John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

Technical Support Package

Improved Thermal-Insulation Systems for Low Temperatures

NASA Tech Briefs
KSC-12092

National Aeronautics and
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Technical Support Package

for

IMPROVED THERMAL-INSULATION SYSTEMS FOR LOW TEMPERATURES

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NASA Tech Briefs

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Improved Thermal-Insulation Systems for Low Temperatures

Brief Abstract

An efficient, easy-to-use thermal-insulation system has been developed that operates at soft vacuum (above 1 torr) with a k-value below 3 mW/m-K. The system has been demonstrated for cryogenic applications (liquid nitrogen at 77 K). New industry and aerospace applications require a versatile, robust, low-cost thermal insulation with overall performance in the moderate range. A primary target for the new thermal-insulation system is a k-value below 3 mW/m-K (R-value greater than 50) at soft vacuum level (from 1 to 10 torr) and boundary temperatures of from 4 K (-452 °F) to 480 K (+400 °F). Many combinations of radiation shields, spacers, and composite materials were tested from high vacuum to ambient pressure using cryostat boil-off methods. System design considerations included installation, outgassing, evacuation, compression, and end effects. Significant improvements over conventional systems was demonstrated for the following factors: thermal performance at soft vacuum level, ease of installation, reduced outgassing, reduced evacuation and heating during manufacture, reduced compression sensitivity, and reduced end/edge effects. The new system was also shown to provide key benefits for high vacuum applications as well; the thermal performance was on the order of that for multi-layer insulation at high vacuum level (below 0.1 mW/m-K*)*. The system consists of the insulation materials, the packaging, and the technology of the requisite wrapping and rolling methods. The system package, which may contain a number of reflection layers electrically (conductively) isolated by spacer with powder between, can be manufactured in roll, sleeve, or blanket forms. The system packages, protected from outside humidity and contaminants, are ready to use for insulating specific products such as pipes, tanks, containers, boxes, etc., which must be thermally guarded.

Section I – Description of the Problem

Known thermal-insulation materials work very well under high vacuum level (below about 1×10^{-4} torr) but have poor thermal performance in the soft vacuum range of 1 torr to 100 torr. The performance of Multilayer Insulation (MLI), also known in the industry as Superinsulation, degrades very rapidly at vacuum levels above 0.1 torr. Ideal MLI consists of many radiation shields stacked in parallel as close as possible without touching. Low thermal conductivity spacers are employed between the layers to keep the highly conductive shields from touching one another. But the ideal design that makes MLI the best also tends to make it the worst. MLI is anisotropic by nature, making it difficult to apply to complex geometries. MLI requires careful attention to detail during all phases of installation. MLI is generally very sensitive to mechanical compression. Even when the state-of-the-art techniques are used by the best practitioners of the art under laboratory conditions, thermal performance is often several times worse than the ideal. In actual cryogenic systems using MLI, the overall heat leak can easily be ten times or more from the ideal. Also, MLI requires lengthy evacuation (pumping), purging, and heating cycles to obtain the required high level of vacuum during manufacturing. All MLI systems, unless they come with dedicated pumping systems, required adsorbents and chemical gettering packs to maintain the high vacuum. Maintenance can be absolutely critical for MLI systems and future field modifications can be cost prohibitive. Although the material stock used in MLI may be relatively inexpensive, the overall system is obviously quite costly. Conventional cryogenic insulation materials can be divided into three levels of thermal performance, in terms of apparent thermal conductivity (k-value in mW/m-K). The performance of an evacuated thermal-insulation system depends very strongly on the degree of vacuum level in the annular space. System k-values below 0.1 can be achieved for multilayer insulation operating at cold vacuum pressure (CVP) below 1×10^{-4} torr. For fiberglass or powder operating at CVP below 1×10^{-3} torr, k-values of about 2 are obtained. For foam and other materials at ambient pressure, k-values around 30 are typical. New industry and aerospace applications require a versatile, robust, low-cost thermal insulation with overall performance in the moderate range. The new thermal-insulation system has a k-value below 3 mW/m-K (R-value greater than 50) at soft vacuum level (1 torr) and boundary temperatures of approximately 77 K (-320 ºF) and 295 K (+70 ºF). The new system mitigates or reduces many of the problems inherent with MLI.

Section II – Technical Description

The objective is to develop a thermal-insulation system, for products like gases or liquids under low or medium-high temperature, which will work effectively at a soft vacuum level in the annular space.

Family of Thermal-Insulation Systems.

There are three basic product forms:

1. Roll: Single layer or multiple layers.
2. Blanket: Multiple layers, tailored layers, packaged custom design for specific temperature extremes.
3. Sleeve: Multiple layers, cylindrically packaged.

System can be optimized for high or soft vacuum and specific geometric configuration.

System components:

1. radiation shields: aluminum foil or double aluminized Mylar. (Key advantage: electrostatic properties of dull side of aluminum include natural affinity for fumed silica powder).
2. spacer: microglass paper, microglass fabric, Q-fiber fabric, or polyester fabric.

3. powder: fumed silica or silica aerogel (hydrophobic treatment is recommended).
4. outer wrapper: microglass paper, fabric, or plastic (encapsulating filter bag with center seam).

Notes:

1. Segmented option: additional lateral seams at regular intervals eliminate spiral head conduction path through radiation shield (significant at high vacuum) and provides additional powder containment in case of wrapper breakage.
2. Layer density: 10 to 20 layers per inch (about 1/16″ thickness per layer).
3. Volumetric compression of powder is typically in the range of 20% to 60%.
4. Bulk density: less than 3.3 pounds per cubic foot (less than the 3.6 lbm/ft^3 for typical MLI).
5. Powder application rate: 1 to 3 lbm of powder per square foot of aluminum (for typical 3.5 lbm/ft^3 powder).
6. Manufacturing: continuous process or serial process, also prepackaged or custom design.
7. Thermal performance: about 0.09 mW/m-K at high vacuum, about 2.4 mW/m-K (R-value 60) at 1 torr (typical for LN2).

Section III – Unique or Novel Features

Key Advantages:

1. Soft vacuum performance is about 5 times better than MLI and other insulators. High vacuum performance is nearly as good as MLI under laboratory conditions and could be superior in actual practice. New system performs better than the world's best bulk insulator (ultra-low density silica aerogel or composites) at soft and at high vacuum levels.
2. Larger spacing gives much less heat leak due to edge/joint effect. Spacing is sufficiently small to provide good radiation shielding while providing maximum suppression of gas conduction. The larger spacing does an excellent job at soft vacuum while still doing a good job at high vacuum; makes for easier handling and installation; and reduces heat leaks due to compression, end effects, and complex configurations.
3. Evacuation and heating times are drastically reduced compared to those required for MLI (about 4 orders of magnitude less stringent vacuum level needed for a soft-vacuum, moderate-performance system).
4. Maintenance and life-cycle costs should be drastically reduced (no high vacuum requirements compared to MLI, no environmental degradation or cracking compared to foam).

Thermal-Insulation System (TIS) claims are divided into three categories:

1. TIS 1 with material configuration: Paper, powder deposited on the paper surface, reflection layer.
2. TIS 2 with material configuration: Fabric, powder mechanically deposited inside fabric, reflection layer.
3. TIS 3 with material configuration: Fabric, powder chemically formed within fabric, reflection layer (aerogel composite spacer concept).

For each category, four methods of production are determined:

a. Prefabricated continuous single-layer or multi-layer rolls.
b. Prefabricated multi-layer cylindrical sleeves.
c. Prefabricated multi-layer blankets.
d. Prefabricated continuous multi-layer packaged blankets.

Cryogenic boil-off test data using Cryostat Apparatus at NASA-KSC:

C107, C113, and C114 test data (New Thermal-Insulation System), March to September 1998.

C108 test data (MLI-reference), April 1998.

C104 test data (Foam-reference), January to February 1998.

Section IV– Potential Commercial Applications

Potential applications include:

Superconducting power transmission cable.

Superconducting equipment (transformers, etc.).

Transfer pipe for liquid cryogens.

Transfer line for medium-high temperature steam, gases, or liquids.

Storage of commodities at low to medium-high temperature.

Transport of products under low to medium-high temperature.

Space launch vehicle propellant tanks and feedlines.

Cold boxes for industrial processes.

Thermal storage devices.

Technology Opportunity

Advanced Materials

Layered Composite Insulation

The National Aeronautics and Space Administration (NASA) seeks to license its Layered Composite Insulation (LCI) technology for use in commercial applications. Designed by the Cryogenics Test Laboratory at the John F. Kennedy Space Center (KSC) in Florida, this easy-to-use system can benefit multiple industries that depend on regulation of low temperatures in equipment and products. The synergistic effect of improvements in materials, design, and manufacture of this new insulation technology exceeds current multilayered insulation (MLI) or foam insulation products.

This new piping insulation can provide cost-saving and product loss-prevention benefits to companies that transfer fluids such as liquefied natural gas, refrigerants, chilled water, crude oil, or low-pressure steam as well as to transport companies that move refrigerated containers by land and sea and need to protect food, medicine, and other perishable commodities.

Potential Commercial Uses

End-users of this technology include those who need:

- To insulate superconducting power transmission cables and equipment.
- To insulate transfer piping for cryogens.
- To insulate distribution lines for medium-high-temperature steam, gases, or liquids.
- To store commodities such as liquid nitrogen, liquid argon, or liquid CO_2.
- To transport products at various temperatures.
- To insulate space launch vehicle propellant tanks and feed lines.
- To insulate storage vessels and thermal storage devices for industrial applications.
- To insulate hot oil piping in undersea drilling operations.

Potential licensees of this technology may include companies that:

- Manufacture multilayered insulation
- Handle or transport cryogens.
- Provide services to industries using cryogens.
- Support industries in which reliable low-temperature regulation is critical.
- Manufacture cryomedical or cryobiological equipment.
- Manufacture refrigeration or transport materials under refrigeration.

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Benefits

- Performs up to six times better than the current MLI method.
- Performs better at soft and high vacuum levels than the world's best bulk insulator (ultra-low-density silica aerogel).
- Provides protection against loss of product or overpressurization of tank in case of vacuum-jacket failure.
- Reduces heat leakage due to innovative edge/joint feature.
- Provides good radiation shielding and maximum suppression of gas conduction with compact spacing between layers.
- Reduces evacuation and heating times compared to the current MLI.
- Reduces installation, maintenance, and life cycle costs (no high-vacuum requirements compared to current MLI and no environmental degradation or cracking compared to foam).

The Technology

The technology combines a unique layered cryogenic insulation system with specific manufacturing, packaging, wrapping, and rolling methods. One of the unique features of the LCI is its superior thermal performance: approximate R-values per inch for cryogenic conditions are R-1600 for high vacuum, R-90 for soft vacuum (about 1 torr), and R-10 for no vacuum.

This new LCI system surpasses the current limitations of current MLI systems in:

- Performance in soft vacuum or degraded vacuum environments
- Sensitivity to mechanical compression
- Daily operational maintenance

The new LCI insulation can currently be continuously rolled or can be manufactured in blanket, sheet, or sleeve form. The LCI can also be utilized on aerospace cryogenic equipment, terrestrial cryogenic tanks, pipes, and valves with multiple commercial applications.

Options for Commercialization

NASA seeks qualified companies to commercialize the Layered Composite Insulation technology. This and other technologies are made available by the KSC Technology Commercialization Office through a variety of licensing and partnering agreements. These include patent and copyright licenses, cooperative agreements, and reimbursable and nonreimbursable Space Act Agreements.

Contact

If your company is interested in the Layered Composite Insulation technology or if you desire additional information, please reference Case Number KSC-12092 and contact:

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Commercialization Checklist

- ✔ Patent pending
- U.S. Patent
- Copyrighted
- ✔ Available for licensing
- Available for no-cost transfer
- Seeking industry partner for further codevelopment

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