

Gas Handling Technology to Support Carbon Neutrality of Ships



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In July 2023, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted the 2023 IMO GHG Reduction Strategy aiming to achieve zero GHG emissions from international shipping by 2050. As the approach to convert conventional heavy oil fuel to gas fuels such as LNG and ammonia is gaining momentum as a means of low-carbonization and decarbonization of ships, gas handling technology for safe and appropriate handling of gas fuels is becoming increasingly important. This report provides an overview of gas handling technology and presents its product development.

1. Introduction

For Mitsubishi Heavy Industries, Ltd. (MHI), our history of building LPG (Liquefied Petroleum Gas) carriers began with the Bridgestone Maru in 1962. In 1989, we started building a series of LPG carriers with a tank capacity of 78,000 m³, and since then, we have built more than 80 LPG carriers while further increasing the tank capacity. On the other hand, we started developing LNG carriers in the 1970s, and delivered the first spherical tank-type LNG carrier, Banshu Maru in 1983. Since then, with technological innovations such as increasing tank capacity and changing from steam turbines to diesel engines, we have built and put into service more than 50 LNG carriers. In the construction of these vessels, we have conducted various studies over the years and established many elemental technologies to realize safe and reliable liquefied gas transportation.

2. Gas handling technology

2.1 Liquefied gas transportation technology

The main components of LPG are propane and butane, and propane constitutes most of the transporting volume. In many cases, carriers transporting LPG are often deployed in trades for which the destination and loading ports cannot be specified, and their cargoes are unloaded at multiple ports, thus flexibility is required in terms of operation. In addition, since multiple liquefied gases with different properties need to be loaded in a mixed or separated manner and re-liquefied, a number of measures have been devised to address various technical issues. The development of ammonia carriers and related equipment, which have been the focus of much attention in recent years, has taken advantage of these findings.

On the other hand, LNG is mainly composed of methane and is generally transported in a liquefied state after being cooled to -162°C under atmospheric pressure. Thus, the most characteristic feature of LNG carriers is the extremely low design temperature of the tanks, and design technology and knowhow for transporting cryogenic cargoes have been accumulated. LNG bunkering vessels and related products, which have recently become common as a low-carbon

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technology, have been commercialized utilizing such technology and knowhow.

2.2 Liquefied gas tank design and analysis technology

Liquefied gas tanks play an important role in liquefied gas carriers and liquefied gas-fueled carriers. In the design of liquefied gas tanks, it is necessary to consider strength such as yield, buckling, and fatigue against acceleration of hull motion, as well as to cope with thermal shrinkage and prevent brittle fracture due to cold cargo. The tanks can be cylindrical, spherical, or rectangular, depending on the application, and all of them have been proven reliable through many years of development of LPG carriers and LNG carriers and their service records. The following sections discuss cylindrical tanks, which are used for LNG and ammonia fuel tanks, and rectangular tanks, which are advantageous for large-capacity ammonia tanks.

Cylindrical tanks are designed based on the concept of pressure vessels, and have the strength to withstand high internal pressure. Therefore, load fluctuations are relatively reduced and fatigue strength is ensured. In the case of ships, the International Maritime Organization (IMO) has adopted the International General Safety Code (IGC Code) for liquefied gas carriers, in which pressure-type tanks are classified as Type C tanks and the necessary strength requirements are stipulated. Type C tanks are exempted from the secondary barrier (a barrier against liquefied gas installed outside the tank to prevent cargo leakage) based on the above-mentioned design concept regarding fatigue strength, which is advantageous in terms of freedom of layout, etc.

On the other hand, for ammonia-fueled ships that need to have a long cruising distance, rectangular tanks are more advantageous than cylindrical tanks in terms of volumetric efficiency and other factors. Rectangular tanks have been proven on LPG carriers and are classified as either Type A or Type B in the IGC code. Type A tanks are required to be completely surrounded by the aforementioned secondary barrier. Type B tanks can narrow the area of the secondary barrier, provided that advanced analysis methods are applied, thus enabling both tank reliability and design flexibility. We have developed a highly reliable Type B tank-type LPG carrier using our direct loading analysis method (MHI-DILAM), an integrated load-structure analysis system developed in-house. This technology is also effective for ammonia-fueled vessels with a large-capacity fuel tank.

We have accumulated design and structural analysis technologies for all tank types through the construction of liquefied gas carriers, and can develop and provide the most suitable tank type according to the applicable conditions.

2.3 Boil-off gas (BOG) reduction and utilization technology

Since LNG carriers transport extremely low-temperature liquefied natural gas under atmospheric pressure, the cargo tanks are equipped with heat-insulating materials with high thermal insulation performance. Even so, it is not possible to completely shut off heat input, so excess BOG generated by heat input is generally discharged to maintain low-temperature and low-pressure conditions. The discharged BOG is consumed as fuel for the propulsion plant, but when the consumption by the propulsion plant is low, or when the ship is anchored or navigates at low speed, there occurs a surplus of BOG, which needs to be disposed of by boilers or gas incinerators, or which needs to be processed by re-liquefaction equipment installed in advance. Therefore, in order to achieve efficient operation, it is effective to avoid or minimize the wasteful disposal of BOG.

For example, under LNG full-loaded conditions, it is considered possible to store intruding heat in the LNG as sensible heat. However, if a high-temperature zone is formed in the liquid surface layer, which is in vapor-liquid equilibrium with the gas phase, heat storage effects may not be sufficient, resulting in a rise in cargo tank pressure. To prevent this, a countermeasure such as the use of LNG spray nozzles to cool the liquid surface layer has been considered, and is also used on vessels built by us. Such design technology and knowhow are also used to support the development of alternative fuel ships and shipbuilding engineering services.

3. Product development of gas handling technology

3.1 VLGC

VLGC (Very Large Gas Carrier) generally refers to large vessels transporting liquefied LPG at low temperatures in cargo tanks of 70,000 m³ or more. In recent years, we have shifted to building VLGCs from in-house to in cooperation with other shipyards. **Figure 1** shows a full view

of the first ship delivered to a customer at Namura Shipbuilding Co., Ltd. in September 2023.

The environment surrounding VLGCs has been changing more and more rapidly. For example, LPG transport to East Asia used to be dominated by imports from the Middle East, but after the shale gas revolution, imports from North America have increased sharply. Since the new Panama Canal was opened in 2016, the specifications of VLGCs have been set to be suitable for passing through the canal, and their range has also increased. From around 2019, fuel conversion from heavy oil to LPG with low CO₂ emissions has been progressing in an attempt to reduce GHG emissions. In line with this trend, cargo tanks are becoming larger and larger because it is more economical to share the LPG in cargo tanks as fuel than to store LPG fuel separately in high-cost deck tanks. Today, the mainstream of newly built VLGCs is those with cargo tanks of 87,000 m³ to 93,000 m³.

LPG and liquefied ammonia have similar physical properties and can be handled similarly, thus VLGCs are attracting attention as a means of transporting ammonia in large volumes. Ammonia is expected to be used as a fuel in thermal power plants in Japan, and VLGCs are increasingly required to be able to carry ammonia as well as LPG in recent business negotiations for purchasing VLGC. Since ammonia has a lower energy density than LPG, when the cargo is used as a fuel, it is necessary in the case of ammonia transportation to have a larger cargo capacity than LPG transportation, which is expected to lead to the further increase in vessel size from the viewpoint of improving transport capacity and efficiency. We believe that VLGCs will play a role in the international transport of ammonia and that the establishment of a steady and safe supply chain will contribute to the realization of an ammonia-based society. We will continue to make efforts to research and develop related technologies in order to respond to changes demanded by society.



Figure 1 VLGC

3.2 Ammonia-fueled ship

MHI can provide a wide range of engineering services for ammonia-fueled ships, from concept design to detailed design. The following introduces some of the key aspects of ammonia-fueled ship engineering.

Ammonia fuel is less flammable and requires about 2.8 times the tank capacity to obtain the same calorific value as heavy oil fuel. In addition, ammonia fuel tanks need to be isolated from the hull of the vessel, and generally require a larger space for installation than heavy oil fuel tanks, which increases the weight of the steel materials used.

As described in Section 2.2, there are two types of ammonia fuel tank shapes: cylindrical and rectangular. Rectangular tanks have high volumetric efficiency, but are restricted by the need for a fuel storage hold space around it as a secondary barrier. Therefore, we consider that it is easy to design a vessel by planning the use of rectangular tanks when large capacity tanks are needed and fuel storage hold spaces can be accommodated, and cylindrical tanks in other cases.

The concept of fuel tank arrangement differs depending on the type of ship. Tankers, as shown in [Figure 2](#), can use the space on the upper deck, so it is preferable to place cylindrical tanks on the upper deck. Container carriers also carry containers on the upper deck as shown in [Figure 3](#), and require large-capacity fuel tanks due to their higher speed than other types of vessels, so it is more effective to place rectangular tanks in a part of the cargo hold. For bulk carriers, it is

preferable to place cylindrical tanks behind or next to the cargo hold as shown in **Figure 4** so that they do not become an obstacle during cargo loading and unloading.

If fuel tanks are too large to place on the planned ship, it is necessary to reduce the ship's cruising range according to the capacity of tanks that can be placed, or to review the cargo holds or main dimensions of the planned ship so that the tanks can be accommodated. In addition, an increase in tank and fuel weight will reduce the maximum loading capacity, and this needs to be accepted or, if not accepted, the displacement needs to be increased. Furthermore, when tanks are placed on the upper deck, attention needs to be paid to the stability, and when they are placed at the stern end, it is necessary to take into account the longitudinal strength allowance.

To ensure safety in the handling of ammonia, a detoxification system is required to reduce the concentration of residual ammonia extracted from fuel combustion equipment, such as engines and marine boilers, and related piping to a level that does not affect human health before discharge, as described in Section 3.5. In addition, to reduce the risk of ammonia leakage, it is necessary to use double tubes for the transfer piping and to keep the vent mast, which discharges ammonia gas to the atmosphere, far enough away from the cabin area.

The smaller the vessel, the more difficult it becomes to maintain the distance between the vent and the cabin area, and the more difficult the ship design becomes.

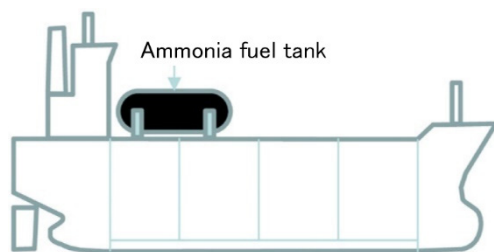


Figure 2 Example of tank placement on tanker (cylindrical tank)

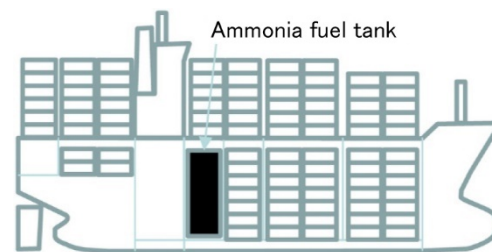


Figure 3 Example of tank placement on container carrier (rectangular tank)

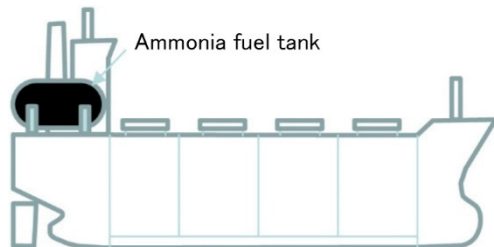


Figure 4 Example of tank placement on bulk carrier (cylindrical tank)

3.3 LNG bunkering ship

LNG bunkering ships supply LNG fuel to LNG-fueled ships. The ship-to-ship bunkering method, in which an LNG bunkering ship comes alongside a ship moored at the wharf or anchored at an anchorage to supply LNG, is suitable for supplying a large volume of LNG fuel to large ships. We have built a new coastal LNG carrier and bunkering ship, KEYS Azalea, for KEYS Bunkering West Japan Co., Ltd.

Figure 5 shows KEYS Azalea. This ship is the first LNG bunkering ship to operate in western Japan and has the following features.

- (1) The main dimensions of the vessel are: Length x Width x Depth x Strength Draft = approximately 82.4 m x 18.2 m x 7.8 m x 4.98 m. The gross tonnage is approximately 4,700 gross tons.
- (2) The cargo tank is a single Type C tank with a volume of approximately 3,500 m³. The center of the tank volume in the longitudinal direction is designed to be located near the ship's center of buoyancy, which minimizes changes in hull trim before and after bunkering and allows for operation with minimal ballast manipulation.
- (3) The LNG transfer system employs a method in which a cryogenic flexible hose is connected to the bunker manifold of the LNG bunker using a hose handling crane. The connection port to the bunker manifold is equipped with a cryogenic quick connection to

speed up the hose connection/disconnection work. The system is also equipped with an emergency disconnect device and a ship-to-ship distance detection device, allowing the hose to be quickly disconnected when the distance to the LNG-fueled ship increases, or in the event of a fire or other emergency.

- (4) Cargo manifolds equipped with two hose handling cranes are located near midship and at the bow on both sides of the ship, allowing flexible selection of manifolds to be used according to the size and shape of the LNG-fueled ship and the bunker station layout.
- (5) For ship-to-ship mooring, a total of four sets of foam fenders and fender davits are provided.
- (6) Side thrusters are installed at the bow and stern of the ship, facilitating berthing in and leaving harbor to reduce the time required for loading and unloading.
- (7) The dual-fuel electric propulsion system that can be fueled by both LNG and MDO (Marine Diesel Oil) is provided for the first time in Japan as an LNG bunkering ship, significantly reducing CO₂, NO_x, SO_x, and PM emissions from the ship compared to conventional ships.



Figure 5 KEYS Azalea

3.4 LNG FGSS

In recent years, the environment for the use of clean and inexpensive LNG as marine fuel is advancing. However, there are issues in using LNG, such as the need for additional investment in dedicated facilities such as fuel tanks and fuel supply equipment, as well as the extreme difficulty of handling LNG. In addition, engines that use LNG as their main fuel have different fuel supply specifications depending on the combustion cycle. Otto-cycle engines require a relatively low gas supply pressure of 2 MPaG or less, while diesel-cycle engines require a high supply pressure of about 30 MPaG.

FGSS (Fuel Gas Supply System) is a generic name for equipment that supplies gas fuel from an LNG fuel tank to multiple fuel combustion devices such as the above engines and marine boilers. We have developed and commercialized low-pressure and high-pressure FGSSs by applying our technologies cultivated in the construction of LNG carriers. These systems have been applied in ships after accumulating experience in delivering them to land-based test facilities for marine dual-fuel engines, thus they are highly reliable systems.

As shown in **Figure 6**, an FGSS consists of the FGSS module (hereinafter referred to as “module”), LNG fuel tank, control system, etc. **Figure 7** shows the module, which contains the LNG vaporizer and other major equipment necessary for fuel supply in a space-saving, easy-to-operate, and easy-to-maintain package and contributes to optimal design of cargo space and shortened processes in shipyards. For LNG fuel tanks, we can propose the best solution by applying various tank types according to the customer's requirements. **Figure 8** is a full view of the LNG fuel Type C tank delivered by us. The control system was developed based on our expertise in IAS (Integrated Automation System, a cargo handling and propulsion plant control system) for LNG carriers, and realizes plant operation with excellent load-following capability and operability in a wide range of operation modes.

In addition to supplying FGSS products, MHI provides comprehensive support services to shipyards and shipowners in Japan and overseas that build and operate LNG-fueled ships in all phases, from initial planning through design, construction, commissioning, and to operation. To

promote the use of LNG-fueled ships, we will meet various needs, including concept design, on-site support for piping and outfitting, etc., gas testing, post-commissioning LNG bunkering support, and special operation support before and after docking.

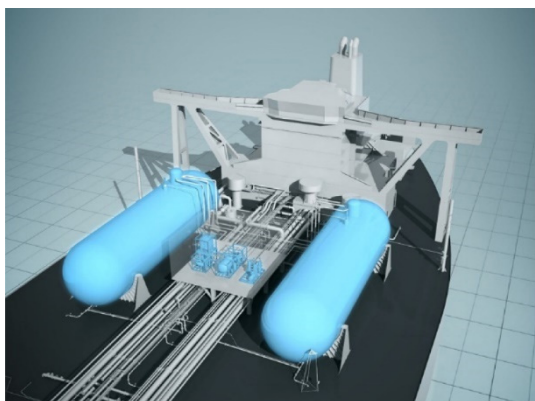


Figure 6 Example of FGSS placed onboard



Figure 7 FGSS module

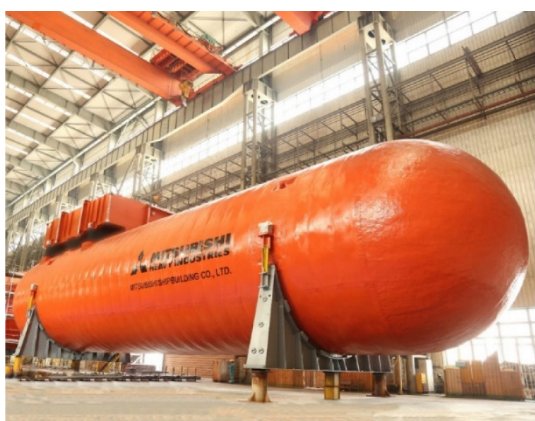


Figure 8 LNG fuel tank

3.5 AFSS and AGAS

AFSS (Ammonia Fuel Supply System) is a generic name for equipment that supplies ammonia as fuel to multiple fuel combustion devices such as engines, marine boilers, etc. AFSSs have the function of sucking ammonia fuel from the tank, adjusting it to the temperature and pressure required by the fuel combustion device, and supplying the amount according to the load of the device. Since the required fuel conditions at the inlet of a fuel combustion device vary depending on the specifications of the device, both a high-pressure fuel supply system (HP-AFSS) supplying liquid ammonia and a low-pressure fuel supply system (LP-AFSS) supplying ammonia gas need to be installed onboard. HP-AFSSs are mainly for diesel-cycle engines, while LP-AFSSs are for Otto-cycle engines and marine boilers. We can offer AFSSs for shipboard plants consisting of multiple engines and boilers and provide modularized elemental equipment as a package.

AGAS (Ammonia Gas Abatement System) is a generic name for equipment that safely disposes of residual ammonia in fuel combustion devices and related piping. In the event of a fuel changeover or emergency shutdown of a fuel combustion device, the ammonia remaining in the device and related piping needs to be discharged to the outside immediately. On the other hand, discharging ammonia into the atmosphere requires a process and time to reduce the concentration below a certain level in consideration of the impact on the crew and the environment. AGASs have an ammonia detoxification function that satisfies these two contradictory requirements.

An AFSS is located in the fuel conditioning room, which is a separate compartment from the engine room where the engine is installed. The piping supplying ammonia fuel from the fuel conditioning room to the engine in the engine room uses double tubes to reduce the risk of leakage.

In 2023, we completed the demonstration test facility shown in **Figure 9** in our Nagasaki District, Research & Innovation Center. Various tests on ammonia fuel handling have been conducted here repeatedly, and we are proceeding with AFSS and AGAS development based on the results obtained.



Figure 9 Ammonia handling demonstration test facility

4. Conclusion

The 2023 IMO GHG Reduction Strategy aiming to achieve zero GHG emissions from international shipping by 2050 was adopted. The maritime industry has started a number of initiatives to achieve the strategic goal. As an approach to convert fuel to gas fuels such as LNG and ammonia is gaining momentum as a specific means, gas handling technology for handling of such gas fuels is becoming increasingly important. We will apply the technologies we have developed to date to VLGCs, ammonia carriers, LNG bunkering ships, LNG FGSSs, AFSSs and AGASs to promote low-carbonization and decarbonization in the maritime industry and strive to realize a carbon-neutral society, while contributing to reducing environmental burdens on a global scale.