

DESCRIPTION

Title of Invention: FUEL SUPPLY SYSTEM AND SHIP

Technical Field

[0001] The present disclosure relates to a fuel supply system for an internal combustion engine and a ship including the fuel supply system.

Background Art

[0002] Conventionally, fuel supply systems for internal combustion engines such as reciprocating engines and gas turbine engines to be installed on, for example, ships have been known. For example, Patent Literature 1 discloses a fuel supply system for a diesel engine. The fuel supply system forcibly vaporizes liquefied gas, and supplies the vaporized gas to the diesel engine as fuel.

[0003] Specifically, in the fuel supply system of Patent Literature 1, the liquefied gas is led out of a tank through a fuel supply line. A pump and a vaporizer are located on the fuel supply line. The pump increases the pressure of the liquefied gas such that the vaporized gas has a pressure higher than the required pressure of the diesel engine, and the vaporizer is located downstream of the pump.

Citation List

Patent Literature

[0004] PTL 1: Japanese Laid-Open Patent Application Publication No. 2016-049881

Summary of Invention

Technical Problem

[0005] Patent Literature 1 describes that the liquefied gas may be liquefied hydrogen. In a case where the liquefied gas is liquefied hydrogen, when the pressure of the liquefied hydrogen is increased by the pump to a pressure higher than the required pressure of the diesel engine, the pressure of the liquefied hydrogen becomes higher than or equal to the critical pressure. Also in a case where the fuel is supplied to an internal combustion engine that is not a diesel engine, when the pressure of the liquefied hydrogen is increased by the pump to a pressure higher than the required pressure of the internal combustion engine, the pressure of the liquefied hydrogen becomes higher than or equal to the critical pressure.

[0006] From the pump, the liquefied hydrogen having a temperature lower than the critical temperature, or supercritical hydrogen having a temperature higher than or equal to the critical temperature, is delivered. In both of these cases, the vaporizer serves as a heater. Particularly

in a case where the liquefied hydrogen having a temperature lower than the critical temperature is delivered from the pump, the liquefied hydrogen transitions into supercritical hydrogen due to the heating by the vaporizer.

[0007] In a case where the amount of supercritical hydrogen used per unit time in the internal combustion engine is less than the delivery flow rate of the pump, it is desirable to, while delivering the liquefied hydrogen having a pressure higher than or equal to the critical pressure from the pump, reduce the pressure of the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure, and cause the pump to suck the pressure-reduced liquefied hydrogen again. However, when the liquefied hydrogen having a pressure higher than or equal to the critical pressure is reduced in pressure, most of the pressure-reduced liquefied hydrogen transitions into hydrogen gas. Therefore, it is desirable to condense the hydrogen gas that is generated as a result of the pressure reduction.

[0008] In view of the above, an object of the present disclosure is to provide a fuel supply system that enables the following: re-liquefaction of hydrogen gas that is generated as a result of reducing the pressure of excess liquefied hydrogen having a pressure higher than or equal to the critical pressure; and suction of the resulting re-liquefied hydrogen by a pump.

Solution to Problem

[0009] One aspect of the present disclosure provides a fuel supply system for supplying supercritical hydrogen to an internal combustion engine as fuel, the fuel supply system including: a tank that stores liquefied hydrogen; a fuel supply line through which the liquefied hydrogen is led out of the tank; a first pump that is located on the fuel supply line; an agitator that is located on the fuel supply line at a position downstream of the first pump; a second pump that is located on the fuel supply line at a position downstream of the agitator and that increases a pressure of the liquefied hydrogen such that the liquefied hydrogen has a pressure higher than or equal to a critical pressure; and a reflux flow line that is branched off from the fuel supply line at a position downstream of the second pump and connects to the agitator and on which a pressure reducing valve is located. The agitator agitates hydrogen gas that is generated as a result of pressure reduction by the pressure reducing valve with the liquefied hydrogen flowing through the fuel supply line to condense the hydrogen gas.

[0010] Another aspect of the present disclosure provides a ship including the above-described fuel supply system.

Advantageous Effects of Invention

[0011] The present disclosure provides a fuel supply system that enables the following: re-liquefaction of hydrogen gas that is generated as a result of reducing the pressure of excess liquefied hydrogen having a pressure higher than or equal to the critical pressure; and suction of the resulting re-liquefied hydrogen by a pump.

Brief Description of Drawings

[0012] FIG. 1 shows a schematic configuration of a re-liquefier according to one embodiment.

FIG. 2 shows a schematic configuration of the re-liquefier according to a variation.

FIG. 3 shows a schematic configuration of the re-liquefier according to another variation.

Description of Embodiments

[0013] FIG. 1 shows a fuel supply system 1A according to one embodiment. The fuel supply system 1A supplies supercritical hydrogen to an internal combustion engine as fuel. For example, the fuel supply system 1A may be installed on a ship, or may be incorporated in land-based power generating equipment. The internal combustion engine is, for example, a reciprocating engine or a gas turbine engine. The reciprocating engine may be an Otto cycle engine, a diesel cycle engine, or a Sabathe cycle engine.

[0014] Specifically, the fuel supply system 1A includes: a tank 2, which stores liquefied hydrogen; and a fuel supply line 3, through which the liquefied hydrogen is led out of the tank 2. In the tank 2, boil off gas (BOG) is generated as a result of evaporation of the liquefied hydrogen.

[0015] In the present embodiment, the tank 2 is a double-shell tank including an inner shell 21 and an outer shell 22. There is a vacuum layer between the inner shell 21 and the outer shell 22. Alternatively, the tank 2 may be a single-shell tank covered with a thermal insulator. In the present embodiment, the tank 2 is a horizontal cylindrical tank. Alternatively, the tank 2 may be a vertical cylindrical tank. Further alternatively, the tank 2 may be a spherical tank, or may be a substantially rectangular parallelepiped tank.

[0016] A first pump 4A, an agitator 5, a second pump 4B, and a heater 6 are sequentially located on the fuel supply line 3 in this order from the upstream side. In the present embodiment, the first pump 4A is located on the fuel supply line 3 at a position downstream of the upstream end of the fuel supply line 3. Further, in the present embodiment, the first pump 4A is located outside the tank 2 and inside a vacuum-insulated pod 11. The vacuum-insulated

pod 11 includes an inner wall and an outer wall, and there is a vacuum layer between the inner and outer walls.

[0017] The inner shell 21 of the tank 2 and the first pump 4A are connected by a lead-out passage 31. The lead-out passage 31 forms an upstream portion of the fuel supply line 3. The interior of the vacuum-insulated pod 11 is filled with liquefied hydrogen or hydrogen gas. A portion of the lead-out passage 31, the portion being positioned inside the outer shell 22 of the tank 2, is configured as a single pipe. A portion of the lead-out passage 31, the portion being positioned between the outer shell 22 and the inner wall or outer wall of the vacuum-insulated pod 11, is configured as a vacuum-insulated double pipe. A portion of the lead-out passage 31, the portion being positioned inside the inner wall or outer wall of the vacuum-insulated pod 11, is configured as a single pipe.

[0018] Alternatively, the inner shell 21 of the tank 2 and the vacuum-insulated pod 11 may be connected by the lead-out passage 31; the interior of the vacuum-insulated pod 11 may be filled with the liquefied hydrogen that is led out of the inner shell 21 of the tank 2 through the lead-out passage 31; and the first pump 4A may suck the liquefied hydrogen from the interior of the vacuum-insulated pod 11. In this case, the lead-out passage 31 and the interior of the vacuum-insulated pod 11 form the upstream portion of the fuel supply line 3.

[0019] The first pump 4A sucks the liquefied hydrogen stored in the tank 2 through the lead-out passage 31. The first pump 4A and the agitator 5 are connected by a first delivery passage 32, and the agitator 5 and the second pump 4B are connected by a suction passage 33. The second pump 4B and the heater 6 are connected by a second delivery passage 34, and a supply passage 35 extends from the heater 6. A shutoff valve is located on the supply passage 35. The shutoff valve switches whether or not to supply the fuel to the internal combustion engine.

[0020] In the present embodiment, the agitator 5 and the second pump 4B are located outside the tank 2, and the agitator 5 is located inside a vacuum-insulated pod 12. The vacuum-insulated pod 12 includes an inner wall and an outer wall, and there is a vacuum layer between the inner and outer walls. For example, the interior of the vacuum-insulated pod 12 is filled with liquefied hydrogen or hydrogen gas. The interior of the vacuum-insulated pod 12 may be kept under vacuum, in which case, the inner wall of the vacuum-insulated pod 12 may be eliminated. Instead of locating the agitator 5 inside the vacuum-insulated pod 12, the surface of the agitator 5 may be covered with a vacuum insulation structure.

[0021] A portion of the first delivery passage 32, the portion being positioned inside the inner wall or outer wall of the vacuum-insulated pod 11, is configured as a single pipe. A

portion of the first delivery passage 32, the portion being positioned between the inner wall or outer wall of the vacuum-insulated pod 11 and the inner wall or outer wall of the vacuum-insulated pod 12, is configured as a vacuum-insulated double pipe. A portion of the first delivery passage 32, the portion being positioned inside the inner wall or outer wall of the vacuum-insulated pod 12, is configured as a single pipe. A portion of the suction passage 33, the portion being positioned inside the inner wall or outer wall of the vacuum-insulated pod 12, is configured as a single pipe. A portion of the suction passage 33, the portion being positioned outside the inner wall or outer wall of the vacuum-insulated pod 12, is configured as a vacuum-insulated double pipe. The second delivery passage 34 may be configured as a single pipe or as a vacuum-insulated double pipe. The supply passage 35 is configured as a single pipe. Alternatively, in a case where the fuel supply system 1A is installed on a ship, a portion of the supply passage 35, the portion being positioned inside the engine room, may be configured as a double pipe.

[0022] The first pump 4A feeds the liquefied hydrogen from the tank 2 to the second pump 4B via the agitator 5. The second pump 4B increases the pressure of the liquefied hydrogen to a pressure higher than the required pressure of the internal combustion engine, such that the liquefied hydrogen has a pressure higher than or equal to the critical pressure. In the present embodiment, the outlet temperature of the second pump 4B is lower than the critical temperature, and the second pump 4B delivers the liquefied hydrogen having a pressure higher than or equal to the critical pressure. For example, in a case where the internal combustion engine is a diesel cycle reciprocating engine, the pressure of the liquefied hydrogen at the outlet of the second pump 4B is from 25 MPaG to 35 MPaG, and the temperature of the liquefied hydrogen at the outlet of the second pump 4B is 20K or higher.

[0023] The heater 6 heats the liquefied hydrogen to a temperature higher than the required temperature of the internal combustion engine. The liquefied hydrogen transitions into supercritical hydrogen due to the heating by the heater 6. For example, in a case where the internal combustion engine is a diesel cycle reciprocating engine, the temperature of the supercritical hydrogen at the outlet of the heater 6 is from 273K to 333K.

[0024] The fuel supply system 1A further includes a reflux flow line 7, which is branched off from the fuel supply line 3 at a position downstream of the second pump 4B and upstream of the heater 6 and which connects to the agitator 5. A portion of the reflux flow line 7, the portion being positioned outside the inner wall or outer wall of the vacuum-insulated pod 12, is configured as a vacuum-insulated double pipe. A portion of the reflux flow line 7, the portion being positioned inside the inner wall or outer wall of the vacuum-insulated pod 12, is

configured as a single pipe.

[0025] A pressure reducing valve 71 and a gas-liquid separator 72 are sequentially located on the reflux flow line 7 in this order from the upstream side. The liquefied hydrogen having a pressure higher than or equal to the critical pressure is reduced in pressure by the pressure reducing valve 71, and consequently transitions into 100% hydrogen gas or a gas-liquid two-phase flow. In a case where the liquefied hydrogen transitions into a gas-liquid two-phase flow as a result of the pressure reduction, the hydrogen gas and the liquefied hydrogen are separated by the gas-liquid separator 72, and then flow out of the gas-liquid separator 72.

[0026] The gas-liquid separator 72 is connected to the tank 2 by a liquid feed line 73. The liquefied hydrogen separated by the gas-liquid separator 72 is returned to the tank 2 through the liquid feed line 73.

[0027] A downstream portion of the liquid feed line 73 penetrates the tank 2 from the outside to the inside. In the illustrated example, the downstream end of the liquid feed line 73 is open near the bottom of the inner shell 21 of the tank 2. Alternatively, the downstream end of the liquid feed line 73 may be configured such that the liquefied hydrogen is sprayable from the downstream end of the liquid feed line 73 inside the tank 2 at a position above the liquid level. A portion of the liquid feed line 73, the portion being positioned outside the outer shell 22 of the tank 2, is configured as a vacuum-insulated double pipe, whereas a portion of the liquid feed line 73, the portion being positioned inside the outer shell 22, is configured as a single pipe.

[0028] The agitator 5 agitates the hydrogen gas flowing out of the gas-liquid separator 72 with the liquefied hydrogen flowing through the fuel supply line 3 to condense the hydrogen gas. Instead of locating the agitator 5 inside the vacuum-insulated pod 12, the surface of the agitator 5 may be covered with a vacuum insulation structure.

[0029] In the present embodiment, a return line 8 is branched off from the suction passage 33 of the fuel supply line 3, and the return line 8 connects to the tank 2. A downstream portion of the return line 8 penetrates the tank 2 from the outside to the inside. In the illustrated example, the downstream end of the return line 8 is open near the bottom of the inner shell 21 of the tank 2. Alternatively, the downstream end of the return line 8 may be configured such that the liquefied hydrogen is sprayable from the downstream end of the return line 8 inside the tank 2 at a position above the liquid level. A portion of the return line 8, the portion being positioned outside the outer shell 22 of the tank 2, is configured as a vacuum-insulated double pipe, and a portion of the return line 8, the portion being positioned inside the outer shell 22, is configured as a single pipe.

[0030] A flow control valve 81 is located on the return line 8. The flow control valve 81,

the first pump 4A, the second pump 4B, and the pressure reducing valve 71 are controlled by control circuitry 9. In FIG. 1, the illustration of part of signal lines is omitted for the purpose of simplifying the drawing.

[0031] Regarding the control circuitry 9, the functionality of the elements disclosed herein may be implemented using circuitry or processing circuitry which includes general purpose processors, special purpose processors, integrated circuits, ASICs (“Application Specific Integrated Circuits”), conventional circuitry and/or combinations thereof which are configured or programmed to perform the disclosed functionality. Processors are considered processing circuitry or circuitry as they include transistors and other circuitry therein. In the present disclosure, the circuitry, units, or means are hardware that carry out or are programmed to perform the recited functionality. The hardware may be any hardware disclosed herein or otherwise known which is programmed or configured to carry out the recited functionality. When the hardware is a processor which may be considered a type of circuitry, the circuitry, means, or units are a combination of hardware and software, the software being used to configure the hardware and/or processor.

[0032] The control circuitry 9 is electrically connected to a pressure meter 91 and a pressure meter 92. The pressure meter 91 is located on the suction passage 33 of the fuel supply line 3, and the pressure meter 92 is located on the second delivery passage 34 of the fuel supply line 3. The pressure meter 91 detects a pressure P1 of the liquefied hydrogen sucked by the second pump 4B. The pressure meter 92 detects a pressure P2 of the liquefied hydrogen that is delivered from the second pump 4B and that has a pressure higher than or equal to the critical pressure. Alternatively, the pressure meter 92 may be located on the supply passage 35 of the fuel supply line 3, and may detect the pressure of the supercritical hydrogen flowing out of the heater 6.

[0033] The control circuitry 9 controls the rotation speed of the first pump 4A such that the pressure P1 detected by the pressure meter 91 is a predetermined value α or higher, and also controls the rotation speed of the second pump 4B such that the pressure P2 detected by the pressure meter 92 is a predetermined value β or higher. The predetermined value α , which is a target value for the inlet pressure of the second pump 4B, is a pressure at which the hydrogen gas fed from the reflux flow line 7 can be condensed (i.e., a pressure higher than or equal to the saturated pressure).

[0034] The control circuitry 9 controls the flow control valve 81 to prevent the delivery flow rate of the first pump 4A from falling below a predetermined minimum flow rate.

Desirably, the flow control valve 81 is fully closed. However, when the flow control valve 81

is in a fully closed state, if the delivery flow rate of the first pump 4A falls below the predetermined minimum flow rate, the control circuitry 9 performs control to open the flow control valve 81 to allow the suction passage 33 to communicate with the tank 2 through the return line 8, such that the delivery flow rate of the first pump 4A becomes higher than or equal to the predetermined minimum flow rate.

[0035] The control circuitry 9 further controls the opening degree of the pressure reducing valve 71 based on the pressure P2 detected by the pressure meter 92. To be more specific, in a case where the pressure P2 detected by the pressure meter 92 is less than a threshold γ , the control circuitry 9 fully closes the pressure reducing valve 71. On the other hand, in a case where the pressure P2 detected by the pressure meter 92 is greater than the threshold γ , the control circuitry 9 opens the pressure reducing valve 71 such that its opening degree corresponds to a deviation ΔP between the pressure P2 and the threshold γ . As a result, the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure is reduced in pressure by the pressure reducing valve 71, and consequently hydrogen gas is generated. The generated hydrogen gas is supplied to the agitator 5, in which the hydrogen gas is condensed.

[0036] In the fuel supply system 1A configured as described above, the hydrogen gas generated as a result of the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure being reduced in pressure by the pressure reducing valve 71 is condensed by the agitator 5 located upstream of the second pump 4B. This enables the following: re-liquefaction of the hydrogen gas that is generated as a result of reducing the pressure of the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure; and suction of the resulting re-liquefied hydrogen by the second pump 4B.

[0037] Further, in the present embodiment, since the first pump 4A, the second pump 4B, and the agitator 5 are located outside the tank 2, maintenance can be readily performed on the first pump 4A, the second pump 4B, and the agitator 5.

[0038] <Variations>

The present disclosure is not limited to the above-described embodiment. Various modifications can be made without departing from the scope of the present disclosure.

[0039] For example, the gas-liquid separator 72 may be absent on the reflux flow line 7, and the liquid feed line 73 may be eliminated. However, by adopting the configuration of the above-described embodiment, the liquefied hydrogen separated by the gas-liquid separator 72 can be returned to the tank 2. Further, regardless of whether or not the gas-liquid separator 72 is located on the reflux flow line 7, the return line 8 may be eliminated.

[0040] As in a fuel supply system 1B according to a variation shown in FIG. 2, the agitator

5 may be located inside the tank 2, and the first pump 4A and the second pump 4B may be located outside the tank 2. According to this configuration, the fuel supply system 1B can be reduced in size.

[0041] As in a fuel supply system 1C according to another variation shown in FIG. 3, the first pump 4A and the agitator 5 may be located inside the tank 2, and the second pump 4B may be located outside the tank 2. In the present variation, the first pump 4A is located on the fuel supply line 3 at the upstream end of the fuel supply line 3. According to this configuration, the fuel supply system 1C can be significantly reduced in size.

[0042] In FIG. 3, the first delivery passage 32 of the fuel supply line 3 penetrates the tank 2 from the inside to the outside, and then penetrates the tank 2 from the outside to the inside. Alternatively, the entire first delivery passage 32 may be located inside the tank 2.

[0043] <Summary>

One aspect of the present disclosure provides, as a first mode, a fuel supply system for supplying supercritical hydrogen to an internal combustion engine as fuel, the fuel supply system including: a tank that stores liquefied hydrogen; a fuel supply line through which the liquefied hydrogen is led out of the tank; a first pump that is located on the fuel supply line; an agitator that is located on the fuel supply line at a position downstream of the first pump; a second pump that is located on the fuel supply line at a position downstream of the agitator and that increases a pressure of the liquefied hydrogen such that the liquefied hydrogen has a pressure higher than or equal to a critical pressure; and a reflux flow line that is branched off from the fuel supply line at a position downstream of the second pump and connects to the agitator and on which a pressure reducing valve is located. The agitator agitates hydrogen gas that is generated as a result of pressure reduction by the pressure reducing valve with the liquefied hydrogen flowing through the fuel supply line to condense the hydrogen gas.

[0044] According to the above configuration, the hydrogen gas generated as a result of the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure being reduced in pressure by the pressure reducing valve is condensed by the agitator located upstream of the second pump. This enables the following: re-liquefaction of the hydrogen gas that is generated as a result of reducing the pressure of the excess liquefied hydrogen having a pressure higher than or equal to the critical pressure; and suction of the resulting re-liquefied hydrogen by the second pump.

[0045] As a second mode, in the first mode, the fuel supply system may further include: a gas-liquid separator that is located on the reflux flow line at a position downstream of the pressure reducing valve; and a liquid feed line that connects the gas-liquid separator and the

tank. According to this configuration, the liquefied hydrogen separated by the gas-liquid separator can be returned to the tank.

[0046] As a third mode, in the first or second mode, the first pump, the second pump, and the agitator may be located outside the tank. According to this configuration, maintenance can be readily performed on the first pump, the second pump, and the agitator.

[0047] As a fourth mode, in the first or second mode, the agitator may be located inside the tank, and the first pump and the second pump may be located outside the tank. According to this configuration, the fuel supply system can be reduced in size.

[0048] As a fifth mode, in the first or second mode, the agitator and the first pump may be located inside the tank, and the second pump may be located outside the tank. According to this configuration, the fuel supply system can be significantly reduced in size.

[0049] Another aspect of the present disclosure provides, as a sixth mode, a ship including the fuel supply system according to any one of the first to fifth modes.

CLAIMS

[Claim 1] A fuel supply system for supplying supercritical hydrogen to an internal combustion engine as fuel, the fuel supply system comprising:

- a tank that stores liquefied hydrogen;
- a fuel supply line through which the liquefied hydrogen is led out of the tank;
- a first pump that is located on the fuel supply line;
- an agitator that is located on the fuel supply line at a position downstream of the first pump;

a second pump that is located on the fuel supply line at a position downstream of the agitator and that increases a pressure of the liquefied hydrogen such that the liquefied hydrogen has a pressure higher than or equal to a critical pressure; and

a reflux flow line that is branched off from the fuel supply line at a position downstream of the second pump and connects to the agitator and on which a pressure reducing valve is located, wherein

the agitator agitates hydrogen gas that is generated as a result of pressure reduction by the pressure reducing valve with the liquefied hydrogen flowing through the fuel supply line to condense the hydrogen gas.

[Claim 2] The fuel supply system according to claim 1, further comprising:

- a gas-liquid separator that is located on the reflux flow line at a position downstream of the pressure reducing valve; and
- a liquid feed line that connects the gas-liquid separator and the tank.

[Claim 3] The fuel supply system according to claim 1 or 2, wherein

the first pump, the second pump, and the agitator are located outside the tank.

[Claim 4] The fuel supply system according to claim 1 or 2, wherein

the agitator is located inside the tank, and the first pump and the second pump are located outside the tank.

[Claim 5] The fuel supply system according to claim 1 or 2, wherein

the agitator and the first pump are located inside the tank, and the second pump is located outside the tank.

[Claim 6] A ship comprising the fuel supply system according to claim 1 or 2.