IHI-SPB Tank for LNG-Fueled Ship

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Much attention is being paid to LNG-fueled vessels as a way of satisfying the IMO's emission control requirements. Japan Marine United Corporation (JMU) has developed an LNG fuel gas system employing an IHI-SPB gas fuel tank. A case study on an LNG-fueled container vessel fitted with this system is being carried out. JMU has converted IHI-SPB cargo containment technology into a fuel tank, allowing confirmation of the high reliability this system offers under harsh sea conditions, such as those found in the Japan-Alaska sea route. This high level of reliability is thanks to JMU's experience in LNG. IHI-SPB fuel tanks can flexibly accommodate shape restrictions, providing the highest volume efficiency for the available space. This case study on a large LNG-fueled container vessel employing an IHI-SPB gas fuel system demonstrates that a minimal loss of container cargo capacity relative to the original design can be achieved.

1. Introduction

Due to environmental concerns such as atmospheric pollution, the International Maritime Organization (IMO) will be enforcing Tier III regulations on Nitrous Oxides (NO_x) and Sulfur Oxides (SO_x) exhausted from marine vessels starting sequentially in 2015, and in Emission Control Areas (ECAs), an 80% reduction in NO_x emissions compared to existing Tier II regulations will be required. On top of that, the sulfur content of fuel must be reduced to 0.1% or less. In order to comply with these regulations, the application of Liquefied Natural Gas (LNG) as a fuel for marine vessels is currently receiving the most attention. Many LNG-fueled ships are already in service in Northern Europe, particularly along the Norway coast, and in addition, the construction of new LNG-fueled ships is being planned.

Meanwhile, Japan Marine United Corporation (JMU) has developed an original Self-supporting Prismatic shape IMO type B tank (IHI-SPB) as an LNG tank for marine vessels, and this tank has been successfully applied to ① LNG ships, ② LPG ships, and ③ LPG FSO/FPSOs.(1) Even compared to tanks being used for LNG ships, the IHI-SPB makes an excellent fuel tank thanks to its flexible accommodation of tank shapes, strength, high reliability, and freedom from sloshing at any liquid level. Consequently, JMU is carrying out the development of an LNG fuel supply system for marine vessels using the IHI-SPB tank.(2)

2. Exhaust gas regulation trends and LNG fuel

2.1 Exhaust gas regulation trends

The revised edition of ANNEX VI of the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973 (hereinafter, MARPOL), which incorporated demands related to the reduction of emissions from marine diesel engines, came into effect in October 2008. This imposed tighter upper limits on NO_x in exhaust gas and the sulfur concentration in fuel oil. The IMO also designated ECAs where the strictest regulations are applied. **Figure 1** shows the ECAs.

The ECAs currently include the Baltic Sea, the North Sea, the North America and the United States Caribbean Sea areas. SO_x regulations have been put in place to regulate the sulfur concentration in fuel oil, so that now ships navigating the ECAs are required to have a fuel oil sulfur concentration of 1% or less as of July 1, 2010, and 0.1% or less as of January 2015.

2.2 Regulation compliance with existing technology, and features of LNG fuel

According to the Tier III regulations by the IMO, navigating the ECAs with existing technology requires: ① a treatment system for exhaust gas (such as by Selective Catalytic Reduction (SCR)) that reduces NO_x by up to 80%, ② the use of low-sulfur fuel (such as diesel), and ③ installation of an exhaust gas purification device for reducing SO_x. These measures require a compartment for installing an SCR system and additional power for running the devices, and thus lead to an increase in fuel usage, and as a result, lead to an increase in CO_2 emissions and an increase in shipping costs. Meanwhile, it is recognized that international shipping transportation is one of the largest sources of carbon emissions, responsible for 3% of total global CO_2 emissions. In the 14th session of the United Nations Framework

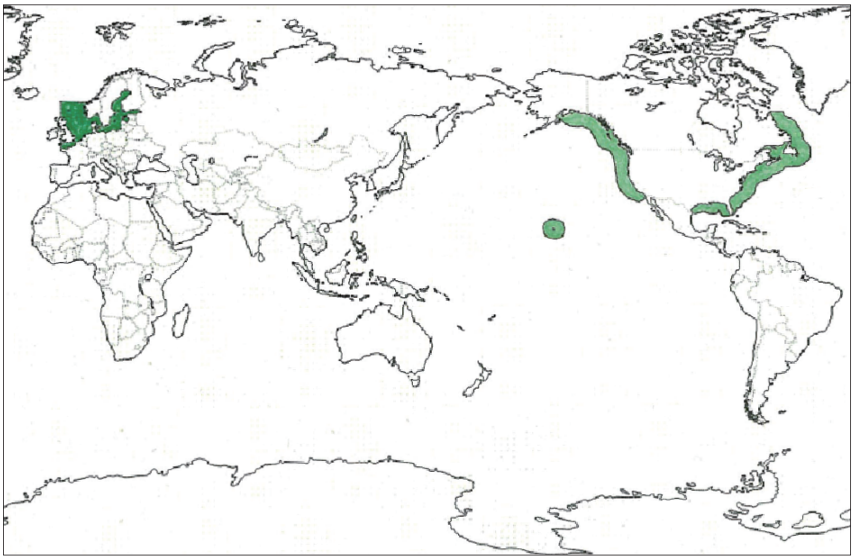

Fig. 1 Emission control area

Convention on Climate Change (COP14) that took place in December 2008, the IMO called for the development of a technologically practical solution to reduce greenhouse gas emissions from marine vessels.

The fuel conversion from petroleum to natural gas not only enables a reduction of NO_x in exhaust gas, but also a reduction in SO_x and CO_2 emissions. By using natural gas, NO_x can be reduced 80 to 90%, making it possible to satisfy the demands of the IMO Tier III regulations. In addition, since natural gas does not normally contain sulfur, SO_x is not present in exhaust, and CO_2 emissions can also be reduced by 20 to 25%. Furthermore, using natural gas also has the advantage of reducing soot, smoke, and particulate matter. Meanwhile, as the price of petroleum continues to rise in recent years, using natural gas as a fuel has the additional advantage of reducing fuel costs. However, since the specific weight of natural gas is lighter than heavy fuel oil, obtaining the same amount of heat requires a tank volume that is approximately double that of heavy fuel oil.

3. The IHI-SPB tank as an LNG fuel tank

3.1 LNG tank categories

The IMO broadly divides LNG tank types into self-supporting tanks and membrane tanks. Self-supporting tanks are further divided into Type-A, Type-B, and Type-C. The IHI-SPB tank is a Type-B tank. **Figure 2** shows the types of LNG tanks.

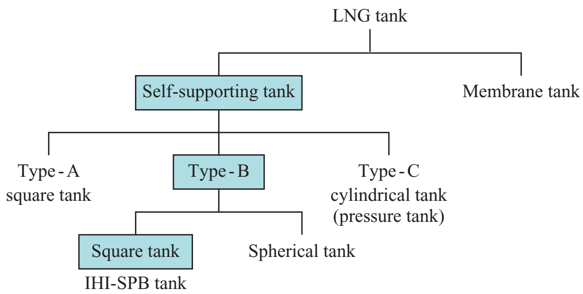

Fig. 2 Type of LNG tank

A membrane tank is made of a thin primary barrier that can contain LNG, but by itself is unable to sustain the liquid load. A self-supporting tank is able to contain and sustain liquid with a primary barrier, but in a Type-A tank, the tank structural design is conducted by a strength calculation method based on class rules, and fatigue strength is not taken into account. Consequently, the installation of a full secondary barrier is mandatory for Type-A tanks.

On the other hand, with a Type-B tank, a detailed strength examination is conducted, taking fatigue strength and quality control into account. For this reason, the tank structural strength is highly reliable, and fatigue cracks do not occur. As a result, the installation of only a partial secondary barrier is enough. Meanwhile, Type-C tanks are designed as pressure tanks and have thick walls, so that the installation of a secondary barrier is not mandatory.

3.2 Features of the IHI-SPB tank as an LNG fuel tank

Figure 3 shows the diagrammatic structure of the IHI-SPB tank. The IHI-SPB tank generally has the following features.

(1) A strong and highly reliable tank structure

Figure 4 shows the record of the ships and marine structures carrying the IHI-SPB tank built by JMU. Since being put into service, none of these tanks have ever been damaged or cracked. If the tank of an LNG-fueled ship were to be damaged, the ship would be unable to make its journey. Also, an LNG leakage due to damage or deterioration of the tank could lead to disasters such as fires and explosions. For these reasons, the tank structure must be strong and reliable, so that it cannot be damaged or cracked. This is particularly true for LNG-fueled ships because the LNG is not merely the ship's cargo, so it is not possible to separate the hull into an LNG area and other safe areas.

(2) No sloshing at any liquid level

Since the amount of LNG inside the tank constantly

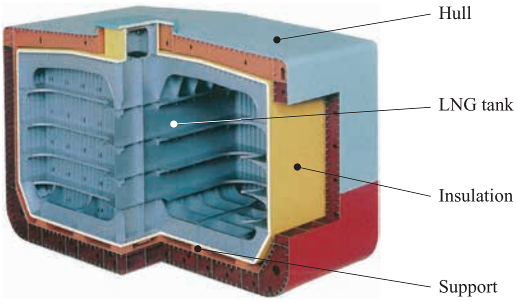

Fig. 3 IHI-SPB tank

changes as LNG as fuel is consumed, suppression of sloshing regardless of the LNG level is another important requirement for an LNG fuel tank. By adequately placing structural members inside the IHI-SPB tank, it is possible to make the natural period of liquid motion inside the tank differ from the natural period of the motion of the ship, and thereby avoid sloshing.

(3) Tanks of arbitrary shape can be built

In order to use LNG as fuel, a ship must be fitted with a new tank specifically for LNG. However, as discussed above, in the case of LNG fuel, the required tank volume is approximately twice as large as that for heavy fuel oil, so more space is taken up by the tank. In order to minimize this disadvantage, it is necessary to reduce the constraints on effective utilization of the internal hull, and the tank's shape, layout, and size as much as possible. In this respect, the IHI-SPB tank can be built in any shape to effectively utilize as much internal hull space as possible and ensure the largest possible tank volume within a given space.

Figure 5 shows IHI-SPB tanks of various shapes. **Figure 5-(a)** shows an IHI-SPB tank (per-tank volume 750 m^3) being installed in the LEG/LNG ship “KAYOH MARU”.[3] **Figure 5-(b)** shows tanks of an LNG ship (per-tank volume 22 250 m^3). The bow tank is not a simple cuboid shape, but instead has a prismatic shape with many knuckled parts. As these tanks demonstrate, IHI-SPB tanks can be made to fit the shape of the hull, and thereby effectively utilize internal hull space and minimize loss of cargo space due to tank installation.

(a) Tank shape for LEG/LNG ship

(b) Tank shape for LNG ship

Fig. 5 IHI-SPB tanks of various shapes

3.3 Comparison of IHI-SPB and Type-C tanks

The fuel tanks used in LNG-fueled ships currently operating in Northern Europe are Type-C tanks. **Table 1** shows a comparison between IHI-SPB and Type-C tanks. Major advantages of the IHI-SPB tank compared to a Type-C tank include the flexibility of the tank shape and the light weight of the tank.

A Type-C tank is a pressure tank with a cylindrical shape. Since ships have a rectangular cross-section, it is easy to infer that installing a cylindrical tank into such a space will

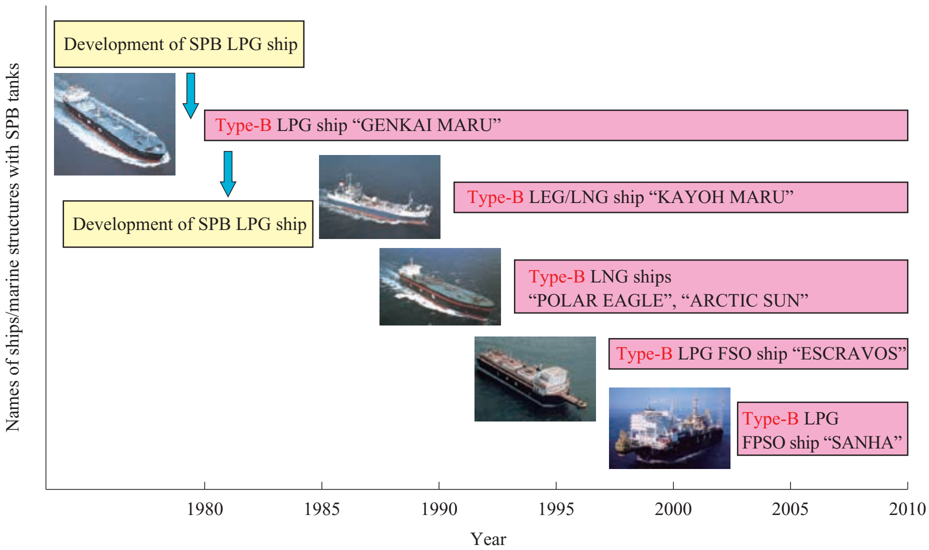

Fig. 4 Construction record for IHI-SPB tanks

Table 1 Comparison between IHI-SPB and Type-C tanks

Feature	IHI-SPB tank	Type-C tank
Tank shape	Square (arbitrary shape)	Cylindrical
Rated tank pressure	< 0.7 bar (0.07 MPa)	< 10 bar (1 MPa)
Tank material	Aluminum alloy (Stainless steel, 9% nickel steel)	Stainless steel (9% nickel steel)
Tank weight	Light	Heavy
Insulation	Expanded foam	Vacuum insulation, expanded foam
Space efficiency	Good	Bad
Tank capacity	Unlimited	Limited

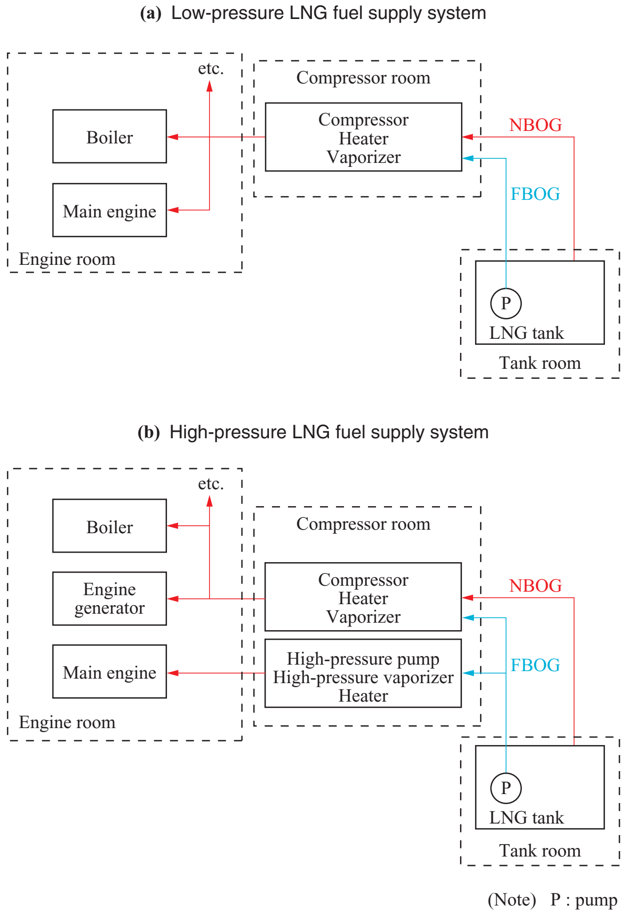

Fig. 6 Concept for gas supply system with IHI-SPB tank

result in less efficient use of internal hull space compared to a prismatic IHI-SPB tank.

Additionally, although Type-C tanks can be designed to handle higher pressures than IHI-SPB tanks, they have thicker walls and are heavier. Furthermore, the Type-C tanks currently being used as LNG fuel tanks include a vacuum heat insulation system, and are covered by thick double walls (inner wall: stainless steel, outer wall: steel), and are extremely heavy as a result. In the hypothetical case of an LNG fuel tank of approximately 2 000 m^3, an aluminum IHI-SPB tank is 1/5 to 1/6 the weight of a Type-C tank. As the tank capacity increases, this difference in weight becomes even greater. An IHI-SPB tank may also be made of stainless steel or 9% nickel steel instead of aluminum, but even if stainless steel or 9% nickel steel is used, the weight is still approximately 1/3 of a Type-C tank. Since there is a limit to the total weight that can be loaded onto a ship, a heavier tank means an equivalent decrease in the amount of cargo that can be loaded onto the ship.

Furthermore, an increase in weight means an increase in the draft of the ship, which adversely affects fuel efficiency. A heavier tank also means that if the tank is installed at a high position, there is a possibility of adversely affecting ship stability. In this respect, the IHI-SPB tank has a major advantage in being more lightweight than a Type-C tank.

3.4 Class approval

So far, the IHI-SPB tank has been successfully used in ① LNG ships, ② LPG ships, and ③ LPG FSO/FPSOs. Although the capacity differs, the design ideas and manufacturing methods are basically the same for IHI-SPB tanks used as cargo tanks for LNG ships, and IHI-SPB tanks used as LNG fuel tanks. The IHI-SPB tank obtained Approval in Principle (AIP) as a fuel tank from the American Bureau of Shipping in 2011 and the Nippon Kaiji Kyokai in 2012.

4. LNG fuel supply system using IHI-SPB tanks

Figure 6 shows examples of LNG fuel supply systems using the IHI-SPB tank. The gas supply system is made up of a gas compressor, an LNG transfer pump, a vaporizer, and a heater. Natural Boil-off Gas (NBOG) inside the tank is pressurized by the gas compressor and supplied to components such as the main engine, engine generator, and boiler. If the amount of NBOG is insufficient for the amount required by the main engine or engine generator, LNG is supplied from the LNG transfer pump installed inside the tank, and Forced Boil-off Gas (FBOG) generated by the vaporizer is supplied.

At present, proposed LNG-fueled main engines include low-pressure systems with a pressure of approximately 6 bar (0.6 MPa) and high-pressure systems with a pressure of approximately 200-300 bar (20-30 MPa), but as illustrated in **Fig. 6**, a fuel supply system using the IHI-SPB tank is compatible with both a low-pressure LNG fuel supply system (**Fig. 6-(a)**) and a high-pressure LNG fuel supply system (**Fig. 6-(b)**).

5. Concept design of LNG-fueled ships

A case study of a 10 000 TEU container ship applying an LNG fuel system using the IHI-SPB tank was carried out. The principal particulars and specifications of the container ship are listed below.

Total length	Approx. 330.0 m
Total width	Approx. 48.0 m
Depth	Approx. 27.0 m
Container loading capacity	10 000 TEU
Route	Far East to Europe
Range	Approx. 20 000 miles

Tank capacity

LNG	Approx. 2 000 m^3 (inside ECA)
Heavy fuel oil	Approx. 10 000 m^3 (outside ECA)
LNG tank arrangement	Under accommodation area
Compressor room arrangement	Under accommodation area

In order to minimize loss of cargo space due to the switch to LNG fuel, the LNG fuel is only for use within the ECAs, whereas heavy fuel oil is used in regions outside the ECAs. When navigating waters outside the ECAs, NBOG produced inside the LNG tank is not consumed by the main engine, so there is a risk of a gas surplus. Such surplus NBOG would be supplied to the engine generator and used for electricity consumption inside the ship.

Figure 7 shows the general arrangement of the ship. The LNG tank and the compressor room are placed under the accommodation area, minimizing the effect of the LNG tank installation on the container area. As a result, it is possible to keep the loss of cargo area due to the switch to LNG fuel to 200 TEU or less. **Figure 8** is a concept drawing of a ship implementing an IHI-SPB tank fuel supply system.

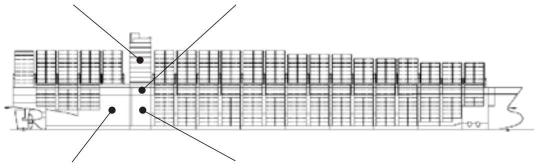

Fig. 7 General arrangement

(Note) IHIMU : IHI Marine United Inc. (predecessor of JMU)

Fig. 8 LNG fueled 10 000 TEU container

6. Conclusion

Currently, LNG-fueled ships are mainly in service in Northern Europe, but are expected to increase in number in the future due to the Tier III regulations from the IMO. Challenges remain in expanding the use of LNG-fueled ships, such as the development of infrastructures for supplying fuel to ships, but efforts are being made to establish the necessary infrastructures both domestically and abroad.

The features of the IHI-SPB tank make it highly suitable as an LNG fuel tank, where the merits of the IHI-SPB tank can be utilized to their fullest extent. We are already receiving many inquiries regarding the IHI-SPB tank for use as an LNG fuel tank, which reflects the high public interest. We have high expectations that use of the IHI-SPB tank as an LNG fuel tank will spread in the future.

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