

SYSTEM AND METHOD FOR SUPPLYING FUEL IN LIQUEFIED NATURAL GAS FUELED SHIP

【TECHNICAL FIELD】

[1] The present invention relates to a system and method for supplying fuel in a liquefied natural gas fueled ship including a liquefied natural gas fueled engine, which enables supply of liquefied natural gas corresponding to fuel supply conditions for the engine using pumps and regasification equipment without using a compressor.

【BACKGROUND ART】

[2] Generally, a ship generates propulsion force by driving an engine that generates power through combustion of fuel. Fuel oil for ships, such as diesel oil, heavy oil, marine diesel oil (MDO), and the like, causes environmental pollution through generation of large amounts of toxic substances during combustion. With recent reinforcement of worldwide regulations for prevention of atmospheric environmental pollution, there is tendency of change of fuel for ships from fuel oil to natural gas. Natural gas is relatively eco-friendly due to a low content of sulfur which generates sulfur compounds and soot materials upon combustion. Corresponding to such tendency, a dual fuel engine configured to use both fuel oil and natural gas is being developed in the art.

[3] On the other hand, natural gas has a gas phase occupying too large a volume at room temperature and normal pressure, thereby providing significant spatial restriction. Accordingly, based on the properties of liquefied natural gas (LNG) having a liquid phase at an extremely low temperature of about -163°C and normal pressure, LNG having an extremely low temperature can be stored in a liquid phase at normal pressure in a specific storage tank covered with an insulating material.

[4] In addition, a liquefied fueled ship (LFS) using liquefied natural gas (LNG) as fuel has been developed and approved as a green-ship by AIP (Approval In Principle) for ships from various countries and meets requirements for conversion to clean energy due to the environmental regulations. A technique for application of such an LFS not only to LNG carriers for transporting LNG as freight but also to general merchant vessels including container ships, tanker ships, and the like has been

developed in the art.

[5] Examples of an engine capable of being fueled by natural gas include an ME-GI (MAN Electronic Gas Injection) engine and a dual fuel (DF) engine.

[6] The ME-GI engine employs a diesel cycle consisting of two strokes, in which natural gas at a high pressure of about 300 bar is injected directly into a combustion chamber near the top dead point of a piston.

[7] The diesel cycle is a constant pressure process in which fuel combustion near the top dead center occurs at a constant pressure, and allows only air for combustion to be suctioned into the cylinder during the upward stroke so as to be adiabatically compressed at a high compression ratio. At the top dead center, the air for combustion reaches a significantly high temperature due to adiabatic compression during the compression stroke such that spontaneous combustion of fuel occurs due to the high temperature of the air upon injection of the fuel toward the adiabatically compressed combustion air.

[8] In the diesel cycle, pressure for fuel injection is suitably adjusted to maintain a constant pressure for fuel combustion at the top dead center in order to prevent further increase in pressure of the air for combustion, which has already reached a high pressure, at the top dead center due to explosion by fuel injection.

[9] Although the diesel engine has higher combustion efficiency with increasing fuel compression ratio, the diesel engine is generally configured to compress fuel at a compression ratio of about 15:1 to about 22:1 in consideration of explosion pressure.

[10] Further, the diesel engine is configured to compress only air in the compression stroke and thus fundamentally does not suffer from knocking due to advanced ignition before the piston reaches the top dead center.

[11] The DF engine employs an Otto cycle consisting of four or two strokes, in which natural gas having a relatively low pressure of about 6.5 or 18 bar is injected into a combustion air inlet and then compressed by a piston moving upward.

[12] The Otto cycle is a constant volume process in which fuel combustion near the top dead center occurs at a constant volume, and allows a mixed gas of fuel and air for combustion to be introduced into a cylinder and compressed therein before the upward stroke. In the cylinder, the temperature of the mixed gas increases during adiabatic compression of the mixed gas and advanced ignition can occur when the mixed gas reaches too high a temperature. Accordingly, the compression ratio of the

Otto cycle is set to be lower than that of the diesel cycle.

[13] Since the compression ratio of the Otto cycle is set to a relatively low value, the Otto cycle is required to reach a high pressure upon explosion of the fuel by an ignition source at the top dead center and thus the fuel should be combusted as quickly as possible to improve efficiency of the engine.

[14] In addition, since an engine employing the Otto cycle allows the mixed gas of the fuel and the air for combustion to be introduced into the cylinder before the upward stroke, the engine can suffer from knocking due to advanced ignition of the fuel before ignition by the ignition source.

[15] Since knocking causes deterioration in efficiency of the engine and damage to the engine, it is important for the engine employing the Otto cycle to prevent the occurrence of knocking.

[16] Capability of preventing advanced ignition of the fuel used for the engine employing the Otto cycle, that is, anti-knocking capability, is adjusted by the octane number for a liquid fuel and by the methane number for a gas fuel. The DF engine is required to have a methane number of 80 or more.

[17] Although the DF engine employing the Otto cycle has lower efficiency than the ME-GI engine employing the diesel cycle, the DF engine enables fuel combustion at a lower temperature to generate less nitrogen oxide (NO_x) caused by high temperature and thus satisfies regulations on nitrogen oxide, that is, IMO Tier III.

[18] As such, there is a need for various devices and an engine supply system configured based on characteristics of LNG and each engine in order to supply LNG stored in a storage tank according to requirements for each engine.

【DISCLOSURE】

【Technical Problem】

[19] FIG. 1 is a schematic diagram of a conventional fuel supply system of an LNG carrier.

[20] Referring to FIG. 1, a conventional fuel supply system may include a boil-off gas supply system adapted to supply boil-off gas discharged from a storage tank T to engines E1, E2, a reliquefaction system that reliquefies the boil-off gas remaining after being supplied to fuel for the engines E1, E2, and a liquefied natural gas (LNG) supply system adapted to supply LNG from the storage tank T to the engines E1, E2.

[21] The boil-off gas supply system includes a multistage compressor 200; the LNG supply system includes a first pump 610, a second pump 620, a vaporizer 700, a first heater 810, and a second decompressor 420; and the reliquefaction system includes a first heat exchanger 110, a first decompressor 410, and a gas/liquid separator 500.

[22] The multistage compressor 200 compresses the boil-off gas discharged from the storage tank T through multiple stages and includes a plurality of compression units 210, 220, 230, 240, 250 and a plurality of coolers 310, 320, 330, 340, 350 each disposed downstream of each compression unit to alternate with the compression units. Generally, a multistage compressor including five compression units and five coolers to compress boil-off gas through five stages is used.

[23] In addition, the multistage compressor 200 may be connected to one or plural branch lines, which resupply the boil-off gas compressed through the compression units to the compression units to regulate the pressure and flow rate of the boil-off gas passing through the multistage compressor 200. For example, as shown in FIG. 1, the branch lines may include a first branch line L1 bifurcating the boil-off gas downstream of the first compression unit 210 to supply the bifurcated boil-off gas upstream of the first compression unit 210 and a second branch line L2 bifurcating the boil-off gas downstream of the fifth compression unit 250 to supply the bifurcated boil-off gas upstream of the compression unit 240.

[24] Boil-off gas compressed through all stages of the multistage compressor 200 is sent to the first engine E1 and boil-off gas compressed through some stages of the multistage compressor 200 is bifurcated midway by a third branch line L3 to be sent to the second engine E2. The first engine E1 may be an ME-GI engine and the second engine E2 may be a DF engine for power generation.

[25] The first pump 610 is disposed inside the storage tank T to discharge LNG stored in the storage tank T and the second pump 620 pressurizes the LNG discharged from the storage tank T by the first pump 610 to a pressure required for the first engine E1.

[26] The vaporizer 700 forcibly vaporizes the LNG pressurized by the second pump 620. Some of the natural gas forcibly vaporized by the vaporizer 700 may be supplied to the first engine E1 and the remaining natural gas may be supplied to the first heater 810.

[27] The first heater 810 heats the natural gas vaporized by the vaporizer 700 to a temperature required for the second engine E2 and the second decompressor 420 decompresses the natural gas heated by the first heater 810 to a pressure required for the second engine E2.

[28] Although FIG. 1 shows the structure wherein the first heater 810 is disposed downstream of the vaporizer 700 and the second decompressor 420 is disposed downstream of the first heater 810, the installation sequence of the first heater 810 and the second decompressor 420 may be changed such that the second decompressor 420 is disposed downstream of the vaporizer 700 and the first heater 810 is disposed downstream of the second decompressor 420.

[29] The first heat exchanger 110 cools the boil-off gas, which has been compressed through all stages of the multistage compressor 200 and branched off along the fifth branch line L5, using the boil-off gas discharged from the storage tank T as a refrigerant through heat exchange therebetween. Among the boil-off gas discharged from the storage tank T, surplus boil-off gas not supplied to the first engine E1 or the second engine E2 is supplied to the first heat exchanger 110 to be subjected to reliquefaction.

[30] The first decompressor 410 expands the fluid that flows along the fifth branch line L5 after being compressed by the multistage compressor 200 and cooled by the first heat exchanger 110. The boil-off gas subjected to compression by the multistage compressor 200, cooling by the first heat exchanger 110 and expansion by the first decompressor 410 is partially or entirely reliquefied.

[31] The gas/liquid separator 500 separates the liquefied natural gas reliquefied through the multistage compressor 200, the first heat exchanger 110 and the first decompressor 410 from the boil-off gas remaining in a gas phase. The liquefied natural gas separated by the gas/liquid separator 500 is returned to the storage tank T and the boil-off gas separated by the gas/liquid separator 500 is merged with the boil-off gas discharged from the storage tank T to be used as refrigerant in the first heat exchanger 110.

[32] When the second engine E2 is an engine employing the Otto cycle such as a DF engine, the methane number of natural gas supplied to the second engine E2 must be reduced to prevent knocking. Here, the natural gas forcibly vaporized by the LNG supply system has a lower methane number than the spontaneously vaporized boil-off

gas supplied by the boil-off gas supply system.

[33] According to the LNG supply system, the liquefied natural gas disposed at a lower portion of the storage tank T is discharged by the first pump 610 disposed at the lower portion of the storage tank T and is then forcibly vaporized due to a high ratio of high specific gravity components therein.

[34] Accordingly, there is a need for regulation of the methane number of the natural gas forcibly vaporized by regasification equipment, such as a vaporizer and the like, in the LNG supply system and the present invention is aimed at providing a system and method for supplying fuel in a liquefied natural gas fueled ship, which can satisfy specifications of a fuel gas required for an Otto cycle engine, such as a methane number of natural gas supplied as fuel for engines, and the like.

【Technical Solution】

[35] In accordance with one aspect of the present invention, a fuel supply system of a liquefied natural gas fueled ship includes: an Otto cycle engine fueled by liquefied natural gas and employing an Otto cycle; a fuel supply pump discharging liquefied natural gas from a storage tank; a high pressure pump pressurizing the liquefied natural gas discharged from the storage tank; a vaporizer vaporizing the liquefied natural gas pressurized by the high pressure pump; an expansion valve adiabatically expanding the natural gas vaporized by the vaporizer; and a gas/liquid separator separating a gas-liquid mixture formed by the expansion valve into gas and liquid, wherein the liquid separated by the gas/liquid separator is returned back to the storage tank and the gas separated by the gas/liquid separator is supplied as fuel for the Otto cycle engine to adjust a methane number of the natural gas fuel supplied to the Otto cycle engine.

[36] Preferably, the fuel supply system further includes: an LNG cooler performing heat exchange between the liquefied natural gas pressurized by the high pressure pump to be supplied to the vaporizer and the liquid separated by the gas/liquid separator to be returned back to the storage tank, wherein the pressurized liquefied natural gas to be supplied to the vaporizer is heated and the liquid to be returned back to the storage tank is cooled in the LNG cooler.

[37] Preferably, the fuel supply system further includes: a fuel gas heater heating the natural gas separated by the gas/liquid separator to be supplied as fuel to the Otto

cycle engine, wherein the natural gas fuel having passed through the expansion valve and the fuel gas heater has a temperature required for the Otto cycle engine.

[38] Preferably, the Otto cycle engine includes an X-DF engine provided as a two-stroke engine for propulsion of the ship; and a dual fuel diesel generator (DFDG) provided as a four-stroke engine for generation of assistant power of the ship, wherein the natural gas fuel having passed through the fuel gas heater is adjusted to have a temperature and pressure required for the X-DF engine.

[39] Preferably, the fuel supply system further includes: a decompression valve decompressing the natural gas fuel to be supplied to the DFDG, wherein the natural gas fuel having passed through the fuel gas heater and the decompression valve may be adjusted to have a pressure required for the DFDG.

[40] Preferably, the fuel supply system further includes: an LNG fuel line providing a path through which the liquefied natural gas is supplied from the storage tank to the engines through the high pressure pump and the vaporizer; and a boil-off gas fuel line providing a path through which boil-off gas generated in the storage tank is supplied as fuel for the engine, wherein the boil-off gas fuel line may include a compressor compressing the boil-off gas and an intercooler cooling the boil-off gas heated through compression by the compressor.

[41] Preferably, the fuel supply system further includes: a boil-off gas cooler performing heat exchange between the compressed and cooled boil-off gas and the pressurized liquefied natural gas to be supplied to the vaporizer, wherein the pressurized liquefied natural gas to be supplied to the vaporizer is heated and the boil-off gas is cooled in the boil-off gas cooler.

[42] Preferably, the fuel supply system further includes: a boil-off gas expansion valve expanding the boil-off gas cooled by the boil-off gas cooler to the same pressure as the gas-liquid mixture supplied to the gas/liquid separator.

[43] Preferably, the fuel supply system further includes: a gas combustion unit (GCU) treating boil-off gas generated in the storage tank.

[44] Preferably, the fuel supply system further includes: a controller controlling a temperature, pressure and flux of a fluid supplied to the high pressure pump, the vaporizer, the expansion valve and the gas/liquid separator or a fluid discharged from the high pressure pump, the vaporizer, the expansion valve and the gas/liquid separator according to variation in load of the Otto cycle engine.

[45] In accordance with another aspect of the present invention, a fuel supply method of a liquefied natural gas fueled ship includes: 1) discharging liquefied natural gas from a storage tank using a fuel supply pump, followed by pressurizing the discharged liquefied natural gas using a high pressure pump; 2) vaporizing the pressurized liquefied natural gas using a vaporizer; 3) expanding the vaporized natural gas; 4) separating a gas-liquid mixture generated by expansion into gas and liquid; and 5) resupplying the liquid separated from the gas-liquid mixture to the storage tank while supplying the gas separated from the gas-liquid mixture to an Otto cycle engine fueled by liquefied natural gas and employing an Otto cycle, whereby the liquefied natural gas stored in the storage tank is supplied as a fuel satisfying requirements of temperature, pressure and methane number for the Otto cycle engine.

[46] Preferably, the fuel supply method further includes: Step 1-1) performing heat exchange between the liquid to be resupplied to the storage tank in Step 5) and the pressurized liquefied natural gas before vaporization of the pressurized liquefied natural gas in Step 2), wherein the pressurized liquefied natural gas is vaporized after being heated by the liquid to be resupplied to the storage tank and the liquid to be resupplied to the storage tank is supplied to the storage tank after being cooled by the pressurized liquefied natural gas.

[47] Preferably, the fuel supply method further includes: Step 5-1) heating the gas fuel separated from the gas-liquid mixture to be supplied to the engine in Step 5); and controlling a pressure, temperature and flux of a fluid in at least one of the steps according to variation in load of the Otto cycle engine, wherein a fluid having passed through Step 5-1) has a pressure, temperature and methane number required for the Otto cycle engine.

[48] Preferably, the fuel supply method further includes: Step 5-2) decompressing the heated gas fuel, wherein a fluid having passed through Step 5-2) has a pressure, temperature and methane number required for the Otto cycle engine.

[49] Preferably, the fuel supply method further includes: discharging boil-off gas from the storage tank, followed by compressing the boil-off gas using a compressor; and supplying the compressed boil-off gas as fuel to the Otto cycle engine, wherein the compressed boil-off gas has a pressure and temperature required for the Otto cycle engine.

[50] Preferably, the fuel supply method further includes: expanding the

compressed boil-off gas, wherein the expanded boil-off gas is sent to Step 4) to be supplied as fuel for the Otto cycle engine.

[51] Preferably, the fuel supply method further includes: cooling the compressed boil-off gas through heat exchange between the compressed boil-off gas and the pressurized liquefied natural gas to be supplied to the vaporizer in Step 2), wherein the compressed and cooled boil-off gas is supplied as fuel to the Otto cycle engine.

【Advantageous Effects】

[52] The fuel supply system and method of a liquefied natural gas fueled ship according to the present invention enables supply of fuel while satisfying specifications of a fuel gas required for an Otto cycle engine.

[53] In particular, the fuel supply system and method according to the present invention can reduce operation costs using a high pressure pump and regasification equipment, which reduce areas and costs for equipment installation, as compared with a conventional system using a boil-off gas compressor. Further, the conventional system fails to secure the methane number or more required for the engine even using the high pressure pump and the regasification equipment, whereas the fuel supply system according to the present invention can secure the methane number required for the engine.

[54] In addition, the fuel supply system and method according to the present invention resupplies surplus boil-off gas to the storage tank through reliquefaction, thereby minimizing the amount of boil-off gas consumed through spontaneous vaporization.

[55] Further, although load applied to an engine of a ship is constantly changed during navigation of the ship, the fuel supply system and method according to the present invention can supply a fuel gas while satisfying requirements for flux, temperature and pressure of the fuel gas corresponding to change of the engine load.

[56] In particular, the fuel supply system and method according to the present invention can efficiently cope with change of the engine load through control of the fluid of the high pressure pump and the temperature and pressure of the equipment and can maintain a constant temperature and pressure for engine fuel.

【DESCRIPTION OF DRAWINGS】

[57] FIG. 1 is a schematic diagram of a conventional fuel supply system of an LNG carrier.

[58] FIG. 2 is a schematic diagram of a fuel supply system of a liquefied natural gas fueled ship according to one exemplary embodiment of the present invention.

【BEST MODE】

[59] 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.

[60] Hereinafter, exemplary embodiments of the present invention will be described in detail 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.

[61] Although liquefied natural gas will be described by way of example in the following embodiments, it should be understood that the present invention may be applied to various kinds of liquefied gas and the following embodiments may be modified in different ways and do not limit the scope of the present invention.

[62] In addition, a fluid in each line in the following embodiments may be in a liquid phase, in a gas/liquid mixed phase, in a gas phase, or in a supercritical fluid phase depending upon system operation conditions.

[63] Further, although a liquefied natural gas (LNG) carrier adapted to carry LNG as freight is described as a ship by way of example in the following embodiments, the embodiments of the present invention may be applied not only to a merchant ship including a storage tank adapted to store LNG therein, but also to any type of ship including an LNG fueled engine and capable of generating propulsion force or power by driving the engine.

[64]

[65] FIG. 2 is a schematic diagram of a fuel supply system of a liquefied natural gas fueled ship according to one exemplary embodiment of the present invention. Hereinafter, a system and method for supplying fuel in a liquefied natural gas fueled ship according to one exemplary embodiment of the present invention will be described with reference to FIG. 2.

[66] Referring to FIG. 2, the fuel supply system according to this embodiment

includes a storage tank 10 adapted to store liquefied natural gas therein and an LNG fuel line LL along which the LNG stored in the storage tank 10 is supplied to engines ME, GE.

[67] According to this embodiment, the storage tank 10 adapted to store the LNG therein may be a membrane tank designed to store LNG having an extremely low temperature at normal pressure or a Type C tank designed to store LNG having an extremely low temperature at a relatively high pressure and may be selected from among these tanks depending upon an installation location and capacity thereof. Preferably, the storage tank 10 according to this embodiment is a membrane tank.

[68] In this embodiment, the engines receiving LNG fuel along the LNG fuel line LL may be Otto cycle engines ME, GE.

[69] In this embodiment, the Otto cycle engines may include an X-DF (eXtra long stroke dual fuel) engine ME acting as a 2-stroke dual fuel main engine (2-stroke DFME) and corresponding to a main propulsion engine of the ship; and assistant engines GE for power generation acting as a 4-stroke dual fuel diesel generator (4-stroke DFDG) engine, in which the X-DF engine ME and the power generation engines GE are fueled by different types of natural gas having different specifications.

[70] For example, according to this embodiment, the X-DF engine ME requires a natural gas fuel having a pressure of about 18 barg, a temperature of about 0°C to 60°C, and a methane number of about 80 or more, and the power generation engines GE require a natural gas fuel having a pressure of about 5 barg, a temperature of about 0°C to 60°C, and a methane number of about 80 or more.

[71] Accordingly, in order to supply LNG to the engines ME, GE while satisfying such requirements for a fuel gas, it is necessary to heat, vaporize and pressurize LNG having an extremely low temperature and stored in a liquid phase at normal pressure while regulating the methane number of the LNG.

[72] In order to allow LNG stored in the storage tank 10 to be supplied to the Otto cycle engines ME, GE as a fuel gas satisfying requirements of pressure, temperature and methane number for the Otto cycle engines ME, GE, the LNG fuel line LL according to this embodiment is provided with a fuel supply pump 11 that discharges the LNG from the storage tank 10; a high pressure pump 20 that pressurizes the LNG discharged from the storage tank by the fuel supply pump 11; a vaporizer 30 that vaporizes the LNG pressurized by the high pressure pump 20; an expansion valve 40

that adiabatically expands natural gas vaporized by the vaporizer 30; and a gas/liquid separator 50 separating a gas-liquid mixture generated by expansion of the natural gas by the expansion valve 40 into gas and liquid.

[73] According to this embodiment, the fuel supply pump 11 may be disposed inside the storage tank 10, preferably, at a lower portion of the interior of the storage tank 10 near a bottom surface of the storage tank 10. That is, the fuel supply pump 11 suctions LNG stored at the lowermost portion of the storage tank 10 to supply the LNG to the high pressure pump 20.

[74] In addition, the fuel supply pump 11 delivers the LNG stored in the storage tank 10 from the interior of the storage tank 10 to the high pressure pump 20, and the discharge pressure and flux of the LNG may be determined based on the size of the storage tank 10, pressure drop of a pipe connecting the fuel supply pump 11 to the high pressure pump 20, the amount of the fuel gas to be supplied to the engines ME, GE, and the like.

[75] According to this embodiment, the high pressure pump 20 may pressurize the LNG having an extremely low temperature and discharged by the fuel supply pump 11 to high pressure. While the LNG is pressurized to high pressure by the high pressure pump 20, the temperature of the LNG is increased. Preferably, the LNG is kept in a liquid phase even with increase in temperature thereof.

[76] For example, the high pressure pump 20 may pressurize LNG discharged from the storage tank 10 and having a pressure of about 1.2 bar and a temperature of about -163°C to a pressure of about 300 bar. Here, the LNG pressurized by the high pressure pump 20 is in a liquid phase having a pressure of about 300 bar and a pressure of -154°C.

[77] Further, the high pressure pump 20 according to this embodiment may be a piston type and may be configured to adjust the flux of LNG by controlling the rate of rotation thereof.

[78] According to this embodiment, the vaporizer 30 acts as a heat exchanger for heating the LNG, which has been pressurized to high pressure by the high pressure pump 20, using a heat source, to allow the pressurized LNG to be partially or entirely vaporized into a gas phase by heat energy in the vaporizer 30.

[79] For example, the vaporizer 30 heats the pressurized LNG to a temperature of about -50°C and natural gas vaporized by the vaporizer 30 may have a pressure of

about 300 bar and a temperature of -50°C.

[80] The heat source for heating the pressurized LNG in the vaporizer 30 may be steam or glycol water. The glycol water may be obtained by heating using waste heat recovered from sea water or a combustion apparatus in the ship. It should be understood that heat source of the vaporizer 30 according to the present invention is not limited thereto.

[81] According to this embodiment, the expansion valve 40 may be a Joule-Thomson valve adapted to adiabatically expand high pressure natural gas having passed through the vaporizer 30. While passing through the expansion valve 40, the high pressure natural gas may be cooled through expansion. Here, decrease in temperature of a fluid is more significant with increasing difference in degree of expansion before and after passage of the fluid through the expansion valve 40.

[82] According to this embodiment, the expansion valve 40 may be configured to adiabatically expand the high pressure natural gas to a pressure of about 17 bar.

[83] For example, in order to supply LNG as a fuel gas to the Otto cycle engine, particularly the X-DF engine ME, the expansion valve 40 may expand the high pressure natural gas, which has passed through the vaporizer 30, to a pressure of about 17 bar, and the natural gas having passed through the expansion valve 40 may have a pressure of about 17 bar and a temperature of -102.5°C and forms a gas-liquid mixture while being cooled by expansion.

[84] Further, in order to supply LNG as a fuel gas to the Otto cycle engine, particularly the power generation engine GE, the expansion valve 40 may expand the high pressure natural gas, which has passed through the vaporizer 30, to a pressure of about 7 bar, and the natural gas having passed through the expansion valve 40 may have a pressure of about 7 bar and a temperature of -122.5°C.

[85] According to this embodiment, the gas/liquid separator 50 separates the gas-liquid mixture formed in the expansion valve 40 into gas and liquid, in which the liquid component separated from the mixture is returned back to the storage tank 10 along an LNG recovery line RL connected from a lower portion of the gas/liquid separator 50 to the interior of the storage tank 10 and the gas component separated from the mixture is supplied as fuel to the Otto cycle engines ME, GE through the LNG fuel line LL connected to an upper portion of the gas/liquid separator 50.

[86] In this embodiment, the gas/liquid separator 50 is used as a means for

controlling the methane number of the fuel gas supplied to the engines ME, GE.

[87] Herein, the methane number refers to a numerical value of resistance against knocking, which refers to a phenomenon due to compression and explosion of an air-fuel mixture through abnormally advanced spontaneous ignition during the upward stroke of a piston in a cylinder of an engine. Strong noise and impact are accompanied with the knocking phenomenon, thereby causing deterioration in lifespan and output of the engine and engine output. Accordingly, a fuel to be supplied to the engine is controlled to have a methane number required for the engine.

[88] The methane number of the fuel increases with decreasing carbon number of the fuel or increasing ratio of hydrogen/carbon, and a higher methane number indicates higher resistance against knocking.

[89] According to this embodiment, the gas component separated from the gas-liquid mixture by the gas/liquid separator 50 to be supplied as fuel to the engines ME, GE is mainly composed of methane (CH_4) and may include trace amounts of heavier hydrocarbons and the liquid component separated from the gas-liquid mixture by the gas/liquid separator 50 to be returned back to the storage tank 10 is mainly composed of heavier hydrocarbons, such as ethane, propane, butane, and the like.

[90] As such, since the gas/liquid separator 50 according to this embodiment enables methane having a low carbon number to be mainly supplied as fuel, a fuel gas having a high methane number can be supplied to the engines ME, GE.

[91] According to this embodiment, the fuel supply system is operated such that the gas-liquid mixture to be supplied to the gas/liquid separator 50, the gas component separated by the gas/liquid separator 50 and discharged to the LNG fuel line LL, and the liquid component separated by the gas/liquid separator 50 and discharged to the LNG recovery line RL have components as listed in Table 1.

[92] The composition of the fluid shown in Table 1 is obtained by HYSYS simulation based on assumption that the fluid is LNG supplied at a flow rate of 500 kg/hr by the fuel supply pump 11 and having a pressure of about 1.2 bar and a temperature of -163°C . As shown in Table 1, the gas component separated by and discharged from the gas/liquid separator 50 has a high concentration of methane and a low fraction of heavy hydrocarbon, and the liquid component separated by and discharged from the gas/liquid separator 50 has a high fraction of heavy hydrocarbon.

[93] Table 1 shows main components only and omits fractions of n-butane, iso-

pentane, nitrogen (N₂), carbon dioxide (CO₂), and the like, which can be contained in trace amounts. Therefore, it should be noted that the sum of the fractions of components shown in Table 1 may not necessarily be 1.0000.

[94]

[95] Table 1

	Gas-liquid mixture (Inlet)	Gas component (Outlet)	Liquid component (Outlet)
Methane	0.8709	0.9943	0.6196
Ethane	0.0854	0.0056	0.2479
Propane	0.0311	0.0001	0.0944
i-Butane	0.0116	0.0000	0.0351

[96]

[97] Since the methane number is determined by the composition of a fuel gas to be supplied to engines and LNG mainly consists of methane together with trace amounts of ethane, propane, butane, pentane, nitrogen, carbon dioxide, and the like, the composition of the fuel gas to be supplied to the engines may be changed depending upon characteristics of the fuel supply system and thus the methane number is also changed.

[98] According to this embodiment, LNG stored at the lowermost portion of the storage tank 10 is delivered by the fuel supply pump 11 to be vaporized and supplied as fuel. Thus, since the LNG has a higher methane number than boil-off gas which is generated in the storage tank 10 through spontaneous vaporization and has high mole fractions of heavier hydrocarbon components such as ethane, propane, and the like, the fuel supply system according to this embodiment can supply more suitable fuel. Further, upon supply of vaporized natural gas to the Otto cycle engine requiring a medium or low pressure fuel, instead of a diesel cycle engine requiring a relatively high pressure engine, through vaporization of natural gas having a liquid phase using the high pressure pump 20 and the vaporizer 30, the fuel supply system according to this embodiment can supply natural gas to the engines after adjusting the methane number of the natural gas using the gas/liquid separator 50.

[99] According to this embodiment, the gas component separated by the gas/liquid separator 50 may be supplied as fuel to the engines ME, GE, and the LNG fuel line LL disposed downstream of the gas/liquid separator 50 may be further provided with a fuel gas heater 60 that heats the fuel gas separated by the gas/liquid separator 50 to be supplied to the engines ME, GE to a temperature required for the engines ME, GE, as shown in FIG. 2.

[100] In this embodiment, the fuel gas to be supplied to the engines ME, GE may be heated to about 45°C by the fuel gas heater 60.

[101] Further, although the LNG fuel line LL according to this embodiment is illustrated as extending from the storage tank 10 to the Otto cycle engine in FIG. 2, it should be understood that the LNG fuel line LL may be branched off upstream of the X-DF engine ME and the power generation engine GE, and downstream of the fuel gas heater 60 to be connected to each of the engines and may supply a fuel gas satisfying fuel requirement for each engine. However, it should be noted that branch-off points according to the present invention are not limited thereto.

[102] In this embodiment, as shown in FIG. 2, the LNG fuel line LL extends from the storage tank 10 and is connected to the X-DF engine ME, and a fuel gas branch line LB is branched off from the LNG fuel line LL upstream of the X-DF engine ME to supply the LNG to the power generation engine GE. The fuel gas branch line LB may be further provided with a decompression valve 70 that reduces the pressure of the fuel gas introduced from the LNG fuel line LL into the fuel gas branch line LB so as to satisfy the fuel requirement for the power generation engine GE.

[103] That is, the LNG stored in the storage tank 10 is supplied to the engines ME, GE after pressurization, vaporization and expansion along the LNG fuel line LL. Here, the LNG fuel line LL extends from the storage tank 10 to the Otto cycle engines ME, GE to allow the LNG fuel to be supplied only to the X-DF engine ME. Further, upon simultaneous supply of the fuel gas to both the X-DF engine ME and the power generation engine GE, the pressure and temperature of the fuel gas to be supplied to the X-DF engine ME may be adjusted to satisfy the fuel requirement for the X-DF engine ME by controlling the high pressure pump 20, the vaporizer 30, the expansion valve 40, and the pressure of the fuel gas to be supplied to the power generation engine GE may be adjusted to satisfy the fuel requirement for the power generation engine GE using the decompression valve 70.

[104] According to this embodiment, the fuel gas supplied to the X-DF engine ME through the LNG fuel line LL may have a pressure of about 17 bar and a temperature of about 45°C, and the fuel gas supplied to the power generation engine GE after being branched off from the LNG fuel line LL to the fuel gas branch line LB and decompressed through the decompression valve 70 may have a pressure of about 6.5 bar and a temperature of about 45°C.

[105] In addition, when the LNG is supplied as fuel to the power generator engines GE along the LNG fuel line LL, the compressed and vaporized natural gas may be expanded to about 7 bar by the expansion valve 40.

[106] Further, according to this embodiment, as shown in FIG. 2, the LNG fuel supply line LL may be further provided with an LNG cooler 31 disposed between the high pressure pump 20 and the vaporizer 30 to perform heat exchange between the LNG pressurized by the high pressure pump 20 and the liquid component separated by the gas/liquid separator 50 to be returned back to the storage tank 10 along the LNG recovery line RL.

[107] For example, in the LNG cooler 31, heat exchange occurs between the LNG pressurized to a pressure of about 300 bar and a temperature of about -154°C by the high pressure pump 20 and the liquid component separated by the gas/liquid separator 50 to be returned back to the storage tank 10 along the LNG recovery line RL and having a temperature of about -122.5°C, such that the pressurized LNG is preheated before supply to the vaporizer 40 and the liquid component is cooled before returning back to the storage tank 10. The pressurized LNG discharged from the LNG cooler 31 after heat exchange and supplied to the vaporizer 40 may have a pressure of about 300 bar and a temperature of -149.3°C, and the liquid component discharged from the LNG cooler after heat exchange and supplied to the storage tank 10 may have a temperature of about -140°C to -152°C.

[108] As such, according to this embodiment, the liquid component separated by the gas/liquid separator 50 to be returned back to the storage tank 10 may be cooled to a lower temperature before returning back to the storage tank 10, thereby minimizing the amount of boil-off gas generated in the storage tank 10.

[109] The fuel supply system according to one embodiment of the invention may further include a boil-off gas fuel line GL along which boil-off gas generated in the storage tank 10 through spontaneous vaporization is supplied to the Otto cycle engines ME, GE together with the LNG fuel line LL along which the LNG is supplied to the engines ME, GE using the high pressure pump 20 and the vaporizer 30.

[110] In this embodiment, the boil-off gas fuel line GL may extend from the storage tank 10 to the LNG fuel line LL, preferably, downstream of the fuel gas heater 60, as shown in FIG. 2.

[111] The boil-off gas fuel line GL may further include a boil-off gas branch line

GB1 branched off from the boil-off gas fuel line GL and connected to the gas/liquid separator 50 of the LNG fuel line LL. The boil-off gas branch line GB1 may be provided with a boil-off gas expansion valve 41 which adiabatically expands a fluid supplied to the gas/liquid separator 50.

[112] The boil-off gas fuel line GL may be provided with a multistage compressor MC that compresses the boil-off gas discharged from the storage tank 10 and a boil-off gas cooler 32 that cools the boil-off gas compressed by the multistage compressor MC.

[113] The multistage compressor MC may include a plurality of compression units adapted to compress the boil-off gas through multiple stages and a plurality of intercoolers each disposed downstream of each compression unit to cool the boil-off gas compressed to have an increased temperature.

[114] According to this embodiment, the multistage compressor MC is a means for treating the boil-off gas generated in the storage tank 10 and may act as a means for supplying the boil-off gas directly to the power generation engine GE or through the gas/liquid separator 50 when there is a problem of failure of the high pressure pump 20 or the vaporizer 30.

[115] The multistage compressor MC according to this embodiment may be a two-stage compressor including two compression units and two intercoolers to compress the boil-off gas through two stages or a single-stage compressor including one compression unit and one intercooler to compress the boil-off gas through one stage.

[116] In the boil-off gas cooler 32 according to this embodiment, heat exchange occurs between the boil-off gas compressed by the multistage compressor MC and the LNG pressurized by the high pressure pump 20 in the LNG fuel line LL such that the boil-off gas compressed by the multistage compressor MC is cooled by cold heat of the LNG pressurized by the high pressure pump 20.

[117] That is, the LNG pressurized by the high pressure pump 20 is discharged from the boil-off gas cooler 32 after being heated thereby and the boil-off gas compressed by the multistage compressor MC is discharged from the boil-off gas cooler 32 after being cooled thereby.

[118] Preferably, the boil-off gas cooler 32 is disposed downstream of the LNG cooler 31. That is, the LNG pressurized by the high pressure pump 20 may be supplied to the vaporizer 30 after primary heating by the LNG cooler 31 through heat exchange

with the reliquefied natural gas separated by the gas/liquid separator 50 to be returned back to the storage tank 10, and then secondary heating by the boil-off gas cooler 32 through heat exchange with the boil-off gas compressed by the multistage compressor MC.

[119] In addition, the fuel supply system according to this embodiment may further include a cooler by-pass line GB along which the compressed boil-off gas is sent downstream of the boil-off gas cooler 32 after bypassing the boil-off gas cooler 32. Preferably, the boil-off gas generated in the storage tank 10 through spontaneous vaporization is compressed by the multistage compressor MC and is then supplied downstream of the fuel gas heater 60 after by-passing the boil-off gas cooler 32 along the cooler by-pass line GB. Further, boil-off gas generated during operation of the high pressure pump 20 may be compressed by the multistage compressor MC, cooled by the boil-off gas cooler 32, expanded by the boil-off gas expansion valve 41, and then supplied to the gas/liquid separator 50 along the boil-off gas branch line GB1.

[120] The boil-off gas expansion valve 41 may expand the boil-off gas to the same pressure as the expansion valve 40 of the LNG fuel line LL. Further, the boil-off gas cooled by the boil-off gas cooler 32 may be cooled to the temperature of the LNG supplied to the gas/liquid separator 50 along the LNG fuel line LL, that is, to about -50°C in this embodiment.

[121] That is, the boil-off gas supplied to the gas/liquid separator 50 along the boil-off gas branch line GB1 and the LNG supplied to the gas/liquid separator 50 along the LNG fuel line LL have the same pressure and the same temperature to prevent deterioration in performance of gas/liquid separation.

[122] Further, although not shown in the drawings, the fuel supply system according to this embodiment may be provided with a gas combustion unit (GCU) as a means for treating the boil-off gas generated in the storage tank 10, instead of the boil-off gas fuel line GL. That is, the boil-off gas generated in the storage tank 10 may be burnt off instead of being used as fuel for the Otto cycle engines.

[123]

[124] As described above, the fuel supply system and method of the LNG fueled ship according to the present invention relate to a system and method for supplying fuel gas to engines of an LFS, particularly a ship to which Otto cycle engines such as a low pressure 2-stroke dual fuel main engine (2SDFME) and a dual fuel diesel

generator (DFDG) engine are applied. According to the present invention, the fuel supply system can supply fuel while satisfying fuel gas conditions for the low pressure Otto cycle engines using the high pressure pump 20 adapted to pressurize LNG in a liquid phase to high pressure, the vaporizer 30 adapted to vaporize the pressurized LNG, the expansion valve 40 adapted to adiabatically expand the vaporized natural gas, and the gas/liquid separator 50 adapted to separate a gas-liquid mixture formed by expansion into gas and liquid. In addition, the fuel supply system and method according to the present invention employs the high pressure pump, thereby achieving reduction in operation costs, particularly energy costs, installation areas and equipment costs, as compared with a conventional system using a boil-off gas compressor.

[125] Further, upon supply of fuel to the low pressure Otto cycle engine, the fuel supply system and method according to the present invention can control the methane number of the fuel using the high pressure pump 20 and the vaporizer 30 and allows some of vaporized natural gas to be resupplied to the storage tank 10 through reliquefaction, thereby minimizing the amount of boil-off gas generated in the storage tank 10 through spontaneous vaporization.

[126] Further, although load applied to the ship engines is constantly changed during navigation, the fuel supply system and method according to the present invention can supply a fuel gas while satisfying requirements for flux, temperature and pressure of the fuel gas corresponding to change of the engine load by controlling the flux of the high pressure pump 20 and the temperature and pressure of each of devices constituting the system through a controller (not shown).

[127] 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.

CLAIMS

1. A fuel supply system of a liquefied natural gas fueled ship, comprising:
 - an Otto cycle engine fueled by liquefied natural gas and employing an Otto cycle;
 - a high pressure pump pressurizing liquefied natural gas discharged from a storage tank;
 - a vaporizer vaporizing the liquefied natural gas pressurized by the high pressure pump;
 - an expansion valve expanding the natural gas vaporized by the vaporizer;
 - a gas/liquid separator separating a gas-liquid mixture formed by the expansion valve into gas and liquid; and
 - an LNG cooler performing heat exchange between the liquefied natural gas pressurized by the high pressure pump to be supplied to the vaporizer and the liquid separated by the gas/liquid separator to be returned back to the storage tank,
 - wherein the liquid separated by the gas/liquid separator is returned back to the storage tank and the gas separated by the gas/liquid separator is supplied as fuel for the Otto cycle engine to adjust a methane number of the natural gas fuel supplied to the Otto cycle engine, and
 - the pressurized liquefied natural gas to be supplied to the vaporizer is heated and the liquid to be returned back to the storage tank is cooled in the LNG cooler.
2. The fuel supply system according to claim 1, further comprising:
 - a fuel gas heater heating the natural gas fuel separated by the gas/liquid separator to be supplied as fuel to the Otto cycle engine,
 - wherein the natural gas fuel having passed through the expansion valve and the fuel gas heater has a temperature required for the Otto cycle engine.
3. The fuel supply system according to claim 2, wherein the Otto cycle engine comprises:
 - an X-DF engine provided as a two-stroke engine for propulsion of the ship;
 - and

a dual fuel diesel generator (DFDG) provided as a four-stroke engine for generation of assistant power of the ship,

wherein the natural gas fuel having passed through the fuel gas heater is adjusted to have a temperature and pressure required for the X-DF engine.

4. The fuel supply system according to claim 3, further comprising:
a decompression valve decompressing the natural gas fuel to be supplied to the DFDG,

wherein the natural gas fuel having passed through the fuel gas heater and the decompression valve is adjusted to have a pressure required for the DFDG.

5. The fuel supply system according to any one of claims 1 to 4, further comprising:

an LNG fuel line providing a path through which the liquefied natural gas is supplied from the storage tank to the engine through the high pressure pump and the vaporizer; and

a boil-off gas fuel line providing a path through which boil-off gas generated in the storage tank is supplied as fuel for the engine,

wherein the boil-off gas fuel line comprises compression units compressing the boil-off gas and an intercooler cooling the boil-off gas heated through compression by the compression units.

6. The fuel supply system according to claim 5, further comprising:
a boil-off gas cooler performing heat exchange between the compressed and cooled boil-off gas and the pressurized liquefied natural gas to be supplied to the vaporizer,

wherein the pressurized liquefied natural gas to be supplied to the vaporizer is heated and the boil-off gas is cooled in the boil-off gas cooler.

7. The fuel supply system according to claim 6, further comprising:
a boil-off gas expansion valve expanding the boil-off gas cooled by the boil-off gas cooler to the same pressure as the gas-liquid mixture supplied to the gas/liquid separator.

8. The fuel supply system according to claim 5, further comprising:
 - a controller controlling a temperature, pressure and flux of a fluid supplied to the high pressure pump, the vaporizer, the expansion valve and the gas/liquid separator or a fluid discharged from the high pressure pump, the vaporizer, the expansion valve and the gas/liquid separator according to variation in load of the Otto cycle engine.
9. The fuel supply system according to any one of claims 1 to 3, further comprising:
 - a gas combustion unit (GCU) treating boil-off gas generated in the storage tank.
10. A fuel supply method of a liquefied natural gas fueled ship, comprising:
 - a pressurization step in which liquefied natural gas discharged from a storage tank is pressurized using a high pressure pump;
 - a vaporization step in which the liquefied natural gas pressurized in the pressurization step is vaporized into natural gas using a vaporizer;
 - an expansion step in which the natural gas vaporized in the vaporization step is expanded;
 - a gas-liquid separation step in which a gas-liquid mixture formed by expansion in the expansion step is separated into gas and liquid; and
 - a fuel supply step in which the liquid separated in the gas-liquid separation step is resupplied to the storage tank and the gas separated in the gas-liquid separation step is supplied as fuel to an Otto cycle engine,
 - whereby the liquefied natural gas stored in the storage tank is supplied as a fuel satisfying requirements of temperature, pressure and methane number for the Otto cycle engine, and further comprising:
 - a heat exchange step in which the liquid to be resupplied to the storage tank in the fuel supply step is heat-exchanged with the pressurized liquefied natural gas before vaporization of the pressurized liquefied natural gas in the vaporization step, wherein the pressurized liquefied natural gas is vaporized after being heated by the liquid to be resupplied to the storage tank and the liquid to be returned back to

the storage tank is supplied to the storage tank after being cooled by the pressurized liquefied natural gas.

11. The fuel supply method according to claim 10, further comprising:
a heating step in which the gas fuel separated to be supplied to the engine in the fuel supply step is heated,

wherein a fluid having passed through the heating step has a pressure, temperature and methane number required for the Otto cycle engine.

12. The fuel supply method according to claim 11, further comprising:
a decompression step in which the gas fuel heated in the heating step is decompressed,

wherein a fluid having passed through the decompression step has a pressure, temperature and methane number required for the Otto cycle engine.

13. The fuel supply method according to claim 10, further comprising:
a compression step in which boil-off gas is discharged from the storage tank and compressed by a compressor; and

a boil-off gas fuel supply step in which the boil-off gas compressed in the compression step is supplied as fuel to the Otto cycle engine,

wherein the compressed boil-off gas has a pressure and temperature required for the Otto cycle engine.

14. The fuel supply method according to claim 13, further comprising:
a boil-off gas expansion step in which the compressed boil-off gas is expanded,

wherein the boil-off gas expanded in the boil-off gas expansion step is sent to the gas-liquid separation step to be supplied as fuel for the Otto cycle engine.

15. The fuel supply method according to claim 13, further comprising:
a boil-off gas cooling step in which the compressed boil-off gas is cooled through heat exchange between the compressed boil-off gas and the pressurized liquefied natural gas to be supplied to the vaporizer in the vaporization step,

wherein the compressed and cooled boil-off gas is supplied as fuel to the Otto cycle engine.