Figure 2).

Figure 2. Coupons after 21 cycles, with no deposits removed.

After the 21 test cycles, specimens were washed with DI water and a nylon brush, rinsed with ethanol, and dried to remove loose corrosion products and insulation from the surface before the first weighing.

Corrosion products were then removed by immersing the test specimens in inhibited 16% (w) hydrochloric acid as per ISO 8407 [4] (Figure 3). Following rinsing, the test specimens were weighed again.

Figure 3. Coupons after 21 cycles. Examples after dismantling and cleaning.

The corrosion coupons were then examined for the extent of localized corrosion as well as for the measurement of pitting depth. A uniform corrosion rate was determined using weight loss measurements. Estimation of the percentage of affected surface allows for the conversion of uniform corrosion rates to local uniform corrosion rates, which are more relevant.

Additionally, dimensional measurements were performed to determine the maximum localized corrosion rate.

Table 1. Corrosion results after 21 cycles.

* An error in the weight was observed in test coupon A1, as some of the original mill scale from the unexposed side of the coupon was removed during cleaning. Upon inspection, the coupon was free from corrosion, and only one very shallow, small pit-like attack was observed using 10x magnification.

For coupons insulated with the mineral wool with inhibitors, only very few, small, and shallow localized attacks were observed. Due to the inherent uncertainties and measurement errors associated with determining the area of the affected surface, calculating the localized corrosion rate was not performed, as this would yield misleading results.

During the 21 cycles of testing, the pH of the water draining from the test was measured:
• For the mineral wool without inhibitors, the pH changed from approximately 8 to approximately 6.
• For the mineral wool with inhibitors, the water remained slightly alkaline with a pH in the range of 8 to 10.

Discussion

Corrosion protection. The intention with the insulation material with inhibitors is to complement the coating systems, providing additional protection in areas with damage, insufficient thickness, or other imperfections.

The corrosion performance testing was undertaken on uncoated steel; however, it is reasonable to anticipate that the inhibitors will also be effective on coated steel with damage.

In the inhibitor screenings and the ASTM G189 testing, deionized water was used, and the effect of chlorides (10 ppm) was tested only as part of the screening process. This testing simulates water ingress in the form of water condensation or rain ingress in inland/non-polluted environments.

As part of the further documentation of the mineral wool with inhibitors, additional testing will be performed using other electrolytes to simulate industrial and coastal environments.

The durability of the inhibitors in the insulation is a natural concern over time. Corrosion inhibitors must have a degree of water solubility to function effectively. Therefore, in cases where major water transport occurs inside the insulation system (liquid water ingress through untight weather protection and drainage via drain holes), it is also anticipated that the inhibitors can be washed out over time.

More testing is required to gauge the long-term durability of the inhibitor in the insulation.

Conclusion

An effective corrosion inhibitor mixture has been identified for CUI environments. This inhibitor blend can be incorporated into mineral wool without compromising the primary properties of the insulation material.

In the event of water ingress, the inhibitors can delay/hinder the corrosion of unprotected carbon steel. Per testing to ASTM G189, the mineral wool with inhibitors has also proven to provide corrosion protection in an accelerated CUI environment.

Mineral wool with inhibitors will not prevent CUI, but it may be used to complement coating systems where initial defects are present, thereby reducing the risk of premature CUI events.

References

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4. ISO 8407:2021, “Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens”, International Organization for Standardization, Geneva, Switzerland.