Choosing the right insulation
Choosing the right insulation for liquefied natural gas (LNG) pipelines is not always as simple as selecting the most efficient or least expensive alternative. This is especially true in both the energy and cryogenic industries. Professionals of these industries must consider all means of heat transfer: conduction, convection and radiation, as it relates to the application at hand. With certain constraints in mind, professionals must balance what they want to accomplish with the cost and benefits both short term and long term with a chosen solution. This article will look at the basic piping materials and insulation materials/techniques available for LNG transfer applications as it relates to what the industry is trying to accomplish.

The energy and cryogenic industries were brought together for the main purpose of economically and efficiently bringing LNG long distances to market. As with most natural resources, the luxury of close proximity between the supply source of natural gas and the consumer markets is rare. Thus, transportation and storage plays one of the most vital roles in the cost effective success of the LNG industry and also presents one of the greatest challenges. Applying the same basic process as the cryogenic industrial gas industry to transport and store LNG has become the preferred method of choice.

The liquefaction facility
The liquefaction facility is where this analysis of the importance of minimising heat gain, and boil off gas as one of the most critical junctures, will begin. This is where the LNG is piped to storage vessels at -260 °F, where it awaits transfer to a ship. These
pipelines are normally either mechanically insulated with up to 8 in. thick glass foam or polyisocyanurate insulation, insulated using a pipe in pipe technique with aerogel (or other ‘powder’ type) insulation, or a high vacuum jacketed insulation using one of several techniques.

The right choice of insulating the pipeline from liquefaction to storage and storage to ship is more easily recognised when viewing what has just been produced and what must be accomplished. Great lengths have been gone through to get the product to this point. The capital and operational costs in the product are at their most competitive point and profitability, no matter what the market price of natural gas is at, now relies almost exclusively on getting the product to market at the lowest cost possible.

The regasification facility

At regasification facilities LNG piping can be a little more complex when choosing the right insulation and design. The distance and environmental/regulatory issues come into play along with the fact that boil off gas is not always detrimental to the regas operation. Maintaining a positive pressure in the vapour space of the storage vessels is required during send out operations and boil off gas during ship offloading can be useful for this purpose. However, this is not always the case, and too much boil off gas requires costly reliequefaction or send-out via compressors. These methods of dealing with boil off gas can cut deeply into profits both operationally or from a capital and maintenance cost standpoint.

Pipeline material choices

The available choices of piping materials will have an impact with the selection of insulation. Design pressures and temperature, along with applicable codes and standards narrow the practical choices of carrier pipe materials to stainless steel, 9% nickel, and Invar 36. Each of these materials has their advantages and disadvantages, and when being considered for use in a particular LNG piping system many factors must be weighed into the final decision.

Some of the basic differences (advantages and/or disadvantages) in these piping materials are:

- Stainless steel (304L specifically) is the most commonly used and most readily available material for this cryogenic application. It is easiest to weld and is pound for pound the least expensive of the three materials listed. However, it has a higher coefficient of thermal expansion and has a lower tensile strength than either the 9% nickel or Invar 36.
- 9% nickel alloy has a higher tensile strength allowing for a thinner wall at higher pressures and a lower coefficient of thermal expansion than stainless steel pipe. However, it is slightly more difficult to weld and pound for pound more expensive than stainless steel.
- Invar 36 (36% Ni-steel) has a high tensile strength and much lower coefficient of thermal expansion than stainless steel and 9% nickel. This can allow much greater distances between expansion loops or other types of thermal contraction compensation. However, without thorough welder training and practice it is very difficult to weld and is prone to cracking. It is also by far the most expensive of the three materials.

Pipeline insulation choices

Many insulation choices have come to the market in recent years for use in the cryogenic LNG piping application. Many of these techniques are aimed more at the installation application rather than the actual thermal properties that they possess. Since installation applications are numerous and constantly changing, focusing on the merits of their thermal advantages and disadvantages is beneficial. As stated above the materials/techniques most commonly used are mechanical insulation such as glass foam and polyisocyanurate, ‘powder’ insulations such as aerogel, perlite, izoflex and high vacuum insulation.

Mechanical insulation

Mechanical insulation such as glass foam and polyisocyanurate are made of rigid sections preformed in the desired diameter and thickness required for the pipeline that is to be insulated. They are applied directly to the carrier pipe in two or three layers using longitudinally split sections that are glued together. Between layers is normally a ‘slip plane’ and/or vapour barrier material to allow for different rates of contraction and prevent moisture into the insulation. Between the carrier pipe and layers of insulation the temperature gradient is from -260 °F at the pipeline to ambient temperature at the outer skin. This causes the pipe and layers of insulation to contract at different rates and as such, a fibreglass or glass wool section is inserted between longitudinal sections to accommodate for these different rates of contraction and overall system movement. On the outside of the insulation layers and vapour barrier is normally an aluminium clad protective cover. At support locations much higher density foam is used or a ‘shoe’ support attached directly to the carrier pipe to allow for the weight and/or thermal stresses of the pipeline. Otherwise the glass foam or polyisocyanurate insulation would simply be crushed under the normal weight of the pipe material. This type of insulation system is installed on site by an insulation contractor who will follow behind the mechanical piping contractor installing the carrier pipeline. From a capital investment standpoint of pipeline and insulation this type of system is normally the most economical. However, this system also allows...
the highest amount of heat leak thus generating the greatest amount of boil off gas. The U value for this type of system is estimated at 0.26 W/m²K. This system also requires greater periodic and routine maintenance than the other insulating techniques.

‘Powder’ insulations
Powder insulations are applied in a variety of methods and are not always literally in a ‘powder’ form. Aerogel is a fine, low density solid state material derived from gel in which the liquid component of the gel has been replaced with gas. Perlite is volcanic ash material, which has been processed to produce a fine, very light glass material. Izoflex is a silica oxide, titanium dioxide and glass fibre mix. All three of these insulations are used in a shop fabricated ‘pipe in pipe’ or ‘pipe in pipe in pipe’ configuration. Aerogel is normally applied to the carrier line in a blanket method and covered with the outer pipe for protection against damage and moisture. Perlite is normally applied by filling the void space between the carrier line and outer pipe. Izoflex is either applied by filling the void space or with the blanket method of wrapping the carrier line. All three types of insulations can have the insulation space between pipes evacuated with a partial or ‘soft’ vacuum to help in reducing convective heat transfer. In some cases a third pipe is added and the space between the second and third is pressurised with an inert gas to prevent flooding in the event of an outer pipe leak. These methods have varying degrees of thermal properties depending on the actual manufacturer’s design and construction methods. Generally the U value thermal performance, at best, is estimated to be at 0.13 W/m²K, which is about half of the mechanically insulated technique.

Vacuum insulation
Vacuum insulation is also a shop fabricated ‘pipe in pipe’ configuration; however, the degree of vacuum is much higher than the ‘soft vacuum’ mentioned with the ‘powder’ insulations. A standard vacuum level for this type of system is approximately 1 x 10⁻⁴ torr (one torr is 1/760 times atmospheric pressure), which virtually eliminates convective heat transfer. The vacuum insulated piping system also incorporates a multi layer radiation insulation to reduce the amount of radiant heat transfer to the inner carrier line and low heat conductive ‘spacer’ system to center the jacket pipe on the carrier line reducing the amount of conductive heat transfer. This type of insulation system is by far the most thermally efficient type of cryogenic insulation available and has an estimated U value thermal performance of 0.026 W/m²K which is approximately 1/5 the heat leak of the powder insulations and 1/10 the heat leak of the mechanical insulations.

Conclusion
As stated above the purpose of this article was to take a basic look at the most popular LNG piping materials available and give an overview of insulation techniques and their thermal performances. Many factors need to be considered for each LNG pipeline application and installation to determine the most efficient, long term product that will provide the best solution. LNG

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