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GETTING TO GRIPS WITH CORROSION UNDER INSULATION

The evolution of third generation polysiloxane coatings for corrosion under insulation mitigation. By James Reynolds, Performance Polymers EMEA.

Corrosion under insulation (CUI) is a well-known industrial problem that has been plaguing asset owners for decades. CUI represents one of the costliest corrosion factors for the oil and gas, petrochemical and general processing industries and can lead to unplanned shutdowns, maintenance repairs and even explosions on live plants. The risks which CUI poses have led to the adoption of many preventive methods aimed at determining best practice for minimising potentially catastrophic CUI issues.

There are three component aspects to CUI:

- Steel: a substrate for processing chemicals (at constant or cyclical temperatures)
- Insulation: for thermal efficiency
- Cladding: for protecting the insulation and steel against atmospheric elements.

In practice, the cladding system is not truly sealed from the atmospheric elements, and so rain, deluge water, steam or cooling tower water is often able to penetrate the system through an ingress point in the cladding material, generally where complex structures make it exceedingly difficult to build a watertight system. Additionally, as the permeable insulation (open cell) types used are sensitive to moisture, condensation build-up is a frequent CUI contributor. Once water has penetrated the system via an ingress point such as cracks, seams, gaps, or unsealed valve sections, it is absorbed into the open-cell insulation, where it causes saturation or accumulates in high concentrations and is able to corrode the steel. Potential contaminants are acid or high salt content, rain, and chemicals (chlorides/sulfides) leaching from insulation systems that can form acidic compounds which accelerate the rate of corrosion. The predominant steel materials used in industrial processing are carbon (CS) and stainless (SS, austenitic or duplex) types. Both are susceptible to CUI via multiple corrosion mechanisms. The temperatures at which extensive CUI (either in cyclical or constant operation) occurs in CS range from -4 to 175 °C. The corresponding temperatures for SS are

RESULTS AT A GLANCE

→ Thermal insulation coatings (TICs) have been used for over 10 years in different applications, including thermal insulation and personnel protection, partly or wholly superseding insulation cladding systems and wire cages for both hot and cold processing.

→ TICs formulated from organic-based polymers and filled with ceramic/glass microspheres or silica-based insulation media have two drawbacks: low film-build requiring 10 or more coats and limited heat resistance of -40 to 180 °C.

→ A new liquid-applied insulation comprising a 3rd generation polysiloxane (TGPS) yields a water-borne (low-VOC), one-component, ambient-curing polysiloxane TIC that allows ultra-high-build (UHB) in excess of 20,000 µm dry film thickness and heat resistance from -60 to 400 °C.

→ Assets can be now protected with a two-coat system comprising TGPS CUI primer and TGPS TIC coating.

→ The polysiloxane confers high weathering resistance and thermal cycling properties in ultra-high film thicknesses, eliminating the cladding needed in traditional insulation systems and providing the necessary film thickness for efficient thermal insulation and personnel protection.

50 to 175 °C. The rate of corrosion is directly related to the CUI system, the suitability of the CUI coating, the type of insulation and the quality of the cladding installation.
Specifiers and asset owners can choose from a wide selection of materials obtainable from a variety of suppliers when designing, building and maintaining plants. To help them with this process, they mainly refer to NACE SP0198 – 2017 [1]. This generally accepted guidance document facilitates selection by listing suitable materials for cladding, insulation and coatings on the basis of operating temperature and chemistry.

SILOXANES IN STANDARDS AND CUI COATING REQUIREMENTS

Within the last 15 years, NACE has introduced inorganic copolymer (IC) and inert multipolymeric matrix (IMM) coatings for industrial CUI mitigation across the recommended full temperature range of -45 to 650 °C. Various versions of IMM are available on the market and, as of 2015, are now in their third generation. From a chemical perspective, IC and IMM coatings are classed as polysiloxane coatings (see CS6 in *Table 1*).
Coating requirements for service under insulation include resistance to heat, thermal cycling, and corrosion, hot saline water immersion (HWI) properties, chemical resistance, and mechanical durability. The coating properties must be present upon application and must not require stoving or curing at elevated temperatures. Issues have been identified in the field with products that require heating to develop their full corrosion and mechanical properties and, therefore, resistance to CUI environments. What must also be highlighted is that, where heat curing proves necessary, specification and use below the curing temperature should be largely avoided because CUI protection will otherwise be limited.

Figure 1: TGPS CUI mitigation coating - shop application prior to transport and installation.

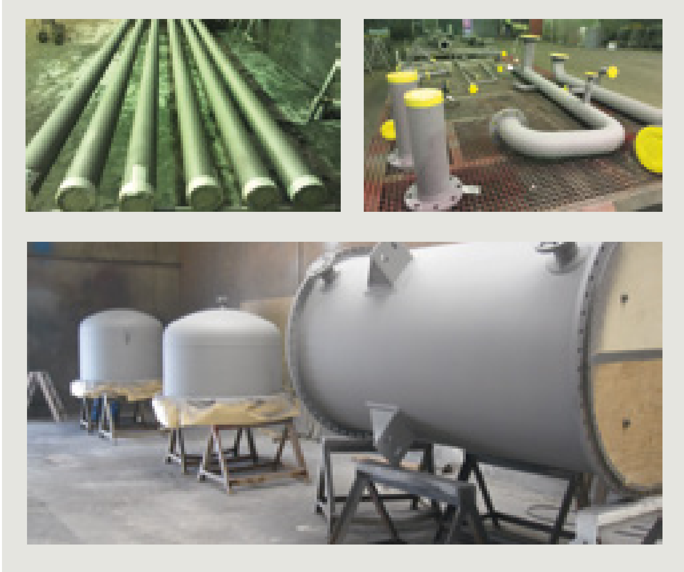

Figure 2: TGPS CUI mitigation system.

Table 1: Under insulation coatings (NACE SP0198-2017 classification) for carbon steel.

System	Chemistry	Temperature range (°C)
CS1	Epoxy	-45 to 60 °C
CS2	Fusion bonded epoxy	-45 to 60 °C
CS3	Epoxy novolak	-45 to 150 °C
CS4	Epoxy phenolic	-45 to 205 °C
CS5	TSA	-45 to 595 °C
CS6	Inorganic copolymer (IC) / Inert multipolymeric matrix (IMM)	-45 to 650 °C

Although an official coating classification is certainly hugely beneficial to specifiers and asset owners in the selection of coatings for preventing CUI, NACE SP0198 -2017 fails to provide any insights into, guidance on or test methods for establishing the coating's performance. To date, multiple laboratory protocols have been developed by manufacturers and asset owners, and most of the methods documented are used universally for testing CUI coatings. Even so, the test standards/methods are still a relatively vague area, and formulators, specifiers and asset owners are often confused or undecided about which test(s) to adopt to demonstrate product suitability and to distinguish between the performance levels of similar products. The industry will therefore welcome the forthcoming ISO 19277 document, which will be the first internationally recognised standard for testing coatings for CUI applications.

TEST PROGRAMME FOR CUI COATINGS

For CUI coatings, a diverse test programme (see *Table 2* for suggested tests) must be deployed to demonstrate resistance to the multi-aggressive environment to which the coating is likely to be subjected during its service life. These tests cover environments ranging from immediately after application to in-service and, therefore, simulate performance levels at ambient temperatures, after heating exposure, and in cyclical operation.

The test programme affords a way of demonstrating the combined and individual properties of coating systems. As no single universal CUI test protocol exists that covers the full range of exposure scenarios for a coating during its service life, this programme provides useful insights into a CUI coating's performance.

As indicated in *Table 2*, there are many potentially catastrophic elements – from application to service – which can attack and jeopardise the integrity of the coating system and so compromise its service life. It is essential to consider the key coating parameters and to demonstrate the performance levels which the protective coating is expected to deliver. Such a test programme can provide valuable evidence of a coating's suitability for CUI use.

POLYSILOXANE CHEMISTRY AND SUITABILITY FOR CUI

To deliver the protection needed in the multi-aggressive environments that occur in service, it is vital to choose the material carefully. Polysiloxane polymers possess particular properties, including resistance to hot water immersion, elevated temperatures, chemicals and

Table 2: Comparison of laboratory and expected service environments for CUI coatings.

Test type	Description	Exposure in practice
CUI cycling test programme	To simulate a typical CUI environment in which the coating demonstrates long-term durability in cyclical operation in such an aggressive scenario.	The subjected coating will be in a CUI environment throughout its required service life.
Thermal resistance	Demonstrates that the coating can endure high temperatures without degradation.	Substrate temperatures are likely to be cryogenic or elevated and cyclical throughout service life.
Salt spray	The product is able to provide high levels of anticorrosive protection to the substrate.	Awaiting service, in transit and in service.
Hot water immersion (HWI)	Immersion is a part of CUI. Hence, the coating must withstand heated immersion so as to prevent any corrosion of the substrate.	In a CUI environment e.g. cyclical wet/dry environments.
Adhesion	To demonstrate that the coating can adhere to the required substrate with sufficient strength so as to provide long-term service life.	Continuously throughout service life.
Chemical resistance	High performance in acidic & hydrocarbon chemical environments shows that the coating can perform, without being degraded by corrosive foreign contaminants.	In service from leaching insulation, awaiting service & in transit, or spillage on-site.
Impact resistance/cylindrical mandrel	Demonstrates that the coating is flexible and hard and can endure in-service stresses.	In service, during maintenance & in transit.
Pencil hardness	Demonstrates the coating's film hardness & the physical state of the polymeric coating in question.	In transit and during service life.
Abrasion	Abrasion testing will reveal the coating system's levels of film hardness, and cohesive and adhesive strength.	In transit and during service life.
QUV weathering	Cyclical weathering demonstrates resistance to UV and condensation cycles.	In storage and transit.
Solvent-wipe	Demonstrates the cure state of the TGPS.	Field testing indicates the cure state.

UV degradation, that enable them to withstand hostile CUI environments. From shop application through to end-use, the polymer and resulting coating provide protection for the substrate via the innate inorganic-polymer backbone.

A polysiloxane polymer has a backbone based on the [-Si-O-Si-]n structure. The silicon-oxygen bond is very resistant to heat and UV degradation due to its elevated bond dissociation energy (452 kJ/mol) and the fact that it is already oxidised. This compares very favourably with traditional congeners such as the carbon-carbon bonds of organic-based polymers that have a lower bond dissociation energy

Table 3: Polysiloxane evolution.

Chemistry	Component	Curing mechanism
First generation polysiloxanes (FGPS)	Two	Ambient
Second generation polysiloxanes (SGPS)	One/two	Thermal (150 – 180 °C)
Third generation polysiloxanes (TGPS)	One	Ambient

Table 4: Test results for second and third generation polysiloxane CUI coatings. All testing was done after curing coatings for 168 hours at 23 °C and 50 % rel. humidity.

Test type	Test procedure	SGPS - A (IMM)	SGPS - B (IC)	TGPS
CUI	1. 16 hours at 204 °C 2. Thermal shock (water, 23 °C) 3. 8 hours in HWI 5 % NaCl (95 °C) Repeat 80 cycles	No cracking, delamination or blistering. Heavy rusting under film	Blistering & cracking present with corrosion spots across film.	No cracking, delamination, blistering or corrosion.
Adhesion: cross-cut & pull-off	PosiTest AT-A Automatic Adhesion Tester	4A – 5A – cross cut (X-cut) 2.5 MPa 100 % adhesion failure	3A – Cross cut (X-cut) 1.5 MPa 100 % adhesion failure	5A – cross cut (X-cut) 5 MPa 100 % cohesive – dolly
Salt spray	Q-FOG cyclical corrosion chamber. 1440 h, C5	Immeasurable corrosion creep & heavy corrosion build-up	High corrosion creep, blistering & corrosion build-up	Max. 1 mm corrosion creep & no blistering
Hot water immersion (HWI)	Immersion for 4000 h at 90 °C (5 % NaCl solution)	Blistering & delamination from substrate; heavy corrosion under film	Cracking, blistering & corrosion build-up on coating film	No cracking or blistering or adhesion loss; 99 % corrosion free
Impact resistance	TQC Direct impact tester	25 cm	< 5 cm	25 cm
Cylindrical mandrel (bend)	TQC Cylindrical bend test 100 mm (SP1820) 0.75 mm panels	32 mm – cracking	32 mm – cracking / delamination	32 mm – microcracking
Pencil hardness	TQC Pencil Hardness Test (750 g) VF2377	2B (ambient-cured, 7 days)	< 9B (ambient-cured, 7 days)	7 H (ambient-cured, 7 days)
Thermal resistance	Heat to 650 °C. Allow to cool to ambient temperature	No cracking blistering or adhesion loss	400 °C heating, no cracking blistering or adhesion loss	No cracking, blistering or adhesion loss
Cryogenic testing	1. Heating at 200 °C for 30 min 2. Cooling to 23 °C for 30 min 3. Immersing in liquid nitrogen at -196 °C for 30 min 4. Directly returned to the oven at 200 °C Repeat cycle 5 times	Not tested	Not tested	No cracking, delamination or blistering. Full corrosive and mechanical properties remain
Abrasion resistance	Taber Abraser (Abrader) – Model 5135	Fails 500 cycles Ambient – to the substrate	Passes 500 cycles Ambient – 100 µm film loss (soft film made accurate measurements difficult)	Passes 500 cycles Ambient – 110 µm film loss
Chemical resistance	Using 10 % HCl & H2SO4, diesel & benzene (hydrocarbons)	24 hours' immersion HCl – coating failure & corrosion H_2SO_4 – coating failure & corrosion Hydrocarbon – coating soft & removed to the substrate	24 hours' immersion HCl – coating failure & corrosion H_2SO_4 – coating failure & corrosion Hydrocarbons – coating soft & easily removed to the substrate	720 h – acid resistance + 1 year – hydrocarbon resistance No removal of coating or blistering. Film remains hard with 100 % integrity
QUV weathering	Cyclical UV/condensation 3000 h	Excessive colour change and chalking	Colour change	No change
Solvent-wipe	Using MEK or xylene 50 rubs using solvent soaked cheesecloth or equivalent	Fails to substrate	Fails to substrate	Passes, no removal of coating

(346 kJ/mol) and the potential to undergo further oxidation, a fact which makes organic polymers more susceptible to degradation. The difference in bond strength partly explains why organic polymers generally have lower temperature tolerances and undergo much faster UV degradation compared to siloxane-based coatings. Hence, where there is a requirement for heat and UV resistance (whether individually or together), polysiloxane chemistry is much more suitable than organic-polymer chemistry.

POLYSILOXANE COATING EVOLUTION

First Generation Polysiloxane (FGPS)

The mid-1990s saw the introduction of a polysiloxane hybrid coating that was composed of an epoxy-siloxane hybrid. It was developed for use as an elevated-temperature coating, whether exposed or under insulation, and was serviceable up to 600 °C. The polysiloxane hybrid chemistry still contained a densely cross-linked organic polymeric structure. In cyclical ambient-hot-ambient service on small-diameter piping or convoluted small shapes, FGPS tended to crack and delaminate from the substrate due to internal stresses arising from the innate two-component highly cross-linked hybrid chemistry. Over the intervening two decades, first-generation polysiloxane continued to be used for ambient-temperature service but is rarely used on high-heat equipment.

Second Generation Polysiloxane (SGPS)

During the last 15 years, IMM (1st/2nd generation) or IC coatings have been widely used for CUI mitigation purposes. These coatings fall into the category of second-generation polysiloxanes (SGPS). For such coating chemistries, the temperature limits are normally in the region of 650 °C. The greater heat tolerance mostly stems from the elimination of organic components, a high concentration of inorganic siloxane-based polymers and greater flexibility. The introduction of these coatings was a step forward in providing protection to substrates under insulation. However, there were issues with field application, such as a soft film which requires heating, typically at > 150 °C. The necessary heating step affects not only the mechanical properties of the coating but also the corrosion, UV, chemical and adhesion properties, all of which are essential for ensuring maximum CUI protection. Hence, there have been many instances of failures in the field, whether before service at > 150 °C or at service temperatures below the curing temperature.

Third Generation Polysiloxane (TGPS)

Now available is a 3rd generation polysiloxane which has been introduced for CUI mitigation purposes. Developed and launched in 2015, the new coating has been tested against multiple laboratory and field test protocols. The characteristics of this coating are that it is a one component, fully ambient-curing inorganic polysiloxane which is ceramic in nature and eliminates the field issues associated with SGPS coatings. With the elimination of the heating step that was previously required for SGPS, full protection is conferred upon application at ambient temperatures as low as 1 °C and across a specified operating range of -196 to 650 °C, without the need for heating to develop the properties required for CUI protection.

POLYSILOXANE CUI PERFORMANCE

The following comprehensive test programme was designed to evaluate CUI coatings in a variety of environments and physical states. One of the best known CUI tests is the CUI cycle test described in *Table 4*. As a wet/dry, thermal cycling test, it provides a useful insight into CUI resistance and can be readily simulated by manufacturers. However, the heating step at 204 °C masks the properties of the heat-curing coating system. Accordingly, to demonstrate the properties conferred prior to heating, other tests must be performed that reveal the coating's performance at lower temperatures of < 150 °C and at elevated temperatures of > 150 °C. The coating system needs to demonstrate that it can provide corrosion, hot water immersion (HWI), mechanical, UV and chemical resistance from ambient application in the absence of heating. Whether the coating is exposed to low temperatures < 150 °C under insulation, in transportation, outdoor storage or general weathering conditions, good performance is critical to its longevity before, during and after installation.

Laboratory testing of TGPS and associated advances in current technologies have supported field-application findings in respect of hardness development, resistance to mechanical damage (transportation) and corrosion resistance prior to service. Consequently, TGPS is now the coating of choice for CUI mitigation for numerous major oil and chemical companies. *Figure 1* shows some applications on asset structures that are being protected by a TGPS coating.

LIQUID-APPLIED INSULATION COATINGS

Thermal insulation coatings (TICs) have been used for over ten years in a range of different applications, including thermal insulation and personnel protection, where they have either partly or wholly replaced traditional insulation cladding systems and wire cages for both hot and cold processing temperatures. Generally, the resulting low thermal conductivity (λ) properties of the coatings allow the hot and cold temperatures of processing equipment, such as pipes, ductwork or tanks, to be lowered to within safe-to-touch limits (personnel protection), and enable temperatures in storage units to be maintained and/or thermal insulation properties to be provided.

For personnel-protection purposes, TIC coatings can replace traditional systems or wire cages, as they are less labour intensive, safer, minimise space requirement, permit faster application to complex structures, and provide thin-film protection for workers, who can touch the outer coating surface without suffering burns. Additionally, the elimination of the need for traditional insulation and cladding abolishes the CUI concept altogether and any corrosion (from mechanical or other sources) which occurs is visible and can be easily rectified during a maintenance programme. TIC coating technologies can be applied at ambient or elevated temperatures for in-service applications and will adhere to a range of anti-corrosion primers, thereby delivering a high-performance coating system that provides anti-corrosion and insulation properties. This benefits of this monolithic coating approach to insulation are mainly to be found in personnel-protection scenarios.

Up to now, TIC coatings have been formulated from predominantly organic-based polymers (acrylics or epoxies) and then filled with ceramic/glass microspheres or silica-based insulation media, the specific media largely determining the resulting low thermal conductivities of the TIC coatings. Currently, there are two major drawbacks of organic-based TIC coatings. First, they have relatively low film-build capabilities between 500 and 1000 µm. It can take up to ten or more coats to achieve the required thickness for providing insulation properties. Second, their heat resistance is limited to -40 to 180 °C.

A new addition to liquid-applied insulation is now available and was com-

Table 5: Thermal insulation coatings overview.

TIC coating	Temperature range °C	λ value (W/m/K)	Film-build capabilities µm per coat
Acrylic	-40 to 180	0.05–0.09	500–1000
Epoxy	0 to 150	0.1	5000–19,000
Polysiloxane	-60 to 400	0.03–0.07	20,000 (800)

mercialised in early 2017. The underlying chemistry is a third-generation polysiloxane which yields a water-borne (low-VOC) one-component, ambient-curing polysiloxane TIC coating. It is designed for ultra-high-build (UHB) in excess of 20,000 µm dry film thickness (DFT) and a temperature tolerance range from -60 to 400 °C which exceeds the current 180 °C limitation of thermal insulation coatings. The polysiloxane TIC coating can be applied over a TGPS CUI primer as a system for high-temperature exposure, personnel protection and thermal insulation purposes.
Additionally, the use of a polysiloxane polymer confers high weathering resistance and thermal cycling properties in ultra-high film thicknesses greater than 20,000 µm, eliminating the cladding needed in traditional insulation systems and providing the film thickness capabilities needed for efficient thermal insulation and personnel protection properties.

TGPS CUI MITIGATION SYSTEM

› TGPS CUI primer – high temperature, anti-corrosion primer
As of 2017, the new developments in polysiloxane coatings, both in anti-corrosion and insulation products, mean that it is now possible to protect assets in respect of thermal insulation, anti-corrosion and personnel protection with a two-coat system.
› TGPS CUI primer – high temperature, anti-corrosion primer
› TGPS TIC coating – low λ, UHB and heat resistance > 180 °C
With this system, coatings can replace traditional coating/insulation systems, which are prone to excessive corrosion build-up in CUI environments. By using a coating system which obviates the need for protective cladding, asset owners can remove the hidden corrosion aspect of CUI. The benefit is easier corrosion monitoring and maintenance in visual inspection programmes, without the need for dismantling/destruction. *Figure 2* shows various site applications of the TGPS CUI mitigation system. The coating was applied on-site (in service) at elevated temperatures between 100 and 220 °C. As a result, the coated substrate temperature was reduced to below the 60 °C threshold for personal protection under ISO 13732.

REFERENCE

[1] NACE International. SP0198-2017, "Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A Systems Approach".

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"Maintenance cycles of the new TGPS system are reduced and improved."

3 questions to James Reynolds

The ISO 19277 document is now available. How satisfied are you with it? Do you miss anything? *The newly published ISO 19277 will allow coating developers and testing instututes to follow the parameters (which has not been available until now) for CUI coatings. In that sense, it will offer comparative data aiding the end-user in their selection process. Regarding modifications, the standard allows for heat curing products to be included (end-users must have caution when specifying such products) and lacks clarity on whether a coating/insulation interation needs to be tested.*

The TGPS based insulation coatings is designed for ultra-high-build in excess of 20,000 µm dry film thickness. How do you apply such a high amount of material in one production step? *The application of the TGPS insulation coating is applied via a peristaltic pump spray machine in a multi-pass single coat method, building the film to the desired thickness.*

How do you compare the maintenance cycles of traditional CUI mitigation systems with your new TGPS based system (e.g. cycle times, labour costs)? *Maintenance cycles of TGPS vs traditional CUI mitigation systems are significantly reduced and improved. Firstly, applying insulation coatings is faster than installing traditional insulation, hence, saving on labour costs. Secondly, the potential hidden corrosion issue (CUI) is no longer present with a TGPS CUI system as the cladding layer is not necessary. Therefore, instead of the traditional three material system (substrate/insulation/cladding) you have two coat (CUI primer and insulation) system, where by, if there was corrosion you could visually inspect the area. As a result, the approach of the TGPS CUI system removes the hidden and costly corrosion issues of CUI.*