TECHNICAL PAPER

Corrosion Under Insulation

Spread of corrosion assessment for insulation systems in a high humidity environment with cycling process temperatures. **A test conducted by the world-renowned corrosion institute InnCoa.**

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Corrosion Under Insulation

Spread of corrosion assessment for insulation systems in a high humidity environment with cycling process temperatures.

ABSTRACT

Corrosion Under Insulation (CUI) is a major issue for oil, gas and chemical process industries. It is estimated that up to 10 percent of annual maintenance costs in these industries are caused by CUI; severe cases of CUI may put personnel, environment and reputation at risk.

The choice of insulation system is a critical factor in the mitigation of CUI. To assess the resistance capabilities of commonly used insulation systems related to the ingress of water vapour and the onset and spread of corrosion in a high humidity environment, a dedicated engineered simulation was conducted by the widely renowned corrosion specialist institute InnCoa, based in Germany.

The insulation systems included ArmaFlex® flexible elastomeric foams (FEF), glass fibre, polyurethane and stone wool.

This paper provides a detailed insight into the applied simulation methodology and the assessment of the tested insulation systems. It will also detail how ArmaFlex closed-cell FEF insulation systems have demonstrated best in class performance on resistance against water vapour ingress and the spread of CUI.

Test conducted by:

INNCOA
SURFACE AND SUBSTRATE ENGINEERING

INTRODUCTION

Corrosion Under Insulation (CUI) is a major issue for oil and gas (both onshore and offshore), chemical process and other related industries. It is estimated that 40 to 60 percent of pipe maintenance costs are a result of CUI, and 10 percent of total annual maintenance costs in these industries are dedicated to repairing damage from CUI [i,ii]. Severe cases of CUI may put personnel, environment and industry reputation at risk[iii].

> "Corrosion under insulation (CUI) refers to the external corrosion of piping and vessels fabricated from carbon manganese, low alloy, and austenitic stainless steel that occurs underneath externally clad or jacketed thermal or acoustic insulation, primary due to the penetration of water"

CUI represents all types of corrosion that may occur on the pipework surface beneath an insulation system and can be triggered by multiple factors or conditions. CUI is insidious; the processes occur hidden beneath the insulation and cladding and are often only discovered much later when the damage caused is extensive. CUI is difficult to detect and can lead to plant shutdowns and in extreme cases may cause catastrophic failures.

The first documented issues related to CUI date from 1965. Although the first ASTM standard[iv] on thermal insulation relevant to CUI was released in the early 1970's, there was hardly any further documentation on CUI available until 1980[v]. In fact, there is still very little comparative material available today related to the actual performance of insulation systems in regards to mitigation of corrosion.

While insulation is primarily installed for heat/cold conservation, frost protection, process control, personnel protection, sound control, condensation control or fire protection, the type of insulation selected is recognised as having an important role in the overall ability of the system to mitigate against CUI. It has been identified, for example, that the following material characteristics have the most influence on CUI: closed and open-cell nature of the insulation material, water absorption, permeability and retention, levels of leachable chlorides and the choice of cladding[vi].

Insulation alone cannot safeguard plant components against corrosion, but appropriate insulation systems can effectively support corrosion mitigation. The choice of material determines whether the insulation withstands water vapour ingress and minimises the risk of corrosion, or allows or potentially accelerates corrosion processes.

To expand industry know-how in this matter, these laboratory tests have been conducted with several well-known industrial insulation systems:

- ArmaFlex flexible elastomeric foam (FEF)
- Glass fibre
- Polyurethane
- Stone wool

At the end of the test the onset and spread of corrosion were measured and assessed.

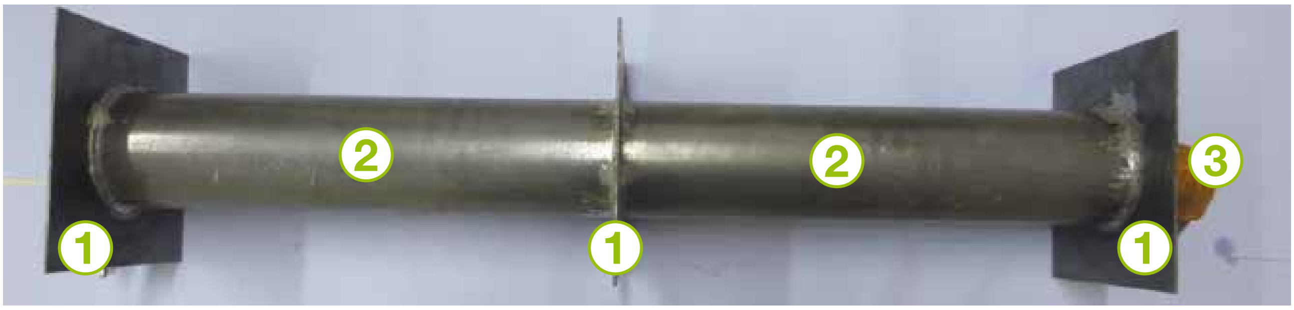
EXPERIMENTAL PROCEDURE

An accelerated 65-day test of different insulation systems was conducted by InnCoa, a corrosion specialist institute based in Neustadt/Donau, Germany. The installation was carried out by an independent professional and qualified insulation contractor, Walter Baum Isolierungen, Munich, Germany.

The institute exposed the insulation systems described below to a high humidity environment in a climatic chamber and assessed the onset and spread of CUI, as result of water ingress at the end of the test. A daily visual inspection took place through the clear hood of the climatic chamber. Photographs were taken of the insulation systems at regular intervals.

// Test setup, materials and installation method

Three carbon steel pipes each (type S253JR) with a diameter of 114.3 mm (4 in nominal size), thickness of 3.6 mm (0.14 in) of a total length of 970 mm (38.2 in) were prepared. On each pipe, two insulation zones (sections), each with approximate length of 480 mm (18.9 in) were created by welding three separation plates. The separation plates were welded tightly such that water or humidity could not escape or enter along the pipe to the adjacent zone. Separation plates were installed at each end of the pipe, as well as in the middle, in order to separate the insulation systems. At the ends of each pipe, connectors for the temperature controlled water circulation were installed.



1. Separation plates | 2. Pipe sections | 3. Pipe connectors

Figure 1: Welded pipe construction without insulation.

The pipes were installed in a series configuration (shown in Fig. 2) within a climatic chamber with air circulation, at an ambient temperature of 35 °C (95 °F) ±5 percent and 80% ±10 percent of relative humidity. The volume of the climatic chamber was 1 m^3 (35 ft^3). The air humidity in the chamber was regulated using the principle of 'critical relative humidity' by placing in the chamber two open pots with a saturated salt solution of Ammonium Sulphate ((NH4)2SO4).

Additionally the air in the chamber was being circulated with four fans with a volume flow rate of approximately 2.5 m^3/min (90 ft^3/min). This helped to ensure that the air within the chamber was well circulated and the humidity was evenly distributed. The pipes were connected in a series configuration and water circulated within the pipes at a rate of approximately 27 litres/min (1 ft^3/min) for both the cooling and heating cycles.

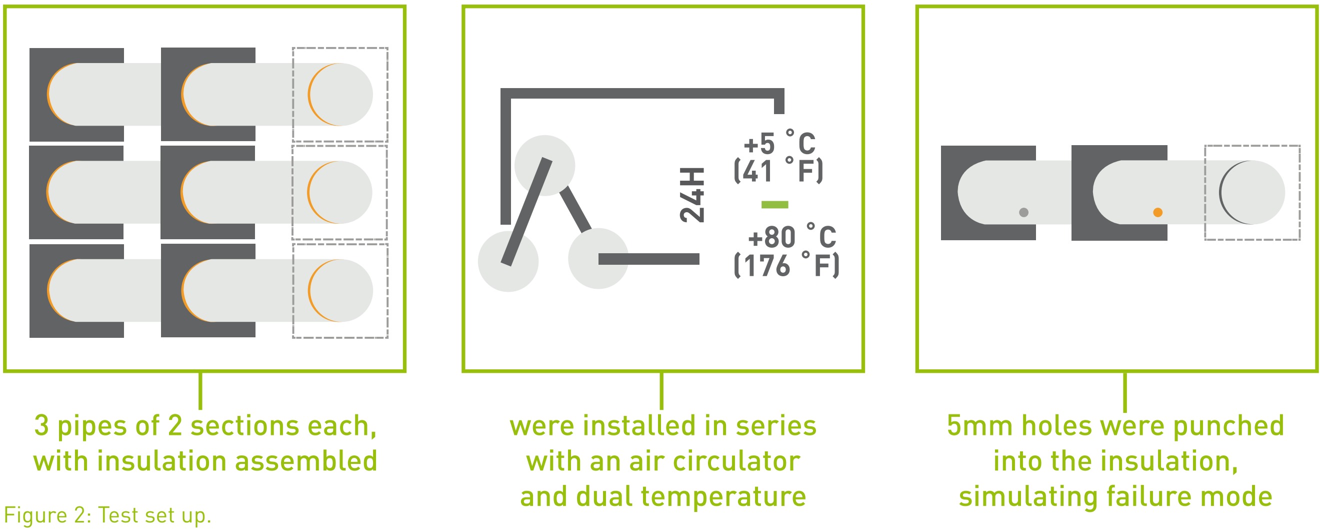


Figure 2: Test set up.

The temperature of the circulating water flow in the series of pipes was adjusted in a 24 hour cycle between 5 °C and 80 °C (41 °F and 176 °F). The profile of the cycling process temperature is shown in Fig. 3 for a 24-hour cycle, the cycles ran continuously (infinite loop) for the duration of the test.

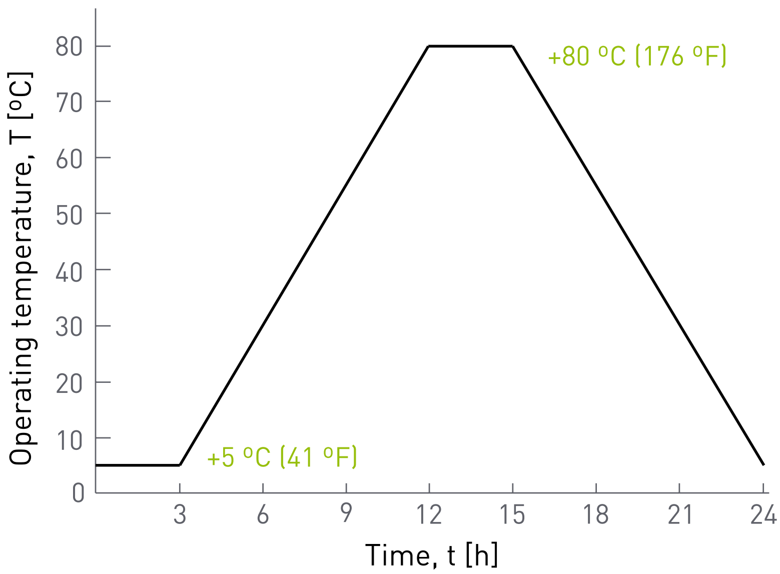


Figure 3: Temperature profile circulator.

EXPERIMENTAL PROCEDURE

A total of five insulation systems were prepared for assessment:

- **Sample A**: Two layers of HT/ArmaFlex® Industrial flexible elastomeric foam (FEF) with flexible polymeric covering (Arma-Chek® R).
- **Sample B**: Two layers of HT/ArmaFlex® Industrial flexible elastomeric foam (FEF) with flexible polymeric covering (Arma-Chek® R). Each layer was applied with full adhesive coverage to the surface of the pipe and to the previously applied layer.
- **Sample C**: Glass fibre (Isover® Ultimate Protect 1000s) with factory applied aluminium vapour barrier foil.
- **Sample D**: Polyurethane (Korff® PUR RG40) with factory applied aluminium vapour barrier foil.
- **Sample E**: Stone wool (Rockwool® 800) with factory applied aluminium vapour barrier foil.


Sample A (ArmaFlex FEF)


Sample B (ArmaFlex FEF)


Sample C (Glass Fibre)


Sample D (PUR)

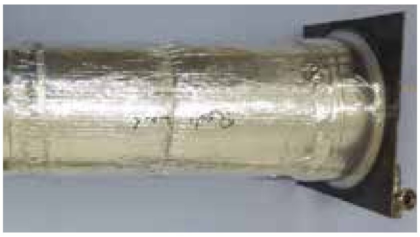

Sample E (Stone Wool)

Figure 4: Insulation systems installed on pipe sections.

The sealing of the insulation to the separation plates was different for each system:
- **Samples A and B:** installed with ArmaFlex® Adhesive HT625 and Arma-Chek mastic sealant.
- **Samples C, D and E** (including factory applied vapour barrier collar) installed with a 50 mm (1.97 in) wide aluminium collar, aluminium tape and silicone sealant.

The insulated pipes were installed in the climatic chamber on a wooden rack and interconnected with tubes for the water cooling/heating cycling. Surface damage to the insulation system was simulated by punching a 5 mm (0.20 in) diameter hole with approximately 10 mm (0.39 in) depth into the insulation and through the covering, using the tool shown in Fig. 5. The purpose of the punching was to simulate a discontinuity in the protective foil or Arma-Chek R covering layer, respectively and some damage to the outer portion of the insulation layer.

Figure 5: Tool to create punch holes in insulation systems.

The insulated pipes installed within the climatic chamber, showing the punching holes, can be seen in Fig. 6:

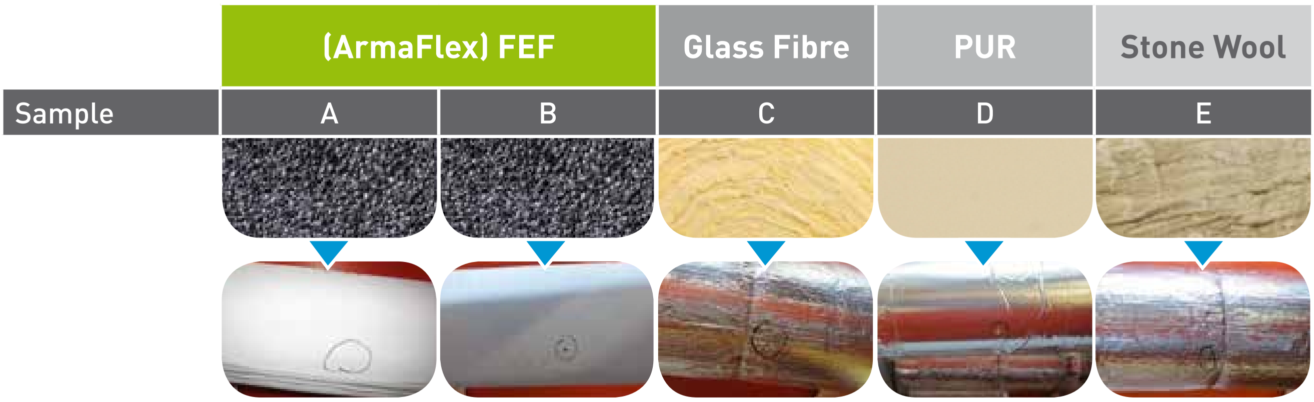
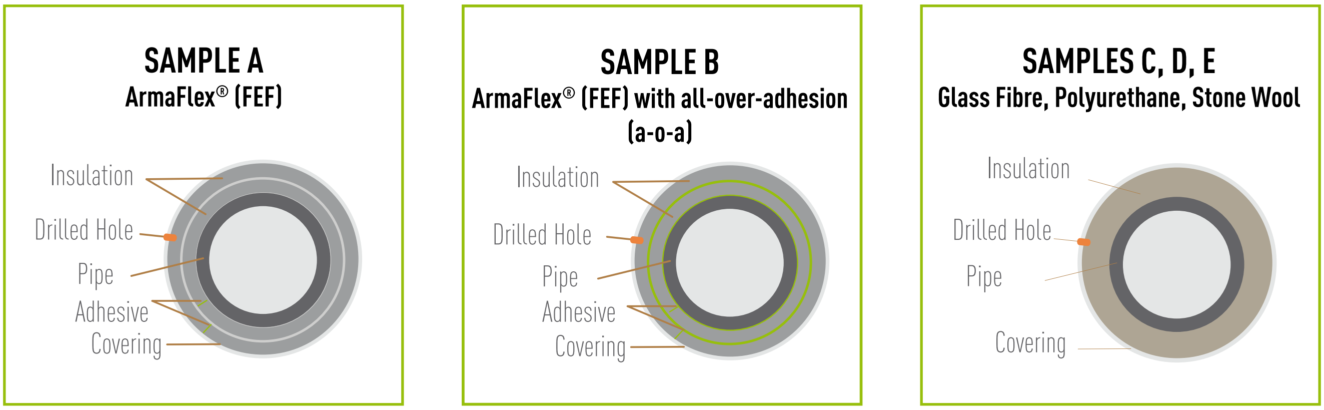


Figure 6: Insulation systems mounted, with punching holes visible.
System B used an "all-over-adhesion" (a-o-a) method.



Adhesive between seams, overlaps and Arma-Chek® R covering.

All-over adhesion between layers and at pipe surface. Arma-Chek® R covering.

Aluminium sleeve and tape.

Figure 7: Detailed configuration of each insulation system.

EXPERIMENTAL PROCEDURE

Samples A, B (FEF)

Samples C, D, E (Traditional)

Samples C, D, E (Traditional)

Figure 8: Sealants applied to each system.

// Test duration and inspection

The corrosion test started 30 March 2016 and finished on 3 June 2016, resulting in 65 days (1560 hours) of total duration. The conditions and samples were checked visually every working day at least once through the clear hood of the climatic chamber, without opening the chamber. With the visual inspection, no irregularities were detected in the insulation systems (with exception of the intentional punch holes nor was any evidence of CUI visible on the exterior of the system.

// Sample dismantling

On 3 June 2016 the testing ended and the insulation was dismantled. The middle section of insulation on all systems was cut out at 5 cm (1.97 in) from the separation plates, photographs of the surface were taken (the area of the hole in the insulation was marked with a white circle on the pipe) and the parts of insulation were weighed.

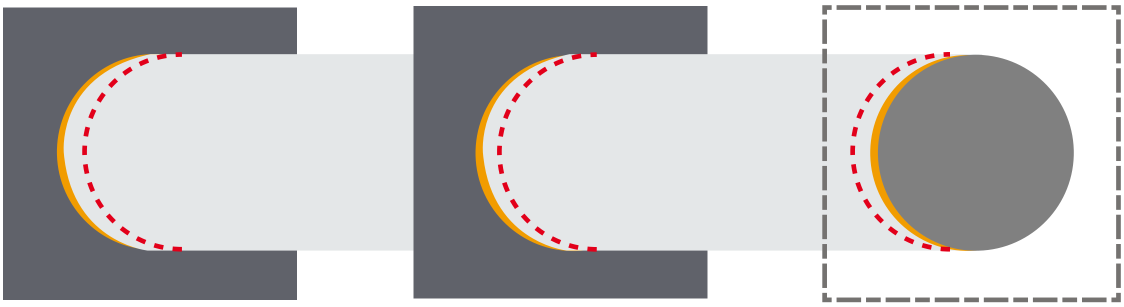


Figure 9: At dismantling, insulation was cut at 5 cm (1.97 in) from the separation plates.

After dismantling, the insulation sections were dried at 60 ºC (140 ºF) in a laboratory oven and weighed in intervals until the mass reached a constant value. According to this measurement, the mass-change as a result of water ingress into the insulation was less than 0.6 percent. Afterwards the 5 cm (1.97 in) sections of insulation oriented to the separation plates were removed and the surface of the pipes were photographed.

// Corrosion assessment and degree of protection rating

The corrosion on the pipe was examined and assessed for each of the removed samples and the surface classified according to ISO 10289 regarding rust/degree of protection.

ISO 10289

ISO 10289 describes the methods for corrosion testing of metallic and other inorganic coatings on metallic substrates - Rating of test specimens and manufactured articles subjected to corrosion test. It classifies the protection rating R_p, protection defect, appearance rating R_A and appearance defect.

The "degree of protection" is classified with a simple scale from 0 to 10. An R_p rating of 10 means 0 percent of surface with corrosion or defects (best rating). An R_p rating of 0 means 50 percent or more of the surface is with corrosion (worst rating).

Area of defects A (%)	Rating R_p or R_A
No defects	10
$0 < A \leq 0.1$	9
$0.1 < A \leq 0.25$	8
$0.25 < A \leq 0.5$	7
$0.5 < A \leq 1.0$	6
$1.0 < A \leq 2.5$	5
$2.5 < A \leq 5.0$	4
$5.0 < A \leq 10$	3
$10 < A \leq 25$	2
$25 < A \leq 50$	1
$50 < A$	0

Table 1: Corrosion protection rating Rp according to ISO 10289.

RESULTS

The capability to protect against corrosion was measured for each of the samples. The analysis of corrosion products was conducted using Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray (EDX) Spectroscopy. An example result from this analysis for a sample with visual signs of corrosion is provided in Fig. 10.

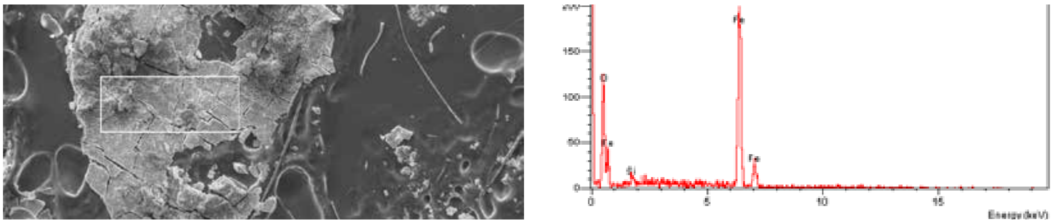


Figure 10:Result from SEM and EDX analysis for Sample C.

// Summary for the findings of all the samples assessed:

A

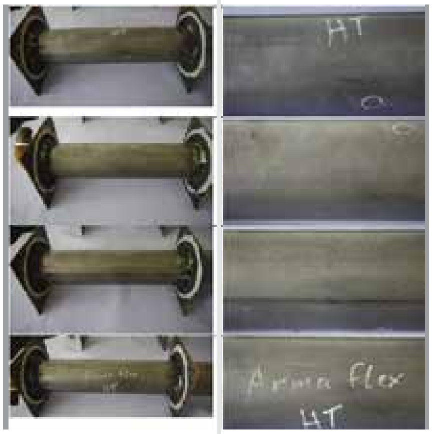


Figure 11: Pipe surface of Sample A, FEF, after 65 days.

Sample A – ArmaFlex (FEF)

The surface area of defects was greater than 0.1% but no greater than 0.2%. This resulted in a degree of protection rating, R_p, of 8.

No irregularities were found in the system configuration following the test. Comparison of sample weights before and after the test allows to conclude that there was slight water absorption into the insulation material during the test.

B

Figure 12: Pipe surface of Sample B, FEF, after 65 days.

Sample B – ArmaFlex (FEF) with all over adhesion fixing

The surface area of defects was 0% This resulted in a degree of protection rating, R_p, of 10.

Despite some evidence of water absorption into the insulation material, no signs of corrosion were found after the 65 days of testing (comparable to the Sample A – flexible elastomeric foam without all-over-adhesion).

C

Figure 13: Pipe surface of Sample C, glass fibre, after 65 days.

Sample C - Glass fibre

The surface area of defects was between 1 and 5%. This resulted in a degree of protection rating, R_p, of 4 to 5.

It was observed that increased corrosion was detected on the pipework in the area under the damage hole. The analysis showed iron oxides with some silicon possibly coming from glass fibres, without any potential corrosion promoters such as chlorides.

Figure 14: Pipe surface of Sample D, polyurethethane, after 65 days.

Figure 15: Pipe surface of Sample E, stone wool, after 65 days.

D

E

Sample D - Polyurethane

The surface area of defects was between 1 and 2.5% This resulted in a degree of protection rating, R_p, of 5.

It was observed that increased corrosion was detected on the pipework in the area under the seam of the insulation shells, which indicated that the seam may be a weak spot in this insulation system. The analysis of corrosion products showed iron oxides with a very small peak of silicon either coming from the polyurethane or from the pipe surface, without any potential corrosion promoters such as chlorides.

Sample E - Stone wool

The surface area of defects was between 5 and 10%. This resulted in a degree of protection rating, R_p, of 3.

It was observed that less corrosion was detected on the pipework in the area under the collars, which indicates that distribution of water vapour was limited at the ends of the sample section. This may be explained by the use of metal collars next to the plates and therefore less annular space between the pipe and the insulation. The analysis of corrosion products showed iron oxides with a very small peak of silicon either coming from the stone wool or from the pipe surface, without any potential corrosion promoters such as chlorides.

SUMMARY OF RESULTS

According to these results, the corrosion protection (respective stability against permeation of water/humidity/moisture through the insulation) gets worse in the sequence B, A, D, C, E - i.e. flexible elastomeric foams exhibit a higher mitigation level against CUI.

Sample (best to worse)	Material	Corroded surface	Rp	Comments
B	ArmaFlex Flexible elastomeric foam (all over adhesion)	No corrosion	10	-
A	ArmaFlex Flexible elastomeric foam	0.1 < A ≤ 0.25	8	-
D	Polyurethane	1 < A ≤ 2.5	5	Not uniform corrosion (local corrosion close to the seam of pipe section)
C	Glass fibre	1 < A ≤ 5	5-4	Not uniform corrosion (more corrosion directly under the hole in the insulation)
E	Stone wool	5 < A ≤ 10	3	Not uniform, less corrosion close to the plate separators at the ends of the section

Table 2: Overview of Rp rating of the tested insulation systems.

Observation of the test results conclude that open and closed-cell insulation materials perform in a fundamentally different way with respect to water vapour ingress and distribution within the insulation volume, as a result of exposure to long-term temperature cycling.

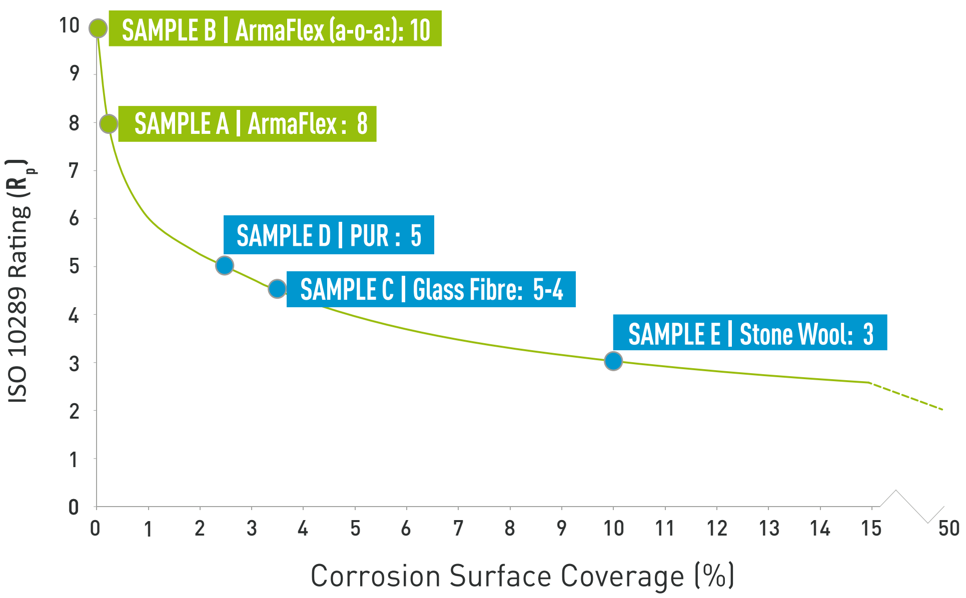


Figure 16: Comparison of Rp performance of tested insulation systems

According to the results ArmaFlex shows an advantage in performance compared to the insulation systems constructed from the other material types. In addition, ArmaFlex flexible elastomeric foams are more tolerant towards small defects in the insulation system.

By contrast, the following summarises the irregularities in the corrosion rates for the other insulation materials tested:

- **Glass fibre**: Local enhanced corrosion under the defect in the shell, reflecting the fact that moisture would spread through wicking in a longer-term test.
- **Polyurethane:** Local corrosion under a seam, evidencing joints being a weak spot in particular.
- **Stone wool:** Uniform corrosion in the middle part with less corrosion at the ends of the section. This may be explained by the use of metal collars next to the plates and therefore less annular space between the pipe and the insulation.

CONCLUSIONS

This test offered a robust comparison of traditional insulation systems and their resistance against water permeation and CUI in a relatively short period of time. Generally speaking, if water enters over time into the insulation systems and migrates to the steel pipe surface, this can lead to CUI.

The test demonstrated that ArmaFlex closed-cell flexible elastomeric foam has an integrated vapour barrier and is more tolerant against small defects in the insulation compared to the other tested insulation systems, whose CUI performance are largely dependent on an additional vapour barrier.

	(ArmaFlex) FEF		Glass Fibre	PUR	Stone Wool
Sample	A	B	C	D	E
Area of Rust %	0.1<A≤0.25	NO corrosion	1<A≤5	1<A≤2.5	5<A≤10
Protection degree R_p*	8	10	5-4	5	3

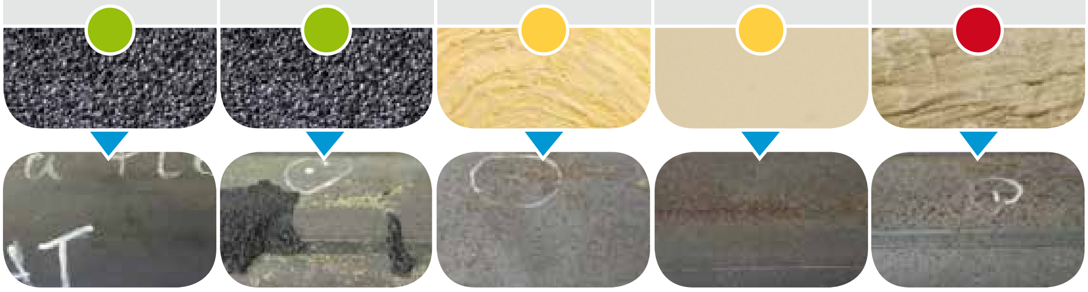


Figure 17:
Test results showing the protection degree R_p against corrosion of each of the insulation systems, according to ISO 10289.

The test has also demonstrated that **the application method of the insulation system plays an important role** in the spread of corrosion. Whereas the insulation systems of Samples A and B were using the same materials, the application method differed.

System B, which had all-over-adhesion to the pipe and between the layers of insulation, showed "no corrosion" at all, resulting in an even better corrosion protection than System A which already demonstrated superior performance compared with the other materials / systems that were tested.

When considering the application of insulation systems for long operation times, especially on cycling systems favourable for water vapour ingress into the insulation and collecting on the pipe surface, ArmaFlex insulation systems such as Sample B (HT/Armaflex Industrial and Arma-Chek R fully bonded to the pipe surface or previous layer) are recommended to mitigate against CUI.

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As the inventors of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal, acoustic and mechanical solutions that create sustainable value for its customers. Armacell's products significantly contribute to global energy efficiency making a difference around the world every day. With 3,000 employees and 25 production plants in 16 countries, the company operates two main businesses, Advanced Insulation and Engineered Foams. Armacell focuses on insulation materials for technical equipment, high-performance foams for high-tech and lightweight applications and next generation aerogel blanket technology.

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