INSULATION JUST GOT BETTER

Performance Testing Innovation for LNG Insulation

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PERFORMANCE TESTING INNOVATION FOR LNG INSULATION

Insulation systems for LNG applications operate under distinct temperatures and pressure conditions that differ significantly from those of conventional mechanical systems. Cryogenic temperatures introduce several challenges, such as system contraction during temperature drops, water vapor drive with increased pressure differentials, gaps or open seams due to extreme thermal gradients, and also the hurdle of insulation materials becoming rigid, brittle and less durable.

General specifications for industrial insulation systems are often derived from manufacturers' technical data, third-party certifications, and historical performance. However, insulation requirements for LNG present significantly more demanding conditions. These conventional qualification methods are frequently insufficient, particularly when evaluating new insulation materials or system designs, due to the extreme thermal, mechanical, and environmental stresses involved.

Current industry standards include AMPP TM-21549 for testing insulation systems on high-temperature piping to mitigate long-term corrosion, and UL 1709 and ISO 22899-1 for qualifying systems for passive fire protection. There are also LNG-specific standards, like ISO 20257, ISO 20519, ASTM F3319, and ASTM F3562, which address specifications and installation practices for insulation. One missing piece in these standards is a method for testing or qualifying insulation systems specifically for LNG process pipework and equipment for performance validation.

To address this need, industry consultants from "Committee INdustrial Insulation" (CINI) proposed a test method in which a cryogenic insulation system undergoes temperature cycling from ambient to cryogenic conditions. The testing involves subjecting the insulation system through ten temperature cycles conducted over a three-week period. This "10 Cryogenic Cycle" test has been performed by the University of Southampton's Cryogenic Services and nC2 Engineering Consultancy, with oversight provided by Lloyd's Register and is an accepted industry practice.

The CINI "10 Cryogenic Cycle" test performed on an aerogel system by the University of Southampton.

PRODUCT TESTING ARMAGEL® XG

Flexible aerogel insulation blanket for combined cryogenic and dual-temperature applications

// ASTM C1728 compliant

// 5, 10 and 20 mm thicknesses

// Integrated zero-perm vapour barrier

// Flexible at cryogenic temperatures

SETTING THE STANDARD:
The "10 Cryogenic Cycle" Test Explained

The "10 Cryogenic Cycle" test is specifically designed to challenge the limits of thermal insulation systems by cycling temperatures from -292°F (-180°C) to ambient and back again over a three-week period, maintaining the low temperature for six hours in "short cycles" and twenty hours in "long cycles." Throughout the test, the insulation system's thermal performance and durability are rigorously evaluated against three key criteria:

- Thermal Performance
- Effects of Moisture
- Mechanical Integrity

The insulation is installed on a horizontally mounted 12-inch (304 mm) pipe, following the manufacturer's recommended standards and practices, including precise placement of insulation and vapor barrier layers. The setup incorporates industry-standard cryogenic pipe supports, vapor-sealed at the surface, with one fixed support and two sliding "shoes" to accommodate thermal expansion and contraction during cycling.

Thermocouples are strategically placed on the pipe surface and between each insulation layer, as illustrated in Diagram 1. The system is then cooled to -292°F (-180°C) using liquid nitrogen and held at that temperature for the specified duration before being cycled back to ambient conditions with warm compressed air. The thermocouples collect data across each layer, providing insight into the system's thermal stability and highlighting any variations in performance due to location or exposure time.

Diagram 1: Test Sensor Placement

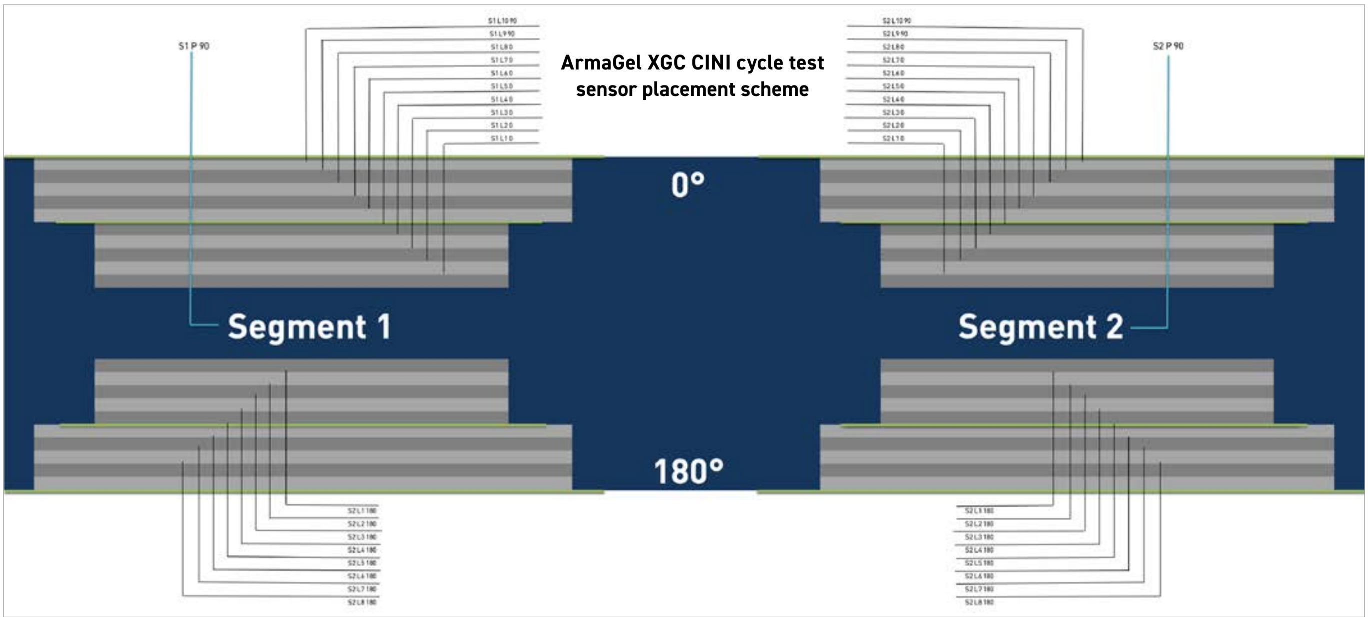
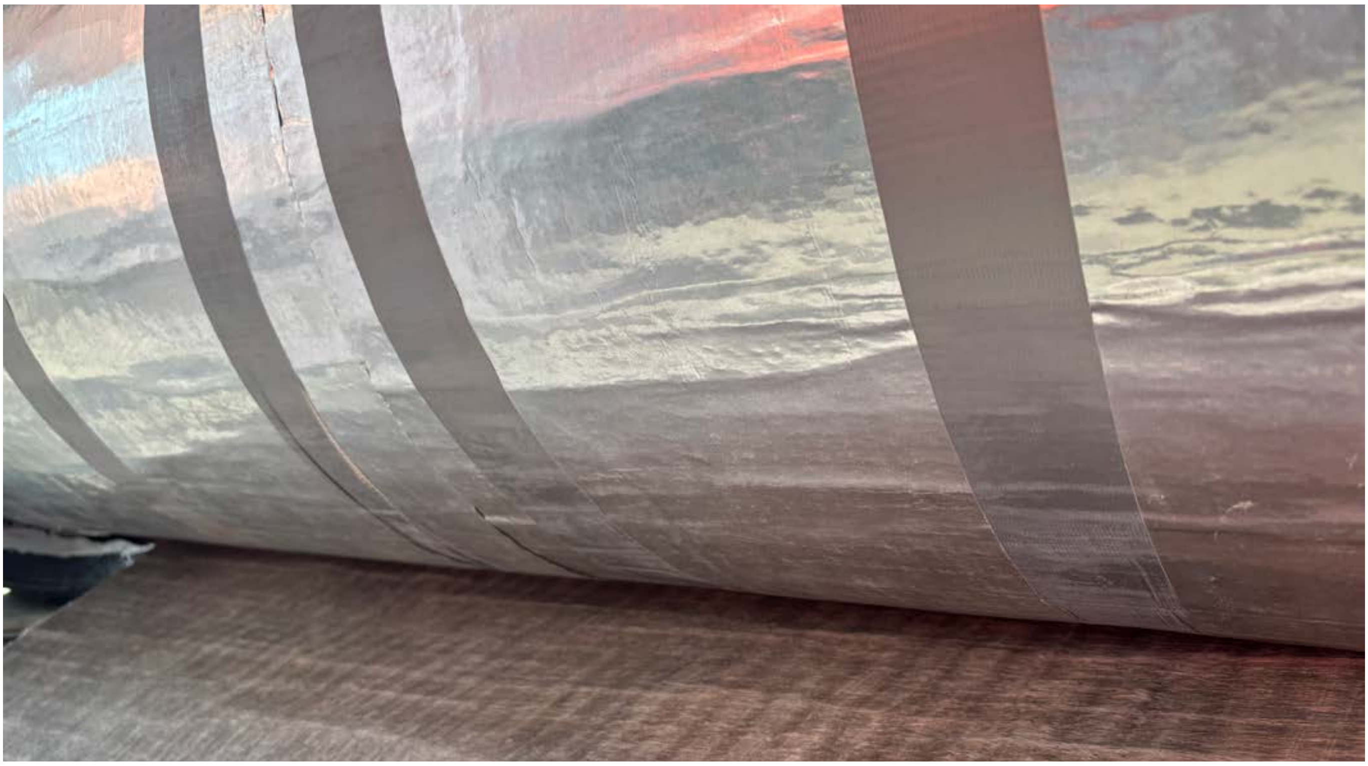


Diagram 1 shows a side view of the sensor placement for a pipe insulated with a multi-layer insulation system (e.g. aerogel) with a primary and secondary vapor barrier, as indicated in green.

Sensor readings capture the temperature profiles across all ten cycles, differentiated by segment (1 and 2) and position (0° and 180°). These measurements can highlight variations in insulation layer positioning and installation quality, as well as signs of thermal convergence and other indicators of insulation degradation.

Moisture-related deterioration, such as persistent condensation or icing at the 180° position (underside of the pipe), failure of vapor barriers to prevent ingress, or other forms of system failure, would also be evident in the temperature profiles. These insights are critical for assessing the long-term reliability and integrity of cryogenic insulation systems under stress.

Upon completion of the testing period, each insulation layer is removed and inspected for signs of moisture ingress and damage, changes in flexibility, delamination, cracking, or other physical deterioration. This inspection addresses these critical concerns in insulation performance that cannot be captured through thermal measurements, making it an important step in LNG system efficiency and management.



The removal of ArmaGel XGC insulation to look for signs of moisture ingress or material degradation.

PREDICTED VS EXPERIMENTAL:
A Case Study in ArmaGel XGC Insulation

One approach to validating a new test method is to compare experimental results with predicted results based on calculations. ASTM C680 provides a framework for calculating surface and interface temperatures across each layer of an insulation system. These theoretical values can then be benchmarked against thermocouple readings obtained during the proposed test.

Table 1 presents temperature data recorded during one of the long cycles for a system comprising ten layers of ArmaGel XGC insulation designed for cryogenic applications, compliant with ASTM C1728, Type I, Grade 1B. The measured values are compared to the expected theoretical temperatures at each layer, as calculated using ASTM C680.

Table 1: Tested vs Calculated Interface Temperatures

Layer	Long Cycle Test* Temperature °C	Calculated** Temperature °C	Temperature Difference °C
Bare Pipe	-182.11	-182.11	0.00
1	-156.54	-158.56	2.02
2	-132.39	-136.34	3.95
3	-111.24	-115.42	4.18
4	-92.02	-96.04	4.02
5	-74.96	-78.01	3.05
6	-58.18	-61.17	2.99
7	-42.58	-45.39	2.81
8	-27.69	-30.53	2.84
9	-14.76	-16.51	1.75
10	-2.59	-3.28	0.69
Ambient	0.92	0.92	0.00

*Measured at the 180° position (i.e. bottom) of the pipe.

**12-inch nominal pipe size, outer surface emissivity of 0.50, and wind velocity of 0.1 m/s.

Fundamentally, the ASTM method of calculation over-simplifies heat transfer by assuming one-dimensional, steady-state flow. The heat flow taking place in the "10 Cryogenic Cycle" test is far more dynamic. ASTM C680 captures system performance at a single point in time, under the assumption that variables such as ambient temperature, process temperature, and wind speed remain constant. In practice though, these conditions can fluctuate and introduce variability leading to significant differences between calculated and observed performance.

Additional variables that can be assessed within the test include changes in ambient temperature over the test duration, the impact of moisture ingress into the insulation system, and material changes resulting from exposure to cryogenic conditions.

Assuming consistent bare pipe and ambient temperatures across both the calculated and tested methods, as shown in Table 1, the greatest temperature difference observed in this ArmaGel XGC insulation system is just over 4°C, with an average temperature difference of less than 3°C. This close alignment between tested and calculated values demonstrates a high degree of correlation and reinforces the reliability of the test methodology. The interface temperatures are consistent throughout the test. If the measured values of the insulation performance had deteriorated due to moisture ingress or loss of mechanical integrity, significant deviations in the performance of the insulation would be observed over the ten cycles. However, the strong agreement between the theoretical and measured values throughout the course of the test confirms the ArmaGel XGC insulation integrity over time.

SETTING THE STANDARD:
The “10 Cryogenic Cycle” Test Explained

One key advantage of this test method is its ability to evaluate the reliability and repeatability of insulation systems through multiple measurements that are taken at various positions, across multiple thermal cycles.

As illustrated in Diagram 2, the consistency of results across all ten cycles demonstrate minimal variability. Thermocouples are strategically placed at multiple positions within each insulation layer and on both sides of the pipe support, as shown in Diagram 1. The tight grouping of lines of the same colour in Diagram 2 indicates strong agreement among thermocouples within each layer. Moreover, the consistency of minimum interface temperatures across cycles confirms the system's stable thermal performance throughout the test.

Diagram 2: Cumulative Interface Temperature Data for 10 Cycles

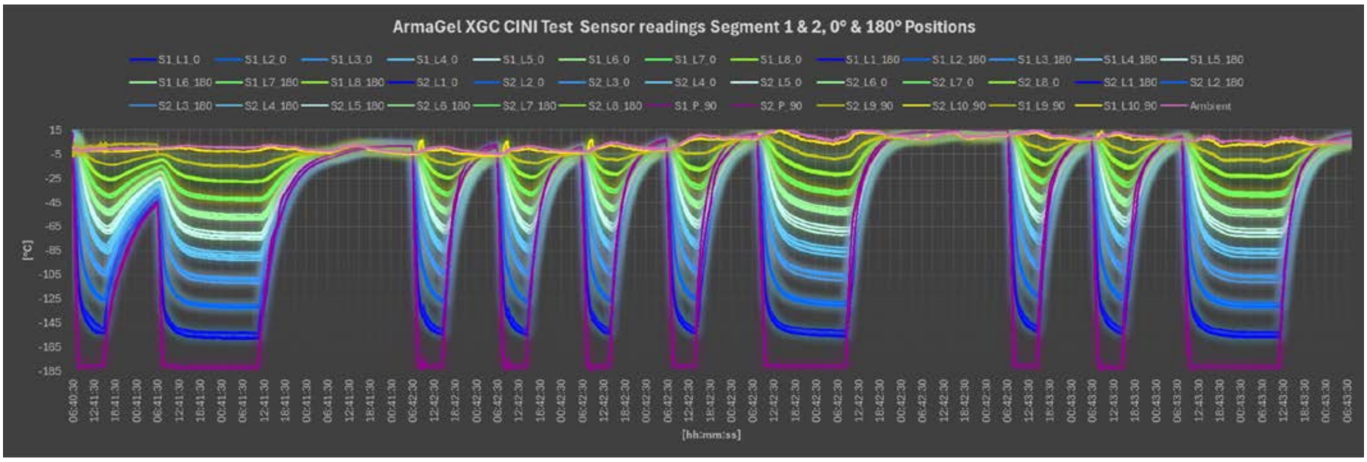


Diagram 2 shows the temperature profiles of all 10 cycles, for all layers, in all segments and positions.

INSULATION SYSTEM QUALIFICATION:
Creating or Updating an Insulation Specification

Whether an owner, engineer, or specifier is designing a new insulation system or developing proprietary pass/fail criteria for product qualification, a reliable and relevant test benchmark is essential for informed decision-making.

The “10 Cryogenic Cycle” test does not set pass/fail criteria but instead provides a framework that enables specifiers to define the performance parameters that meet their project requirements. This flexibility allows for tailored qualification based on three key areas:

- **Thermal Performance** – Do the measured temperatures align with calculated values based on the manufacturer's published thermal conductivity? Does the temperature profile of each insulation layer remain distinct, or is there overlap or convergence between layers? Is the thermal performance of the system consistent throughout the duration of the test?
- **Effects of Moisture** – Is the insulation thickness sufficient to prevent excessive or sustained condensation? Are there any signs of water ingress within the system?
- **Mechanical Integrity** – Does the insulation withstand thermal contraction and mechanical stress without compromising seals at seams, joints, or supports? Following testing, does the system retain its original condition, or are there signs of degradation or failure?

The visual inspection of the insulation for signs of moisture or changes in material integrity.

FAST-TRACKING SYSTEM INNOVATION:
Product Development, Management, and Improvement

A standardised test method for qualifying insulation systems would benefit not only LNG project managers and specifiers, but also insulation manufacturers. During the research and development phase, manufacturers would be able to use the test data to identify potential failure risks, such as the performance of factory-laminated vapor barriers or changes in material rigidity and compression at cryogenic temperatures.

Even after product development is complete, the detailed results enable manufacturers to analyse and optimise their recommended insulation systems. While changes in thermal conductivity, number of layers, or overall thickness are more apparent, the test also allows for comparison of more nuanced design changes. For example, a manufacturer might evaluate the impact of repositioning a secondary vapor barrier relative to the pipe support, or compare the effectiveness of a separate metallized-film vapor barrier versus taped seams on the insulation facer.

While the University of Southampton Cryogenic Services and nC² Engineering Consultancy and other similarly recognized testing laboratories can conduct this test, insulation manufacturers could perform it in-house so long as it is independently reviewed, witnessed, and certified by a recognized third party such as Lloyd's Register, to give it credibility.

FOR FURTHER CONSIDERATION:
Recommendations for LNG Applications

Insulation systems designed to operate at -260°F (-167°C) in LNG environments must be tested using methods that reflect real-world application conditions. While industry standards exist for qualifying these insulation systems in building services, acoustics, passive fire protection, and high-temperature oil and gas applications, they do not reflect the unique thermal, pressure, and environmental demands of LNG operations. The “10 Cryogenic Cycle” test was developed specifically to address this critical gap, making it a credible method for evaluating and qualifying the performance of insulation systems. The efficacy of the proposed test method has been demonstrated by comparing experimental and calculated results for an ArmaGel XGC insulation system. Repeated testing has shown consistent data across all measurements, temperatures, and cycles. The test method directly addresses key performance concerns for LNG insulation, including thermal performance, moisture effects, and mechanical integrity.

Industry leaders and LNG system experts encourage specifiers and engineers to look at all available tools, testing methods, and new technologies to meet their application needs, as well as challenge existing resources to find the best materials and solutions. The ”10 Cryogenic Cycle” test offers a practical and data-driven approach to support specification and system selection in one of the industry’s most demanding environments, and stakeholders across the industry are already recognising its potential as a benchmark for qualifying and comparing insulation systems.

About the Author

Luke Rogers is the Technical Manager for Armacell, LLC in the Energy division, with a territory spanning the United States and Canada. With nearly 20 years of experience in technical thermal insulation, Luke works with owners, operators, specifiers, and engineers in developing specifications and acting as a technical resource for insulation opportunities.

ABOUT ARMACELL

As the inventor of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal and mechanical insulation solutions that create sustainable value for its customers. Armacell’s products significantly contribute to driving energy efficiency worldwide. With more than 3,100 employees and 26 production plants in 20 countries, Armacell operates two main businesses, Advanced Insulation and Engineered Foams. Armacell focuses on insulation materials for technical equipment, high-performance foams for acoustic and lightweight applications, recycled PET products, next-generation aerogel technology and passive fire protection systems.

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