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CRYOGENIC INSULATION FOR DEWAR VESSELS

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Abstract: *This paper represents cryogenic insulation for dewar vessels. There are several types of insulation that can be used in cryogenic equipment. These include: Expanded foams, Gas-filled powders and fibrous material, Vacuum alone ,Evacuated powders and multilayer insulations. These insulations are listed in order of increasing performance and, generally ,in order of increasing cost. The specific insulation to be used for a particular application is determined through a compromise between cost, ease of application ,weight ,ruggedness, and so on, in addition to the effectiveness of the insulation is considered.*

Keywords: Cryogenic insulation system, categories of insulation materials, application methods and types of insulation

INTRODUCTION

In today's world, the use of cryogenics and low-temperature refrigeration is taking a more and more significant role. From the food industry, transportation, energy, and medical applications to the Space Shuttle, cryogenic liquids must be stored, handled, and transferred from one point to another. To minimize heat leaks into storage tanks and transfer lines, high-performance materials are needed to provide high levels of thermal isolation.

Complete knowledge of thermal insulation is a key part of enabling the development of efficient, low-maintenance cryogenic systems. What is important is to save money on the energy bill or to be able to effectively control a system.

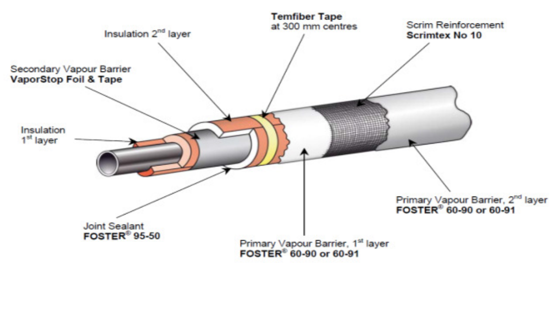

Fig:1 Cryogenic insulation

Space launch and space exploration are both energy intensive endeavors. Cryogenics is called upon to meet this demand. Insulation is then needed to make the cryogenics effective. Thermal insulation systems for the next generation of space launch activities represent a critical area of new technology needs. Design a fantastic rocket ship and then put some foam insulation on the cryo tanks: What's the big deal? Who cares about insulation? What seems like a simple system obtained from a relatively simple development process turns out to be a very complicated system indeed. We currently rely on 1960's derivative technologies and a bolt-on approach to insulation problems. A long-term approach is suggested in order to address the energy efficiency hurdles that we face for both future exploration and industry.

Cryogenic insulation systems:

- Advanced cryogenic insulation systems are required to meet future space mission requirements and reduce system mass and active cooling system power
- Research confirms lack of comprehensive thermo physical properties of MLI systems
- Emerging technologies and assembly/fabrication techniques capable of improving MLI performance identified. Developed fundamental layer-by-layer design and simulation tool for MLI systems for rapid design and analysis – models seams and penetrations
- Modeled conduction/radiation down struts/attachment points

- Developed patented test rig for validating MLI performance down to liquid hydrogen temperatures with up to 300 layers

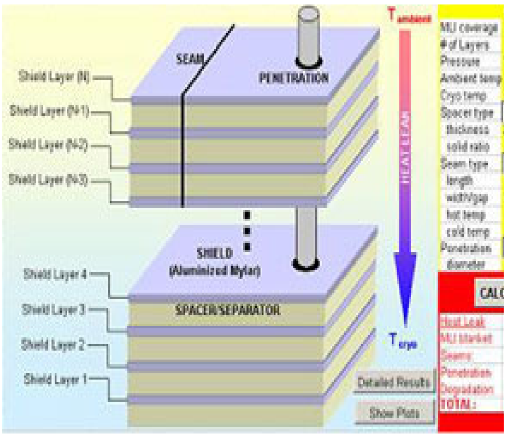

Fig:2 Cryogenic insulation systems

- Provides wide range of data for a variety of cryogenic insulation configurations
- MLI applications :
- Space-based platforms
- Spacecraft
- Launch vehicles, missiles
- Lunar Landers
- Stationary and road able dewars
- Superconducting device

CATEGORIES OF INSULATION MATERIALS

- Insulation materials may be categorized (Turner and Malloy, 1981) into one of five major types 1) Cellular, 2) Fibrous, 3) Flake, 4) Granular, and 5) Reflective.
- **Cellular insulations** are composed of small individual cells either interconnecting or sealed from each other to form a cellular structure. Glass, plastics, and rubber may comprise the base material and a variety of foaming agents are used.
- Cellular insulations are often further classified as either open cell or closed cell Generally, materials that have greater than 90% closed cell content are considered to be closed cell materials.

Fibrous insulations are composed of small diameter fibers that finely divide the air space. The fibers may be organic or inorganic and they are normally held together by a binder.. Fibrous insulations are further classified as either wool or textile-based insulations. Textile-based insulations are composed of woven and non-woven fibers and yarns. **Flake insulations** are composed of small particles or flakes which finely divide the air space. These flakes may or may not be bonded together. Vermiculite, or expanded mica, is flake insulation.

Granular insulations are composed of small nodules that contain voids or hollow spaces. These materials are sometimes considered open cell materials since gases can be transferred between the individual spaces. Calcium silicate and molded perlite insulations are considered granular insulation.

Spray Foam Insulation

The Spray Foam System is developed to improve insulation efficiency, minimize maintenance and reduce application time. Our Spray Foam System is based on a long experience from working with polyurethane foam for LPG, LEG and LNG cargo tank insulation.

Why Spray Foam Insulation?

• Very short application time at the ship yard
• Improved weather exposure resistance during assembly
• No protection needed for storage of insulated tanks outdoors
• Improved insulation life time
• No maintenance in operatio

Advantages

Insulation System

• The risk of voids in the insulation is eliminated by the spray method
• No joints in the foam, hence increased tightness
• Increased insulation efficiency
• Complete bonding to all surfaces
• No space for moisture accumulation
• Excellent corrosion protection

Application Method

• Insulation applied by 4 to 6 skilled operators
• Onboard or on land application
• Easy to repair
• Low material consumption
• Easy material handling
• Small storage volumes
• Short application time

Many types of insulations that can be used in cryogenics equipment. These include:

TYPES OF INSULATIONS

1. expanded foams,
2. gas-filled powders and fibrous material,
3. vacuum alone,
4. evacuated powders and fibrous materials,
5. opacified powdwers,and
6. Multilayer insulations.

These insulations are listed in order of increasing performance and,generally,in order of increasing cost.The specific insulation to be used for a particular application ,weight,ruggedness, and so on,in addition to the effectiveness of insulation.

(1)Expanded-foam insulations.

Expanded-foam insulations have cellular structure formed by evolving gas during the manufacture of the foam. some examples of foam insulation include polyurethane foam, polystyrene foam, rubber silica, and glass foam. The thermal conductivity of the foam insulations depends upon the gas used to foam the insulation plus a contribution due to internal radiant heat transfer and solid conduction.

The foaming gas used with many of the expanded foams is carbon dioxide, which has a low vapor pressure at liquid-nitrogen temperature. The thermal conductivity of the fresh foam is decreased when one side is initially cooled to liquid-nitrogen temperatures because much of the c

CO_2 condenses within the insulation. Ambient air for a few months, however, air diffuses into the cells and replaces some of the CO_2, and thermal conductivity may increase as 40 percent. If the foam is exposed to an atmosphere of hydrogen or helium for an extended period of time, the thermal conductivity may be increased by as much as a factor of 3or 4 because of the higher thermal conductivity of H2 and He gas, compared with CO_2.

The foams can bemused as insulation if contraction joints are provided in the foam and if the foam is enclosed with a plastic liner, such as Mylar, to prevent diffusion of water vapor and air into the joints.

(2)Gas-filled powders and fibrous insulations.

Porous insulations include fiber glass, powdered cork, perlite, Santocel, rock wool, and Vermiculite. The primary mechanism for insulation in gas-filled powders and fibrous materials is the reduction or elimination of convection due to the small size of the voids within the material. in addition, for the case of very fine powders, the distance between the powder particles may become smaller than the mean free path of the gas within the insulation, and the gaseous conduction mechanism shifts from continuum to free-molecular conduction. In this case, the effective thermal conductivity of the gas is decreased, and the apparent thermal conductivity of the material is correspondingly smaller than that for powders with larger particles. The diffusion of moisture can also be prevented by continually purging the insulation with dry-nitrogen gas at a pressure above atmospheric pressure. This procedure has been used for LNG containers in which a vacuum insulation is not economical.

(3)Vacuum insulation

Vacuum insulation alone is used extensively for small laboratory-size Dewars. The use of vacuum insulation essentially eliminates two components of heat transfer solid conduction and gaseous convection. Heat is transferred across the annular space of a vacuum-insulated vessel by radiation from the hot outer jacket to the cold inner vessel and by gaseous conduction through the residual gas within the annular space. In addition to the heat transferred by radiation, energy is transmitted by gaseous conduction through the residual gas in the vacuum space. If the pressure of the gas is low enough that the mean free path of the gas molecules is greater than the distance between the two surfaces, the type of conduction differs from the usual continuum-type conduction at ambient pressure. For ordinary conduction with constant thermal conductivity, there is a linear temperature gradient within the medium transmitting heat. On the other hand, for free molecular conduction, the gas molecules rarely strike each other; thus an individual gas molecule travels across the gas space without transferring energy to other gas molecules.

(4)Evacuated-powder and fibrous insulations

Gaseous conduction is one of the primary modes of heat transfer within powder and fibrous insulations; one obvious method of reducing the heat-transfer rate through these insulations is to evacuate the gas from the insulation. The variation of the apparent thermal conductivity for typical powder insulation. As the pressure of the within insulation is reduced from atmospheric to pressures on the order of 2kpa (15 torr), there is little change in the thermal conductivity. In this range of pressure, the thermal conductivity of the residual gas within the insulation is relatively expected that the insulation thermal conductivity should also be relatively independent of pressure. As the gas pressure is lowered further, a second region is reached in which the thermal conductivity of the insulation is linearly proportional to the gas pressure. The insulation thermal conductivity begins to level off and approaches the constant value for radiation and solid conduction alone as the pressure of the gas is decreased.

For highly evacuated powders and fibrous insulations room temperature, the radiant contribution is larger than the solid-conduction contribution to the total heat-transfer rate. On the other hand, the radiant contribution becomes smaller than the solid- conduction contribution for temperatures. Between liquid-nitrogen and liquid hydrogen or helium temperature. For this reason, evacuated powders are superior in performance compared with vacuum alone for heat transfer between ambient and liquid-nitrogen temperature. Since solid conduction becomes predominant at lower temperatures, it is usually more advantageous to use vacuum alone when the heat transfer occurs between LN_2 and LH_2 or LHe temperatures.

(5)Opacified-powder insulations

Because a fairly large portion of the total heat transferred through evacuated powders with one surface at room temperature and the other at cryogenic temperatures is radiant energy, one would expect that insulation performance could be improved by any method that reduce radiant heat transfer. This improvement in performance has been accomplished by the addition of copper or aluminum flakes to evacuated powder. The apparent thermal conductivity of two opacified powders as a function of the weight fraction of opacifier.A safety standpoint, copper flakes were found to be preferable to aluminum because aluminum has a large heat of combustion in combination with oxygen. If an aluminum opacified powder were used to insulate a liquid-oxygen container, there would be a constant hazard from any leaks of oxygen into the vacuum space. Copper opacified powders have been used with complete safety. Opacified powders have the disadvantage that vibration can cause packing of the Metal flakes. If many flakes get packed together, a"thermal short" develops, and the thermal conductivity of the insulation is increased.

(6)Multilayer insulations

Multilayer insulations consist of alternating layers of a highly reflecting material, such as aluminum foil, copper or aluminized Mylar, and a low-conductivity spacer, such as fiberglass mat or paper, glass fabric, or nylon net. The reflecting layers may also be separated by crinkling or embossing the sheets so that they touch only at a few discrete points, and a spacer is not required. This insulation was first developed by p.peterson of Sweden in1951.Since that time several investigators have studied various types of multilayer insulation and application techniques for improving the insulation performance (Kropschot et al.).Multilayer insulations must be evacuated to pressures below 10 MPa (7.5×10^{-5} torr) to be effective. The amazingly low thermal conductivity of multilayer insulations can be explained by the fact that all modes of heat transfer-radiation, solid conduction, and gaseous conduction-are reduced to a bare minimum. Radiation is minimized by using many layers of a highly reflecting metal foil. Solid conduction through the spacer material to allow contact at only a few points. Gaseous conduction

Different Applications.

Combined heat transfer in multi-layered radiation shields for vacuum insulation panels: Theoretical/numerical analyses and experiment. [1]

In this paper Radiation and conduction heat transfer in stacked radiation shields to be used in the VIP (vacuum insulation panel) is investigated. Test radiation shields are multi-layered films of 32 nm Al, 12 lmPET and 32 nm Al thicknesses, folded with regular span and stacked in staggered manner. Radius of curvature of the folded parts is measured by a three-dimensional scanner and the contact radius is calculated using Hertz contact theory. Depth wise conduction around the contact spot and two-dimensional radial conduction models are adopted for the theoretical and the numerical analyses, together with measured surface emissivity.[2] Measurement of the effective thermal conductivity of radiation shields is conducted using a vacuum guarded hot plate apparatus. Measurements show very low values between 0.3 and 1.0 MW/m K. Theoretical and numerical results agree with measurements with maximum relative error of 29.1% and 18.3%, respectively. A simplified conduction model is also proposed and shown to be very useful for practical applications. We find that the stacked radiation shields have very high insulation performance, the numerical model is fairly reliable and finally, conduction is negligibly small compared with radiation for this shield. [3]

Spray-on foam insulations for launch vehicle cryogenic tank. [4]

This paper described about the Spray-on foam insulation (SOFI) has been developed for use on the cryogenic tanks of space launch vehicles beginning in the 1960s with the Apollo program. The use of SOFI was further developed for the Space Shuttle program. The External Tank (ET) of the Space Shuttle, consisting of a forward liquid oxygen tank in line with an aft liquid hydrogen tank, requires thermal insulation over its outer surface to prevent ice formation and avoid in-flight damage to the ceramic tile thermal protection system on the adjacent Orbiter. The insulation also provides system control and stability throughout the lengthy process of cool down, loading, and replenishing the tank. There are two main types of SOFI used on the ET: acreage (with the rind) and closeout (machined surface). The thermal performance of the seemingly simple SOFI system is a complex array of many variables starting with the large temperature difference of 200–260 K through the typical 25-mm thickness. Environmental factors include air temperature and humidity, wind speed, solar exposure, and aging or weathering history. Additional factors include manufacturing details, launch processing operations, and number of cryogenic thermal cycles.

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