MITIGATING CORROSION UNDER INSULATION (CUI)

SPREAD OF CORROSION ASSESSMENT ON ARMAFLEX INSULATION SYSTEMS IN A CONTINUOUS SALT-WATER SPRAY ENVIRONMENT

test conducted by
TNO/Endures

armacell®

1. A CORROSIVE PROBLEM

Defined simply, Corrosion Under Insulation (CUI) describes any type of corrosion that occurs due to moisture build up within the insulation system. That insulation might be thermal or acoustic. CUI usually occurs between 0°C and 120°C and is particularly critical above 60°C. It is especially prevalent in the oil and gas sector, where steel pipework is used extensively, and because facilities tend to be located in areas that are fertile for CUI. These include marine and offshore, hot/humid and high rainfall environments. In addition, variable processing conditions create heating and cooling process within the pipework that encourages a build-up of water within the insulation system.

CUI is insidious: It is hard to see – without first removing the insulation – and facilities can have hundreds of kilometres of pipework that need to be manually inspected. It is also a serious problem that can shut plants down – often at the cost of millions of dollars per day. In extreme cases, corrosion has been known to trigger catastrophic safety incidents.[1]

The World Corrosion Organization estimates that corrosion costs the global economy $2.2 trillion.[2] According to its figures, almost 45 percent of the cost of this corrosion – about $1 trillion annually – happens in the oil, gas and petrochemical industries.[2] Despite the numbers, CUI is widely acknowledged to be one of the most important issues facing plant operators. When it comes to insulation materials little research exists into the best method of preventing CUI to extend the pipework's life and optimise safety.

With this in mind, Armacell, a company that designs and manufacturers thermal and acoustic insulation systems for use in the oil and gas industry, commissioned leading test laboratory TNO/Endures, to review the performance of its closed-cell FEF (Flexible Elastomeric Foam) thermal insulation. Based in Amsterdam, TNO/Endures is a renowned authority on corrosion, especially in offshore and marine environments, and on the technologies and methods employed to extend the life of industrial equipment and facilities. Its research and findings are explained below.

2. TEST METHODOLOGY

While recognised standards and procedures for assessing the performance of anti-corrosive treatments exist, there are currently very few international standards available that address the specific influence of the insulation on CUI behaviour. Those that are available include ASTM International standards for determining the influence of insulation on Stress Corrosion Cracking (SCC) – specifically ASTM C692 and ASTM C871 or EN 13468.

Armacell offers insulation that satisfies the requirements of ASTM C692 – known as the 'drip test procedure' and offers low leachable chlorides when tested in accordance with ASTM C871 or EN 13468*. Armacell's insulation materials are also pH neutral. However, no standards exist to test the performance of insulation in respect to CUI mitigation when it is installed as a complete system on pipework. With this in mind, TNO/Endures[3] replicated a test method first developed with the global energy giant Shell back in 2009 and conducted by TNO/Endures to assess a range of insulation materials. This methodology is widely recognised by the oil and gas industry as an acceptable CUI analysis protocol and is seen by many specialists to be the precursor to a formal international standard.

* Specimen preparation in accordance with EN 13486: neither cut nor blended.

ARMAFLEX FLEXIBLE ELASTOMERIC FOAM (FEF) – THE BENEFITS

Armacell's Armaflex tested by TNO/Endures is designed to offer excellent thermal efficiency as well as provide an effective barrier to water and water vapour ingress. Armaflex is a light, flexible insulation material that is easy to install and provides an excellent level of adhesion both to itself and to the pipework on which it is applied. The result is a virtually seamless solution. The qualities of closed-cell FEF insulation materials are identified in the renowned work of Mr S. Winnik[4] : Corrosion Under Insulation (CUI) Guidelines (20 Mar 2008, S.Winnik). It says:

> *˘The closed-cell materials (e.g. flexible elastomeric foams and cellular glass) can provide a more effective barrier to water ingress than open-cell insulation materials (e.g. mineral wool and calcium silicate).˘*

Oil and gas customers who expect their installations to be operating from between 25 and 40 years are increasingly turning to Armacell insulation as part of their strategy to combat the threat from CUI – recognising that it can deliver a longer life cycle compared to traditional systems. Sites where Armaflex is installed include:

- The Terra Nova floating production storage and offloading facility in Canada
- BP's floating production storage and offloading facility in Angola
- Shell's floating exploration platform for the EA field in Nigeria
- Mobil's Kipper Tuna production platform in Australia
- BP's Glen Lyon (Quad 204) FPSO and Clair Ridge offshore platforms in the North Sea

TEST CONDITIONS

Heated water (80°C) was run through the steel test pipe in a closed controlled circulation system. This created the right temperature inside the pipe to provide optimum conditions for corrosion on the pipe's surface. In addition, to simulate extremely harsh environmental conditions, a sprinkler system was installed to continuously spray heated salt-water over the insulated pipe. These conditions were maintained for a period of 6 months**.

The steel pipe used by TNO/Endures was made of A106 carbon steel. It was 114 mm in diameter, 1000 mm in length with a wall thickness of 5.5 mm. It was divided into two parts by steel discs welded at both ends and in the middle. For the purposes of this test – to accelerate failure – the pipe was not treated with any coating (e.g. thermally sprayed aluminium or anti-corrosive paint) that are typically used for corrosion protection in real-life installations. Such treatments should always be considered as part of any real-life CUI mitigation strategy, regardless of the performance of the insulation system selected.

In a working deployment where Armaflex is used, it is highly unlikely that the insulation would be damaged. However, to investigate how well Armaflex mitigates against CUI in a 'worst case' scenario, TNO/Endures artificially created the conditions for CUI to occur. It prepared the two parts of the pipe (A) and (B), as follows:

ACCELERATED TEST TO FAILURE

The introduction of 5mm holes into the insulation of pipe A, and the external cladding of pipe B, created an extreme test environment. In a real-world situation it is highly unlikely that warm salt water would spray continuously over pipework and ingress so directly. It was therefore inevitable that where the water came into contact with the untreated pipe surface at the damaged areas, corrosion would naturally occur. A key objective of the test was to investigate how the insulation system prevented the spread of water and corrosion to other sections of the pipe – as would typically take place when open cell insulation systems are used.

There are currently no international standards for assessing the performance of insulation with respect to CUI. However, Shell has established an approach that is recognised as the de-facto standard for the industry and this method was used by TNO/Endures in its research.

** The salt water solution refers to ASTM B117, 5% NaCl solution at 35°C

Pipe A

- Layer 1 – 25mm of **HT/Armaflex Industrial** insulation all over adhered to pipe.
- Layer 2 – 25mm **HT/Armaflex Industrial** insulation all over adhered to the first insulation layer.

To simulate failure modes within the insulation system, 5mm*** holes in 3 rows - each row with two holes (at 2, 6 and 10 o'clock positions) – were introduced to the upper and lower surfaces.

The holes were drilled through the insulation to allow water to ingress directly to the pipe surface. The bottom holes were prepared to allow water that might enter the system to drain away. The two holes in each row were made 15 cm from the edge or the middle disc and 20 cm in between.

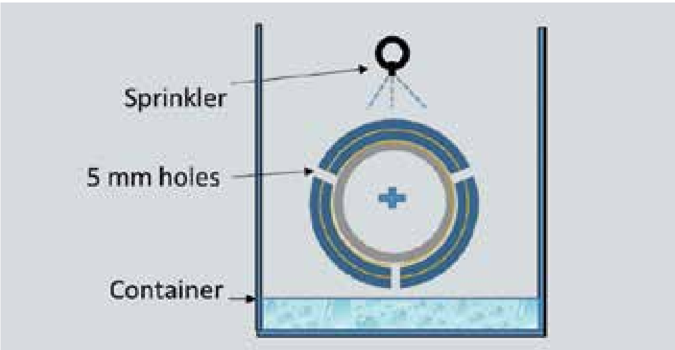

Fig 1. Test set up showing position of drilled holes

Pipe B

As with pipe A, two layers of **HT/Armaflex Industrial** insulation were applied to the pipe with Armaflex expansion spacers added to the 2nd layer (9 mm thick). The expansion spacers were introduced to mimic insulation systems installed with rigid covering in a real offshore facility. In this case a glass reinforced plastic (GRP) external weather barrier was used to cover the insulation. Holes were again drilled on the top of the insulation system and underneath but this time through the external weather barrier only. The insulation was left undamaged.

Figure 2. The test set up, pipe A is on the right and pipe B is on the left

*** In 'real-life' situations drain holes tend to be of a larger size, e.g. 50mm or greater

3. POST SIX MONTHS ANALYSIS

At the end of the six months the insulation was removed from pipe A and the insulation with weather barrier from pipe B. To better observe the pipes the corroded areas were chemically cleaned for 10 minutes at 20°C in a fresh solution. The solution was prepared as follows: mixing 1000 ml of hydrochloric acid with 1000 ml deionized water and adding 10 g of hexamethylenetetramine. After cleaning, the surfaces were rinsed in deionised water and dried in flowing air.

Experts from TNO/Endures ran the following tests:

- A visual examination
- Measurement of the thickness of the pipe wall with an ultrasonic meter
- Measurement of corrosion depth (using a negative replica microscope)

3.1 RESULTS – PIPE A

Whenever salt water comes into contact with steel pipe and oxygen is present, corrosion will occur. Corrosion would be accelerated in this test because the salt water was sprayed continuously, and the temperature of the pipe at 80°C created the optimal conditions for it to flourish. Given that salt water was allowed to directly come into contact with the surface of pipe A extensive corrosion could be expected at these damaged locations.

However, as the following images reveal, where corrosion occurred this was limited to the immediate areas around the holes drilled on the top of the pipe (at 2 and 10 o'clock).

Fig 3. Insulation layers (dark grey) and adhesive layers (brownish) – corrosion localised only to the immediate areas around the holes drilled into the insulation

It is important to note that it is the heating of the adhesive used by Armacell (from the 80°C of the water in the pipe) that has caused the general brown discoloration of the pipe surface – it is not the result of corrosion.

Notably, the underside of the pipe shows no sign of corrosion development (see Fig. 4). This means that no salt water reached the lower part of the pipe. The test institute concluded that this was due to the vapour barrier properties of the adhesive used by Armacell and of the closed-cell FEF material. The Institute says:

"No significant corrosion is observed in this area, which means that no salt water reached the lower part of the pipe through the holes and this can be attributable to the barrier properties of the good adhesive and the closed cell FEF insulation material.[5]"

Figure 4. Image of the lower, underside, of the pipe

PIPE A: CORROSION MEASUREMENTS

Given the extreme conditions of the test, it was inevitable that some localised corrosion would take place. A key part of the investigation was to look for the spread of corrosion outside of the damaged areas. The test demonstrated that corrosion was contained to the damage area and did not spread to the underside of the pipe, with limited lateral spread.

Fig 5. Close up of the deepest area of the localised corrosion (Pipe A)

The lack of corrosion spread was put down to the barrier properties of the closed cell FEF insulation material. **This performance was surpassed by pipe B.**

3.2 RESULTS – PIPE B

With pipe B, the drilled 5mm holes only penetrated the protective cladding. During the removal of the insulation it was noted that the outer layer of insulation was damp to touch. However, the inner layer remained completely dry. In its report the institute said: *"The outer layer of the insulation materials is wet but the inner insulation is still dry which is attributable to the barrier adhesive layer between the two insulation layers. No corrosion has been observed on the steel surface.[5]"*

The test laboratory noted that the 5mm hole on the underneath side of the weather barrier (protective cladding) had become blocked and water had pooled between this barrier and the insulation. However, both here, and across the whole pipe, the institute reports that: *"No corrosion has been observed on the steel surface."*

Fig 6. Pipe B with no corrosion

Based on the performance of pipe B, the TNO/Endures team concluded that:

- **The importance of adhesive:** Using a good adhesive and insulation materials with strong barrier properties can improve corrosion resistance of the insulation systems.
- **Resist the weather:** Using a weather barrier (protective cladding) can enhance the performance of the insulation system in respect of CUI.

4. CONCLUSIONS

This test performed by TNO/Endures was engineered to ensure that CUI took place. This was achieved on pipe A by introducing holes in the insulation that allowed the saltwater to directly contact the pipe. The constant flow of warm salty water represents an extreme test environment – one that's unlikely to be encountered in an operational facility.

The goal of the test was to see how well Armacell's insulation systems mitigated the spread of corrosion. In this respect the material on pipe A performed well: corrosion was limited to the areas around the holes only and had not spread across the surface of the pipe. In a working environment the pipe is further protected with an anti-corrosive treatment and the insulation system always covered with a weather protection.

In the case of pipe B, no corrosion was found at all. Water reached inside the weather barrier (protective cladding) but as Armaflex insulation acts as a barrier to water penetration, this prevented water from reaching the surface of the pipe.

This test shows that in an extreme environment, Armacell's closed-cell FEF insulation system, with its integrated water vapour barrier, is highly effective at mitigating CUI.

VALIDATING THE PERFORMANCE OF CLOSED-CELL INSULATION

The test results are consistent with feedback from operators and contractors. Reinhard Müller, Project Manager Kaefer Industrie GmbH says:

"When traditional insulation systems are used there is a risk of condensation forming in the insulation or between the mineral wool and the metal jacket. If this moisture penetrates to the pipe there is a high risk of corrosion. By using the closed-cell Armaflex material and the non-metal Arma-Chek R cladding we were able to avoid the risk of corrosion under insulation (CUI)."

OIL MAJORS MANDATING THE USE OF ARMAFLEX

Fig 7: This cold water pipeline has been protected by Armaflex for 20 years - the picture shows maintenance inspection of the original system.

Speaking under anonymity a major oil company recently confirmed that it has mandated the use of Armaflex on all new oil platforms after finding serious and potentially catastrophic problems with facilities insulated with traditional mineral wool and metal jacketing systems. Other oil majors are considering a similar move. Indeed, the recognition is growing that following decades long deployments across the world in regions as diverse as Norway, Africa, Russia and the North Sea, **– Armaflex is the best-performing CUI mitigation system available.**

REFERENCES

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4. Corrosion Under Insulation (CUI) Guidelines (20 Mar 2008, S.Winnik)
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PROJECT REFERENCES

Armacell's Industrial Insulation Systems have been specified and installed in major Oil and Gas projects around the world. The thermal and acoustic systems are designed not only to effectively mitigate Corrosion Under Insulation (CUI) but also to meet international standards such as ISO 15665 when it comes to noise control.

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