

# Development of Efficient, Environmentally Friendly and Flexible Shipboard Regasification Vessel



KENJI TSUMURA\*1

MASARU OKA\*1

TOSHIO OGATA\*2

MAKOTO TABIRA\*2

*Mitsubishi Heavy Industries, Ltd., (MHI) has developed an efficient, environmentally friendly and flexible shipboard regasification vessel, responding to the increasing need for liquefied natural gas (LNG) carriers and floating storage units equipped with gasification facilities, drawing from expertise garnered through its experience in designing and building numerous LNG carriers. It features excellent fuel efficiency, low environmental load and flexibility allowing optimal operation under various offshore site conditions. In addition, it ensures overall reliability with the advantages of the characteristics of a spherical tank LNG carrier. The details of this vessel and the technologies involved are outlined below.*

## 1. Introduction

As the increasingly diverse LNG trade prompts expanded needs in regasification terminals, numerous projects premised on employing LNG carriers with regasification facilities (regasification vessels or RVs) or floating storage and regasification units (FSRUs) with LNG tanks and regasification facilities are currently under way and some are already in operation. Several advantages apply to RVs and FSRUs when compared with land-based regasification terminals. These include the relative ease in securing sites and construction permits, short lead times, low cost, low level of risk associated with delayed delivery and cost increases and mobility of facilities. These advantages contribute to popularity in developed countries, including the U.S., where the construction of land-based terminals is difficult due to environmental concerns, as well as in emerging countries that need to set up a plant in a short amount of time to satisfy current short-term demand for gas imports while long-term needs may still be unclear.

MHI has developed a unique shipboard regasification vessel with a seawater LNG regasification system and a main steam turbine plant as its power source based on a spherical-tank LNG carrier, which has proved to be highly reliable over more than 30 years of operation. The controllable-emission regasification vessel (hereinafter called a CERV) that we have developed features excellent fuel efficiency, low environmental load and flexibility allowing optimal operation under offshore site conditions such as in low-temperature areas, as well as in areas where the seawater cannot be used.

## 2. Outline of the Details of the Mitsubishi Shipboard Regasification Vessel

### 2.1 Major particulars

The cargo tank capacity class ranges from 80-km<sup>3</sup> to 200-km<sup>3</sup>, allowing designs that meet various customer needs. The particulars for a 177-km<sup>3</sup> FSRU are introduced here as an example (Table 1).

This CERV is designed based on a conventional 177-km<sup>3</sup> LNG carrier and its main dimensions remain the same through the effective utilization of deck space.

\*1 Manager, Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Headquarters

\*2 Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Headquarters

**Table 1 Specifications for a 177-km<sup>3</sup> FSRU**

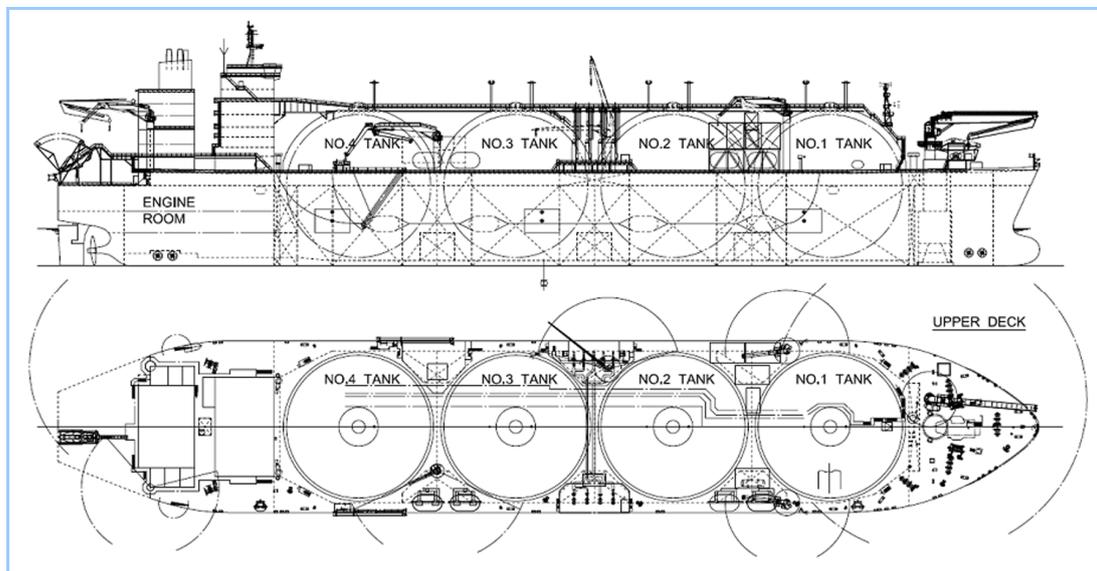
Class of vessel	Det Norske Veritas (DNV)
	+1A1, Tanker for liquefied gas, ship type 2G NAUTICUS (Newbuilding) PLUS, CSA-FLS,
	CLEAN, E0, F-AMC, TMON, BIS, REGAS-2, DYNPOS-AUT
Length overall	300.00m
Breadth	53.00m
Depth	28.50m
Designed draught	11.50m
Cargo tank capacity	177,000m <sup>3</sup> (100% at -163°C)
Regasification capacity	750 mm scf/d Max
Main engine	Steam turbine × 1 set
Boiler	Dual-fuel main boiler × 2 sets
	Gas boiler × 2 sets
Generator	Steam turbine generator × 3 sets
	Gas engine generator × 2 sets
	Auxiliary diesel generator × 1 set
	Emergency generator × 1set

## 2.2 Tank type

In a conventional LNG carrier, the tank is rarely used under slack loading conditions. On the other hand, the tanks of shipboard regasification vessels are slack loaded during gas sendout and the tanks of FSRUs are always slack loaded, since FSRUs do not sail and are continuously gasifying LNG received from shuttle vessels. Therefore, the LNG tanks must be highly reliable under slack loading conditions. By incorporating a spherical-tank system that is resistant to sloshing, our vessel can be operated with any possible combinations of cargo tanks and liquid levels and offers high reliability and operational flexibility.

## 2.3 Layout

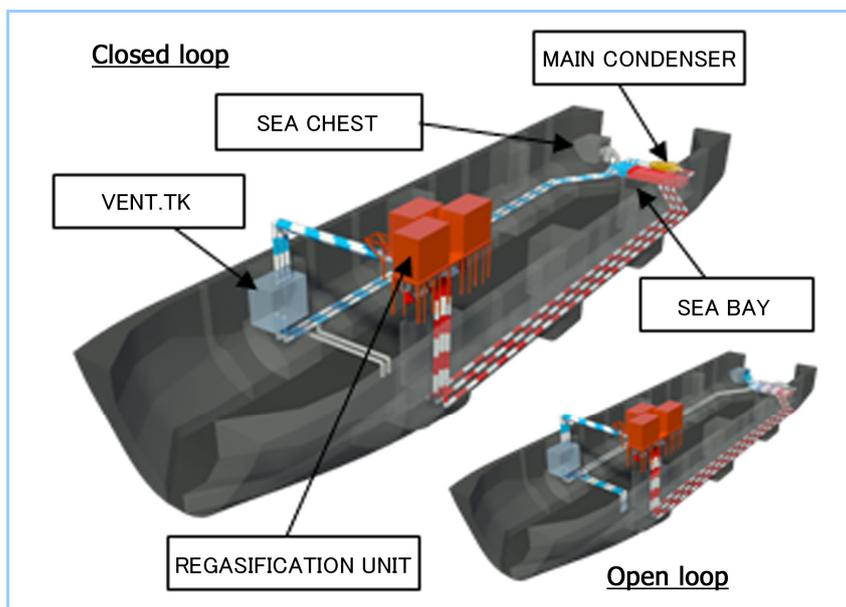
The general layout of the vessel is shown in **Figure 1**. The vessel is characterized by its distinctive layout, which is explained below.



**Figure 1 General layout plan**

### (1) Regasification system

- A cascade heating system, which utilizes seawater as a heat source, is applied for LNG regasification (refer to Article 3 for details). The equipment, including a propane tank for the intermediate cooling media, is installed between tank No. 1 and tank No. 2, making effective use of the deck areas between the tank covers.
- The heating seawater system incorporates MHI's CERV concept. The seawater pump, installed in the engine room, is connected to the regasification system by a dedicated seawater pipe or duct that passes through the ballast tank. The cooled seawater discharged from the regasification system is recirculated or discharged via the vent tank (**Figure 2**).



**Figure 2** Seawater supply system

- (2) Turret
 

A turret is used to moor the vessel and offload the gas. The turret compartment is located in the forward area.
- (3) Tank layout
  - The vent tank is arranged in part of the ballast tank compartment near the regasification system in order to detect gas leakage into the seawater discharged from the system.
  - The slop tank, which is used to temporarily store the seawater that floods into the turret compartment during connecting/disconnecting operations, when contamination by oil may occur, is installed in the forward area.
  - A deck drain tank, sewage holding tank and gray water holding tank are arranged as environmental measures.
- (4) NO<sub>x</sub> removal system (hereinafter called a selective catalytic remover or SCR)
 

The vessel uses a steam turbine plant. The NO<sub>x</sub> concentration in the exhaust gas of the steam turbine plant is much lower than that of a diesel engine (refer to Chart 3 for details). Therefore, the installation of an SCR is rarely required, but if there is a local requirement, it would be mounted on the exhaust lines of the gas engines and boilers.
- (5) Thruster
 

Thrusters, which are used for heading and positioning control during mooring and buoy connection, are installed in the forward and aft sections.
- (6) Ballast water treatment system
 

Ballast water treatment systems, expected to be required by the International Maritime Organization (IMO), are installed.
- (7) Offshore crane
 

Offshore cranes are installed for the safe handling of spare parts, food and crews.

## 2.4 LNG reception

The vessel receives LNG from shuttle vessels that come alongside and it is furnished with the following equipment:

- A loading arm is installed on the starboard side between tank No. 2 and tank No. 3. A normal manifold is arranged on the port side, so that the vessel can receive LNG at conventional LNG loading terminals.
- A quick-release hook system is arranged for easy emergency departure. Primary and secondary fender systems are provided to prevent hull damage caused by contact with shuttle vessels.
- In order to ensure safe mooring and cargo handling, as well as high operability, thrusters are used to achieve optimal heading and positioning control according to waves, wind and tidal currents.

### 3. Outline of the CERV Concept

#### 3.1 Plant configuration

A cascade heating system that uses seawater as a heat source is employed for LNG regasification.

The system applies two-stage heating processes at the low-temperature side and the high-temperature side. LNG, pressurized by the booster pump to a level exceeding the required sendout pressure (10MPa, for example), is sent to the heat exchanger on the low-temperature side, which uses propane as an intermediate heating medium and gasified. The gas temperature is increased to the required temperature by the heat exchanger on the high-temperature side, which uses seawater for direct heating. The gas is then offloaded via the turret. Meanwhile, the seawater used for heating is first sent to the heat exchanger on the high-temperature side, the outlet of which is connected to the heat exchanger on the low-temperature side. The seawater discharged from the heat exchanger on the low-temperature side has a lower temperature than that of the supplied seawater. The system comes in two patterns, “open loop” and “closed loop,” depending on the handling of the cooled discharge water and the operational pattern can be selected in the system to meet the specific requirements of the site. (Figure 3).

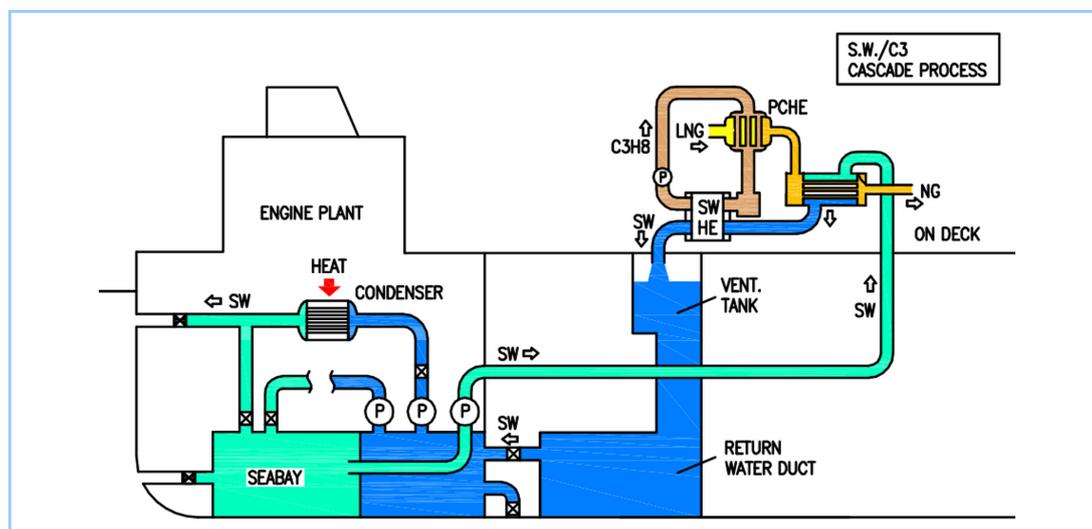


Figure 3 Seawater loop for regasification

#### 3.2 Characteristics

In the open-loop system, the seawater used as a heating medium is supplied from outside the vessel and cooled seawater is discharged from the vessel. The heat required for gasification is obtained from the surrounding environment, with no heat from fuel. This is the most economical method, but in some coastal regions, the pumping of seawater is regarded as an environmental burden and is prohibited.

In the closed-loop system, seawater is recirculated in the vessel and is not pumped from the sea outside the vessel. The closed-loop system is good for underwater environments, but is inferior in terms of fuel economy, since it requires a large amount of fuel for heating.

The vessel can be switched between “open loop” and “closed loop” systems and can be operated under the optimal conditions specific to the site. The advantage of the CERV concept, which allows the selection of operational mode in accordance with site-specific requirements and eliminates the necessity of preparing RVs and FSRUs tailored to each specific site, is its versatility.

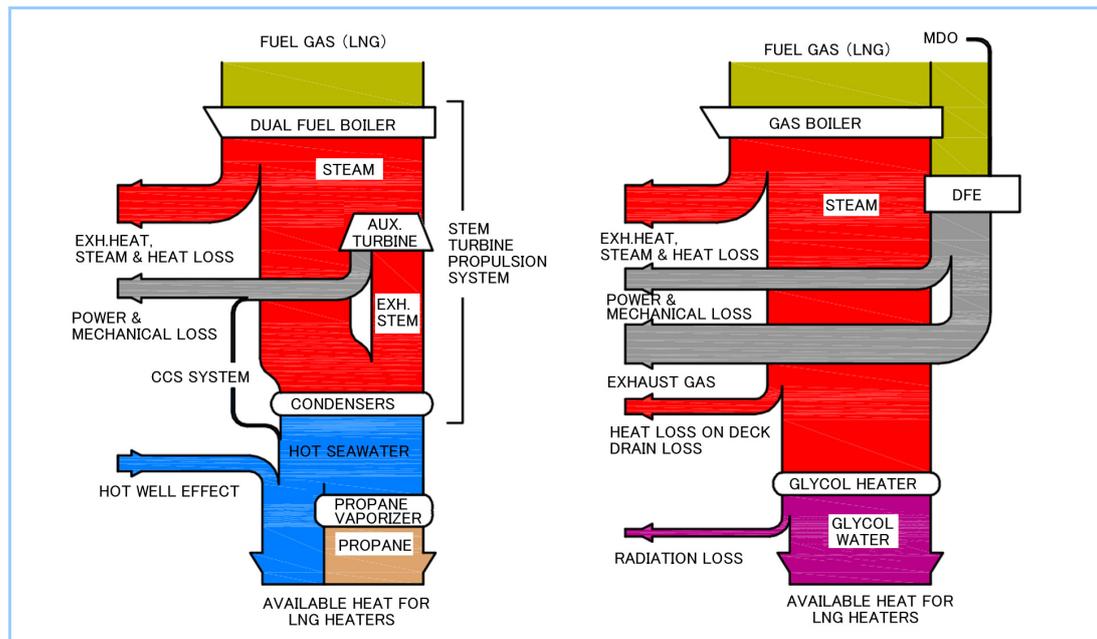
#### 3.3 Fuel economy and environmental load

Onboard regasification vessels are normally fueled with part of the LNG they carry as cargo or boil-off gas and it is better to avoid the use of fuel oils (such as heavy oil) as much as possible, which is preferable in terms of both cost and environmental burden.

In the open-loop system, LNG is consumed to generate a total of 10 to 20 MW of electric power, which is necessary for the pumping of LNG and sea water and positioning control by thrusters. A larger amount of LNG is consumed in the closed-loop system, which requires additional fuel for heating.

The highly reliable main steam turbine plant, which is the only system that can be operated on gas only and has been used for many years as the propulsion system for LNG carriers, is used on the CERV as a power plant to supply the required electric power and as a power source for heating. The heat exhausted from the steam turbine generator is dumped into the seawater and becomes the heat source for regasification via seawater.

Many modern LNG vessels incorporate efficient diesel engine propulsion systems (in the form of low-speed diesel engines directly connected to the propeller shafts or as a generator for electric propulsion). However, they cannot be fueled with gas only and require fuel oil (such as diesel oil or heavy oil) as pilot fuel, with a certain ratio to the total amount of fuel. Moreover, most of the heat exhausted from internal combustion engines is released into the atmosphere and the exhaust heat is not readily utilized as a heat source for regasification, although they do offer high generating efficiency (**Figure 4**).



**Figure 4** Heat flow

In **Table 2**, the CERV is compared with other vessels incorporating open-loop and closed-loop systems, in terms of fuel economy and related performance issues. The table shows that the CERV is superior to the others with regards to fuel economy and environmental performance.

**Table 2** Comparison by plant

	CERV		Closed-loop system vessel	Open-loop system vessel
LNG regasification system	Cascade seawater heating system		Hot glycol solution heating system	Cascade seawater heating system
Propulsion machinery (main engine for shuttle operation)	2×3 MW class thruster (27 MW class steam turbine)		2×3 MW class thruster (27 MW class electric propulsion motor)	2×3 MW class thruster (27 MW class steam turbine)
Generator *1	2×3 MW class ST 2×5 MW class GE		3×11 MW class DFE 1×6 MW class DFE	2×3 MW class ST 2×5 MW class ST
Boiler	2×60 T/H class main boiler		2×100 T/H class gas boiler	2×60 T/H class main boiler
Regasification loop	Closed loop	Open loop	Closed loop	Open loop
LNG fuel consumption	100 (Ref.)	25	130	42
Pilot fuel oil	Not necessary (gas only)		Marine diesel oil	Not necessary (gas only)
Emission to air	SOx	None		None
	NOx *3	1	1.5	3 (Reference)
	Methane slip	None	Up to 2% of the total amount of fuel	2 to 3% of the total amount of fuel

\*1 Symbols: ST – steam turbine generator, DFE – dual fuel engine generator, GE – gas engine generator, MDO – marine diesel oil

\*2 SOx amount is given by the S component of oil × 2 kg-SOx/kg-S

\*3 When NOx removal systems such as an SCR are not installed

## **4. Outline of the Boil off management**

### **4.1 Pressure accumulation**

The internal pressure of the cargo tanks of LNG carriers increases due to LNG gasification caused by external heat intrusion, which necessitate the treatment of the gas to control internal pressure. The gas generated from the tanks is called boil-off gas (BOG). The design vapor pressure (pressure setting of the tank safety valve) is normally 25kPaG and the vapor pressure is maintained within the range of approximately 5 – 15 kPaG during operation. BOG is generated to maintain the pressure. BOG is normally utilized as boiler fuel for propulsion and the electrical power supply of the vessel. However, gas is produced by forced vaporization of LNG when the amount of gas is less than the demand, while gas is disposed of by combustion when the amount of gas exceeds the demand. In shipboard regasification vessels, the required amount of gas varies in response to the regasification load, selected operation mode (open or closed loop) and thruster load.

In our vessel, the amount of BOG generated inside the tank is controlled by increasing the normal operating pressure to intentionally increase the boiling point of the LNG inside the tank and absorbing the external heat as the LNG temperature rises. It is possible to balance the amounts of generated gas and consumed gas by utilizing this phenomenon and BOG can be efficiently and safely utilized even when gas consumption is reduced. Meanwhile, when gas consumption increases, the amount of BOG can be increased by lowering the tank pressure, reducing fuel loss due to forced vaporization. To achieve this operation, the design vapor pressure of the tank must be set at a value higher than 25kPaG in order to maintain the operating pressure at a high level. This method is especially effective for spherical-tank types, since there is no limit on the design vapor pressure and the pressure can be set at a high value (the pressure specified by the IGC code is a maximum of 70kPaG for membrane and prismatic-tank types).

### **4.2 Measures against stratification by LNG of different grades**

When LNG of differing densities are stored in a single tank, rich LNG sometimes moves toward the bottom and lean LNG moves toward the top, resulting in stratification. The lean LNG in the upper area is heated by external heat and generates BOG for thermal balance, thus becoming higher in density. Meanwhile, the temperature of the rich LNG at the bottom increases with the passage of time, since it is not cooled by natural boil-off. Thus it becomes lighter in density and the density difference between the LNG in the upper area and the bottom area decreases. A sudden mixing (rollover) occurs when the density difference becomes too small to form layers, generating a huge amount of BOG in a short period of time and possibly leading to a sudden increase in the internal pressure of the tank. Various measures are taken in onshore tanks to avoid the risk of a sudden pressure increase.

In the case of conventional LNG vessels, the risk of stratification is low because they tend to be used in specific projects over long periods and LNG from different sources are not stored in the same tank. On the other hand, in the case of shipboard regasification vessels – especially FSRUs moored to buoys and continuously carrying out regasification – the receiving of LNG from different sources is considered the same as onshore LNG tanks. FSRUs periodically receive LNG from shuttle vessels, but they sometimes receive LNG when an amount of LNG is already stored in the tanks as a reserve considering operational limitations due to delayed arrivals of shuttle vessels or bad weather. This could result in stratification due to the loading of different grades of LNG.

In our vessel, newly loaded LNG and that remaining in the tanks are naturally mixed due to the differences in density as a countermeasure against stratification. In order to homogenize the LNG inside the tank, LNG is loaded from the bottom of the tank when it is lighter than the remaining LNG and it is loaded from the top of the tank when it is heavier.

## **5. Conclusion**

To develop the Mitsubishi CERV, an efficient, environmentally friendly and flexible shipboard regasification vessel, MHI concentrated the technologies accumulated via designing and building many LNG vessels. The safety of this new system has been evaluated and confirmed by risk assessments through cooperation with external companies and organizations, including operator and classification society. We hope this new vessel will contribute to the diversification of the LNG value chain and the promotion of the global use of LNG, an inexpensive and environmentally friendly fuel.