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# SELECTION OF CRYOGENIC INSULATION FOR LNG TRANSFER LINE

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**Abstract:** *Selection of the efficient and inexpensive insulation for the Liquefied Natural gas at the cryogenic temperature is not as easy as it seems from the very first instance. Scientists must consider all ways and modes of heat transfer like, Conduction, convection and Radiation. Thermal insulation has important functions in LNG applications. In storage system, Insulation has to be provided to minimize product loss due to evaporation as a result of heat in-leak. Piping, which abounds in a baseline LNG plant or in a receiving terminal, has to be well insulated for several reasons. Increased activities in the field of LNG have brought to the minds of many gas-industry representatives the possibility of pipelining natural gas in its liquids, rather than gaseous form. Many insulation choices have available in the market place now a day for use in LNG piping and storage applications. The selection of the insulation material is very important because the LNG is produced at a far way distance and it has to be liquefied for storage and transferred to a long distance at a cryogenic temperature. So, the loss of the LNG by evaporation due to heat transfer from surrounding ambient temperature must be minimised as much lowest as possible. The operating cost and other adhered cost must be most competitive from the point of view of profitability, no matter what the market price of the natural gas is at, now almost depend on getting the product to the market at the lowest cost possible. So, it is utmost important to select the best insulation material available in the market for arriving at a competitive pricing of LNG.*

## I. INTRODUCTION

The insulation of cryogenic plant makes high demands of the material which is to be used. Important selection criteria are low evaporation losses, the lowest possible energy losses during re-liquefaction and, of course, safe storage of the refrigerants. An important requirement is that condensation is prevented and the risk of corrosion under the insulation (CUI) is minimized. Further-
more, the insulation must absorb the tremendous vibrations and impact resulting from the extreme temperature cycles and with-stand external mechanical strain. Apart from the materials used the technical construction of the insulation system plays a critical role. Materials traditionally used in this field are rigid foams (on the basis of PUR/PIR, for example) or cellular glass, which are combined with additional vapour barriers and/or contraction joints.

## II. NEED FOR INSULATION FOR TRANSPORTATION OF LNG

First, product conservation is important and heat in-leak has to be kept Minimum. Second, the cryogenic liquid transported in the piping boils, unless sufficiently sub cooled, as result of the environmental heat leak. The resulting vapour formation might cause other problems due to two phase flow. By providing effective insulation and by sub cooling the liquid initially, pipe transport can be accomplished with sensible heat gain only, without producing vapour. Third, Insulation has to be provided for safety reasons. Cold surfaces below about 200 F (266 K) can present a safety hazard when in contact with human skin, which “sticks” to the cold surface, resulting in severe injury. Forth, cold surfaces exposed to the surrounding atmosphere are subject to water vapour condensation whenever the surface temperature drops below the dew point. Not only is condensation a nuisance (e.g., Water dripping from an overhead pipe or piece of equipment), but also it can be the source of serious corrosion problems. Hence, the pipe or piece of equipment has to be sufficiently insulated to prevent condensation. Complete elimination of condensation is not possible for all conditions. The LNG plants also have significant warm equipment and piping. These have to be insulated to reduce heat loss and to provide safety to personnel.

Another important application of insulation is fire protection. In case of a fire, usually in the neighboring area the equipment has to be protected to prevent structural damage.

LNG can be transported by Road, Rail, and Marine or through insulated pipeline.

- **Following are four modes of transportation of LNG:**

i.. Road transport
ii. Rail Transport
iii. Marine Transport
iv. Pipeline transport

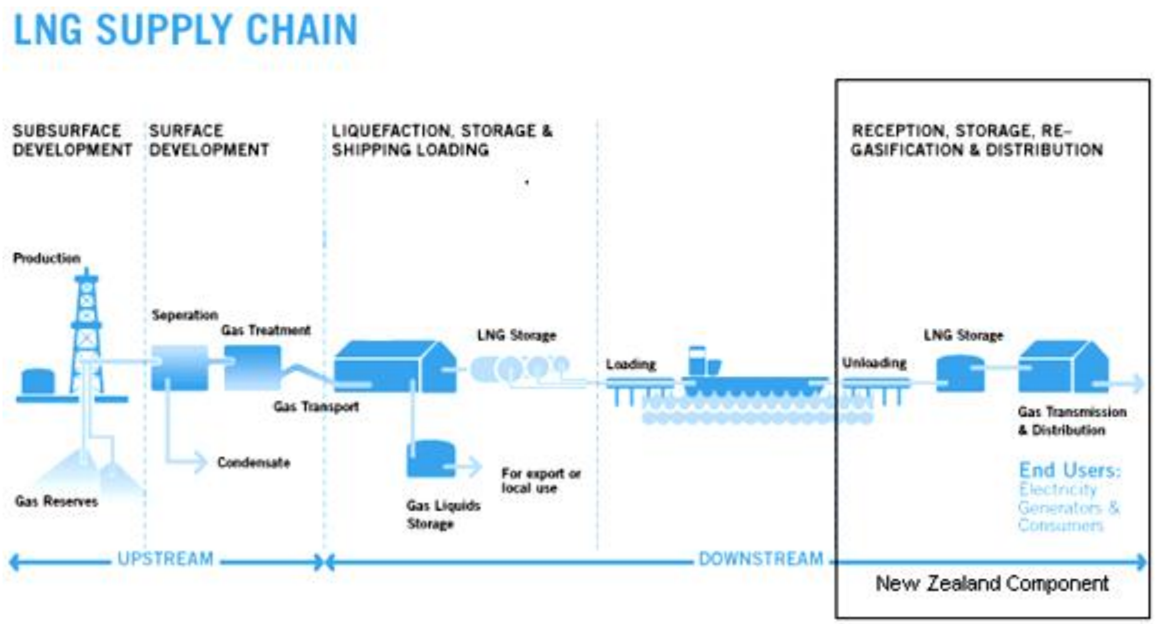



*Fig. 1 LNG supply chain*

### i. Road Transport

Since, 1960 tank truck have been used for LNG transportation on highways. Tank trucks can carry LNG over shorter distances. They may transport natural gas directly to end users, or to the distribution points such as pipeline for further transport. They use thermal insulation-perlite in vacuum.

*Fig. 2 Road and Marine Transportation*

Road tankers with a carrying capacity of 6 to 10 tonnes of LNG are in use. The inner shell is stainless steel with a maximum pressure of 7.5 bars. The relative high pressure means that long journeys can be accomplished without blowing methane to atmosphere. On public roads and in majority of applications a liquid LNG pumps for transfer to storage is not necessary. These tanks are insulated by 125 mm of PUF and are protected by an outer skin of air tight thin gauge aluminum cladding.

**ii. Rail Transport**

We can transport LNG by rail similarly like $O_2$ and $N_2$ are transported by rail. It is just like a limited size tank car. The inner shell is stainless steel with a vacuum space between inner shell and mild steel outer vessel, filled with perlite.

The demand for LNG rail cars will develop, as LNG becomes a more widely available and used product for the gas industry.

**iii. Marine transport**

One of the most important means of transportation is shipping. LNG carriers can be used to transport LNG across oceans over thousands of miles. Ocean going ships with a carrying capacity of 11,000 tons are in use and LNG ships with carrying capacity of 30,000 tonnes will be in use in near future.

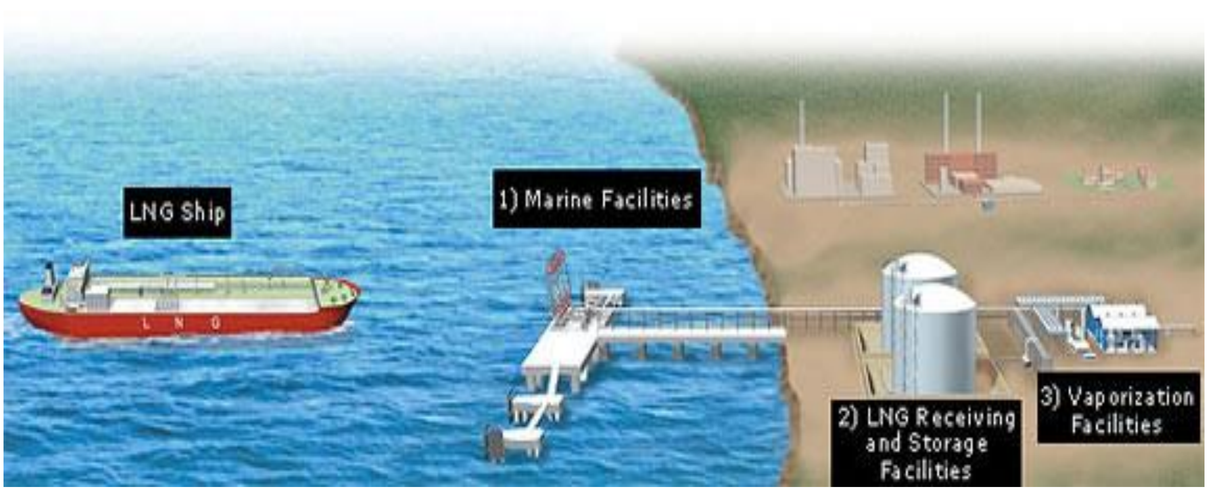


***Fig.4 marine facilities***

**iv. Pipeline transport**

Increased activity in the field of liquefied natural gas (LNG) has brought to the minds of many gas-industry representatives the possibility of pipelining natural gas in its liquid, rather than gaseous, form.

The advantage of liquefying the gas for transportation is that more standard cubic feet of natural gas can be carried through a given cross-sectional area of pipe in comparison with pressurized transmission systems at ambient temperature. Any advantage of increased throughput must, however, be weighed against the necessary costs to initially liquefy the gas and to keep it cold through insulation and re-liquefaction (LNG pipelines will, most likely, be operated over a temperature range of -259 F (111k) to -140 F (177k). Aside from considerations of the possibility of competitive transfer by liquefying the natural gas before transmission, projects are envisioned which may transfer already liquefied LNG between storage depots over considerable distances. In general, three broad areas in which the potential for transmitting LNG would appear to exist are

- Short imperative transfers, such as in-plant piping and lines from storage to loading or unloading facilities
- Optional transport methods, where a choice between trucking, barging, or pipelining LNG might exist (e. g., transporting LNG from a central liquefaction plant to satellite storage depots or between storage depots)
- Base- load operations where transmission of LNG might be considered to markets over relatively long distances.

Pipelines used in LNG plants and receiving terminals are numerous and vary greatly in size. Some of the important aspects are

- Heat leaks
- Thermal stress
- Protection from water vapor penetration
- Leak detection
- Avoidance of condensation and icing
- Fire protection

## III. CRITERIA FOR THE SELECTION OF INSULATION

In summarizing the various Insulation requirements, it can be stated that insulation is for

- Energy conservation
- Reduction of product loss
- Reduction of heat leak (Cold system)
- Reduction of heat loss (Warm system)
- Avoidance of condensation and frost formation
- Fire protection

There are many variations of pipe-insulations systems. One of the simplest design is single-layer polyurethane Insulation. Staggered polyurethane layers 2 to 2.5 inch thick are employed with either butt or lap joints. The innermost layer has an oversized diameter to allow the pipe to move without binding when it contracts. Polyurethane foam has a contraction co-efficient 4 to 8 times greater than the pipe material, usually 304L stainless steel.

## IV. IMPORTANT PROPERTIES OF CRYOGENIC INSULATION

- **Thermal conductivity (k)** the value of thermal conductivity should be as low as possible. The value of thermal conductivity depends on various factors. i.e. temperature (T), density (ρ), type and structure of particles and pores, moisture content and the type of gas contained in pores. The value of thermal conductivity increases with increase in temperature and moisture content. Material of lower thermal conductivity (k) permits the use of lower thickness for a given heat leak. Also it reduces the external surface area of the insulated system. Which ultimately reduce the material cost as well as heat in- leak.

- **Moisture permeability** This is very important parameter in cryogenic engineering as high moisture permeability can ruin the thermal conductivity of the insulation. i.e., increase of moisture permeability to 10% from dry state in perlite doubles the thermal conductivity of perlite.

- **Co-efficient of linear expansion**

A lower thermal co-efficient of linear expansion reduces shrinkages and cracking of the insulating material during cooling.

- **Specific heat**

The specific heat of all solids decreases with temperature and tends to zero at 0 k. since most cryogenic insulation have a finely dispersed structure, they are capable of absorbing large amount of air at low temperature. The heat evolved by adsorption raises the apparent specific heat of the material. The quantity of heat adsorbed depends on the structure of the material and the gas pressure.

- **Cost factor**

After considering other technical properties the cost cannot be ignored. The cost factor consideration is to calculate the pay-back period for profit through cold conservation and proportionate investment cost. For example, pay-back period for foam insulation is less than multilayer insulation. (MLI)

## V. VARIOUS TYPES OF INSULATION

There are several types of insulations are available in the market. A few of them are listed as below in increasing order of performance and in increasing order of cost too.

i. Expanded foam
ii. Gas filled powder and fibrous materials
iii. Vacuum alone
iv. Evacuated powder and fibrous materials
v. Opacified powder and
vi. Multilayer insulation

Polyurethane foam is the preferred selection of most of the users in LNG industry out of the above list.

**Polyurethane Foam :**

Polyurethane foam is remarkable material. Developed around the end of world war II by Bayer in Germany, it has gradually become one of the most widely used thermal-insulating materials. The capabilities of tailoring certain properties of urethane to particular needs are significant. For example, the density can easily be varied. Although density can be as low as 1.2 $lb/ft^3$. (1.2 x 16=19.2 $kg/m^3$). Higher densities, such as 4 to 6 $lb/ft^3$ (64 to 96 $kg/m^3$), are used when thermal stresses are important, and when high compressive strength is needed, for example pipe supports.

The excellent thermal-insulating property of urethane foam is due to the very low solid content in the thin cellular structure and to the low gaseous conduction. The closed cells are filled with Freon-11 or Freon-12, which have a significantly lower thermal conductivity than air.

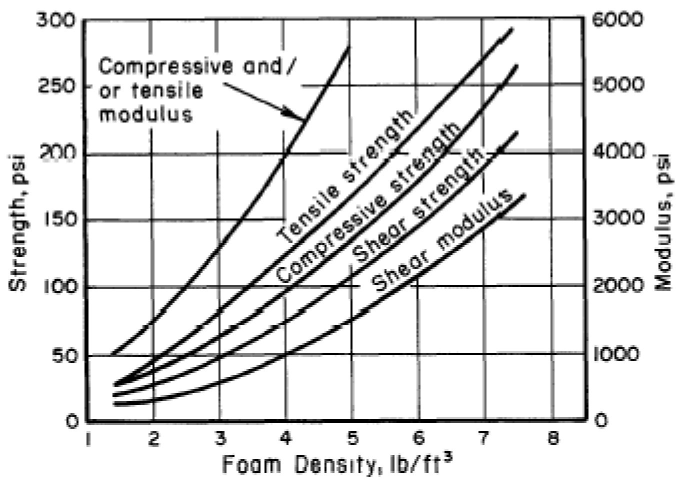
**Polyurethane foam used in LNG applications comes in many forms :**

- Molded
- Bun stock
- Laminated stock
- Sprayed
- Foamed in-place

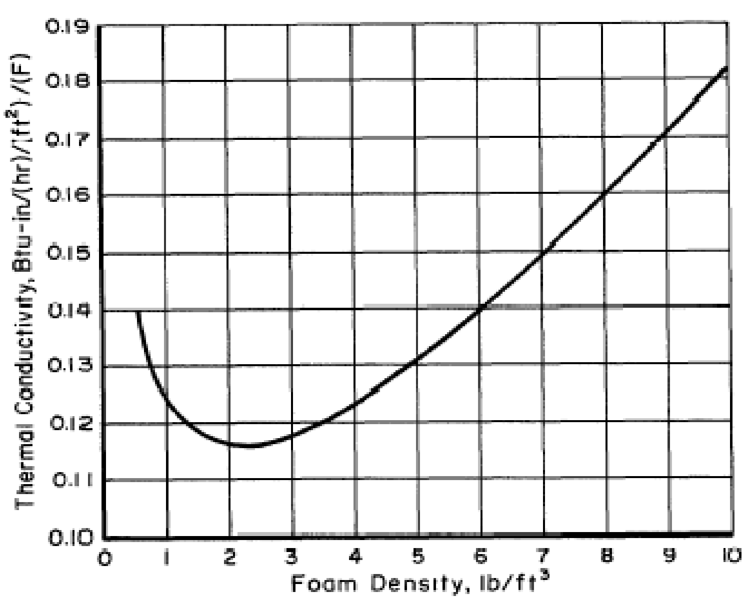
- Frothed

The density of rigid urethane foam affects most properties. The mechanical properties such as tensile and compressive strengths increases with density as indicated. However, with increasing density, the k factor (co-efficient of conductivity) also increases with the disadvantageous effect of greater heat influx through the insulation walls. The best choice for a particular application from thermal considerations will be that density which just satisfies the tensile and compressive strength requirements. Below shown fig. gives the relationship between temperature and thermal conductivity for various materials. It is evident from figure that urethane in the 2 lb/ft$^3$ (32 kg/m$^3$) formulation has the lowest thermal conductivity of all the foams under present considerations. Below shown fig.presents tensile, shear and compressive strengths of urethane foam as a function of temperature.




1 Psi = 6.89 KPa and 1 lb/ft$^3$ = 16 kg/m$^3$

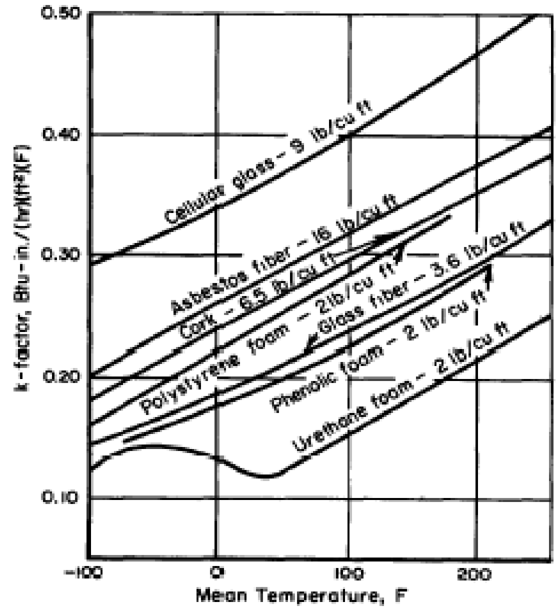
**Variations of Mechanical Properties with the Density of PUF**




1 Psi = 6.89 KPa and 1Btu/h ft$^2$ $^0$f /in =0.1442W/m-K

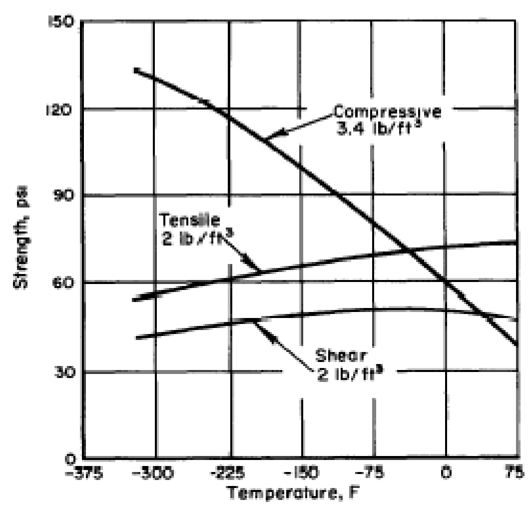
 

**Thermal conductivity of PUF as a function of Density [1]**




F = 1.8 $^{o}$C + 32 and 1Btu/h ft$^{2}$ $^{0}$f /in =0.1442 W/m-K

**Effect of temperature on thermal conductivity for various insulation Material**




F = 1.8 $^{o}$C + 32 and 1 Psi = 6.89 KPa

**Tensile properties of Urethane foam as a function of Temperature**

**Typical structural properties of 64 kg/m$^3$ (4 lb/ft$^3$) PUF**

| Temperature | Strength($\sigma$) | | Modulus(E) | | Strain at tensile failure % |
|---|---|---|---|---|---|
| | Compressive | Tensile | Compressive | Tensile | |
| K | MPa | MPa | MPa | MPa | |
| 294.26 | 0.69 | 0.99 | 20.35 | 33.19 | 5.9 |
| 191.3 | 0.915 | 1.069 | 52.75 | 53.88 | 3.48 |
| 143.0 | 1.021 | 1.106 | 67.95 | 63.59 | 2.34 |
| 111.35 | 1.09 | 1.13 | 77.91 | 69.95 | 1.6 |

In order to prepare a insulation foam, it is utmost necessary to generate nucleating bubbles within the gelling mixture. Such blowing or foaming action can be gained by using either or both of the following:

- A physical evaporating agent (eg R11, 141B), generally a solvent having lower boiling point which evaporates by the heat of the reactions.
- A chemical blowing agent (water), which undergoes chemical reactions with the isocyanate to liberate a gaseous product (carbon dioxide gas).

The use of blowing agent(s) fulfils several functions:

- since it partially absorb the heat of reaction during evaporation it leads to closed cells
- it is fairly insoluble in the polymer, but it is soluble in the liquid mixture
- it exhibits only a slight tendency to diffuse through the cell walls so that it remains within the cells

The low thermal conductivity of rigid polyurethane foam is due to the use of 141B. Thermal conductance of the foam is a combination of several factors:

- Thermal conductivity of the cell gas
- Thermal conductivity of the cell material
- Convection of the cell gas
- Thermal radiation.

## VI. CONCLUSION

As from the above graph we can see that evacuated insulations are the most thermally efficient. Most large scale needs, however vacuum insulation on the grounds of cost and suitability. The three classes of un evacuated insulations are in mostly competitive in thermal insulation at lower temperature for instance in Big LNG Storage tanks, LNG Ships tankers and LNG transfer lines. Polystyrene (PS) and PUF are widely used in the current generation of LNG Ships. These foams are also known as cellular plastics or expanded plastics, offering both the high insulation and higher strength to weight ratio. The main disadvantage is their lower maximum temperature limits, lack of mechanical integrity upon thermal cycling and degradation of insulating properties with time. From the above characteristics of various insulation we can conclude that Polyurethane foam is having the lowest thermal conductance amongst a range of common thermal insulation material. Expanded polystyrene (EPS) and low density (20-50 kg/m³) rigid polyurethane foam systems significantly have gained the highest market acceptance for applications where low thermal/heat transmission is required in designed system- refrigeration cold rooms and in industrial /commercial applications where high insulation value systems are required.

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