Utilization of Cold Energy in Intermediate Fluid-type Vaporizer (IFV) for LNG Receiving Terminals

Tomohiro SUZUKI[*1] · Shinji EGASHIRA[*1] · Yuji SUMIDA[*2]

[*1] Static Equipment Department, Industrial Machinery Division, Machinery Business
[*2] Industrial Machinery Plant, Industrial Machinery Division, Machinery Business

Abstract

Intermediate fluid-type vaporizers (IFVs), a type of LNG vaporizers, have been used as vaporizers that enable the utilization of the cold energy of LNG in, for example, cryogenic power generation. Recently, there is an increasing number of cold energy utilization projects using chilled water from an IFV for, e.g., the intake air cooling of gas turbines. This paper introduces the latest trends in LNG receiving terminals including offshore receiving terminals, the features of IFVs as LNG vaporizers for cold energy utilization, and examples of cold energy utilization using IFV including gas-turbine-intake air cooling.

Introduction

The demand for natural gas, a clean fuel, is increasing globally. Since many natural gas consumption areas, including Japan, are located far from gas producing areas, natural gas is once transported as liquefied natural gas (hereinafter referred to as LNG) in the cryogenic state (approximately -160 ℃). In consumption areas, LNG is reheated to the ambient temperature and gasified to be used as power generation fuel and city gas.

As a leading manufacturer, Kobe Steel has delivered many LNG vaporizers in Japan and other countries. In recent years, there are increasing inquiries from regions other than the ones for which the company has delivery records, as well as inquiries for projects aiming at the effective utilization of LNG cold energy.

LNG is transported by sea from gas producing areas on large LNG carriers and is unloaded from LNG receiving terminals in each consumption area. The LNG receiving terminals are classified into primary receiving terminals and secondary receiving terminals (satellite terminals). Primary receiving terminals are the first facilities to receive the marine-transported LNG. Secondary receiving terminals are facilities that regasify the LNG land-transported by lorries and the like.

This paper outlines the latest trends of primary receiving terminals and the effective utilization of LNG cold energy using intermediate fluid-type vaporizers (hereinafter referred to as "IFVs") adopted in these primary receiving terminals.

1. Trends of primary LNG-receiving terminals

1.1 Diversification of areas

LNG was formerly received by onshore LNG receiving terminals in Japan, South Korea, Taiwan, former Western European countries, and China. LNG recipient countries, however, have diversified with increasing demand, as a result of the recent shale gas revolution in the United States and global efforts toward CO_2 reduction to prevent global warming, which has increased gas thermal power generation. In recent years the LNG receiving areas have the following characteristics.

- An increase in the construction of LNG receiving terminals in countries that had not previously received LNG, including the Middle East and Latin America areas.
- An increase in construction plans for LNG receiving terminals in Southeast Asian countries such as the Philippines and Myanmar, which used to produce and consume natural gas domestically.

1.2 Diversification in form of LNG receiving terminals

Conventionally, LNG receiving terminals were constructed onshore in coastal areas, and seawater was mainly used as a heat source for vaporizing LNG and raising it to the ambient temperature. In addition, the heat of combustion has been used in cold areas and seasons when the seawater temperature is low. Meanwhile, in countries other than traditional LNG importing countries such as Japan, South Korea, and Taiwan, offshore receiving terminals have started to be built in place of the conventional onshore receiving terminals for the purpose of the prompt introduction of LNG receiving terminals and reduction of construction cost. In addition, the number of offshore terminals is gradually increasing in countries that have newly started receiving LNG.

These offshore LNG receiving terminals take the following two forms.

(1) A Floating Storage Re-gasification Unit (hereinafter referred to as "FSRU")
(2) A Floating Storage Unit + Re-gasification Unit (hereinafter referred to as "FSU +Re-gas")

Many LNG receiving terminals in the above forms have been introduced in developing countries, and as of 2019, twenty-seven FSRU terminals are already in operation. This indicates that FSRUs account for approximately 10% of the gas vaporization capacity, including that of the onshore LNG receiving terminals. As for FSU + Re-gas, three terminals are in operation, and one terminal is to begin operation shortly.[1)]

1.2.1 FSRU

An FSRU is a form of terminal in which an LNG carrier equipped with vaporization equipment is moored offshore and is used as an LNG receiving terminal. One terminal that has adopted IFV as its LNG vaporizer, there is an FSRU that is run by OLT (Offshore LNG Toscana) off the coast of Livorno, Tuscany, Italy. **Fig. 1** shows the appearance of the FSRU and the appearance of three IFV units mounted as LNG vaporizers. FSRUs have the following three features.

- In addition to the fact that, unlike onshore terminals, no civil engineering work is necessary, there is no need for the onshore construction of an LNG tank, since a carrier equipped with an LNG tank is built at the shipyard. This makes it possible to shorten the construction period and to reduce the construction cost.
- Since the terminal itself is a ship, it can be moved by ship and used in other places in the future.
- An offshore terminal restricts the utilization of LNG cold energy to shipboard. There is, however, no utilization application on board so far, and no LNG cold energy has been utilized effectively.

The main LNG vaporization processes in current FSRUs occurs in shell-and-tube type vaporizers. This type of vaporizer uses ethylene glycol water warmed by the heat of seawater to exchange heat with LNG, and many terminals employ this type of LNG vaporizer.

1.2.2 FSU + Re-gas

An FSU + Re-gas is a form of terminal in which the regasification equipment in FSRU is built onshore or on a fixed platform to be used as an LNG receiving terminal. One terminal in the form of FSU + Re-gas whose IFV is adapted as an LNG vaporizer is a gas turbine combined cycle (hereinafter referred to as "GTCC") run by ElectroGas Malta (EGM) in the Republic of Malta. The appearance of the FSU + Re-gas and GTCC is shown in **Fig. 2**. The features of an

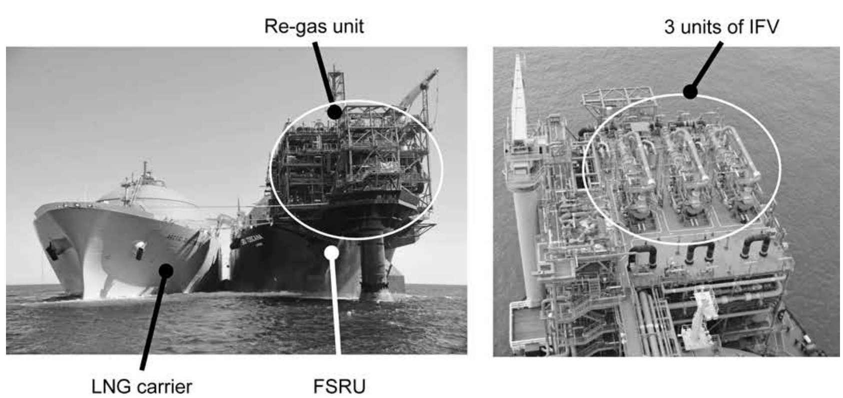


Fig. 1 FSRU and LNG carrier (left), and IFVs on FSRU (right) by OLT of Italy (photo courtesy of Offshore LNG Toscana)

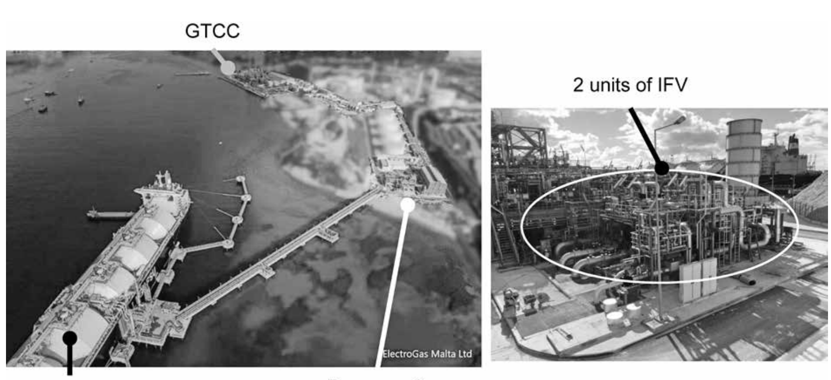


Fig. 2 FSU and power plant (left), and IFVs on re-gas unit (right) by EGM of Malta (photo courtesy of ElectroGas Malta Ltd.)

FSU + Re-gas terminal are as follows.

- Similar to FSRUs, the construction of LNG tanks, which account for most of the construction period/time and cost of onshore terminals, is no longer required, which can shorten construction periods.
- The regasification equipment is built onshore instead of onboard, allowing the use of a secondhand LNG carrier, which is a normal practice for FSUs. This expands the choices for shipping companies placing orders, in comparison with FSRU.
- Unlike FSRUs, many of which are based on fixed-term lease contracts, regasification equipment can be owned by a group or by a local government as infrastructure.
- The onshore construction of regasification equipment facilitates the effective utilization of LNG cold energy, as in the case of onshore primary receiving terminals.

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

2.1 Overview of LNG vaporizers

LNG vaporizers commonly used in onshore LNG receiving terminals include open rack vaporizers (hereinafter referred to as ORVs), IFVs, and submerged combustion vaporizers (hereinafter referred to as SCVs). ORVs and IFVs are LNG vaporizers using seawater as their heat source. An SCV is a backup vaporizer that is used only when and where the seawater temperature is too low to be used as the heat source. It is configured to vaporize LNG by the heat of the combustion of fuel with an underwater burner and requires consideration of environmental regulations and the like for the combustion exhaust gas.[2)]

Among these LNG vaporizers, IFVs have many introduction records for LNG cold energy utilization.

2.2 IFV

2.2.1 Overview of IFV configuration and vaporization process

An IFV is a vaporizer that utilizes heat sources such as seawater to vaporize LNG through a heating fluid such as propane. It was developed by Osaka Gas Co., Ltd. in the 1970s under the name of TRI-EX and consists of three components; namely, intermediate fluid evaporator (hereinafter referred to as E-1), an LNG vaporizer (hereinafter referred to as E-2), and an NG heater (hereinafter referred to as E-3).

Fig. 3 shows the schematic diagram of an IFV. The LNG supplied into the heat-transfer tube of E-2 undergoes heat exchange with the intermediate fluid gas in the upper part of the E-1 shell. Almost all the LNG is vaporized and then transferred to the E-3 shell side through a connecting piping. At E-3, the natural gas is heated by heat-exchange with seawater flowing in the heat transfer tube and is sent out as gas at the ambient temperature. On the other hand, the intermediate fluid, condensed by heat-exchange with LNG on the outer surface of the heat transfer tube, E-2, drops to the bottom in the E-1 shell to exchange heat with the seawater flowing in the heat transfer tube and then is vaporized as intermediate fluid gas to vaporize LNG in the E-2 tube again.

Propane is mainly used for the intermediate fluid. As an option for customers who have concerns about using propane, a flammable gas, as the intermediate fluid in limited spaces, as is the case

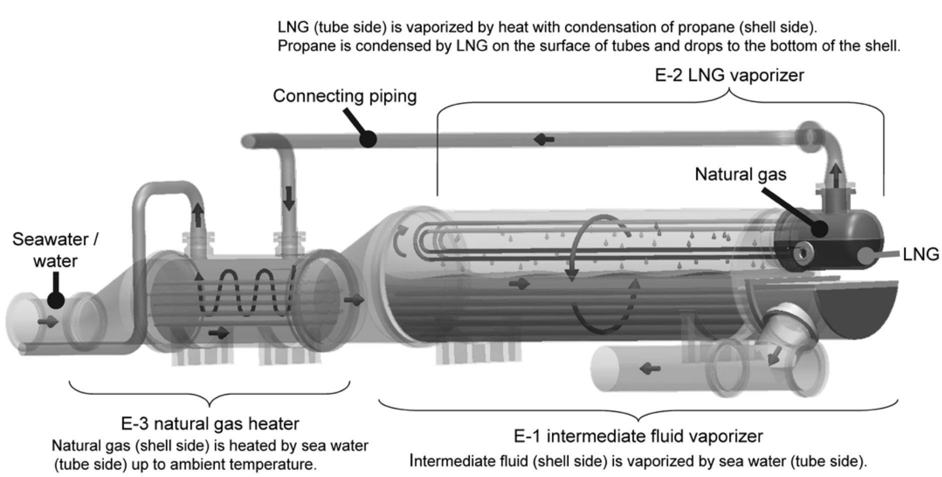


Fig. 3 Schematic diagram of intermediate fluid vaporizer (IFV)

in an FSRU, it is suggested to use a non-flammable heat medium as an alternative.[3)]

Titanium alloy is used for the heat transfer tubes (transfer tubes E-1 and E-3 heat) through which seawater flows to assure extremely high seawater corrosion resistance.

2.2.2 Characteristics of IFV

The characteristics of an IFV as an LNG vaporizer are as follows:

(1) The running cost is low since the heat source is mainly seawater.
(2) The heat exchange is performed between LNG and heat source fluid via an intermediate fluid with a low freezing point, which avoids problems such as channel blockage due to freezing of the heat source fluid.
(3) The use of titanium alloy as the material of the heat transfer tube prevents the occurrence of erosion and corrosion even if seawater of poor quality is used as the heat source.
(4) The intermediate fluid and cooled heat-source fluid after heat exchange can be applied to cold energy utilization.

One embodiment of the application to cold energy utilization in (4) above is the LNG cryogenic power generation system that utilizes propane as the intermediate fluid. This was developed for the purpose of saving energy in an LNG receiving terminal and has been actively introduced mainly in the LNG receiving terminals of gas companies at various locations in Japan since the 1970s. The appearance and process outline of the cryogenic power generation plant are shown in **Fig. 4** and **Fig. 5**, respectively. These cryogenic power generation plants are still in operation, including the one operated by Osaka Gas Co., Ltd.

A decision was made in the late 2010s to introduce cryogenic power generation systems using Kobe Steel's IFVs in an update project for a terminal in Japan and an LNG terminal in Shanghai, China.

3. Utilization of LNG cold energy by IFVs

As described in Section 2.2, an increasing number of projects are considering IFVs as LNG vaporizers to utilize the cold energy of LNG. This section describes LNG cold energy utilization using IFVs that are already running at LNG receiving terminals.

3.1 Overview of LNG cold energy utilization

LNG is a cryogenic fluid of approximately -160 ℃, and its cold energy has been disposed

Fig. 4 Appearance of LNG cryogenic power generation plant in Osaka Gas Co., Ltd.

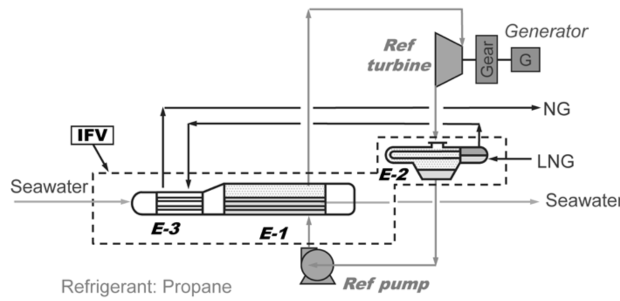


Fig. 5 Schematic diagram of process flow for LNG cryogenic power generation system (Rankine cycle)

of in seawater after heat exchange without being effectively utilized. Hence, the owners of LNG receiving terminals have been working on the effective utilization of LNG cold energy from the economic aspect of terminal operation and from the aspect of CO_2 reduction.

The following applications are considered for the cold energy utilization of LNG in LNG receiving terminals:

(1) LNG cold energy power generation systems.
(2) Utilization in dry-ice production, freezer warehouses, etc.
(3) Cooling systems for gas turbine intake air.
(4) The supply of cold energy to cooling equipment used in plant factories and data centers.

Applications (1) and (2) above have long been adapted to LNG receiving terminals, mainly by gas companies in Japan. The following sections outline (3) and (4), which are increasingly being introduced in the LNG receiving terminals in subtropical areas such as Southeast Asia.

3.2 Utilization of LNG cold energy for cooling gas-turbine intake air

In an IFV, a heat source fluid such as seawater flows through its pipes. Therefore, it is possible to reciprocally circulate the heat source with one heat-source circulation pump between an LNG vaporizer and the destination of cold energy utilization. In an ORV, on the other hand, seawater flows down on the outer surface of a heat transfer tube from the upper part of the heat exchanger body, open to the ambient air, to perform heat exchange. For this reason, two heat-source circulation pumps are required for the supply to the ORV and for delivery to the destination of cold energy utilization. In addition, since the ambient air is encountered during the flow-down on the heat transfer tubes, it is necessary to control foreign matter and water quality. In this sense, an IFV is regarded as more effective for the cold energy utilization of the heat source circulation type.

3.2.1 Intake air cooling of gas turbines

A gas turbine mixes compressed intake air with fuel in its combustor and burns the mixture to utilize the pressure of the combustion gas for rotating the generator to generate electricity. The temperature of the air taken in by a compressor is specified to be 15 ℃ by the ISO standard, and the rated output is also designed at the atmospheric temperature of 15 ℃.

In hot and humid subtropical areas, there are many places where the temperature becomes higher than 15 ℃ throughout the year. In those areas, the mass of air sent to the combustor of a gas turbine decreases due to the decrease in air density. As a result, the power generated by the gas turbine becomes lower and the power generation decreases. If air at 35 ℃ is cooled down to 15 ℃, for example, the air density increases by 10%, and the power generation increases by 10%. For these reasons, there is a significant economic benefit in working on the cooling of gas turbine intake air in hot and humid subtropical areas.

There are several types of intake air cooling. Among them, the most efficient type directly cools the intake air with chilled water. In other words, it is a type in which chilled water is supplied to the intake air cooling coil incorporated in the intake air filter chamber, such that direct heat exchange is performed with the intake air to lower the intake air temperature to 15 ℃ or below. **Fig. 6** shows a schematic diagram of the process flow of intake air cooling in a gas turbine using an IFV. One of the embodiments of gas-turbine intake-air cooling is found in GTCCs in Southeast Asia, to give one example. At these power plants, chilled water is supplied from a turbo chiller using electric power to perform the intake air cooling of gas turbines to improve power generation efficiency.[4)]

In the LNG receiving terminals that have recently been constructed in Southeast Asia, and other such areas, there are an increasing number of projects called "Gas-to-Power," in which an LNG receiving terminal and GTCC are constructed together. These projects are suitable for the intake air cooling of gas turbines utilizing LNG cold energy for the following reasons:

- They are mostly in high temperature areas where the temperature exceeds 15 ℃ throughout the year.
- The distance between the LNG receiving terminal and GTCC is short, facilitating the transfer of the heating fluid.
- Because the business entity of the LNG receiving terminal and the business entity of the gas thermal power plant are often the same, it is easy to make investment decisions because there is no conflict between the operational aspect and the interests of economic benefit.

3.2.2 Advantages of IFV in intake air cooling system

Two types of LNG vaporizers have been installed

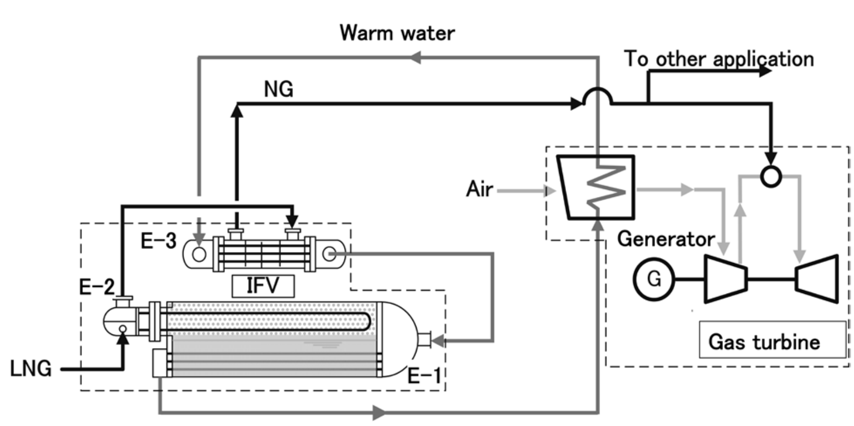


Fig. 6 Schematic diagram of process flow for cooling intake air of gas turbine using IFV

in gas turbine intake air cooling systems utilizing LNG cold energy, namely, shell-and-tube LNG vaporizers (hereinafter referred to as "STVs") using ethylene glycol as the circulating heat source,[5] and IFVs using industrial water as the circulating heat source.[2] STVs have been introduced to several systems in Caribbean countries, and IFVs have been introduced to systems in the Republic of Malta and the Kingdom of Thailand, in addition to Japan. The advantages of the system using IFV are as follows:

- The temperature of the heat source required for the intake of an air-cooling system is approximately 5 ℃, which is within the temperature range where even the industrial water used by an IFV as its circulating heat source does not freeze. This keeps the systems running.
- In an STV, direct heat exchange occurs between LNG and the circulating heat source. Therefore, industrial water at 5 ℃ is likely to freeze, making the STV's adoption difficult. An IFV, on the other hand, uses intermediate fluid for the LNG vaporization process and can be operated without concern about freezing even if industrial water of 5 ℃ is used as the circulating heat source.
- The circulating heat source of an IFV can be industrial water, which is less expensive to prepare than glycol water. The circulating heat source is often utilized simultaneously by applications other than the gas turbine intake air cooling. In these applications, if a storage tank for temperature adjustment is required, the difference in filling cost between water and glycol water will be even greater.
- Glycol water, which is corrosive to the pipes, requires water quality management, but industrial water basically requires no water quality management.

Thanks to the advantages of IFVs as described above, there are an increasing number of LNG vaporizer projects adapting IFVs that use industrial water as their circulating heat source.

From the viewpoint of energy saving, the following effects can be expected for intake air cooling using IFVs:

- If an IFV has an LNG flow rate capacity of 100 tonnes/hour, it has a cooling capacity of approximately 20,000 kW, and the consumption energy (or the power of water circulation pump) required to supply cold energy to the IFV is approximately 700 kW. On the other hand, a turbo refrigeration system with the same cooling capacity consumes approximately 4,200 kW (refrigerator power, cooling tower fan power and water circulation pump power) of energy and, thus, a greater economic effect is achieved by LNG cold energy utilization using an IFV.

The total power generation at the terminal in the Republic of Malta, shown in Fig. 2, is 150 MW. The output recovery effect of the gas turbine in summer is 6%, and an effect of 9 MW has been confirmed to be obtained by cold energy utilization of an LNG. In this terminal, cooling water sent to the compressor for boil-off gas is supplied from an IFV in addition to the gas turbine intake air cooling.[6]

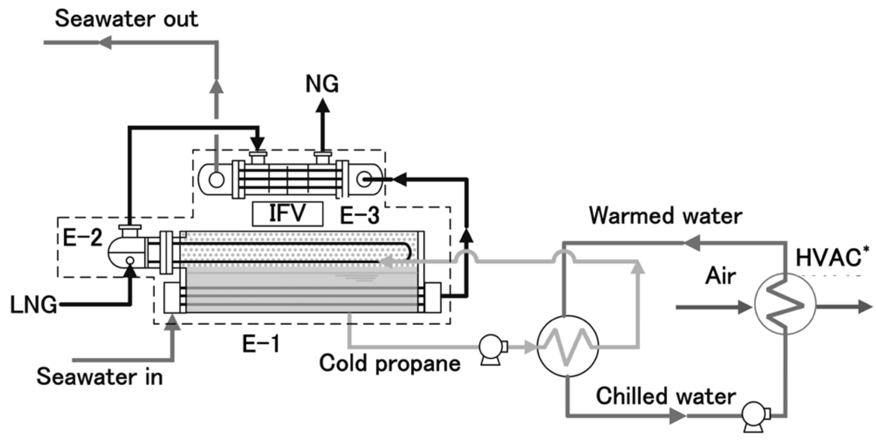
In the case of a gas-to-power terminal, the amount of LNG for generating the chilled water required for the intake air cooling of the gas turbine is approximately 3 times the amount of gas (natural gas vaporized from LNG) sent from the LNG vaporizer (assuming an inlet air temperature of 35 ℃ and an outlet temperature of approximately 15 ℃). This means that there are cases where the output recovery by intake air cooling may not be sufficient when the entire amount of gas vaporized by the LNG vaporizer is consumed by the gas turbine. As a result, the gas may often be sent, not only to the gas turbine, but also to the gas conduit and other parts.

When the above utilization environment is in place and the cold energy of LNG is utilized for the intake air cooling of the gas turbine, the maximum amount of energy that can be obtained from 1 tonne of LNG is 180 kWh. This offers a significant advantage in utilization efficiency over the 23 kWh/tonne for the cryogenic power generation system (propane Rankine cycle type) described in Section 2.2.

3.3 Other types of LNG cold energy utilization using IFVs

Other than gas turbine intake air cooling systems, IFVs have been utilized for chilled water supply to large cooling systems such as those for plant-cultivation factories. The methods used for supplying chilled water from IFVs include the following:

(1) Cases where chilled water is directly supplied as a circulating heat source to the utilizer as in the case of gas turbine intake air cooling.
An LNG receiving terminal in the Kingdom of Thailand utilizes the chilled water directly supplied from IFV to the cooling of a cultivation factory for plants such as tulips, together with the intake air cooling of the gas turbine installed in the LNG receiving terminal.



*Heating, Ventilation, and Air Conditioning

Fig. 7 Process flow of IFV for supplying cold energy to air conditioning apparatus

Fig. 8 Appearance of IFV for supplying cold energy to air conditioning apparatus in Kagoshima Terminal of NIPPON GAS Co., Ltd.

(2) Cases where propane (liquid) cooled by cold energy of LNG in E-1 of an IFV is extracted by a circulation pump, and the propane liquid is heat-exchanged with circulating water to be indirectly supplied to the destination where the cold energy is utilized.

In this case, the normal operation is to circulate propane while utilizing seawater as a vaporization heat source. Therefore, this has the advantage that gas can be sent to the conduit without being affected by the operational situation of the destination of cold energy utilization.

The system overview and IFV appearance for such a case are shown in **Fig. 7** and **Fig. 8**, respectively. In the terminal shown in Fig. 8, an IFV sends intermediate fluid in a liquid state at 3 ℃ to a heat exchanger to turn the circulating water into cooling water of 8 ℃. This cooling water is circulated between the fan coil unit (FCU) in a fully artificial light-type plant factory and utilized for cooling air conditioning. The temperature in the plant factory is kept at 18 to 25 ℃.[7] A fully artificial light-type plant factory has high operational costs, for utilities, as an example; however, the utilization of LNG cold energy is reported to reduce the cost by approximately 40%.

Conclusions

This paper has outlined the latest trends of primary LNG-receiving terminals, the characteristics of IFVs, and LNG cold energy utilization using IFVs.

Kobe Steel has been developing and proposing LNG vaporizer systems optimal for developing LNG vaporizers in accordance with diversification in the forms of LNG receiving terminals and for improving the efficiency of cold energy utilization in the LNG receiving terminals. We will continue to develop this technology and maintain our position as the world's top manufacturer of LNG vaporizers.

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