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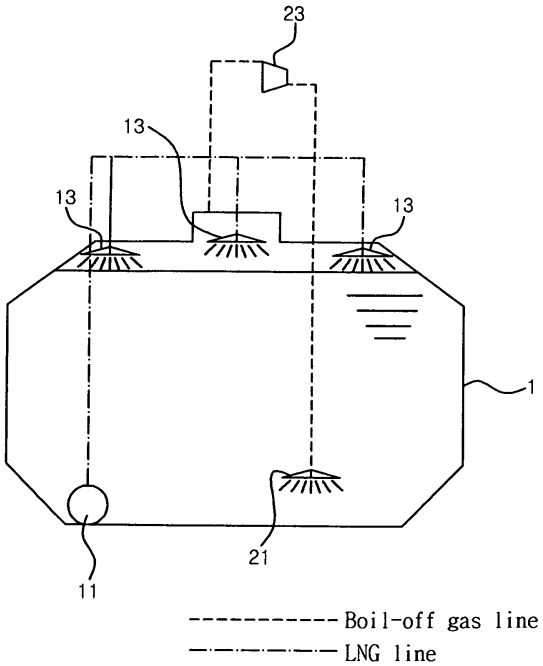
(54) LNG tank and method of treating boil-off gas

(57) An LNG storage tank and a method of treating boil-off gas using the same are disclosed. The LNG storage tank and the method of treating boil-off gas enable the pressure of the LNG storage tank to be maintained in a stable state without consuming boil-off gas generated in the LNG tank as propulsion fuel or without re-liquefying the boil-off gas. The storage tank comprises a thermal insulation wall, and has strengthened structure to permit a pressure increase resulting from heat influx to the LNG tank and boil-off gas generation. The method comprises permitting a pressure increase by the boil-off gas generation and LNG cargo temperature increase in the storage tank without treating the generated boil-off gas in the storage tank, so that the boil-off gas is accumulated without extracting or loss in the storage tank.

Fig. 2



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates generally to a liquefied natural gas (LNG) storage tank and a method of treating boil-off gas using the same, and more particularly to an LNG storage tank that can store natural gas in a liquid state and a method of treating boil-off gas using the same.

2. Description of the Related Art

[0002] Generally, liquefied natural gas (LNG) is produced by cooling natural gas (NG) into a cryogenic liquid state at a production location and is transported by LNG carriers to a distant destination. At the destination, LNG is regasified through a floating storage and regasification unit (FSRU) or an unloading terminal on land and then supplied to consumers.

[0003] In the case where LNG is transported by an LNG regasification vessel (LNG-RV), LNG is regasified in the LNG-RV itself not through the FSRU or the unloading terminal.

[0004] Since the liquefaction of natural gas occurs at a cryogenic temperature of approximately -163 °C at ambient pressure, LNG is likely to be vaporized if the temperature of LNG increases slightly above -163 °C at ambient pressure. For example, in the case of LNG carriers, although an LNG storage tank is equipped with thermal insulation structure, it is impossible to completely prevent heat ingress to LNG through the storage tank, so that LNG is continuously vaporized and boil-off gas is generated in the LNG storage tank during the transportation of LNG by the LNG carrier.

[0005] When boil-off gas is generated in the LNG storage tank as described above, the pressure of the LNG storage tank increases and becomes dangerous.

[0006] Conventionally, to maintain the pressure of the LNG storage tank in a stable state, boil-off gas generated in the LNG storage tank is consumed as fuel for propulsion of the LNG carrier.

[0007] A steam turbine propulsion system driven by steam generated in boilers by burning boil-off gas and heavy fuel oil has a problem of low propulsion efficiency.

[0008] On the other hand, there is a dual fuel diesel electric propulsion system which uses compressed boil-off gas as fuel for the diesel engine and the system has higher propulsion efficiency than the steam turbine propulsion system. But there are many difficulties in maintenance due to a complicated integration of medium speed diesel engines and units for electric propulsion in the system. Furthermore, since boil-off gas must be supplied as fuel, this system employs a gas compression method which is more expensive in initial and operational costs compared with liquid compression.

[0009] In addition, such conventional methods using boil-off gas as fuel fails to achieve the highest efficiency of two-stroke slow speed diesel engine, which is generally adopted for marine use.

[0010] There is another method which re-liquefies the boil-off gas from the LNG tank and returns it to the tank. For this system, however, complicated and expensive re-liquefaction plant must be installed.

[0011] Furthermore, when the boil-off gas amount exceeds the capacity of the propulsion system or the re-liquefaction plant, the surplus must be burnt by a gas combustion unit or the like. And so, auxiliary units such as gas combustion units are installed and the valuable gas is lost by burning.

[0012] According to techniques disclosed in Korean Patent Laid-open Publication Nos. 2001-0014021, 2001-0014033, 2001-0083920, 2001-0082235, and 2004-0015249, etc., boil-off gas generation in the LNG storage tank is suppressed by maintaining the LNG storage tank at a high pressure of about 200 bars without installing an insulation wall on the LNG storage tank. However, since the LNG storage tank must have a significantly high thickness to withstand a high pressure of about 200 bars, there are problems of high manufacturing costs and requirement of additional components, such as a high-pressure compressor.

SUMMARY OF THE INVENTION

[0013] Therefore, the present invention has been made in view of the above problems, and an object of the present invention is to provide an LNG storage tank configured to maintain the LNG storage tank at a safe level without separately treating the boil-off gas, and a method of treating boil-off gas using the same.

[0014] In accordance with an aspect of the present invention, the above and other objects can be accomplished by the provision of an LNG storage tank comprising a thermal insulation wall and having strength to withstand a pressure increment caused by boil-off gas generated in the LNG storage tank to permit a pressure increase resulting from boil-off gas generation in the LNG storage tank.

[0015] In accordance with another aspect of the present invention, a method of treating boil-off gas is provided, comprising: permitting a pressure increase caused by boil-off gas generation in an LNG storage tank without treating

boil-off gas generated in the LNG storage tank, so that the boil-off gas is accumulated in the LNG storage tank.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The above and other objects, features and advantages of the present invention will become apparent from the following description of preferred embodiments given in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic view illustrating the conception of heat ingress and absorption of heat in an LNG storage tank for LNG carriers according to the present invention;
Fig. 2 is a schematic view illustrating an LNG storage tank for LNG carriers according to an exemplary embodiment of the present invention; and
Fig. 3 is a schematic diagram illustrating an LNG unloading method at an unloading terminal by using the LNG storage tank for the LNG carriers according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Exemplary embodiments of the present invention will be described in detail with reference to the accompanying drawings hereinafter.

[0018] An LNG storage tank of the present invention is applicable to an LNG carrier, a floating storage and regasification unit (FSRU), an unloading terminal on land, and an LNG regasification vessel (LNG-RV), etc.

[0019] Hereinafter, an LNG storage tank applicable to the LNG carrier will be described as an example.

[0020] Fig. 1 is a schematic view illustrating the conception of heat ingress and absorption of heat in an LNG storage tank for LNG carriers according to the present invention. In the prior art, the pressure of the LNG storage tank for the LNG carrier is maintained in a predetermined range, so that most of heat ingress into the LNG storage tank contributes to boil-off gas generation, all of which should be treated in the LNG carrier. On the other hand, according to the present invention, an LNG storage tank for an LNG carrier is constructed to permit a pressure increase therein, causing an increase in saturation temperature, whereby most of heat ingress is absorbed by large heat capacity of LNG and natural gas (NG) vapor in the storage tank, noticeably reducing the boil-off gas generation. For example, when the pressure of the LNG storage tank for the LNG carrier according to an exemplary embodiment becomes 0.7 bars from initial pressure of 0.06 bars, the saturation temperature is increased by about 6 K.

[0021] Fig. 2 is a schematic view illustrating an LNG storage tank for an LNG carrier according to an exemplary embodiment of the invention. The LNG storage tank 1 for the LNG carrier comprises an insulation wall built thereon and has an inner pressure of approximately 0.06 bars (gauge pressure) at the point of departure when LNG is loaded in an LNG production terminal. Then, as boil-off gas is generated in the LNG storage tank during the LNG carrier's voyage, the pressure of the LNG storage tank gradually increases. For example, when LNG is loaded into the LNG storage tank 1 of the LNG carrier at the location where LNG is produced, the LNG storage tank 1 has an inner pressure of 0.06 bars, and, when the LNG carrier arrives at a destination after a voyage of about 15~20 days, the inner pressure of the LNG storage tank 1 can increase to 0.7 bars (gauge pressure).

[0022] The LNG storage tank 1 for the LNG carrier according to the invention comprises the thermal insulation wall and is designed by taking account the pressure increase caused by boil-off gas generation, that is, to have sufficient strength to withstand a pressure increment caused by the boil-off gas generation. Thus, the boil-off gas generated in the LNG storage tank 1 is accumulated therein without any loss or extraction from the LNG tank during the LNG carrier's voyage.

[0023] For example, the LNG storage tank 1 for the LNG carrier according to the embodiment of the invention comprises the thermal insulation wall, and, preferably has construction capable of withstanding a pressure of 0.4 to 2 bars (gauge pressure), and more preferably a pressure of 0.6 to 1.5 bars (gauge pressure). Since such an LNG storage tank 1 of the present invention can be sufficiently embodied by constructing the storage tank 1 to have a high thickness or by suitably reinforcing a conventional LNG storage tank for LNG carriers through addition of a reinforcing steel structure thereto without significantly changing the design and construction of the conventional LNG storage tank, it is very economical in view of manufacturing costs.

[0024] Various conventional LNG storage tanks for LNG carriers with a thermal insulation (heat dissipation) wall built on the storage tank are known in the related art as described below. The thermal insulation wall is not shown in Fig. 1.

[0025] First, the LNG storage tank for the LNG carriers can be classified into an independent type tank and a membrane type tank. This classification of the LNG storage tank depends on whether or not the load of cargo directly acts on the thermal insulation wall, and is described in detail hereinafter.

[0026] In the following Table 1, GTT No. 96-2 and GTT Mark III have been renamed from GT and TGZ, respectively, when the names of Gaz Transport (GT) Corporation and Technigaz (TGZ) Corporation was changed to GTT (Gaz Transport & Technigaz) Corporation in 1999.

Table 1

Classification	Membrane Type		Independent Type	
	GTT Mark □	GTT No. 96-2	MOSS	IHI-SPB
Material-thickness of tank	SUS 304L-1.2 mm	Invar steel-0.7 mm	Al alloyed steel (5083)-50 mm	Al alloyed steel (5083) Max. 30 mm
Material for heat dissipation-thickness	Reinforced Polyurethane Foam-250 mm	Plywood Box+Perlite-530 mm	Polyurethane Foam-250 mm	Polyurethane Foam-250 mm

[0027] GT type and TGT type tanks are disclosed in US Patent Nos. 6,035,795, 6,378,722, and No. 5,586,513, US Patent Publication No. 2003-0000949, Korean Patent Laid-open Publication Nos. 2000-0011347 and 2000-0011346, etc.

[0028] Korean Patent Nos. 499710 and 0644217 discloses thermal insulation walls embodied according to other conceptions.

[0029] As such, there are many conventional LNG storage tanks for the LNG carriers having variously shaped thermal insulation walls, all of which are designed to suppress the boil-off gas generation as much as possible.

[0030] The present invention can be applied to the conventional LNG storage tank for the LNG carriers that have various shapes of thermal insulation walls, as described above. Most of the conventional LNG storage tanks for the LNG carrier are constructed to withstand a pressure of 0.25 bars or less, and to allow boil-off gas generated in the LNG storage tank to be consumed as the fuel for propulsion of the system or to be re-liquefied to maintain the LNG storage tank at 0.2 bars or less and to be discharged outside through a safety valve when the pressure of the storage tank increases over 0.2 ~ 0.25 bars.

[0031] In addition, the LNG storage tank according to the present invention is constructed to reduce the LNG tank pressure by reducing the local temperature and pressure increase. The LNG storage tank is maintained at a uniform temperature distribution by injecting boil-off gas having a higher temperature from an upper portion of the LNG storage tank toward a lower portion of the LNG storage tank and by spraying LNG from the lower portion of the LNG storage tank toward the upper portion of the LNG storage tank having a higher temperature.

[0032] In Fig. 2, the LNG storage tank 1 is provided at the lower portion with an LNG pump 11 and a boil-off gas injection nozzle 21, and is provided at the upper portion with an LNG spray 13 and a boil-off gas compressor 23. The boil-off gas having the higher temperature in the upper portion of the LNG storage tank 1 is injected into the lower portion of the LNG storage tank 1 through the boil-off gas nozzle 21 at the lower portion of the LNG storage tank 1 by the boil-off gas compressor 23. Additionally, LNG having the lower temperature in the lower portion of the LNG storage tank 1 can be sprayed toward the upper portion of the LNG storage tank 1 through the LNG spray 13 at the upper portion of the LNG storage tank 1 by the LNG pump 11. As a result, the temperature distribution of the LNG storage tank 1 can be uniformly maintained, which enables a reduction in the boil-off gas generation.

[0033] Further, if LNG is loaded in a sub-cooled state into an LNG carrier at a production terminal where LNG is produced, it is possible to further reduce the boil-off gas generation during LNG transportation to a destination. To prevent the pressure of an LNG storage tank for the LNG carrier from being lowered to a negative pressure (0 atm or less) after LNG is loaded in the sub-cooled state at the production terminal, a vapor region of an LNG storage tank may be filled with nitrogen.

[0034] Next, a method of treating boil-off gas using an LNG storage tank for LNG carriers according to the present invention will be described.

[0035] During the voyage of an LNG carrier, an LNG storage tank 1 according to the present invention permits a pressure increase in the LNG storage tank 1 caused by heat influx and boil-off gas generation therein without treating the boil-off gas, so that most of the heat influx to the LNG tank can be absorbed as internal energy of LNG and NG vapor in the LNG storage tank 1, and so, the LNG tank pressure increases only by a small portion corresponding to the saturation pressure at the increased LNG temperature by the increase in internal energy. Then, when the LNG carrier arrives at a destination, the boil-off gas accumulated in the LNG storage tank is treated at an unloading terminal.

[0036] Fig. 3 is a schematic diagram illustrating the construction for treating boil-off gas at an unloading terminal with the LNG storage tank for LNG carriers according to the exemplary embodiment of the present invention.

[0037] The unloading terminal is installed with a plurality of LNG storage tanks 2, a plurality of compressor 3, a re-condenser 4, a high pressure LNG pump P and a vaporizer 5.

[0038] When LNG is unloaded from the LNG storage tank of the LNG carrier to an LNG storage tank of the unloading terminal, additional boil-off gas can be generated due to inflow of LNG having a higher pressure into the LNG storage tank of the unloading terminal since the pressure of the LNG storage tank of the LNG carrier is higher than that of the

LNG storage tank of the unloading terminal.

[0039] The generated boil-off gas can be supplied to consumers after being compressed in multiple stages by a high pressure mode of the compressor 3 at the unloading terminal. Here, the boil-off gas compressed by a low pressure mode of the compressor 3 can be supplied to the consumers after being re-condensed by the re-condenser 4 and vaporized.

[0040] Instead of being supplied into the LNG storage tank 2 of the unloading terminal, LNG in the LNG storage tank 1 of the LNG carrier may be directly supplied to the re-condenser 4 so as not to generate boil-off gas due to higher LNG pressure than that of the LNG storage tank of the unloading terminal.

[0041] On the other hand, if the re-condenser 4 is not installed at the unloading terminal, LNG can be directly supplied to a suction side of the high pressure LNG pump P.

[0042] In the case where the plurality of LNG storage tanks 2 are installed at the unloading terminal as described above, when LNG is sent to the plural LNG storage tanks 2 of the unloading terminal, the boil-off gas generation can be minimized in the respective LNG storage tanks 2 due to dispersion of the boil-off gas generation to the plurality of LNG storage tanks 2, so that the boil-off gas can be accommodated in the respective LNG storage tanks 2 themselves at the unloading terminal.

[0043] Further, according to the invention, since the LNG storage tank of the LNG carrier is operated at higher pressure than an existing design pressure, it is possible to omit a process of filling boil-off gas or NG vapor, which is required to maintain the inner pressure of the LNG storage tank of the LNG carrier when unloading LNG from the LNG carrier to the unloading terminal as the flash gas is generated in the LNG tank of the LNG carrier.

[0044] Furthermore, if a conventional LNG storage tank of the unloading terminal or a floating storage and regasification unit (FSRU) or an LNG regasification vessel (LNG-RV) is modified or a new LNG storage tank of the unloading terminal or floating storage and regasification unit (FSRU) or LNG regasification vessel (LNG-RV) is built such that the storage pressure of the LNG storage tank corresponds to the pressure of the LNG storage tank of the LNG carrier according to the invention, it is possible to employ an existing unloading technique to these LNG storage tanks since there is no additional flash gas generation during unloading of LNG from the LNG carrier to any of these LNG storage tanks at the unloading terminal or FSRU or LNG-RV.

[0045] According to a conventional operating method, most of the boil-off gas generated in the LNG storage tank of the LNG carrier should be consumed as fuel for propulsion system or re-liquefied to lower the pressure of the LNG storage tank. According to the present invention, however, since the pressure of the LNG storage tank of the LNG carrier can be maintained by consuming or re-liquefying only reduced capacity or a portion of the boil-off gas, it is possible to apply the present invention to conventional LNG carriers configured to use the boil-off gas as propulsion fuel or with onboard re-liquefaction system.

[0046] According to the present invention, since restrictions on the LNG storage tank pressure maintenance during transportation of LNG are lifted, application of the present invention is not restricted to the case where the LNG carrier is operated without any boil-off gas treating apparatus and it can be used for conventional LNG carriers with boil-off gas treating equipment as well.

[0047] If the storage tank of an LNG-FSRU (Floating Storage and Regasification Unit) is constructed based on the present invention, the boil-off gas management for the LNG- FSRU can be more flexible and the re-condensing unit may not be required.

[0048] According to the present invention, an LNG-RV (Regasification vessel) can have above mentioned advantages of the LNG carrier and the LNG-FSRU.

[0049] As apparent from the above, according to the present invention, in the case of LNG carriers, during the voyage, boil-off gas can be accumulated in the LNG storage tank which is designed to withstand the increased pressure caused by boil-off gas generation and the accumulated boil-off gas can be treated at an unloading terminal when unloading. In this way, there is much flexibility in selection of propulsion system and system simplicity can be attained by the independency of the propulsion system.

[0050] Further, according to the present invention, in the case of the LNG carriers, it becomes unnecessary to employ various components for boil-off gas related equipment and propulsion system (such as a boiler/steam turbine, a re-liquefaction apparatus, a gas-based engine, a compressor for fuel gas supply etc.), which have been required in the prior art for treating the boil-off gas. Moreover, according to the present invention, it is possible to employ a high efficiency general purpose marine engine as a propulsion system.

[0051] Further, in the case of the LNG carriers, the LNG storage tank of the present invention can be very efficiently used along with the existing systems of treating boil-off gas or the re-liquefaction apparatus. In particular, even when the boil-off gas generation exceeds the capacity of a propulsion system or re-liquefaction plant, the surplus boil-off gas can be preserved in the LNG storage tank without any loss by burning, thereby providing cost savings in an LNG carrier operation.

[0052] Although particular embodiments of the present invention have been shown and described herein, it should be understood that various modifications, variations or corrections may readily occur to those skilled in the art, and thus,

the description and drawings herein should be interpreted by way of illustrative purpose without limiting the scope and sprit of the present invention.

Claims

1. An LNG storage tank comprising a thermal insulation wall and having strength to withstand a pressure increment caused by boil-off gas generation in the LNG storage tank so as to permit a pressure increase resulting from the generation of the boil-off gas in the LNG storage tank.

2. The LNG storage tank according to claim 1, designed to withstand a pressure of 0.3 ~ 2 bars (gauge pressure).

3. The LNG storage tank according to claim 1, designed to withstand a pressure of 0.6 ~ 1.5 bars (gauge pressure).

4. The LNG storage tank according to claim 1, manufactured by adding a reinforcing steel structure to an existing general LNG storage tank.

5. The LNG storage tank according to claim 1, wherein a temperature distribution in the LNG storage tank is uniformly maintained.

6. The LNG storage tank according to any one of claims 1 to 5, wherein boil-off gas having a higher temperature at an upper portion of the LNG storage tank is injected into a lower portion of the LNG storage tank having a lower temperature and LNG having a lower temperature at the lower portion of the LNG storage tank is sprayed into the upper portion of the LNG storage tank having a higher temperature.

7. The LNG storage tank according to claim 6, further comprising:

   an LNG pump and a LNG spray for LNG pumping; and
   a boil-off gas compressor and boil-off gas injection nozzle for boil-off gas injection.

8. The LNG storage tank according to claim 1, wherein the LNG storage tank is applicable to an LNG carrier, a floating storage and regasification unit (FSRU), an unloading terminal on land or an LNG regasification vessel (LNG-RV).

9. A method of treating boil-off gas, comprising: permitting a pressure increase caused by boil-off gas generation in an LNG storage tank without treating the boil-off gas generated in the LNG storage tank, so that the boil-off gas is accumulated in the LNG storage tank.

10. A method of treating boil-off gas, comprising: allowing most of heat influx into an LNG storage tank to be absorbed by increased internal thermal energy of LNG and NG within the LNG storage tank without treating the boil-off gas generated in the LNG storage tank, so that boil-off gas is accumulated in the LNG storage tank.

11. The method according to claim 9, wherein the LNG storage tank is permitted to have a pressure of 0.3 ~ 2 bars (gauge pressure).

12. The method according to claim 9, wherein the LNG storage tank is permitted to have a pressure of 0.6 ~ 1.5 bars (gauge pressure).

13. The method according to claim 9 or 10, wherein a temperature distribution in the LNG storage tank is uniformly maintained.

14. The method according to claim 9, wherein the LNG storage tank is applicable to an LNG carrier, a floating storage and regasification unit (FSRU), an unloading terminal on land or an LNG regasification vessel (LNG-RV).

15. The method according to claim 14, wherein boil-off gas accumulated in the LNG storage tank of the LNG carrier is treated at an unloading terminal after the LNG carrier arrives at a destination.

16. The method according to claim 15, wherein boil-off gas generated in an LNG storage tank of the unloading terminal when LNG is unloaded from the LNG storage tank for the LNG carrier is supplied to consumers after being compressed

by a high pressure compressor at the unloading terminal.

17. The method according to claim 15, wherein boil-off gas generated in an LNG storage tank of the unloading terminal when LNG is unloaded from the LNG storage tank for the LNG carrier is supplied to consumers after being compressed by a low pressure boil-off gas compressor, re-condensed and vaporized at the unloading terminal.

18. The method according to claim 15, wherein LNG in the LNG storage tank for the LNG carrier is supplied to consumers after being directly supplied from the LNG storage tank for the LNG carrier to either an inlet of a re-condenser or a suction side of a high pressure pump and vaporized at the unloading terminal.

19. The method according to claim 15, wherein LNG in the LNG storage tank for the LNG carrier is supplied to a plurality of LNG storage tanks at the unloading terminal, supplied from the plurality of LNG storage tanks of the unloading terminal to reduce flash gas regeneration effects in the unloading terminal.

20. The method according to claim 14, wherein each of the LNG storage tank of the unloading terminal or a floating storage and regasification unit (FSRU) or an LNG regasification vessel (LNG-RV) is constructed such that a storage pressure of the LNG storage tank of the unloading terminal or the floating storage and regasification unit (FSRU) or the LNG regasification vessel (LNG-RV) is increased to correspond to a storage pressure of the LNG storage tank of the LNG carrier.

Fig. 1

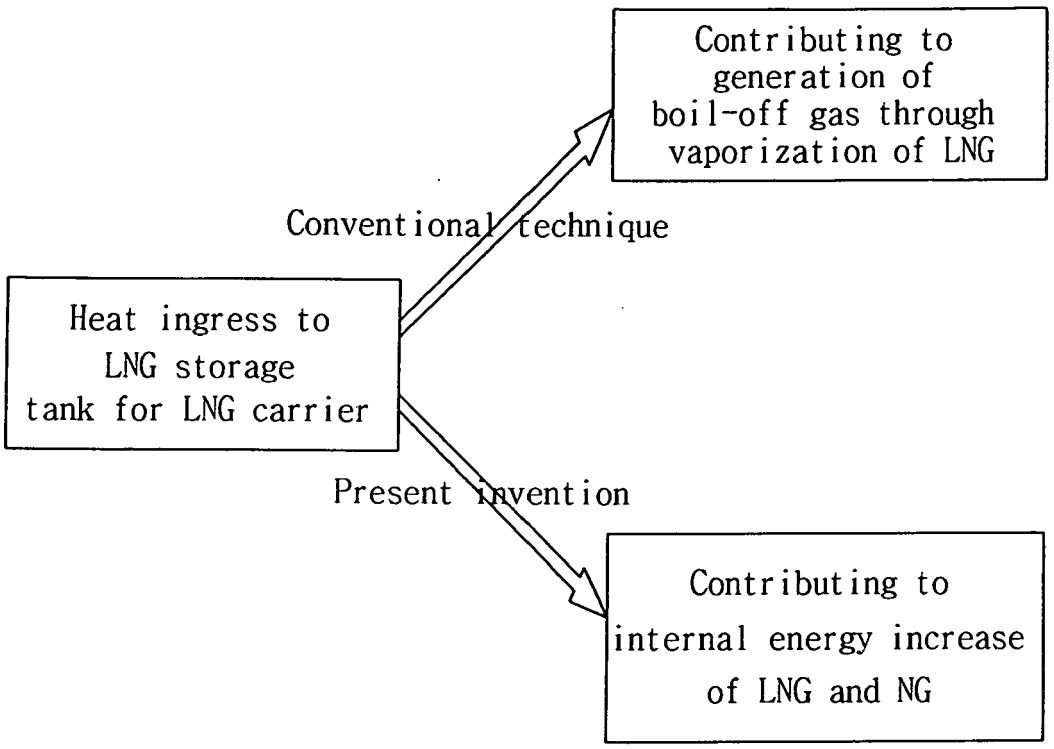

Contributing to generation of boil-off gas through vaporization of LNG
Conventional technique
Heat ingress to LNG storage tank for LNG carrier
Present invention
Contributing to internal energy increase of LNG and NG

Fig. 2

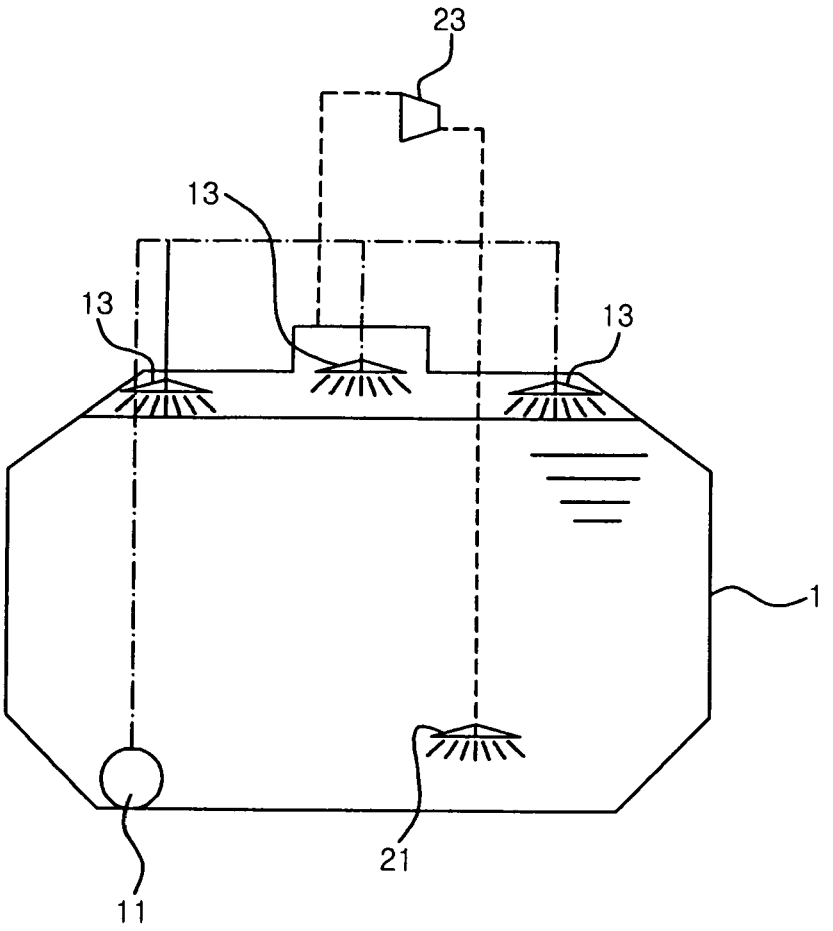
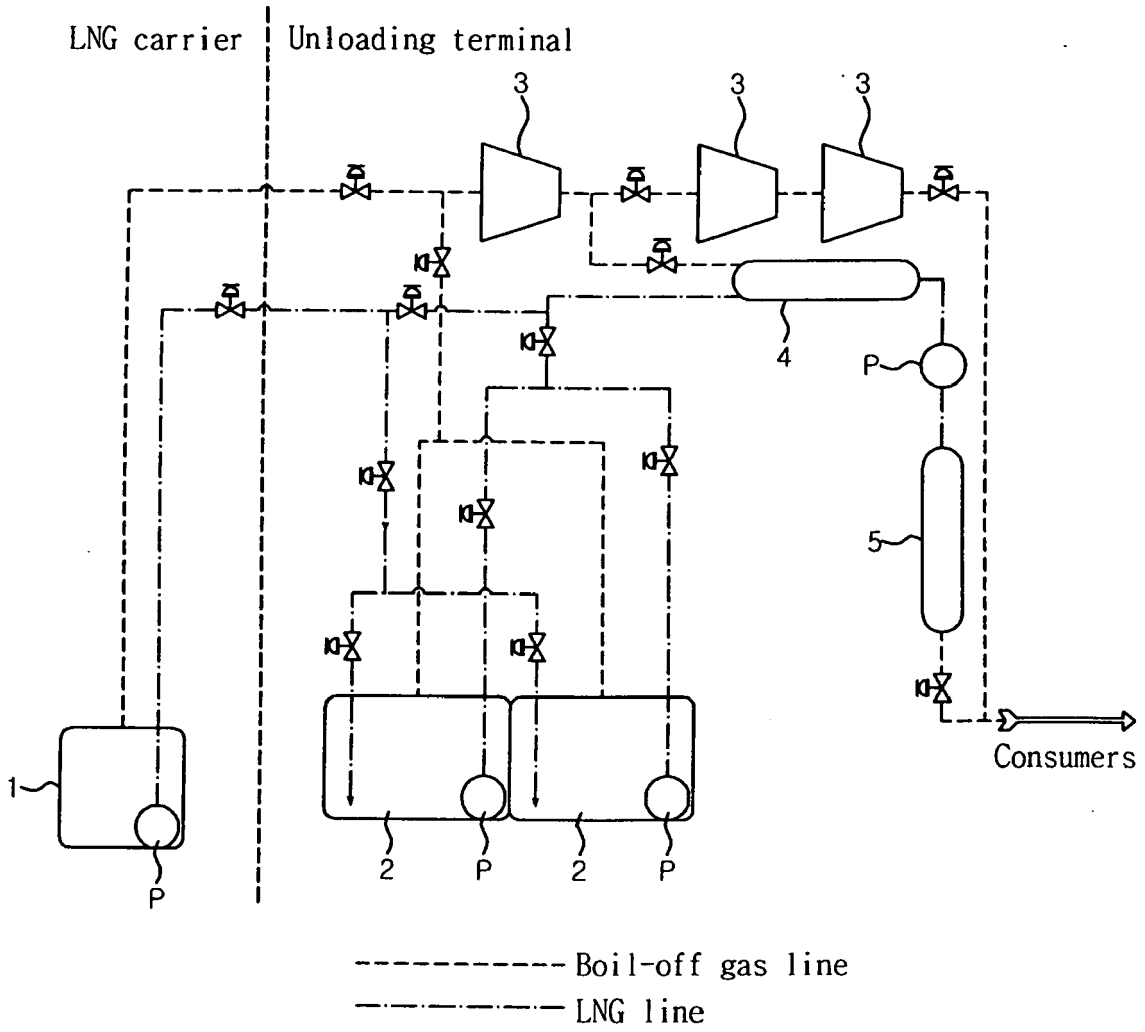


Fig. 3


LNG carrier
Unloading terminal
3
3
3
4
P
5
Consumers
1
P
2
P
2
P
Boil-off gas line
LNG line

REFERENCES CITED IN THE DESCRIPTION

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