Development of LNG Facility for Marine Applications: MHI-GEMS

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Recently, Liquefied Natural Gas (LNG) use has been increasing, while the number of new consumers has also risen. LNG is one means for the distribution of Natural Gas, and the feature of Natural Gas is that it can be a clean energy source among natural resources, such as oil and gas which are extracted underground. Recently, vast extractable deposits have been found around the world, including the so-called "shale gas". LNG has several advantages in consideration of the entire energy supply chain, such as higher transportation efficiency, and a well-organized distribution infrastructure, supported by mature industries and their markets. Particularly, in marine applications, floating infrastructure, Floating LNG production (FLNG) or Floating storage and regasification unit (FSRU), is presenting many business opportunities to those who can set up facilities in the short term, and at a competitive initial cost; moreover, it can help those who want to be free from geopolitical risk. Also in the marine fuel sector, LNG might be the best possible solution in regard to environmental issues, by replacing marine heavy oil, while saving on total costs. MHI is currently addressing activities to contribute to LNG market expansion to the marine industry, "MHI-GEMS" as we call it, which is representing our business serving onboard LNG equipment and its integration into the whole system design to shipbuilders worldwide.

1. Introduction

Recently, among large-scale merchant ships, only LNG carriers (LNGC) are using LNG as their propulsion. LNGC have a huge amount of LNG in their cargo tanks, while keeping their tank pressure low for better transportation efficiency.

Boil off gas (BOG) from cryogenic liquid should be extracted from tanks to keep the tank pressure low, because such gas can take heat away from the liquid, compensating for heat coming through insulators of cargo tanks into the cryogenic liquid.

BOG should be treated in a safe and efficient way, and the best way had been steam turbine propeller drives utilizing steam boilers that can fire the gas.

Other ships use marine heavy oil as their main fuel. Marine heavy oil is produced as a residual fluid from the crude oil refinery process, therefore, the heavy oil is the cheapest among marine fuels, an adequate supply to the market is ensured, and it is easy to get in any part of the world.

However, heavy oil has a serious issue regarding exhaust emissions because it involves sulfur compounds originally contaminated in crude oil. Sulfur removal in the refinery process increases the oil price; in addition, refined oil is not readily available throughout the world.

On the other hand, the LNG price per heat value is coming down and lowering the price of heavy oil. This tendency is accelerating, particularly in the area of emissions control, and circumstances are proving favorable for LNG. However, LNG requires additional investment for

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cryogenic liquid storage and high pressure fuel gas process equipment, which are special equipment built to handle evaporating liquid in a cryogenic state. The equipment is not familiar to shipyards and ship owners who have no experience of LNGCs. Furthermore, at present, there are no LNG bunkering points and no guidelines for LNG handling. Improvements in marine infrastructure have just started.

2. Marine engineering business

2.1 Background

At MHI's Nagasaki and Yokohama shipyards we have undertaken new building and repair business of LNGC and LPGC for many years, and accumulated the experience and knowhow of related technologies, such as cryogenic storage, liquefaction, gasification, combustion, and fuel gas production.

The MHI ship building and ocean engineering division started the marine engineering business promotion sector in July 2012, and the new business is giving ship building engineering support to many domestic shipyards and shipyards of emerging nations.

The following are our services in this business

- Development of innovative technology, and experimental support for rule making
- System engineering support, mainly for LNG/LPG parts
- Gas ship equipment module supply

2.2 Verification site in Nagasaki

The growing LNG industry is positive to innovating technologies.

MHI is addressing the needs for new technologies and products, which have been verified in our testing facility before proposing to the market.

We have had an LNG test facility in the Nagasaki research center since 2010, and we have completed the development of a variety of equipment. A full-scale fuel gas supply system for a GI engine (ME-GI) is one of such developments, and a large-scale regasification system for FSRU is another example; they shall both be introduced later.

Figure 1 shows an overview of extremely high pressure fuel gas supply equipment prepared for evaluation of a gas shut off safety system contracted by the Japanese government.

2.3 Safety assessment

New concepts or advanced technologies should be examined in respect to safety before their actual application, because, in most cases, there are no applicable safety guidelines and rules.

Hazards Identification/Hazard & Operability study (HAZID/HAZOP) or similar methods for safety assessment are effective to assure the safety and reliability of the designated system.

We have well trained personnel for these assessments who have experience of FLNG and FSRU (**Figure 2**).

Figure 1 Testing of high-pressure gas safety facility (high-pressure gas production area only)

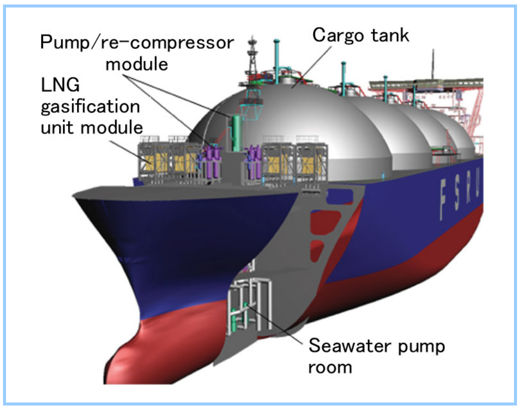

Figure 2 Design example of MORV (Marine Open Rack Vaporizing System) equipped FSRU using refitted LNG carrier

2.4 Equipment supply business as MHI-GEMS

"Gas ship equipment module and system (GEMS)" is our business supplying modules and systems for gas ships and floaters like LNGC, LPGC, FSRU and FLNG.

Figure 3 shows the functions we provide in GEMS, covering gas ship demand; moreover, a new line up is under development corresponding to requests from our customers.

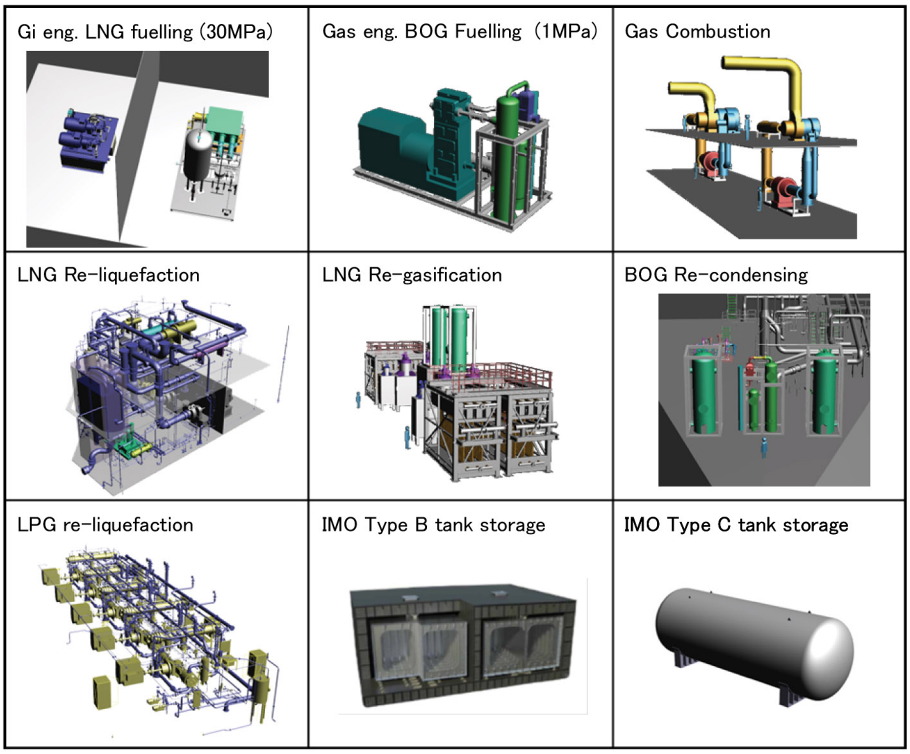

Figure 3 MHI-GEMS product lineup

3. LNG as marine fuel

3.1 Gas fuel in diesel engines

Recently, an oil fuelled two cycle diesel engine directly coupled to a propeller shaft is the standard marine engines, because of their high thermo efficiency of more than 50% (LHV, lower heat value base) utilizing heavy oil. They took over from steam turbine propulsion at the time of oil crises in the 1970s, and have maintained their dominant position.

The engine has a diesel process to generate power: high pressure gas is injected into the cylinder filled with highly pressurized air to ignite, and the explosive power is transferred through a piston and crank mechanism to the rotating power of the propeller shaft.

In the marine industry, three principal vender groups exist, and MAN B&W's ME/MC has the dominant market share. They have developed their gas injection engine technology (ME-GI) and some licensee agreements with suppliers are already in place.

On the other hand, four cycle medium/high speed engines are also considered as marine propulsion generator engines for propulsion electric motor systems.

For smaller vessels, the engine can couple with a speed reduction gear set and propeller but is limited for controllable pitch; however, the engine size is limited compared to two cycle engines.

In this paper, we focus on two cycle engines, because they will be advantageous in the larger output vessels we are interested in.

3.2 High pressure gas production equipment.

A four cycle engine mostly adopts the Otto cycle for their combustion principle, which requires comparably low pressure, less than 1.0 MPaG, and their fuel gas supply system has been well established.

On the other hand, a two cycle diesel engine requires extremely higher pressure, around 15 to 30 MPaG at the engine side; we are proposing a fuel gas supply system (FGSS) for a GI engine, which has been developed and verified by MHI, and have been performing demonstration tests in Nagasaki since 2011.

An almost identical system has been delivered to an engine manufacturer in Japan (MITSUI Tamano works, in Okayama Prefecture), as a gas test facility for the GI engines manufactured by the company (**Figures 4 & 5**).

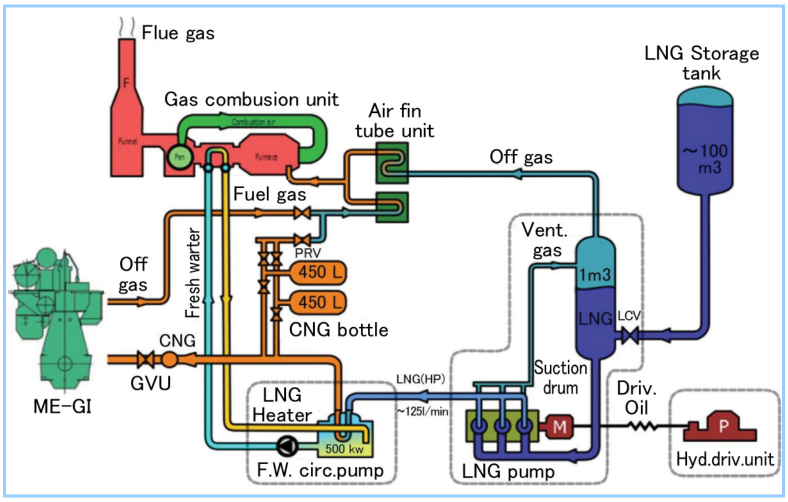

Figure 4 Facility design for Mitsui Engineering & Shipbuilding Co., Ltd. Tamano Works

Figure 5 Facility of Tamano Works

This FGSS supplies engine fuel gas up to 125 liters per minute according to the amount of LNG consumed. In particular, our system is adopting dedicated technology developed for marine applications, such as our long lifetime high pressure sealing material for high pressure pumping elements and our cryogenic pumping element, built to withstand continuous and long-term use.

Hydraulic drivers for LNG pumping are another example, realizing high levels of safety, compactness, and reliable fuel gas supply to the engine thanks to their variable speed pumping concept. This variable speed regulates the gas pressure and flow requested by the engine under synergetic control using a gas buffer module.

3.3 Onboard fuel LNG tank system

An LNG fuel ship provides LNG fuel for a storage tank facility.

A large-scale LNG carrier has been applied type B (Spherical or Prismatic shape) defined by the International Maritime Organization (IMO), or a GTT licensed membrane system for the cargo containment system; however, in smaller vessels, Type A or C (Pressure vessel).

During transportation at an atmospheric pressure, LNG is in a saturated liquid phase, which has an extremely low temperature, around -160°C, and it still remains far lower than the surrounding environment even at higher pressures (higher saturated temperature).

The abovementioned cargo containment system has various high performance thermo insulation functions; however, they can’t be free from tank pressure increases owing to the small amount of heat penetrating the insulation layers.

To maintain the LNG tank pressure at an allowable level, and avoiding venting the gas out into the environment, it is necessary to install BOG combustion and/or a liquefaction function onboard.

Figures 6 & **7** show an LNG carrier built by MHI Nagasaki and delivered in October 2000 that is equipped with both gas fueling to the boiler for power generation and a liquefaction plant to turn excessive BOG into cargo liquid to compensate for heat penetrating through the insulator.

Figure 6 LNG carrier built by MHI S/S LNG Jamal (OGIT/NYK Line) MHI Hull #: 2157

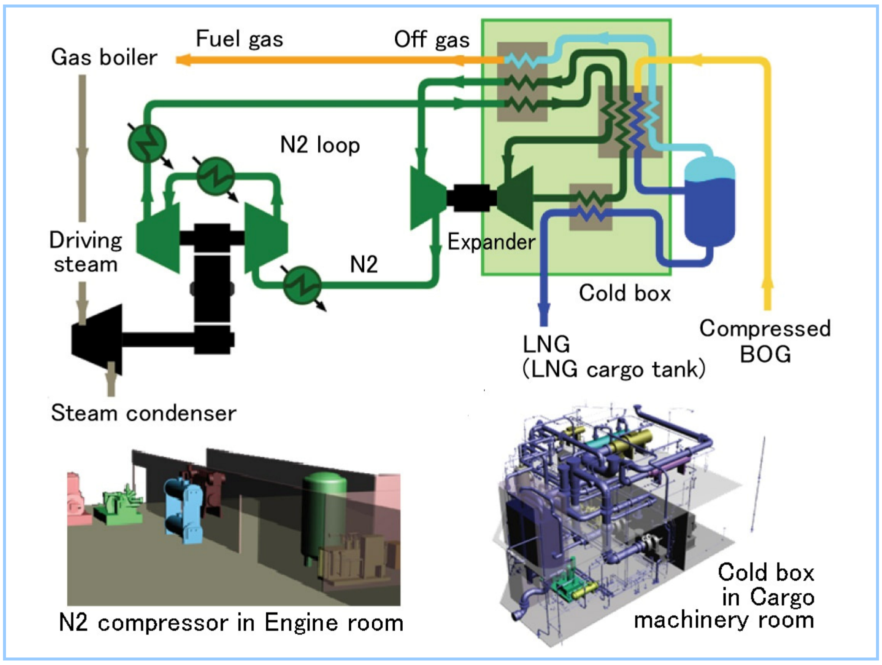

Figure 7 World's first BOG re-liquefaction system

The vessel has a steam turbine plant to fire BOG and marine heavy oil as fuel for propulsive power, onboard power, and liquefaction power.

In the long history of LNGC, this liquefaction plant is a world-first onboard system, developed as a gas liquefaction process with a nitrogen refrigeration cycle, aiming for safety while maximizing LNG transportation by using marine heavy oil in the same way as an LPG carrier.

This vessel has been a breakthrough for "two stroke diesel propulsion" among LNG carriers. Actually, soon after its introduction, in the early 2000s, a large fleet of Qatari ships adopted the diesel propulsion system with a similar liquefaction plant for the same refrigeration concept.

On the other hand, LNG fuel ships, which have smaller capacities for LNG storage, mostly adopt "type C" as their tank system to achieving higher pressure in storage, resulting in greater convenience for the vessel's pressure handling.

But, one must know that LNG has different features to LPG or similar liquid gas in that they are a supercritical fluid at an ambient temperature, which means you can't maintain them in liquid form even under high pressure conditions because they keep evaporating until the liquid disappears.

Therefore, gas combustion and/or liquefaction (refrigeration) are also necessary functions to design into lower tank pressure requirements, and to give another function to the control liquid temperature in the storage tank.

Figure 8 shows our proposal for a system composed of GEMS' products, Gas combustion unit (GCU), Cold box and Nitrogen refrigeration cycle.

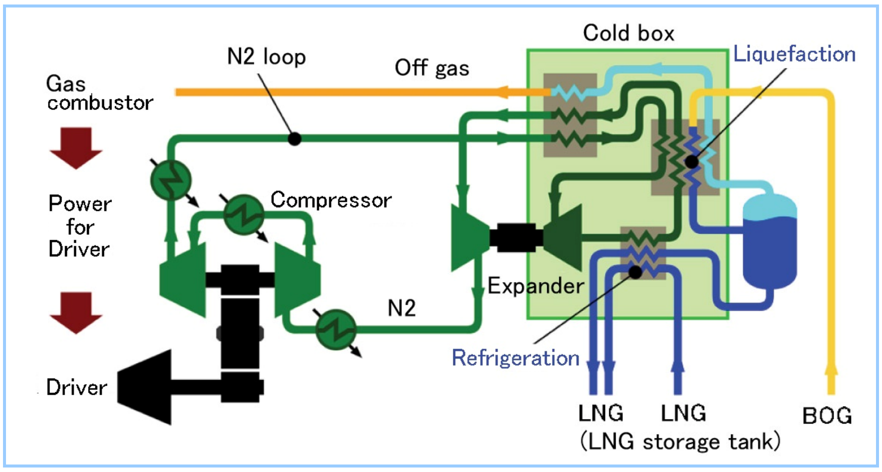

Figure 8 Pressure control system concept for LNG storage tank

This system realizes the ability to handle storage tank pressure by extracting the off gases, firing them, and/or turning them into liquid or cooling down the liquid directly by a nitrogen refrigeration cycle. The refrigeration cycle can be associated with a gas combustion system to drive the cycle by the fuel of the gas itself. They are all effective for the safe, efficient, and quick handling of LNG storage tank pressure.

4. LNG supply chain – Development of LNG regasification unit

In the last decade, some floating storage and regasification units (FSRU) have been built and some have been converted from LNGCs; they are thought to be a solution to expanding LNG receiving terminals in the shortest timeframe and at the lowest cost.

In the same decade, many newly built LNG carriers have been delivered; however, the older vessels were suffering due to the oversupply in the market. FSRU was one of the ways to survive, and this lasted until LNG deals hit record highs after the sudden energy crisis in Japan caused by the Great East Japan Earthquake in 2011.

Recently, many FSRU are planned to be built because there is already an established plan to develop an LNG infrastructure.

Because FSRU are not on the ground but floating in the ocean, regasification facilities should be prepared for both static inclination and rolling motion.

All FSRU ever built have adopted unique LNG vaporizers, which are not adopted for onshore applications in spite of their high cost and complications in operation and construction. The Open Rack Vaporizer type (hereafter ORV) has been adopted as the main vaporizer for onshore application, since it is cost competitive and simple to operate.

In the marine industry, ORVs are considered to be weak in non-static environments, and actually, we have proven this to be correct in our inclination testing; however, the Marine Open Rack Vaporizer (MORV) we've developed is much tougher in a floating environment.

Figure 9 shows the overview of our inclination test facility using LNG to demonstrate performance in non-static conditions.

MORV operate at angles of around 10° while static or non-static; they would be supplied in module form with functions for LNG pumping, heating water circulation, gas regulation, and boil off re-condensation, if required.

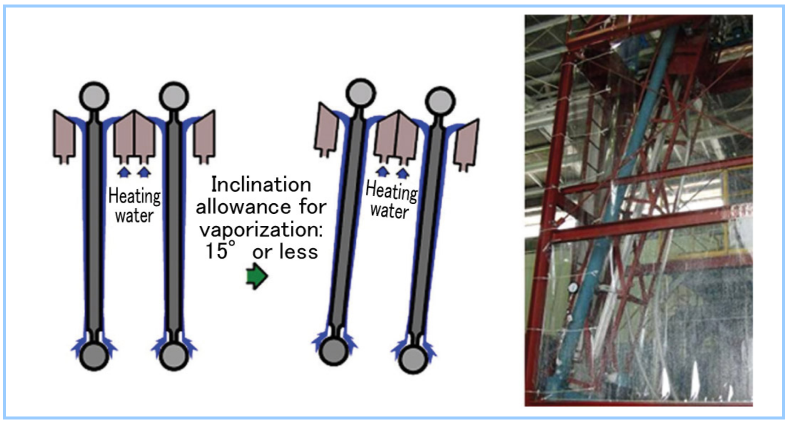

Figure 9 MORV inclining performance test

Figure 2 shows the image of the regasification system of a MORV, onboard an FSRU converted from a spherical-tanked LNGC. In general, the installation space onboard is too narrow to install additional equipment, therefore, the whole system is divided into trains with identical functions to each other, and a train, typically 100 MM SCFD (square standard feet per day) as a maximum unit, has compact modulation components and supplies high pressure gas up to 10MPaG at delivery point.

MORV, in general, use seawater as a heating media; however, a "combined loop" option can be proposed for "closed loop" demand. In this option, a seawater loop of a power plant and a regasification plant are linked and integrated for heat compensation, and one can change over between being closed or open to the ocean according to environmental, economic, or operational conditions.

5. Conclusion

We, the marine engineering business department in MHI, are addressing the concept of LNG as a marine fuel and LNG supply chain expansion to floaters, through engineering and equipment supply businesses.

This paper is focused on the introduction of an engine fuel gas supply system and MORV, which are examples from our GEMS as products of well-established technologies.

A fuel gas supply system for a gas injection engine is already at the commercial stage as an engine shop test facility, and we are ready to deliver the system for onboard equipment.

MORV is not a new or unusual technology but basically identical to the proven, experienced and cost competitive heat exchanger. The only difference is its toughness in non-static environments.

This can make change the common sense of present FSRU, and help to get rid of specialized processes such as propane cascades or other unusual systems.

In closing, mentioning our forthcoming actions, we will move into the business of floating facilities, such as LNG storage and distribution, LNG production from natural gas, LNG fuelled electric power generation, according to how the LNG industry evolves.

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