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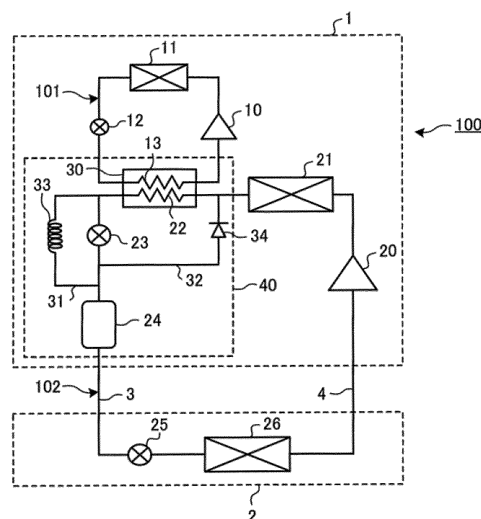
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(54) **BINARY REFRIGERATION DEVICE**

(57) A cascade refrigeration system includes a higher-stage refrigeration cycle, a lower-stage refrigeration cycle, and a cascade condenser. In the higher-stage refrigeration cycle, a higher-stage compressor, a higher-stage condenser, a higher-stage expansion valve, and a higher-stage evaporator are sequentially connected by pipes, and a higher-stage refrigerant is circulated. In the lower-stage refrigeration cycle, a lower-stage compressor, a first lower-stage condenser, a second lower-stage condenser, a lower-stage liquid receiver, a first lower-stage expansion valve, and a lower-stage evaporator are sequentially connected by pipes, and a lower-stage refrigerant is circulated. The cascade condenser includes the higher-stage evaporator and the second lower-stage condenser to exchange heat between the higher-stage refrigerant flowing in the higher-stage evaporator and the lower-stage refrigerant flowing in the second lower-stage condenser. The lower-stage refrigeration cycle is provided with a natural circulation circuit having a vapor refrigerant pipe that connects the lower-stage liquid receiver and a position between the first lower-stage condenser and the second lower-stage condenser and that has a check valve provided at a position on the vapor refrigerant pipe.

FIG. 1



Description

Technical Field

[0001] The present invention relates to a cascade refrigeration system usable for freezing or refrigeration.

Background Art

[0002] Hitherto, as a refrigeration system for a low-temperature refrigerated warehouse or cold storage warehouse, there has been used a cascade refrigeration system having a higher-stage refrigeration cycle, which is a refrigeration cycle apparatus configured to circulate a higher-temperature refrigerant therein, and a lower-stage refrigeration cycle, which is a refrigeration cycle apparatus configured to circulate a lower-temperature refrigerant therein. For example, the cascade refrigeration system has a multistage configuration in which the lower-stage refrigeration cycle and the higher-stage refrigeration cycle are coupled to each other by a cascade condenser, which is configured to be able to exchange heat between a lower-stage condenser in the lower-stage refrigeration cycle and a higher-stage evaporator in the higher-stage refrigeration cycle.

[0003] Of such cascade refrigeration systems, there is a cascade refrigeration system in which, during a defrosting operation, a primary side refrigeration cycle, that is, a higher-stage refrigeration cycle is operated when a compressor of a secondary side refrigeration cycle, that is, a lower-stage compressor of a lower-stage refrigeration cycle is stopped (see Patent Literature 1, for example). In the cascade refrigeration system described in Patent Literature 1, a lower-stage condenser of the lower-stage refrigeration cycle is cooled by cooling a cascade heat exchanger by an evaporator of the higher-stage refrigeration cycle to control an increase in pressure in the lower-stage refrigeration cycle.

[0004] In addition, there is a refrigeration system including an expansion tank in a lower-stage refrigeration cycle to control an increase in pressure in the lower-stage refrigeration cycle during stoppage of a lower-stage compressor (see Patent Literature 2, for example).

Citation List

Patent Literature

[0005]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2004-190917

Patent Literature 2: International Publication No. WO 2014/064744

Summary of Invention

Technical Problem

[0006] In the cascade refrigeration system described in Patent Literature 1, refrigerant in the lower-stage refrigeration cycle is cooled by a cascade condenser of the cascade heat exchanger, that is, a condenser of a lower-stage refrigerant circuit. Therefore, the refrigerant in the lower-stage refrigeration cycle does not flow in the lower-stage condenser when the lower-stage compressor is stopped. Thus, when, for example, a certain amount of the refrigerant is condensed, and the inside of the lower-stage condenser of the lower-stage refrigeration cycle is filled with the liquid refrigerant in the cascade heat exchanger, the refrigerant is not adequately cooled and an increase in pressure due to an increase in temperature in the lower-stage refrigeration cycle is not controlled sufficiently. As a result, the system needs high design pressures for on-site pipes, unit coolers, showcases, and other units, causing an increase in cost. In addition, there is a case where, when the pressure of the refrigerant in the lower-stage refrigeration cycle exceeds the design pressure, the refrigerant may be discharged from a safety valve. In such a case, the lower-stage refrigeration cycle needs to be replenished with refrigerant.

[0007] Furthermore, in the refrigeration system described in Patent Literature 2, a space for installing the expansion tank is required, and thus installation of the refrigeration system may be limited.

[0008] The present invention has been made to solve the above-mentioned problems, and therefore has an object to provide a cascade refrigeration system in which an increase in pressure due to an increase in temperature in a lower-stage refrigeration cycle is suppressed with a simple configuration.

Solution to Problem

[0009] According to an embodiment of the present invention, there is provided a cascade refrigeration system including: a higher-stage refrigeration cycle in which a higher-stage compressor, a higher-stage condenser, a higher-stage expansion valve, and a higher-stage evaporator are sequentially connected by pipes and in which a higher-stage refrigerant is circulated; a lower-stage refrigeration cycle in which a lower-stage compressor, a first lower-stage condenser, a second lower-stage condenser, a lower-stage liquid receiver, a first lower-stage expansion valve, and a lower-stage evaporator are sequentially connected by pipes and in which a lower-stage refrigerant is circulated; and a cascade condenser including the higher-stage evaporator and the second lower-stage condenser to exchange heat between the higher-stage refrigerant flowing in the higher-stage evaporator and the lower-stage refrigerant flowing in the second lower-stage condenser, wherein the lower-stage refrigeration cycle is provided with a natural circulation circuit hav-

ing a vapor refrigerant pipe that connects the lower-stage liquid receiver and a position between the first lower-stage condenser and the second lower-stage condenser and that has a check valve at a position in a middle of the vapor refrigerant pipe.

Advantageous Effects of Invention

[0010] According to the cascade refrigeration system of an embodiment of the present invention, the natural circulation circuit having the vapor refrigerant pipe is provided. When the lower-stage compressor is stopped, the higher-stage refrigeration cycle is operated and lower-stage refrigerant is circulated by using the natural circulation circuit. Therefore, an increase in pressure of the refrigerant in the lower-stage refrigeration cycle can be controlled, and thus the design pressures for devices are not required to be set to high values. As a result, costs for on-site pipes, unit coolers, showcases, and other units in the system can be reduced. In addition, because an expansion tank is not required, a space for installing the refrigeration system is not limited.

Brief Description of Drawings

[0011]

[Fig. 1] Fig. 1 is a refrigerant circuit diagram of a cascade refrigeration system according to Embodiment 1 of the present invention.

[Fig. 2] Fig. 2 is an equipment layout of a natural circulation circuit according to Embodiment 1 of the present invention.

[Fig. 3] Fig. 3 is an equipment layout of the natural circulation circuit according to Embodiment 1 of the present invention.

[Fig. 4] Fig. 4 is an equipment layout of a natural circulation circuit according to Embodiment 2 of the present invention.

Description of Embodiments

[0012] A cascade refrigeration system of embodiments of the present invention is described in details below with reference to the drawings. Note that, the present invention should not be limited by the following embodiments. Also note that, in the drawings, a size of each component may differ from that in an actual system.

Embodiment 1

[0013] Fig. 1 is a refrigerant circuit diagram of a cascade refrigeration system according to Embodiment 1 of the present invention. A cascade refrigeration system 100 includes a higher-stage refrigeration cycle 101 and a lower-stage refrigeration cycle 102. The higher-stage refrigeration cycle 101 and the lower-stage refrigeration cycle 102 are thermally coupled to each other by a cas-

cade condenser 30. Each of the elements constituting the higher-stage refrigeration cycle 101 and lower-stage refrigeration cycle 102 is housed in an outdoor unit 1 or a cooling unit 2, which is to be described later.

[0014] As refrigerant to be enclosed in the lower-stage refrigeration cycle 102, in consideration of possible refrigerant leakage, carbon dioxide (CO₂) having a small effect on global warming is used. As refrigerant to be enclosed in the higher-stage refrigeration cycle 101, R410A, R32, R404A, HFO-1234yf, propane, isobutene, CO₂, ammonia, or other refrigerant is used, for example. In this specification, refrigerant to be enclosed in the lower-stage refrigeration cycle 102 is referred to as a lower-stage refrigerant, and refrigerant to be enclosed in the higher-stage refrigeration cycle 101 is referred to as a higher-stage refrigerant.

[0015] The higher-stage refrigeration cycle 101 is a refrigeration cycle in which the higher-stage refrigerant is circulated. In the higher-stage refrigeration cycle 101, a higher-stage compressor 10, a higher-stage condenser 11, a higher-stage expansion valve 12, and a higher-stage evaporator 13 are sequentially connected by a refrigerant pipe to form a refrigerant circuit. In this specification, a refrigerant circuit of the higher-stage refrigeration cycle 101 is referred to as a higher-stage refrigerant circuit.

[0016] The lower-stage refrigeration cycle 102 is a refrigeration cycle in which a lower-stage refrigerant is circulated. In the lower-stage refrigeration cycle 102, a lower-stage compressor 20, a first lower-stage condenser 21, a second lower-stage condenser 22, a lower-stage liquid receiver 24, a first lower-stage expansion valve 25, and a lower-stage evaporator 26 are sequentially connected by a refrigerant pipe to form a refrigerant circuit. The lower-stage refrigeration cycle 102 also has a second lower-stage expansion valve 23 that is provided between the second lower-stage condenser 22 and the lower-stage liquid receiver 24. In this specification, a refrigerant circuit of the lower-stage refrigeration cycle 102 is referred to as a lower-stage refrigerant circuit.

[0017] The cascade refrigeration system 100 includes the abovementioned cascade condenser 30. In the cascade condenser 30, the higher-stage evaporator 13 and the second lower-stage condenser 22 are configured to be coupled to each other so that heat can be exchanged between the refrigerant passing through the higher-stage evaporator 13 and the refrigerant passing through the second lower-stage condenser 22. That is, the cascade condenser 30 is an inter-refrigerant heat exchanger. With the cascade condenser 30, the lower-stage refrigerant circuit and the higher-stage refrigerant circuit form a multistage structure.

[0018] The higher-stage compressor 10 is configured to suck the refrigerant passing through the higher-stage refrigerant circuit, compress the refrigerant sucked, and discharge the refrigerant in a gaseous state having a high temperature and a high pressure. In Embodiment 1, the higher-stage compressor 10 is formed of a compressor

in which a rotation speed is controlled by an inverter circuit, for example, such that an amount of refrigerant to be discharged can be adjusted.

[0019] The higher-stage condenser 11 is configured to exchange heat between air or brine, for example, and the refrigerant flowing in the higher-stage refrigerant circuit to condense and liquefy the refrigerant. In Embodiment 1, the higher-stage condenser 11 exchanges heat between an outdoor air and the refrigerant. The cascade refrigeration system 100 has a higher-stage condenser fan, which is not shown. With the higher-stage condenser fan, the outdoor air is sent to the higher-stage condenser 11 to facilitate the heat exchange in the higher-stage condenser 11. The higher-stage condenser fan is formed of a fan capable of adjusting an air flow rate.

[0020] The higher-stage expansion valve 12 is configured to reduce the pressure of, and expand, the refrigerant flowing in the higher-stage refrigerant circuit, and is formed of a refrigerant flow control unit such as an electronic expansion valve or other device, or a refrigerant flow adjustment unit, for example. That is, the higher-stage expansion valve 12 is formed of a pressure reducing device or an expansion device capable of controlling an amount of expansion.

[0021] The higher-stage evaporator 13 is configured to evaporate and gasify the refrigerant flowing in the higher-stage refrigerant circuit by heat exchange. In Embodiment 1, the higher-stage evaporator 13 is formed of, for example, a heat transmission tube or other device, through which the refrigerant flowing in the higher-stage refrigerant circuit passes in the cascade condenser 30. In the cascade condenser 30, heat is exchanged between the refrigerant flowing in the higher-stage evaporator 13 and the refrigerant flowing in the lower-stage refrigerant circuit.

[0022] The lower-stage compressor 20 is configured to suck the refrigerant passing through the lower-stage refrigerant circuit, compress the refrigerant sucked, and discharge the refrigerant in a gaseous state having a high temperature and a high pressure. In Embodiment 1, the lower-stage compressor 20 is formed of a compressor in which a rotation speed is controlled by an inverter circuit, for example, such that an amount of refrigerant to be discharged can be adjusted.

[0023] The first lower-stage condenser 21 is configured to exchange heat between air or brine, for example, and the refrigerant flowing in the higher-stage refrigerant circuit to condense and liquefy the refrigerant. In Embodiment 1, the first lower-stage condenser 21 exchanges heat between an outdoor air and the refrigerant. The cascade refrigeration system 100 has a lower-stage condenser fan, which is not shown. With the lower-stage condenser fan, the outdoor air is sent to the first lower-stage condenser 21 to facilitate the heat exchange in the first lower-stage condenser 21. The lower-stage condenser fan is formed of a fan capable of adjusting an air flow rate.

[0024] The second lower-stage condenser 22 is con-

figured to further condense the refrigerant that has been condensed and liquefied in the first lower-stage condenser 21 to obtain a subcooled refrigerant. In Embodiment 1, the second lower-stage condenser 22 is formed of, for example, a heat transmission tube or other device, through which the refrigerant flowing in the lower-stage refrigerant circuit passes in the cascade condenser 30. In the cascade condenser 30, heat is exchanged between the refrigerant flowing in the second lower-stage condenser 22 and the refrigerant flowing in the higher-stage refrigerant circuit.

[0025] The second lower-stage expansion valve 23 is configured to reduce the pressure of, and expand, the refrigerant flowing in the lower-stage refrigerant circuit, and is formed of a refrigerant flow control unit such as an electronic expansion valve or other device, or a refrigerant flow adjustment unit, for example. That is, the second lower-stage expansion valve 23 is formed of a pressure reducing device or an expansion device capable of controlling an amount of expansion.

[0026] The lower-stage liquid receiver 24 is provided downstream of the second lower-stage condenser 22 and the second lower-stage expansion valve 23. The lower-stage liquid receiver 24 is configured to temporarily store refrigerant.

[0027] The first lower-stage expansion valve 25 is configured to reduce the pressure of, and expand, the refrigerant flowing in the lower-stage refrigerant circuit, and is formed of a refrigerant flow control unit such as an electronic expansion valve or other device, or a refrigerant flow adjustment unit, for example. That is, the first lower-stage expansion valve 25 is formed of a pressure reducing device or an expansion device capable of controlling an amount of expansion.

[0028] The lower-stage evaporator 26 is configured to evaporate and gasify the refrigerant flowing in the higher-stage refrigerant circuit by heat exchange. Through the heat exchange with the refrigerant at the lower-stage evaporator 26, an object to be cooled is directly or indirectly cooled.

[0029] In Embodiment 1, the lower-stage refrigeration cycle 102 includes a natural circulation circuit 40. The natural circulation circuit 40 has a subcooled refrigerant pipe 31 and a vapor refrigerant pipe 32. The subcooled refrigerant pipe 31 connects a position between the second lower-stage condenser 22 and the second lower-stage expansion valve 23 and a position between the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24. The vapor refrigerant pipe 32 connects a position between the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24 and a position between the first lower-stage condenser 21 and the second lower-stage condenser 22. A capillary tube 33 is provided in a middle of the subcooled refrigerant pipe 31. The capillary tube 33 is a pressure adjustment unit of the present invention. A check valve 34 is provided in a middle of the vapor refrigerant pipe 32.

[0030] Each of the components of the abovementioned

cascade refrigeration system 100 is housed in the outdoor unit 1 or the cooling unit 2. The cooling unit 2 is used as a refrigerating/freezing showcase or a unit cooler, for example. In Embodiment 1, the higher-stage compressor 10, the higher-stage condenser 11, the higher-stage expansion valve 12, the higher-stage evaporator 13, the lower-stage compressor 20, the first lower-stage condenser 21, the second lower-stage condenser 22, the second lower-stage expansion valve 23, the lower-stage liquid receiver 24, the subcooled refrigerant pipe 31, the vapor refrigerant pipe 32, the capillary tube 33, and the check valve 34 are housed in the outdoor unit 1. Meanwhile, the first lower-stage expansion valve 25 and the lower-stage evaporator 26 are housed in the cooling unit 2. The outdoor unit 1 and the cooling unit 2 are connected to each other by two pipes, that is, a liquid pipe 3 and a gas pipe 4.

[0031] Fig. 2 is an equipment layout of the natural circulation circuit according to Embodiment 1 of the present invention. In Embodiment 1, in the natural circulation circuit 40, the second lower-stage condenser 22 of the cascade condenser 30 is disposed at an upper part of the outdoor unit 1, the lower-stage liquid receiver 24 is disposed at a lower part of the outdoor unit 1, and the second lower-stage expansion valve 23 is arranged at an intermediate part of the outdoor unit 1, and as described above, the second lower-stage condenser 22, the lower-stage liquid receiver 24, and the second lower-stage expansion valve 23 are sequentially connected by pipes. That is, in the top-bottom direction of the outdoor unit 1, the second lower-stage condenser 22 is positioned higher than the lower-stage liquid receiver 24 is. Further, the subcooled refrigerant pipe 31 and the vapor refrigerant pipe 32 are connected as described above to obtain a difference in height in the circuit. As illustrated in Fig. 2, in the top-bottom direction of the outdoor unit 1, the vapor refrigerant pipe 32 is disposed higher than the subcooled refrigerant pipe 31.

[0032] The check valve 34 of the vapor refrigerant pipe 32 is configured to prevent the refrigerant that is discharged from the lower-stage compressor 20 illustrated in Fig. 1 and then flows out from the first lower-stage condenser 21, from entering the vapor refrigerant pipe 32.

(Overview of Operations in Normal Cooling Operation)

[0033] Operations of components in a normal cooling operation, in which air as an object to be cooled is cooled, in the cascade refrigeration system 100 having the abovementioned configuration are described based on flows of the refrigerants circulating in the refrigerant circuits.

(Operation of Higher-stage Refrigeration Cycle)

[0034] First, operation of the higher-stage refrigeration cycle 101 is described with reference to Fig. 1. The high-

er-stage compressor 10 sucks the higher-stage refrigerant, compresses it into a high-temperature and high-pressure gaseous state and discharges it. The discharged higher-stage refrigerant flows into the higher-stage condenser 11. The higher-stage condenser 11 exchanges heat between the outdoor air, which is supplied by the higher-stage condenser fan (not shown), and the higher-stage refrigerant in a gaseous state to condense and liquefy the higher-stage refrigerant. The condensed and liquefied higher-stage refrigerant passes through the higher-stage expansion valve 12. The higher-stage expansion valve 12 reduces the pressure of the condensed and liquefied higher-stage refrigerant. The higher-stage refrigerant that has been reduced in pressure flows into the higher-stage evaporator 13 in the cascade condenser 30. In the higher-stage evaporator 13, heat is exchanged between the higher-stage refrigerant and the lower-stage refrigerant passing through the second lower-stage condenser 22 to evaporate and gasify the higher-stage refrigerant. The evaporated and gasified higher-stage refrigerant is sucked into the higher-stage compressor 10.

(Operation of Lower-stage Refrigeration Cycle)

[0035] Next, operation of the lower-stage refrigeration cycle 102 is described with reference to Fig. 1. The lower-stage compressor 20 sucks and compresses the lower-stage refrigerant to discharge the lower-stage refrigerant in a high-temperature and high-pressure gaseous state. The discharged lower-stage refrigerant flows into the first lower-stage condenser 21. The first lower-stage condenser 21 exchanges heat between the outdoor air, which is supplied by the lower-stage condenser fan (not shown), and the lower-stage refrigerant to condense the lower-stage refrigerant. The condensed lower-stage refrigerant flows into the second lower-stage condenser 22 in the cascade condenser 30. The second lower-stage condenser 22 exchanges heat between the lower-stage refrigerant and the higher-stage refrigerant passing through the higher-stage evaporator 13 to further condense the lower-stage refrigerant to obtain the lower-stage refrigerant in a subcooled and liquefied state. The subcooled and liquefied lower-stage refrigerant passes through the second lower-stage expansion valve 23. The second lower-stage expansion valve 23 reduces the pressure of the subcooled and liquefied lower-stage refrigerant to obtain the refrigerant having an intermediate pressure. The lower-stage refrigerant that has been reduced in pressure to the intermediate pressure then passes through the lower-stage liquid receiver 24, and becomes the lower-stage refrigerant having a low pressure after being reduced in pressure at the first lower-stage expansion valve 25. The lower-stage refrigerant that has been reduced in pressure to the low pressure flows into the lower-stage evaporator 26. The lower-stage evaporator 26 exchanges heat between an indoor air of the refrigerated warehouse and the lower-stage refrigerant to evaporate and gasify the lower-stage re-

frigerant. The evaporated and gasified lower-stage refrigerant is sucked into the lower-stage compressor 20.

(Operations of Higher-stage Refrigeration Cycle and Natural Circulation Circuit during Stoppage of Lower-stage Refrigeration Cycle)

[0036] Here, a method of controlling a pressure increase in the lower-stage refrigerant circuit during stoppage of the lower-stage refrigeration cycle 102 is described. The stoppage of the lower-stage refrigeration cycle 102 described here indicates mainly a case in which the lower-stage compressor 20 is in a stop state.

[0037] In the cascade refrigeration system 100 according to Embodiment 1, even when the lower-stage refrigeration cycle 102 is stopped in power failure or other occasions, the higher-stage refrigerant circuit of the higher-stage refrigeration cycle 101 is operated with another power supply. Therefore, the lower-stage refrigerant can be cooled by the higher-stage evaporator 13 of the cascade condenser 30, and an increase in pressure of the lower-stage refrigerant due to an increase in temperature can be reduced. However, because the lower-stage refrigerant is not circulated, operation of the higher-stage refrigeration cycle 101 alone cannot sufficiently cool down the lower-stage refrigerant, and hence an increase in pressure in the lower-stage refrigerant circuit is not controlled adequately. To solve this problem, in Embodiment 1, the abovementioned natural circulation circuit 40 is provided in the lower-stage refrigeration cycle 102 to circulate the lower-stage refrigerant.

[0038] In the natural circulation circuit 40, the subcooled refrigerant, the heat of which has been exchanged in the cascade condenser 30, passes through the second lower-stage expansion valve 23 and the pipe, at which the second lower-stage expansion valve 23 is provided, or passes through the subcooled refrigerant pipe 31, and then drips into the lower-stage liquid receiver 24. At this time, as illustrated in Fig. 2, there is a difference in height in the top-bottom direction between the subcooled refrigerant pipe 31 and the vapor refrigerant pipe 32, and the subcooled refrigerant falls into the lower-stage liquid receiver 24 by gravity. Therefore, the subcooled refrigerant does not enter the vapor refrigerant pipe 32, to which the second lower-stage condenser 22 is connected above.

[0039] As the subcooled refrigerant drips into the lower-stage liquid receiver 24, which is located below, the volume of the subcooled refrigerant remaining above the second lower-stage condenser 22 is reduced, and thus a part higher than the second lower-stage condenser 22 has a negative pressure and a part at or around the lower-stage liquid receiver 24 has a positive pressure. As a result, the vapor refrigerant stored in the lower-stage liquid receiver 24 is sucked to the higher side, where the second lower-stage condenser 22 is located, via a pipe connecting the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24, and the vapor refrigerant pipe 32 that branches off from the pipe. The

vapor refrigerant that has been sucked to the higher side flows into the second lower-stage condenser 22, and then the heat of the vapor refrigeration is exchanged again in the second lower-stage condenser 22 to obtain a subcooled refrigerant, and the subcooled refrigerant drips into the lower-stage liquid receiver 24. Such natural circulation of the refrigerant flowing in the natural circulation circuit 40 is repeated, and thus an increase in pressure in the lower-stage refrigerant circuit is controlled efficiently.

[0040] The subcooled refrigerant pipe 31 is provided to make the subcooled refrigerant circulate even at the time of power failure or malfunction, such as a case where the second lower-stage expansion valve 23, which is an electronic expansion valve, is closed. In addition, the capillary tube 33 installed in a middle of the subcooled refrigerant pipe 31 is provided to reduce the pressure of the lower-stage refrigerant, similarly to the second lower-stage expansion valve 23, even when the subcooled refrigerant flowing out from the second lower-stage condenser 22 of the cascade condenser 30 in a normal cooling operation is bypassed to the subcooled refrigerant pipe 31.

[0041] Fig. 3 is an equipment layout of the natural circulation circuit according to Embodiment 1 of the present invention. The capillary tube 33, which is provided in a middle of the subcooled refrigerant pipe 31, may be replaced with a solenoid valve 35, as illustrated in Fig. 3. The solenoid valve 35 is a pressure adjustment unit of the present invention. When the solenoid valve 35 is used, the solenoid valve 35 is set to "close" in a normal cooling operation and to "open" at the time of power failure. With such setting, in a normal cooling operation, the subcooled refrigerant flowing out from the second lower-stage condenser 22 of the cascade condenser 30 does not enter the lower-stage liquid receiver 24 via the subcooled refrigerant pipe 31. Meanwhile, when the second lower-stage expansion valve 23 is closed at the time of power failure or malfunction, the lower-stage refrigerant is bypassed to the subcooled refrigerant pipe 31, and flows into the lower-stage liquid receiver 24.

[0042] The abovementioned capillary tube 33 or the solenoid valve 35 is not required depending on pressure losses of the second lower-stage expansion valve 23 and the pipe on which the second lower-stage expansion valve 23 is installed.

[0043] In the cascade refrigeration system 100 according to Embodiment 1, even when the lower-stage refrigeration cycle 102 is stopped, the higher-stage refrigeration cycle 101 is operated with another power supply, and the lower-stage refrigerant in the lower-stage refrigerant circuit is cooled by the second lower-stage condenser 22 of the cascade condenser 30. In addition, the natural circulation circuit 40 is provided in the lower-stage refrigeration cycle 102 to circulate the lower-stage refrigerant by itself, and hence the increase in pressure due to the increase in temperature can be controlled efficiently. As a result, high design pressures are not required for

on-site pipes, unit coolers, showcases and other units in the system, and thus the cost of equipment can be reduced.

Embodiment 2

[0044] Fig. 4 is an equipment layout of a natural circulation circuit according to Embodiment 2 of the present invention. Fig. 4 illustrates an equipment layout of a natural circulation circuit 40a of a cascade refrigeration system 100a according to Embodiment 2. Configuration and operation of the natural circulation circuit 40a are described based on Fig. 4. Note that, in Fig. 4, components similar to those in Embodiment 1 are denoted by the same reference symbols. In Embodiment 2, differences from Embodiment 1 described above are mainly described, and description of the same functions and configurations as Embodiment 1, such as configurations of refrigerant circuits, is omitted.

[0045] The natural circulation circuit 40a of the cascade refrigeration system 100a includes a subcooled refrigerant pipe 31 and a vapor refrigerant pipe 32a. The subcooled refrigerant pipe 31 connects a position between the second lower-stage condenser 22 and the second lower-stage expansion valve 23 and a position between the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24. The vapor refrigerant pipe 32a connects a position between the second lower-stage condenser 22 and the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24. That is, the vapor refrigerant pipe 32a is directly connected to the lower-stage liquid receiver 24.

[0046] In Embodiment 2, in the natural circulation circuit 40a with such configuration, the connecting location of the vapor refrigerant pipe 32a is provided at the lower-stage liquid receiver 24. Thus, the subcooled refrigerant dripping into the lower-stage liquid receiver 24 due to heat exchange in the cascade condenser 30 and the vapor refrigerant being sucked from the lower-stage liquid receiver 24 are not mixed in the pipe connecting the second lower-stage expansion valve 23 and the lower-stage liquid receiver 24. As a result, a pressure loss can be reduced, and therefore, the refrigerant flowing in the natural circulation circuit 40a can be circulated by itself more efficiently.

Reference Signs List

[0047] 1 outdoor unit 2 cooling unit 3 liquid pipe 4 gas pipe 10 higher-stage compressor 11 higher-stage condenser 12 higher-stage expansion valve 13 higher-stage evaporator 20 lower-stage compressor 21 first lower-stage condenser 22 second lower-stage condenser 23 second lower-stage expansion valve 24 lower-stage liquid receiver 25 first lower-stage expansion valve 26 lower-stage evaporator 30 cascade condenser 31 subcooled refrigerant pipe 32 vapor refrigerant pipe 32a vapor refrigerant pipe 33 capillary tube 34 check valve 35

solenoid valve 40 natural circulation circuit 40a natural circulation circuit 100 cascade refrigeration system 100a cascade refrigeration system 101 higher-stage refrigeration cycle 102 lower-stage refrigeration cycle

Claims

1. A cascade refrigeration system, comprising:

a higher-stage refrigeration cycle in which a higher-stage compressor, a higher-stage condenser, a higher-stage expansion valve, and a higher-stage evaporator are sequentially connected by pipes and in which a higher-stage refrigerant is circulated;

a lower-stage refrigeration cycle in which a lower-stage compressor, a first lower-stage condenser, a second lower-stage condenser, a lower-stage liquid receiver, a first lower-stage expansion valve, and a lower-stage evaporator are sequentially connected by pipes and in which a lower-stage refrigerant is circulated; and

a cascade condenser including the higher-stage evaporator and the second lower-stage condenser to exchange heat between the higher-stage refrigerant flowing in the higher-stage evaporator and the lower-stage refrigerant flowing in the second lower-stage condenser, wherein

the lower-stage refrigeration cycle is provided with a natural circulation circuit having a vapor refrigerant pipe that connects the lower-stage liquid receiver and a position between the first lower-stage condenser and the second lower-stage condenser and that has a check valve at a position in a middle of the vapor refrigerant pipe.

2. The cascade refrigeration system of claim 1, further comprising

a second lower-stage expansion valve being provided between the second lower-stage condenser and the lower-stage liquid receiver in the lower-stage refrigeration cycle, wherein

the natural circulation circuit has a subcooled refrigerant pipe that connects a position between the second lower-stage condenser and the second lower-stage expansion valve and a position between the second lower-stage expansion valve and the lower-stage liquid receiver and that has a pressure adjustment unit at a position in a middle of the subcooled refrigerant pipe.

3. The cascade refrigeration system of claim 2, wherein the vapor refrigerant pipe is connected at a position between the second lower-stage expansion valve and the lower-stage liquid receiver.

4. The cascade refrigeration system of claim 1 or 2,
wherein the vapor refrigerant pipe is directly connected to the lower-stage liquid receiver.
5. The cascade refrigeration system of any one of
claims 2 to 4, wherein the pressure adjustment unit
is a capillary tube. 5
6. The cascade refrigeration system of any one of
claims 2 to 4, wherein the pressure adjustment unit
is a solenoid valve. 10
7. The cascade refrigeration system of any one of
claims 1 to 6, wherein the second lower-stage condenser is disposed higher than the lower-stage liquid receiver in the natural circulation circuit. 15
8. The cascade refrigeration system of any one of
claims 2 to 7, wherein the vapor refrigerant pipe is
disposed higher than the subcooled refrigerant pipe
in the natural circulation circuit. 20

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FIG. 1

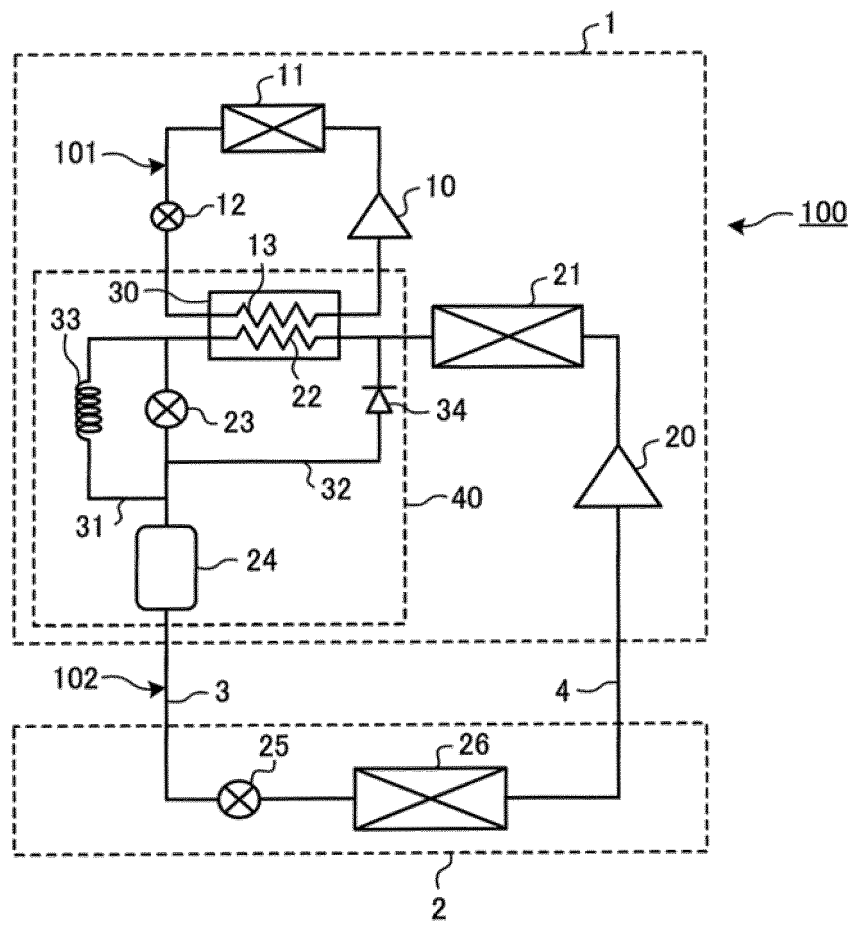


FIG. 2

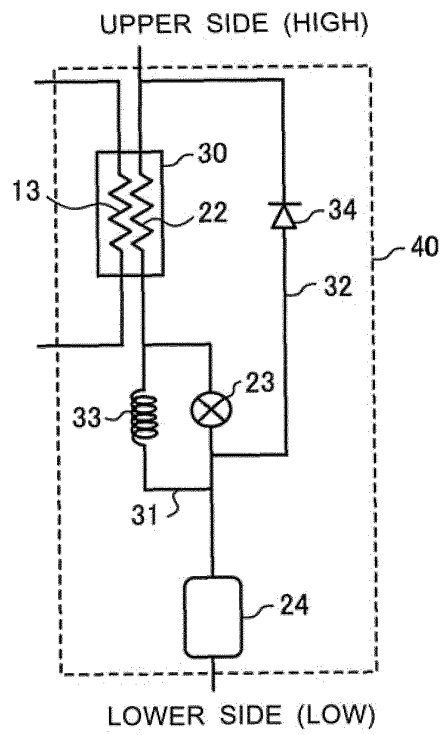


FIG. 3

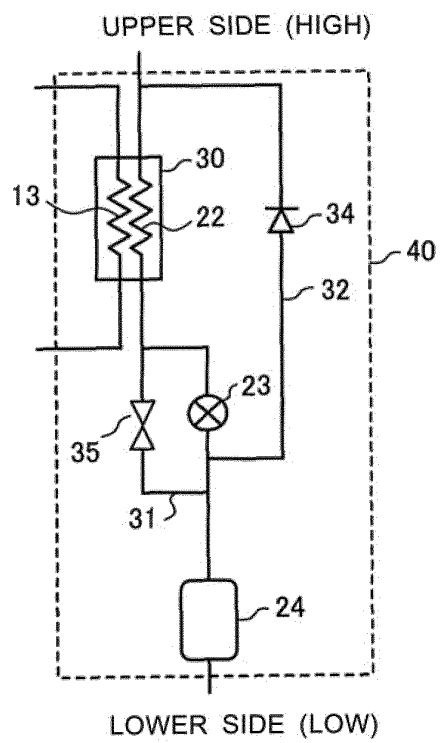
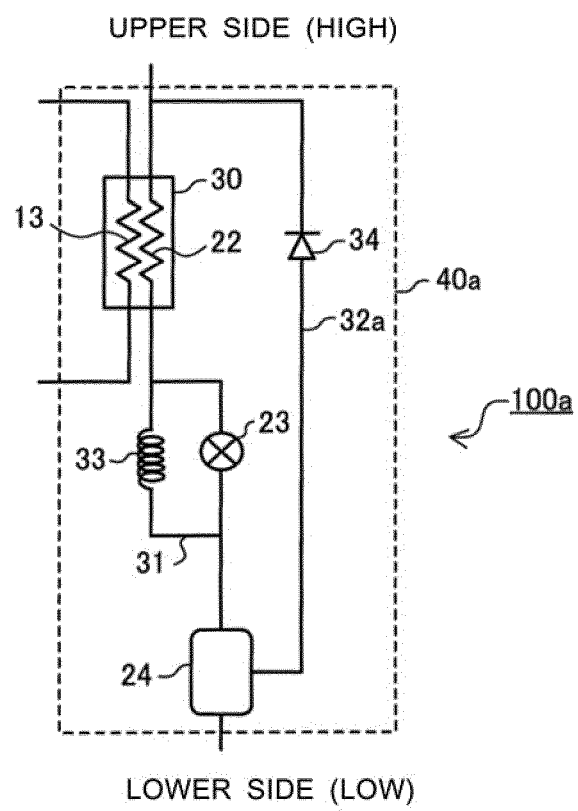


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/016407

A. CLASSIFICATION OF SUBJECT MATTER

F25B7/00(2006.01) i, F25B1/00(2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F25B7/00, F25B1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2017

Kokai Jitsuyo Shinan Koho 1971-2017 Toroku Jitsuyo Shinan Koho 1994-2017

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 2014/045400 A1 (Mitsubishi Electric Corp.), 27 March 2014 (27.03.2014), paragraphs [0005] to [0007], [0011] to [0029], [0047] to [0055]; fig. 8 & JP 14-45400 A1 & EP 2910870 A1 paragraphs [0012] to [0015], [0019] to [0105], [0152] to [0176]; fig. 8	1-2, 4-5, 7-8 3, 6
Y	JP 2004-190917 A (Sanyo Electric Co., Ltd.), 08 July 2004 (08.07.2004), paragraphs [0025] to [0027]; fig. 1 (Family: none)	1-2, 4-5, 7-8

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

05 July 2017 (05.07.17)

Date of mailing of the international search report

18 July 2017 (18.07.17)

 Name and mailing address of the ISA/
 Japan Patent Office
 3-4-3, Kasumigaseki, Chiyoda-ku,
 Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/016407

5	C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
10	Y	WO 2011/077720 A1 (Daikin Industries, Ltd.), 30 June 2011 (30.06.2011), paragraphs [0356] to [0358]; fig. 32 & JP 5516602 B2 & US 2012/0255318 A1 paragraphs [0401] to [0403]; fig. 32 & EP 2518422 A1 & CN 102667368 A	2, 4-5, 7-8
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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2004190917 A [0005]
- WO 2014064744 A [0005]