

Safety practice

Corrosion under insulation – a continuing threat to industry

Andrew Duncan and Andrew Piercy, Intertek Production & Integrity Assurance

Summary

Corrosion Under Insulation (CUI) is a significant safety risk to the oil & gas production, oil refining and process industries, and also to society-critical infrastructure such as hospitals. The problem incurs significant costs associated with inspection, stripping insulation, scaffolding, shutdowns due to leaks and replacement of corroded equipment. More importantly than the costs are the safety risks from process fluid leaks.

As with all risks to health and safety there is a hierarchy of risk control measures which will help in ensuring risks are As Low As Reasonably Practicable (ALARP). The paper discusses how improving installation practices and the application of Corrosion Threats Assessments, Risk Based Assessment and NDT techniques such as Pulsed Eddy Current are helping to identify, quantify and manage the risks.

Keywords: Corrosion under insulation, CUI

Introduction

For many years Corrosion Under Insulation (CUI) has been a significant safety risk to the oil & gas production, oil refining and process industries, and also to society-critical infrastructure such as hospitals. The problem continues to dog industry, incurring significant costs associated with inspection, stripping insulation, scaffolding, shutdowns due to leaks and replacement of corroded equipment. More important than the costs associated with CUI are the safety risks from process fluid leaks.

CUI is most commonly associated with corrosion under insulation, however, the same phenomenon can occur under fireproofing and intumescent coatings.

Whilst CUI is usually considered a risk associated with carbon and stainless steels in the high hazard process industries, it is also found in HVAC (Heating, Ventilation and Air Conditioning) units in infrastructure such as hospitals, where it has the potential to cause downtime and disruption of vital areas such as Critical Care Units and operating theatres.

Some cooling systems use potentially hazardous fluids such as ammonia, and whilst the industry with which the cooling system is associated with may not be designated high hazard (such as skating rinks and food cold storage) a leak of ammonia into an enclosed space has potentially high consequences (for example, in 2013 some 15 people died and 25 others were injured when

ammonia leaked at a cold storage unit in Shanghai, China). If ammonia is used in cooling systems associated with food production, leaks could also contaminate the food product. This article separately addresses CUI in the high hazard industries and society-critical infrastructure.

CUI in high hazard industries

The UK's Health & Safety Executive (HSE) offshore leak statistics for 1992 to 2018 and 2015 to 2018 show a significant number of hydrocarbon leaks associated with CUI as the cause. UK Duty Holders are required to report hydrocarbon leaks under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 (RIDDOR). Whilst some care should be taken with this data because the reporting system in place requires the Duty Holder to give their first impressions of the cause of the leak, which may not be initially assessed by a materials and corrosion specialist, they do give a reasonable overview of the problem.

The HSE has published a number of CUI related articles involving refineries and offshore installations which are listed at the end of this article. These show that CUI is not limited to damaging carbon steels but is also a threat to stainless steels, including Duplex stainless steel. One of the first major findings of the damaging effects of CUI on duplex stainless steel was found in the 1980s on a 22% Cr duplex stainless steel separator on an offshore oil and gas platform in the Norwegian sector of the North Sea which experienced external chloride stress corrosion cracking.

Sources of water causing CUI include the external environment (marine environment, rain, deluge systems) and also by condensation under the insulation, "sweating", which can leach corrosive ions from insulation.

The UK's Oil & Gas Authority (OGA, www.ogauthority.co.uk) has a key theme of asset integrity in which it identifies two key problems as being (i) process vessel inspection and (ii) corrosion under insulation. The OGA website states that:

"It is estimated that the total cost to the UKCS (UK Continental Shelf) from CUI and VI (vessel inspection) is in excess of £300 million per annum, of which over £100 million relates to OPEX incurred due to the limitations of the current VI and CUI inspection methods",

And

"CUI can be difficult to detect due to the insulation cover that masks the corrosion problem, and insulation removal is expensive. CUI can lead to unplanned downtime and raised potential for loss of hydrocarbon containment and associated risks".



Figure 1: Images of CUI (Reproduced with kind permission from the Energy Institute from their Guidance on Corrosion Management ¹)

The Petroleum Safety Authority Norway (PSA) has similar references to CUI on its website, as does the USA's Bureau of Safety and Environmental Enforcement (BSEE), and the Australian Regulator NOPSEMA. CUI is truly a worldwide problem.

What has changed with CUI

CUI remains a threat to health and safety, the environment and business continuity, however, a number of organisations provide helpful information and guidance on how to locate and inspect for CUI:

- the Energy Institute (EI, www.energyinstitute.org)
 - the Association for Materials Protection and Performance (AMPP) – formerly National Association of Corrosion Engineers (NACE International, www.nace.org)
 - the Oil and Gas Technology Centre (OGTC, www.theogtc.com)
 - HOIS (Harwell Offshore Inspection Services), (ESR Technology, www.esrtechnology.com)
- ESR's website states: "CUI is an area of focus because of significant safety and cost implications to the oil and gas industry":
- CUI has caused ruptures and fires leading to damage costing tens of millions of pounds on single assets in addition to the risk of loss of life and damage to the environment
 - it is estimated that 60% of piping failures are due to CUI
 - CUI is unpredictable — and usually makes its presence known before it is found
 - traditional methods of detection involve stripping and replacing insulation which is costly and time consuming"

Non-Destructive Testing (NDT) inspection service providers have

developed and significantly improved inspection techniques such as Guided Wave and Pulsed Eddy Current (PEC) techniques to identify and quantify CUI.

Corrosion Threats Assessment (CTA) procedures have improved, with guidance being developed and widely followed by industry on the Risk Based Assessment (RBA) approach to managing CUI. The following stages may be applied when undertaking a CUI CTA:

- identify all safety critical elements (SCE) which have insulation
- identify the age of the SCEs
- identify the materials of construction of the SCEs and hence the likely mode of failure
- identify the risk mitigation measures on the insulated SCEs, such as coatings, and the likely effectiveness of those mitigation measures
- determine the consequences of failure of the SCEs so that a Risk Based Assessment can be performed — this is typically done using a 5 x 5 matrix of threat vs consequences of failure
- identify the temperature of operation of SCEs with insulation, and using the available guidance calculate the likely corrosion rates
- using the available guidance to identify locations most at risk of CUI
- implement inspection methods to locate and quantify CUI.

A note of caution — experience has shown there to be an element of uncertainty as to where CUI can occur and at what rates. This makes the RBA approach less than 100% certain, and the best approach to identifying CUI has been to remove the insulation to allow visual inspection, which is expensive, time consuming and disruptive. Developing NDT technologies are helping to overcome these uncertainties. There is an anecdotal case of an offshore operator who removed some 90% of the insulation to undertake visual inspections, with the remaining 10% considered to be at low risk, several months after reinstating the insulation a hydrocarbon leak occurred in an area of the 10% where insulation had not been removed.

There is also a case where an operator removed 100% of the insulation to inspect the pipework which showed everything in good order, only for a failure to occur less than two years later because the insulation weather proofing was inadequately

re-installed, allowing water into the insulation and thereby creating a CUI problem where there was none before. Even where cladding has been correctly installed, damage can occur due to workers stepping on insulated equipment creating gaps in the weather proofing allowing water ingress.

Management of CUI

As with all risks to health and safety there is a hierarchy of risk control measures which typically follows that in Table 1 and which will help to contribute to ensuring risks are As Low As Reasonably Practicable (ALARP).

Energy Institute guidance on CUI

The EI has produced *Guidance for Corrosion Management in Oil and Gas Production and Processing*¹, and also an *External Corrosion Awareness Handbook: A Guide for Visual Recognition of External Integrity Threats to Upstream Oil and Gas Production Plant* (currently being revised). Section I.12 of the EI Guidance covers CUI, extracts of which are included below:

Despite the advances in CUI NDT technology the EI Guidance for Corrosion Management states that “insulation removal is still the most effective form of thorough inspection”.

The CUI section on carbon steels in the EI Guidance for Corrosion Management identifies a number of factors to take into consideration, including:

- CUI can be more aggressive than atmospheric corrosion due to increased time of wetness as the insulation holds the water against the surface and can also cause salt concentrations
- the time of wetting is an important factor for CUI
- water ingress occurs through defects in the cladding during installation and also damage occurring on the surface – so personnel must not walk on insulated equipment
- coating life and remaining life under insulation are unpredictable
- the presence of wet insulation can reduce expected coating life from ~30 years down to less than two years, and for thermally sprayed aluminium (TSA) from ~60 years down to ~five years
- thin-walled piping such as small-bore tubing are likely to fail first

Hierarchy of risk management	Guidance	What this means for CUI
<i>Elimination</i>	Inherent safety aspects in the hierarchy of risk management, e.g. redesign the job or substitute so the hazard is removed	Because CUI requires the presence of insulation (or intumescent coatings) to create the hazard, removal of insulation where possible eliminates the hazard. Substituting cages for personnel protection rather than insulation is an example
<i>Substitution</i>	Replace the material or process with a less hazardous one	Use low chloride and sulphate insulating materials
<i>Engineering controls</i>	Use work equipment or other measures to reduce the risk	Apply coatings to the metal surface to provide corrosion protection Use materials resistant to stress corrosion cracking
<i>Administrative controls</i>	Procedural approach to managing risk	Of limited use for managing CUI other than to identify where insulation is on site
<i>Personal protective equipment (PPE)</i>	Only for where all other measures have been tried	It is usually mandatory for personnel working on potentially hazardous sites and equipment to wear PPE, however this is not a suitable approach to managing the consequences of CUI, particularly in the event of sudden escape of toxic fluids

Table 1: Hierarchy of risk control measures

- likelihood of CUI occurring increases with age of the asset.

The CUI section on corrosion resistant alloys (CRA) in the EI Guidance for Corrosion Management identifies a number of factors to take into consideration, including:

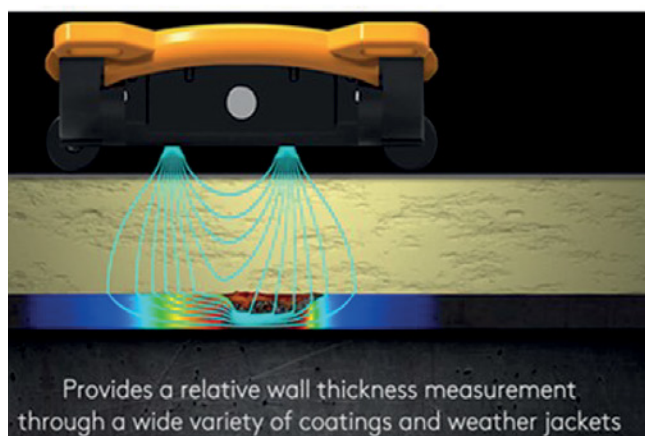
- stress corrosion cracking has occurred for austenitic and duplex stainless steels*
- periodic inspection for cracking is of limited value for pre-empting failure because it can progress rapidly to failure, whereas inspecting for coating damage has value as a way to identify susceptible areas*
- in marine environments the presence of chlorides should be considered as almost inevitable under insulation*

The EI Guidance identifies that TSA is generally superior to organic coatings for mitigating CUI.

Inspecting for CUI

The available guidance suggests the only guaranteed method for identifying the presence of CUI is to strip the insulation and visually inspect. However, work performed by inspection service providers and by ESR HOIS shows there is increasing confidence in non-destructive / non-invasive techniques such as Pulsed Eddy Current and Guided Wave techniques.

There have been recent developments in the application of the Pulsed Eddy Current technique. Pulsed Eddy Current (PEC) is an advanced electromagnetic inspection technology used to identify the presence of CUI through insulation, however it has not always been 100% capable of accurately sizing defects through insulation. Recent advances in UT probe technology using the Lyft system is claimed to enable highly accurate single pass coverage for general corrosion of a 457 mm grid for metal thicknesses of 6 to 25 mm and up to 102 mm cladded insulation at high inspection rates. Quantifying the depth of localised pitting corrosion remains a challenge, but the technique will average the data for pits and will identify to the user areas for closer inspection. The images below provided by kind permission of Intertek Industry Services (<https://www.intertek.com/industries-services/>) indicate the probe reading through insulation and the 3-D image which can be produced.



CUI in society-critical infrastructure

Commercial, residential, local government, medical and industrial buildings all contain closed water systems. While pipework failures due to CUI (or other causes) may be inconvenient or disruptive to many of these installations, in critical infrastructure like hospitals, pipework failure can literally shut down wards, operating theatres and clinics. Other major vulnerable societal infrastructure could include educational establishments.

The pipework systems will typically include potable (drinking) water, chilled water (CHW) and low temperature hot water (LTHW); medical gases systems could also potentially be indirectly affected. The complexities of these systems can vary enormously, for example, centralised district heating systems with a common boiler installation or individual hot water heaters and air conditioning units. Newer installations may be based around renewable energy sources, for example, ground source heat pumps or PV cells. Whatever the type of system, the pipework carrying the water will be thermally insulated, it will contain valves and branches, it could be installed on rooftops, running through duct work, above false ceilings or beneath floors. All of these are susceptible to CUI depending on the pipework materials, insulation materials and environment.

CUI of pipework systems is a frequently encountered problem, not only in carbon steel but other materials such as copper and its alloys. Though plastic pipework is becoming more common, particularly for smaller installations, copper is still a widely used material for pipework, along with its alloys for valves and other fittings. As we will see, copper is susceptible to a particularly insidious form of CUI.

In recent years, installations of copper and carbon steel have shifted from metallurgical jointing, such as soldering, welding and brazing, towards mechanical jointing, for example, crimping and push-fits, that are faster and cheaper to install, but may be more susceptible to leaking. Copper pipework has always been supplied in low wall thicknesses depending on the pipe diameter, typically 0.8 to 1.5 mm, but carbon steel pipework, which traditionally would have been 3 to 6 mm in wall thickness, is also now supplied for pipework systems in these lower wall thickness — so-called thin-walled carbon steel (TWCS). This much lower wall thickness

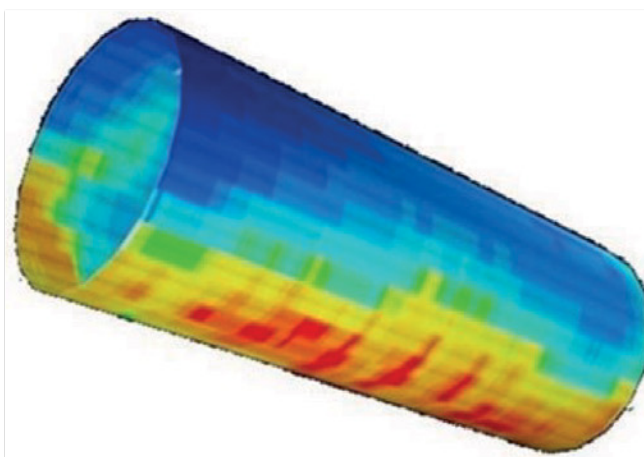


Figure 2: The probe reading through insulation and the 3-D image which can be produced (By kind permission of Intertek Industry Services (<https://www.intertek.com/industries-services/>))

reduces the potential time-to-failure if CUI (or any other corrosion mechanism) is initiated.

The main types of thermal insulation used on pipework systems are compressed mineral fibre, rigid phenolic foam and flexible foam. Of these, the rigid phenolic foam is the most problematic with respect to CUI. The compressed mineral fibre and rigid phenolic foam insulations are supplied in sections and usually feature an external aluminium foil layer. Some versions of rigid phenolic foam also feature a coating or barrier film on the inner surface that would be in contact with the metal pipe surface. The applied sections of insulation are usually joined together with aluminium foil tape.

Unlike the process and oil & gas industries discussed above, insulated pipework systems in, for example, hospitals, are not normally subject to, or amenable to, routine or planned/risk-based inspection for corrosion, whether that is CUI or any other mechanism. The first knowledge of a CUI-related problem is usually when a leak is detected in a false ceiling of a critical area, or when corrosion has been found during a mechanical intervention, such as extension of an existing installation for a new wing or clinic. This means that it is vitally important that installation practices, both the pipework itself and insulation/lagging, are followed to minimise the risk of CUI.

External pipework

Air handling units (AHU) for air conditioning systems are often situated on roof tops. It is not unusual to have long pipe runs in racks across roofs with all the pipework and instrumentation insulated and protected from the elements by tape, cladding and boxes, etc. The pipework can be copper or carbon steel, with the carbon steel often painted and/or galvanized; TSA is not typically



Figure 3: Examples of rooftop pipework CUI problems and poor insulation installations are shown below

used for infrastructure systems. Externally situated pipework is far more susceptible to corrosion than internal pipework, so protection from wetting is of paramount concern.

In the UK, BS 5970² provides guidance and recommendations for the installation of thermal insulation and specifically references the potential risk of corrosion:

"General corrosion can occur if wet insulation is allowed to remain in contact with carbon steel surfaces for prolonged periods, particularly if acidic products are present in the water or if they can be extracted from the insulating material itself."

Rigid phenolic foam insulation can leach acids when wetted, producing extremely corrosive conditions to both carbon steel and copper. While compressed mineral fibre does not usually leach acid species and should not contain appreciable chloride ions, if the insulation is wetted, this creates a poultice effect and a high time of wetness thus encouraging corrosion. If the insulated pipework is close to the coast, the environment will be classed as marine (Corrosivity Class C5³) and thus significantly more corrosive if the insulation becomes wet. Even if carbon steel pipework is galvanised, zinc corrosion protection performs poorly under constantly wetted conditions, increasing the zinc consumption rate and producing voluminous, non-protective 'white rust'.

BS 5970 provides visual examples/illustrations of good practice and specific guidance on how to minimise the risk of water ingress to insulation by addressing, for example, cutting and fit, orientation of seams, direction of overlaps, staggering of layered joints, use of sealants and the use and positions of rivets and fasteners. The insulation manufacturers also produce guidance and installation documents for their products. All of these can have an impact on whether CUI can or will occur. The most common areas for CUI are where the insulation is punctured by pipe supports and brackets or is incomplete around flanges, ports, instrumentation and valves.

Some examples of rooftop pipework CUI problems and poor insulation installations are shown in Figure 3.

Internal pipework

Internal building piping systems CUI problems are not usually encountered due to wetting of the pipework and insulation from external sources. Sources of moisture and wetting of insulation and pipework surfaces within buildings are typically from pipework leaks or condensation. Leaks can occur from mechanical joints after initial installation or maintenance. If these leaks are not detected, the installed (or reinstated) insulation can quickly become saturated with water. Just as with the externally situated pipework, once the insulation is wetted the pipework will begin to corrode. However, Intertek's experience from site and laboratory investigations of these types of CUI problems on carbon steel/galvanised steel is that the corrosion tends to be relatively localised to the joints. If these leaks are in plant rooms, for example, where maintenance personnel are regularly in attendance, it may be detected or noticed, and the corrosion stopped by cleaning, repairs, and re-insulation. However, if pipework is running through ductwork or above false ceilings, the first indications of a problem might not be found for a long period of time. Examples of lightly corroded galvanised TWCS pipework are shown in Figure 4.

Copper pipework can also suffer external corrosion due to water system leaks, but this is not usually a significant problem



Figure 4: Examples of lightly corroded galvanised TWCS pipework are shown below

with main LTHW circuits. The main problem with copper pipework and CUI is encountered in air conditioning systems where chilled water or refrigerant circuits, such as ammonia, are used and is known as *Ant's Nest* (ANC) or *Formicary Corrosion*. There is relatively little information on this form of attack in the general corrosion literature, but the mechanism and causes have been investigated and reported in conference proceedings and specialist corrosion publications.

The first reported cases were in Belgium in 1965, but the main investigation work was conducted in Japan in the 1980s and 1990s. These studies have shown that the corrosion occurs in the simultaneous presence of moisture, oxygen and organic acid species, primarily formic acid.

Typically, the copper surface will be discoloured with surface corrosion products varying from dull grey-black to red-brown or purple and/or blue/green, depending on the specific environment. While the colours of the external corrosion products can indicate the probability of ANC having occurred, visual examination alone cannot determine the severity of the sub-surface corrosion.

The corrosion initiates on the external tube surface. Pitting comprises a series of small interconnecting tunnels of random direction resulting from branching of the pits. The micro-tunnels associated are commonly filled with corrosion products such as Cu_2O , copper (I) oxide.

In most cases of ANC that Intertek has seen, the source of the corrosive organic acid species is phenolic foam insulation material commonly used for lagging pipework. Usually, the extracts from these foam materials contain a substantial phosphate and/or sulphate concentration, are highly acidic (pH's of < 1 have been measured) and contain formate and other organic acid species. Ammonia has also been detected in some foam extract samples. If the foam becomes wet either by condensation due to breaks in, or poor installation of, the insulation vapour barrier, or due to system water leaks, then the acid species can leach out of the foam and attack the copper tubing.

The photographs in Figure 5 show examples of the external corrosion products and discolouration, and the microscopic pitting through the pipe wall thickness.

Another form of corrosion that could be classed as CUI is external stress corrosion cracking (SCC) of susceptible alloys. In infrastructure systems, the material most commonly affected by SCC is brass. Brass alloys are used extensively for valves, tees,

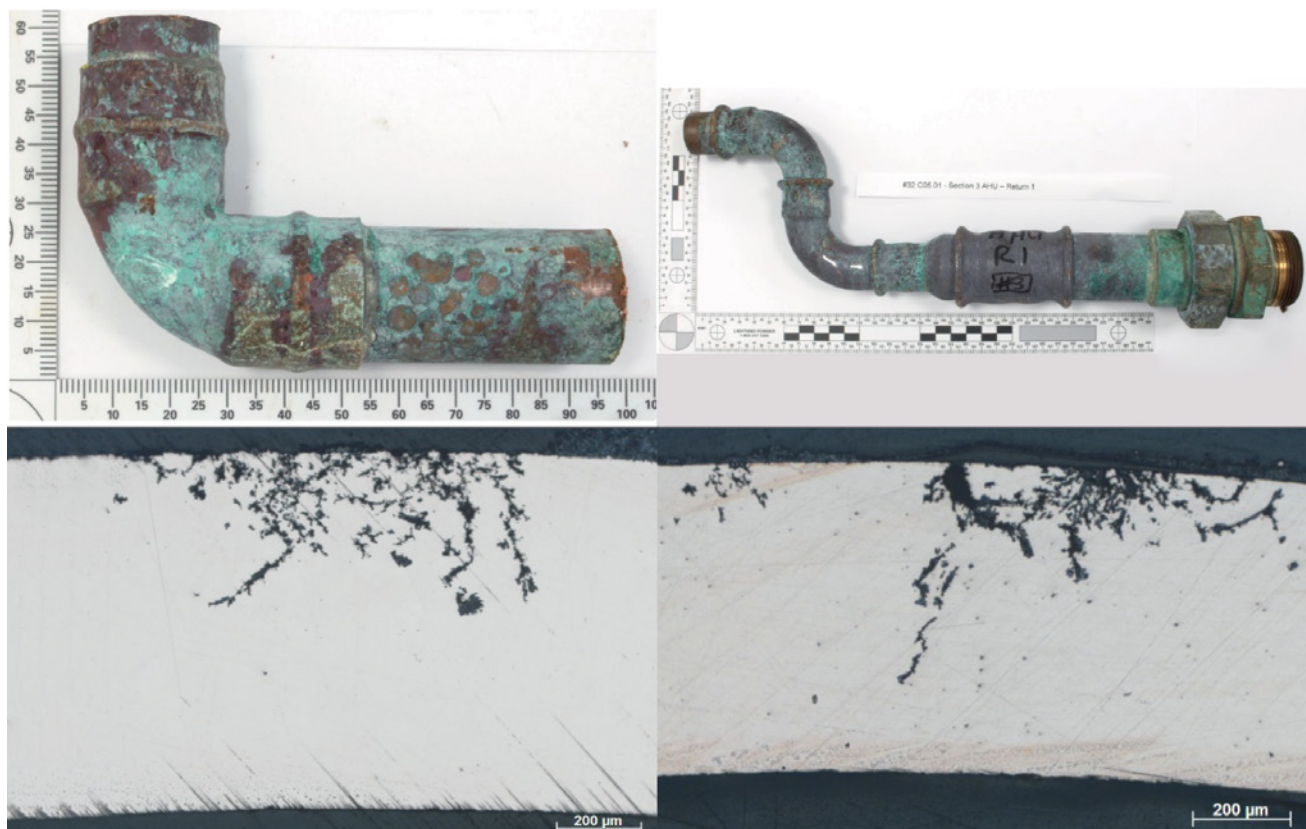


Figure 5: Examples of the external corrosion products and discolouration, and the microscopic pitting through the pipe wall thickness

fittings, nuts, etc. These are inherently stressed by a combination of manufacturing and installation stresses and can therefore crack in the presence of certain corrosives. As noted above, some insulating foams can leach out ammonia if they become wet. Ammonia and ammoniacal compounds are the main SCC-causing agents for brass alloys. Intertek has also seen examples of brass fittings suffering SCC where the benign insulation has become damp around toilet and wash-room facilities.

Conclusions

In conclusion, CUI remains a significant safety and business interruption risk to high hazard process industries and society-critical infrastructure such as hospitals.

Finding CUI still carries with it some uncertainties, however, improving installation practices and the application of Corrosion Threats Assessments, Risk Based Assessment and NDT techniques such as Pulsed Eddy Current are helping to identify, quantify and manage the risks.

Continued industry investment in NDT techniques is required to help to identify the areas at risk and pro-actively manage degradation to prevent future failures.

References and further reading

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- European Federation of Corrosion WP13 WP15 Corrosion

Under Insulation (CUI) Guidelines, No 55

- Energy Institute Guidance for Corrosion Management in Oil and Gas Production and Process, 2nd edition
- Energy Institute External Corrosion Awareness Handbook: A Guide for Visual Recognition of External Integrity Threats to Upstream Oil and Gas Plant (2nd edition to be published 2021)
- Ant Nest Corrosion – Exploring the Labyrinth, P Elliot and R A Corbett, Paper 990342, NACE Corrosion Conference 1999

Standards

- API 510 Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration
- API 570 Piping Inspection Code: In-Service Inspection, Rating, Repair and Alteration of Piping Systems
- API 571 Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
- API 574 Inspection Practices for Piping System Components
- API 580 Risk Based Inspection
- API 581 Risk Based Inspection Technology
- API RP 583 Corrosion Under Insulation and Fire Proofing
- DNV-RP-G101 Risk Based Inspection of Offshore Topsides Static Mechanical Equipment
- DNVGL-RP-G109 Managing the Significant Threat of Corrosion Under Insulation (CUI)
- EFC 55 Corrosion Under Insulation Guidelines
- NACE SP0198 The Control of Corrosion of Metals Under Insulation and Fireproofing Materials – A Systems Approach
- BS 5970:2012 Thermal insulation of pipework, ductwork, associated equipment and other industrial installations in the temperature range of -100°C to +870°C. Code of practice

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3. *BS EN ISO 12944-2, BS EN ISO 9223 Paints and varnishes – Corrosion protection of steel structures by protective paint systems, Classification of environments, Corrosion of metals and alloys, Corrosivity of atmospheres, Classification, determination and estimation.*