GTT MARS™ – NEW MEMBRANE CONTAINMENT SYSTEM FOR LPG CARRIERS

François DURAND - Innovation Project Manager
Saint-Remy-Lès-Chevreuse (France)- GTT

Mélodie NORIS – Business Development Manager
Saint-Remy-Lès-Chevreuse (France)- GTT

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Ce document décrit la nouvelle technologie membranaire de GTT qui a été conçue pour les très grands transporteurs de gaz. Il apporte une proposition de valeur innovante au marché du transport de GPL rendant les navires plus sûrs, réduit leurs coûts de construction et d'exploitation initiaux, et augmente l'efficacité globale en permettant de plus grandes capacités de transport.

La technologie de GTT est une solution légère et compacte qui permet de concevoir un navire plus efficace avec des dimensions réduites et une consommation de carburant réduite, ou encore l'optimisation de la capacité de chargement. Cette cargaison supplémentaire pourrait être monétisée: + 26% des revenus dans le contexte actuel de faibles taux de fret (basé sur un indice de la Baltique de 30 $ / t) pour un voyage du Golfe persique vers l'Inde, avec deux rejets sur la côte Est et Ouest; ou utilisé pour la propulsion du navire par exemple. Cela donnera plus de flexibilité pour passer au GPL en cas de besoin et respectera la nouvelle réglementation environnementale sur les émissions de carburant imposée par l'OMI. En outre, la flexibilité est augmentée par la réduction du temps de refroidissement à seulement 3 heures, ce qui empêche de garder un talon qui peut également être monétisé. Ensuite, GTT MARS ne subit aucun choc thermique. Enfin, les essais grandeur nature démontrent la haute résistance de la membrane en cas de collision en mer.

En résumé, GTT apporte quatre principaux produits livrables au secteur du transport maritime: une augmentation des revenus, une plus grande flexibilité opérationnelle, des émissions plus vertes et une sécurité améliorée.

SUMMARY

This paper describes GTT’s new membrane technology which has been designed for the Very Large Gas Carriers. It brings an innovative value proposition to the LPG shipping market making vessels safer, reduces their initial build and operational costs, and increases overall efficiency by allowing greater loads.

GTT's technology is a **light and compact** solution, which enables the design of a more efficient vessel with reduced dimensions and lower fuel consumption, or the **optimization of the cargo capacity**. This extra cargo could be either **monetized**: **+26% of revenue** in the current low freight rate environment (based on a $30/t Baltic Index) for a voyage from Arabian Gulf to India, with two discharges in the East and West coast ; or used for the propulsion of the ship for instance. This will afford more **flexibility** to switch to LPG when needed, and **comply** with the new environmental **regulation on fuel emissions** imposed by the IMO. Besides, the flexibility is increased by the reduction of cooling down time to only 3 hours, which prevent from keeping a heel that can also be monetized. Then, GTT MARS does not suffer any **thermal shock**. Finally, full scale tests demonstrate the **high resistance** of the membrane in the event of a **collision** at sea.

In summary, GTT brings four main deliverables to the shipping industry: increased revenue, greater operational flexibility, greener emissions and improved safety.

1. INTRODUCTION

For over 50 years, GTT has been developing and providing efficient solutions for the containment of liquefied gas, both at low temperatures and under cryogenic conditions, for shipping or storage, both onshore and offshore. To handle the cargo, holds need to be coated with cryogenic lining that can withstand the substantial loads. Envelopes, known as membrane, contain the LNG at a temperature up to -163°C, sealing it with a totally impermeable layer between the liquid cargo and the vessel's hull. Creator of the patented concept, GTT is the reference player of the LNG market. The GTT membrane technology allows cost reduction of shipping LNG and loading it, in bulk, into a vessel's holds. The membrane structure fits perfectly to the contours of the vessel's hull, making it possible to optimize storage space and reduce the vessel construction and operation cost. The continuous improvement of GTT solutions allows constant reduction of the boil-off gas rate of the membrane containment systems. Proof of the success of GTT solutions is based on the fact that more than 300 LNG carriers are equipped with membrane technology.

Some of the existing ships, including some of the first LNG carriers, have been operated in the past for LPG and ethylene trade as well (Annabella 35,000 m3 built in 1975, Ben Franklin 120,000 m3 built in 1975, Descartes 50,000 m3 built in 1975). More recently, on board the Shell Prelude Floating Liquefaction platform (FLNG), four tanks are dedicated to LPG condensates, featuring exactly the same technology as the eight tanks dedicated to LNG. Finally, six Very Large Ethane Carriers (VLEC) for Reliance that have been recently delivered by Samsung Heavy Industry also transport LPG. While this demonstrates that the traditional membrane technology is adapted to the carriage of LPG or other cryogenic gases, it is fair to mention that the traditional membrane is overdesigned (design temperature of -163 °C while LPG requires -55°C) and needed to be optimized to the requirements of this very specific LPG market.

Until now, the only solutions available on the market were self-supporting tanks. The objective was to design a dedicated technology tailored to the LPG market for gas carriers, which adds a new value proposal to the transportation of LPG. In an environment with low shipping rates, reducing the total cost of ownership is essential. This is what GTT proposes to offer with this innovative MARS™ technology: cutting construction cost for the shipyards, reducing operational cost and bringing increased safety and greater efficiency to the shipowner.

2. CONTAINMENT SYSTEMS DESIGN

2.1. The different types of containment systems

Developed by the International Maritime Organization (IMO), the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) governs all gas carriers built after June 1986. According to the IGC code, the entire cargo containment system consists of the following elements: primary barrier (cargo tank), secondary barrier (if fitted), thermal insulation, any intervening spaces, and adjacent structure, if necessary, to support these elements. The IGC Code differentiates between Independent tanks and Integrated tanks, as can be seen in the graphic below.

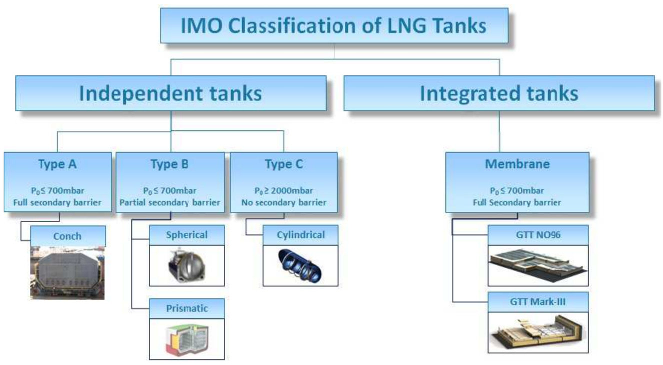

Figure 1: IMO Classification of LNG Tanks (source GTT)

Independent tanks are self-supporting, do not form part of the ship's hull, and are not essential to the hull strength.

Membrane tanks, the predominant type of Integrated tank, rely on the mechanical strength of the inner hull for support and consist of two relatively thin continuous membranes to contain the liquefied gas. These are separated by insulated inter-barrier space layers that transmit the cargo load and any internal pressure to the inner hull.

2.2. MARS™ containment system

Until now, the only containment system solutions available for the LPG market were using independent tanks, whose steel structures are additional to those of the vessel and which significantly increase the weight of the LPG carrier. With an integrated tank concept specially designed for LPG, MARS™ offers a much lighter containment system and overall vessel lightship weight.

MARS™ containment system is based on a single membrane concept specifically conceived to LPG cargo characteristics: **temperature higher than -55°C and density up to 700 kg/m^3**. The insulation is fitted on the inner hull of the ship, which acts as the secondary barrier of the tank, and supports the primary barrier. This primary barrier is made of corrugated stainless steel.

Stainless steel membrane

The primary barrier of the containment system is a stainless steel membrane. Its characteristics are the same as the GTT traditional Mark III primary barrier: a 1.2mm thick, corrugated, 304L stainless steel membrane. MARS™ membrane differentiates from Mark III membrane on the pitch of the corrugation which has been increased from 340mm to 600mm, benefiting from the higher temperatures (-55°C) compared to LNG (-163°C).

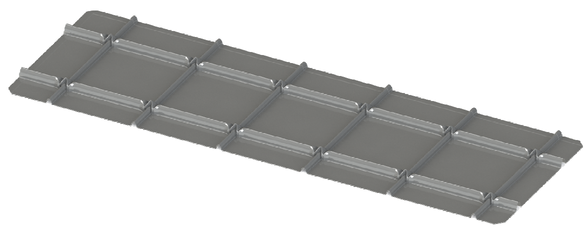

Figure 2: 304L Primary membrane sheet (source GTT)

Insulating plywood boxes

The membrane is supported by a single layer of insulating material components.

The mechanical strength of the insulation is provided by a structure made of plywood. This structure forms a box with several vertical bulkheads that give a high rigidity to the assembly.

The thermal performance of the insulation is then ensured by filling the box with glass wool.

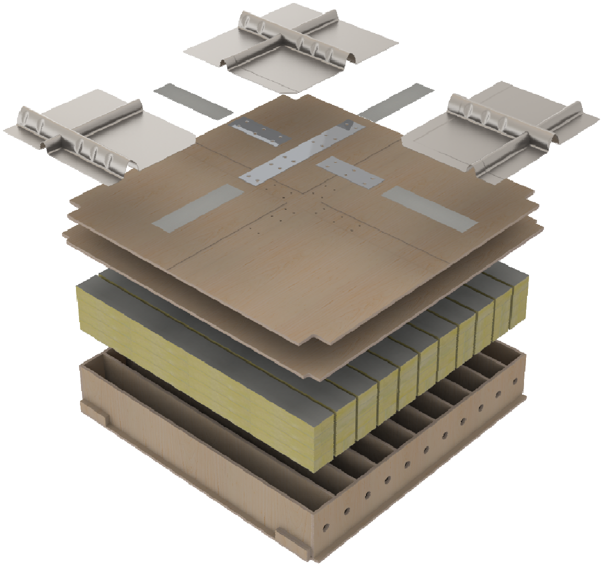

Figure 3: Insulation box 3D exploded view (source GTT)

The membrane is directly welded on anchoring strips placed on the top of the plywood boxes.

Mechanical anchoring of the insulation

The containment system is fastened to the inner hull by a purely mechanical system.

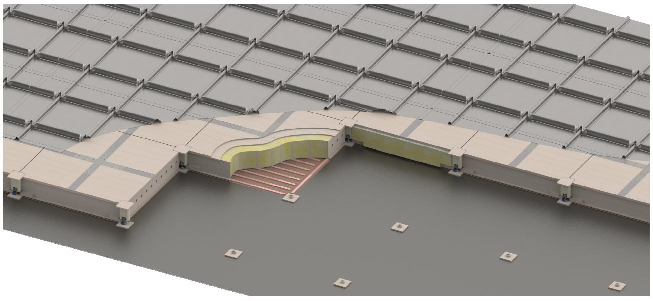

Figure 4: Lay-out in the tank of MARS™ (source GTT)

Each box is laid on several mastic ropes whose purpose is to compensate the hull deviation and to distribute the loads on the insulation to the hull.

The anchoring of the box to the hull is achieved by a coupler system.

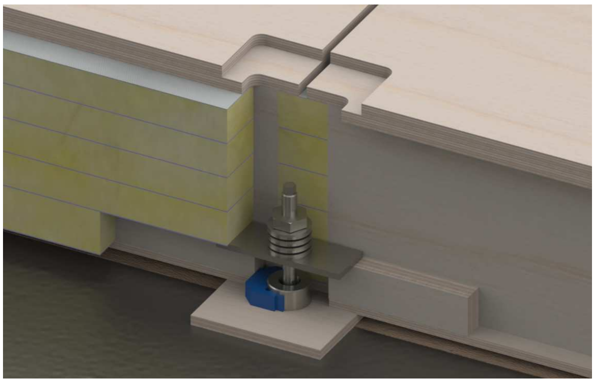

Figure 5: Coupler system in position in the tank (source GTT)

Each box is maintained at every corner by a setting plate which is pressing the box on the hull thanks to the compression of spring washers.

This assembly is attached to the hull by a ball joint connection. Consequently, the anchoring system can freely follow the hull deformations under cargo or ballast pressures.

Smart corner solutions

MARS™ technology relies on very simple concepts for the special areas of the tank.

The solution used for the corners is based on a very simple system of border boxes that allows a highly standardized arrangement.

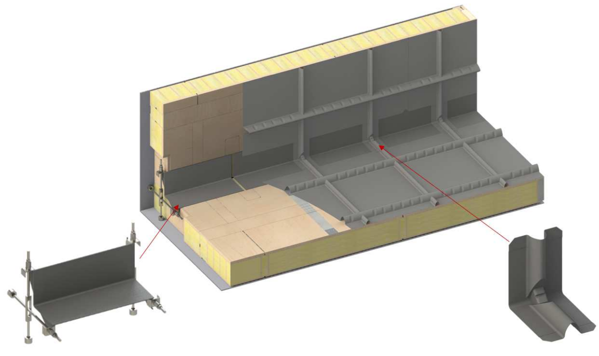

Figure 6: Corner area arrangement in the tank (source GTT)

The border boxes are made according to the same design philosophy as the flat wall components: plywood boxes, filled with glass wool, that are fastened to the inner hull with mechanical couplers.

But these boxes are supporting a steel corner component which is connected to the inner hull by another type of coupler (relying on the same principle as for the flat wall). The membrane is then welded directly to the steel corners.

Consequently, when the membrane is pulling on the corners, due to the thermal contraction of the primary barrier or the hull elongation of the ship, the force is not sustained by the insulation but by the inner hull itself.

Hull acts as the secondary barrier

For cargo temperature over -55°Cn the IGC Code allows to use the hull as the secondary barrier.

In this regard, the inner hull of the ship shall be made of low temperature steel (FH grade), as is the case for Type A tanks.

2.3. MARS™ containment system features

Zero stress concept

The orthogonal corrugation pattern enables the membrane to accommodate any thermal or hull deflection stresses well within the fatigue limit, therefore providing an outstanding lifetime.

High resistance

The strength of plywood boxes is adjusted to sustain the loads induced by liquid motion in the tank.

Modular concept

This modular system calls for standard prefabricated components that can accommodate any shape and capacity of tanks and are designed for mass production and simple assembly.

Safety

The insulation space is continuously flushed with nitrogen gas. The integrity of the membrane is then permanently monitored by detection of hydrocarbon in the nitrogen.

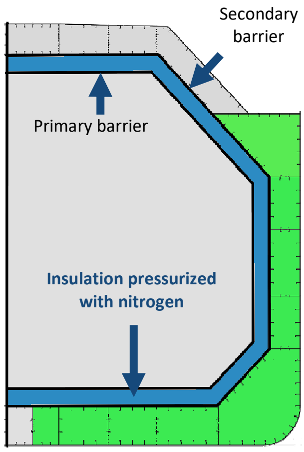

Figure 7: Permanent monitoring with gas detection within insulation space under nitrogen (source GTT)

Strong resistance to collision

Additionally, the MARS™ stainless steel membrane benefits from a high resistance to collision and grounding due to its flexibility. It can adapt to very large deformation without any loss of tightness. GTT, DNV GL and the Hamburg University of Technology (TUHH) built a large scale mock up, nearly 4 m X 4 m, and tested it experimentally. During the test illustrated in Figures 8 & 9 below, a displacement of 1 m has been measured and small corrugations have been completely unfolded without any crack or loss of integrity.

Figure 8: Mock-up placed in the test rig

Figure 9: Deformation of the mock-up in experiment

The behaviour of the primary membrane under large deformations has been tested separately in cryogenic conditions yielding the same results as the large-scale test.

There have been no incidents or liquid leaks since the membrane has existed.

Reliability

All materials used in MARS™ are sea-proven in GTT's technologies.

Densified wood and glass-wool are easily procured, low cost raw materials, and are available worldwide.

2.4. Validation by Classification Societies

Classification Societies have been able to fully review each step of the development of MARS™. The four main classifications societies Lloyds Register, DNV GL, ABS and BV granted their Approval In Principle (AIP). In April 2017, after a deep review of the technology and of all support calculations notes and tests, Lloyds Register granted their General Approval for all the critical points of design of the containment system. This is a very important milestone for the development of the technology as it demonstrates MARS™ meets the gas and maritime industry requirements and is ready to be ordered.

3. IMPACT ON SHIP'S DESIGN

3.1. Lower lightship weight

Because it is fully integrated, MARS™ makes it possible to turn this reduction of weight into a cargo capacity increase. The solution also adapts to any shape and size of ship.

To illustrate this benefit, GTT has performed a basic design study of a typical 84,000m^3 by starting from an actual design of Very Large Gas Carrier (VLGC) equipped with Type A tanks.

While keeping the same overall dimensions and the same propulsion, the ship has been modified to replace the Type A tanks with MARS™ tank type technology. As a result, the single hull has been replaced by a double hull in order to have a flat surface inside the hold to fit the membrane.

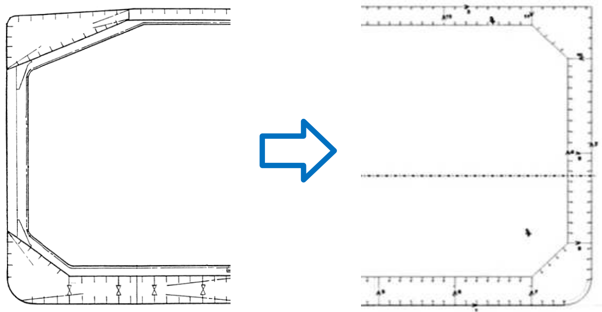

Figure 10: From single hull to full double-hull structure (source GTT)

In the end, considering that the 4 Type A tanks (≈5,000 tons) were removed, that the hull has been modified (around 2,700 additional tons of steel for double hull) and fitted with MARS™ tanks (≈1,300 tons), the MARS™ solution provides a weight reduction of **1,000 tons** on the 84,000 m^3 design.

Therefore, if a 84,000 m^3 vessel equipped with a self-supporting tank weighs 19,000 tons, the same vessel equipped with GTT's technology would weigh only 18,000 tons.

That reduction in weight translates immediately into increased cargo capacity: **removing 1,000 tons of steel makes room for 2,000 m^3 more cargo.**

3.2. Tank shapes flexibility

MARS™ provides more flexibility in terms of tank shapes providing more options to ship's designer to optimize the vessel performances.

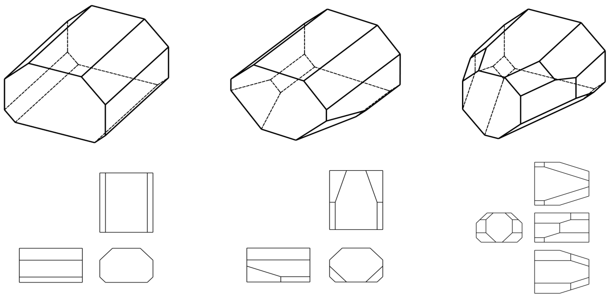

Figure 11: Three different types of shapes possible (source GTT)

3.3. GTT MARS™ 91,000 m^3 ship design

GTT's 91k design is a vessel that has the same dimensions as a typical 84k Type A ship:

- Length O.A.: 228.6m
- Breadth: 36.6m
- Design draft: 11.8m
- Service speed: 16.5Kn

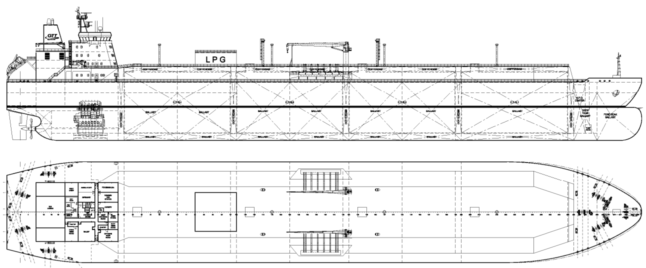

Figure 12: GTT Membrane 91k ship design (source GTT)

Cargo capacity is then adjusted on liquid density: 91,700 m^3 of propane (density=0.58) or 86,000 m^3 of propene (density=0.62) can be loaded, keeping the draft constant at 11.8m. This means an additional capacity up to 7,000 m^3.

Another philosophy of design could fit with the advantages given by the membrane: a 84,000 m^3 vessels, with reduced dimensions, and so less fuel consumption.

3.4. Impact on ship's construction

The industrial scheme is being developed with selected shipyards. It is expected that the construction time for a vessel equipped with MARS™ will be similar to vessels equipped with other containment systems.

4. IMPACT ON SHIP'S OPERATION

MARS™ is a light and compact solution, which enables the design of a more efficient vessel with reduced dimensions, lower fuel consumption, or the optimization of the cargo capacity. This extra cargo could be either monetized or used for the propulsion of the ship for instance. This will provide more flexibility to switch to LPG when needed, and comply with the new environmental regulations on fuel emissions imposed by the IMO.

4.1. Heat capacity of the containment system

MARS™ is mainly composed of plywood (with remaining steel and glass wool) while self- supporting tank technology is exclusively composed of steel (and some foam). Additionally, MARS™ tank is about 1/3 of the weight of an equivalent self-supporting tank. Those two effects together result in a heat capacity about three times lower for a MARS™ tank compared to Type A tanks. It takes one third as much energy and quantity of LPG to cool down the tank. Cooling down operation time is then significantly reduced: **3 hours with GTT membrane technology compared to 20 hours for a self-supporting tank.**

4.2. Resistance to thermal shock

Because of the ability of the membrane to absorb thermal elongation, due to the corrugation patterns, MARS™ is not sensitive to thermal shock and loading can be done without the need to pre-cool the tank.

The above features have significant impact on the OPEX (OPErating EXpenditures) and flexibility in operation.

4.3. The future of LPG carriers operation

GTT's technology is a light and compact solution, which enables the design of a more efficient vessel with reduced dimensions and lower fuel consumption, or the optimization of the cargo capacity.

Additional revenue

This extra cargo could be monetized and represents an additional +26% of revenue in the current low freight rate environment (based on a $30/t Baltic Index) for a voyage from Arabian Gulf to India, with two discharges in the East and West coast.

LPG as a fuel

This extra cargo could also be used for the propulsion of the ship. This will afford more flexibility to switch to LPG when needed, and comply with the new environmental regulation on fuel emissions imposed by the IMO in 2020.

Other operations

This extra cargo could also give greater flexibility to the operators, for many different operations: STS is one of them.

5. CONCLUSION

Simpler than membrane technologies for LNG carriers, MARS™ technology is based on the state-of-the-art GTT membrane. Its safety and quality track record, with reduced cooling-down duration, low heat capacity, lower lightship weight and high resistance to collision offer significant advantages to shipowners.

MARS™ brings increased efficiency, greater operational flexibility and improved safety to the LPG market.

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