

DESCRIPTION

Title of Invention: HYDROGEN FUEL SUPPLY SYSTEM AND METHOD OF LIQUEFYING HYDROGEN

Technical Field

[0001] The present disclosure relates to a hydrogen fuel supply system and a method of liquefying hydrogen.

Background Art

[0002] PTL 1 below discloses a control device which, when receiving liquefied gas from a cargo tank into a storage tank, sends the liquefied gas to the storage tank in a state in which the liquefied gas is cooled to a subcooled state by a refrigerator.

Citation List

Patent Literature

[0003] PTL 1: International Publication No. WO 2022/209850

Summary of Invention

Technical Problem

[0004] In recent years, hydrogen fuel has been attracting attention from the viewpoint of environmental protection. In a hydrogen fuel supply system that supplies hydrogen gas to a hydrogen fueled engine, when returning surplus hydrogen to a liquefied hydrogen tank, the surplus hydrogen can be liquefied by cooling using a refrigerator. However, when a large-capacity refrigerator is used, the weight, manufacturing cost, operating cost, and size of the hydrogen fuel supply system increase, which is not preferable.

[0005] An object of the present disclosure is to provide a hydrogen fuel supply system capable of omitting or downsizing a refrigerator that liquefies hydrogen to be returned to a liquefied hydrogen tank.

Solution to Problem

[0006] A hydrogen fuel supply system according to one aspect of the present disclosure includes: a liquefied hydrogen tank that stores liquefied hydrogen; a supply line that connects the liquefied hydrogen tank and a hydrogen fueled engine and supplies hydrogen gas to the hydrogen fueled engine; a pressurizing pump that is located in the supply line and pressurizes the liquefied hydrogen to critical pressure or higher; a return line that connects the liquefied

hydrogen tank and a portion of the supply line which is located downstream of the pressurizing pump; a pressure-reducing temperature-increasing valve that is located in the return line and increases a temperature of return hydrogen by depressurizing the return hydrogen to pressure close to an inversion temperature curve, the return hydrogen being part of the hydrogen pressurized by the pressurizing pump and having flowed into the return line; a heat exchanger that is located across the supply line and the return line and cools the return hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, by using supply hydrogen as a refrigerant, the supply hydrogen being another part of the hydrogen pressurized by the pressurizing pump and being to be supplied to the hydrogen fueled engine; and a pressure-reducing liquefaction valve that is located in the return line and converts the return hydrogen, which has passed through the heat exchanger, into the liquefied hydrogen by depressurizing the return hydrogen.

Advantageous Effects of Invention

[0007] The hydrogen fuel supply system according to one aspect of the present disclosure can omit or downsize a refrigerator that liquefies the hydrogen to be returned to the liquefied hydrogen tank.

Brief Description of Drawings

[0008] FIG. 1 is a block diagram of a hydrogen fuel supply system.

Description of Embodiments

[0009] Hereinafter, an embodiment will be described. FIG. 1 is a block diagram of a hydrogen fuel supply system 100 according to the embodiment. As shown in FIG. 1, the hydrogen fuel supply system 100 according to the present embodiment includes a liquefied hydrogen tank 11, a supply line 12, a pressurizing pump 13, a heater 14, a return line 15, a pressure-reducing temperature-increasing valve 16, a heat exchanger 17, and a pressure-reducing liquefaction valve 18. Hereinafter, these components will be described in order.

[0010] The liquefied hydrogen tank 11 is a tank that stores liquefied hydrogen. The liquefied hydrogen tank 11 includes a liquid phase portion 21 and a gas phase portion 22. The liquid phase portion 21 is filled with the liquefied hydrogen, and the gas phase portion 22 is filled with hydrogen gas. When the internal pressure of the liquefied hydrogen tank 11 increases and exceeds an allowable value, part of the hydrogen gas is discharged from the gas phase portion 22. Normally, the hydrogen gas discharged from the liquefied hydrogen tank 11

is disposed of by being released into the atmosphere or burned. Therefore, in order to avoid wasteful consumption of hydrogen fuel, it is desirable to suppress the internal pressure of the liquefied hydrogen tank 11.

[0011] The supply line 12 is a pipe that connects the liquefied hydrogen tank 11 and a hydrogen fueled engine 101. The hydrogen fueled engine 101 is equipment that uses the hydrogen gas as fuel. Examples of the hydrogen fueled engine 101 include a gas engine and a boiler. The supply line 12 acquires the liquefied hydrogen from the liquid phase portion 21 of the liquefied hydrogen tank 11, converts the acquired liquefied hydrogen into the hydrogen gas, and supplies the hydrogen gas as the fuel to the hydrogen fueled engine 101.

[0012] The pressurizing pump 13 is a pump that is located in the supply line 12 and pressurizes the liquefied hydrogen. The pressurizing pump 13 pressurizes the liquefied hydrogen, acquired from the liquefied hydrogen tank 11, to critical pressure or higher. The pressurizing pump 13 may be constituted by pumps or may be constituted by only one pump. For example, the pressurizing pump 13 may include a low-pressure pump and a high-pressure pump that further pressurizes the liquefied hydrogen that has been pressurized by the low-pressure pump.

[0013] The heater 14 is equipment that is located in the supply line 12 and heats the hydrogen. The heater 14 of the present embodiment is located in a portion of the supply line 12 which is located downstream of the pressurizing pump 13. Therefore, the heater 14 heats the hydrogen that has been pressurized by the pressurizing pump 13. The hydrogen heated by the heater 14 is supplied to the hydrogen fueled engine 101.

[0014] The return line 15 is a line that connects the supply line 12 and the liquefied hydrogen tank 11. The return line 15 of the present embodiment is connected to a portion of the supply line 12 which is located downstream of the pressurizing pump 13 and upstream of the heater 14. The return line 15 acquires surplus hydrogen, which is part of the hydrogen pressurized by the pressurizing pump 13 and is not supplied to the hydrogen fueled engine 101, from the supply line 12. Then, the return line 15 converts the acquired hydrogen into the liquefied hydrogen and returns the liquefied hydrogen to the liquefied hydrogen tank 11.

[0015] Hereinafter, hydrogen that is part of the hydrogen pressurized by the pressurizing pump 13, flows into the return line 15, and is returned to the liquefied hydrogen tank 11 is referred to as “return hydrogen,” and hydrogen that is another part of the hydrogen pressurized by the pressurizing pump 13 and supplied to the hydrogen fueled engine 101 is referred to as “supply hydrogen.” To be specific, the hydrogen pressurized by the pressurizing pump 13 is divided into the return hydrogen and the supply hydrogen. When most of the return hydrogen

can be converted into the liquefied hydrogen, the internal pressure of the liquefied hydrogen tank 11 can be suppressed, and therefore, wasteful consumption of the hydrogen fuel can be suppressed. Moreover, the return hydrogen flowing into the return line 15 is higher in temperature than the liquefied hydrogen and liquefied gas in the liquefied hydrogen tank 11 but is at a cryogenic temperature (-200°C or lower, for example), and is high in pressure (20 MPaG or higher, for example).

[0016] The pressure-reducing temperature-increasing valve 16 is a valve that is located in the return line 15 and depressurizes the return hydrogen acquired from the supply line 12. The pressure-reducing temperature-increasing valve 16 may be constituted by a single valve or may be constituted by valves. Here, a process in which high-pressure gas is depressurized and expanded by a valve is an isenthalpic expansion, which is referred to as Joule-Thomson expansion. In Joule-Thomson expansion, if the pressure is higher than the inversion temperature curve, the temperature increases due to depressurization. Hydrogen has a characteristic in that its inversion temperature curve lies in a lower temperature region than those of other gases such as natural gas. Therefore, by depressurizing high-pressure cryogenic hydrogen, the temperature of the hydrogen increases until it reaches the inversion temperature curve, and, at pressure lower than the inversion temperature curve, the temperature can be decreased to a liquefaction temperature, which can be utilized herein. The pressure-reducing temperature-increasing valve 16 can increase the temperature of the return hydrogen by depressurizing the return hydrogen to pressure close to the inversion temperature curve.

[0017] The heat exchanger 17 is equipment that cools the return hydrogen. The heat exchanger 17 is located across a portion of the supply line 12 which is located downstream of its portion to which the return line 15 is connected and upstream of the heater 14 and a portion of the return line 15 which is located downstream of the pressure-reducing temperature-increasing valve 16. Then, the heat exchanger 17 cools the return hydrogen by performing heat exchange between the return hydrogen and the supply hydrogen. To be specific, the return hydrogen is cooled by using the supply hydrogen as a refrigerant. Since the return hydrogen is increased in temperature by the pressure-reducing temperature-increasing valve 16, the temperature of the return hydrogen at an inlet of the heat exchanger 17 is higher than the temperature of the supply hydrogen.

[0018] The pressure-reducing liquefaction valve 18 is a valve that liquefies the return hydrogen, which has passed through the heat exchanger 17, by depressurizing the return hydrogen. The pressure-reducing liquefaction valve 18 is located in a portion of the return line

15 which is located downstream of the heat exchanger 17. The pressure-reducing liquefaction valve 18 may be constituted by a single valve or may be constituted by valves. In the present embodiment, the pressure of the return hydrogen at an inlet of the pressure-reducing liquefaction valve 18 is close to or lower than the pressure of the inversion temperature curve, and the pressure-reducing liquefaction valve 18 can reduce the temperature of the return hydrogen by depressurizing the return hydrogen. When the pressure of the return hydrogen at the inlet of the pressure-reducing liquefaction valve 18 is higher than the pressure of the inversion temperature curve, the return hydrogen is temporarily increased in temperature by being depressurized, but can be reduced in temperature by being further depressurized.

[0019] When the return hydrogen is reduced in temperature by being depressurized by the pressure-reducing liquefaction valve 18, the return hydrogen is liquefied and converted into the liquefied hydrogen. Then, since the return hydrogen that has passed through the heat exchanger 17 has been cooled by the supply hydrogen, the proportion of the return hydrogen that is liquefied by being depressurized by the pressure-reducing liquefaction valve 18 increases. As a result, the hydrogen fuel supply system 100 according to the present embodiment can liquefy the return hydrogen without using a refrigerator. However, the hydrogen fuel supply system 100 may include a refrigerator that cools the return hydrogen. Even in this case, since the return hydrogen is cooled by the supply hydrogen, a large-capacity refrigerator for liquefying the return hydrogen is unnecessary. Therefore, the hydrogen fuel supply system 100 according to the present embodiment can omit or downsize the refrigerator.

[0020] **Conclusion**

A first aspect disclosed in the present specification is a hydrogen fuel supply system including: a liquefied hydrogen tank that stores liquefied hydrogen; a supply line that connects the liquefied hydrogen tank and a hydrogen fueled engine and supplies hydrogen gas to the hydrogen fueled engine; a pressurizing pump that is located in the supply line and pressurizes the liquefied hydrogen to critical pressure or higher; a return line that connects the liquefied hydrogen tank and a portion of the supply line which is located downstream of the pressurizing pump; a pressure-reducing temperature-increasing valve that is located in the return line and increases a temperature of return hydrogen by depressurizing the return hydrogen to pressure close to an inversion temperature curve, the return hydrogen being part of the hydrogen pressurized by the pressurizing pump and having flowed into the return line; a heat exchanger that is located across the supply line and the return line and cools the return hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, by using supply hydrogen as a refrigerant, the supply hydrogen being another part of the hydrogen

pressurized by the pressurizing pump and being to be supplied to the hydrogen fueled engine; and a pressure-reducing liquefaction valve that is located in the return line and converts the return hydrogen, which has passed through the heat exchanger, into the liquefied hydrogen by depressurizing the return hydrogen.

[0021] According to this configuration, a refrigerator that liquefies the hydrogen to be returned to the liquefied hydrogen tank can be omitted or downsized,

[0022] A second aspect disclosed in the present specification is a method of liquefying hydrogen, including: dividing pressurized hydrogen into first hydrogen and second hydrogen; increasing a temperature of the first hydrogen by depressurizing the first hydrogen to pressure close to an inversion temperature curve; cooling the first hydrogen, which has been increased in temperature, by heat exchange between the first hydrogen and the second hydrogen; and converting the first hydrogen, which has been cooled, into liquefied hydrogen by further depressurizing the first hydrogen.

[0023] The “return hydrogen” and the “supply hydrogen” in the embodiment correspond to the “first hydrogen” and the “second hydrogen” in the second aspect, respectively. According to the above method, a refrigerator that liquefies the first hydrogen can be omitted or downsized.

CLAIMS

- [Claim 1] A hydrogen fuel supply system comprising:
- a liquefied hydrogen tank that stores liquefied hydrogen;
 - a supply line that connects the liquefied hydrogen tank and a hydrogen fueled engine and supplies hydrogen gas to the hydrogen fueled engine;
 - a pressurizing pump that is located in the supply line and pressurizes the liquefied hydrogen to critical pressure or higher;
 - a return line that connects the liquefied hydrogen tank and a portion of the supply line which is located downstream of the pressurizing pump;
 - a pressure-reducing temperature-increasing valve that is located in the return line and increases a temperature of return hydrogen by depressurizing the return hydrogen to pressure close to an inversion temperature curve, the return hydrogen being part of the hydrogen pressurized by the pressurizing pump and having flowed into the return line;
 - a heat exchanger that is located across the supply line and the return line and cools the return hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, by using supply hydrogen as a refrigerant, the supply hydrogen being another part of the hydrogen pressurized by the pressurizing pump and being to be supplied to the hydrogen fueled engine; and
 - a pressure-reducing liquefaction valve that is located in the return line and converts the return hydrogen, which has passed through the heat exchanger, into the liquefied hydrogen by depressurizing the return hydrogen.
- [Claim 2] A method of liquefying hydrogen, comprising:
- dividing pressurized hydrogen into first hydrogen and second hydrogen;
 - increasing a temperature of the first hydrogen by depressurizing the first hydrogen to pressure close to an inversion temperature curve;
 - cooling the first hydrogen, which has been increased in temperature, by heat exchange between the first hydrogen and the second hydrogen; and
 - converting the first hydrogen, which has been cooled, into liquefied hydrogen by further depressurizing the first hydrogen.