

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 an apparatus which pressurizes boil-off gas naturally generated in a LNG tank, condenses part of the pressurized boil-off gas by cooling using subcooled LNG, and returns it to the LNG tank.

Citation List

Patent Literature

[0003] PTL 1: Japanese Patent No. 7119063

Summary of Invention

Technical Problem

[0004] In recent years, hydrogen fuel has been attracting attention from the viewpoint of environmental protection. In a hydrogen fueled engine, when hydrogen gas obtained by pressurizing liquefied hydrogen is returned to a tank again, the hydrogen gas can be liquefied using a refrigerant. However, to do this, new power is necessary. When the power is not added, it is theoretically impossible to liquefy the entire amount of hydrogen gas. Even when the pressure of high-pressure hydrogen is reduced to original pressure, part of the hydrogen becomes hydrogen gas. This is because realizing a system having an efficiency of 100% is impossible due to, for example, heat generated from a pressurizing pump. When the liquefied hydrogen that was in the liquefied hydrogen tank becomes the hydrogen gas and returns to the liquefied hydrogen tank, the internal pressure of the liquefied hydrogen tank increases, and this is not preferable.

[0005] An object of the present disclosure is to provide a hydrogen fuel supply system capable of converting a high proportion of hydrogen, which has been pressurized to critical pressure or higher, into liquefied hydrogen when depressurizing the hydrogen and returning the hydrogen 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 the high-pressure hydrogen, which has been pressurized by the pressurizing pump, by depressurizing the high-pressure hydrogen to pressure close to an inversion temperature curve; a catalyst reactor that is located in the return line and brings the hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, into contact with a para-ortho conversion catalyst; and a pressure-reducing liquefaction valve that is located in the return line and converts the hydrogen, which has passed through the catalyst reactor, into the liquefied hydrogen by depressurizing the hydrogen.

Advantageous Effects of Invention

[0007] In the hydrogen fuel supply system according to one aspect of the present disclosure, when depressurizing the hydrogen, which has been increased in pressure to critical pressure or higher, and returning the hydrogen to the liquefied hydrogen tank, a high proportion of the hydrogen can be converted into the liquefied hydrogen.

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 catalyst reactor 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 supercritical 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. When most of the hydrogen returned to the liquefied hydrogen tank 11 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. The hydrogen acquired by the return line 15 from the supply line 12 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).

[0015] The pressure-reducing temperature-increasing valve 16 is a valve that is located in the return line 15 and depressurizes the 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 a high-pressure fluid 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 is utilized herein. In the present embodiment, the high-pressure cryogenic hydrogen at an inlet of the pressure-reducing temperature-increasing valve 16 is temporarily increased in temperature by being depressurized to a level just before the inversion temperature curve.

[0016] The catalyst reactor 17 is equipment that brings hydrogen into contact with a para-ortho conversion catalyst. The catalyst reactor 17 is located in a portion of the return line 15 which is located downstream of the pressure-reducing temperature-increasing valve 16. Here, hydrogen includes orthohydrogen in which proton spin directions are identical and parahydrogen in which proton spin directions are different. When the temperature of the hydrogen increases, parahydrogen is converted into orthohydrogen, and this increases the proportion of orthohydrogen. Since the conversion from parahydrogen to orthohydrogen is an endothermic reaction, the temperature of the hydrogen decreases during the conversion. However, it takes several days from the start of the conversion from parahydrogen to orthohydrogen until an equilibrium state is reached. Therefore, even if the temperature of the hydrogen is increased by the pressure-reducing temperature-increasing valve 16, the endothermic reaction does not occur immediately.

[0017] Therefore, in the hydrogen fuel supply system 100 according to the present embodiment, the hydrogen that has been increased in temperature by the pressure-reducing

temperature-increasing valve 16 is brought into contact with the para-ortho conversion catalyst by the catalyst reactor 17. In the hydrogen that has contacted the para-ortho conversion catalyst, the conversion from parahydrogen to orthohydrogen is promoted. Therefore, the proportion of orthohydrogen in the hydrogen increases to a value corresponding to the temperature of the hydrogen, i.e., a value in the equilibrium state. Thus, the endothermic reaction occurs during the conversion, and the temperature of the hydrogen decreases. For example, iron hydroxide can be utilized as the para-ortho conversion catalyst.

[0018] The pressure-reducing liquefaction valve 18 is a valve that liquefies the hydrogen, which has passed through the catalyst reactor 17, by depressurizing the hydrogen. The pressure-reducing liquefaction valve 18 is located in a portion of the return line 15 which is located downstream of the catalyst reactor 17. The pressure-reducing liquefaction valve 18 may be constituted by a single valve or may be constituted by valves. In the present embodiment, by further depressurizing the hydrogen from a state in which the temperature has been lowered by the endothermic reaction beyond the inversion temperature curve to a tank pressure, the temperature of the hydrogen can be reduced to the liquefaction temperature. When the pressure of the hydrogen at the inlet of the pressure-reducing liquefaction valve 18 is higher than the inversion temperature curve, the hydrogen is temporarily increased in temperature by being depressurized, but can be reduced in temperature by being further depressurized.

[0019] When the hydrogen is reduced in temperature by being depressurized by the pressure-reducing liquefaction valve 18, the temperature of the hydrogen falls under the boiling point, and the hydrogen is converted into the liquefied hydrogen. Then, as described above, the temperature of the hydrogen that has passed through the catalyst reactor 17 is low, and by depressurizing the hydrogen from this state by the pressure-reducing liquefaction valve 18, the proportion of the hydrogen that is liquefied increases. Therefore, according to the hydrogen fuel supply system 100 of the present embodiment, a high proportion of the high-pressure hydrogen can be converted into the liquefied hydrogen. As a result, the internal pressure of the liquefied hydrogen tank 11 can be suppressed, and wasteful consumption of the hydrogen fuel can be suppressed.

[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 the high-pressure hydrogen, which has been pressurized by the pressurizing pump, by depressurizing the high-pressure hydrogen to pressure close to an inversion temperature curve; a catalyst reactor that is located in the return line and brings the hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, into contact with a para-ortho conversion catalyst; and a pressure-reducing liquefaction valve that is located in the return line and converts the hydrogen, which has passed through the catalyst reactor, into the liquefied hydrogen by depressurizing the hydrogen.

[0021] According to this configuration, when depressurizing the pressurized hydrogen and returning the hydrogen to the liquefied hydrogen tank, a high proportion of the hydrogen can be converted into the liquefied hydrogen.

[0022] A second aspect disclosed in the present specification is a method of liquefying hydrogen, including: increasing a temperature of pressurized high-pressure hydrogen by depressurizing the high-pressure hydrogen to pressure close to an inversion temperature curve; bringing the hydrogen, which has been increased in temperature, into contact with a para-ortho conversion catalyst; and converting the hydrogen, which has been brought into contact with the para-ortho conversion catalyst, into liquefied hydrogen by further depressurizing the hydrogen.

[0023] According to this method, when converting the pressurized hydrogen into the liquefied hydrogen by depressurizing the pressurized hydrogen, a high proportion of the hydrogen can be converted into the liquefied hydrogen.

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 the high-pressure hydrogen, which has been pressurized by the pressurizing pump, by depressurizing the high-pressure hydrogen to pressure close to an inversion temperature curve;
- a catalyst reactor that is located in the return line and brings the hydrogen, which has been increased in temperature by the pressure-reducing temperature-increasing valve, into contact with a para-ortho conversion catalyst; and
- a pressure-reducing liquefaction valve that is located in the return line and converts the hydrogen, which has passed through the catalyst reactor, into the liquefied hydrogen by depressurizing the hydrogen.

[Claim 2] A method of liquefying hydrogen, comprising:

- increasing a temperature of pressurized high-pressure hydrogen by depressurizing the high-pressure hydrogen to pressure close to an inversion temperature curve;
- bringing the hydrogen, which has been increased in temperature, into contact with a para-ortho conversion catalyst; and
- converting the hydrogen, which has been brought into contact with the para-ortho conversion catalyst, into liquefied hydrogen by further depressurizing the hydrogen.