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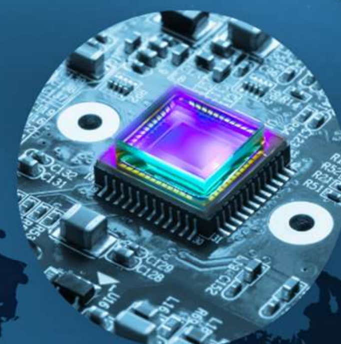

Stay cool under pressure

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Cryopreservation In Life Sciences

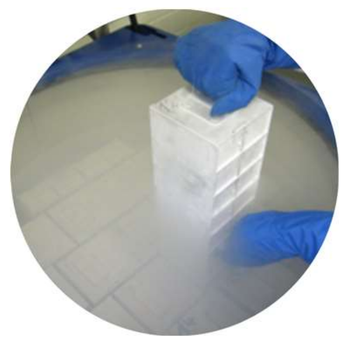
What is Cryopreservation

Cryopreservation, a remarkable scientific process, holds the key to preserving life at sub-zero temperatures. This technique has revolutionized fields ranging from medicine to biology, offering new avenues for organ transplantation, fertility treatments, and even the conservation of endangered species.

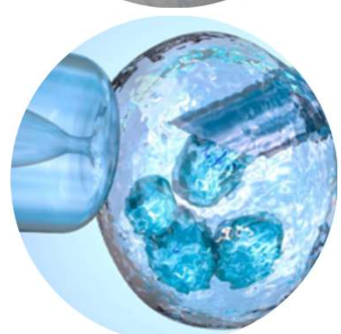
Defining Cryopreservation

Cryopreservation involves the preservation of living cells, tissues, or even whole organisms by cooling them to extremely low temperatures, typically below -130°C (-202°F) or even colder. At such frigid temperatures, biochemical reactions slow down to a near halt, effectively preserving the biological material in a state of suspended animation.

Applications in Medicine



One of the most significant applications of cryopreservation is in the field of medicine. Organ transplantation, a critical medical procedure, often faces challenges due to the limited availability of compatible donor organs. Cryopreservation has the potential to address this issue by allowing for the storage of organs for longer periods, increasing the chances of finding suitable recipients.



Furthermore, in the realm of reproductive health, cryopreservation has enabled advancements in fertility treatments. Sperm, eggs, and embryos can be cryopreserved, allowing individuals to preserve their fertility for later use. This is especially beneficial for those undergoing cancer treatments or other medical procedures that may affect their reproductive capabilities.

Biological Research and Conservation

Cryopreservation plays a crucial role in biological research and conservation efforts. Scientists can store cell lines, tissues, and genetic material for future studies, enabling ongoing research even after the original samples are long gone. This is particularly valuable for understanding diseases, conducting experiments, and advancing various scientific fields.

The conservation of endangered species also benefits from cryopreservation. By preserving genetic material from endangered animals, scientists can safeguard biodiversity and potentially reintroduce species back into their natural habitats in the future.

Liquid Nitrogen Piping Systems for Cryopreservation

In the realm of cryopreservation, where the preservation of biological materials hinges on extreme cold, the role of liquid nitrogen piping systems is paramount. Super insulated piping systems provide a robust solution that aligns technological ingenuity with the intricate demands of preserving biological materials. By addressing the challenges posed by heat leaks and temperature variations, CSM contributes to advancing the field of cryopreservation and ensuring that the promise of extreme cold continues to unlock new possibilities for medical, research, and conservation endeavors.

CSM specializes in designing and manufacturing super insulated piping systems with extremely low heat leaks, allowing for the transfer of liquid nitrogen from storage tanks to freezer units. The main benefits of their innovative systems include:

1. Reduced Vapor Formation: By minimizing heat leaks, CSM's piping systems help reduce vapor formation within the pipeline. This reduction in vapor formation ensures a consistent and uninterrupted supply of liquid nitrogen to the freezer, preventing disruptions in the normal supply process.

2. Mitigated Warm Vapor Intrusion: The low heat leak design also minimizes warm vapor intrusion into the freezing unit. This intrusion, if left unchecked, could disrupt the freezing temperature within the unit and compromise the biological viability of preserved materials.

3. Consistent Temperature and Pressure: CSM's piping systems ensure a dependable supply of liquid nitrogen to the freezer, maintaining a consistent low temperature and low-pressure environment. This consistency is crucial for optimal cryopreservation outcomes.

CSM Cryogenic Pipe Solution

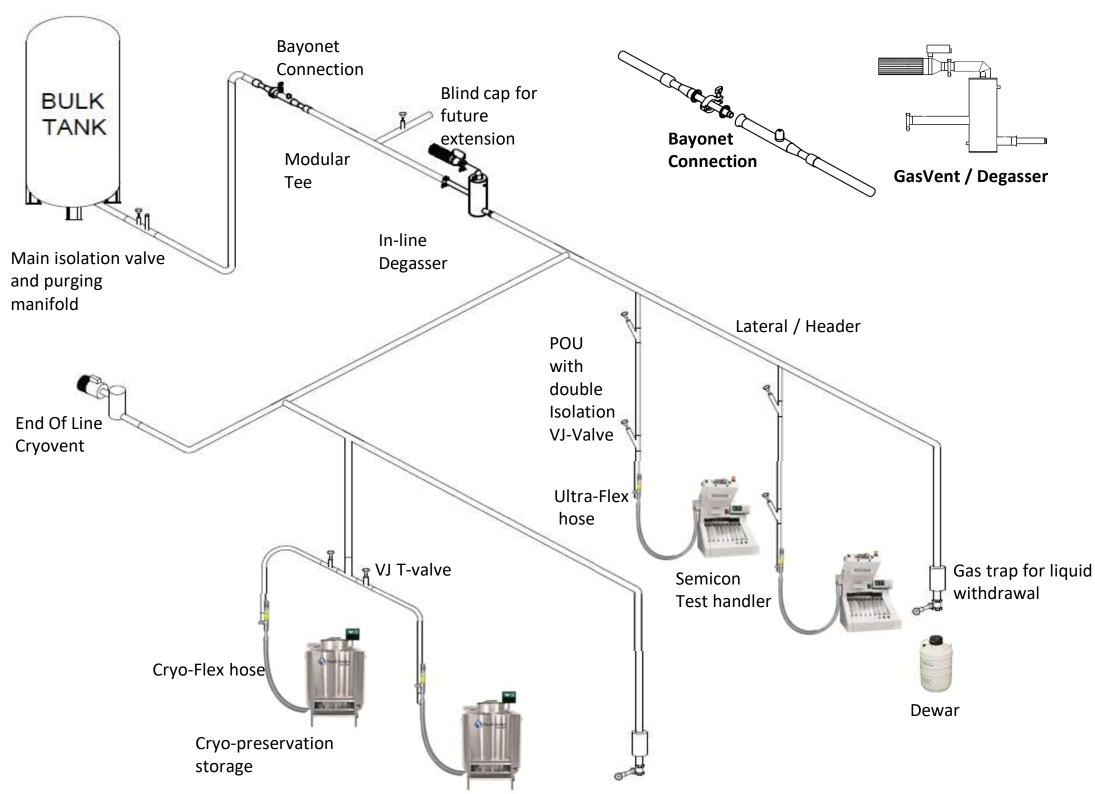
Introduction

The transfer of liquid cryogens such as liquid nitrogen over any distance in a plant, whether indoors or outdoors, requires special piping insulation. Issues that need to be considered in cryogenic liquid transfer includes the economic loss of cryogen through evaporation and quality degradation of the cryogen delivered at the point of use.

Under normal operational circumstances, the liquid in the system is constantly vaporizing into gaseous nitrogen due to constant heat leak. The accumulated gas in the pipeline will result in excessive gas within the transfer system which causes:

1. Diminished cryogen cooling capacity, warmer liquid with higher enthalpy
2. Excessive vapor phase resulted in higher gas content in liquid
3. Inconsistent delivery of liquid nitrogen due to plug and slug flow conditions
4. Variation in cool-down time from one point to another
5. Increased in operating cost due to higher heat loss

Typical Cryogenic Piping Installation



Rigid Vacuum Jacketed Pipe

Rigid VJP is easier to install than traditional foam insulated copper pipe and is designed to be maintenance-free for a minimum of 10 years, with no system heat leaks performance deterioration over that period. Pipe sections are joined with vacuum-insulated bayonet connectors that provide frost-free connections.

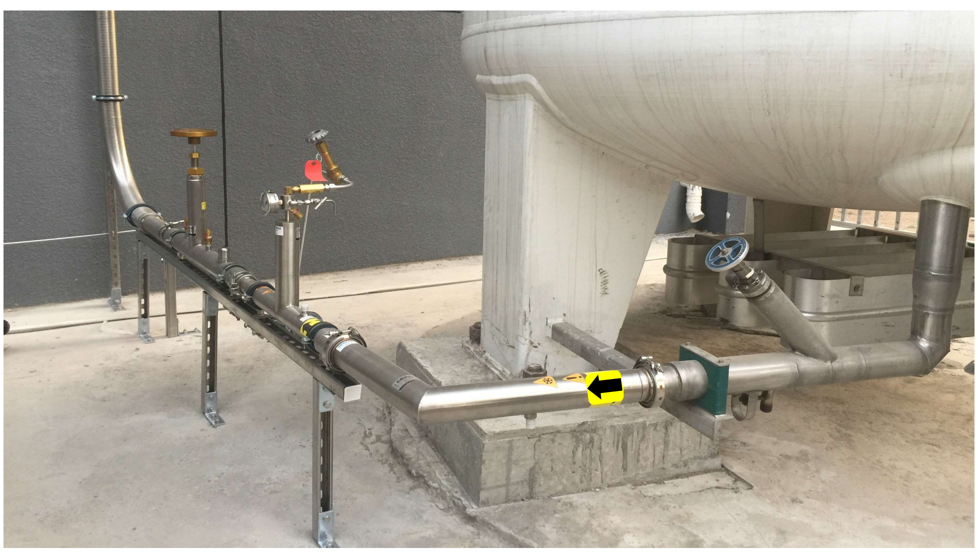
The thermal barrier between the inner and outer lines are so effective that the outer pipe remains at room temperature even while -196˚C (-320˚F) liquid nitrogen is flowing through the inner line. Rigid VJP can also be exposed to direct sunlight without affecting the system's performance.

CSM provides various pipe standard option of rigid VJP, such as Rigid-T (ASTM/EN tube sizes) with C-series bayonet connection; and Rigid-P (ASTM pipe sizes) with B-series bayonet or Welded connection.

Flexible Vacuum Jacketed Pipe

Pre-engineered modular flexible vacuum jacketed transfer hose has added advantage over the rigid VJP, especially when system upgrade is frequently done. This option is cost saving as the flexibility of the pipe reduces the necessity for precise system layout measurements. It allows the whole system to be easily reused if use-point locations and plant layout are changed. Flexible can be added if required to the existing system without major rework expenses. Additionally, flexible VJP can be coiled for shipment by air freight, thus eliminate the need for expensive logistics.

CSM provides various flexible VJP options to suit different flexibility requirement. Semi-Flex is a semi-rigid VJP but spool length up to 18 meters with modest bend radius for on site installation without necessary to use an elbow. Cryo-Flex is more flexible but limited to shorter spool length below 4 meters, usually use as tie-in hose to bulk storage tank or equipment, or a flexible section to overcome offset or misalignment in a Rigid VJ Piping system.



Semi-Flex liquid nitrogen piping system at a semiconductor facility

Advantages of CSM Vacuum Jacketed Pipe

- Significant reduction in loss of liquid cryogen caused by heat leaks.
- Quick return on investment in new vacuum jacketed pipe installation.
- Virtually no decrease in thermal performance of vacuum jacketed pipe over 10 years.
- The Cryorigid vacuum jacketed pipe system is maintenance free for 10 years minimum.
- Longest life cycle backed by a 10-year warranty.
- Increase in freezing capacity due to improved quality of liquid nitrogen.
- Consistent delivery of liquid nitrogen at the use points due to reduction of vapor content.
- Improved process safety due to elimination of frosty and dripping conditions.

What We Offer

- A 5 + 5 years warranty on all Cryorigid vacuum jacketed pipe.
- On-site measurements.
- Most efficient layout of the vacuum jacketed pipe system required for your application.
- Detailed proposal describing every component of the vacuum jacketed pipe system.
- Manufacturer's specifications of the system presented for your review.
- Isometric CAD drawing showing every detail of the proposed system.
- A Heat Leak Guide to show LN2 losses of current foam insulated copper pipe system.
- Break-even analysis on anticipated return on investment and long-term financial benefits to operation's bottom line.
- Cash flow analysis to show immediate effect the new system will have on your plant operation.

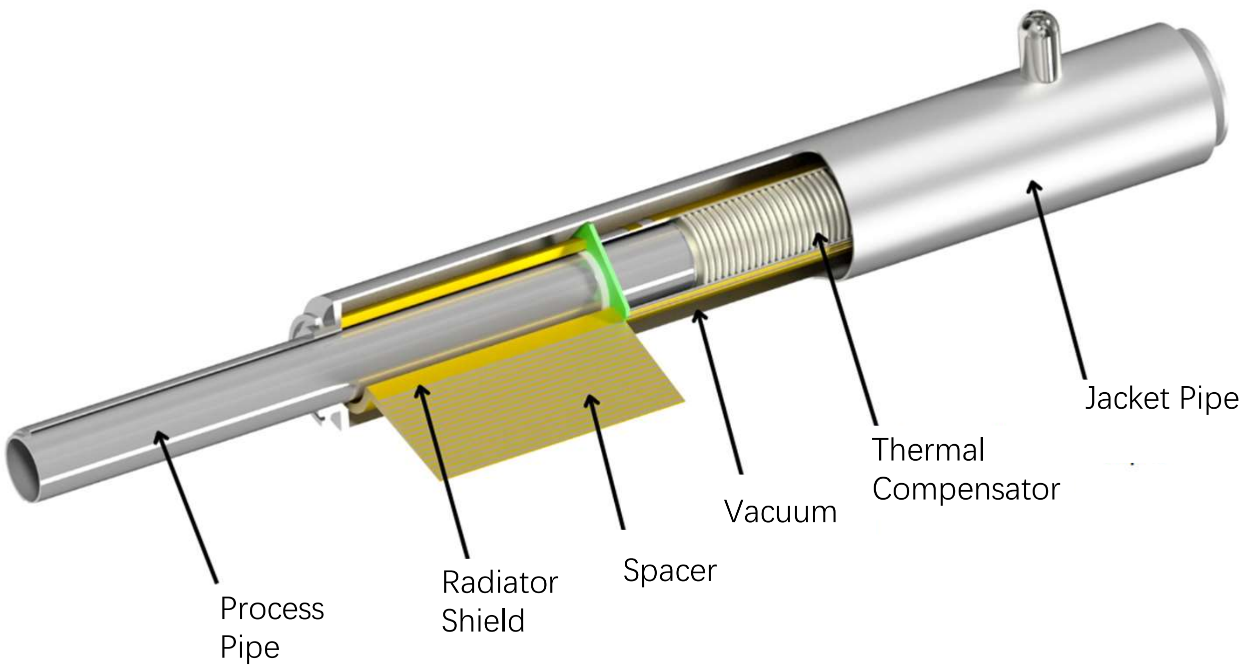
Vacuum Jacketed Technology

Introduction

Vacuum Jacketed Pipes, also known as VJPs, were first developed in the early 1900s. However, the technology did not become commercially available until the 1960s when it was used to insulate cryogenic transfer lines. Since then, VJPs have been widely used in various industries, including in the transportation of liquefied natural gas (LNG), in the food and beverage industry, in the semiconductor industry, and in medical applications. In recent years, VJPs have also gained popularity in building construction for their energy-efficient properties.

Vacuum Jacketed Pipes (VJPs) have come a long way in terms of insulation technology. Over the years, there have been many advancements in the materials and design used in VJPs, which have greatly improved their insulating capabilities.

One major development has been the use of advanced insulation materials, such as multilayer insulation. VJPs have also benefited from advances in manufacturing technology. For example, modern VJPs are produced using advanced welding techniques and automated manufacturing processes, which ensure a high level of quality control and consistency in the production process. However, despite these advancements, it is not possible to completely eliminate heat transfer (leaks) in any system.

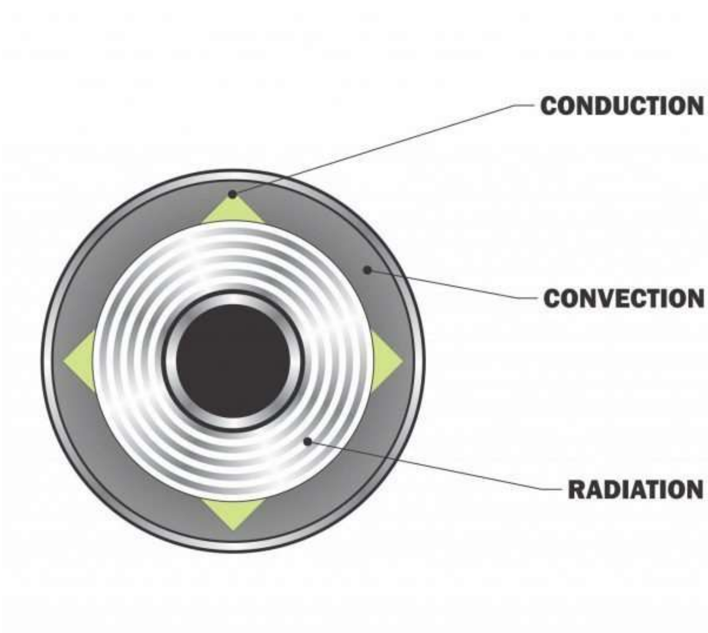


Heat Leaks

The technology in transfer piping for LN2 and other cryogenic fluids has made substantial advances since the early 1990s. Not only are today's transfer lines better insulated to minimize the heat leaks and loss of LN2 through evaporation, but they are also easier to install and are virtually maintenance-free.

Two types of vacuum jacketed piping (VJP) systems (also referred to as vacuum insulated) — rigid and flexible — are available for process plant installations where long runs of piping are required to transfer LN2 from a bulk storage vessel at the back of the plant to one or several use points.

Primarily, VJP is designed to reduce heat leaks by addressing three modes of heat transfer: conduction (both solid and molecular conduction), convection, and radiation.



Conduction - CSM VJP reduces conduction by using low conductivity radial supports to prevent the inner pipe from touching the outer pipe.

Convection - is prevented by removing the gas molecules from the space between the inner and the outer pipe at high vacuum 10^{-5}Torr. Vacuum helps reduce molecular conduction to near zero.

Radiation - the inner pipe is wrapped with multiple layers of reflective radiation shield and low conductive spacer material to reduce radiation heat transfer.

The inner pipe which carries the cryogenic liquid is wrapped with multiple layers of super-insulation, consisting of alternating layers of radiant heat barrier material and non-conductive spacer material. Also, the vacuum annulus contains molecular sieve and getter materials to absorb gas molecules to further improve the vacuum quality and lengthen the vacuum life. Most importantly, the space between the two lines is evacuated and then sealed in a static vacuum system or by an on-site vacuum pump in dynamic vacuum system.

You can download more information about multi-layer insulation from CSM blog site *www.csm-cryogenic.com/cryo-blog/super-insulation-technology*

Major Challenge in Vacuum Jacketed Technology

When liquid nitrogen is transported through a vacuum jacketed pipe (VJP) system, heat transfer can occur due to imperfections or defects in the vacuum jacket design, construction or gradual loss of insulation performance due to hydrogen and other molecules outgassing within the vacuum insulation system.

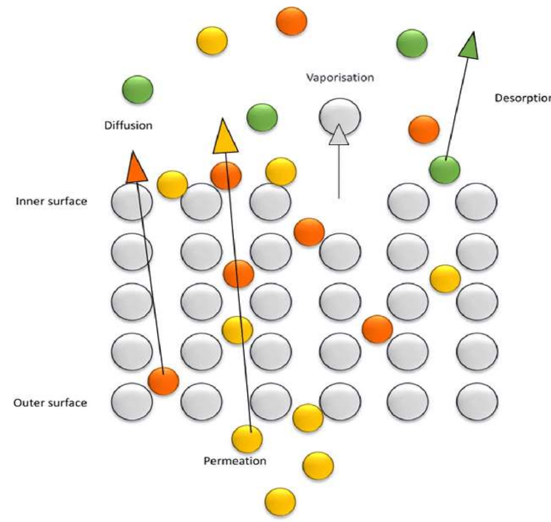
There are 4 main mechanisms which contribute to outgassing:

1. Vaporisation of the actual surface material itself

2. Desorption — this is the reverse process of adsorption; the release of molecules bound at the surfaces of the material

3. Diffusion — this is the movement of molecules from the inner structure of the material to the surface

4. Permeation — this is the movement of molecules from the external atmosphere through the jacket pipe wall to the vacuum surface



Outgassing

Outgassing, which is the process by which gases trapped within the VJP system are released over time. As the gases within the VJP system are released, they can reduce the vacuum pressure within the system, which can result in a reduction in the thermal insulation performance of the VJP. This is because the vacuum pressure within the VJP system is critical to its thermal insulation properties. A high vacuum level (lower vacuum pressure) reduces the thermal conduction between the inner and outer pipes, which helps to maintain the temperature of the transported fluid.

To mitigate the effects of outgassing, CSM use materials that have low outgassing rates, maintain high vacuum quality within the VJP system, and perform proper cleaning and degassing of the materials used in the VJP. In addition, VJP manufacturers may also incorporate getter & molecular sieve materials into the VJP system.

Getters & Molecular Sieve

Getters & molecular sieves are materials that are used in vacuum jacketed pipes (VJPs) to absorb or trap gases, including those released through outgassing, to help maintain the vacuum quality within the VJP system and preserve its thermal insulation properties. However, if the getters become exhausted, their ability to absorb or trap gases is diminished, which can lead to a loss of insulation performance in the VJP.

Exhaustion of getters can occur due to a variety of factors, including exposure to gases that cannot be absorbed or trapped by the getter material, gas saturation, or simply the natural degradation of the getter material over time.

When a getter becomes exhausted, it can no longer effectively absorb or trap gases, and any remaining gases within the VJP system can begin to degrade the vacuum quality. This can lead to an increase in thermal conduction between the inner and outer pipes.

Thermal Conductivity for Vacuum Jacketed Pipe (VJP)

CSM VJP deploys high-quality multilayer insulation (MLI) materials with controlled thicknesses of 0.06mm for the fiberglass spacer and 6 micrometers for the aluminum foil. The fiberglass spacer is composed of a material with a low conductance of less than 1.0 W/m2-K. Additionally, the aluminum foil undergoes special treatment to achieve an emissivity of less than 0.04.

For a well-evacuated MLI, The K_{ta} value obtained is approximately $1.1 \times 10^{-2} mW/m \cdot K$ at vacuum pressure of $1 \times 10^{-4}\ torr$, at mean temperature, $T_m = \frac{300+77}{2} = 188.5 \approx 190K$.

The apparent thermal conductivity may be determined from

$$k_{ta} = \frac{1}{(\frac{N}{\Delta x})}\left[h_c + \left(\frac{e}{2-e}\right)\sigma\left(T_H^2 + T_C^2\right)(T_H + T_C)\right]$$, Where

h_c is the solid conductance of the spacer material

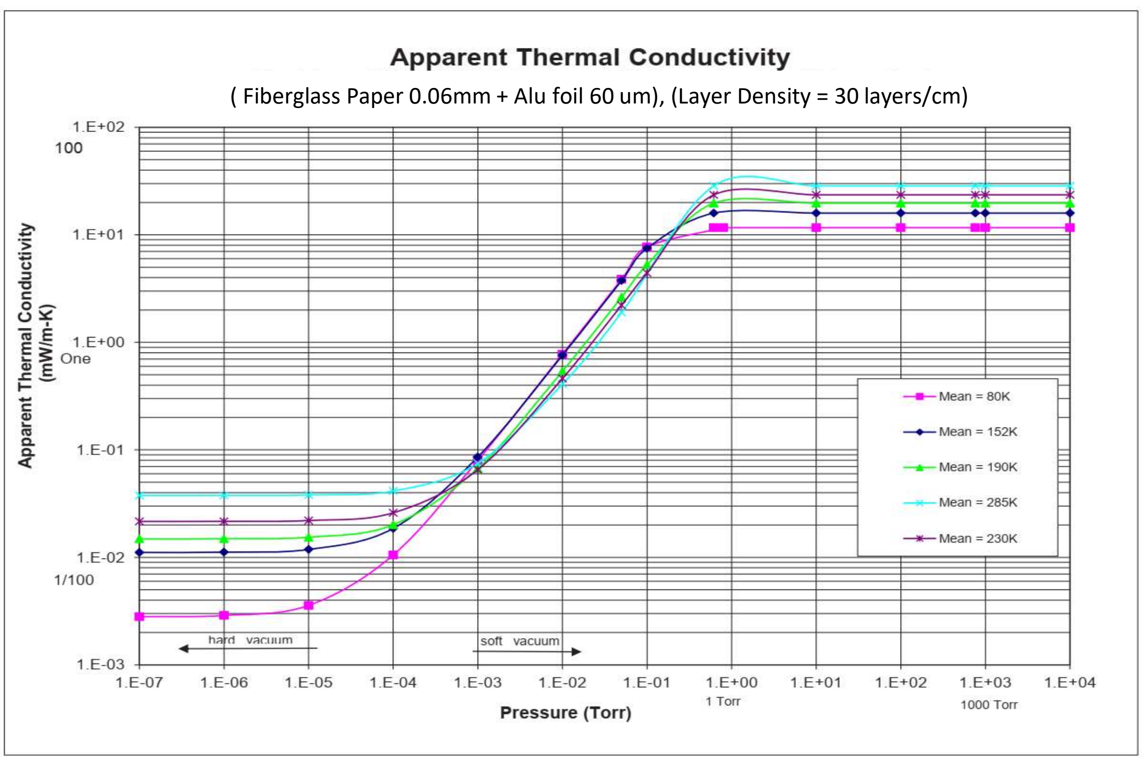
σ is the Stefan-Boltzmann constant

$\sigma = 0.1714 \times 10^{-8}\ Btu/h\text{-}ft^2\text{-}°R^4 = 5.669 \times 10^{-8}\ W/m^2\text{-}K^4$

e is the emissivity of the radiation shields

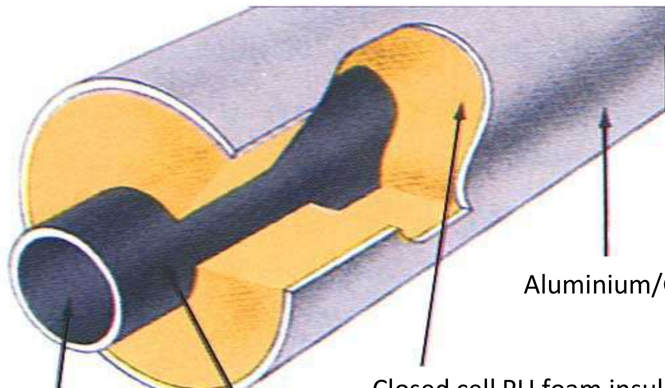
T_H and T_C are the boundary temperatures of the insulation (absolute temperature)

$N/\Delta x$ is the layer density (one "layer" is defined as one sheet of foil plus one sheet of spacer material)



Thermal Conductivity for Foam Insulated Pipe (FIP)

For decades, the accepted method of insulating cryogenic transfer pipe (typically copper or schedule 10s stainless steel pipe) was to use foam insulation covered by a protective polyvinyl chloride layer. This type of insulation is inexpensive and works well when new, providing typical heat transfer rates above 10 – 20W/m (10 - 20 BTU/hr/ft) at LN2 temperatures. However, its performance deteriorate rapidly within five years, and becomes less effective in preventing vaporization of the liquid as the product ages.



If you are using liquid nitrogen (LN2) in your processing operation and your transfer lines are more than 5 years old, you might be losing money every day. You probably see ice spot or frost along the pipeline and a water puddle on the floor, but it won't alarm you that something is amiss. Instead, what typically happens is that you will gradually use more and more LN2 with each passing year without even realizing.

The following theoretical model has been developed (Bootes & Hoogendoorn 1987) to predict the thermal conductivity of closed cell foams:

$$k_t = 0.4(1-\Phi)\, k_s + k_g + 4F_e\, d\, \sigma\, T_m^3$$ where,

Φ is the porosity of the foam (volume of void per unit total volume

k_s is the thermal conductivity of the solid foam material

k_g is the thermal conductivity of the gas within the cavities

d is the thickness of the foam

σ is the Stefan-Boltzmann constant

$$\sigma = 0.1714\times10^{-8}\,\text{Btu/hr-ft}^2\text{-R}^4 = 5.669\times10^{-8}\,\text{W/m}^2\text{-K}^4$$

T_m is the mean insulation absolute temperature = $1/2 \text{ x } (T_H + T_C)$
F_e is the emissivity factor

$$\frac{1}{F_e} = \frac{d}{d_c}\left(\frac{1+r-t}{1-r+t}\right) + 1,$$ Where

r is the reflectivity of the foam material

t is the transmissivity of the form material

d_c is the size of the foam cells

Typical values for the reflectivity and transmissivity of polyurethane foam are 0.034 and 0.493, respectively. Cell sizes on the order of 0.01-0.02 in. (0.25-0.50mm) can easily be achieved.

In this example, we estimate thermal conductivity for polyurethane foam insulation having a porosity of 0.96 operating between 300K (540°R) and 80K (144°R). The thermal conductivity of the solid material is 0.288 W/m-K, and the thermal conductivity of the gas (CO_2) in the foam is 0.0166 W/m-K. The thickness of the foam layer is 150mm (5.91 in.), and the size of the cavities within the insulation is 0.50mm (0.02 in.). The reflectivity and transmissivity may be assumed to be the same as polyurethane.

The emissivity factor is calculated as:

$$1 / F_e = d / d_c \times [(1 + r - t) / (1 - r + t)] + 1$$

$$1 / F_e = 150/0.50 \times [(1 + 0.034 - 0.493) / (1 - 0.034 + 0.493)] + 1 = 111.2$$

$$F_e = 0.00899$$

The mean temperature of the insulation is T_m=1/2 x (300+88) =190K.

The thermal conductivity K_t of the foam insulation is estimated as:

$$K_t = (0.40 \text{ x } (1-0.96) \text{ x } 0.288) + 0.0166 + (4 \text{ x } 0.00899 \text{ x } 0.150 \text{ x } (5.669\times10-8) \text{ x } 1903)$$

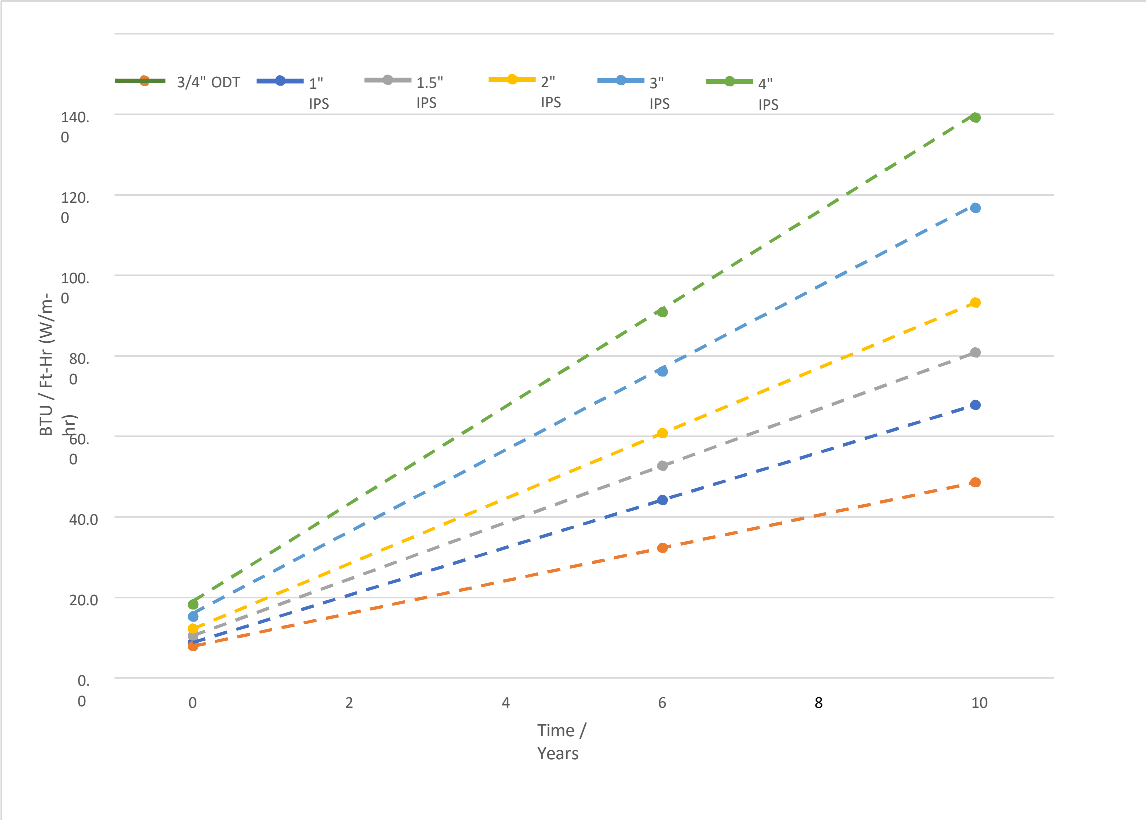
$$K_t = 0.00461+0.0166+0.00210$$

$$K_t = 23.31 \text{ mW/m-k}$$

In comparison to vacuum jacketed pipe, polyurethane foam insulation incurs k_s (the first term) of 20% of the total heat transfer, gaseous conduction k_g (the second term) is 71%, and radiation (the third term) is 9% of the total.

On the other hand, in vacuum jacketed pipe, the MLI produce K_{ta} value of $1.1 \times 10^{-2} mW/m \cdot K$, with the bulk of heat transfer occurs via radiation, accounting for approximately 99%.

Estimated Heat Leak Performance for PU foam insulation in 10 Years



Above heat leak data in this document are derived from a test using boil-off calorimeter system in accordance to ASTM standards C1774, C740, C335.

Making A Smart Choice

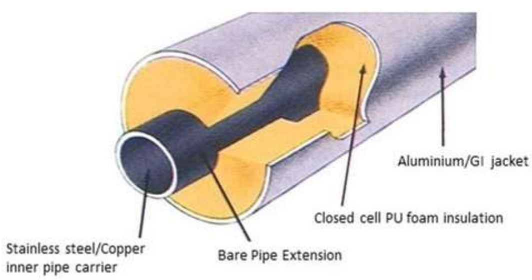
Value vs. Cost of Heat Leak

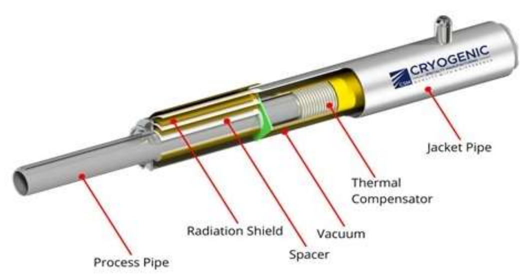
Due to the extreme temperature difference between liquid nitrogen and ambient air, a large amount of heat will transfer even through a very short section of uninsulated or poorly-insulated pipe component very quickly. This can have a substantial impact on the entire system.

Even though the loss is not immediately visible nor is it significant for one day, but over time that loss can add up to thousands of dollars. Increased heat leak at any point in the system can cause two-phase fluid that increases pressure drop, causing irregular flow of liquid, which reduces the overall flow rate. Two- phase flow will create significantly higher pressure drops through the pipe system, irregular liquid delivery, results in warmer liquid at the cryogen use point and shortens the life of valve seats and other components within the system.

Getting the Return on Your Investment

Although the initial purchase price of a VJP system can be higher than for non-vacuum insulated FIP, VJP systems typically provide a quick payback by reducing operating costs. These systems can significantly minimize the liquid losses caused by heat leaks, provide a longer life cycle than conventional foam-insulated copper piping, and do not decrease in performance over time. They can also increase production efficiency by improving the quality of the LN2 flowing through the lines (delivering colder LN2 to the use point) and can improve process safety by eliminating frosty and dripping conditions.





Heat Leak / Performance Comparison Chart

The table below summarizes the comparison of heat leaks between the Vacuum Insulated stainless steel pipe and the PU insulated copper pipe of various sizes:

Line Size	Vacuum Jacketed Pipe BTU/HR/FT (Watt / mtr)	Insulated Copper BTU/Hr/ft (Watt / mtr)		Bare Copper BTU/Hr/ft
		New	After 5 Yrs Old	
¾" ODT	0.42	7.9	32.3	165
1" IPS	0.49	8.8	44.2	280
1 ½" IPS	0.52	10.5	52.7	397
2" IPS	0.69	12.2	60.8	530
3" IPS	1.20	15.2	76.1	769
4" IPS	1.40	18.2	90.8	1000

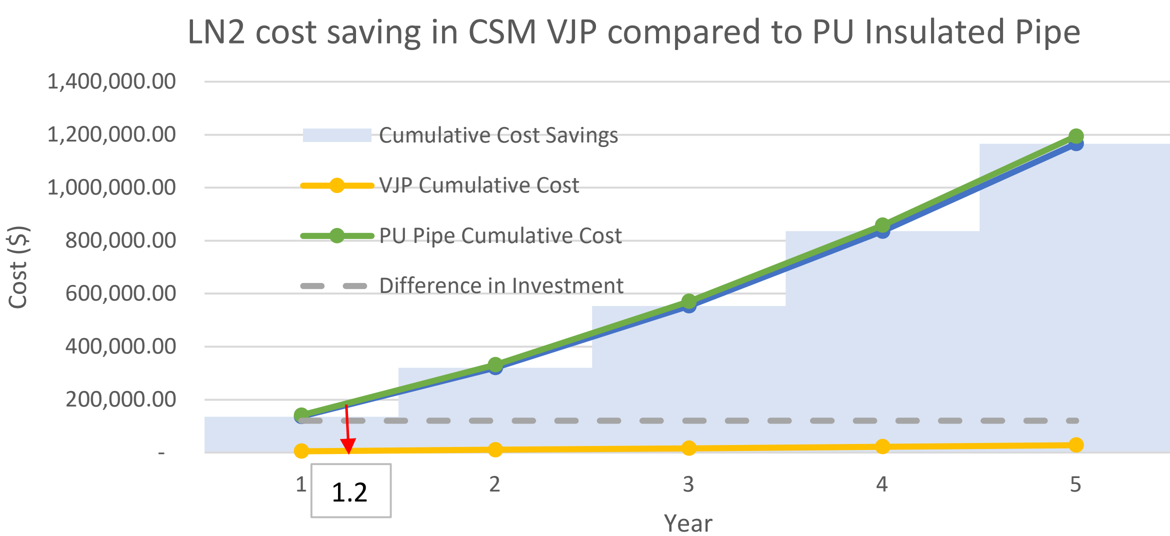
Case #1:

Consider a food production company that utilizes a 30-meter (100-foot) run of vacuum jacketed pipe (VJP), along with a 0.5-meter (2-foot) connection of foam-insulated pipe.
For the VJP with a diameter of 1.0 inch, the typical heat transfer rate is approximately 0.5W/m (0.52 BTU/hr/ft). Thus, the total heat leak for the 30-meter run of VJP can be calculated as 30 x 0.5 = 15W (52 BTU/hr).
On the other hand, for the foam-insulated copper pipe, the typical heat transfer rate is around 20W/m (20 BTU/hr/ft). Consequently, the heat leak for the 2-foot section of foam-insulated copper pipe can be determined as 0.5 x 20 = 10W (40 BTU/hr).

Result:
The 2% length of foam insulated copper pipe section is responsible for 40% of the total heat leaks into the entire 30 meters of VJ piping system.

Case #2:

A semiconductor plant is currently undertaking a project involving a 100meters (300ft) of 1.5"NB piping system to supply liquid nitrogen to six units of HALT/HASS equipment. They have received two quotations: one for a copper piping system with 3" PU insulation priced at $40,000.00, and another for an SS304L vacuum insulated piping system priced at $160,000.00.
To conduct a ROI (Return on Investment) analysis, the project engineer needs to estimate the heat leaks and LN2 loss for both systems. The analysis is based on the assumption that the cost of LN2 will average $0.50 per Liter over the next ten years. The results of the ROI analysis are presented below.



A comparison of liquid nitrogen losses between the two piping systems reveals that the vacuum insulated system significantly reduces losses compared to the copper piping system. As a result, the company can justify the additional investment cost of $120,000.00 for the vacuum insulated system with ROI within just 1.2 years.

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