THE BATTLE AGAINST CORROSION UNDER INSULATION

Mark Rubio, Energy Business Manager, and Neil Wilds, Global Product Director – CUI, Sherwin-Williams Protective & Marine, consider performance improvements, such as liquid coatings, that can offer longer maintenance-free service for LNG assets.

The hidden dangers of corrosion under insulation (CUI) span the oil and gas industry from upstream operations to midstream infrastructure and downstream applications, including the production of LNG (Figure 1). CUI is a severe form of localised corrosion that occurs when water, inorganic salts, and other contaminants become trapped beneath insulation covering pipes, valves, tanks, and other assets, leading to the formation of corrosion cells that are hidden from view and can spread unnoticed (Figure 2).

In oil and gas operations, elevated process temperatures may accelerate corrosion rates, leading to pitting and metal loss that may cause leaks and potentially catastrophic failures, with the potential to harm personnel and, in extreme cases, cause the loss of life. Yet, in LNG operations, cold/cryogenic temperatures can also contribute to increased CUI risks. A perfect recipe for corrosion – moisture, oxygen, and chlorides – exists in both temperature scenarios, but moisture from condensation can be especially prevalent under insulation in cryogenic LNG operations due to the extreme temperature differentials with ambient air. Studies show that moisture causes 85% of insulation system failures in LNG operations. At the same time, some LNG applications also operate at high heat, compounding CUI threats across entire facilities.

Because cryogenic temperatures are required for numerous LNG refinery applications, most assets are made from stainless steel rather than the carbon steel that is commonly used in other oil and gas refining operations.

Figure 1. A variety of stainless steel assets exposed to cryogenic service and highly corrosive environments in LNG operations are often insulated, elevating the risks for corrosion under insulation (CUI) to develop and proliferate.

Figure 2. CUI can eat away at steel substrates, leading to weakening of the metal to the point that dangerous leaks or explosions may occur.

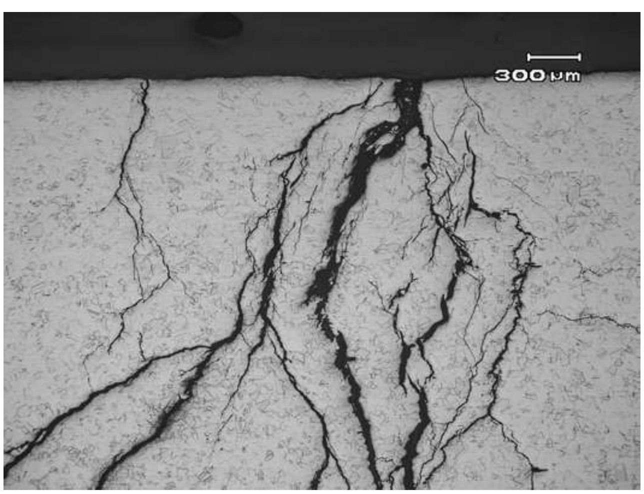

Figure 3. A magnified view of chloride stress corrosion cracking on type 304 stainless steel shows tiny surface cracks that weaken the structure of the steel, making it susceptible to potential gas leaks.

Stainless steel provides added strength, hardness, and corrosion resistance, helping LNG facilities better protect their production assets, including at very low temperatures. However, stainless steel is still susceptible to corrosion, with chloride stress corrosion cracking (CSCC) being especially virulent when chlorides from salts are in contact with the metal, whether it is exposed or covered with insulation. Such CSCC causes tiny surface cracks to develop in stainless steel, weakening its structure (Figure 3). These cracks may become so pervasive that there could be potential for gas leaks to develop and explosions to occur.

Given the corrosive threats associated with insulated assets used in LNG production, facility operators are best served by covering assets with protective coatings that create a barrier between the metal substrate below and the chlorides, moisture, and other exposures on the surface. Such coatings should be considered an integral part of a robust insulation system, as they help to mitigate the corrosion process and enable assets to operate longer before requiring maintenance. Still, a faulty insulation system may lead to corrosion taking place and can put an asset out of commission prematurely.

Traditional organic coatings in CUI service range from only 5 – 13 years before facilities need to proceed with costly inspection and repainting activities. However, more advanced coating technologies are being formulated to properly address typical coating failure mechanisms, offering improved performance and thereby extending the lifetime of coated assets. Those formulations are engineered to better withstand the varied exposures assets may face before and after they are insulated, including elevated and extremely low operational temperatures, exposure to chlorides before and during service, rough handling during transport, outdoor storage prior to installation, and high moisture conditions from humidity and condensation. Not only are some of these new liquid coatings performing better than traditional CUI coatings, but they are also faster, easier, and more economical to apply compared to thermal sprayed aluminium (TSA), which is sometimes used in LNG applications.

LNG production environments are ripe for CUI

LNG facilities operate at approximate temperatures as low as -162˚C (-260˚F) and require an effective thermal insulation system on assets to prevent them from excessive heat gain and to maintain these temperatures to ensure effective and safe operation.

The need to better address CUI in LNG refining applications is pressing. The world is in a grip of geopolitical turmoil and therefore global LNG demand is rising, with numerous projects planned to meet growing needs. As existing facilities expand and new ones are constructed, LNG operators will need proven, cost-effective CUI-mitigation solutions that improve the safety and long-term productivity of their facilities.

That need is especially prevalent due to many LNG facilities being located in hot, humid coastal environments. Salt in the atmosphere of these locations is sure to make its way onto piping and other equipment at such facilities. For example, piping and equipment may be shipped uninsulated to project sites. Along that entire journey, atmospheric chlorides may settle on the surface of assets and not be washed off before becoming trapped under insulation systems during onsite installations. Those chlorides are likely to encounter water and dissolve into a corrosive solution because roughly 60% of insulation systems pick up corrosion-inducing moisture over time due to cracks and gaps that form in the protective cladding installed over top. In addition, salts that settle on the surface of cladding are likely to dissolve from exterior moisture and then leach into the insulation system via gaps, adding more fuel for the corrosion process.

As moisture penetrates an insulation system or condensation forms within it and dissolves trapped chlorides or contaminants within the insulation itself, a highly corrosive solution forms and comes into direct contact with the metal substrate – or the protective coating applied to the steel substrate – creating a ripe environment for CUI. Adding process heat to the equation further exacerbates corrosion potential, as the corrosive solution may boil on the substrate. If conditions are right, the moisture may evaporate, leaving spots of concentrated chloride on the steel surface. In other cases, the moisture may never evaporate, leaving a wet, salty solution in constant contact with the substrate. In either case, the chlorides can lead to CUI forming on carbon and stainless steels, with the CUI commonly presenting in the form of CSCC on stainless steels.

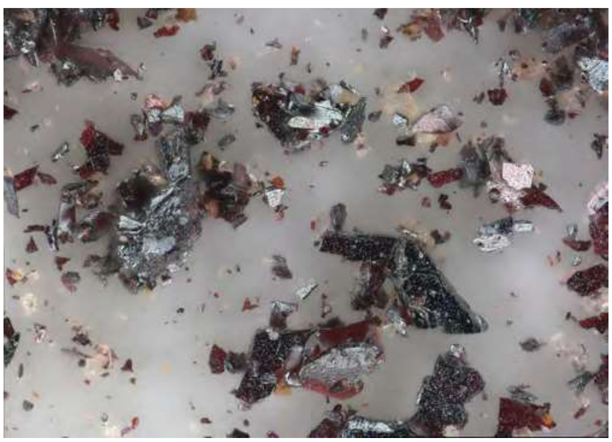

Figure 4. High concentrations of micaceous iron oxide (MIO) pigment embedded in liquid coatings adds durability against impacts, chemicals and corrosion.

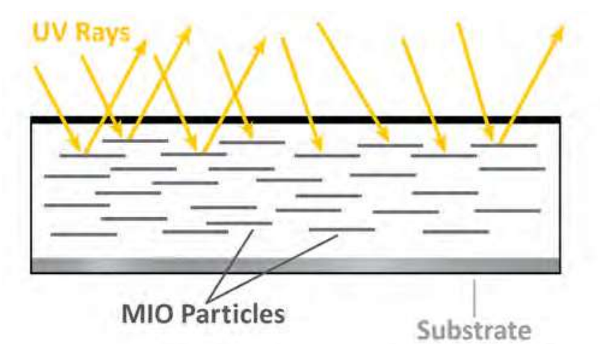

Figure 5. Embedded in a coating, MIO flakes set up parallel to the substrate like plates, forming a barrier that deflects UV rays and also mitigates the penetration of moisture, oxygen, and other elements into the coating.

Hidden beneath an insulation system, CSCC can go unnoticed until the next insulation inspection cycle. Even then, it may be hard to spot. Over time, tiny surface cracks that are imperceptible to the human eye will develop and continue to grow and spread along microscopic grain boundaries within the stainless steel. The cracks typically follow the direction of the highest tensile stress on the metal. Eventually, the steel may become so weak and brittle that it cracks open, leading to leaks or more catastrophic events that place personnel and facilities in danger. Most often, such failures are sudden and unexpected, and they are more likely to occur when processes are running at elevated temperatures, adding to risks.

Though CUI can occur in a broad band of temperatures, it becomes a significant concern for insulated carbon steel operating at temperatures between 0˚C (32˚F) – 150˚C (302˚F), and is most severe at about 93˚C (200˚F). Austenitic stainless steel piping systems that operate between 60˚C (140˚F) – 205˚C (400˚F), are the most susceptible to CSCC forming under insulation.

Mitigating CUI and CSCC with coatings

To mitigate the issues of CUI and CSCC, LNG facilities should use some sort of protective coating on stainless steel or carbon steel substrates to maintain a barrier between the substrate and the corrosive exposures on the surface. This is true whether an asset is insulated or not.

The choice of a protective barrier coating is critical, as different technologies offer a range of performance in mitigating corrosion. The type of exposures an asset will encounter – including cryogenic and elevated temperatures; chloride, moisture, and UV exposures; and surface damage – will certainly influence the coating selection. In addition, the total cost of ownership will be a factor, including the costs to initially coat an asset and those encountered when recoating that asset in the future to maintain corrosion protection.

One type of coating used on stainless steel LNG assets is thermal sprayed aluminium (TSA), which can provide up to 25 – 30 years of maintenance-free CUI service. However, the application costs and sustainability impact for TSA are very high, as the process is cumbersome and aluminium material is applied using energy-intensive spray equipment. Surface preparation must be very meticulous, with applicators carefully abrasive blasting every square inch of the substrate, conducting tape tests to check for dust contamination and performing salt contamination tests to ensure no contaminants are left on the prepared steel surface. TSA applications require the same level of care, with applicators spraying multiple layers of molten metal particles onto steel surfaces, checking the layer thickness frequently and, in most cases, applying a sealant at the end.

Spray-applied organic liquid coatings – including high-temperature epoxy phenolics; high-temperature, high-solids alkylated amide epoxies; and ultra-high-solids novolac amine epoxies – are used most widely in LNG service. Applicators still need to carefully abrasive blast all steel surfaces and ensure they are contaminant-free and have a proper anchor profile, but the coatings are much faster, easier, and less expensive to apply than TSA.

Among the newer liquid coating options for combatting CUI and CSCC are formulations featuring high concentrations of micaceous iron oxide (MIO) pigment (Figure 4), including minimum concentrations of 25% MIO pigment by weight in the dried coating film. This heavy load of MIO reinforcements provides greater durability against impacts, chemicals, and corrosion compared to other formulations when coated assets are insulated and placed into service. Flakes of MIO in the dried coating film form a layered barrier that deflects UV rays and provides enhanced UV erosion resistance, protecting the epoxy-based coatings from degrading before insulation is installed on assets (Figure 5). The flakes also mitigate the penetration of moisture, oxygen, and other elements into the coating to enhance corrosion protection.

Notably, a newer MIO-enhanced, two-component, high-solids alkylated amide epoxy (AAE) coating offers excellent protection from CUI for long-term asset durability (Figure 6). In testing, the coating has consistently outperformed traditional epoxy phenolics and other AAE technologies in a corrosive offshore CX environment in terms of heat, corrosion, erosion, and thermal shock properties, including excellent heat and crack resistance at high dry film thicknesses (DFTs). In addition, the coating has epoxy-type mechanical resistance, minimising damage potential during the transport of coated steel assets. As an environmental benefit, it also features much less solvent than other AAE CUI-mitigation coatings – with a volume solids of 78% compared to 65% for typical alternatives.

Another new alternative coating – an ultra-high-solids advanced CUI epoxy novolac – performs even better than the MIO-enhanced formulations. The coating was developed with a functional chemical enhancement for CUI mitigation. It represents a new class of CUI-mitigation coatings, as it is free from the flake-filled pigmentation that is common in alternative coatings. It is also more sustainable than alternatives, as the ultra-high volume solids coating is solvent free, while most other CUI-mitigation epoxies typically have between 60 – 80% volume solids. This advancement reduces the release of volatile organic compounds (VOCs) for better environmental stewardship, diminishes the overall carbon footprint, and lowers permitting costs for applicators.

In testing, the advanced CUI epoxy coating far surpassed the capabilities of solvent-based epoxy phenolic and novolac coatings designed for CUI mitigation. It displayed best-in-class temperature, corrosion, chemical and mechanical resistance, while providing the most versatile DFT range among CUI-mitigation coatings. Analyses included various heat cycling, simulated CUI, BS EN 927-6:2016 UV erosion and DFT tolerance testing for thermal resistivity. In addition, the coating showed excellent results following ISO 12944-9 CX cyclic anticorrosion testing, as well as in a series of CUI simulation tests performed in accordance with AMPP TM21442 in excess of 204˚C (400˚F).

Figure 6. Applied to an industrial valve that will be insulated prior to service, an MIO-enhanced, high-solids alkylated amide epoxy coating will offer excellent protection from CUI.

Both the AAE and ultra-high-solids epoxy novolac coatings were also tested against the ISO19277:2018 standard, which uses a vertical pipe test method known as the 'Houston pipe test.' The test evaluates a coating's resistance to accelerated CUI conditions with periodic shutdown periods.

Long-term CUI-mitigation performance

With the battle against CUI never ending, steel assets that will be covered in insulation should almost always have some sort of coating applied on top to slow the corrosion process and reduce the total cost of ownership for LNG production assets. That recommendation also holds true for most non-insulated assets. Such coatings applied to stainless steel assets that encounter chloride exposures – whether they are insulated or not – will also help facilities mitigate the dangers of CSCC for safer overall operations.

The performance of various liquid organic coatings in testing, particularly the epoxy novolac formulation, show great promise for these technologies to become preferred specification solutions for combatting CUI. Each formulation offers the ability to mitigate the corrosion process for as long as possible, with the epoxy novolac anticipated to last significantly longer than the traditional coatings that have been used in the industry until now. LNG