

Description

Title of the Invention: COOLING SYSTEM

Technical Field

5 [0001] Embodiments of the present invention relate to a cooling system that utilizes decreasing temperature of a refrigerant caused by reduction of pressure.

Background Art

10 [0002] Vapor compression type refrigeration devices are widely used in many fields.

[0003] In the vapor compression type refrigeration device, a refrigerant is compressed by a compressor and the refrigerant flowing out from the compressor is cooled by a condenser. The refrigerant flowing out from the condenser is expanded by an expansion valve, and the refrigerant flowing out from the expansion valve exchanges heat with a temperature control target in an evaporator. The refrigerant absorbs heat from the temperature control target in the evaporator to cool it. The refrigerant flowing out from the evaporator circulates to the compressor and then releases heat in the condenser.

25 [0004] The refrigerant used in the vapor compression type refrigeration device is usually a fluorine based refrigerant. The fluorine refrigerant is a greenhouse

gas and flammable in some cases, but has various advantages such as the ability to achieve highly-efficient operation.

[0005] Meanwhile, in consideration of the impact of
5 the fluorine based refrigerant on the environment,
development of fluorine refrigerants for vapor
compression type that allow the global warming
potential (GWP) to be kept lower has been underway.
Then, HFO refrigerants for vapor compression type with
10 a very low GWP have already been put to practical use.
Specifically, for example, an HFO refrigerant with a
GWP of 10 or less has been put to practical use.
However, this refrigerant is not necessarily
sufficiently safe in terms of flammability and
15 toxicity. For this reason, the development of
refrigerants for vapor compression that have a low GWP
and are capable of ensuring safety is still actively
underway.

[0006] Further, the compressor used in the vapor
20 compression type refrigeration device operates for a
long period of time. For this reason, it is necessary
to lubricate a driving portion such as a rotation
portion with lubricating oil. However, the lubricating
oil has a problem of flowing out to the refrigerant
25 side. Then, the flowing out of lubricating oil causes
the compressor to run out of oil in some cases, which

impairs the stability of the operation of the compressor in some cases. Further, the cooling efficiency of the evaporator is impaired in some cases by the lubricating oil that has stagnated in the evaporator. For this reason, vapor compression type refrigeration devices leaves room for various improvements also in terms of using a compressor.

[0007] Meanwhile, as a cooling device without using a compressor, a boiling cooling device such as those disclosed in JP2011-142298A, WO2017/119113A1, and JP2021-162195A has been known.

[0008] The boiling cooling device is capable of efficiently cooling a temperature control target by absorbing heat due to latent heat by vaporizing a liquid when the liquid is caused to exchange heat with the temperature control target. Then, a pump is usually necessary to circulate the liquid or its vaporized gas, but the pump requires no lubricating oil or only a small amount of lubricating oil. Further, the energy consumption of the pump is relatively small. Therefore, it can be said that the boiling cooling device is a device with excellent environmental performance.

[0009] However, in the boiling cooling device, the temperature of the liquid to be circulated is usually close to the boiling point under the atmospheric pressure, and cooling at, for example, temperature

ranges significantly below 0°C is not possible, so that the cooling temperature and the temperature control target are very limited. For this reason, it is difficult to achieve high refrigeration capacity at low or ultra-low temperature ranges using the boiling cooling device.

Summary of Invention

[0010] In recent years, while the development of HFO refrigerants has been underway as described above, development of antifreezes with a low environmental impact has also been underway. Then, an HFO solvent that has a low GWP, is non-flammable, and can be used as an antifreeze has been put to practical use. Such a solvent is not suitable for vapor compression type refrigeration devices because its boiling point under the atmospheric pressure is, for example, 70°C or higher. However, if a thermal cycle can be realized using such an HFO solvent, there is a possibility that a cooling system that is capable of ensuring a low environmental impact, high safety, and high refrigeration capacity, which are currently strongly desired, can be realized.

[0011] In this regard, the present inventors have conducted extensive research to realize a novel cooling system that is capable of using, for example, the above-mentioned HFO solvent as a refrigerant in a

thermal cycle. More generally, they have conducted extensive research to realize a novel cooling system that is capable of shifting substances in a range different from the range of refrigerants that can be used in vapor compression type refrigeration devices to refrigerants that can be used in a thermal cycle. They have found that the above cooling system can be realized with a structure in which the refrigerant is cooled by lowering the temperature by reducing the pressure and then the heat absorbed by the refrigerant is released under the atmospheric pressure, leading to the present invention.

[0012] That is, an object of the present invention is to provide a cooling system that allows a substance that has not been used in existing refrigeration methods to be used as a refrigerant in a thermal cycle or allows the range of substances that can be used as a refrigerant in a thermal cycle to be expanded.

[0013] An embodiment of the present invention relates to the following aspects "1" to "18".

[0014] [1] A cooling system, including:
a container that includes an outflow port and an inflow port and stores a refrigerant in liquid form;
a pressure reducing device that is connected to the outflow port and adjusts a pressure in the container to be lower than an atmospheric pressure by

sucking gas from the container through the outflow port; and

a refrigerant circulation device that includes a refrigerant flow path to be connected to the pressure
5 reducing device and the inflow port and causes the refrigerant in liquid form liquefied from the gas sucked from the container by the pressure reducing device to flow into the container through the inflow port,

10 the cooling system cooling a temperature control target with the refrigerant in the container.

[0015] [2] The cooling system according to [1], in which

the pressure reducing device includes

15 a gas flow path to be connected to the outflow port,

a gas suction pump that is provided in the gas flow path and sucks the gas from the container into the gas flow path, and

20 a reservoir tank that is connected to the gas flow path and stores the gas flowing out from the gas flow path and/or the refrigerant in liquid form liquefied from the gas, and

25 the refrigerant flow path is connected to the reservoir tank.

[0016] [3] The cooling system according to [2], in

which

a pressure in the reservoir tank is higher than the pressure in the container, and the reservoir tank liquefies at least part of the gas flowing out from the gas flow path to the refrigerant in liquid form and stores the refrigerant in liquid form.

[0017] [4] The cooling system according to [2] or [3], in which

the refrigerant circulation device further includes a circulation pump that is provided in the refrigerant flow path and sucks the refrigerant in liquid form from the reservoir tank into the refrigerant flow path.

[0018] [5] The cooling system according to any one of [2] to [4], in which

the pressure reducing device further includes a cooling unit that cools a portion of the gas flow path downstream of the gas suction pump and/or the reservoir tank.

[0019] [6] The cooling system according to any one of [2] to [5], in which

the refrigerant circulation device further includes a buffer container that is provided in the refrigerant flow path so as to form part of the refrigerant flow path and stores the refrigerant in liquid form, and

the refrigerant in liquid form sucked from the reservoir tank into the refrigerant flow path flows into the container after passing through the buffer container.

5 [0020] [7] The cooling system according to [6], further including

a heat exchanger that is connected to the refrigerant flow path and cools the refrigerant in liquid form circulated in the refrigerant flow path,

10 the buffer container being provided at a portion of the refrigerant flow path upstream of a portion to which the heat exchanger is connected.

[0021] [8] The cooling system according to [6] or [7], in which

15 the reservoir tank is provided above the buffer container.

[0022] [9] The cooling system according to any one of [2] to [8], in which

20 the gas suction pump is configured to suck the gas by rotation of a motor, and

the gas suction pump adjusts a rotation speed of the motor in accordance with a temperature in the container, the pressure in the container, a temperature of a heat medium cooled by the refrigerant, or a
25 temperature of the temperature control target.

[0023] [10] The cooling system according to any one

of [2] to [9], in which

a flow rate control valve that controls a flow rate of the gas circulated in the gas flow path by adjusting the degree of opening is provided at a
5 portion of the gas flow path upstream or downstream of the gas suction pump, and

the degree of opening of the flow rate control valve is adjusted in accordance with a temperature in the container, the pressure in the container, a
10 temperature of a heat medium cooled by the refrigerant, or a temperature of the temperature control target.

[0024] [11] The cooling system according to any one of [2] to [10], further including

a gas supply device that supplies gaseous matter
15 into the container,

the gas supply device adjusting an amount of the gaseous matter to be supplied into the container in accordance with the temperature in the container, the pressure in the container, the temperature of the heat
20 medium cooled by the refrigerant, or the temperature of the temperature control target.

[0025] [12] The cooling system according to any one of [1] to [11], further including

a heat exchanger that is connected to the
25 refrigerant flow path and cools the liquid refrigerant circulated in the refrigerant flow path,

the refrigerant circulation device including a three-way valve that is provided at a portion of the refrigerant flow path downstream of a portion to which the heat exchanger is connected and includes a first
5 port, a second port, and a third port,

the three-way valve being capable of adjusting a flow rate of the refrigerant that flows into the first port and flows out from the second port and a flow rate of the refrigerant that flows into the first port and
10 flows out from the third port,

the three-way valve constituting part of the refrigerant flow path in a flow path between the first port and the second port,

the third port and the portion of the refrigerant flow path upstream of the portion to which the heat exchanger is connected being connected via a bypass flow path.
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[0026] [13] The cooling system according to [12], in which

20 the three-way valve reduces the flow rate of the refrigerant that flows into the first port and flows out from the second port and increases the flow rate of the refrigerant that flows into the first port and flows out from the third port in a case where a liquid
25 level height of the liquid refrigerant in the container exceeds a predetermined height, and

the three-way valve increase the flow rate of the refrigerant that flows into the first port and flows out from the second port and reduces the flow rate of the refrigerant that flows into the first port and flows out from the third port in a case where the liquid level height of the liquid refrigerant in the container falls below the predetermined height.

[0027] [14] The cooling system according to [12], in which

the three-way valve blocks circulation of the refrigerant that flows into the first port and flows out from the second port and allows the refrigerant that flows into the first port and flows out from the third port to be circulated in a case where a liquid level height of the liquid refrigerant in the container exceeds a predetermined height, and

the three-way valve allows the refrigerant that flows into the first port and flows out from the second port to be circulated and blocks circulation of the refrigerant that flows into the first port and flows out from the third port in a case where the liquid level height of the liquid refrigerant in the container falls below the predetermined height.

[0028] [15] The cooling system according to any one of [1] to [14], further including

a heat medium circulation device that includes a

heat medium flow path for circulating a heat medium,

the heat medium flow path including a heat exchange unit that is disposed in the container and causes the heat medium to exchange heat with the refrigerant,

the heat medium flow path sending the heat medium from an outside of the container to the heat exchange unit and sending the heat medium heat-exchanged in the heat exchange unit to the outside of the container.

[0029] [16] The cooling system according to any one of [1] to [15], in which

the refrigerant is a substance that has a boiling point of 30°C or higher under an atmospheric pressure.

[0030] [17] The cooling system according to any one of [1] to [16], in which

the refrigerant has a GWP of 10 or less.

[0031] [18] The cooling system according to any one of [1] to [17], in which

the refrigerant is HFO-1336mzz-Z.

[0032] According to the present invention, it is possible to allow a substance that has not been used in existing refrigeration methods to be used as a refrigerant in a thermal cycle or allow the range of substances that can be used as a refrigerant in a thermal cycle to be expanded.

Brief Description of Drawings

[0033] [Fig. 1] Fig. 1 is a diagram schematically showing a cooling system according to a first embodiment.

[Fig. 2] Fig. 2 is a block diagram showing a functional configuration of a controller constituting the cooling system in Fig. 1.

[Fig. 3] Fig. 3 is a pressure-enthalpy chart of an example of a refrigerant used in the cooling system in Fig. 1.

[Fig. 4] Fig. 4 is a diagram schematically showing a cooling system according to a second embodiment.

[Fig. 5] Fig. 5 is a diagram schematically showing a cooling system according to a third embodiment.

[Fig. 6] Fig. 6 is a diagram schematically showing a cooling system according to a fourth embodiment.

Mode(s) for Carrying Out the Invention

[0034] Embodiments will be described below.

[0035] <First embodiment>

Fig. 1 is a schematic diagram of a cooling system S1 according to a first embodiment. The configuration of the cooling system S1 will be described first.

[0036] (Configuration of cooling system)

As shown in Fig. 1, the cooling system S1 according to the first embodiment includes a sealed container 10, a pressure reducing device 20, a refrigerant circulation device 30, a heat exchanger 40,

a heat medium circulation device 50, a gas supply device 60, and a controller 100.

[0037] In the cooling system S1, a liquid refrigerant is stored in the sealed container 10. The pressure reducing device 20 is a device that is connected to the sealed container 10 and sucks the gas present in the sealed container 10 or the gas vaporized in the sealed container 10 to reduce the pressure in the sealed container 10. Then, the refrigerant circulation device 30 is connected to the pressure reducing device 20, circulates the refrigerant in liquid form obtained by being liquefied from the gas sucked from the sealed container 10 by the pressure reducing device 20, and causes the refrigerant in liquid form to flow into and return to the sealed container 10. Further, the refrigerant circulation device 30 is connected to the heat exchanger 40 outside the sealed container 10. The refrigerant circulated by the refrigerant circulation device 30 circulates between the sealed container 10 and the heat exchanger 40. Then, the cooling system S1 cools the heat medium circulated by the heat medium circulation device 50 in the sealed container 10, and the heat medium circulation device 50 sends the cooled heat medium to a temperature control target T. Further, the refrigerant circulation device 30 releases, from the heat exchanger

40, the heat absorbed by the refrigerant from the heat medium. Further, in this embodiment, the pressure reducing device 20 releases heat also from a cooling unit 25 described below. This allows the heat medium to be cooled in a continuous manner.

[0038] In the cooling system S1, as described below, the pressure in the sealed container 10 is reduced to a pressure lower than the atmospheric pressure by the pressure reducing device 20. Meanwhile, the refrigerant circulation environment in the refrigerant circulation device 30 outside the sealed container 10 and the refrigerant circulation environment in the heat exchanger 40 are set to a pressure higher than the pressure in the sealed container 10, e.g., the atmospheric pressure. In such an environment, when the refrigerant flows from the heat exchanger 40 into the sealed container 10, the refrigerant expands and the temperature of the refrigerant drops (decreases) in the sealed container 10. As a result, the heat medium can be cooled by the refrigerant whose temperature has dropped in the sealed container 10. At this time, the refrigerant evaporates due to heat exchange with the heat medium, and in this case, the heat medium can be efficiently cooled by the latent heat of vaporization of the refrigerant. Then, the above evaporated refrigerant is in a gaseous state and sucked by the

pressure reducing device 20.

[0039] The refrigerant to be circulated by the refrigerant circulation device 30 is not particularly limited, but is, for example, a substance that becomes liquid under the atmospheric pressure and at a standard environmental temperature (e.g., 25°C), which becomes - 5°C or lower when expanded in an environment of, for example, 0.1 atm, desirably a substance that becomes - 30°C or lower when expanded in an environment of 0.01 atm. In the case of using such a substance as a refrigerant, cooling to a low-temperature range is possible. Note that in the present specification, the atmospheric pressure means 1 atm, in other words, 0.1 MPa (Abs). The respective portions of the cooling system S1 will be described below in detail.

[0040] The sealed container 10 is a container that include a first outflow port 11, a second outflow port 12, an inflow port 13, a gas receiving port 14, a heat medium inlet 15, and a heat medium outlet 16 and prevents gas and liquid from flowing out and leaking from any portion other than these port portions (11 to 16). The sealed container 10 has a structure capable of maintaining its shape when the internal pressure is reduced, and is so-called a vacuum insulated container.

[0041] The maintenance of the shape of the sealed container 10 during reduction of pressure depends on

the internal pressure to be reduced, but the outer shell portion of the sealed container 10 is favorably formed of a hard metal having a large thickness, for example, in the case where the pressure is reduced to 0.1 atm. However, the specific structure of the sealed container 10 should be determined as appropriate in accordance with the expected degree of reduction of pressure and is not particularly limited. Further, the sealed container 10 may include a container body having an opening and a lid for opening and closing the opening. In this case, it is necessary to ensure sufficient airtightness and sealing when the lid is closed.

[0042] The sealed container 10 is configured to store the refrigerant in liquid form, a reference symbol Lf indicates a liquid pool of the refrigerant in liquid form, and a reference symbol Gf indicates a gas phase portion. That is, in this embodiment, the sealed container 10 stores the refrigerant in liquid form while forming the gas phase portion Gf. The pressure reducing device 20 described below reduces the pressure in the sealed container 10 by sucking the gas in the sealed container 10. Here, in the case where the gas phase portion Gf is formed, the refrigerant in liquid form is prevented from entering the pressure reducing device 20, which allows the operation state of the

pressure reducing device 20 to be stabilized. Further, the breakdown of the pressure reducing device 20 can be suppressed.

[0043] The environment in which both the refrigerant
5 in liquid form and the gas phase portion Gf are present in the sealed container 10 can be created by controlling the operations of the pressure reducing device 20, the refrigerant circulation device 30, and the gas supply device 60.

10 [0044] The first outflow port 11 is an opening that is connected to the pressure reducing device 20 and intended to cause a gas to flow out therefrom. Therefore, the first outflow port 11 is favorably opened to the gas phase portion Gf of the sealed
15 container. Further, the gas receiving port 14 is connected to the gas supply device 60 as described below. This gas receiving port 14 is also favorably opened to the gas phase portion Gf of the sealed container 10, similarly to the first outflow port 11.
20 The first outflow port 11 and the gas receiving port 14 are favorably provided in the top wall or the upper part of the side wall of the sealed container 10. In the illustrated example, the first outflow port 11 and the gas receiving port 14 are formed in the top wall of
25 the sealed container 10.

[0045] The second outflow port 12 is an opening for

discharging the refrigerant in liquid form in the sealed container 10. The inflow port 13 is an opening for receiving the refrigerant in liquid form circulated by the refrigerant circulation device 30. The second
5 outflow port 12 and the inflow port 13 are favorably opened to the liquid phase portion of the sealed container 10 and favorably provided in the bottom wall or the lower part of the side wall of the sealed container 10. In the illustrated example, the second
10 outflow port 12 is formed in the bottom wall of the sealed container 10 and the inflow port 13 is formed below the middle portion in the up-and-down direction of the side wall of the sealed container 10. Further, the heat medium inlet 15 and the heat medium outlet 16
15 are favorably opened to the liquid phase portion of the sealed container 10. In the illustrated example, the heat medium inlet 15 and the heat medium outlet 16 are formed in the bottom wall of the sealed container 10.

[0046] The pressure reducing device 20 is a device
20 that is connected to the first outflow port 11 and sucks the gas from the sealed container 10 through the first outflow port 11 to adjust the pressure in the sealed container 10 to be lower than the atmospheric pressure. In detail, the pressure reducing device 20 in
25 this embodiment includes a gas flow path 21 to be connected to the first outflow port 11, a gas suction

pump 22 that is provided on the gas flow path 21 and
sucks the gas from the sealed container 10 into the gas
flow path 21, and a reservoir tank 23 that is connected
to a downstream end 21B of the gas flow path 21 and
5 stores the gas flowing out from the downstream end 21B.

[0047] The gas flow path 21 includes an upstream end
21A to be connected to the first outflow port 11 and
the downstream end 21B to be connected to the reservoir
tank 23. The gas suction pump 22 is provided at a
10 portion between the upstream end 21A and the downstream
end 21B of the gas flow path 21.

[0048] The type of gas suction pump 22 is not
particularly limited, but the gas suction pump 22 is
favorably a dry vacuum pump in which lubricating oil
15 does not flow out or hardly flows out to the suction
path (gas flow path 21) side. The dry vacuum pump may
be a diaphragm type dry vacuum pump, a rocking piston
type dry vacuum pump, a rotary vane type dry vacuum
pump, a scroll type dry vacuum pump, or the like, and
20 is of a type different from the types illustrated
above. However, the gas suction pump 22 may be a wet
type vacuum pump.

[0049] The gas suction pump 22 in this embodiment is
a dry vacuum pump. Then, the gas suction pump 22
25 includes a motor 22M that is controlled by an inverter,
such as an AC motor and a brushless DC motor. Then, the

gas suction pump 22 is configured to adjust the amount of gas to be sucked by adjusting the rotation speed (number of rotation) of the motor 22M, which allows the pressure in the sealed container 10 to be adjusted. In detail, the rotation speed of the motor 22M is adjusted by adjusting the frequency of the AC current to be supplied to the motor 22M by an inverter (not shown).

[0050] Further, in this embodiment, the gas flow path 21 is provided with a flow rate control valve 24, and the pressure in the sealed container 10 can be adjusted also by adjusting the degree of opening of the flow rate control valve 24. The flow rate control valve 24 is capable of adjusting the flow rate of the gas to be circulated through the gas flow path 21 by adjusting the degree of opening. This adjusts the amount of gas to be sucked, and thus, the pressure in the sealed container 10 can be adjusted.

[0051] The gas suction pump 22 and the flow rate control valve 24 may simultaneously operate to adjust the pressure in the sealed container 10. Further, the degree of opening of the flow rate control valve 24 may be adjusted while the operation state of the gas suction pump 22 is maintained constant. Alternatively, the operation state of the gas suction pump 22 may be controlled while the degree of opening of the flow rate control valve 24 is maintained constant.

[0052] Although the flow rate control valve 24 is provided in the gas flow path 21 at a portion upstream of the gas suction pump 22 in this embodiment, it may be provided at a portion downstream of the gas suction pump 22. The flow rate control valve 24 includes, for example, a butterfly valve, but is not particularly limited thereto.

[0053] The gas suction pump 22 and the flow rate control valve 24 are electrically connected to the controller 100 and controlled by the controller 100. In this embodiment, the gas suction pump 22 is electrically connected to the controller 100 via an inverter (not shown). The flow rate control valve 24 may be a valve in which the degree of opening of the valve body is adjusted by an electric motor such as a stepping motor and a servo motor. In this case, the controller 100 is electrically connected to the above electric motor. Note that the flow rate control valve 24 may be a solenoid proportional valve or the like.

[0054] The pressure in the reservoir tank 23 is higher than the pressure in the sealed container 10 and is set to, for example, the atmospheric pressure. This makes it easier for the reservoir tank 23 to liquefy at least part of the gas flowing out from the downstream end 21B of the gas flow path 21 into a refrigerant in liquid form and store the refrigerant in liquid form.

The reservoir tank 23 may include, for example, an openable/closable lid to suppress power consumption of the gas suction pump 22 when the pressure rises, for safety, and for depositing or supplying a refrigerant.

5 That is, the reservoir tank 23 may include a container body having an opening and a lid for opening and closing the opening. In this case, it is necessary to ensure sufficient airtightness and sealing when the lid is closed.

10 [0055] In this embodiment, the pressure reducing device 20 further includes the cooling unit 25 that cools a portion of the gas flow path 21 downstream of the gas suction pump 22. This promotes liquefaction of the gas flowing out from the downstream end 21B of the
15 gas flow path 21, and for example, the pressure rise in the reservoir tank 23 can be suppressed. The cooling unit 25 includes, for example, a cooling fan. However, the configuration of the cooling unit 25 is not particularly limited, and the cooling unit 25 may be a
20 heat exchanger or the like. Note that the cooling unit 25 may cool the reservoir tank 23. In this case, the cooling unit 25 may cool the inside or outside of the reservoir tank 23.

[0056] The refrigerant circulation device 30
25 includes a refrigerant flow path 31 that is connected to the pressure reducing device 20 and the inflow port

13, and a circulation pump 32 that is provided in the refrigerant flow path 31 and sucks the refrigerant in liquid form in the reservoir tank 23 into the refrigerant flow path 31. In detail, the refrigerant flow path 31 is connected to the reservoir tank 23 in the pressure reducing device 20. The refrigerant circulation device 30 circulates the refrigerant in liquid form received from the reservoir tank 23 and causes the refrigerant in liquid form to flow into the sealed container 10 from the inflow port 13.

[0057] Further, the refrigerant circulation device 30 in this embodiment further includes a buffer container 33 and a three-way valve 34 provided in the refrigerant flow path 31. In this embodiment, the circulation pump 32, the buffer container 33, and the three-way valve 34 are provided in the refrigerant flow path 31 so as to constitute part of the refrigerant flow path 31. Although the circulation pump 32 is disposed downstream of the buffer container 33 and the three-way valve 34 is disposed downstream of the circulation pump 32, such an arrangement is not particularly limited.

[0058] The refrigerant flow path 31 includes an upstream end 31A to be connected to the reservoir tank 23 and a downstream end 31B to be connected to the inflow port 13. The upstream end 31A is connected to

the bottom wall of the reservoir tank 23 to communicate with the reservoir tank 23. The circulation pump 32, the buffer container 33, and the three-way valve 34 are provided at portions of the refrigerant flow path 31 between the upstream end 31A and the downstream end 31B.

[0059] The type of circulation pump 32 is not particularly limited, and the circulation pump 32 may be a non-positive displacement pump or a positive displacement pump. The circulation pump 32 includes a motor 32M that is controlled by an inverter, such as an AC motor and a brushless DC motor. Then, the circulation pump 32 is configured to adjust the amount of liquid to be sucked by adjusting the rotation speed of the motor 32M, which allows the flow rate of the refrigerant circulated through the refrigerant flow path 31 to be adjusted. In detail, the rotation speed (number of rotation) of the motor 32M is adjusted by adjusting the frequency of the AC current to be supplied to the motor 32M by an inverter (not shown).

[0060] Further, when the refrigerant passes through the circulation pump 32, the pressure of the refrigerant increases. When the pressure of the refrigerant increases, the temperature of the refrigerant rises. The above-mentioned heat exchanger 40 is connected to the refrigerant flow path 31. The

heat exchanger 40 is connected to the refrigerant flow path 31 downstream of the circulation pump 32. This allows the heat exchanger 40 to efficiently cool the refrigerant.

5 [0061] The buffer container 33 includes a reception port 33A that receives the refrigerant sucked from the inside of the reservoir tank 23 and a discharge port 33B that causes the refrigerant to flow out therefrom. As a result, the refrigerant in liquid form sucked from
10 the inside of the reservoir tank 23 into the refrigerant flow path 31 passes through the buffer container 33 from the reception port 33A to the discharge port 33B and then flows into the sealed container 10.

15 [0062] The buffer container 33 is configured to store a certain amount of the refrigerant in liquid form. The buffer container 33 in this embodiment stores the refrigerant in liquid form such that the storage space is filled. The storage space of the buffer
20 container 33 does not necessarily need to be filled with a refrigerant in liquid form. However, the more the amount of refrigerant in liquid form occupying the storage space of the buffer container 33, the smoother the refrigerant can be discharged from the discharge
25 port 33B. From this viewpoint, the storage space of the buffer container 33 is favorably filled with a

refrigerant in liquid form. Even if it is not, the amount of refrigerant in liquid form stored in the storage space of the buffer container 33 is favorably 50% or more and may be 70% or more, 80% or more, or 90% or more in terms of volume ratio to the above storage space.

[0063] In this embodiment, the discharge port 33B is provided in the lower part of the side wall of the buffer container 33. This allows the refrigerant to smoothly pass through the buffer container 33.

[0064] The buffer container 33 receives the refrigerant in liquid form from the reception port 33A. In this embodiment, by disposing the reservoir tank 23 above the buffer container 33, the refrigerant in liquid form stored in the reservoir tank 23 can be smoothly sent to the buffer container 33 by its own weight. The reception port 33A is provided in the upper part of the buffer container 33, specifically, the top wall. This allows the pipe length of the portion of the refrigerant flow path 31 between the reservoir tank 23 and the buffer container 33 to be reduced.

[0065] The buffer container 33 basically receives the refrigerant in liquid form from the reception port 33A, but may receive gas containing the refrigerant in vapor form that has not liquefied. Here, the refrigerant in liquid form or gas received by the

buffer container 33 may have a relatively high temperature. However, in the case where the refrigerant in liquid form or gas from the reservoir tank 23 flows into the buffer container 33 storing the refrigerant in liquid form, the temperature of the refrigerant circulated by the refrigerant circulation device 30 can be prevented from being disturbed undesirably. That is, even if the refrigerant in liquid form or gas received by the buffer container 33 has a relatively high temperature, the refrigerant or gas can be caused to flow out from the buffer container 33 after being mixed with the refrigerant in liquid form that has been stored in the buffer container 33, so that the temperature of the refrigerant circulated downstream of the buffer container 33 can be prevented from being disturbed undesirably.

[0066] The three-way valve 34 is provided at a portion of the refrigerant flow path 31 downstream of the portion to which the heat exchanger 40 described below is connected. The three-way valve 34 includes a first port 341, a second port 342, and a third port 343. Then, the three-way valve 34 is capable of adjusting the flow rate of the refrigerant that flows into the first port 341 and flows out from the second port 342 and the flow rate of the refrigerant that flows into the first port 341 and flows out from the

third port 343.

[0067] The three-way valve 34 constitutes part of the refrigerant flow path 31 in the flow path between the first port 341 and the second port 342. Further,
5 the third port 343 is connected, via a bypass flow path 38, to a portion of the refrigerant flow path 31 upstream of the portion to which the heat exchanger 40 is connected. In detail, the bypass flow path 38 is connected to the buffer container 33. As a result, in
10 this embodiment, the three-way valve 34 is capable of sending part or all of the refrigerant cooled by the heat exchanger 40 in the refrigerant flow path 31 to the buffer container 33 without sending it to the sealed container 10.

15 [0068] The amount of refrigerant in liquid form stored in the sealed container 10 can increase or decrease depending on the operation state of the cooling system S1. In the case where the amount of refrigerant in liquid form stored in the sealed
20 container 10 is excessively large, there is an increased risk that the pressure reducing device 20 sucks in the refrigerant in liquid form. In such a case, for example, the three-way valve 34 is capable of preventing the amount of refrigerant in liquid form in
25 the sealed container 10 from becoming excessively large by reducing the flow rate of the refrigerant to be

circulated to the sealed container 10 or blocking the refrigerant.

[0069] The three-way valve 34 in this embodiment is a proportional three-way valve. The three-way valve 34
5 may be a valve in which the degree of opening of the valve body is adjusted by an electric motor such as a stepping motor and a servo motor. In this case, the above electric motor is electrically connected to the controller 100. However, the three-way valve 34 may be
10 a solenoid proportional three-way valve or a two-position three-way valve.

[0070] Further, although the second outflow port 12 in the sealed container 10 is an opening for discharging the refrigerant in liquid form in the
15 sealed container 10 as described above, in this embodiment, the second outflow port 12 is connected to the refrigerant flow path 31, specifically, the buffer container 33, via a vent flow path 28. Then, the vent flow path 28 is provided with a vent control valve 29.
20 When the vent control valve 29 is opened, the vent flow path 28 is capable of causing the refrigerant in liquid form in the sealed container 10 to directly flow into the buffer container 33. The vent control valve 29 may be opened when the amount of refrigerant in liquid form
25 stored in the sealed container 10 becomes excessively large.

[0071] The heat exchanger 40 is connected to a portion of the refrigerant flow path 31 downstream of the circulation pump 32 and upstream of the three-way valve 34. As described above, the cooling system S1
5 cools the heat medium circulated by the heat medium circulation device 50 in the sealed container 10. Then, the refrigerant circulation device 30 releases, from the heat exchanger 40, the heat absorbed by the refrigerant from the heat medium. That is, the heat
10 exchanger 40 cools the refrigerant in liquid form circulated in the refrigerant flow path 31.

[0072] The heat exchanger 40 in this embodiment is a liquid-cooled type heat exchanger and is connected to a cooling water flow path 44 that circulates cooling
15 water for cooling the refrigerant. The cooling water may be water or other liquid. Further, the heat exchanger 40 may be an air-cooled type heat exchanger.

[0073] The heat medium circulation device 50 includes a heat medium flow path 51 for circulating a
20 heat medium, and a heat exchange unit 52 and a pump 53 that are provided in the heat medium flow path 51. In the heat medium circulation device 50 in this embodiment, the heat exchange unit 52 and the pump 53 are provided between an upstream end 51A and a
25 downstream end 51B of the heat medium flow path 51, and the upstream end 51A and the downstream end 51B of the

heat medium flow path 51 are connected to the temperature control target T. As a result, the heat medium circulation device 50 circulates the heat medium via the temperature control target T.

5 [0074] In detail, the heat medium flow path 51 in this embodiment enters the sealed container 10 from the heat medium inlet 15 in the sealed container 10 and then extends to the outside of the sealed container 10 from the heat medium outlet 16. Then, the upstream end
10 51A, the downstream end 51B, and the temperature control target T of the heat medium flow path 51 are located outside the sealed container 10. Further, in the heat medium circulation device 50 in this embodiment, the heat exchange unit 52 is provided at a
15 portion of the heat medium flow path 51 located in the sealed container 10, i.e., the heat exchange unit 52 is disposed in the sealed container 10. As a result, the heat medium flow path 51 sends the heat medium from the outside of the sealed container 10 to the heat exchange
20 unit 52 and sends the heat medium heat-exchanged in the heat exchange unit 52 to the outside of the sealed container 10.

[0075] The heat medium is not particularly limited but is an antifreeze in this embodiment. The heat
25 medium may be the same as the refrigerant circulated between the sealed container 10 and the heat exchanger

40. That is, the heat medium is, for example, a substance that becomes -5°C or lower when expanded in an environment of, for example, 0.1 atm, desirably a substance that becomes -30°C or lower when expanded in
5 an environment of 0.01 atm, from the state under the atmospheric pressure and at a standard environmental temperature (e.g., 25°C). In the case where the refrigerant and the heat medium are the same, it is advantageous in terms of production efficiency and
10 cost. However, the heat medium may be water or the like.

[0076] The heat exchange unit 52 causes the circulated heat medium to exchange heat with the refrigerant in the sealed container 10. The heat
15 exchange unit 52 may include a heat exchanger such as a fin tube or may be formed of a tube material and form a configuration such as a shell-and-tube together with the sealed container 10. Further, the heat exchange unit 52 may be a structure that is in contact with the
20 outer surface of the sealed container 10. In this case, the entire heat medium circulation device 50 is disposed outside the sealed container 10.

[0077] The pump 53 is provided at a portion of the heat medium flow path 51 located outside the sealed
25 container 10. The type of pump 53 is not particularly limited, and the pump 53 may be a non-positive

displacement pump or a positive displacement pump. The pump 53 includes a motor 53M that is controlled by an inverter, such as an AC motor and a brushless DC motor. Then, the pump 53 is configured to adjust the amount of liquid to be sucked by adjusting the rotation speed (number of rotation) of the motor 53M, which allows the flow rate of the refrigerant circulated through the heat medium flow path 51 to be adjusted. In detail, the rotation speed of the motor 53M is adjusted by adjusting the frequency of the AC current to be supplied to the motor 53M by an inverter (not shown).

[0078] Note that in this embodiment, the upstream end 51A and the downstream end 51B of the heat medium flow path 51 are connected to the temperature control target T. However, the heat medium circulation device 50 may include a temperature control unit that connects the upstream end 51A and the downstream end 51B of the heat medium flow path 51, and the temperature control unit may exchange heat with the temperature control target T. Further, the heat medium circulation device 50 may be configured to discharge the heat medium from the downstream end 50B.

[0079] The gas supply device 60 is connected to the gas receiving port 14 of the sealed container 10 and is capable of supplying gaseous matter into the sealed container 10. The gas supply device 60 is provided to,

for example, suppress a sudden drop in pressure in the sealed container 10. In detail, the gas supply device 60 is capable of adjusting the amount of gaseous matter to be supplied into the sealed container 10 in

5 accordance with the temperature in the sealed container 10, the pressure in the sealed container 10, the temperature of the heat medium cooled by the refrigerant, or the temperature of the temperature control target T.

10 [0080] In detail, the gas supply device 60 includes a gas flow path 61, a gas flow rate adjustment valve 62 provided in the gas flow path 61, and a gas source 63 that is connected to the upstream end of the gas flow path 61 and supplies gas to the gas flow path 61. The

15 gas flow rate adjustment valve 62 is electrically connected to the controller 100 and controlled by the controller 100. The gas flow rate adjustment valve 62 may be a valve in which the degree of opening of the valve body is adjusted by an electric motor such as a

20 stepping motor and a servo motor. In this case, the controller 100 is electrically connected to the above electric motor. Note that the gas flow rate adjustment valve 62 may be a solenoid proportional valve or the like.

25 [0081] In this embodiment, the gas stored in the gas source 63 is nitrogen. However, the gaseous matter

stored in the gas source 63 may be an inert gas such as neon and argon. The gaseous matter to be supplied is favorably controlled to a temperature similar to that of the refrigerant in the sealed container 10 when it is supplied into the sealed container 10.

[0082] Further, the cooling system S1 further includes a refrigerant temperature sensor 71 that detects the temperature in the sealed container 10, a pressure sensor 72 that detects the pressure of the sealed container 10, a liquid level sensor 73 that detects the liquid level height of the refrigerant in liquid form in the sealed container 10, and a heat medium temperature sensor 74 that detects the temperature of the heat medium that is cooled by the refrigerant in the sealed container 10 and flows out to the outside of the sealed container 10.

[0083] The refrigerant temperature sensor 71 detects the temperature of the refrigerant in liquid form in the sealed container 10 and specifies the detected temperature as the temperature in the sealed container 10. However, the refrigerant temperature sensor 71 may detect the temperature of the gas phase portion in the sealed container 10 and specify the detected temperature as the temperature of the refrigerant in the sealed container 10.

[0084] The pressure sensor 72 detects the pressure

of the gas phase portion Gf in the sealed container 10 and specifies the detected pressure as the pressure in the sealed container 10. The liquid level sensor 73 is an optical sensor such as a laser displacement meter, and calculates the height of the liquid surface by applying light to the liquid surface of the refrigerant from the top wall of the sealed container 10 and receiving the reflected light. However, the liquid level sensor 73 may be a float type sensor. The heat medium temperature sensor 74 detects the temperature of the heat medium circulated downstream of the heat exchange unit 52 in the heat medium flow path 51 and outside the sealed container 10. The respective sensors (71 to 74) are electrically connected to the controller 100, and the detection results of the sensors are sent to the controller 100.

[0085] The controller 100 is electrically connected to the above-mentioned sensors (71 to 74) and is also electrically connected to the gas suction pump 22, the flow rate control valve 24, the circulation pump 32, the three-way valve 34, and the gas flow rate adjustment valve 62. The controller 100 may include, for example, a computer including a CPU, a ROM, and the like. In this case, the controller 100 performs various types of processing in accordance with the program stored in the ROM. Note that the controller 100 may

include another processor and an electrical circuit
(e.g., FPGA (Field Programmable Gate Alley)).

[0086] (Functional configuration of controller)

Fig. 2 is a block diagram showing a functional
5 configuration of the controller 100. As shown in Fig.
2, the controller 100 includes a sensor information
acquisition unit 101, a circulation pump adjustment
unit 102, a bypass amount adjustment unit 103, a
rotation speed adjustment unit 104, a valve-opening-
10 degree adjustment unit 105, and a gas supply amount
adjustment unit 106. Note that the controller 100 may
include, for example, one computer or a plurality of
computers. In the case where the controller 100
includes a plurality of computers, the above plurality
15 of functional units may be divided into the plurality
of computers.

[0087] The sensor information acquisition unit 101
is a unit that acquires detection results of the above-
mentioned refrigerant temperature sensor 71, the
20 pressure sensor 72, the liquid level sensor 73, and the
heat medium temperature sensor 74. The sensor
information acquisition unit 101 provides one or more
pieces of information relating to the acquired
detection results to the bypass amount adjustment unit
25 103, the rotation speed adjustment unit 104, the valve-
opening-degree adjustment unit 105, and the gas supply

amount adjustment unit 106.

[0088] The circulation pump adjustment unit 102 is a unit that is electrically connected to the circulation pump 32 and controls the operation of the circulation pump 32. In detail, the circulation pump adjustment unit 102 is connected to the motor 32M in the circulation pump 32 via an inverter. Then, the circulation pump adjustment unit 102 adjusts the flow rate of the refrigerant circulated in the refrigerant flow path 31 by adjusting the frequency of the AC current to be supplied to the motor 32M from the inverter.

[0089] A target flow rate of the refrigerant is input to and held in the circulation pump adjustment unit 102 by, for example, an input device (not shown), and the circulation pump adjustment unit 102 adjusts the rotation speed of the motor 32M of the circulation pump 32 such that the flow rate of the refrigerant matches the target flow rate.

[0090] The bypass amount adjustment unit 103 is a unit that is electrically connected to the three-way valve 34 and controls the operation of the three-way valve 34. In detail, a target height of the liquid surface of the refrigerant in liquid form in the sealed container 10 is input to and held in the bypass amount adjustment unit 103 by, for example, an input device

(not shown). Then, the bypass amount adjustment unit 103 controls the three-way valve 34 using the detection result from the liquid level sensor 73 such that the liquid level height of the refrigerant in liquid form in the sealed container 10 is maintained at the above target height as a predetermined height. That is, the three-way valve 34 is controlled in accordance with the difference between the liquid level height that is a detection result from the liquid level sensor 73 and the target height.

[0091] Specifically, in this embodiment, in accordance with a command from the bypass amount adjustment unit 103, the three-way valve 34 reduces the flow rate of the refrigerant that flows into the first port 341 and flows out from the second port 342 and increases the flow rate of the refrigerant that flows into the first port 341 and flows out from the third port 343 in the case where the liquid level height of the refrigerant in liquid form in the sealed container 10 exceeds the predetermined height. Further, the three-way valve 34 increase the flow rate of the refrigerant that flows into the first port 341 and flows out from the second port 342 and reduces the flow rate of the refrigerant that flows into the first port 341 and flows out from the third port 343 in the case where the liquid level height of the refrigerant in

liquid form in the sealed container 10 falls below the predetermined height.

[0092] Note that the three-way valve 34 may block the circulation of the refrigerant that flows into the first port 341 and flows out from the second port 342 and allow the refrigerant that flows into the first port 341 and flows out from the third port 343 to be circulated in the case where the liquid level height of the refrigerant in liquid form in the sealed container 10 exceeds the predetermined height. Meanwhile, the three-way valve 34 may allow the refrigerant that flows into the first port 341 and flows out from the second port 342 to be circulated and block the circulation of the refrigerant that flows into the first port 341 and flows out from the third port 343 in the case where the liquid level height of the refrigerant in liquid form in the sealed container 10 falls below the predetermined height.

[0093] The rotation speed adjustment unit 104 is a unit that is electrically connected to the gas suction pump 22 and controls the operation of the gas suction pump 22. In detail, the rotation speed adjustment unit 104 is connected to the motor 22M in the gas suction pump 22 via an inverter. Then, the rotation speed adjustment unit 104 adjusts the flow rate of the gas circulated in the gas flow path 21 in the pressure

reducing device 20 by adjusting the frequency of the AC current to be supplied to the motor 22M from the inverter.

[0094] A target temperature of the heat medium to be
5 circulated by the heat medium circulation device 50 is input to and held in the rotation speed adjustment unit 104 by, for example, an input device (not shown), and the rotation speed adjustment unit 104 adjusts the rotation speed of the motor 22M of the gas suction pump
10 22 such that, for example, the temperature detected by the heat medium temperature sensor 74 matches the target temperature to reduce the pressure in the sealed container 10. That is, the gas suction pump 22 may be controlled in accordance with the difference between
15 the temperature of the heat medium that is a detection result from the heat medium temperature sensor 74 and the target temperature.

[0095] Note that although the gas suction pump 22 of the pressure reducing device 20 is controlled such that
20 the temperature of the heat medium matches the target temperature in the control example described above, instead of this, the rotation speed of the motor 22M may be adjusted such that the temperature in the sealed container 10 (detection result of the refrigerant
25 temperature sensor 71), the temperature of the temperature control target T (detection result of a

temperature sensor (not shown)), or the pressure in the sealed container 10 matches the corresponding target value.

[0096] Further, the valve-opening-degree adjustment unit 105 is a unit that is electrically connected to the flow rate control valve 24 and controls the operation of the flow rate control valve 24. The valve-opening-degree adjustment unit 105 adjusts the flow rate of the gas circulated in the gas flow path 21 in the pressure reducing device 20 by adjusting the degree of opening of the flow rate control valve 24.

[0097] The valve-opening-degree adjustment unit 105 may adjust the degree of opening of the flow rate control valve 24 in accordance with the temperature in the sealed container 10 (detection result of the refrigerant temperature sensor 71), the pressure in the sealed container 10 (detection result of the pressure sensor 72), the temperature of the heat medium cooled by the refrigerant (detection result of the heat medium temperature sensor 74), or the temperature of the temperature control target T (detection result of a temperature sensor (not shown)). In this embodiment, such control of the flow rate control valve 24 may be performed after the gas suction pump 22 is controlled such that the temperature of the heat medium matches the target temperature and the operation state of the

gas suction pump 22 is maintained constant. When the cooling operation actually starts, the temperature or pressure of the refrigerant in the sealed container 10 fluctuates in some cases. In such a case, the degree of opening of the flow rate control valve 24 may be adjusted in accordance with the temperature in the sealed container 10, the pressure in the sealed container 10, the temperature of the heat medium cooled by the refrigerant, or the temperature of the temperature control target T such that the temperature or pressure matches the target temperature or target pressure.

[0098] Note that the gas suction pump 22 and the flow rate control valve 24 may simultaneously operate. Further, the degree of opening of the flow rate control valve 24 may be adjusted while the operation state of the gas suction pump 22 is maintained constant. Alternatively, the operation state of the gas suction pump 22 may be controlled while the degree of opening of the flow rate control valve 24 is maintained constant.

[0099] Further, the gas supply amount adjustment unit 106 is a unit that is electrically connected to the gas flow rate adjustment valve 62 and controls the operation of the gas flow rate adjustment valve 62. The gas supply amount adjustment unit 106 adjusts the

amount of gaseous matter to be supplied into the sealed container 10 by adjusting the degree of opening of the gas flow rate adjustment valve 62.

[0100] The gas supply device 60 may control the
5 amount of gaseous matter to be supplied into the sealed container 10 in accordance with the temperature in the sealed container 10 (detection result of the refrigerant temperature sensor 71), the pressure in the sealed container 10 (detection result of the pressure
10 sensor 72), the temperature of the heat medium cooled by the refrigerant (detection result of the heat medium temperature sensor 74), or the temperature of the temperature control target T (detection result of a temperature sensor (not shown)) by controlling the gas
15 flow rate adjustment valve 62 by the gas supply amount adjustment unit 106.

[0101] (Configuration of refrigerant)

Next, the refrigerant to be circulated in the cooling system S1 will be described. As described
20 above, in this embodiment, the refrigerant is, for example, a substance that becomes liquid under the atmospheric pressure and at a standard environmental temperature (e.g., 25°C), which becomes -5°C or lower when expanded in an environment of, for example, 0.1
25 atm, desirably a substance that becomes -30°C or lower when expanded in an environment of 0.01 atm, from this

state. Further, the refrigerant is desirably a refrigerant having a low environmental impact with a global warming potential (GWP) of 10 or less.

[0102] Specifically, in this embodiment, HFO-
5 1336mzz-Z, which has a GWP of 2 and is non-flammable, is suitably used as a refrigerant. In this case, the heat medium to be circulated by the heat medium circulation device 50 may also be HFO-1336mzz-Z. More specifically, the refrigerant may be Opteon SF33 (TM)
10 manufactured by Chemours-Mitsui Fluoroproducts Co., Ltd.

[0103] Fig. 3 is a pressure-enthalpy chart of HFO-1336mzz-Z. When the pressure of HFO-1336mzz-Z is reduced to 0.0149 MPa from the state (St1) in which the temperature is approximately 33°C close to room
15 temperature at approximately 0.100 MPa close to the atmospheric pressure, the temperature of HFO-1336mzz-Z drops to approximately -10°C (St2). Further, when the pressure is reduced to 0.001 MPa, the temperature drops to approximately -50°C or lower. Then, it evaporates
20 (St3) when absorbing heat to some extent from the state St2 in which the temperature has dropped to approximately -10°C. When it is decompressed to approximately 0.100 Mpa close to the atmospheric pressure from this state St3, the temperature rises to
25 approximately 50°C while being the gas phase, which is higher than room temperature (St4). Then, when being

cooled at room temperature from the state St4, it is cooled to approximately 33°C while being condensed into a gas-liquid mixed phase.

[0104] When such HFO-1336mzz-Z is cooled by the heat exchanger 40, HFO-1336mzz-Z transitions to the above state St1, and then flows into the sealed container 10, whereby it can be reduced in pressure and is capable of transitioning to, for example, the state St2. Then, HFO-1336mzz-Z is capable of transitioning from the state St2 to the state St3 by exchanging heat with the heat medium. After that, HFO-1336mzz-Z is capable of transitioning from the state St3 to the state St4 by flowing out from the sealed container 10 to the outside of the pressure reducing device 20. Therefore, HFO-1336mzz-Z can be suitably used in the cooling system S1.

[0105] There are various other refrigerants that can be used in the cooling system S1, and for example, water or ethanol may be used.

[0106] (Operation)

An example of the operation of the cooling system S1 will be described below.

[0107] First, in the cooling system S1, a target temperature of the heat medium circulated by the heat medium circulation device 50 is input and held. Then, the sealed container 10, the reservoir tank 23, and the

buffer container 33 are filled with a predetermined amount of refrigerant in liquid form, and then, the circulation pump 32 of the refrigerant circulation device 30 and the pump 53 of the heat medium

5 circulation device 50 are driven. At this time, the three-way valve 34 and the vent control valve 29 are controlled such that the liquid level height of the refrigerant in liquid form in the sealed container 10 is a predetermined height. Then, after the liquid level

10 height of the refrigerant in liquid form in the sealed container 10 reaches the predetermined height, the three-way valve 34 blocks the circulation of the refrigerant that flows into the first port 341 and flows out from the second port 342 and allows the

15 refrigerant that flows into the first port 341 and flows out from the third port 343 to be circulated. That is, a state in which the refrigerant in liquid form does not flow from the refrigerant circulation device 30 into the sealed container 10 is created.

20 [0108] After that, the pressure reducing device 20 is driven to reduce the pressure in the sealed container 10 to be lower than the atmospheric pressure by the pressure reducing device 20. In the pressure reducing device 20, the rotation speed of the motor 22M

25 of the gas suction pump 22 is adjusted until the temperature detected by the heat medium temperature

sensor 74 matches the target temperature. Then, after the temperature detected by the heat medium temperature sensor 74 matches the target temperature, at least one of the rotation speed of the motor 22M of the gas suction pump 22, the degree of opening of the flow rate control valve 24, or the degree of opening of the gas flow rate adjustment valve 62 of the gas supply device 60 is controlled to maintain the target temperature. In this way, the start-up operation is completed. In the state after the rotation speed of the motor 22M of the gas suction pump 22 is adjusted such that the temperature detected by the heat medium temperature sensor 74 matches the target temperature, the pressure in the sealed container 10 is reduced to be lower than the atmospheric pressure by the pressure reducing device 20, and the refrigerant circulation environment in the refrigerant circulation device 30 outside the sealed container 10 and the refrigerant circulation environment in the heat exchanger 40 are set to a pressure higher than the pressure in the sealed container 10, e.g., the atmospheric pressure. However, the refrigerant circulation environment in the refrigerant circulation device 30 and the refrigerant circulation environment in the heat exchanger 40 do not necessarily need to be strictly the atmospheric pressure and may be a pressure slightly lower than the

atmospheric pressure.

[0109] After that, the heat medium circulated by the heat medium circulation device 50 transitions to the state of cooling the temperature control target T. The refrigerant flows out from the sealed container 10, is cooled by the cooling unit 25 and the heat exchanger 40, and then flows into the sealed container 10 again. This allows the heat medium to be continuously cooled by the refrigerant.

[0110] That is, when describing the operation state in the cooling system S1 with reference to Fig. 3, the refrigerant that has absorbed the heat of the heat medium flows out from the sealed container 10 and is then cooled by the cooling unit 25 and the heat exchanger 40 to transition from the state St4 to the state St1 in Fig. 3. After that, the refrigerant flows into the sealed container 10 to be reduced in pressure and transitions to the state St2. Then, the refrigerant transitions from the state St2 to the state St3 by exchanging heat with the heat medium in the sealed container 10. After that, the refrigerant flows out from the sealed container 10 to the outside of the pressure reducing device 20 to transition from the state St3 to the state St4. Then, the refrigerant is cooled by the cooling unit 25 and the heat exchanger 40 to transition from the state St4 to the state St1. In

this way, the heat medium is continuously cooled by the refrigerant.

[0111] The cooling system S1 according to the first embodiment described above includes the sealed
5 container 10 that includes the first outflow port 11 and the inflow port 13 and stores the refrigerant in liquid form, the pressure reducing device 20 that is connected to the first outflow port 11 and adjusts the pressure in the sealed container 10 to be lower than
10 the atmospheric pressure by sucking gas from the sealed container 10 through the first outflow port 11, and the refrigerant circulation device 30 that includes the refrigerant flow path 31 to be connected to the pressure reducing device 20 and the inflow port 13 and
15 causes the refrigerant in liquid form liquefied from the gas sucked from the sealed container 10 by the pressure reducing device 20 to flow into the sealed container 10 through the inflow port 13, the cooling system S1 cooling the temperature control target T with
20 the refrigerant in the sealed container 10.

[0112] According to such a cooling system S1, it is possible to allow a substance that has not been used in existing refrigeration methods to be used as a
refrigerant in a thermal cycle or allow the range of
25 substances that can be used as a refrigerant in a thermal cycle to be expanded.

[0113] That is, as described above, in this embodiment, a substance that becomes liquid under the atmospheric pressure and at a standard environmental temperature (e.g., 25°C), which becomes -5°C or lower when expanded in an environment of, for example, 0.1 atm from this state, can be used as a refrigerant as an example. Meanwhile, if the above substance is used in a vapor compression type refrigeration cycle that has been widely used until now, for example, the compressor compresses the liquid, so that the compressor does not function properly and the substance does not evaporate in the evaporator. Therefore, the above refrigerant is not suitable for the vapor compression type refrigeration cycle. On the other hand, the cooling system S1 does not use compression and is capable of cooling the heat medium by reducing the pressure of the above refrigerant in the sealed container 10, releasing the heat of the heat medium from the cooling unit 25 and the heat exchanger 40, and realizing a thermal cycle. Therefore, according to this embodiment, it is possible to allow a substance that has not been used in existing refrigeration methods to be used as a refrigerant in a thermal cycle or allow the range of substances that can be used as a refrigerant in a thermal cycle to be expanded. Note that in this embodiment, the pressure reducing device 20 includes

the cooling unit 25, and heat is dissipated by the cooling unit 25 and the heat exchanger 40. Meanwhile, a configuration in which heat is dissipated by only the cooling unit 25 without providing the heat exchanger 40 may be adopted, or heat is dissipated by only the heat exchanger 40 without providing the cooling unit 25.

[0114] Then, as described above, the cooling system S1 allows, for example, HFO-1336mzz-Z, which has a GWP of 2 and is non-flammable, to be used as a refrigerant.

This allows a cooling operation that ensures a low GWP and safety, which has not been realized in the vapor compression type refrigeration cycle, to be realized. Such a cooling system S1 that has ensured a low GWP, a low environmental impact, and safety has not been known, including other cooling systems. Therefore, the realization of such a cooling system S1 has the potential to greatly contribute to the global environmental protection. Further, since no compressor is used in the cooling system S1, lubricating oil is prevented from flowing out to the refrigerant side, which is also beneficial.

[0115] Further, in this embodiment, various measures are taken to economically and stably operate the cooling system S1.

[0116] For example, the pressure reducing device 20 includes the gas flow path 21 to be connected to the

first outflow port 11, the gas suction pump 22 that is provided in the gas flow path 21 and sucks the gas from the sealed container 10 into the gas flow path 21, and the reservoir tank 23 that is connected to the downstream end 21B of the gas flow path 21 and stores the gas flowing out from the downstream end 21B. This makes it easier to vaporize the gas in the reservoir tank 23 and prevents the refrigerant in a gaseous state from returning to the sealed container 10 by the refrigerant circulation device 30.

[0117] In particular, in this embodiment, the pressure in the reservoir tank 23 is higher than the pressure in the sealed container 10, and the reservoir tank 23 liquefies at least part of the gas flowing out from the downstream end 21B of the gas flow path 21 to the refrigerant in liquid form and stores the refrigerant in liquid form. This effectively prevents the refrigerant in a gaseous state from returning to the sealed container 10 by the refrigerant circulation device 30.

[0118] Further, the refrigerant circulation device 30 further includes the buffer container 33 that is provided in the refrigerant flow path 31 so as to form part of the refrigerant flow path 31 and stores the refrigerant in liquid form. Then, the gas stored in the reservoir tank 23 or the refrigerant in liquid form

liquefied from at least part of the gas is caused to flow into the buffer container 33. With this configuration, the gas or refrigerant in liquid form from the reservoir tank 23 can be caused to flow out from the buffer container 33 after being mixed with the refrigerant in liquid form stored in the buffer container 33. This prevents the temperature of the refrigerant circulated downstream of the buffer container 33 from being disturbed undesirably.

[0119] Further, the refrigerant circulation device 30 includes the three-way valve 34 that is provided at a portion of the refrigerant flow path 31 downstream of the portion to which the heat exchanger 40 is connected and includes the first port 341, the second port 342, and the third port 343. Then, the three-way valve 34 constitutes part of the refrigerant flow path 31 in the flow path between the first port 341 and the second port 342. Further, the third port 343 and a portion of the refrigerant flow path 31 (in this embodiment, the buffer container 33) upstream of the portion to which the heat exchanger 40 is connected are connected via the bypass flow path 38.

[0120] This allows the cooling system S1 to stably operate, improving the accuracy of temperature control.

For example, in the case where the amount of refrigerant in liquid form stored in the sealed

container 10 is excessively large, there is a high risk that the pressure reducing device 20 sucks the refrigerant in liquid form. In this case, there is a risk that the operation of the pressure reducing device 20 becomes unstable or the pressure reducing device 20 is damaged. For example, in such a case, the three-way valve 34 is capable of preventing the amount of refrigerant in liquid form in the sealed container 10 from becoming excessively large by reducing the flow rate of the refrigerant to be circulated to the sealed container 10 or blocking the refrigerant.

[0121] <Second embodiment>

Next, a cooling system S2 according to a second embodiment will be described with reference to Fig. 4. Note that the same components in this embodiment as those in the first embodiment will be denoted by the same reference symbols and duplicated description will be omitted.

[0122] This embodiment is different from the first embodiment in that the vent flow path 28 connecting the sealed container 10 and the buffer container 33 and the vent control valve 29 on the vent flow path 28 are not provided. Even with such a cooling system S2 according to the second embodiment, effects similar to those in the first embodiment are achieved. Then, according to this embodiment, it is possible to simplify the device

configuration.

[0123] <Third embodiment>

Next, a cooling system S3 according to a third embodiment will be described with reference to Fig. 5.

5 Note that the same components in this embodiment as those in the first and second embodiments will be denoted by the same reference symbols and duplicated description will be omitted.

[0124] In this embodiment, the refrigerant
10 circulation device 30 does not include the circulation pump 32 and the three-way valve 34. Then, the heat exchanger 40 is disposed inside the buffer container 33. Note that the heat exchanger 40 may be connected to the outer wall of the buffer container 33 or may be
15 connected to a portion of the refrigerant flow path 31 upstream or downstream of the buffer container 33.

[0125] Further, in this embodiment, the refrigerant flow path 31 is provided with a return amount adjustment valve 80. The return amount adjustment valve
20 80 is a valve for adjusting the flow rate of the refrigerant in liquid form that flows from the reservoir tank 23 into the sealed container 10. In detail, the return amount adjustment valve 80 is controlled by the controller 100 and adjusts the flow
25 rate of the refrigerant in liquid form that flows into the sealed container 10 such that, for example, the

liquid level height of the refrigerant in liquid form in the sealed container 10 is maintained at a predetermined height. The return amount adjustment valve 80 may be an open/close valve or a proportional valve.

[0126] An example of the operation of the cooling system S3 will be described below.

[0127] First, in the cooling system S3, a target temperature of the heat medium circulated by the heat medium circulation device 50 is input and held. Then, the sealed container 10, the reservoir tank 23, and the buffer container 33 are filled with a predetermined amount of refrigerant in liquid form, and then, the pump 53 of the heat medium circulation device 50 is driven. At this time, the return amount adjustment valve 80 is controlled such that the liquid level height of the refrigerant in liquid form in the sealed container 10 is a predetermined height. In this embodiment, when the return amount adjustment valve 80 is opened, the refrigerant in liquid form naturally flows into the sealed container 10 by its own weight, but the circulation pump 32 may be provided. Then, after the liquid level height of the refrigerant in liquid form in the sealed container 10 reaches the predetermined height, the return amount adjustment valve 80 is closed.

[0128] After that, the pressure reducing device 20 is driven, and the pressure in the sealed container 10 is reduced to be lower than the atmospheric pressure by the pressure reducing device 20. In the pressure
5 reducing device 20, the rotation speed of the motor 22M of the gas suction pump 22 is adjusted until the temperature detected by the heat medium temperature sensor 74 matches the target temperature. Then, after the temperature detected by the heat medium temperature
10 sensor 74 matches the target temperature, at least one of the rotation speed of the motor 22M of the gas suction pump 22, the degree of opening of the flow rate control valve 24, and the degree of opening of the gas flow rate adjustment valve 62 of the gas supply device
15 60 is controlled to maintain the target temperature. In this way, the start-up operation is completed. In the state after the rotation speed of the motor 22M of the gas suction pump 22 is adjusted such that the temperature detected by the heat medium temperature
20 sensor 74 matches the target temperature, the pressure in the sealed container 10 is reduced to be lower than the atmospheric pressure by the pressure reducing device 20, and the refrigerant circulation environment in the refrigerant circulation device 30 outside the
25 sealed container 10 is set to a pressure higher than the pressure in the sealed container 10, e.g., the

atmospheric pressure. However, the refrigerant circulation environment in the refrigerant circulation device 30 does not necessarily need to be strictly the atmospheric pressure and may be a pressure slightly lower than the atmospheric pressure.

[0129] After that, the heat medium circulated by the heat medium circulation device 50 transitions to the state of cooling the temperature control target T. The refrigerant flows out from the sealed container 10, is cooled by the cooling unit 25 and the heat exchanger 40, and then flows into the sealed container 10 again. As a result, the heat medium is continuously cooled by the refrigerant.

[0130] Even with such a cooling system S3 according to the third embodiment, it is possible to achieve effects similar to those in the first embodiment and simplify the device configuration.

[0131] <Fourth embodiment>

Next, a cooling system S4 according to a fourth embodiment will be described with reference to Fig. 6. Note that the same components in this embodiment as those in the first to third embodiments will be denoted by the same reference symbols and duplicated description will be omitted.

[0132] This embodiment achieves further simplification by excluding the buffer container 33

from the refrigerant circulation device 30 in the third embodiment and not using the heat exchanger 40. The cooling system S4 can be operated in the manner described in the third embodiment. Such an embodiment is beneficial in terms of simplifying the device.

[0133] Although embodiments of the present invention have been described above, the present invention is not limited to the embodiments described above and various modifications can be made to the above-mentioned embodiments.

Claims

[Claim 1] A cooling system, comprising:

a container that includes an outflow port and an inflow port and stores a refrigerant in liquid form;

5 a pressure reducing device that is connected to the outflow port and adjusts a pressure in the container to be lower than an atmospheric pressure by sucking gas from the container through the outflow port; and

10 a refrigerant circulation device that includes a refrigerant flow path to be connected to the pressure reducing device and the inflow port and causes the refrigerant in liquid form liquefied from the gas sucked from the container by the pressure reducing
15 device to flow into the container through the inflow port,

the cooling system cooling a temperature control target with the refrigerant in the container.

[Claim 2] The cooling system according to claim 1,
20 wherein

the pressure reducing device includes

a gas flow path to be connected to the outflow port,

a gas suction pump that is provided in the
25 gas flow path and sucks the gas from the container into the gas flow path, and

a reservoir tank that is connected to the gas flow path and stores the gas flowing out from the gas flow path and/or the refrigerant in liquid form liquefied from the gas, and

5 the refrigerant flow path is connected to the reservoir tank.

[Claim 3] The cooling system according to claim 2, wherein

10 a pressure in the reservoir tank is higher than the pressure in the container, and the reservoir tank liquefies at least part of the gas flowing out from the gas flow path to the refrigerant in liquid form and stores the refrigerant in liquid form.

15 [Claim 4] The cooling system according to claim 3, wherein

20 the refrigerant circulation device further includes a circulation pump that is provided in the refrigerant flow path and sucks the refrigerant in liquid form from the reservoir tank into the refrigerant flow path.

[Claim 5] The cooling system according to claim 3, wherein

25 the pressure reducing device further includes a cooling unit that cools a portion of the gas flow path downstream of the gas suction pump and/or the reservoir tank.

[Claim 6] The cooling system according to claim 3,
wherein

the refrigerant circulation device further
includes a buffer container that is provided in the
refrigerant flow path so as to form part of the
5 refrigerant flow path and stores the refrigerant in
liquid form, and

the refrigerant in liquid form sucked from the
reservoir tank into the refrigerant flow path flows
10 into the container after passing through the buffer
container.

[Claim 7] The cooling system according to claim 6,
further comprising

a heat exchanger that is connected to the
15 refrigerant flow path and cools the refrigerant in
liquid form circulated in the refrigerant flow path,

the buffer container being provided at a portion
of the refrigerant flow path upstream of a portion to
which the heat exchanger is connected.

[Claim 8] The cooling system according to claim 6,
20 wherein

the reservoir tank is provided above the buffer
container.

[Claim 9] The cooling system according to claim 2,
25 wherein

the gas suction pump is configured to suck in the

gas by rotation of a motor, and

the gas suction pump adjusts a rotation speed of the motor in accordance with a temperature in the container, the pressure in the container, a temperature of a heat medium cooled by the refrigerant, or a temperature of the temperature control target.

[Claim 10] The cooling system according to claim 2, wherein

a flow rate control valve that controls a flow rate of the gas circulated in the gas flow path by adjusting the degree of opening is provided at a portion of the gas flow path upstream or downstream of the gas suction pump, and

the degree of opening of the flow rate control valve is adjusted in accordance with a temperature in the container, the pressure in the container, a temperature of a heat medium cooled by the refrigerant, or a temperature of the temperature control target.

[Claim 11] The cooling system according to claim 10, further comprising

a gas supply device that supplies gaseous matter into the container,

the gas supply device adjusting an amount of the gaseous matter to be supplied into the container in accordance with the temperature in the container, the pressure in the container, the temperature of the heat

medium cooled by the refrigerant, or the temperature of the temperature control target.

[Claim 12] The cooling system according to claim 1, further comprising

- 5 a heat exchanger that is connected to the refrigerant flow path and cools the refrigerant in liquid form circulated in the refrigerant flow path, the refrigerant circulation device including a three-way valve that is provided at a portion of the refrigerant flow path downstream of a portion to which the heat exchanger is connected and includes a first
- 10 port, a second port, and a third port, the three-way valve being capable of adjusting a flow rate of the refrigerant that flows into the first port and flows out from the second port and a flow rate of the refrigerant that flows into the first port and flows out from the third port,
- 15 the three-way valve constituting part of the refrigerant flow path in a flow path between the first port and the second port,
- 20 the third port and the portion of the refrigerant flow path upstream of the portion to which the heat exchanger is connected being connected via a bypass flow path.
- 25 [Claim 13] The cooling system according to claim 12, wherein

the three-way valve reduces the flow rate of the refrigerant that flows into the first port and flows out from the second port and increases the flow rate of the refrigerant that flows into the first port and
5 flows out from the third port in a case where a liquid level height of the refrigerant in liquid form in the container exceeds a predetermined height, and

the three-way valve increases the flow rate of the refrigerant that flows into the first port and flows
10 out from the second port and reduces the flow rate of the refrigerant that flows into the first port and flows out from the third port in a case where the liquid level height of the refrigerant in liquid form in the container falls below the predetermined height.

15 [Claim 14] The cooling system according to claim 12, wherein

the three-way valve blocks circulation of the refrigerant that flows into the first port and flows out from the second port and allows the refrigerant
20 that flows into the first port and flows out from the third port to be circulated in a case where a liquid level height of the refrigerant in liquid form in the container exceeds a predetermined height, and

the three-way valve allows the refrigerant that
25 flows into the first port and flows out from the second port to be circulated and blocks circulation of the

refrigerant that flows into the first port and flows out from the third port in a case where the liquid level height of the refrigerant in liquid form in the container falls below the predetermined height.

5 [Claim 15] The cooling system according to claim 1, further comprising

a heat medium circulation device that includes a heat medium flow path for circulating a heat medium,

the heat medium flow path including a heat
10 exchange unit that is disposed in the container and causes the heat medium to exchange heat with the refrigerant,

the heat medium flow path sending the heat medium from an outside of the container to the heat exchange unit and sending the heat medium heat-exchanged in the
15 heat exchange unit to the outside of the container.

[Claim 16] The cooling system according to claim 1, wherein

the refrigerant is a substance that has a boiling
20 point of 30°C or higher under an atmospheric pressure.

[Claim 17] The cooling system according to claim 16, wherein

the refrigerant has a GWP of 10 or less.

[Claim 18] The cooling system according to claim
25 17, wherein

the refrigerant is HFO-1336mzz-Z.