US 20200393196A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2020/0393196 A1

(43) Pub. Date: Dec. 17, 2020

CHO et al.

(54) DEVICE AND METHOD FOR PROCESSING BOIL-OFF GAS IN LIQUEFIED GAS REGASIFICATION SYSTEM

(71) Applicant: DAEWOO SHIPBUILDING & MARINE ENGINEERING CO., LTD., Geoje-si, Gyeongsangnam-do (KR)

(72) Inventors: Du Hyeon CHO, Seoul (KR); Su Kyung AN, Gwangmyeong-Si (KR); Young Hyun KIM, Geoje-Si (KR)

(21) Appl. No.: 16/957,015

(22) PCT Filed: Dec. 28, 2018

(86) PCT No.: PCT/KR2018/016899

§ 371 (c)(1),
(2) Date: Jun. 22, 2020

(30) Foreign Application Priority Data

Dec. 29, 2017 (KR) 10-2017-0183742

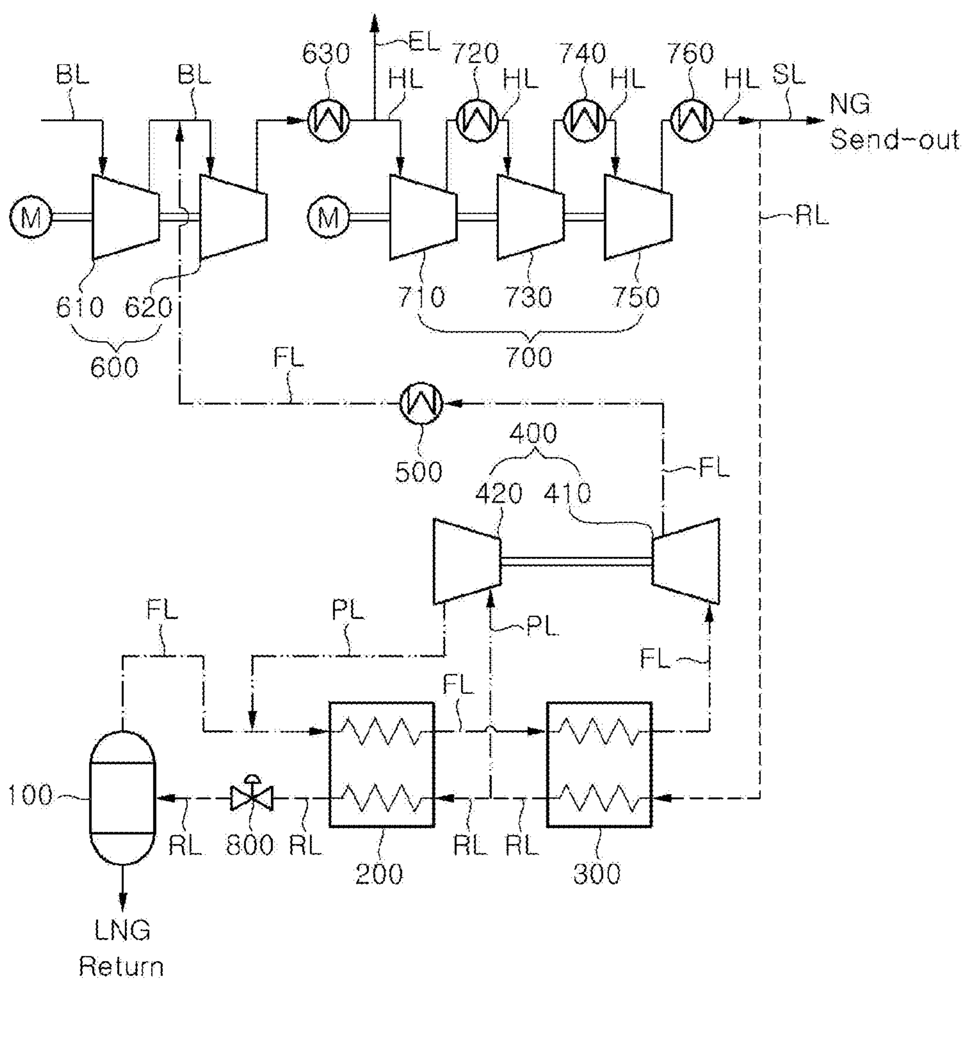
Publication Classification

(51) Int. Cl.
F25J 1/00 (2006.01)
F25J 1/02 (2006.01)

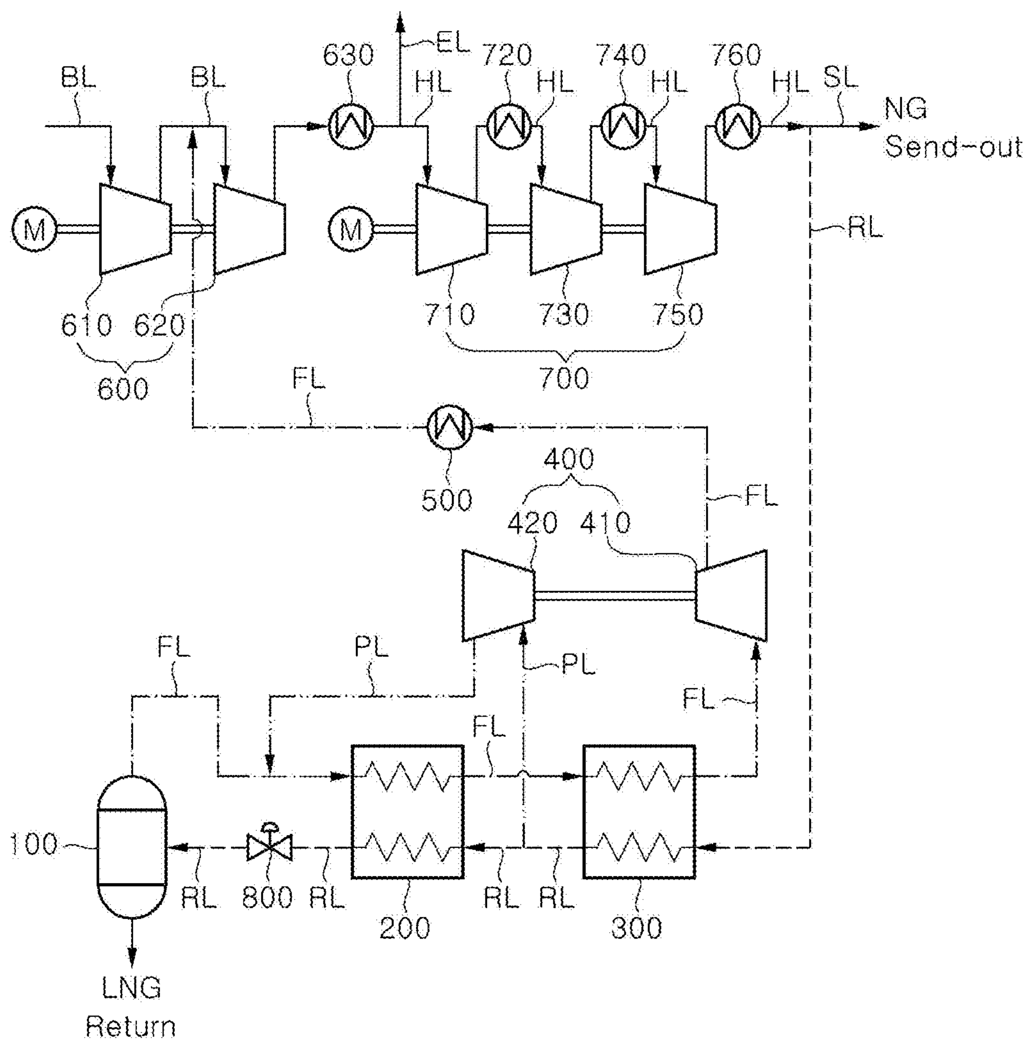
(52) U.S. Cl.
CPC *F25J 1/0025* (2013.01); *F25J 1/0202* (2013.01); *F25J 1/0045* (2013.01)

(57) ABSTRACT

A device for processing boil-off gas in a liquefied gas regasification system includes a fuel compressor for compressing boil-off gas at a pressured required by a fuel consumer; a high-pressure compressor installed at the rear end of the fuel compressor in series with the fuel compressor so as to compress the low-pressure boil-off gas, which has been compressed by the fuel compressor, at a pressure required by a regasified gas consumer; a low-temperature heat exchanger for cooling the high-pressure boil-off gas compressed by the high-pressure compressor; a pressure-reducing device for reducing the pressure of the high-pressure boil-off gas, which has been cooled by the low-temperature heat exchanger, to the inner pressure of a liquefied gas storage tank for storing the liquefied gas; and a liquefied gas drum for separating flash gas generated by the pressure-reducing device in the pressure-reducing process.



【FIG. 1】


BL
BL
630
EL
720
740
760
HL
HL
HL
HL
SL
NG
Send-out
M
M
RL
610
620
710
730
750
600
700
FL
400
500
FL
420
410
FL
PL
PL
FL
FL
100
RL
800
RL
200
RL
RL
300
LNG
Return

DEVICE AND METHOD FOR PROCESSING BOIL-OFF GAS IN LIQUEFIED GAS REGASIFICATION SYSTEM

TECHNICAL FIELD

[0001] The present invention relates to a device and method for processing boil-off gas in a liquefied gas regasification system, and, more particularly, to a device and method for processing boil-off gas in a liquefied gas regasification system, which can allow reliquefaction and recovery of boil-off gas even when there is little or no regasified gas to be delivered in the liquefied gas regasification system.

BACKGROUND ART

[0002] Generally, natural gas is transported in a liquid state to a distant destination by an LNG carrier after being transformed into liquefied natural gas (LNG) through liquefaction at extremely low temperatures at a production site. LNG is obtained by cooling natural gas to a cryogenic temperature of about −163° C. and has a volume of about 1/600 that of natural gas in a gaseous state. Thus, LNG is suited to long distance transport by sea.

[0003] LNG transported by an LNG carrier may be regasified on the land or at sea before being supplied to onshore gas consumers. Examples of ships adapted to regasify LNG received from an LNG carrier at sea and supply the regasified LNG to gas consumers include LNG regasification ships and floating offshore structures (hereinafter collectively referred to as "LNG regasification ship"), such as an LNG regasification vessel (LNG RV), which is an LNG carrier provided with an LNG regasification system, and a floating storage and regasification unit (FSRU).

[0004] In general, a regasification facility provided to an LNG regasification ship includes: a high-pressure pump compressing low-pressure LNG stored in an LNG storage tank to a pressure required for a gas consumer; and a vaporizer (high-pressure vaporizer) vaporizing the compressed LNG by heating to a temperature required for a gas pipe network (regas network) using a heating medium, such as seawater. Regasified gas obtained through the high-pressure pump and the vaporizer is delivered to the gas consumer via the gas pipe network.

DISCLOSURE

Technical Problem

[0005] An LNG storage tank provided to an LNG regasification ship stores LNG in a liquid state at an extremely low temperature of about −163° C. Accordingly, it is preferable that the LNG storage tank be insulated such that LNG can be maintained in a liquid state. However, even when the LNG storage tank is insulated, LNG can naturally vaporize due to intrusion of external heat and the like. When boil-off gas (BOG) continues to be generated due to natural vaporization of LNG, the pressure of the LNG storage tank rises.

[0006] If the pressure of the LNG storage tank rises excessively, there is a risk of explosion and like. Accordingly, if the pressure of the LNG storage tank exceeds a preset value, a safety valve is opened to discharge boil-off gas from the LNG storage tank.

[0007] In the LNG regasification ship, the boil-off gas discharged from the LNG storage tank is recondensed using cold heat of LNG and is then supplied to a high-pressure pump and a vaporizer along with LNG to be regasified before being supplied to a gas consumer.

[0008] Here, since the boil-off gas is recondensed using cold heat of LNG to be regasified, the amount of boil-off gas which can be recondensed is proportional to the amount of LNG to be regasified. That is, the boil-off gas can be treated by recondensation only when the amount of LNG to be regasified is sufficient to allow recondensation of the boil-off gas discharged from the LNG storage tank.

[0009] In the LNG regasification ship, uncondensed boil-off gas not receiving sufficient cold heat from LNG due to reduction in amount of LNG to be regasified or boil-off gas generated during interruption of regasification of LNG can be returned to the LNG storage tank. In addition, boil-off gas in excess of the capacity of the LNG storage tank to receive boil-off gas, determined by the allowable pressure level of the LNG tank, can be supplied as a fuel to an engine.

[0010] However, boil-off gas in excess of both the capacity of the LNG storage tank and fuel requirements of the engine needs to be sent to a gas combustion unit (GCU) to be combusted or needs to be vented to the air.

[0011] However, since boil-off gas mainly contains methane that has the highest boiling point among components constituting LNG, burning or venting the boil-off gas is a great economic loss.

[0012] Embodiments of the present invention have been conceived to solve such a problem in the art and it is an aspect of the present invention to provide a device and method for processing boil-off gas in a liquefied gas regasification system, which allows reliquefaction and recovery of boil-off gas without waste even when the amount of LNG to be regasified is not sufficient to allow recondensation of boil-off gas.

Technical Solution

[0013] In accordance with one aspect of the present invention, there is provided a device for processing boil-off gas in a liquefied gas regasification system, the device including: a fuel compressor compressing boil-off gas to a pressure required for a fuel demand site; a high-pressure compressor disposed in series with the fuel compressor downstream of the fuel compressor and compressing the low-pressure boil-off gas compressed by the fuel compressor to a pressure required for a regasified gas demand site; a low-temperature heat exchanger cooling the high-pressure boil-off gas compressed by the high-pressure compressor; a decompression unit decompressing the high-pressure boil-off gas cooled by the low-temperature heat exchanger to an internal pressure of a liquefied gas storage tank; and a liquefied gas drum separating flash gas generated during decompression by the decompression unit, wherein reliquefied boil-off gas separated by the liquefied gas drum is returned to the liquefied gas storage tank.

[0014] The device may further include: an expander expanding and cooling some of the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger, wherein the low-temperature heat exchanger may cool the high-pressure boil-off gas through heat exchange with the boil-off gas expanded and cooled by the expander.

[0015] The device may further include: a high-temperature heat exchanger precooling the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger to an inlet temperature of the expander, wherein some of the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger from the high-temperature heat exchanger may be sent to the expander.

[0016] The high-temperature heat exchanger may cool the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger and the expander through heat exchange with the expanded boil-off gas heated through heat exchange in the low-temperature heat exchanger and discharged from the low-temperature heat exchanger.

[0017] The device may further include: a gas compressor compressing the expanded boil-off gas subjected to heat exchange in the low-temperature heat exchanger and discharged from the low-temperature heat exchanger to a pressure of a flow of the boil-off gas compressed by the fuel compressor, wherein the boil-off gas compressed by the gas compressor may be joined with the flow of the boil-off gas compressed by the fuel compressor.

[0018] The gas compressor may be connected to the expander via a common shaft.

[0019] The device may further include: a gas cooler regulating a temperature of the boil-off gas compressed and heated by the gas compressor.

[0020] The flash gas separated by the liquefied gas drum may be joined with a flow of the expanded boil-off gas to be supplied to the low-temperature heat exchanger.

[0021] In accordance with another aspect of the present invention, there is provided a method for processing boil-off gas in a liquefied gas regasification system, the method including: compressing boil-off gas to a low pressure required for a fuel demand site; compressing the low-pressure boil-off gas to a high pressure required for a regasified gas demand site; cooling the high-pressure boil-off gas; decompressing the cooled high-pressure boil-off gas to an internal pressure of a liquefied gas storage tank; and separating flash gas generated during decompression of the cooled high-pressure boil-off gas and returning reliquefied boil-off gas to the liquefied gas storage tank.

[0022] Cooling the high-pressure boil-off gas may include: expanding and cooling some of the high-pressure boil-off gas before cooling the high-pressure boil-off gas; and liquefying at least part of the high-pressure boil-off gas through heat exchange between the expanded and cooled boil-off gas and the high-pressure boil-off gas.

[0023] The method may further include: precooling the high-pressure boil-off gas through heat exchange with the expanded boil-off gas heated while cooling the high-pressure boil-off gas, before performing heat exchange between the expanded and cooled boil-off gas and the high-pressure boil-off gas.

[0024] Precooling the high-pressure boil-off gas may include: cooling the high-pressure boil-off gas to an inlet temperature of an expander expanding the high-pressure boil-off gas.

[0025] The expanded boil-off gas heated while cooling the high-pressure boil-off gas may be compressed to a pressure of a flow of boil-off gas to be compressed by a fuel compressor before being joined with the flow of the boil-off gas.

[0026] Expansion work in expanding the high-pressure boil-off gas may be recovered as compression work in compressing the expanded boil-off gas.

[0027] The separated flash gas may be joined with a flow of the expanded boil-off gas exchanging heat with the high-pressure boil-off gas.

Advantageous Effects

[0028] In a device and method for processing boil-off gas in a liquefied gas regasification system according to the present invention, boil-off gas can be recondensed and recovered without waste even when the amount of liquefied gas to be regasified or fuel consumption is not sufficient to recondense boil-off gas, thereby allowing efficient recovery of boil-off gas without waste.

[0029] In addition, according to the present invention, through efficient processing of boil-off gas, the internal pressure of a liquefied gas storage tank can be kept constant within a safe operating range while reducing the amount of discarded LNG.

DESCRIPTION OF DRAWINGS

[0030] FIG. **1** is a schematic diagram of a device for processing boil-off gas in a liquefied gas regasification system according to one embodiment of the present invention.

BEST MODE

[0031] The above and other aspects, features, and advantages of the present invention will become apparent from the detailed description of the following embodiments in conjunction with the accompanying drawings.

[0032] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings. It should be noted that like components will be denoted by like reference numerals throughout the specification and the accompanying drawings. It should be understood that the present invention may be embodied in different ways and is not limited to the following embodiments.

[0033] As used herein, "liquefied gas" may refer to a gas that can be transported in liquid form by being liquefied at low temperature, for example, liquefied petrochemical gas such as liquefied natural gas (LNG), liquefied ethane gas (LEG), liquefied petroleum gas (LPG), liquefied ethylene gas, and liquefied propylene gas. In addition, "liquefied gas" may also refer to a gas in a liquid state, such as liquefied carbon dioxide, liquefied hydrogen, and liquefied ammonia. However, in the following embodiments, the present invention will be described using LNG, which is a typical liquefied gas, as an example.

[0034] Although LNG mainly contains methane and further contains ethane, propane, butane, and the like, the composition of LNG may vary depending on the place of production.

[0035] In addition, in one embodiment of the present invention, an LNG regasification ship may include any ship that is provided with an LNG regasification facility to regasify LNG and supply the regasified LNG to gas consumers, including self-propelled ships, such as LNG regasification vessels (RVs), and floating offshore structures, such as floating storage regasification units (FSRUs). Further, the LNG regasification ship may include floating storage power plants (FSPPs), which produce electricity using regasified gas as fuel and supply the produced electricity to onshore power consumers while regasifying LNG and supplyng the regasified LNG to gas consumers.

[0036] However, a device and method for processing boil-off gas in a liquefied gas regasification system according to the following embodiments will be described as applied to a ship such as an LNG FSRU provided with a regasification system or an LNG FSPP provided with both a regasification system and a power generation system.

[0037] In addition, a ship according to one embodiment of the present invention regasifies LNG at sea to supply the regasified LNG to onshore gas consumers via a pipe network (regas network) and also produces electricity using LNG as fuel to supply the produced electricity to onshore power consumers.

[0038] Although a device and method for processing boil-off gas in a liquefied gas regasification system according to one embodiment of the present invention will be described as applied to a ship, it will be understood that the device and method for processing boil-off gas may also be applied to onshore facilities.

[0039] FIG. **1** is a schematic diagram of an LNG regasification system according to one embodiment of the present invention. Now, a device and method for processing boil-off gas in the LNG regasification system according to one embodiment of the present invention will be described with reference to FIG. **1**.

[0040] Referring to FIG. **1**, the device for processing boil-off gas in the LNG regasification system according to this embodiment includes: a fuel compressor **600** compressing boil-off gas to a pressure required for a fuel demand site; a high-pressure compressor **700** compressing the boil-off gas to a pressure required for a regasified gas demand site; an expander **420** expanding the high-pressure boil-off gas compressed by the high-pressure compressor **700**; and a low-temperature heat exchanger **200** liquefying the high-pressure boil-off gas using cold heat of the boil-off gas cooled by being expanded by the expander **420**.

[0041] Although not shown in FIG. **1**, an LNG FSRU or an LNG FSPP, to which this embodiment is applied, includes an LNG regasification system. The LNG regasification system may include: an LNG storage tank (not shown); a high-pressure pump (not shown) compressing LNG to be regasified to a pressure required for the regasified gas demand site; and a vaporizer (not shown) vaporizing the compressed LNG and supplying the vaporized LNG to the regasified gas demand site.

[0042] LNG stored in the LNG storage tank is compressed to a pressure required for the regasified gas demand site by the high-pressure pump, is vaporized by the vaporizer, and is supplied to the regasified gas demand site.

[0043] The LNG storage tank stores LNG at an extremely low temperature of about −163° C. and a pressure of about 0.5 bar to 1.1 bar. That is, the LNG storage tank is preferably insulated such that LNG can be stored in a constant liquid state.

[0044] However, even when the LNG storage tank is insulated, LNG can naturally vaporize due to intrusion of external heat into the LNG storage tank, thereby generating boil-off gas (BOG). Accordingly, the LNG storage tank may be designed to withstand pressure rise caused by boil-off gas generated in the LNG storage tank until a preset pressure is reached. In addition, the LNG storage tank may be designed such that, when the internal pressure of the storage tank exceeds the preset pressure, a safety valve is opened to discharge the boil-off gas from the LNG storage tank.

[0045] A boil-off gas line BL according to this embodiment connects the LNG storage tank to the fuel compressor **600**, such that the boil-off gas discharged from the LNG storage tank is supplied to the fuel compressor **600** through the boil-off gas line BL.

[0046] The fuel compressor **600** compresses the boil-off gas delivered through the boil-off gas line BL to a low pressure required for the fuel demand site.

[0047] In this embodiment, the fuel demand site may be a power generation engine (dual fuel diesel electric (DFDE) engine) that generates electricity using boil-off gas compressed to a low pressure as fuel. The power generation engine may be, for example, a dual fuel diesel generator (DFDG). The DFDG is a generator connected to an engine shaft and uses a four-stroke cycle.

[0048] In addition, the DFDE engine uses an Otto cycle, in which low-pressure natural gas at a pressure of about 2 bar to about 8 bar, or about 6.5 bar is injected into a combustion air inlet and then compressed by a piston moving upward.

[0049] That is, the fuel compressor **600** according to this embodiment compresses boil-off gas to a pressure of about 2 bar to 8 bar, or about 5 bar to 6.5 bar. Boil-off gas compressed by the fuel compressor **600** will hereinafter be referred to as "low-pressure boil-off gas".

[0050] Referring to FIG. **1**, the fuel compressor **600** according to this embodiment may be a two-stage compressor that includes two compression units, such as a first fuel compression unit **610** and a second fuel compression unit **620**, to compress boil-off gas to low pressures in two stages. Although the fuel compressor **600** is described as being a two-stage compressor in this embodiment, it will be understood that the present invention is not limited thereto.

[0051] In addition, the first fuel compression unit **610** and the second fuel compression unit **620** may be connected to each other via a common shaft.

[0052] The device for processing boil-off gas according to this embodiment may further include: a first cooler **630** disposed downstream of the fuel compressor **600** to cool the low-pressure boil-off gas heated by being compressed by the first fuel compression unit **610** and the second fuel compression unit **620**.

[0053] Although the first cooler **630** is shown as disposed downstream of the second fuel compression unit **620** in FIG. **1**, it will be understood that the present invention is not limited thereto and the first cooler may be disposed both downstream of the first fuel compression unit **610** and downstream of the second fuel compression unit **620**.

[0054] The first cooler **630** according to this embodiment may be a seawater cooler that cools the low-pressure boil-off gas through heat exchange with cooling water, seawater, or the like, or may be an atmospheric cooler that cools the low-pressure boil-off gas through heat exchange with air.

[0055] The first cooler **630** may cool the low-pressure boil-off gas to a temperature required for the fuel demand site or to an inlet temperature of the high-pressure compressor **700** described below.

[0056] The device for processing boil-off gas according to this embodiment may further include: a fuel supply line EL disposed downstream of the first cooler **630** to be connected to the fuel demand site; and a high-pressure gas line HL disposed downstream of the first cooler **630** to be connected to the high-pressure compressor **700**.

[0057] That is, the low-pressure boil-off gas compressed by the fuel compressor **600** and cooled by the first cooler **630** is delivered to the fuel demand site through the fuel supply line EL or delivered to the high-pressure compressor **700** through the high-pressure gas line HL.

[0058] A flow rate of the low-pressure boil-off gas sent to the fuel supply line EL or the high-pressure gas line HL may be controlled by a controller (not shown). For example, the controller may perform control such that some of the low-pressure boil-off gas corresponding to fuel requirements of the fuel demand site, that is, load-dependent fuel requirements of the power generation engine, is first sent to the fuel supply line EL and the other low-pressure boil-off gas remaining after supply to the fuel demand site is sent to the high-pressure gas line HL.

[0059] The high-pressure gas line HL according to this embodiment may connect the fuel compressor **600** to the high-pressure compressor **700**, and the fuel compressor **600** and the high-pressure compressor **700** according to this embodiment may be connected to each other in series via the high-pressure gas line HL. That is, all or a portion of the low pressure boil-off gas compressed by the fuel compressor **600** is supplied to the high-pressure compressor **700** through the high-pressure gas line HL.

[0060] The high-pressure compressor **700** compresses the low-pressure boil-off gas to a delivery pressure, that is, a pressure required for the regasified gas demand site. Here, the regasified gas demand site may be an onshore gas terminal, and, in this embodiment, the pressure of regasified gas required for the regasified gas demand site may range from about 50 barg to about 100 barg.

[0061] That is, the high-pressure compressor **700** compresses the low-pressure boil-off gas to a pressure of about 50 barg to 100 barg. Boil-off gas compressed by the high-pressure compressor **700** will hereinafter be referred to as "high-pressure boil-off gas".

[0062] The high-pressure compressor **700** is connected to the regasified gas demand site via a regasified gas delivery line SL, such that the high-pressure boil-off gas compressed by the high-pressure compressor **700** can be supplied to the onshore gas terminal along with a regasified gas vaporized by the vaporizer through the regasified gas delivery line SL. The regasification gas delivery line SL may also be connected to the vaporizer of the LNG regasification system.

[0063] Referring to FIG. **1**, the high-pressure compressor **700** according to this embodiment may be a three-stage compressor that includes three compression units, such as a first high-pressure compression unit **710**, a second high-pressure compression unit **730**, and a third high-pressure compression unit **750**, to compress the low-pressure boil-off gas in three stages. Although the high-pressure compressor **700** is described as being a three-stage compressor in this embodiment, it will be understood that the present invention is not limited thereto.

[0064] In addition, the first high-pressure compression unit **710**, the second high-pressure compression unit **730** and the third high-pressure compression unit **750** may be connected to one another via a common shaft.

[0065] According to this embodiment, a cooler may be disposed downstream of each of the compression units of the high-pressure compressor **700**. That is, the device for processing boil-off gas according to this embodiment may further include: a second cooler **720** disposed downstream of the first high-pressure compression unit **710** to cool the boil-off gas to be supplied to the second high-pressure compression unit **730** from the first high-pressure compression unit **710**; a third cooler **740** disposed downstream of the second high-pressure compression unit **730** to cool the boil-off gas to be supplied to the third high-pressure compression unit **750** from the second high-pressure compression unit **730**; and a fourth cooler **760** disposed downstream of the third high-pressure compression unit **750** to cool the boil-off gas discharged from the third high-pressure compression unit **750**.

[0066] Each of the second cooler **720**, the third cooler **740**, and the fourth cooler **760** according to this embodiment may be a seawater cooler that cools the high-pressure boil-off gas through heat exchange with cooling water, seawater, or the like, or may be an atmospheric cooler that cools the high-pressure boil-off gas through heat exchange with air.

[0067] The device for processing boil-off gas according to this embodiment may further include: a reliquefaction line RL branched off of the regasified gas delivery line SL connecting the high-pressure compressor **700** to the regasified gas demand site and connected to the low-temperature heat exchanger **200**.

[0068] That is, among the high-pressure boil-off gas compressed by the high-pressure compressor **700**, a portion of the high-pressure boil-off gas remaining after supply to the regasified gas demand site is delivered to the low-temperature heat exchanger **200** through the reliquefaction line RL to be reliquefied and recovered.

[0069] In addition, the device for processing boil-off gas according to this embodiment may further include: a decompression valve decompressing the high-pressure boil-off gas cooled by the low-temperature heat exchanger **200**; and a liquefied gas drum **100** performing gas/liquid separation by separating flash gas generated during decompression by the decompression valve **800** from the decompressed boil-off gas.

[0070] The high-pressure boil-off gas cooled by the low-temperature heat exchanger **200** is decompressed by the depressurization valve **800** and is then subjected to gas/liquid separation by the liquefied gas drum **100** to allow recovery of reliquefied boil-off gas in a liquid state.

[0071] The reliquefied boil-off gas, from which the flash gas has been separated by the liquefied gas drum **100**, may be returned to the LNG storage tank. Thus, the decompression valve **800** may decompress the high-pressure boil-off gas to an internal pressure of the LNG storage tank such that the reliquefied boil-off gas can be returned to the LNG storage tank.

[0072] The device for processing boil-off gas according to this embodiment may further include: a flash gas line FL connecting the liquefied gas drum **100** to a low-temperature inlet of the low-temperature heat exchanger **200**. The gaseous flash gas separated by the liquefied gas drum **100** is supplied to the low-temperature heat exchanger **200** through the flash gas line FL.

[0073] The gaseous flash gas separated by the liquefied gas drum **100** may be used as a refrigerant cooling the high-pressure boil-off gas introduced into the low-temperature heat exchanger **200** through a high-temperature inlet of the low-temperature heat exchanger **200**.

[0074] The device for processing boil-off gas according to this embodiment may further include: an expansion line PL branched off of the reliquefaction line RL upstream of the low-temperature heat exchanger **200** and connected to the expander **420**.

[0075] That is, some of the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger **200** from the high-pressure compressor **700** through the reliquefaction line RL may be supplied to the expander **420** through the expansion line PL.

[0076] In addition, the expansion line PL may be connected between an outlet of the expander **420** and the flash gas line FL. That is, the boil-off gas expanded by the expander **420** may be joined with a flow of the flash gas to be introduced into the low-temperature heat exchanger **200** through the flash gas line FL.

[0077] Boil-off gas is cooled while being expanded by the expander **420**. Thus, according to this embodiment, the expanded boil-off gas may be used as a refrigerant cooling the high-pressure boil-off gas in the low-temperature heat exchanger **200**.

[0078] As used herein, "cooling" includes liquefaction, condensation, and supercooling of boil-off gas. For example, the high-pressure boil-off gas may be introduced in a liquid state, a gaseous state, or a gas-liquid mixed state into the low-temperature heat exchanger **200** and may be liquefied or supercooled through heat exchange in the low-temperature heat exchanger **200**.

[0079] In the low-temperature heat exchanger **200** according to this embodiment, the high-pressure boil-off gas exchanges heat with a mixture of the flash gas and the expanded boil-off gas, such that the high-pressure boil-off gas is cooled and the mixture is heated.

[0080] The device for processing boil-off gas according to this embodiment may further include: a high-temperature heat exchanger **300** disposed upstream of a point at which the expansion line PL is branched off of the reliquefaction line RL and precooling the high-pressure boil-off gas to be introduced into the low-temperature heat exchanger **200**.

[0081] The high-temperature heat exchanger **300** according to this embodiment may cool the high-pressure boil-off gas to an inlet temperature of the expander **420**.

[0082] Some of the high-pressure boil-off gas precooled by the high-temperature heat exchanger **300** is supplied to the expander **420** and the other high pressure boil-off gas remaining after supply to the expander **420** is supplied to the low-temperature heat exchanger **200** to be cooled.

[0083] In the high-temperature heat exchanger **300**, the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger **200** and the expander **420** exchanges heat with a flow of the mixture discharged from the low-temperature heat exchanger **200** after being used to cool the high-pressure boil-off gas, such that the high-pressure boil-off gas is cooled and the mixture is heated.

[0084] The high-pressure boil-off gas cooled by the high-temperature heat exchanger **300** is divided and supplied to the low-temperature heat exchanger **200** and the expander **420**.

[0085] According to this embodiment, the flash gas line is connected between the liquefied gas drum **100**, the low-temperature heat exchanger **200**, the high-temperature heat exchanger **300**, and the fuel compressor **600**.

[0086] The flow of the mixture heated by the high-temperature heat exchanger **300** is joined with a flow of the low-pressure boil-off gas to be compressed by the fuel compressor **600** through the flash gas line FL.

[0087] That is, the flow of the mixture used as a refrigerant cooling the high-pressure boil-off gas in the low-temperature heat exchanger **200** and the high-temperature heat exchanger **300** is recovered to the fuel compressor **600** to be compressed to low pressure.

[0088] In this way, according to this embodiment, generated boil-off gas is completely recovered without any waste, thereby allowing efficient processing of the boil-off gas.

[0089] In FIG. **1**, the flash gas line FL is shown as joined upstream of the second fuel compression unit **620** of the fuel compressor **600**. That is, according to this embodiment, the flow of the mixture used as a refrigerant in the low-temperature heat exchanger **200** and the high-temperature heat exchanger **300** is joined with the flow of the boil-off gas to be introduced into the second fuel compression unit **620**. However, it will be understood that the present invention is not limited thereto. For example, the flash gas line FL may be joined with the boil-off gas line BL at a point upstream of the fuel compressor **600**, at which a flow of the boil-off gas compressed by the fuel compressor **600** has a most similar pressure to the flow of the mixture through the flash gas line FL.

[0090] In this embodiment, the flow of the mixture will be described as joined with the flow of the boil-off gas upstream of the second fuel compression unit **620**.

[0091] In addition, the device for processing boil-off gas according to this embodiment may further include: a gas compressor **410** compressing the flow of the mixture to be introduced into the boil-off gas line BL through the flash gas line FL to a pressure of the boil-off gas to be introduced into the second fuel compression unit **620**; and a gas cooler **500** regulating the temperature of the flow of the mixture compressed by the gas compressor **410**.

[0092] The gas compressor **410** according to this embodiment may be connected to the expander **420** via a common shaft. That is, expansion work in the expander **420** is recovered as compression work in the gas compressor **410**. In this embodiment, the gas compressor **410** and the expander **420** are described as used in conjunction with each other via the common shaft to form a compander **400**, as shown in FIG. **1**.

[0093] Next, an operating principle of the device for processing boil-off gas in the LNG regasification system set forth above will be described with reference to FIG. **1**.

[0094] In this embodiment, it is assumed that boil-off gas introduced into the fuel compressor **600** through the boil-off gas line BL has a flow rate of about 2.3 ton/hr, a pressure of about 0 barg, and a temperature is about −120° C. However, it will be understood that the present invention is not limited thereto and process conditions described in this embodiment, such as the flow rate, pressure, and temperature of a fluid, may be varied depending on the delivery pressure of regasified gas or the composition of LNG.

[0095] First, the boil-off gas introduced into the fuel compressor **600** through the boil-off gas line BL is compressed to about 2.2 barg by the first fuel compression unit **610** and is heated to −27° C. while being compressed.

[0096] The boil-off gas compressed by the first fuel compression unit **610** is introduced into the second fuel compression unit **620** through the boil-off gas line BL. Here, through the flash gas line FL, a flow of the mixture used as a refrigerant in the low-temperature heat exchanger **200** and the high-temperature heat exchanger **300** is joined with a flow of the boil-off gas compressed by the first fuel compression unit **610**. The flow of the mixture through the flash gas line FL may have a flow rate of about 6.9 ton/hr, a pressure of about 2.2 barg, and a temperature of about 43° C.

[0097] A net flow of boil-off gas into the second fuel compression unit **620**, that is, a mixed flow of the boil-off gas compressed by the first fuel compression unit **610** and the mixture delivered through the flash gas line FL, has a flow rate of about 9.5 ton/hr, a pressure of about 2.2 barg, and a temperature of about 23.3° C.

[0098] In the second fuel compression unit **620**, the flow of the boil-off gas is compressed to about 5.5 barg. Some of the low-pressure boil-off gas compressed by the second fuel compression unit **620** is supplied to the fuel demand site and the other low-pressure boil-off gas is introduced into the high-pressure compressor **700**.

[0099] In this embodiment, it is assumed that the low-pressure boil-off gas sent to the fuel supply line EL to be supplied to the fuel demand site has a flow rate of about 0.7 ton/hr, and the low-pressure boil-off gas sent to the high-pressure gas line HL to be introduced into the high-pressure compressor **700** has a flow rate of about 8.8 ton/hr. The flow rate of the low-pressure boil-off gas sent to the high-pressure gas line HL to be introduced into the high-pressure compressor **700** corresponds to about 10 million standard cubic feet per day (MMSCFD).

[0100] The boil-off gas introduced into the high-pressure compressor is compressed to about 15.5 barg by the first high-pressure compression unit **710**, is compressed to about 40 barg by the second high-pressure compression unit **730**, and is compressed to about 100 barg by the third high-pressure compression unit **750**.

[0101] Some of the high-pressure boil-off gas compressed to 100 barg by the high-pressure compressor **700** is supplied to the regasified gas demand site through the regasified gas delivery line SL and the other high-pressure boil-off gas is sent to the reliquefaction line RL.

[0102] In the present embodiment, a boil-off gas processing method will be described with reference to the case in which regasified gas demand by the regasified gas demand site can be met by regasified gas supplied from the vaporizer because regasification is not performed, that is, there is no regasified gas demand by the regasified gas demand site, or regasified gas demand by the regasified gas demand site is low.

[0103] In other words, in this embodiment, it is assumed that the high pressure boil-off gas compressed by the high-pressure compressor **700** is entirely sent to the reliquefaction line RL without being sent to the regasified gas delivery line SL.

[0104] The high pressure boil-off gas compressed by the high-pressure compressor **700** and having a pressure of 100 barg, a temperature of about 43° C., and a flow rate of 8.8 ton/hr (10 MMSCFD) is supplied to the high-temperature heat exchanger **300** through the reliquefaction line RL. In the high-temperature heat exchanger **300**, the high-pressure boil-off gas is cooled to about 25° C.

[0105] Some of the high-pressure boil-off gas cooled by the high-temperature heat exchanger **300** is sent to the expander **420** through the expansion line PL and the other high-pressure boil-off gas remaining after supply to the expansion line PL is supplied to the low-temperature heat exchanger **200** through the reliquefaction line RL.

[0106] In this embodiment, it is assumed that the high-pressure boil-off gas cooled by the high-temperature heat exchanger **300** and having a flow rate of about 8.8 ton/hr is distributed to the expansion line PL at a flow rate of 6.5 ton/hr and the low-temperature heat exchanger **200** at a flow rate of about 2.3 ton/hr.

[0107] In the low-temperature heat exchanger **200**, the high pressure boil-off gas having a flow rate of about 2.3 ton/hr and a temperature of −25° C. is cooled (liquefied) to about −157° C.

[0108] The high-pressure boil-off gas cooled by the low-temperature heat exchanger **200** is decompressed to about 0.5 barg by the depressurization valve **800** and is cooled to about −168.1° C. while being decompressed.

[0109] The reliquefied boil-off gas passing through the decompression valve **800** and having a pressure of about 0.5 barg, a temperature of −168.1° C., and a flow rate of 2.3 ton/hr is supplied to the liquefied gas drum **100**, and is then subjected to gas/liquid separation in the liquefied gas drum **100** before being returned to the LNG storage tank.

[0110] According to this embodiment, reliquefied boil-off gas in a liquid state, from which flash gas having a flow rate of about 0.4 ton/hr of has been separated by the liquefied gas drum **100**, is returned to the LNG storage tank at a flow rate of about 1.9 ton/hr.

[0111] The gaseous flash gas separated by the liquefied gas drum **100** and having a flow rate of about 0.4 ton/hr, a pressure of 0.5 barg, and a temperature of −168.1° C. is supplied to the low-temperature heat exchanger **200** through the flash gas line FL to recover cold heat therefrom.

[0112] Here, a flow of the flash gas to be supplied to the low-temperature heat exchanger **200** is joined with a flow of the boil-off gas expanded by the expander **420**.

[0113] As described above, the high-pressure boil-off gas having a flow rate of about 6.5 ton/hr, a pressure of 100 barg, and a temperature −25° C. is introduced into the expander **420**. The high-pressure boil-off gas is expanded to about 0.5 barg by the expander **420** and is cooled to −158.6° C. while being expanded.

[0114] A flow of a mixture of the boil-off gas expanded by the expander **420** and having a flow rate of about 6.5 ton/hr, a pressure of 0.5 barg, and a temperature of −158.6° C. and the flash gas separated by the liquefied gas drum **100** and having a flow rate of 0.4 ton/hr, a pressure of 0.5 barg, and a temperature of −168.1° C. is supplied as a refrigerant to the low-temperature heat exchanger **200**, wherein the flow of a mixture has a flow rate of about 6.9 ton/hr, a pressure of 0.5 barg, and a temperature of −159 ° C.

[0115] The flow of the mixture is heated to about −90.7° C. while cooling the high-pressure boil-off gas in the low-temperature heat exchanger **200**.

[0116] The flow of the mixture heated while cooling the high-pressure boil-off gas in the low-temperature heat exchanger **200** is supplied as a refrigerant to the high-temperature heat exchanger **300**.

[0117] The flow of the mixture is heated to about 40.0° C. while cooling the high-pressure boil-off gas in the high-temperature heat exchanger **300**.

[0118] The flow of the mixture heated while cooling the high-pressure boil-off gas in the high-temperature heat exchanger **300** is compressed to about 2.2 barg by the gas compressor **410** and is then adjusted to about 43° C. by a fifth cooler **500** before being joined with a flow of the boil-off gas to be supplied to the second fuel compression unit **620**.

[0119] As described above, according to the present invention, boil-off gas generated in an LNG regasification system is liquefied using cold heat recovered by expanding the boil-off gas itself, rather than being recovered by condensing the boil-off gas using cold heat of LNG to be regasified, whereby all of the boil-off gas can be reliquefied and recovered regardless of the flow rate of regasified gas or fuel consumption.

[0120] Although some embodiments have been described herein, it should be understood that these embodiments are provided for illustration only and are not to be construed in any way as limiting the present invention, and that various modifications, changes, alterations, and equivalent embodiments can be made by those skilled in the art without departing from the spirit and scope of the invention. The scope of the present invention should be defined by the appended claims and equivalents thereto.

1. A device for processing boil-off gas in a liquefied gas regasification system, the device comprising:

a fuel compressor compressing boil-off gas to a pressure required for a fuel demand site;

a high-pressure compressor disposed in series with the fuel compressor downstream of the fuel compressor and compressing the low-pressure boil-off gas compressed by the fuel compressor to a pressure required for a regasified gas demand site;

a low-temperature heat exchanger cooling the high-pressure boil-off gas compressed by the high-pressure compressor;

a decompression unit decompressing the high-pressure boil-off gas cooled by the low-temperature heat exchanger to an internal pressure of a liquefied gas storage tank; and

a liquefied gas drum separating flash gas generated during decompression by the decompression unit,

wherein reliquefied boil-off gas separated by the liquefied gas drum is returned to the liquefied gas storage tank.

2. The device according to claim **1**, further comprising:

an expander expanding and cooling some of the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger,

wherein the low-temperature heat exchanger cools the high-pressure boil-off gas through heat exchange with the boil-off gas expanded and cooled by the expander.

3. The device according to claim **2**, further comprising:

a high-temperature heat exchanger precooling the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger to an inlet temperature of the expander,

wherein some of the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger from the high-temperature heat exchanger is sent to the expander.

4. The device according to claim **3**, wherein the high-temperature heat exchanger cools the high-pressure boil-off gas to be supplied to the low-temperature heat exchanger and the expander through heat exchange with the expanded boil-off gas heated through heat exchange in the low-temperature heat exchanger and discharged from the low-temperature heat exchanger.

5. The device according to claim **3**, further comprising:

a gas compressor compressing the expanded boil-off gas subjected to heat exchange in the low-temperature heat exchanger and discharged from the low-temperature heat exchanger to a pressure of a flow of the boil-off gas compressed by the fuel compressor,

wherein the boil-off gas compressed by the gas compressor is joined with the flow of the boil-off gas compressed by the fuel compressor.

6. The device according to claim **5**, wherein the gas compressor is connected to the expander via a common shaft.

7. The device according to claim **5**, further comprising:

a gas cooler regulating a temperature of the boil-off gas compressed and heated by the gas compressor.

8. The device according to claim **3**, wherein the flash gas separated by the liquefied gas drum is joined with a flow of the expanded boil-off gas to be supplied to the low-temperature heat exchanger.

9. A method for processing boil-off gas in a liquefied gas regasification system, comprising:

compressing boil-off gas to a low pressure required for a fuel demand site,

compressing the low-pressure boil-off gas to a high pressure required for a regasified gas demand site,

cooling the high-pressure boil-off gas,

decompressing the cooled high-pressure boil-off gas to an internal pressure of a liquefied gas storage tank; and

separating flash gas generated during decompression of the cooled high-pressure boil-off gas and returning reliquefied boil-off gas to the liquefied gas storage tank.

10. The method according to claim **9**, wherein cooling the high-pressure boil-off gas comprises:

expanding and cooling some of the high-pressure boil-off gas before cooling the high-pressure boil-off gas; and

liquefying at least part of the high-pressure boil-off gas through heat exchange between the expanded and cooled boil-off gas and the high-pressure boil-off gas.

11. The method according to claim **10**, further comprising:

precooling the high-pressure boil-off gas through heat exchange with the expanded boil-off gas heated while cooling the high-pressure boil-off gas, before performing heat exchange between the expanded and cooled boil-off gas and the high-pressure boil-off gas.

12. The method according to claim **11**, wherein precooling the high-pressure boil-off gas comprises:

cooling the high-pressure boil-off gas to an inlet temperature of an expander expanding the high-pressure boil-off gas.

13. The method according to claim **11**, wherein the expanded boil-off gas heated while cooling the high-pressure boil-off gas is compressed to a pressure of a flow of boil-off gas to be compressed by a fuel compressor before being joined with the flow of the boil-off gas.

14. The method according to claim **13**, wherein expansion work in expanding the high-pressure boil-off gas is recovered as compression work in compressing the expanded boil-off gas.

15. The method according to claim **11**, wherein the separated flash gas is joined with a flow of the expanded boil-off gas exchanging heat with the high-pressure boil-off gas.

* * * * *