DESCRIPTION

Title of Invention: LIQUID HYDROGEN LOADING/UNLOADING SYSTEM, AND BOIL-OFF GAS TRANSPORT SYSTEM

Technical Field

[0001] The present disclosure relates to a liquid hydrogen loading/unloading system that loads and unloads liquid hydrogen, and a boil-off gas transport system that transports boil-off gas.

Background Art

[0002] There are loading/unloading systems that load and unload liquefied gas; for example, the loading/unloading system disclosed in Patent Literature (PTL) 1 is known as one example of said loading/unloading systems. The loading/unloading system disclosed in PTL 1 is provided at a liquefied natural gas (LNG) receiving terminal, for example. The loading/unloading system includes loading/unloading equipment. With the loading/unloading equipment, LNG is delivered from a delivery tank (for example, a tank on an LNG tanker) to a receiving tank (for example, a tank at a terminal). Meanwhile, at the time of delivery, boil-off gas in the receiving tank is returned to the delivery tank as return gas. This keeps the pressure in the delivery tank from becoming negative.

Citation List

Patent Literature

[0003] PTL 1: Japanese Laid-Open Patent Application Publication No. 2011-99500

Summary of Invention

Technical Problem

[0004] The loading/unloading equipment included in the loading/unloading system disclosed in PTL 1 includes various elements. A sealing device is provided on each of the elements in order to prevent gas leakage through gaps between components. In the sealing device, seal gas is used as well as a mechanical seal with a gasket or the like. Nitrogen is used as the seal gas.

[0005] The liquefied gas to be loaded or unloaded by the loading/unloading system disclosed in PTL 1 is liquefied natural gas (LNG); an example of the liquefied gas to be loaded or unloaded other than LNG is hydrogen. The liquefaction temperature of hydrogen is lower than the solidification temperature of nitrogen. Therefore, if hydrogen is loaded or unloaded

using the same loading/unloading system as that for LNG, the seal gas, i.e., nitrogen, is solidified. In this case, it is conceivable that the sealing device will fail to function. Similarly, in a boil-off gas transport system including transport equipment that transports boil-off gas, it is also conceivable that a sealing device in the transport equipment will fail to function.

[0006] Thus, an object of the present disclosure is to provide a liquid hydrogen loading/unloading system and a boil-off gas transport system in which the likelihood of a sealing device failing to function due to solidification of seal gas can be reduced.

Solution to Problem

[0007] A liquid hydrogen loading/unloading system according to the present disclosure includes: a hydrogen tank that stores liquid hydrogen; loading/unloading equipment that loads the liquid hydrogen into the hydrogen tank and unloads the liquid hydrogen from the hydrogen tank; a sealing device that is provided in the loading/unloading equipment and provides a hermetic seal between an interior of the loading/unloading equipment and an atmosphere with first seal gas; and a seal gas supply system that supplies boil-off gas resulting from vaporization in the hydrogen tank to the sealing device as the first seal gas.

[0008] With the liquid hydrogen loading/unloading system according to the present disclosure, the boil-off gas, i.e., hydrogen, is used as seal gas for the sealing device, and thus liquefaction of the seal gas can be reduced. Accordingly, the likelihood of the sealing device failing to function due to solidification of seal gas can be reduced.

[0009] A boil-off gas transport system according to the present disclosure includes: a hydrogen tank that stores liquid hydrogen; transport equipment that transports boil-off gas resulting from vaporization in the hydrogen tank; and a sealing device that is provided in the transport equipment and provides a hermetic seal between an interior of the transport equipment and an atmosphere with first seal gas. The sealing device is supplied with the boil-off gas as the first seal gas.

[0010] With the boil-off gas transport system according to the present disclosure, the boil-off gas, i.e., hydrogen, is used as seal gas for the sealing device, and thus liquefaction of the seal gas can be reduced. Accordingly, the likelihood of the sealing device failing to function due to solidification of seal gas can be reduced.

Advantageous Effects of Invention

[0011] According to the present disclosure, the likelihood of a sealing device failing to function due to solidification of seal gas can be reduced.

[0012] The above object, other objects, features, and advantages of the present disclosure will be made clear by the following detailed explanation of preferred embodiments with reference to the attached drawings.

Brief Description of Drawings

[0013] Fig. 1 is a configuration diagram illustrating a liquid hydrogen loading/unloading system according to Embodiment 1 of the present disclosure.

Fig. 2 is a cross-sectional view illustrating a sealing device in the liquid hydrogen loading/unloading system illustrated in Fig. 1.

Fig. 3 is a configuration diagram illustrating the flow of boil-off gas in a period different from a loading/unloading period in the liquid hydrogen loading/unloading system illustrated in Fig. 1.

Fig. 4 is a configuration diagram illustrating the flow of boil-off gas in a loading/unloading period in the liquid hydrogen loading/unloading system illustrated in Fig. 1.

Fig. 5 is a configuration diagram illustrating a liquid hydrogen loading/unloading system according to Embodiment 2 of the present disclosure.

Fig. 6 is a configuration diagram illustrating a liquid hydrogen loading/unloading system according to Embodiment 3 of the present disclosure.

Fig. 7 is a configuration diagram illustrating a boil-off gas transport system according to Embodiment 4 of the present disclosure.

Description of Embodiments

[0014] Hereinafter, liquid hydrogen loading/unloading systems 1, 1A, 1B according to Embodiments 1 to 3 of the present disclosure and a boil-off gas transport system 1C according to Embodiment 4 of the present disclosure will be described with reference to the aforementioned drawings. Note that the concept of directions mentioned in the following description is used for the sake of explanation; the orientations, etc., of elements disclosed are not limited to these directions. Each of the liquid hydrogen loading/unloading systems 1, 1A, 1B and the boil-off gas transport system 1C described below is merely one embodiment of the present disclosure. Thus, the present disclosure is not limited to the embodiments and may be subject to addition, deletion, and alteration within the scope of the essence of the disclosure.

[Embodiment 1]

<Liquid Hydrogen Loading/unloading System>

[0015] The liquid hydrogen loading/unloading system 1 illustrated in Fig. 1 loads liquid

hydrogen into a tank 2 provided on a vessel or onshore equipment and unloads the liquid hydrogen from the tank 2. In the present embodiment, the liquid hydrogen loading/unloading system 1 is provided on land such as ports and harbors. The tank 2 is provided on a vessel (for example, a tanker) and can store liquid hydrogen. The liquid hydrogen loading/unloading system 1 performs loading into and unloading from the tank 2 on the vessel. Note that the liquid hydrogen loading/unloading system 1 does not necessarily need to be provided on land. For example, the liquid hydrogen loading/unloading system 1 may be provided on a vessel. To describe the liquid hydrogen loading/unloading system 1 in more detail, the liquid hydrogen loading/unloading system 1 includes a hydrogen tank 11, loading/unloading equipment 12, a sealing device 13, a seal gas supply system 14, and drainage equipment 15.

<Hydrogen Tank>

[0016] The hydrogen tank 11 can store liquid hydrogen. The hydrogen tank 11 includes an insulation structure such as a vacuum insulation structure. The hydrogen tank 11 maintains the temperature of liquid hydrogen 11a stored therein at a temperature lower than the boiling point of liquid hydrogen. In the hydrogen tank 11, part of liquid hydrogen is vaporized. A portion of the hydrogen tank 11 other than where the liquid hydrogen is stored is filled with boil-off gas 11b. Note that the tank 2 is configured similar to the hydrogen tank 11.

<Loading/unloading Equipment>

[0017] The loading/unloading equipment 12 loads and unloads the liquid hydrogen between the hydrogen tank 11 and the tank 2. Specifically, the liquid hydrogen stored in the hydrogen tank 11 is transported to the tank 2, or the liquid hydrogen stored in the tank 2 is transported to the hydrogen tank 11. More specifically, the loading/unloading equipment 12 includes a liquid hydrogen pipe 21, a return gas pipe 22, a hydraulic pump 23, and a return gas blower 24.

[0018] The liquid hydrogen pipe 21 is a pipe connecting the hydrogen tank 11 and the tank 2. More specifically, the liquid hydrogen pipe 21 is connected to the hydrogen tank 11. Furthermore, the liquid hydrogen pipe 21 can be connected to the tank 2 via a joint not illustrated in the drawings. In the state of being connected to the tank 2, the liquid hydrogen pipe 21 allows the liquid hydrogen to flow from the hydrogen tank 11 to the tank 2 or from the tank 2 to the hydrogen tank 11.

[0019] The return gas pipe 22 is a pipe connecting the hydrogen tank 11 and the tank 2. More specifically, the return gas pipe 22 is connected to the hydrogen tank 11, for example. Similar to the liquid hydrogen pipe 21, the return gas pipe 22 can be connected to the tank 2 via a joint not illustrated in the drawings. Furthermore, the return gas pipe 22 allows the boil-off gas (return gas) to flow from the hydrogen tank 11 to the tank 2 or from the tank 2 to the hydrogen

tank 11.

[0020] The hydraulic pump 23 is interposed in the liquid hydrogen pipe 21. The hydraulic pump 23 is capable of sending the liquid hydrogen from a delivery tank (that is the tank 2 in the present embodiment) to a receiving tank (that is the hydrogen tank 11 in the present embodiment). Thus, it is possible to load and unload the liquid hydrogen between the hydrogen tank 11 and the tank 2. Note that in the case where the delivery tank is the hydrogen tank 11, the hydraulic pump 23 sends the liquid hydrogen in a direction opposite to said direction. The hydraulic pump 23 does not necessarily need to be provided in the loading/unloading equipment 12 and may be provided on a loading/unloading vessel. The hydraulic pump 23 may be provided inside the tank 2 or the hydrogen tank 11.

[0021] The return gas blower 24 is interposed in the return gas pipe 22. The return gas blower 24 is capable of sending the return gas from the receiving tank (that is the hydrogen tank 11 in the present embodiment) to the delivery tank (that is the tank 2 in the present embodiment). Note that in the case where the delivery tank is the hydrogen tank 11, the return gas blower 24 sends the return gas in a direction opposite to said direction. To describe the return gas blower 24 in more detail, the return gas blower 24 is a compressor, for example. Specifically, the return gas blower 24 compresses the return gas and sends the compressed return gas. More specifically, the return gas blower 24 includes a casing 31 and an impeller 32, as illustrated in Fig. 2.

[0022] The casing 31 is interposed in the return gas pipe 22. More specifically, a flow path 31a and a shaft insertion hole 31b are formed in the casing 31. The flow path 31a is interposed in the return gas pipe 22. Specifically, one end and the other end of the flow path 31a are connected to the hydrogen tank 11 and the tank 2, respectively, via the return gas pipe 22. The shaft insertion hole 31b is a hole formed in the casing 31. The shaft insertion hole 31b has one end open to the flow path 31a and the other end open to the atmosphere.

[0023] The impeller 32 includes a shaft 32a and an impeller portion 32b. The shaft 32a is inserted through the shaft insertion hole 31b of the casing 31 and is rotatably supported thereon. A prime mover such as an engine or an electric motor that is provided outside the casing 31 and is not illustrated in the drawings is connected to one axial end of the shaft 32a. The impeller portion 32b is provided at the other axial end of the shaft 32a. The impeller portion 32b is disposed in the flow path 31a. When the shaft 32a is rotated by the prime mover, the impeller portion 32b compresses the return gas flowing through the flow path 31a. Subsequently, the impeller portion 32b sends the return gas to one of the hydrogen tank 11 and the tank 2 according to the direction of rotation of the shaft 32a.

[0024] The loading/unloading equipment 12 configured as described above operates as follows in a loading/unloading period during which the liquid hydrogen is loaded or unloaded between the hydrogen tank 11 and the tank 2. Specifically, in the loading/unloading equipment 12, at the time of loading or unloading the liquid hydrogen, the hydraulic pump 23 operates according to a direction of transportation in which the liquid hydrogen is transported. The direction of transportation herein refers to a direction from the delivery tank to the receiving tank. For example, in the case where the delivery tank is the tank 2, the receiving tank is the hydrogen tank 11. In the case where the delivery tank is the hydrogen tank 11, the receiving tank is the tank 2. When the hydraulic pump 23 operates, the liquid hydrogen is transported from the delivery tank to the receiving tank. Furthermore, at the time of transporting the liquid hydrogen, the loading/unloading equipment 12 operates the return gas blower 24 together with the hydraulic pump 23 according to the direction of transportation. Specifically, the return gas blower 24 sends the return gas in a direction opposite to the direction of transportation. Thus, the occurrence of an excessive pressure reduction in the delivery tank can be minimized, and the occurrence of an excessive pressure increase in the receiving tank can be minimized.

<Sealing Device>

[0025] The sealing device 13 is provided in the loading/unloading equipment 12. Furthermore, the sealing device 13 provides a hermetic seal between the interior of the loading/unloading equipment 12 and the atmosphere with seal gas. More specifically, with the seal gas, the sealing device 13 provides a hermetic seal between the atmosphere and the interior of the loading/unloading equipment 12 in which hydrogen having an extremely low temperature flows. In the present invention, the “hermetic seal” refers to keeping gas flowing in the loading/unloading equipment 12, that is, the boil-off gas, from being released to the atmosphere. Furthermore, in the present invention, the “extremely low temperature” refers to a temperature lower than or equal to a temperature at which nitrogen is solidified. In the present embodiment, the sealing device 13 is provided in the return gas blower 24 of the loading/unloading equipment 12. Furthermore, the sealing device 13 provides a hermetic seal between the interior of the return gas blower 24 and the atmosphere with seal gas. Note that the return gas blower 24 is one example of a target on which the sealing device 13 is provided; the sealing device 13 may be provided on a pipe or another device in the loading/unloading equipment 12. The sealing device 13 is particularly preferable in the case of providing a hermetic seal between two members that move relative to each other. However, the sealing device 13 may be used to provide a hermetic seal between two members that do not move relative to each other. The sealing device 13 constitutes a boil-off gas transport system 60 together with the hydrogen tank 11 and the return

gas blower 24 which is one example of the transport equipment. Note that in the present embodiment, the boil-off gas transport system 60 includes the seal gas supply system 14 to be described later. To describe the sealing device 13 in more detail, the sealing device 13 includes three sealing members 13a to 13c, a first seal gas chamber 34, and a second seal gas chamber 35.

[0026] The three sealing members 13a to 13c are provided between the casing 31 and the shaft 32a in the return gas blower 24. More specifically, each of the sealing members 13a to 13c is formed in the shape of a circular ring. Note that each of the sealing members 13a to 13c includes one or more seals. The first sealing member 13a, the second sealing member 13b, and the third sealing member 13c are provided at intervals on the exterior of the shaft 32a in the order from the inside of the return gas blower 24. The sealing members 13a to 13c are interposed between the shaft insertion hole 31b of the casing 31 and the shaft 32a and provide a hermetic seal between the shaft insertion hole 31b and the shaft 32a.

[0027] The first seal gas chamber 34 and the second seal gas chamber 35 are arranged between the interior of the return gas blower 24 and the atmosphere. The first seal gas chamber 34 is supplied with the first seal gas, which is boil-off gas. The second seal gas chamber 35 is provided closer to the atmosphere than the first seal gas chamber 34 is. The second seal gas chamber 35 is supplied with the second seal gas, which is nitrogen gas, from a nitrogen supply device 16. The sealing device 13 provides a hermetic seal between the interior of the return gas blower 24 and the atmosphere with the first seal gas and the second seal gas supplied to the two seal gas chambers 34, 35. Note that the second seal gas is not limited to the nitrogen gas and may be another gas such as argon gas.

[0028] More specifically, the first seal gas chamber 34 and the second seal gas chamber 35 are formed on the shaft insertion hole 31b of the casing 31. The first seal gas chamber 34 is formed between the first sealing member 13a and the second sealing member 13b, and the second seal gas chamber 35 is formed between the second sealing member 13b and the third sealing member 13c. More specifically, the first seal gas chamber 34 and the second seal gas chamber 35 are formed in the circumferential direction around the entire perimeter of the shaft insertion hole 31b and are recessed radially outward. In other words, each of the first seal gas chamber 34 and the second seal gas chamber 35 is formed in the shape of a circular ring so as to surround the entire perimeter of the shaft 32a in the circumferential direction.

[0029] In the sealing device 13 configured as described above, the sealing members 13a to 13c keep the return gas in the return gas blower 24 from being released to the atmosphere. Furthermore, by the first seal gas chamber 34, the sealing device 13 captures the return gas slightly leaking through the sealing member 13a. Thus, the sealing device 13 reduces the

leakage of the return gas into the atmosphere. Furthermore, by the second seal gas chamber 35, the first seal gas leaking from the first seal gas chamber 34 through the second sealing member 13b is captured. Thus, the sealing device 13 reduces the leakage of the first seal gas. In this manner, in the sealing device 13, a hermetic seal is provided between the interior of the return gas blower 24 and the atmosphere with the first seal gas and the second seal gas.

<Seal Gas Supply System>

[0030] The seal gas supply system 14 supplies the boil-off gas resulting from vaporization in the hydrogen tank 11 to the sealing device 13 as the first seal gas. More specifically, the seal gas supply system 14 includes a boil-off gas recovery line 41, a compressor 42, a boil-off gas reservoir 43, and a supply line 44. The boil-off gas recovery line 41 is connected to the hydrogen tank 11. The boil-off gas in the hydrogen tank 11 is brought to the boil-off gas recovery line 41. In the present embodiment, the boil-off gas recovery line 41 is connected to the return gas pipe 22 so as to form a branch.

[0031] The compressor 42 is interposed in the boil-off gas recovery line 41. The compressor 42 draws in the boil-off gas brought to the boil-off gas recovery line 41, and compresses the boil-off gas. Subsequently, the compressor 42 sends the boil-off gas to a downstream area of the boil-off gas recovery line 41.

[0032] The boil-off gas reservoir 43 stores the boil-off gas transported by the compressor 42. More specifically, the boil-off gas reservoir 43 is connected to the boil-off gas recovery line 41. The boil-off gas compressed by the compressor 42 (that is, the compressed gas) is sent to the boil-off gas reservoir 43 through the boil-off gas recovery line 41. The boil-off gas reservoir 43 stores therein the compressed gas sent thereto. The compressed gas is held in the boil-off gas reservoir 43 at room temperature.

[0033] The supply line 44 is connected to the boil-off gas reservoir 43. Furthermore, the supply line 44 is connected to the sealing device 13. This means that the boil-off gas reservoir 43 is connected to the sealing device 13 via the supply line 44. More specifically, the supply line 44 is connected to the first seal gas chamber 34 in the sealing device 13.

[0034] In the seal gas supply system 14 configured as described above, the boil-off gas in the hydrogen tank 11 is stored into the boil-off gas reservoir 43. More specifically, in the seal gas supply system 14, the boil-off gas in the hydrogen tank 11 is stored into the boil-off gas reservoir 43 in a non-loading/unloading period during which the loading and unloading tasks are not performed in the loading/unloading equipment 12. In other words, in the seal gas supply system 14, the compressor 42 is driven in the non-loading/unloading period. Thus, the boil-off gas in the hydrogen tank 11 is drawn in by the compressor 42 via the boil-off gas recovery line

41. Furthermore, the boil-off gas is compressed by the compressor 42 and sent to the boil-off gas reservoir 43. As a result, the compressed gas is stored into the boil-off gas reservoir 43.

[0035] On the other hand, in the seal gas supply system 14, the boil-off gas stored in the boil-off gas reservoir 43 is sent to the sealing device 13 as the first seal gas in the loading/unloading period. More specifically, in the seal gas supply system 14, the first seal gas is supplied from the boil-off gas reservoir 43 to the first seal gas chamber 34 of the sealing device 13. Furthermore, the second seal gas is supplied from the nitrogen supply device 16 to the second seal gas chamber 35. This means that the first seal gas and the second seal gas are supplied to the sealing device 13. Thus, the sealing device 13 provides a hermetic seal between the interior of the return gas blower 24 and the atmosphere.

<Drainage Equipment>

[0036] The drainage equipment 15 drains the first seal gas supplied to the first seal gas chamber 34. More specifically, the drainage equipment 15 is connected to the first seal gas chamber 34 and the atmosphere. The drainage equipment 15 drains, to the atmosphere, the first seal gas supplied to the first seal gas chamber 34. Furthermore, the drainage equipment 15 is connected to the second seal gas chamber 35 in addition to the first seal gas chamber 34. The drainage equipment 15 further drains, to the atmosphere, the second seal gas supplied to the second seal gas chamber 35. More specifically, the drainage equipment 15 drains mixed gas containing the first seal gas and the second seal gas to the atmosphere.

[0037] In the present embodiment, the drainage equipment 15 includes a vent line 51 and a valve 52. The vent line 51 is connected to the first seal gas chamber 34 and the second seal gas chamber 35 and is connected to the atmosphere. Furthermore, the valve 52 is provided on the vent line 51. In the drainage equipment 15, the valve 52 is open while the return gas blower 24 is driven. As a result, the mixed gas containing the two kinds of seal gas supplied to the seal gas chambers 34, 35 is released to the atmosphere through the vent line 51.

<Advantageous Effects of Liquid Hydrogen Loading/unloading System>

[0038] In the liquid hydrogen loading/unloading system 1, the compressor 42 operates in the non-loading/unloading period. Thus, the boil-off gas resulting from vaporization in the hydrogen tank 11 is drawn in and compressed by the compressor 42 through the boil-off gas recovery line 41 as indicated by the bold line in Fig. 3. Subsequently, the boil-off gas is sent to the boil-off gas reservoir 43 as the compressed gas. As a result, the compressed gas is stored in the boil-off gas reservoir 43.

[0039] Furthermore, the liquid hydrogen loading/unloading system 1 operates as follows in the loading/unloading period. Specifically, in the liquid hydrogen loading/unloading system 1,

the tank 2 is connected to the loading/unloading equipment 12, and thus loading or unloading of the liquid hydrogen is started. The following describes an example where the delivery tank is the tank 2 and the receiving tank is the hydrogen tank 11 as indicated by the bold line in Fig. 4. Specifically, in the liquid hydrogen loading/unloading system 1, the hydraulic pump 23 operates in the loading/unloading period. Thus, the liquid hydrogen is transported from the tank 2 to the hydrogen tank 11. Meanwhile, in the liquid hydrogen loading/unloading system 1, the return gas blower 24 also operates in the loading/unloading period. The return gas blower 24 sends the boil-off gas in the hydrogen tank 11 to the tank 2 as the return gas. Note that in the case where the delivery tank is the hydrogen tank 11 and the receiving tank is the tank 2, each of the liquid hydrogen and the return gas is sent in a direction opposite to said direction.

[0040] Furthermore, in the liquid hydrogen loading/unloading system 1, while the return gas blower 24 operates, the compressed gas stored in the boil-off gas reservoir 43 is supplied from the seal gas supply system 14 to the sealing device 13 as seal gas (refer to the bold dash-dot-dot line in Fig. 4). More specifically, the valve 52 can be opened in the drainage equipment 15 while the return gas blower 24 operates. Thus, the compressed gas in the boil-off gas reservoir 43 is supplied to the supply line 44 of the seal gas supply system 14 as seal gas. Subsequently, the seal gas flows to the first seal gas chamber 34 of the sealing device 13 through the supply line 44. In the first seal gas chamber 34, the return gas slightly leaking through the sealing member 13a is captured by the first seal gas. Thus, it is possible to reduce the leakage of the return gas as it is to the atmosphere. Furthermore, the second seal gas which is nitrogen gas is supplied from a supply device not illustrated in the drawings to the second seal gas chamber 35. In the second seal gas chamber 35, the first seal gas leaking from the first seal gas chamber 34 through the second sealing member 13b is captured. Thus, it is possible to reduce the leakage of the first seal gas as it is to the atmosphere. In this manner, the sealing device 13 provides a hermetic seal between the interior of the return gas blower 24 and the atmosphere with the first seal gas and the second seal gas.

[0041] The first seal gas in the first seal gas chamber 34 is drained to the atmosphere through the vent line 51. Therefore, the first seal gas can be constantly supplied to the first seal gas chamber 34, meaning that the reduction in the temperature of the first seal gas can be minimized. Furthermore, together with the first seal gas, the second seal gas is drained to the atmosphere through the vent line 51. Therefore, the second seal gas can be constantly supplied to and drained from the second seal gas chamber 35, meaning that the reduction in the temperature of the second seal gas can be minimized. In other words, solidification of the second seal gas, i.e., nitrogen, can be further reduced.

[0042] In the liquid hydrogen loading/unloading system 1 according to the present embodiment, the boil-off gas, i.e., hydrogen, is used as the first seal gas for the sealing device 13, and thus liquefaction of the first seal gas can be reduced. Accordingly, the likelihood of the sealing device 13 failing to function due to solidification of the first seal gas can be reduced.

[0043] Furthermore, in the liquid hydrogen loading/unloading system 1, the second seal gas chamber 35 in which nitrogen gas flows is located closer to the atmosphere than the first seal gas chamber 34 is, and therefore solidification of the nitrogen gas in the second seal gas chamber 35 can be reduced. Therefore, the likelihood of the sealing device 13 failing to function due to solidification of the seal gas, i.e., nitrogen gas, can be reduced. Furthermore, by interposing the nitrogen gas between the boil-off gas and the atmosphere, it is possible to keep the first seal gas from being released as it is to the atmosphere.

[0044] Furthermore, in the liquid hydrogen loading/unloading system 1, the boil-off gas is stored into the boil-off gas reservoir 43 in the non-loading/unloading period. Subsequently, in the loading/unloading period, the stored boil-off gas can be supplied to the sealing device 13 as seal gas. Thus, a large amount of seal gas can be supplied to the sealing device 13.

[0045] Furthermore, in the liquid hydrogen loading/unloading system 1, the boil-off gas is compressed and supplied to the boil-off gas reservoir 43, and thus a larger amount of boil-off gas can be stored into the boil-off gas reservoir 43. Thus, a larger amount of seal gas can be supplied to the sealing device 13 during the period.

[0046] Furthermore, in the liquid hydrogen loading/unloading system 1, the first seal gas in the first seal gas chamber 34 is drained through the drainage equipment 15. Thus, it is possible to keep supplying the first seal gas from the seal gas supply system 14 to the first seal gas chamber 34, meaning that the first seal gas is less likely to remain in the first seal gas chamber 34 and be cooled by the return gas. In other words, the reduction in the temperature of the first seal gas can be minimized. Accordingly, the reduction in the temperature of the second seal gas can also be minimized, meaning that the likelihood of the sealing device 13 failing to function due to solidification of the nitrogen gas can be further reduced.

[0047] In the liquid hydrogen loading/unloading system 1, the sealing device 13 is provided in the return gas blower 24 included in the loading/unloading equipment 12. Therefore, it is possible to prevent the occurrence of the return gas blower 24 failing to operate due to solidification of the seal gas.

[0048] In the boil-off gas transport system 60, the boil-off gas, i.e., hydrogen, is used as the first seal gas for the sealing device 13, and thus liquefaction of the first seal gas can be reduced. Accordingly, the likelihood of the sealing device 13 failing to function due to solidification of

the first seal gas can be reduced.

[Embodiment 2]

[0049] A liquid hydrogen loading/unloading system 1A according to Embodiment 2 has a configuration similar to the configuration of the liquid hydrogen loading/unloading system 1 according to Embodiment 1. Therefore, the following discussion will focus on elements of the liquid hydrogen loading/unloading system 1A according to Embodiment 2 that are different from those of the liquid hydrogen loading/unloading system 1 according to Embodiment 1; elements of the liquid hydrogen loading/unloading system 1A according to Embodiment 2 that are the same as those of the liquid hydrogen loading/unloading system 1 according to Embodiment 1 are assigned the same reference signs and as such, description of the elements will be omitted.

[0050] The liquid hydrogen loading/unloading system 1A according to Embodiment 2 includes the hydrogen tank 11, the loading/unloading equipment 12, the sealing device 13, the seal gas supply system 14, and drainage equipment 15A, as illustrated in Fig. 5. The drainage equipment 15A returns, to the seal gas supply system 14, the first seal gas drained. More specifically, the first seal gas is drained from the first seal gas chamber 34 to the drainage equipment 15A. The drainage equipment 15A returns, to the seal gas supply system 14, the first seal gas drained. More specifically, the drainage equipment 15A includes a mixed gas recovery line 53, a mixed gas blower 54, a hydrogen regeneration device 55, a hydrogen recovery line 56, a vent line 51A, and the valve 52.

[0051] The mixed gas recovery line 53 is connected to the first seal gas chamber 34 and the second seal gas chamber 35. The seal gas is drained from each of the first seal gas chamber 34 and the second seal gas chamber 35 to the mixed gas recovery line 53. Mixed gas obtained by mixing the two kinds of seal gas flows through the mixed gas recovery line 53. The mixed gas blower 54 is interposed in the mixed gas recovery line 53. The mixed gas blower 54 sends, to a downstream area of the mixed gas recovery line 53 (specifically, the hydrogen regeneration device 55 to be described later), the mixed gas flowing through the mixed gas recovery line 53.

[0052] The hydrogen regeneration device 55 is connected to the first seal gas chamber 34 and the second seal gas chamber 35. More specifically, the hydrogen regeneration device 55 is connected to the first seal gas chamber 34 and the second seal gas chamber 35 via the mixed gas recovery line 53. The hydrogen regeneration device 55 separates the mixed gas as the first seal gas and the second seal gas. Subsequently, the hydrogen regeneration device 55 separates the first seal gas (i.e., hydrogen) from the mixed gas, and returns the first seal gas to the seal gas supply system 14.

[0053] In the present embodiment, the hydrogen regeneration device 55 separates the first

seal gas and the second seal gas from the mixed gas in the following manner, for example. Specifically, the return gas pipe 22 passes through the hydrogen regeneration device 55. In the hydrogen regeneration device 55, heat is exchanged between the mixed gas and the return gas flowing through the return gas pipe 22. Thus, the hydrogen regeneration device 55 liquefies or solidify the second seal gas (i.e., nitrogen) in the mixed gas. Meanwhile, the first seal gas, i.e., hydrogen, is kept in the gaseous state. Therefore, in the hydrogen regeneration device 55, the first seal gas and the second seal gas are separated from the mixed gas. Note that the method for separation is not limited to said method in which a temperature cycle is used, and other methods (for example, pressure swing adsorption (PSA)) may be used.

[0054] Furthermore, in the non-loading/unloading period, the hydrogen regeneration device 55 re-vaporizes the second seal gas, i.e., nitrogen, liquefied or solidified. More specifically, nitrogen is liquefied or solidified by the return gas as described earlier. Therefore, when the flow of the return gas in the return gas pipe 22 stops in the non-loading/unloading period, the liquefied or solidified nitrogen is re-vaporized.

[0055] The hydrogen recovery line 56 returns the first seal gas, i.e., hydrogen, separated by the hydrogen regeneration device 55, to the seal gas supply system 14. More specifically, the hydrogen recovery line 56 is connected to the hydrogen regeneration device 55 and the compressor 42. The hydrogen separated by the hydrogen regeneration device 55 is brought to the hydrogen recovery line 56. The hydrogen brought to the hydrogen recovery line 56 is drawn in and compressed by the compressor 42. Subsequently, the compressed gas is sent to the boil-off gas reservoir 43 through the boil-off gas recovery line 41. In this manner, the hydrogen separated by the hydrogen regeneration device 55 is stored into the boil-off gas reservoir 43 as compressed gas. Note that an on/off valve 56a is interposed in the hydrogen recovery line 56. The hydrogen recovery line 56 is closed by the on/off valve 56a in the loading/unloading period. This prevents the boil-off gas from flowing back to the hydrogen regeneration device 55.

[0056] The vent line 51A drains the gas flowing through the hydrogen recovery line 56. More specifically, the vent line 51A is connected to the hydrogen recovery line 56 and the atmosphere. Furthermore, the valve 52 is provided on the vent line 51A. The valve 52 is opened at the time of draining the vaporized nitrogen in the non-loading/unloading period, and the valve 52 is closed in the loading/unloading period. Thus, the second seal gas separated by the hydrogen regeneration device 55 can be drained to the atmosphere.

<Advantageous Effects of Liquid Hydrogen Loading/unloading System>

[0057] In the liquid hydrogen loading/unloading system 1A, the loading and unloading tasks are performed between the hydrogen tank 11 and the tank 2 in the loading/unloading period

as in the liquid hydrogen loading/unloading system 1 according to Embodiment 1. Furthermore, in the liquid hydrogen loading/unloading system 1A, the first seal gas is supplied from the seal gas supply system 14 to the sealing device 13 (refer to the bold dash-dot-dot line in Fig. 5)

[0058] Meanwhile, in the liquid hydrogen loading/unloading system 1A, the mixed gas containing the seal gas drained from the first seal gas chamber 34 and the seal gas drained from the second seal gas chamber 35 is brought to the mixed gas recovery line 53. Furthermore, the mixed gas blower 54 sends the mixed gas to the hydrogen regeneration device 55. Subsequently, the hydrogen regeneration device 55 separates the first seal gas and the second seal gas contained in the mixed gas from each other. Furthermore, the separated first seal gas, i.e., hydrogen, is drawn in and compressed by the compressor 42 through the hydrogen recovery line 56. Subsequently, the compressed hydrogen is stored into the boil-off gas reservoir 43. The hydrogen stored in the boil-off gas reservoir is re-supplied as the first seal gas to the first seal gas chamber 34 through the seal gas supply system 14. In other words, the separated first seal gas is regenerated as the first seal gas.

[0059] In the liquid hydrogen loading/unloading system 1A according to the present embodiment, the drainage equipment 15A returns, to the seal gas supply system 14, the first seal gas drained, meaning that the first seal gas can be reused. Furthermore, in the liquid hydrogen loading/unloading system 1A, hydrogen can be regenerated from the mixed gas drained from the sealing device 13.

[0060] The liquid hydrogen loading/unloading system 1A according to Embodiment 2 produces advantageous effects that are substantially the same as those produced by the liquid hydrogen loading/unloading system 1 according to Embodiment 1.

[Embodiment 3]

[0061] A liquid hydrogen loading/unloading system 1B includes the hydrogen tank 11, the loading/unloading equipment 12, sealing devices 13, 13B, the seal gas supply system 14, and the drainage equipment 15, as illustrated in Fig. 6. The sealing device 13B is provided on the compressor 42 which is one example of the transport equipment according to the present embodiment. The sealing device 13B is connected to the supply line 44 of the seal gas supply system 14 and the drainage equipment 15 in such a manner as to be parallel to the sealing device 13. Note that the sealing device 13B may be connected to drainage equipment 15 different from the drainage equipment 15 connected to the sealing device 13. The boil-off gas is supplied from the seal gas supply system 14 to the sealing device 13B as the first seal gas. Subsequently, the sealing device 13B provides a hermetic seal between the interior of the compressor 42 and the atmosphere with the first seal gas.

[0062] Note that the structure of the sealing device 13B is similar to the structure of the sealing device 13. More specifically, the compressor 42 according to the present embodiment is configured to transport the boil-off gas 11b by an impeller as with the return gas blower 24. Therefore, the structure of the sealing device 13B is similar to the structure of the sealing device 13. Accordingly, regarding the sealing device 13B, the description of the sealing device 13 will be referred to, and detailed description of the sealing device 13B will be omitted. Furthermore, in the liquid hydrogen loading/unloading system 1B, the sealing device 13B constitutes a boil-off gas transport system 60B together with the hydrogen tank 11 and the compressor 42 (more specifically, the seal gas supply system 14).

[0063] In the boil-off gas transport system 60B, the boil-off gas 11b, i.e., hydrogen, is used as the first seal gas for the sealing device 13B, and thus liquefaction of the first seal gas can be reduced. Accordingly, the likelihood of the sealing device 13B failing to function due to solidification of the first seal gas can be reduced.

[0064] In the boil-off gas transport system 60B, the sealing device 13B is provided on the compressor 42 which sends the boil-off gas 11b to the boil-off gas reservoir 43. Therefore, it is possible to prevent the occurrence of the compressor 42 failing to operate due to solidification of the seal gas. Thus, it is possible to keep sending the boil-off gas 11b to the boil-off gas reservoir 43.

[0065] The liquid hydrogen loading/unloading system 1B and the boil-off gas transport system 60B produce advantageous effects that are substantially the same as those produced by the liquid hydrogen loading/unloading system 1 and the boil-off gas transport system 60 according to Embodiment 1.

[Embodiment 4]

<Boil-off Gas Transport System>

[0066] A boil-off gas transport system 60C illustrated in Fig. 7 transports the boil-off gas 11b from the tank 2 to onshore equipment 3. The onshore equipment 3, which is equipment that uses the boil-off gas 11b as a fuel, a raw material, or the like, is a power plant, a factory, and the like. In the present embodiment, the onshore equipment 3 is a power plant that generates electric power using hydrogen. Note that the onshore equipment 3 does not necessarily need to include the tank 2 such as that described earlier. The boil-off gas transport system 60C includes the hydrogen tank 11, transport equipment 12C, a sealing device 13C, the seal gas supply system 14, and the drainage equipment 15.

[0067] The transport equipment 12C transports the boil-off gas 11b resulting from vaporization in the hydrogen tank 11. More specifically, the transport equipment 12C is

connected to the hydrogen tank 11 and the onshore equipment 3. In the present embodiment, the transport equipment 12C is connected to the hydrogen tank 11 so as to be parallel to the seal gas supply system 14. The transport equipment 12C compresses the boil-off gas 11b resulting from vaporization in the hydrogen tank 11 and transports the compressed boil-off gas 11b to the onshore equipment 3. In the present embodiment, the transport equipment 12C is a compressor. Note that the transport equipment 12C has a structure similar to the structure of each of the compressor 42 and the return gas blower 24. Therefore, the structure of the sealing device 13C is also similar to the structure of the sealing device 13. Accordingly, regarding the structure of each of the transport equipment 12C and the sealing device 13C, the description of the structure of each of the return gas blower 24 and the sealing device 13 will be referred to, and detailed description of the structure of each of the transport equipment 12C and the sealing device 13C will be omitted.

[0068] In the boil-off gas transport system 60C, the transport equipment 12C is a compressor that compresses the boil-off gas 11b and transports the compressed boil-off gas 11b to the onshore equipment 3. Therefore, it is possible to prevent the occurrence of the transport equipment 12C failing to operate due to solidification of the seal gas. Thus, it is possible to keep sending the boil-off gas 11b to the onshore equipment 3.

[0069] The boil-off gas transport system 60C produces advantageous effects that are substantially the same as those produced by the boil-off gas transport system 60 according to Embodiment 1.

[Other Embodiments]

[0070] In Embodiments 1 to 3, the liquid hydrogen loading/unloading systems 1, 1A, 1B are equipment for loading and unloading liquid hydrogen to and from a loading/unloading vessel (not illustrated in the drawings), but may be equipment mounted on a loading/unloading vessel and used for loading and unloading liquid hydrogen to and from onshore equipment. In this case, the tank mounted on the loading/unloading vessel is the hydrogen tank. Furthermore, the liquid hydrogen loading/unloading systems 1, 1A, 1B may perform the loading and unloading tasks between onshore equipment and a transport vehicle. In the liquid hydrogen loading/unloading systems 1, 1A, 1B, the target hermetically sealed by the sealing device 13 is the return gas blower 24, but may be a pipe included in the loading/unloading equipment 12 or other devices.

[0071] The above-described structure of each of the sealing devices 13, 13B in the liquid hydrogen loading/unloading systems 1, 1A, 1B according to Embodiments 1 to 3 and the sealing device 13C in the boil-off gas transport system 60C according to Embodiment 4 is merely one

example; other structures may be applied thereto. The sealing device 13 may be a sealing device that does not include the second seal gas chamber 35, but includes only the first seal gas chamber 34, for example; it is sufficient that the sealing device 13 provide a hermetic seal between the interior of the loading/unloading equipment 12 and the atmosphere with at least the first seal gas.

[0072] Furthermore, in Embodiments 1 to 4, the seal gas supply system 14 includes the boil-off gas reservoir 43, but does not necessarily need to include the boil-off gas reservoir 43. For example, part of the boil-off gas may be supplied to the sealing device 13 as the first seal gas in the loading/unloading period. Furthermore, in Embodiments 1 to 3, the boil-off gas stored in the boil-off gas reservoir 43 does not necessarily need to be supplied only to the sealing devices 13, 13B, 13C, but may also be supplied to the onshore equipment 3.

[0073] While the return gas blower 24 and the compressor 42 are cited as one example of the transport equipment in the boil-off gas transport systems 60, 60B, 60C according to Embodiments 1 to 4, the transport equipment may be a pump. It is sufficient that the transport equipment can transport the boil-off gas 11b; particularly, it is sufficient that the transport equipment can increase the pressure of the boil-off gas 11b to be transported. The boil-off gas transfer system 60C according to Embodiment 4 includes one item of transport equipment 12C, but may include two or more items of transport equipment 12c. The sealing device 13C is provided on every item of transport equipment 12C or at least one item of transport equipment 12C. The compressor in the transport equipment 12C is not limited to a centrifugal compressor such as that including an impeller, but may be a compressor of another type such as a reciprocating compressor.

[0074] From the foregoing description, many modifications and other embodiments of the present invention would be obvious to a person having ordinary skill in the art. Therefore, the foregoing description should be interpreted only as an example and is provided for the purpose of teaching the best mode for carrying out the present invention to a person having ordinary skill in the art. Substantial changes in details of the structures and/or functions of the present invention are possible within the spirit of the present invention.

CLAIMS

1. **A liquid hydrogen loading/unloading system** comprising:

a hydrogen tank that stores liquid hydrogen;

loading/unloading equipment that loads the liquid hydrogen into the hydrogen tank and unloads the liquid hydrogen from the hydrogen tank;

a sealing device that is provided in the loading/unloading equipment and provides a hermetic seal between an interior of the loading/unloading equipment and an atmosphere with first seal gas; and

a seal gas supply system that supplies boil-off gas resulting from vaporization in the hydrogen tank to the sealing device as the first seal gas.

2. The liquid hydrogen loading/unloading system according to claim 1, wherein:

the sealing device includes **a first seal gas chamber** and **a second seal gas chamber** disposed between the interior of the loading/unloading equipment and the atmosphere;

the first seal gas is supplied from the seal gas supply system to the first seal gas chamber; and

the second seal gas chamber is located closer to the atmosphere than the first seal gas chamber is, and second seal gas flows in the second seal gas chamber.

3. The liquid hydrogen loading/unloading system according to claim 1 or 2, wherein:

the seal gas supply system includes **a boil-off gas reservoir;** and

the boil-off gas reservoir is connected to the sealing device and stores the boil-off gas.

4. The liquid hydrogen loading/unloading system according to claim 3, wherein:

the seal gas supply system includes a **compressor**; and

the compressor compresses the boil-off gas to be supplied to the boil-off gas reservoir.

5. The liquid hydrogen loading/unloading system according to any one of claims 1 to 4, further comprising:

drainage equipment, wherein:

the sealing device includes **a first seal gas chamber** disposed between the interior of the loading/unloading equipment and the atmosphere;

the first seal gas is supplied from the seal gas supply system to the first seal gas chamber; and

the **drainage equipment** is connected to the first seal gas chamber and drains the first seal gas supplied to the first seal gas chamber.

6. The liquid hydrogen loading/unloading system according to claim 5, wherein:

the drainage equipment returns, to the seal gas supply system, the first seal gas drained.

7. The liquid hydrogen loading/unloading system according to claim 6, wherein:

the sealing device includes the first seal gas chamber and **a second seal gas chamber** disposed between the interior of the loading/unloading equipment and the atmosphere;

the first seal gas is supplied from the seal gas supply system to the first seal gas chamber;

the second seal gas chamber is located closer to the atmosphere than the first seal gas chamber is, and second seal gas flows in the second seal gas chamber;

the drainage equipment includes **a hydrogen regeneration device** that is connected to the first seal gas chamber and the second seal gas chamber and separates the first seal gas and the second seal gas from each other; and

mixed gas of the first seal gas and the second seal gas drained respectively from the first seal gas chamber and the second seal gas chamber is brought to the hydrogen regeneration device, and the hydrogen regeneration device separates the first seal gas from the mixed gas and returns the first seal gas to the seal gas supply system.

8. The liquid hydrogen loading/unloading system according to any one of claims 1 to 7, wherein:

the loading/unloading equipment includes **a return gas blower** that sends the boil-off gas to **a delivery tank** that delivers the liquid hydrogen into the hydrogen tank; and

the sealing device is provided in the return gas blower.

9. **A boil-off gas transport system** comprising:

a hydrogen tank that stores liquid hydrogen;

transport equipment that transports boil-off gas resulting from vaporization in the hydrogen tank; and

a sealing device that is provided in the transport equipment and provides a hermetic seal between an interior of the transport equipment and an atmosphere with first seal gas, wherein:

the boil-off gas is supplied to the sealing device as the first seal gas.

10. The boil-off gas transport system according to claim 9, comprising:

a seal gas supply system that includes the transport equipment and **a boil-off gas reservoir** and supplies the boil-off gas to the sealing device as the first seal gas, wherein:

the boil-off gas reservoir stores the boil-off gas transported by the transport equipment; and

the seal gas supply system supplies the boil-off gas stored in the boil-off gas reservoir to the sealing device as the first seal gas.

11. The boil-off gas transport system according to claim 9, further comprising:

a seal gas supply system that supplies the boil-off gas resulting from vaporization in the hydrogen tank to the sealing device as the first seal gas, wherein:

the transport equipment is a **compressor** that compresses the boil-off gas and transports the boil-off gas to **onshore equipment**.