LNG Vaporizer for LNG Re-gasification Terminal

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Kobe Steel leads the world in LNG vaporizers. We design and fabricate "open rack type vaporizers (ORVs)" and "intermediate fluid type LNG vaporizers (IFVs)" for large LNG receiving terminals. This paper introduces the trends in the present LNG receiving terminals, the features of LNG vaporizers and topics having to do with the company's development of vaporizers.

Introduction

Natural gas is a clean fuel and the demand for it is increasing worldwide. In consuming countries such as Japan, far from gas producing regions, natural gas is received as liquefied natural gas (LNG) in a cryogenic state (approximately -160℃), warmed up to normal temperature to be regasified, and is used as fuel for power generation and city gas.

As a leading manufacturer of LNG vaporizers, Kobe Steel has been actively developing its business in Japan and overseas. The recent trend is for the number of projects to increase in countries where the company has no delivery record and in areas where the environment and heat sources are different from the traditional ones.

LNG receiving terminals are classified into two categories: i.e., primary receiving terminals for receiving LNG imported in large LNG vessels, and secondary receiving terminals (satellite terminals) for receiving and regasifying LNG transported by trucks or the like from a primary receiving terminal. This paper outlines the latest trends in primary receiving terminals (hereinafter simply referred to as "receiving terminals") with a special focus on the LNG vaporizers used in these terminals.

1. Trends in LNG receiving terminals

1.1 Diversification of regions

In the past, LNG was imported by a limited number of advanced countries, including Japan, South Korea, Taiwan, and western European countries, such as France and Spain. Since the turn of the century, however, the countries receiving LNG have diversified as the demand has increased. The following describes the recent circumstances of LNG receiving regions.

- In the countries with high economic growth, such as in India and Brazil, the number of projects for LNG receiving terminals is increasing. A large number of projects are underway or planned, particularly in China.
- In regions such as the Middle East and Central and South America, or in countries that hitherto have not imported LNG, the number of projects for LNG receiving terminals is increasing.
- New construction projects for LNG receiving terminals are underway or planned in countries, such as Indonesia and Malaysia, that used to be exporters of LNG.
- With the shale gas revolution, US terminals that used to receive LNG are being converted into liquefaction and exporting terminals.

1.2 Diversification in the types of LNG receiving terminals

Conventionally, LNG receiving terminals have been built along coasts and used seawater−or fuel in cold districts during cold seasons−as their heat sources for vaporizing and warming LNG to normal temperature gas. Recently, new types of LNG receiving terminals have emerged, and the number of projects they are involved in is gradually increasing. These new types include the following:

①Floating storage regasification units (hereinafter FSRUs), and

②LNG vaporizer systems with air heat sources

1.2.1 Floating storage regasification units (FSRU)

FSRUs are LNG receiving terminals consisting of vessels that have been modified to accommodate equipment such as vaporizers; they are moored offshore. The following describes the features of FSRUs:

- The use of existing LNG vessels eliminates the need for civil engineering work and the construction of LNG tanks, which would be required for land terminals, enabling the shortening of the period of construction.
- FSRUs are mobile and can be used in other locations.
- In the event of a mishap, damage to the general public and neighbors can be avoided, thus making protest campaigns against the construction unlikely.

Fig. 1 Image of FSRU in operation [1)]

- Measures must be taken against the pitching and rolling of the hull.

FSRUs have already been put into service in Brazil, for example. **Fig. 1**[1)] shows an image of the outside of an FSRU. The vessel on the left is an LNG carrier, and the one on the right is an FSRU. The equipment on the top shelf of the FSRU's bow structure includes an intermediate fluid type vaporizer (hereinafter, an IFV).

1.2.2 LNG vaporizer systems with air heat-source

Seawater is generally used as a heat source for vaporizing and warming LNG in primary receiving terminals, except for those built in cold areas. Using seawater requires significant investment in facilities for the intake and discharge of water. In addition, environmental regulations must be followed for the cold seawater discharged after the heat exchange with LNG.

To avoid these issues, a non-seawater vaporizer system was devised in which LNG is vaporized by the sensible heat of aqueous glycol solution. The cooled glycol solution is warmed by the heat of air blown by a fan and is reused for vaporizing LNG. This system is currently operating at the DAHEJ terminal in India, while others are being constructed or planned at other terminals in this country.

This vaporizer system is basically designed to be operated at an atmospheric temperature of 15℃ or higher and is applicable only to areas where the ambient temperature is high enough.

2. Structure and features of LNG vaporizers for primary receiving terminals

2.1 Outline

Currently, over thirty LNG receiving terminals are operating in Japan, and there are many others overseas. This section describes the structures and features of the vaporizers generally used in these terminals: namely, open rack vaporizers (ORVs), intermediate fluid type vaporizers (IFVs) and submerged combustion vaporizers (SCVs).

2.2 Open rack vaporizers (ORV)

2.2.1 Overall structure of ORVs and the vaporizing process

Fig. 2 schematically outlines an ORV. An ORV is a vaporizer in which LNG, flowing inside a heat-transfer tube, exchanges heat with seawater that flows outside the heat-transfer tube to gasify the LNG. The LNG flows in from an inlet nozzle near the bottom and passes through an inlet manifold and a header pipe to be sent to a set of panels, each consisting of a curtain-like array of heat-transfer tubes. As LNG flows upward inside the heat-transfer tubes, it exchanges heat with seawater that flows downward in a film-like manner outside the heat-transfer tubes. This produces normal temperature gas to be sent out from an outlet nozzle via an outlet header and manifold pipe.

Each panel generally consists of close to a hundred heat-transfer tubes. Several of these panels (3 to 8) are unified into a block by a manifold pipe and are hung from a ceiling frame placed over a concrete structure at the installation site. A slide-type support is provided under the block so as to absorb thermal expansion/contraction. The surfaces of these panels, each consisting of aluminum alloy, are spray-coated with aluminum-zinc alloy that serves as a sacrificial anode to protect the base material from being corroded by seawater.

The heat-transfer tubes for ORVs are made of aluminum alloy having excellent low-temperature characteristics, such as low-temperature toughness, as well as excellent thermal conductivity and workability, and are provided with fins to increase

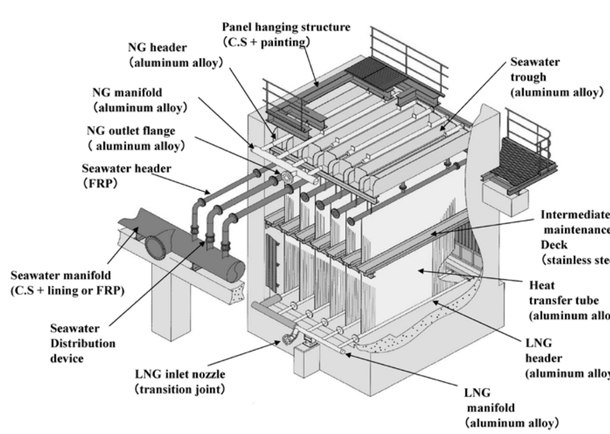

Fig. 2 Schematic of Open Rack Vaporizer (ORV)

the heat transfer area. Inside each heat-transfer tube, there is a cruciate profile of aluminum alloy, spirally twisted and fixed through the entire length. This structure promotes turbulent flow, which improves the heat transfer performance while preventing LNG mist from spilling to the outlet.

2.2.2 Heat transfer tube with dual structure: SUPERORV ® note)

When an ORV is in operation, the outer wall temperature at the lower part of each heat-transfer tube sinks lower than the freezing point of seawater, causing icing to build-up on the tubes. Especially, when the seawater temperature is low, icing thickness and height increases significantly, which causes a significant heat-transfer resistance. As a measure, Kobe Steel has developed a new heat-transfer tube (SUPERORV) that has a duplex-pipe structure at its lower part to suppress icing on the outer surface of the heat-transfer tube. This has significantly improved the vaporizing performance. SUPERORVs are now in actual use in heat exchangers. **Fig. 3** shows the structure of the SUPERORV heat-transfer tube.

2.2.3 ORV features

ORVs have the following features and are most generally used for primary receiving terminals.

① The use of seawater as a heat source achieves low running costs (in most cases incurring only the cost of powering the pumps).

② The system is simple and has excellent operability, allowing visual observations from the outside of the heat-transfer tubes during its operation, which ensures very high reliability.

③ Increasing or decreasing the number of panels or blocks easily allows a design appropriate for the vaporizing capacity, enabling the designing of vaporizers with large capacities, exceeding 300 tonnes/h, for example.

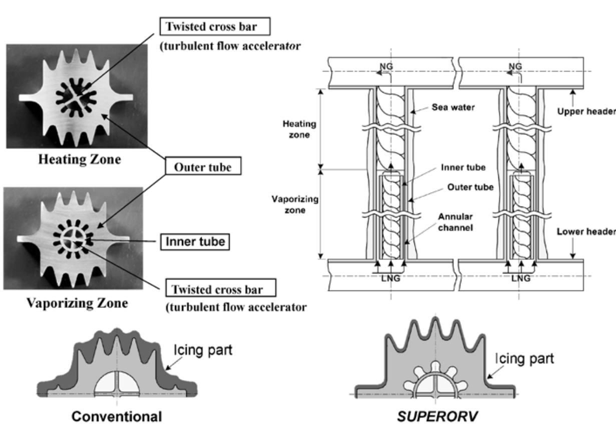

Fig. 3 Configuration of SUPERORV heat transfer tube

note) SUPERORV is a registered trademark of Kobe Steel.

2.3 Fluid type vaporizers (IFV)

2.3.1 Structure of IFV and its vaporizing process

An IFV is a vaporizer in which a heat source, such as seawater, is used to vaporize LNG via a heating medium such as propane. It was originally developed by OSAKA GAS Co., Ltd. in the 1970s under the name of TRI-EX. An IFV has a structure combining three types of shell-and-tube heat exchangers, i.e., an intermediate fluid vaporizer (E1), LNG vaporizer (E2) and NG trim heater (E3).

Fig. 4 schematically shows an IFV. LNG is first introduced into the heat-transfer tube of the E2. Next, the LNG exchanges heat with intermediate fluid gas above the E1 shell and is almost entirely vaporized and then transferred to the shell side of the E3 via an interconnecting line. Here, the LNG exchanges heat with seawater that flows inside of heat-transfer tube and is warmed up to be delivered as gas at a normal temperature. On the other hand, as a result of the heat exchange with LNG, the intermediate fluid is condensed on the outer surface of the heat-transfer tube of the E2, drops down into the E1 shell and exchanges heat with the seawater flowing inside yet other heat-transfer tubes, and is vaporized again as the intermediate fluid gas for vaporizing the LNG flowing inside the E2 tube. Propane is used as the intermediate fluid in most cases.

Those tubes in which seawater flows (i.e., the heat-transfer tubes of E1 and E3) are made of titanium alloy to ensure very high corrosion resistance against seawater.

2.3.2 Features of IFVs

The following describes the features of IFVs:

① As in the case of ORVs, the use of seawater as the major heat source achieves a low running

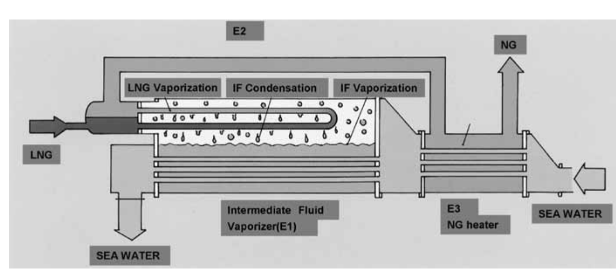

Fig. 4 Schematic of Intermediate Fluid type Vaporizer (IFV)

cost.

②Heat is exchanged between LNG and a heat source fluid via an intermediate medium, which avoids the freezing of the heat source fluid and its consequences such as the blockage of flow passages.

③The use of titanium alloy for the material of heat-transfer tubes avoids problems, including erosion and corrosion, even when low quality seawater is used as the heat source.

④The intermediate fluid and the chilled heat-source fluid after the heat exchange can be utilized as cold heat-sources.

Above feature ③ is embodied, for example, in the IFV that Kobe Steel delivered to the Shanghai LNG terminal in China, at which location the seawater contains 10,000 ppm of suspended solids (125 times the value of 80ppm recommended for ORVs). Since startup in 2009, the operation has been steadily continuing. Similarly, an IFV was adopted by the Ningbo LNG terminal in China and has been running since November 2012 at a location where the seawater contains a large amount of suspended solids.

2.4 Submerged combustion vaporizers (SCV)

2.4.1 Outline structure of the SCV and its vaporizing process

An SCV has a structure in which an underwater burner, burning fuel-gas, generates heat to vaporize LNG. It comprises a tank, an underwater burner, a bundle of heat-transfer tubes, combustion-air fan and fuel-supply control device (**Fig. 5**).

Both the bundle of heat-transfer tubes, which are a heat exchanging portion, and the underwater burner, a heat source, are submerged in the water inside the bath. This water is heated by the underwater burner. Because high-temperature combustion gas is exhausted into the water, the latent heat of steam contained in the combustion gas is effectively utilized. Inside the bath, the exhausted gas also forms a two-layer flow of mixed bubbles containing micro-bubbles, acting on the heat-transfer tube bundle to promote a more efficient heat exchange. The underwater burner and combustion-gas distribution mechanism, as well as an exhaust stack, are all provided inside the bath.

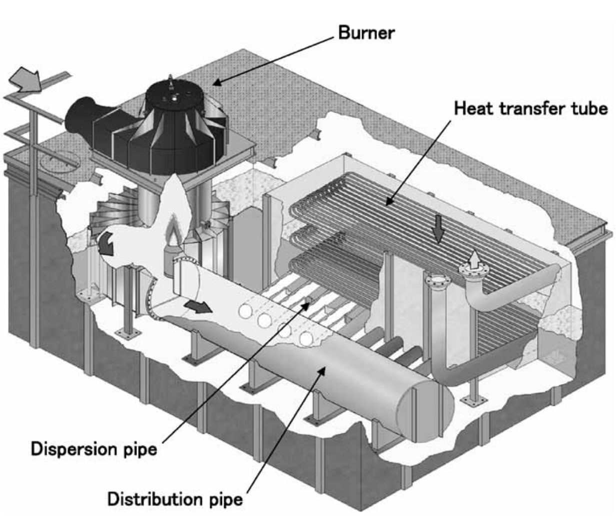

Fig. 5 Schematic of Submerged Combustion Vaporizer (SCV)

2.4.2 Features of SCV

The following describes the features of SCV:

①The use of combustion gas as a heat source allows the vaporizer to be smaller than other types of vaporizers of the same capacity.

②Even when the fuel gas is suddenly stopped, the supply of vaporizer gas continues, although for a limited time, thanks to the heat capacity of the heated water in the bath.

③Unlike ORVs and IFVs, an SCV does not require any facility for water intake and discharge, which reduces the construction cost.

④The running cost is very high because approximately 1.5% of the vaporized LNG is consumed as fuel.

⑤Regulations on the combustion exhaust gas must be complied with.

3. Initiative for diversification in the types of LNG receiving terminals

As described in section 1.2, the types of LNG receiving terminals have been diversified in recent years. This section describes Kobe Steel's initiative for diversifying terminal types.

3.1 Initiative for FSRU

3.1.1 Kobe Steel's history of LNG vaporizers for FSRU

As described in 1. 2. 1, the hulls of FSRUs pitch and roll, which must be taken into consideration for LNG vaporizers. In 1999, Kobe Steel studied an LNG vaporizer for a receiving terminal on board a vessel, in response to a request from the then Mobil Corporation (currently ExxonMobil Corporation). The study revealed that an IFV is the best fit, as long as a measure is taken against the sloshing (a waving phenomenon caused by moving liquid surface) of the intermediate medium propane. On the basis of this result, Kobe Steel applied for a patent on an

IFV comprising a measure against sloshing, and the patent was granted.

Although this project planned by Mobil Corporation was not realized in the end, Kobe Steel later received an order for three IFVs, each having a vaporizing capacity of 150tonnes/h, from SAIPEM S.P.A. in Italy. The purchase order was placed for LNG vaporizers used in an FSRU to be operated offshore of Livorno, Toscana, Italy by Offshore LNG Toscana (OLT). Notwithstanding the delay of the OLT FSRU project due to the client's circumstances after the delivery of the IFVs, they are slated to be put into service in the summer of 2013 after trial operations.

This project is subject to Italian ship classification (RINA), which involves a certification process and onsite inspections by RINA including manufacturer certification and process certification of the materials used for each pressure containment part of the IFVs, welding factory certification and welding method/welder certification, all of which have been implemented. A strength evaluation analysis was required, mainly for saddles and equipment joints, using the data of hull pitching and rolling that assumes a one-hundred-year storm. Also required was a sloshing analysis of the intermediate medium propane, and a certification procedure in writing, including assessments of various risk factors.

Fig. 6 shows the OLT FSRU under construction.

3.1.2 Future issues for LNG vaporizers used in FSRUs

Since an FSRU is built by modifying an LNG vessel, installation space is limited. Thus its LNG vaporizer must have a small footprint and low weight. Recently, circumstances have called for not only the supply of vaporizers alone, but also the package supplying of LNG vaporizer equipment, including peripheral piping, electrical apparatus, instrumentation and pumps.

In response to such requirements, Kobe Steel is moving forward with the downsizing of IFV with improved performance and the modularization of LNG vaporizer equipment.

Fig. 6 Outside view of OLT FSRU (under construction)

3.2 Initiative for LNG vaporizer systems with air heat-sources

3.2.1 Development of IFV with air heat-source (Air-IFV)

As described in 1. 2. 2, an LNG vaporizer for a primary receiving terminal has been put into service at the DAHEJ terminal in India. The vaporizer uses air instead of seawater for its heat source. This system uses aqueous glycol solution, which is once cooled by exchanging heat with LNG and warmed up by air blown by fans to be reused for heat exchange with LNG. More than a hundred air blowers are required for the total 600tonnes/h of LNG vaporizing capacity.

On the basis of existing IFV technology, Kobe Steel has devised a new IFV with air heat-source (hereinafter "Air-IFV"), which employs air instead of seawater for its heat source and propane as its intermediate fluid to exchange heat with LNG. The newly developed system is more advantageous in the following points, compared with the aforementioned system that uses aqueous glycol solution as the intermediate medium.

①The new system exploits the latent heat of the vaporization and condensation of propane, and requires a smaller circulating volume than that required by conventional systems utilizing the sensible heat of a liquid such as aqueous glycol solution. This enables the reduction of the electric power cost of running circulating pumps.

②When propane is warmed up, a high boiling heat-transfer coefficient is obtained on the vaporizing side of propane, which reduces the amount of air compared with that required when aqueous glycol solution is used for warming. As a result, the number of fans and their power cost are reduced.

Fig. 7 depicts a schematic process flow of an

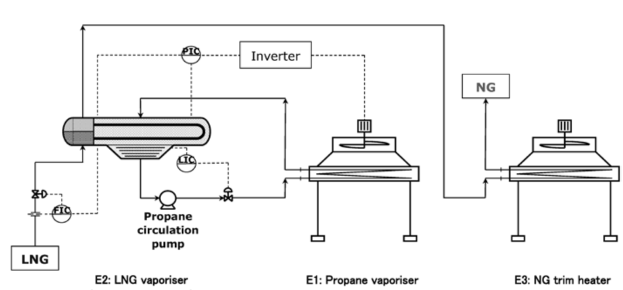

Fig. 7 Schematic process of Air-IFV

Air-IFV. The volume of air is inverter controlled, in response to the circulation volume of propane and atmospheric temperature, such that the pressure of propane in the LNG vaporizer (E2; propane condenser) is kept constant, which serves to reduce the power cost.

3.2.2 Future development of Air-IFVs

Currently, studies are being conducted with the aim of putting Air-IFVs into service. Priority is being given to the verification of the evaporation characteristics of propane when an air heat-source is used, in order to establish the technique for designing a propane evaporator usable at a practical level. We will strive to design the details, including the control method, to provide LNG vaporizing equipment for launching in the market.

Conclusions

This paper outlines the latest trends of LNG primary receiving terminals, the features of LNG vaporizers for these primary receiving terminals and Kobe Steel's efforts to develop LNG vaporizers.

Kobe Steel, as the world's leading manufacturer of LNG vaporizers, will continue brushing up its own technologies for ORVs and IFVs and will strive to develop and propose LNG vaporizer systems optimized for diversifying the types of LNG receiving terminals.

References

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