COVER STORY

PROTECTING CRITICAL COMPONENTS

Piping components are subject to extreme thermal, mechanical, and chemical conditions that can accelerate failure mechanisms. **Mateus Camparotto, Alkegen, Brazil,** explores how insulation solutions can help to protect components and mitigate against issues such as corrosion under insulation, thermal fatigue, creep, and oxidation.

In the chemical processing and hydrocarbon industry, equipment often operates in high-temperature, high-pressure, and corrosive environments, requiring reliable engineering solutions to ensure safety, thermal performance, and structural integrity.

In these conditions, insulation materials act as an important tool for minimising heat loss, protecting the metal components, reducing energy consumption, and preventing premature failures due to overheating, thermal creep, and corrosion under insulation (CUI).

Critical components of these systems, especially in reforming furnaces, include 'pigtails', which are curved pipes that connect process lines to manifolds, typically located at the inlet and outlet of the thermal equipment.

These tubes are often made of high-performance alloys, such as Incoloy 800H/800HT, and are designed to accommodate the thermal expansion of the system, withstand severe operating conditions, and ensure process flow continuity even under repeated thermal cycling. Tubular reformer designs feature a variety of tube and burner arrangements within the furnace. The four most common arrangements are bottom-fired, top-fired, terrace wall, and side-fired reformers.

However, because of their external location, complex geometry, and direct exposure to industrial environments, pigtails pose significant challenges in terms of thermal insulation. Conventional approaches rely on metal-cladding insulation blankets (Figure 1), which present some technical limitations, such as difficulty sealing and adapting to curved geometries, susceptibility to moisture intrusion and CUI, difficulty in visual inspection and maintenance, and accelerated performance degradation due to thermal cycling, solar radiation, rain, and corrosive chemical environments.

Recurrent pigtail failures caused by thermal fatigue, creep, oxidation, intergranular cracking, and carbide precipitation have been reported in the literature and they are often unpredictable and difficult to detect, which can result in significant production losses, unplanned downtime, and operator and equipment safety risks. Despite the importance of these components, there has been a lack of solutions designed specifically for these areas.

This article proposes a modular insulation solution that focuses on thermal performance, moisture resistance, and ease of installation and maintenance to meet the specific requirements of the chemical processing and hydrocarbon processing sectors.

Materials

The system analysed in this study is the Moldafrax Pipe Insulation, a modular and customised thermal insulation solution developed for applications in metal pipes with complex geometries, such as pigtails. The system has been designed to meet the requirements of thermal efficiency, weather protection, mechanical resistance, and ease of installation/maintenance.

The system consists of four main components (Figure 2), which can be customised according to project conditions:

- Vacuum-formed sleeves (a): these are the structural elements of the system, manufactured by vacuum forming process from high-purity refractory fibres, resulting in bipartite modules that are easy to install. They are available in two versions:
  - Refractory ceramic fibre (RCF): suitable for highly demanding thermal applications, with stability up to 1260°C (2300°F).
  - Alkaline earth silicate (AES): a non-bio-persistent option, exempt from classification as a carcinogen, with resistance to thermal shock.
- Inner layer of insulating blanket (b): installed between the metal surface and the mould, it acts as a forming and sealing layer.
- Water protection (c): varies according to the configuration chosen:
  - Coated version: elastomeric coating applied externally.
  - Water-repellent version: hydrophobic formulation incorporated into the vacuum formed part, which means it is full-thickness water repellent.

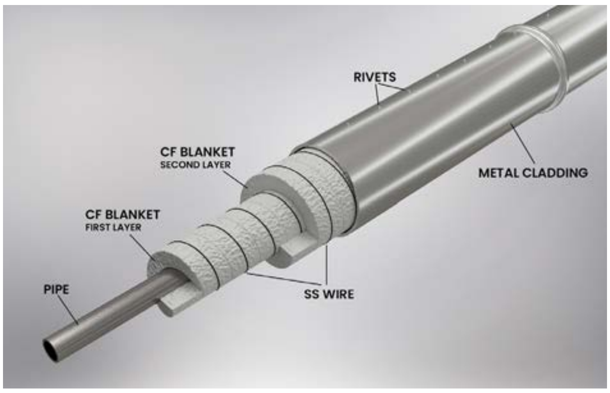

Figure 1. Assembly diagram of the conventional solution.

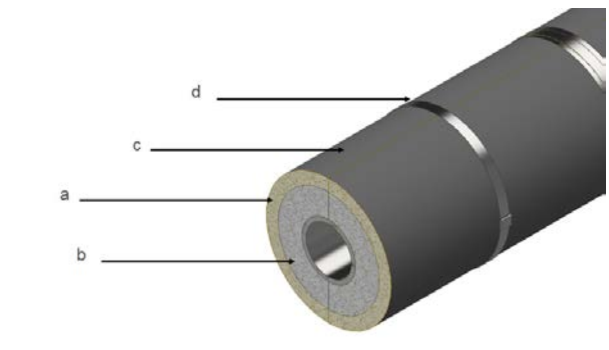

Figure 2. Moldafrax Pipe Insulation composition.

- Fastening system (d): 304 stainless steel band-type clamps.

The combined configurations allow adaptation to different regulatory, environmental, and operational demands.

Methods

Manufacturing and dimensional adaptation

All of the system's components are custom designed based on the dimensional layout of the pipe. The vacuum forming process allows the manufacture of parts with curves, branches, and diameter transitions, resulting in continuity of the thermal barrier.

Qualification tests and regulatory compliance

The Moldafrax Pipe Insulation system was subjected to a battery of laboratory tests based on ASTM international standards, with the aim of verifying its chemical stability, resistance to humidity, and compatibility with metal alloys used in service:

- ASTM C1104 – test method for determining the water vapour sorption of unfaced mineral fibre insulation: verifies the material's ability to absorb moisture from the ambient air. The samples were subjected to thermal cycling and controlled relative humidity conditions for 96 hrs.
- ASTM C692 – test method for evaluating the effects of thermal insulations on stainless steel: this test measures the potential corrosivity induced by thermal insulators, alongside the evaluation of the potential for external stress corrosion in stainless steel exposed to thermal insulating materials.
- ASTM C871 – test method for chemical analysis of thermal insulation for leachable chloride, fluoride, sodium, and potassium ions: determines the amount of potentially corrosive soluble ions and pH of the solution extracted from the materials.
- ASTM C795 – standard specification for thermal insulation for use in contact with austenitic stainless steel: evaluates the compatibility of insulating materials with high-temperature metal alloys such as Incoloy 800H and specifies the requirements for the use of insulation in contact with stainless steels. Compliance with this standard is obtained by combining the results of the C692 and C871 tests.

The procedures strictly followed the methods indicated in each standard, with adequate preparation of the specimens, temperature control, humidity, and exposure time according to each methodology and were carried out by third-party laboratories.

Thermal performance assessment by simulation

Thermal conductivity of materials

The thermal conductivity of the materials used in insulation systems is one of the main factors determining their effectiveness in reducing heat loss. Tables 1 and 2 show the thermal conductivity of the conventional solution (ceramic fibre blanket – 128 kg/m³) and the alternative solution analysed in this article.

Simulation operating conditions

To compare the thermal performance of insulation solutions with similar efficiencies, the simulation considered an exposed pipe operating at a constant temperature of 800°C (1472°F) with an external ambient temperature of 30°C (86°F). The objective is to assess the thermal behaviour of two insulation options for pigtails: the traditional multilayer system and the Moldafrax Pipe Insulation (Table 3).

Comparison of systems

- Conventional system: two layers of 1 in. (total of 50.8 mm) ceramic fibre blanket (128 kg/m³), finished with stainless steel cladding. Each layer is secured with stainless steel wire.
- Moldafrax Pipe Insulation system: a pre-moulded system consisting of 20 mm of vacuum-formed sleeve plus 38.1 mm of ceramic fibre blanket already shaped within the sleeve, which will be compressed during installation to approximately 30.8 mm.

Table 1. Thermal conductivity

	96 kg/m³ (6 pcf)	128 kg/m³ (8 pcf)
	W/m.K (Btu.in/h.ft².F)	
400°C (752°F)	0.087 (0.60)	0.080 (0.55)
600°C (1112°F)	0.140 (0.97)	0.120 (0.83)
800°C (1472°F)	0.220 (1.52)	0.180 (1.25)
1000°C (1832°F)	0.360 (2.50)	0.280 (1.94)

Table 2. VF part – thermal conductivity

	W/m.K	Btu.in/h.ft².F
200°C (392°F)	0.049	0.34
400°C (752°F)	0.068	0.47
600°C (1112°F)	0.094	0.65
800°C (1472°F)	0.130	0.90
1000°C (1832°F)	0.170	1.18

Table 3. Thermal simulation

	Convetional insulation	Moldafrax Pipe Insulation
System configuration	2 layers of 25.4 mm ceramic fibre blanket (128 kg/m³)	1 x 20 mm Moldafrax sleeve + 1 x 38.1 mm FB blanket (compressed to 30 mm)
Operating temperature	800°C	800°C
Ambient temperature	30°C	30°C
Pipe diameter	33.4 mm	33.4 mm
Surface emissivity	0.56 (metal cladding)	0.90
Cold face temperature	112°C	96°C
Heat loss	910 W/m²	887 W/m²

Emissivity

Although both systems present similar thermal conductivity values, the emissivity of the external surface can impact the radiative performance of the insulation. Emissivity is a measure of a material's ability to emit thermal radiation relative to a perfect black body ($\varepsilon = 1$). Materials with high emissivity radiate heat more efficiently and may contribute to more stable thermal distribution and a lower cold-face temperature. In the conventional system with metallic cladding, the surface emissivity is around 0.56 (rolled stainless steel, according to FLIR data). In contrast, the Moldafrax system exhibits a higher emissivity of approximately 0.90, due to the non-reflective mineral nature of the moulded surface.

Assembly

The conventional insulation consists of layers of ceramic fibre blanket, typically with a density of 128 kg/m³ (8 pcf). The first layer of blanket is wrapped around the pipe, ensuring the necessary compression and avoiding gaps between the strips. The blanket layer is secured with steel wire. This step is repeated according to the number of layers required to complete the insulation. After assembling the insulation, the cladding is installed using stainless steel sheets and rivets to minimise water penetration.

The Moldafrax system is supplied in ready-to-install, pre-moulded modules, composed of half sleeves with the ceramic blanket already bonded to the inner surface. This pre-assembly accelerates the installation process and ensures uniform adherence of the blanket to the metal surface during placement (Figure 3).

The first half of the sleeve is positioned directly onto the pipe. The ceramic blanket is compressed against the pipe, which allows it to accommodate surface irregularities, diameter variations, and minor interferences.

Next, the second half of the sleeve is installed with the application of a special adhesive along the contact surfaces between the two halves to ensure proper sealing of the modules, preventing moisture penetration and maintaining the integrity of the insulation. After both halves are fitted together, the assembly is secured with stainless steel bands, providing uniform pressure, mechanical stability, and easy removal during inspections or maintenance.

A compressed water-resistant ceramic fibre joint is applied between adjacent modules, acting as a thermal expansion joint that absorbs the pipe's movement during thermal cycles.

Installation of the curved (elbow) section follows the same principle as the straight sleeves. The first moulded half of the elbow is positioned with a precise fit, aligned with the straight insulation section.

The second half of the elbow is installed with adhesive sealing, ensuring tight fit and leak protection in the transition between straight and curved pipe sections. Both elbow halves are secured using stainless steel bands, providing mechanical stability even under repeated thermal expansions.

Figure 3. Installation of Moldafrax Pipe Insulation.

Finally, an additional wider band is applied over the ceramic fibre joint to prevent water ingress and resist weather conditions. This final step reinforces the system's seal and contributes to extending the service life of the insulation.

Results and discussion

Testing showed that the Moldafrax Pipe Insulation system meets the highest performance standards for critical industrial applications. In terms of moisture resistance, ASTM C1104 test results showed adsorption below 1.07% by mass and 0.3% by volume. This indicates that the system is able to effectively prevent water vapour absorption. This result is critical to preventing CUI, especially in outdoor installations.

ASTM C692 test results showed that 304SS coupons did not show cracks after 28 days under temperature and humidity conditions, which confirms the safety of the material against stress corrosion cracking during service.

In addition, the ASTM C871 test showed a pH of 9.4, below the maximum limit of 12.5 established by the standard. The concentrations of soluble ions were also below the specified values. These indicators demonstrate low chemical aggressiveness and reinforce the safety of the system in contact with sensitive metals.

Based on these results, the system is classified as compliant with ASTM C795 for use in direct contact with high temperature metal alloys such as Incoloy 800H.

The Moldafrax Pipe Insulation system helps protect against CUI by incorporating water protection directly into its components. As it is a modular system, with pre-moulded parts, its installation can be completed quickly due to layers applied in the field (insulating blankets and metal cladding), which means a significant reduction in downtime.

Both test results and after-installation observations show that the Moldafrax Pipe Insulation system is an efficient solution, capable of minimising failures described in the literature and increasing the reliability of critical equipment in chemical processing and hydrocarbon processing industries.

Conclusion

The pipe insulation system discussed in this article has demonstrated technical and operational performance, establishing itself as an alternative to traditional thermal insulation methods. Laboratory results meet ASTM international standards, especially with regard to moisture resistance, chemical compatibility, and thermal stability.
Low water absorption, controlled pH, and the absence of stress corrosion prove its suitability for critical operating conditions.

In addition to the technical benefits, the pre-formed system offers an operational advantage, allowing for up to six times faster installation and eliminating complex steps, such as metal cladding. This feature contributes to reduced equipment downtime and maintenance costs.

Bibliography

- KAPPES, M., 'Localized corrosion and stress corrosion cracking of stainless steel in halides other than chlorides solutions: a review', (December, 2019).
- BENITO, M., and SANZ, J.L., 'New trends in Reforming Technologies: from Hydrogen Industrial Plants to Multifuel Microreformers', (October, 2005).
- MAHARAJ, C, et al., 'Failure análisis and creep remaining life of hydrogen reformer outlet pigtail tubes,' (August, 2008).
- LI, G., CAI, Q., LU, X., ZHU, X., and XU, S., 'Failure analysis of cracking in the welded joints of hydrogen reformer outlet pigtail tubes.,' School of Mechanical and Power Engineering, Nanjing Tech University, China, (November, 2022).
- DYBKJÆR, I., 'Tubular reforming and autothermal reforming of natural gas – an overview of available processes', Fuel Processing Technology, Vol. 42., (1995).
- ZAREIE-KORDSHOULI, F., et al., 'Process and metallurgical evaluation of outlet pigtails damage in the primary steam reformer of an industrial ammonia plant', Engineering Failure Analysis, Vol. 59, (2016).
- LI, H., et al. 'A review on pyrolysis and coking of liquid hydrocarbons in heated pipe', Applied Energy, Vol. 394, (2025).
- WILDS, N., 'Corrosion Under Insulation', Trends in Oil and Gas Corrosion Research and Technologies, pp. 409 – 429 (2017).
- BAHADORI, A., 'Material Selection for Thermal Insulation', Thermal Insulation Handbook for the Oil, Gas and Petrochemical Industries, pp. 239 – 301, (2014).
- 'Reference documentation thermography,' FLIR, 2019, https://support.flir.com/DSDownload/Assets/T810442-en-US_A4.pdf.