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Membrane Technology for Offshore LNG

Frédéric Deybach, Gaztransport & Technigaz

Abstract

Environmental and financial issues will make LNG FPSOs and LNG FSRUs a reality.

The technical specificity of the membrane technology, with an outstanding record on LNG carriers, make it particularly adequate for offshore applications. Cost effective and reliable it also offers a great operational flexibility.

It has already found its first application in the LNG offshore industry : El Paso LNG Bridge™ are being currently built in Korea.

Introduction

The membrane containment system is widely used on LNG carriers and it has been so for more than 30 years with an outstanding record for safety and reliability (two third of current new orders are placed with membranes).

After reviewing some of the history of LNG, the nature of the membrane technology is described.

Environmental and financial issues that will make LNG FPSOs and LNG FSRUs a reality are addressed. Issues such as the growing concern about the location of gas terminals, and of course the benefit of having a mobile unit transferable to any part of the globe.

The technical specificity of the membrane make it particularly adequate for offshore applications:

- Large free open deck available for the installation of a liquefaction or a regasification plant.
- A containment system designed to withstand liquid motion and allows for all filling levels.
- Safety heightened by a strong and simple design of the hull structure, by a low windage area and by a continuous monitoring of membrane tightness.
- Light components allowing for on-site repairs & maintenance.
- Operation flexibility with no continuous cooling down required.

Background

The commercial use of Liquefied Natural Gas (LNG) was introduced in the 1960's to monetize natural gas reserves that were remote from the consumers. In order to transport this gas on long distances with no consumer on the way, the most cost effective way was to place it on ships. To maximize the amount transported, the cargo is liquefied to take advantage of the density increase (multiplied by nearly six hundred (x600)). The pressure at which natural gas remains in its liquid form at ambient temperature being unacceptable, LNG is stored and transported at ambient pressure and low temperature : -163°C. This low temperature is maintained by insulating the liquid from outside heat. Today this principle is applied both for land storages and for LNG vessels.

The containment system of the LNG must therefore face two challenges : resist such low temperature and provide sufficient insulation to keep natural gas in its liquefied state. A third challenge is of course to do that in a cost-effective way. Today, three metallic materials are used that retain ductility at this temperature : aluminum, stainless steel and nickel steel. Two different approaches have been developed : self supporting tanks (the structure of the tank in contact with the LNG is able to resist by itself the pressure of the cargo column) and membrane tanks (the membrane contains the cargo but relies on the ship / building structure to resist the pressure).

For LNG vessels, two systems dominate the market : self supporting aluminum spherical tanks (referred to as Moss-Rosenberg system) and membrane tanks with several sub-varieties (referred to as Gaztransport & Technigaz (G.T.T.) system), self supporting prismatic tanks account for less than 6% of the vessels built. Both membrane system and spherical system have been first installed on LNG carriers in the late 60's and have an outstanding record for safety and reliability.

The membrane system can be found on about 45% of the current LNG fleet (61 vessels out of a fleet of 137 vessels, as of February 1st 2003). This fleet is expending quickly (see Figure 1), with 56 vessels under construction or on firm order, out of which two thirds (2/3) are with membrane containment system (36 vessels).

It seemed therefore logical to widen the application of this successful technology and use it for offshore purposes, which appears to be the next step to go in the LNG production.

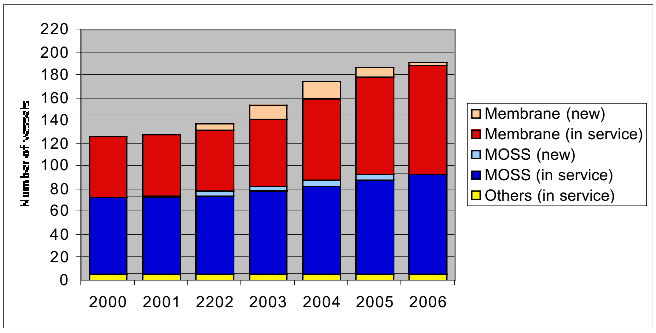

Figure 1 : World LNG fleet evolution

The membrane technology

As stated above the membrane technology consists of a cryogenic liner that is anchored to the structure of the vessel. More precisely to its inner hull as LNG carriers are double hull vessels. This double hull is particularly important for LNG carriers as the volume of ballast required is important, 80% of the cargo weight, in order to maintain these fast vessels (usually 19.5 knots) at almost a constant draft. The double bottom and longitudinal double hull are used as ballast capacities. The inner hull therefore handles the loads caused by the pressure of the liquid height, the ship bending moment and the thermal contraction of the containment system.

The IMO Gas Code requires in the case of membrane technology to have two barriers able to hold tightly the liquid cargo in order to prevent the low temperature liquid to reach the hull structure should a significant leak occur through the primary membrane. The hull being made of ordinary steel, it would become brittle if LNG came in contact. Therefore all vessels with membrane containment system have two membranes, a primary membrane in contact with the LNG and a secondary membrane which ensures that LNG is kept away from the inner hull.

The containment system shall also present insulating characteristics able to maintain a temperature acceptable for the steel inner hull and able to minimize the heat transferred to the cargo thus minimizing its evaporation in Boil Off gas. The most extreme conditions have been retained to set the criteria and so the hull temperature is considered in degraded conditions with LNG on the secondary membrane and with the lowest design external temperatures (usually –18°C air temperature and 0°C sea water temperature). Most of the heat transferred to the cargo results in Boil Off which rate shall be maintained below a design value (usually equivalent to 0.15% of the cargo volume per day in the highest design external temperatures, usually +45°C air temperature and +32°C sea water temperature). As for mechanical stresses, this insulation must withstand the thermal cycles and resist the loads created by the liquid static and dynamic pressure, and transfer it to the inner hull structure.

Two systems, No 96 and Mark III, dominate the membrane market and a third, CS1, received approval from most of the Classification Societies in 2002.

No 96

The No 96 system is a cryogenic liner made of two identical metallic membranes and two independent insulation layers (see Figure 2). The primary and secondary membranes are made of invar, a 36% nickel-steel alloy, 0.7 mm thick. The primary membrane contains the LNG cargo, while the secondary membrane, identical to the primary, ensures a 100% redundancy in case of leakage. Each of the 500-mm wide invar strakes is continuously spread along the tank walls and is evenly supported by the primary and the secondary insulation layers.

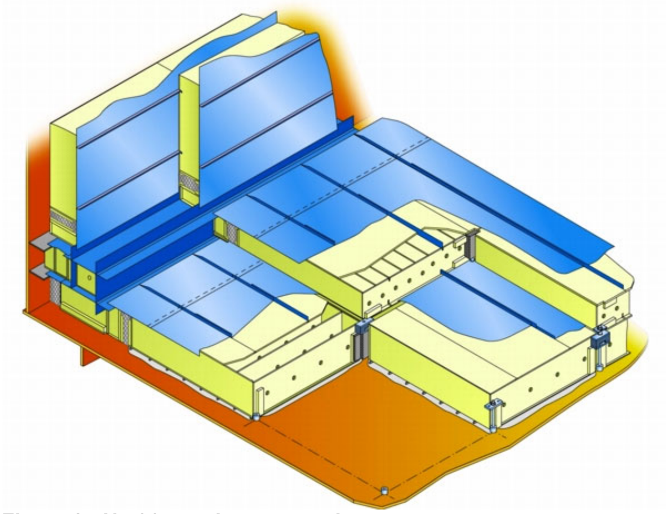

Figure 2 : No 96 membrane containment system

The primary and secondary insulation layers consist of a load bearing system made of prefabricated plywood boxes filled with expanded perlite. The standard size of the boxes is 1 m x 1.2 m. The thickness of the primary layer is adjustable from 170 mm to 250 mm, to match any B.O.R. requirement. ; the typical thickness of the secondary layer is 300 mm. The primary layer is secured by means of the primary couplers, themselves fixed to the secondary coupler assembly. The secondary layer is laid and evenly supported by the inner hull through load-bearing resin ropes, and fixed by means of the secondary couplers anchored to the inner hull.

Mark III

The Mark III system is a cryogenic liner composed of a primary metallic membrane positioned on top of a prefabricated insulation panel including a complete secondary membrane (see Figure 3). The primary membrane is made of corrugated stainless steel 304 L, 1.2 mm thick. It contains the LNG cargo and is directly supported by and fixed to the insulation system. Standard size of the corrugated sheets is 3 m x 1m. The secondary membrane is made of a composite laminated material: a thin sheet of aluminium between two layers of glass cloth and resin. It is positioned inside the prefabricated insulation panels between the two insulation layers.

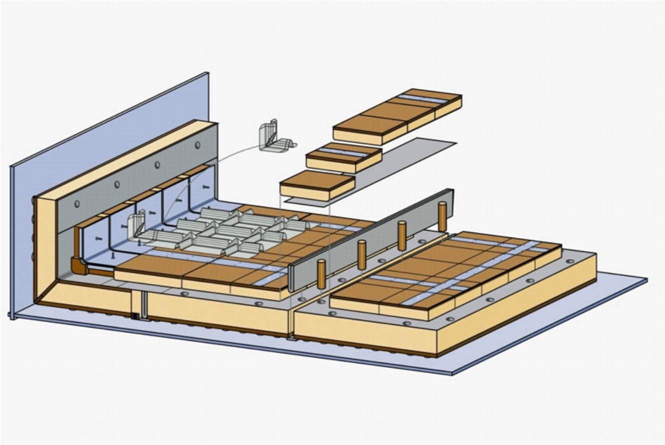

Figure 3 : Mark III membrane containment system

The insulation consists of a load-bearing system made of prefabricated panels in reinforced polyurethane foam including both primary and secondary insulation layers and the secondary membrane. The standard size of the panels is 3 m x 1 m. The thickness of the insulation is adjustable from 250 mm to 350 mm to fulfill any B.O.R. requirement. The panels are bonded to the inner hull by means of resin ropes which serve a double purpose: anchoring the insulation and spreading evenly the loads.

CS1

The CS1 system is a cryogenic liner composed of a primary metallic membrane positioned on top of a prefabricated insulation panel including a complete secondary membrane (see Figure 4). The primary membrane is made of invar, a 36% nickel-steel alloy, 0.7 mm thick. The primary membrane contains the LNG cargo. Each of the 500 mm wide invar strakes is continuously spread along the tank walls and is evenly supported by and fixed to the insulation. The secondary membrane is made of a composite laminated material: a thin sheet of aluminium between two layers of glass cloth and resin. It is positioned inside the prefabricated insulation panels between the two insulation layers.

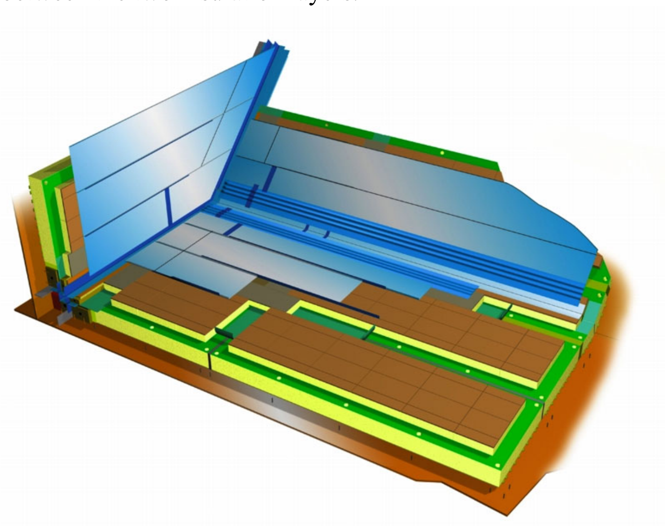

Figure 4 : CS1 membrane containment system

The insulation consists of a load-bearing system made of prefabricated panels in reinforced polyurethane foam including both primary and secondary insulation layers as well as the secondary membrane. The standard size of the panels is 3 m x 1 m. The panels are bonded to the inner hull by means of resin ropes which serve a double purpose: anchoring the insulation and spreading evenly the loads.

Environmental and financial aspects

More and more population become aware of environmental issues and public authorities as well as multinational companies are hard pressed to take actions that will contribute to the effort for the protection of the environment. The energy sector, for some time now, has been under scrutiny for the pollution it generates. All the majors have chosen to go along with the general trend and "green and clean" is definitely the motto from one end of the supply chain to the other. In this light, natural gas has been identified as one of the cleanest energy available on the market and every year more reserves are discovered and reported.

Today all LNG terminals, both loading terminals where gas coming from the field is liquefied or receiving terminals, where liquid gas is regasified to be sent to end consumers, all of those are located on-shore. Loading terminals are close to gas fields, usually remote from populated areas and therefore attracting little attention. Receiving terminals are close to the consumers and that means densely populated areas. The setting up of either type of facilities has become arduous because of security and environmental aspects, notwithstanding the inherent constrains to such projects.

Challenges for loading terminals

For a new loading terminal, the main challenge is often to bring materials, equipment and qualified workers to a remote site to build a complex liquefaction plant and enough storage tanks to match the continuous production of LNG and the cyclic arrival of vessels. Another challenge is to find the proper site, close enough to the gas fields and with enough protection from the open sea and enough depth to allow LNG carriers to berth. This will become less easy as time passes due to the constant increase in the size of LNG carriers and due to the exploitation of offshore fields, often far from the coast and in deep water, making the under-water gas pipelines a burden for the economics of the project. Finally, liquefaction plants and the associated storage tanks and terminal infrastructure are expensive units that require complicated financial setups and decades to be amortized. Therefore large enough gas quantities for long term contracts become imperative. This makes small gas fields not viable and countries with political unrest unlikely candidates.

Challenges for receiving terminals

For a new receiving terminal, the main challenge is usually to obtain the authorizations to build the terminal. In industrial countries, the number of possible locations along the coast, with enough protection from the open sea, enough depth to allow for LNG carriers and close enough to gas distribution networks, is usually limited because of the high density of industrial and housing occupancy. A zealous analysis of the impact on the environment and the hostility of the neighboring communities make the process tedious and uncertain. This is especially true in countries like Japan (currently the largest importer of LNG with the existing sites at maximum capacity and with very limited shore sites) and the USA (country with the largest potential for importation increase and the most active environmental and NIMBs (not in my backyard) opposition). In the USA, the legislation imposing open access to shore facilities was also a main obstacle. Who would invest such large amounts if any competitor could benefit from it at a marginal cost?

The offshore alternative

For both loading and receiving terminals, an offshore location is the obvious alternative. For offshore loading terminals the generally accepted name is LNG FPSO (Liquefied Natural Gas Floating Production Storage and Offloading) or FLNG (Floating Liquefied Natural Gas); for offshore receiving terminals the generally accepted name is LNG FSRU (Liquefied Natural Gas Floating Storage Regasification Unit), (see Figure 5). The terminal will be away from the coast, far from the eyes of the public or above a gas field, in waters deep enough to allow any vessel to come and load or unload. It will be a movable asset that can be relocated to a new site when the gas field is declining, when political unrest places it in danger or when better price levels are available elsewhere. It will be built in a shipyard, which is where the required skills and efficiency are, and then will be towed or propelled to its location.

Figure 5 : Membrane 280,000 m3 LNG FSRU

However challenges remain for the offshore alternative. The main challenge for an offshore terminal will be to reach a high level of compaction in order to concentrate on one platform a complex liquefaction or regasification plant and its services (water, gas and power), the accommodations for the operators, several cargo tanks, totaling a volume of usually more than 250,000 m^3, plus the required condensate tanks, and a docking and liquid transfer installation to load or unload the LNG carriers.

Another challenge will be to find a location with a benign enough environment to allow liquefaction or regasing plants to operate on a continuous basis and liquid transfers from terminal to vessel to be made. Special care in the design of the platform will be made to minimize its motion for the sea-states that it will encounter.

Finally the terminal will have to operate on site for 20 or 40 years with as few shut downs as possible.

Why membrane technology is particularly well adapted for offshore applications

These constrains having been clearly identified, the membrane technology appears to have the right answers to most if not all of them. The technical specificity of the membrane provides a high flexibility in the design of platform as well as in the operation of the facility. It also presents a very cost effective solution.

Design aspects

As was explained earlier, the membrane containment system is a liner that is anchored to the inner hull and therefore will suit any size and geometry induced by the platform design. This design may derive from the surface needed for the topside. This is particularly true for FPSO having a very large liquefaction plant. In that case the cargo tank geometry will be adapted to fit the required volume in the structure below deck.

The tanks are fitted inside the hull and leave an open flat deck well suited for the installation of the liquefaction or regasification plant topside. This flat deck also means that the height of the vessel is limited, reducing the accelerations that the equipment of the plant will endure and reducing the windage of the platform. This reduced windage will have an immediate benefit on the power needed to maintain a heading in case of side winds.

The tanks have a prismatic shape usually with a chamfer at the bottom and at the top of the tanks. The continuous double bottom, double walls, double deck and transverse cofferdams between tanks allows for a strong and simple hull structure. The chamfers give more rigidity with large brackets in the wing tanks and in the bilge area. The simplicity and the robustness of the ship beam make it easier to design for the lifetime of the platform (usually 40 years). The structure of the wall ballast tanks protects the cargo from possible collisions. The residual kinetic energy of the incoming vessel may locally deform the inner hull, however the flexibility of the membrane will enable it to accommodate the deformation without losing tightness. These elements all contribute in heightening the safety of these expensive assets.

The LNG carriers usually operate with a limited range of filling levels in the tank. They are full during the laden voyage to maximize the amount of LNG transported and they are almost empty during the ballast return voyage to maximize the volume delivered. The amount kept on board after unloading depends on the length of the return voyage and the way the vessel is operated. The objective is to have the tanks in a temperature condition compatible with the next loading in the most cost-effective way. For short voyages, the LNG heel may be spread in all tanks in order to maintain a cold bottom and enable loading without cooling down. For medium voyages, the LNG heel may be kept in one tank to limit evaporation and aging of the LNG and used for cooling down of the other tanks before arrival. For long voyages, the tanks may be heeled-out and cooled down by the loading terminal. The liquid motion in the tanks is therefore traditionally considered for high filling levels (usually 80% of tank height and above) and for low filling levels (usually 10% of tank length and below). As explained above, on LNG vessels the containment system has been designed to withstand the pressures created by the liquid at these filling levels. The FPSOs and FSRUs will operate at all filling levels as they will continuously liquefy natural gas (level going up on FPSO) or continuously regasify LNG (level going down on FSRU). Liquid motion studies have been performed for several offshore projects following a methodology approved by several Classification Societies. This methodology has already been applied on the Azure Project [1]. The different options studied on that occasion, considered the environmental conditions specific to several potential locations for FPSOs and FSRUs, in particular in North West Australia. As is the standard for offshore floating structures, the sea states considered covered a 100 years return period. The liquid motion was analyzed for the different combinations of ship motion (for example roll + pitch + sway) and filling levels. The pressures were measured for the worst cases and were always found below the design pressure of the components of the containment system as used today on LNG carriers. It is to be noted that LNG vessels with an onboard regasification unit will be operating in similar conditions as offshore platforms during the regasing phase [2]. Such vessels are being built in Korea for El Paso and have been validated for all filling levels (see Figure 6).

Figure 6 : LNG Carrier with regasification

The design of the membrane technology relies on modular components that are assembled. The same components are used on vessels of different capacity or geometry, covering a wide range (today from 18,000 m^3 to 145,000 m^3). The same components will be used on the offshore platforms, regardless of their capacity and geometry.

The existing technology, sea proven and with which the shipyards are familiar, can be used on offshore platforms, with no filling level restriction.

Operational aspects

By design, the membrane technology presents two independent insulation spaces, usually referred to as inter-barrier space (between primary and secondary membranes) and secondary insulation space (between secondary membrane and inner hull). The former is also sometimes referred to as primary insulation space. These spaces are inerted with nitrogen. The presence of natural gas in both spaces is continuously monitored, offering a high degree of safety. At all time the crew knows the precise state of the tightness of the primary membrane. The monitoring of the secondary insulation space will only give information on the tightness of the secondary membrane in case of gas present in the inter-barrier space. The tightness of the secondary membrane is regularly tested by setting a pressure difference between the two spaces (around 500 mb) and monitoring the vacuum decay over a period of time. This means that tightness test of the membranes does not require physical inspections inside the tanks. Therefore it does not require shutting down tanks, with inerting and airing them and the associated time lost. The saving in labor is also considerable.

As described above, the individual components of the containment system assembled inside the tanks are of small size and limited weight (less than 50 kg for a No 96 box and less than 110 kg for a Mark III or a CS1 flat panel). Therefore, in the event of a major repair concerning the containment system, the individual components could be transported to the site of the platform and the repair performed on board without shutting down the plant and towing the platform back to a shipyard. Although improbable, an accident can never be ruled out and a fire inside a tank, an important LNG spillage on the deck or an important collision damaging significantly the inner hull may require renewal of some part of the containment system. Such repairs are sometimes made on LNG vessels and the procedure is well known. To have to wait for a quiet weather period during which the ship motion will be limited enough to erect a scaffolding inside the tank in complete safety is of far less financial consequences than to completely shut down the plant and all tanks to go to a repair shipyard.

The reduced thickness of the membranes (0.7 mm for invar and 1.2 mm for stainless steel) implies instantaneous temperature homogeneity in the membrane, and therefore no thermal stresses. The design or material properties of these membranes also limit significantly the thermal stresses in the plane of the membrane. This means that the membrane can be at different temperatures at different levels of the tank. Therefore, during normal operation of the tanks when the level of the liquid drops, the containment system is able to warm up and will cool down again when the liquid rises. No continuous cooling down is necessary. Moreover, the thermal capacity of the containment system being small, the amount of energy needed to cool down the mass of the containment is also limited. The evaporation of cargo due to the cooling down of the containment system is limited. These two characteristics allow for a large flexibility in the operation of the tanks.

Financial aspects

The structure of the platform is made of steel, a cost-effective material widely available. The simplicity of the hull design makes blocks easy to prefabricate and to assemble. The shipyards can use their current production tools, methods and organization that have proven their efficiency in shipbuilding.

The shipyards proposing membrane containment systems are currently the most competitive on the market for LNG vessels. They will use the same containment technology and will fully benefit from their experience on LNG vessels with highly trained teams and an efficient network of suppliers.

Finally, after completion of the hull, the arrangement of the topside, with the liquefaction or the regasification plant, will be done in parallel with the erection of the containment system installation inside the tanks. This will give a large flexibility in the schedule of the building. Moreover, unless the topside has specific requirements, that work will be performed at an outfitting quay with a minimal time spent in the dry-dock (today, in most shipyards the time in the dry-dock does not exceed three months for standard LNG carriers).

Conclusion

In order to satisfy the ever-increasing demand for energy, offshore gas resources shall be monetized in a very near future. In order to take into account the public concern and limit the impact on the environment, new LNG facilities will often have to be offshore. LNG FPSOs and FSRUs will answer these needs. Using the membrane technology successfully applied today on LNG carriers, is the most suitable choice : cost effective and reliable it also offers a great operational flexibility. The merits of the membrane technology in the offshore industry has already been recognized : the first LNG carriers with onboard regasification have a membrane containment system.

References

[1] L. Spittael, M. Zalar, P. Laspalles, L. Brosset : "Methodology for liquid motion analysis" – Gastech 2000 conference – November 2000 – Houston, Texas, USA.

[2] W.S. Wayne, K.G. Powell : "Modification of LNG Carriers for Regasification" – OTC 15230 – May 2003 – Houston, Texas, USA.