MIO ADDITIVES EFFECTIVELY MITIGATE CORROSION UNDER INSULATION

Micaceous iron oxide pigments reflect ultraviolet light, block moisture and create a stronger coating matrix, promoting asset longevity before and during service.

By Bruce Toews, Global Market Director – Oil & Gas, and Neil Wilds, Global Product Director – CUI/Testing,
Sherwin-Williams Protective & Marine

In the battle against corrosion under insulation (CUI), most coatings come up short. The moisture, heat and contaminants that get trapped within insulation installed on pipes, valves, tanks and other assets create an environment that's ripe for coating film loss and corrosion (Figure 1). When coatings lack sufficient film builds, reinforced additives and other important properties, they're prone to degrading in the hot, damp environment under insulation. Some epoxy-based coatings may even begin to degrade before insulation is installed over them due to aggressive environments such as marine atmospheric conditions and ultraviolet (UV) light from the sun, making them that much more prone to CUI when in service.

Even coatings that have robust anti-corrosive properties will eventually corrode under insulation. The phenomenon is inevitable over time. Therefore, the key to success is to mitigate the effects of CUI for as long as possible to help assets realize long service lives and owners keep costs in check. To meet this mitigation goal, coating manufacturer Sherwin-Williams has performed extensive testing of various epoxy-based formulations with successful corrosion-fighting track records in other uses for their resistance to CUI. These efforts have identified four primary coatings – a high-temperature epoxy phenolic, a high-temperature epoxy, an ultra high-solids novolac amine epoxy and an inert multipolymeric matrix (IMM) coating – that deliver enhanced CUI performance compared to many of today's traditionally specified coatings.

A common additive ingredient – micaceous iron oxide (MIO) – enables these four coatings to effectively mitigate CUI. Flakes of MIO added to the coating formulations align parallel to the substrate within the coating matrix to form an interlocked shield of overlapping plates that block UV light, moisture, oxygen and other corrosion-causing elements from penetrating the coating and reaching the substrate. The MIO flakes also enhance the coating's chemical resistance, as well as strengthen the cured coating, making it harder and more resistant to impacts, while also retaining flexibility. In addition, the UV-blocking capability of the flakes helps to prevent epoxy coatings from chalking and losing film thickness when left exposed to sunlight and rain (Figure 2).

Testing of the four MIO-filled coatings has revealed that the additive pigment is enabling excellent coating performance in different CUI-inducing environments. Results vary based on the coating formulation, ambient and operational temperatures, system pressures, and other variables, but the testing demonstrates that these four coatings are highly viable options for mitigating CUI.

Figure 1. *Although pipes and other assets are coated prior to being covered with insulation, CUI is inevitable over time. Choosing an optimal coating system that mitigates CUI will slow down that process, providing longer service lives and reduced ownership costs.*

Figure 2. *Applying coatings embedded with micaceous iron oxide (MIO) to large pipes and valves can effectively protect those assets from damage and corrosion prior to service, as well as mitigate the effects of CUI when assets are later insulated and placed into service.*

MIO ADDITIVE HELPS CURB CUI AND UV DEGRADATION

With waterlogged insulation trapping moisture against a coated steel substrate, CUI essentially takes place in a partially immersed environment. So it should be no surprise that some coatings previously relegated to immersion service applications are being proven to be quite adept at mitigating CUI. This includes established interior tank and process vessel linings that are now finding uses in exterior applications under insulation. Among these products, some of the best performing epoxy-based linings featured MIO flakes, which prompted Sherwin-Williams to test these formulations for use in mitigating CUI. Tests are revealing two primary benefits from the MIO reinforcements – greater durability against impacts, chemicals and corrosion when the coated assets are insulated and placed into service, as well as enhanced UV resistance, which protects coatings from degrading before insulation is installed on assets.

MIO flakes come from processed micaceous hematite ore. The chemically inert material is insoluble in water, organic solvents and alkalis, making it highly suitable for immersion and immersion-like environments. It is also heat stable up to its melting point of over 1000°C (2700°F), easily permitting its use in high-heat applications under insulation. This thermal resistance is far higher than the 650°C (1200°F) maximum reached by aluminum flakes, another popular flake pigment. Aluminum flakes are also not resistant to halogens, acids or alkalis, making MIO flakes a better choice for mitigating CUI potential.

Embedded in a coating's matrix, MIO flakes create an interwoven barrier that enhances the coating's hardness, flexibility and resistance to impacts, chemicals, permeation and undercutting corrosion. The hard, yet flexible, finish is therefore more resistant to damage, installation and service. By preventing damage in the first place and then protecting against various stresses during service, the coatings very effectively slow the progression of CUI, leading to long asset service lives and lower costs of ownership.

One key to mitigating CUI is to ensure the applied coatings are still in good shape at the time an asset is covered with insulation. That timing may be in as little as a month or two after the coatings are applied or, more likely, it could take several months to a year or more for some assets to go into service. For example, bulk valves coated in the United Kingdom may take months to arrive at a job site in the Middle East and even more months to be installed. During that time, the valves may face extensive exposure to marine environments, as well as UV light, which can wreak havoc on epoxy coatings. The longer an epoxy coating is exposed to UV light, the more likely it is to chalk and begin to lose film thickness. That cycle continues with repeated UV exposures that chalk the coating material and heavy rains that wash the deteriorated material away. By the time an asset goes into service, it may have lost a significant amount of its protective epoxy coating. In some cases, the applied epoxy may erode away completely, exposing the applied primer below.

Any loss of thickness from a protective epoxy coating will diminish the coating's ability to mitigate CUI, as thinner coatings offer less protection under insulation. Therefore, the goal is to retain as much of the originally applied coatings as possible, which is where the MIO additives help. The MIO flakes line up as parallel particles in the cured coating's film, creating a series of overlapping plates that act like tiny mirrors to reflect and absorb UV rays, drastically reducing the erosive effects of UV exposure (Figure 3). Chalking and coating erosion rates are therefore greatly reduced. As a result, MIO flakes added to coatings enhance CUI mitigation from the moment they're applied, preventing excessive film loss before installation, resisting damage during transportation and installation, and finally, maintaining long-term corrosion protection when covered with insulation.

An additional benefit MIO additives offer relates to reducing volatile organic compound (VOC) emissions during application. MIO pigments impart thickness into coatings, allowing manufacturers to remove solvents from formulations. The resulting higher-volume solids coatings release fewer VOCs upon curing, providing a welcome environmental benefit that can also help coating application shops reduce their VOC permitting expenses.

PUTTING MIO FORMULATIONS TO THE TEST

MIO has long been a popular additive for a variety of coatings, providing added strength to tank linings for hydrocarbon service, corrosion mitigation in zinc-rich primed systems for offshore platforms, and long-term protection in coatings applied to iconic structures such as the Eiffel Tower. However, coatings featuring the additive have not traditionally been tested for their resistance to erosion under conditions that promote CUI. Testing was therefore necessary before recommending MIO-embedded coatings for the immersion-like service under insulation.

Over the past two years, Sherwin-Williams and its lab partners subjected a variety of coating formulations featuring MIO to specific tests to determine their resistance to CUI. These included:

- **Southwest Research Institute (SwRI) Testing:** A premier independent, nonprofit research and development organization, the SwRI is a well-known coatings testing provider for the oil and gas industry. The organization subjected various coating systems to a series of accelerated corrosion tests that emulate operational conditions, specifically focusing on CUI testing.
- **ISO 19277:2018:** 1 ISO 19277:2018 covers qualification testing and acceptance criteria for protective coating systems used under insulation on new carbon and austenitic stainless steel in the petroleum, petrochemical and natural gas industries. It establishes three CUI environmental categories with operating temperatures ranging from -45°C to 204°C (-49°F to 400°F) for topside and aboveground service, along with acceptance criteria for each environment. Each environment has a minimum temperature of -45°C, with its peak temperature varying by category, including 60°C (140°F) for the CUI-1 category, 150°C (302°F) for CUI-2 and 204°C for CUI-3. Sherwin-Williams used the optional Houston Pipe Test method included in this standard to test the four coating formulations. For the test, lab technicians wrapped a coated steel pipe with calcium silicate insulation and subjected it to artificial aging and heat conditioning via cyclical salt spray and water immersion exposures, as well as repeated heating and cooling, with dry film thickness (DFT) measurements and adhesion testing performed following exposures.

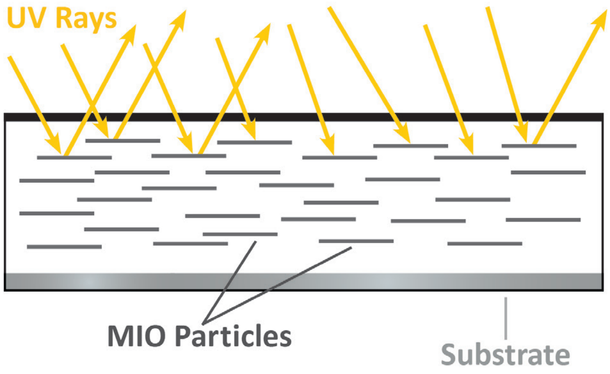

Figure 3. *MIO pigments embedded in a coating form a barrier that deflects ultraviolet rays to minimize UV degradation of the coating. The layered pigment structure also mitigates the penetration of moisture, oxygen and other elements into the coating.*

- **Cryogenic Testing:** Much of the focus on mitigating CUI relates to CUI that occurs when assets are operating at ambient and higher temperatures. However, CUI is also possible under cryogenic conditions, which are highly prone to forming condensation under insulation. As in heated applications, that moisture may never escape the insulation and will be a constant corrosive influence on the coatings and steel. For this testing, lab technicians subjected a coated sample to five cycles of extreme temperature conditions. The first step included one hour of exposure at -196°C (-320°F) followed by one hour at ambient temperatures. Technicians then exposed the sample to one hour of 200°C (392°F) temperatures followed by another hour of ambient conditions, completing one cycle. After each cycle, technicians examined the samples for defects, such as blistering and cracking.

- **DFT Tolerance Tests:** Another important test determines how well coatings applied at different thicknesses resist cracking when exposed to thermal cycling under insulation. This thermal resistivity test helps manufacturers determine the appropriate specifications for coating DFTs in specific operating temperature ranges. For the test, coated steel panels are subjected to annealing for eight hours at 200°C followed by cooling to room temperature for 16 hours for five cycles. Between each cycle, lab technicians evaluate the test panel for signs of cracking, blistering or flaking under 10x magnification based on ISO 4628.2. Each tested coating is applied to panels at increasing thicknesses to help determine if a coating has a particular threshold at which it cannot be applied without cracking. The test panels included a perpendicularly welded plate to demonstrate how the coatings performed in areas with sharp corners.

CUI TESTING RESULTS: HIGH-EMPERATURE EPOXY PHENOLIC

High-temperature epoxy phenolic coatings are common CUI-mitigation workhorses for the industry and have been used extensively. Recently, however, the industry has faced some failures with certain formulations, prompting a necessary review of technologies to ensure asset owners are effectively protecting their investments.

Among the various MIO-infused coatings tested for their resistance to CUI, a high-temperature epoxy phenolic showed positive results for use on pipes, valves and vessels operating from cryogenic temperatures to 205°C (401°F), with excursions to 230°C (450°F). The two-component, amine-cured coating was initially formulated for use as an internal lining due to its resistance to chemicals and hydrocarbon products, as well as a lining for secondary containment vessels. Performing well in these environments, the coating was a prime candidate for testing its resistance to CUI. Not surprisingly, it performed well on the following tests:

- **ISO 19277:** The high-temperature epoxy phenolic coating did not show any signs of deterioration until the test temperature approached 179°C (354°F). Thereafter, cracking and rusting began to form, with significant rusting not appearing until temperatures approached 200°C.
- **Cryogenic:** Applied in two coats at total DFT of 8-10 mils for this test, the coating system showed no signs of breakdown after five cyclic temperature exposures, including assessments for blistering, rusting, cracking or flaking.
- **DFT Tolerance:** Following the first cycle of annealing at 200°C and resting at room temperature, cracking was observed in the welded areas of samples coated at 9-10 mils DFT. At higher DFTs from 20-31 mils, the coating also showed cracking in the samples' face and weld areas after the first cycle. Hence, the coating's maximum temperature rating of 205°C.

The high-temperature epoxy phenolic tested has a higher volume of solids than other traditionally used systems, making it a good choice for reducing VOC permitting costs. That reduction is advantageous, as such coatings are typically applied in a shop environment on newly coated assets. However, the high-temperature epoxy phenolic may also be used for maintenance repair work, provided the surface can be prepared properly to the SSPC-SP6/NACE 3 commercial blast cleaning standard or, if that's not possible, the SSPC-SP11 power tool cleaning to bare metal standard.

CUI TESTING RESULTS: HIGH-TEMPERATURE EPOXY

As portions of the market have moved away from select mis-formulated high-temperature epoxy phenolics with some well-publicized failures, high-temperature epoxies have gained significant traction in CUI-mitigation service. The coatings cover a similar operating temperature range as epoxy phenolics, while often offering material cost savings.

One such high-temperature epoxy, which is based on flake-filled advanced alkylated amide technology, has tested well for resisting CUI when exposed to a temperature range from cryogenic to 200°C. This two-component, high-solids epoxy is pigmented with a high load of MIO. Its high flake-load enables the coating to be applied directly to marginally prepared surfaces, making it ideal for maintenance repair applications. However, it is also an excellent option for newly coated assets, offering significant protection of sharp edges, corners and welds. With a solids volume ranging from 75% to 81% and VOC levels of <250 grams/liter, the product is suitable for shop applications.

Testing results confirmed that the high-temperature epoxy is a highly suitable entry level epoxy for mitigating CUI:

- **ISO 19277:** The coating outperformed the high-temperature epoxy phenolic in the Houston Pipe Test, performing well up to 220°C (428°F) with no cracking, flaking or rusting occurring before this temperature.
- **Cryogenic:** The coating was applied in two 5-mil DFT coats and showed excellent stability in thermal cycling with no cracking, flaking or disbondment after five cyclic temperature exposures.
- **DFT Tolerance:** The coating demonstrated very good crack resistance up to 19 mils, with better crack tolerance after heating cycles compared to the tested high-temperature epoxy phenolic. In fact, cracking was only observed in the weld areas of the test sample. The coating also showed less yellowing than the epoxy phenolic.

CUI TESTING RESULTS: ULTRA HIGH-SOLIDS NOVOLAC AMINE EPOXY

Certain applications, such as where low solids coating systems are prohibited or film thickness tolerance is particularly important, require the more robust formulation of an ultra high-solids novolac amine epoxy. Such coatings offer superior protection compared to conventional epoxy phenolics and epoxies due to their higher film builds and higher solids formulations. They have also performed well from cryogenic temperatures to 200°C.

The ultra high-solids novolac amine epoxy tested for CUI mitigation was originally engineered for immersion service in ballast tanks, oil tanks and refined fuel storage tanks due to its excellent chemical resistance and durability. It offers high film builds and excellent edge retention properties, making it a good choice for higher DFT applications. The coating's solids volume is approximately 95%, which is significantly higher than the typical 60% to 70% volume solids for traditional epoxy phenolics, making it an optimal shop coating for new assets.

Flipping its use to the exterior of assets, the two-component coating was expected to perform well in CUI service. Testing confirmed the coating is an excellent choice for mitigating CUI on covered valves, pipes and vessels:

- **ISO 19277:** The product performed very well with no defects up to 200°C, demonstrating better results than both the high-temperature epoxy phenolic and the high-temperature epoxy.
- **Cryogenic:** The coating system applied in two 4- to 5-mil DFT coats showed no signs of breakdown after five cyclic temperature exposures.
- **DFT Tolerance:** The novolac amine epoxy had excellent results in DFT tolerance testing compared to all other epoxies tested. No cracking was observed after five cycles in all of the DFTs tested, including above 30 mils. The product showed heavy yellowing in the test, but that did not affect its crack resistance performance.

CUI TESTING RESULTS: INERT MULTIPOLYMERIC MATRIX (IMM) COATING

For certain applications, a completely different formulation – an inert multipolymeric matrix (IMM) coating embedded with MIO – is needed to accommodate the operational and environmental conditions of the assets coated with insulation. Such applications include insulated pipes, valves and process vessels (Figure 4) that face very high-temperature service and aggressive cyclic service at high temperatures.

Figure 4. *An MIO-embedded IMM coating can effectively mitigate CUI when applied to process vessels operating at high temperatures and covered with insulation.*

The niche IMM material tested for CUI mitigation service meets a very wide operational temperature range from cryogenic to 649°C (1200°F). Available in a single-component version for maintenance applications and a two-component version for shop applications, it is a self-priming formulation that enables single-coat, direct-to-metal applications. It can also be applied to assets operating with surface temperatures up to 260°C (500°F), enabling processes to remain in operation during coating applications.

The tested silicone-based IMM coating is harder than any other silicone coating used in the petrochemical industry. This high level of hardness provides superior protection from impacts and abrasions, chemical attacks and moisture penetration. At the same time, the material is designed to expand and contract, along with the assets it's protecting, during extreme temperature fluctuations. Therefore, unlike epoxies, which are extremely hard but not very flexible, the IMM coating can perform well against the stresses of thermal shock. An epoxy may become brittle and crack under thermal shock conditions, whereas the IMM coating will remain intact. With its silicone-oxygen bonding, the MIO-embedded IMM coating also has a stronger bond than epoxy-based coatings, which have carbon-to-carbon bonding.

Testing results showed the following:

- **SwRI:** The IMM coating met the most stringent pass criteria for oil and gas atmospheric systems and resisting stress corrosion cracking.
- **ISO 19277:** The coating outperformed all the other systems in the Houston Pipe Test, performing well up to 265°C (509°F) with no cracking, flaking or rusting occurring before this temperature.
- **Cryogenic:** Applied in two 5-mil DFT coats, the IMM coating showed no signs of breakdown after five cyclic temperature exposures.
- **DFT Tolerance:** At all of the DFTs tested, including above 24 mils, the coating showed no signs of cracking following the five testing cycles.

Beyond effectively mitigating CUI, the tested IMM coating offers an application benefit compared to other IMM formulations. It does not require heat curing following application to fully harden. Most other IMM coatings dry at ambient temperatures but don't fully cure until they reach 120°C to 176°C (250°F to 350°F). Without heat curing or the need of a primer, those coatings are more likely to incur damage when assets are transported or installed, creating a weak point in the protective coating for corrosion to attack. A special additive in the tested two-component IMM formulation allows it to cure and harden at lower temperatures, saving the time and expense of heat curing for faster, less expensive shop applications. The coating is the first known product to pass atmospheric testing without a heat cure.

EFFECTIVELY MITIGATING CUI

Addressing the issue of CUI is a continuous learning curve that requires repeated testing and evaluation of coating formulations to find the right combinations that enable long service lives and safer operations. For example, inorganic zinc coatings used to be extensively specified for mitigating CUI. However, they have been found to break down easily in the CUI sweet spot of 50°C to 120°C (120°F to 250°F) when they don't have a topcoat. Following this discovery, new standards now discourage the use of inorganic zincs under insulation without a topcoat.

As the four tested MIO-embedded coating formulations are deployed to the field and subjected to the rigors of service under insulation, it will be important for owners and operators to carefully inspect these systems to verify that lab testing results match real-life outcomes. With their added MIO additive reinforcements, the coatings are expected to offer excellent resistance to damage prior to installation as well as highly effective CUI mitigation when they're covered with insulation and placed into service. If field inspections confirm the anticipated positive results, the industry now has four new vetted options for curbing the difficult phenomenon of CUI and realizing longer asset service lives.

REFERENCES

International Organization for Standardization. (2018). Petroleum, petrochemical and natural gas industries – Qualification testing and acceptance criteria for protective coating systems under insulation (ISO 19277: 2018). Retrieved from https://www.iso.org/standard/64240.html.

International Organization for Standardization. (2016). Paints and varnishes – Evaluation of degradation of coatings – Designation of quantity and size of defects, and of intensity of uniform changes in appearance (ISO 4628:2016) – Parts 1-5. Retrieved from https://www.iso.org/ics/87.040/x/.

ABOUT THE AUTHORS

Bruce Toews is Global Market Director – Oil & Gas for Sherwin-Williams Protective & Marine. He has been with The Sherwin-Williams Company for more than 30 years. Previously, he was the Global Market Director for Process Industries and the Vice President of Global Accounts for Sherwin-Williams Protective & Marine. His 32-year coatings industry experience includes work as Sales Director and the Vice President of Sales for the International Division. He also has marketing management and sales management experience. He is a NACE Coating Inspector Program (CIP) Level 3 instructor as well as a committed member of AMPP (Association for Materials Protection and Performance). Contact: bruce.a.toews@sherwin.com

Neil Wilds is Global Product Director – CUI/Testing for Sherwin-Williams Protective & Marine. With 35 years of technical coatings experience, he is focused on developing strategies for long-term asset protection from the effects of corrosion under insulation (CUI) in the oil and gas (upstream, midstream and downstream), chemical and power industries. He also directs the development of specifications and testing programs with asset owners and operators. Wilds is a member of several coatings associations and is actively involved in developing coatings corrosion and CUI test standards with the Association for Materials Protection and Performance. He is also the current chairman of the North East Branch of the Institute of Corrosion. Wilds holds a degree in applied chemistry from Northumbria University. Contact: neil.wilds@sherwin.com

THE SHERWIN-WILLIAMS DIFFERENCE

Sherwin-Williams Protective & Marine delivers world-class industry subject matter expertise, unparalleled technical and specification service, and unmatched regional commercial team support to our customers around the globe.

The industry experts at Sherwin-Williams Protective & Marine are renowned authorities in their respective fields of knowledge – including Bridge & Highway, Flooring, Food & Beverage, Fire Protection, Marine, Oil & Gas, Freight Rail, Power Generation, Steel Fabrication and Water & Wastewater. Our global technology expertise in areas including tank linings, passive fire protection, corrosion under insulation (CUI) testing and fusion-bonded epoxy drives game-changing innovation and influences global industry standards.

North America
sherwin-williams.com/protective
swprotective@sherwin.com

SHERWIN-WILLIAMS.