A FLEXIBLE DESIGN FOR A FLEXIBLE MARKET

Kjetil Sjølie Strand, LNT Marine, Norway, provides an overview of a new LNG containment system developed specifically to address the need for more local and regional distribution of LNG.

The global demand for energy is growing, driven by population growth and urbanisation. Natural gas resources are available and a viable solution to meet the growing energy demands. Therefore, LNG markets are growing and expanding into emerging markets. Consequently, the demand for LNG shipping is also changing. More local and regional transportation of LNG is needed in areas where large scale terminals do not exist. Demand for a more diverse and flexible fleet of smaller LNG carriers is thus evolving.

Figure 1. Cargo tank installation at China Merchants Heavy Industry (CMHI).

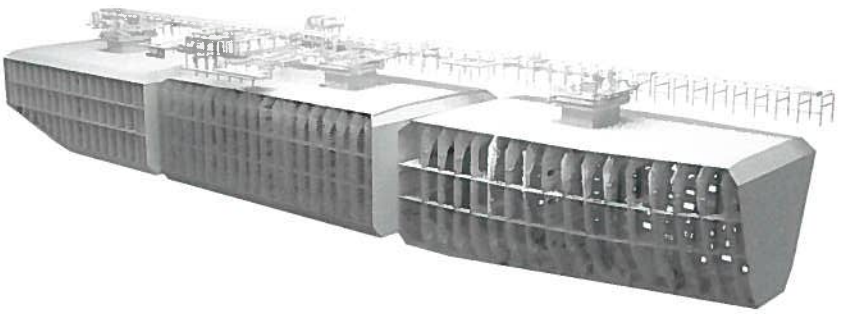

Figure 2. Independent tank Type A.

Type A tanks have traditionally been used on fully refrigerated LPG carriers, and have so far not been adopted on LNG carriers. The main reason for the lack of LNG containment systems based on Type A tanks is most likely the requirement for a full secondary barrier. If the cargo temperature at atmospheric pressure is below -10°C, a complete secondary barrier is required. The secondary barrier is an important safety feature as it is capable of containing any envisaged leakage of liquid cargo for a period of 15 days. For LPG carriers (which do not carry cargoes below -55°C), this is solved by constructing the inner hull using low temperature steel. This is, however, neither feasible nor permitted for LNG and other cryogenic cargoes with temperatures below -55°C. Thus, one of the key challenges in the development of a containment system for LNG based on independent tank Type A, was to come up with a suitable system configuration and solution for the secondary barrier.

In order to meet the IMO requirements for a full secondary barrier, it was decided to develop an inverted insulation system fixed to the ship's hull, with a liquid-tight inner surface to contain any leak from the cargo tank. Thus, the conceptual design was to place an independent tank Type A, without insulation, on a tank support system inside an insulated hold space. This design involving a Type A tank within a cold-box formed the basis for the trademark LNT A-BOX.

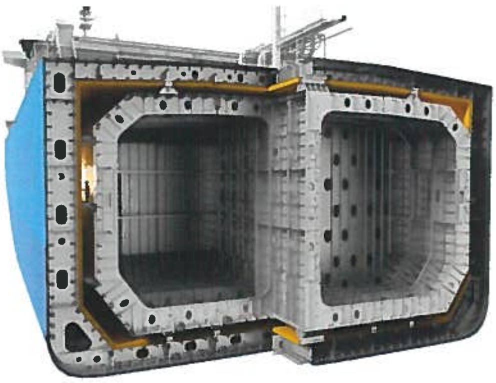

Figure 3. LNT A-BOX® configuration.

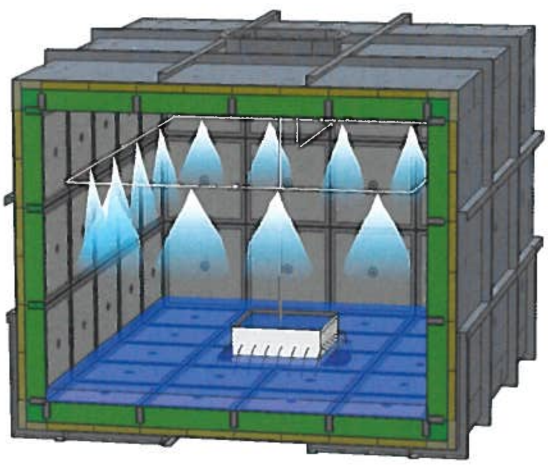

Figure 4. LNT A-BOX® mock-up test unit.

A simple, efficient and flexible containment system suitable for the small and mid-size LNG segments, that could also enable more shipyards to build LNG carriers at a reasonable cost, was the prime goal when the development of the LNT A-BOX® containment system started more than 10 years ago. It was decided early on to base the system on independent tank Type A, as Type A tanks are known to offer the simplest design and construction among the tank designs as per the International Maritime Organization (IMO) International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). Independent tank Type A are tanks which are designed primarily using classical ship-structural analysis procedures, in accordance with the requirements of a recognised standard. Its internal structure mitigates sloshing and eliminates loading limitations.

Development process

Class approvals

A key element in the development and commercialisation of a new containment system is class approvals. LNT initiated an approval in principle (AiP) process with DNV GL in 2012. The AiP is the first stage of class approvals and is much like a feasibility study. However, the process is important and valuable for the development of the system, as it considers how rules will be interpreted with regards to the new system and defines the regulatory framework for the development process.

No showstoppers were identified during the AiP process, and the certificate from DNV GL was issued in 1H13. Later, similar processes were conducted with the American Bureau of Shipping (ABS), Bureau Veritas (BV) and China Classification Society (CCS), which have all issued their own AiP for the LNT A-BOX.

For the insulation and secondary barrier system, separate AiP, as well as general approval for ship applications (GASA), have also been obtained, prior to the final project approvals. In addition, class societies provided assistance regarding the establishment of test criteria and witnessed a number of key tests over the years of development, including the mock-up units and smaller tests.

Testing

Expert competence, experience, advanced computer-aided design (CAD), finite element model (FEM) and other tools for design and analysis can take you a long way, but for the development of a novel containment system, testing at component and system levels are necessary to justify the structural behaviour, integrity and tightness of the technology. During the development of the LNT A-BOX an extensive test program was carried out.

An attractive solution for the insulation and secondary barrier system would have been a spray foam insulation to be sprayed directly on the hull compartment plating and a coating acting as the secondary barrier. Some possible solutions on this were proposed and tested in small scale, but it was quite soon concluded that global thermal stresses and risk for cracks and delamination would be a big challenge. Consequently, it was decided to focus on a system based on relatively small panels in order to have a flexible system that could absorb hull deflections and thermal contractions.

Thus, further testing focused on different designs and solutions for the insulation panels, with a secondary barrier to be fitted on the inner surface and not at least the flexible joint and flexible cross joints between adjacent panels. Over the years, numerous tests, including laboratory tests on components such as the secondary barrier flexible joints, to verify structural robustness as well as liquid tightness, have been conducted. Panel fabrication and testing of single panels, so-called open mock-up tests and more complete mock-up units have also been performed. This has been crucial for the development process, whereas some have revealed problems and solutions not working, but also verified and demonstrated what works. The most significant tests during the development process were the mock-up units in Xiamen Shipbuilding Industry (XSI).

The first round of tests were carried out in XSI in 2012. The mock-up tank (approximately 80 m^3) was built with insulation, a secondary barrier, a representative bottom support, a drip tray, a drop line into the drip tray and a spray system. The purpose of the mock-up was to test the practical installation of the insulation and secondary barrier system, and to simulate a tank collapse by flooding the secondary barrier with liquid nitrogen. During the first test, anomalies in the temperature curves were observed and testing ceased. During inspection after warm-up and ventilation, certain failures and weaknesses of the system were identified.

The next one and a half years were spent making improvements to the insulation and secondary barrier system based on the weaknesses observed at the first mock-up test. Once these had been made, in the fall of 2013, the installation of a new and improved panel system and secondary barrier commenced. Cooldown testing with N2 commenced in early 2014, and this time without any major issues or anomalies. In total, four cooldown cycles to liquid level and flooding of the secondary barrier were carried out, and no unexpected temperature drops or other signs of leaks were observed. Interior inspections after the completion of testing also confirmed that the system was intact. Thus, it was proven that the system was liquid-tight at -196°C and could resist low temperatures, as well as exposure to liquid without being damaged. ABS, DNV GL and BV witnessed the testing and concluded that the test was successful. This was proof that the conceptual solution could work; a major milestone in the system development.

Figure 5. Mock-up test program successfully completed at Xiamen Shipbuilding Industry.

Ship project development

Market entry

As the mock-up test was successfully completed, and class approvals and statements were issued, the development began focusing more towards ship project developments. Saga LNG Shipping announced plans to order a mid-size LNG carrier, and LNT responded by initiating the development of a 45 000 m^3 LNG carrier based on the LNT A-BOX.

The mid-size vessel class was selected for multiple reasons. As mentioned earlier, the market development and outlook underpinned a growing demand for vessels to support local

Figure 6. LNT45 after successful completion of gas trials in East China Sea.

and regional trades and growth in emerging markets. For small ships, Type C tanks have been established as the conventional technology of choice. For traditional large LNG carriers, GTT's membrane systems and Moss are also established and well proven. When it comes to the mid-size segment, there are very few vessels and none of the existing technologies have clear market leader position. Therefore, the mid-size segment of vessels presents a great opportunity to enter the market.

Specifications and contracts

Consequently, LNT developed a concept design for a 45 000 m^3 LNG carrier, dubbed the LNT45. The specifications and makers list for the ship project were developed in close cooperation with representatives of Saga and the yards. After a period of discussions with XSI, it was decided to enter into technical and commercial discussions with China Merchants Heavy Industry (CMHI). CMHI not only had the facilities and resources to take on the project, but also the right mindset and attitude to be the yard partner for such a pioneering project.

LNT45 – *Saga Dawn*

The LNT45 concept design was developed in-house by LNT. LNT's main focus is, however, on the cargo containment systems, and as a part of the agreements with CMHI it was agreed to commission an external ship design company for the development of basic design and class approval. LNT focused on the design and engineering for the containment system, including cargo tanks, cargo tank support system, insulation and secondary barrier system, and safety and auxiliary systems. LNT was also responsible for the supply of the insulation and secondary barrier system, and supervision of construction and installation of the entire containment system. LNT's engineering was done partly in-house and in cooperation with external engineering resources, and throughout the process there was a close dialogue with ABS' team of gas experts.

Construction process

The cargo tank construction was subcontracted by CMHI to SWS Shenghui. SWS developed the detail design for the tanks based on LNT's basic and class approved drawings. LNT supervised the construction from start to completion.

LNT established a production line for the insulation panels with a Chinese partner. In addition, an open mock-up and training centre was built in CMHI with the purpose of verifying all installation procedures, and to give the yard personnel training before starting installation onboard the hull. This facility provided invaluable training and insight for both LNT and the yard.

For the installation onboard the vessel, CMHI built warehouse-style covers over the hold spaces to provide a controlled climate for the installation jobs. After the completion of tank construction and installation of insulation and secondary barrier system in the hold spaces, the cargo tanks were lifted in, aligned and installed in the hold spaces.

Testing and trials

The *Saga Dawn* conducted sea trials in December 2018, whilst gas trials were carried out from late May to mid-June 2019. All three cargo tanks were cooled down and loaded with liquid during the course of testing, and the secondary barrier system tightness were tested prior to and after cooldown with satisfactory results.

Conclusion

The LNT A-BOX is the result of an idea to develop a simple and efficient cargo containment system for LNG. Based on independent tank Type A and a flexible and light panel insulation system, the LNT A-BOX offers a simple and construction friendly containment system. The tank system is flexible in shape and geometry, and allows for flexible hull designs for LNG carriers or floaters in essentially any size segment. **LNG**