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(71) Applicant: **Fujitsu General Limited**
Kawasaki-shi, Kanagawa 213-8502 (JP)

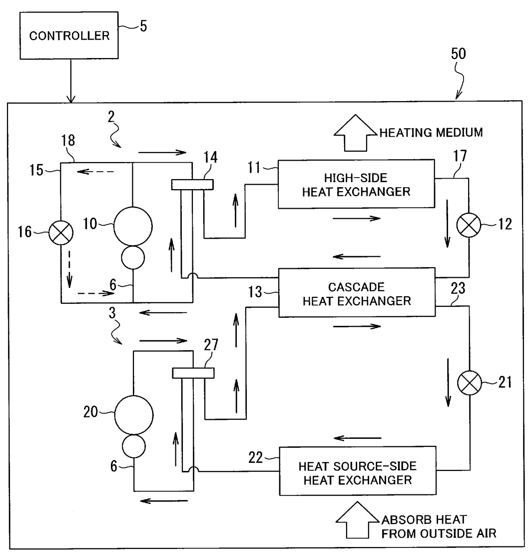
(72) Inventors:
- **NAKATA, Shohei**
  Kawasaki-shi, Kanagawa 213-8502 (JP)
- **MAEMA, Yoshinari**
  Kawasaki-shi, Kanagawa 213-8502 (JP)
- **KANEI, Kazuki**
  Kawasaki-shi, Kanagawa 213-8502 (JP)

(74) Representative: **TBK**
Bavariaring 4-6
80336 München (DE)

(54) TWO-STAGE REFRIGERATION DEVICE

(57) There is provided a cascade refrigeration system that promptly performs a start-up operation and suppresses a decrease in reliability of a compressor and suppresses an increase in power consumption. The cascade refrigeration system includes: a high-side refrigerant circuit (2) having a high-side first circulation path (17) containing a high-side compressor (10), a high-side heat exchanger (11), a high-side expansion valve (12), and a cascade heat exchanger (13) where a high-side refrigerant and a low-side refrigerant exchange heat, sequentially connected; and a low-side refrigerant circuit (3) containing a low-side compressor (20), the cascade heat exchanger (13), a low-side expansion valve (21), and a heat source-side heat exchanger (22) sequentially connected, in which the high-side refrigerant circuit (2) includes: a high-side second circulation path (18) in which a discharge side and a suction side of the high-side compressor (10) are connected by a high-side bypass path (15) and through which the high-side refrigerant discharged from the high-side compressor (10) circulates to the suction side of the high-side compressor (10) through the high-side bypass path (15); and a high-side opening and closing valve (16) performing switching between the high-side first circulation path (17) and the high-side second circulation path (18).

FIG. 3



EP 4 502 498 A1

Description

Technical Field

[0001] The present invention relates to a cascade refrigeration system, and particularly relates to a cascade refrigeration system that enables a smooth start-up to a steady-state operation.

Background Art

[0002] A conventional cascade refrigeration system includes a high-side refrigerant circuit in which a compressor, a condenser, an expansion mechanism, and an evaporation unit of an intermediate heat exchanger are sequentially connected and through which a high-side refrigerant circulates and a low-side refrigerant circuit in which a compressor, a condensing unit of an intermediate heat exchanger, an expansion mechanism, and an evaporator are sequentially connected, through which a low-side refrigerant circulates, and in which the high-side refrigerant and the low-side refrigerant exchange heat in the intermediate heat exchanger. Such a cascade refrigeration system can dissipate heat in the condenser of the high-side refrigerant circuit or obtain a cold source of a refrigerator in the evaporator of the low-side refrigerant circuit.

[0003] In such a cascade refrigeration system, when the low-side refrigerant circuit and the high-side refrigerant circuit are simultaneously activated, the refrigerant is not condensed in the condenser until the discharge temperature sufficiently rises, and therefore the refrigerant circulation amount cannot be sufficiently ensured in the high-side refrigerant circuit, sometimes leading to a low-pressure cutoff of the high-side refrigerant circuit. Further, the low-side refrigerant circuit is activated in a state where the refrigerant circulation amount of the high-side refrigerant circuit cannot be sufficiently ensured. Therefore, the low-side refrigerant of the low-side refrigerant circuit does not sufficiently exchange heat with the high-side refrigerant in the intermediate heat exchanger, sometimes leading to a high-pressure cutoff of the low-side refrigerant circuit. The conventional cascade refrigeration system has had a high risk that in any case results in an abnormal stop before a steady-state operation is achieved.

[0004] Therefore, in the cascade refrigeration system disclosed in PTL 1, when the low-side refrigerant reaches a predetermined first pressure after the low-side refrigerant circuit is activated, the low-side refrigerant circuit is stopped and the high-side refrigerant circuit is activated. Then, when the low-side refrigerant of the low-side refrigerant circuit is depressurized to a prescribed second pressure, the low-side refrigerant circuit is activated. Therefore, in the start-up, there is no risk of causing either a high-pressure abnormality of the low-side refrigerant circuit or a low-pressure abnormality of the high-side refrigerant circuit, thus enabling a smooth start-up to a steady-state operation.

Citation List

Patent Literature

[0005] PTL 1: JP 2013-213592 A

Summary of Invention

Technical Problem

[0006] However, the cascade refrigeration system disclosed in PTL 1 alternately operates the compressor of the low-side refrigerant circuit and the compressor of the high-side refrigerant circuit, and therefore requires time for the start-up and undergoes a decrease in reliability of the compressors. Further, the cascade refrigeration system disclosed in PTL 1 has a problem of an increase in power consumption due to repeated activation and stop of the compressors.

[0007] In view of the above-described problem, it is an object of the present invention to provide a cascade refrigeration system capable of promptly performing a start-up operation, and suppressing the decrease in reliability of the compressor and suppressing the increase in power consumption in the cascade refrigeration system.

Solution to Problem

[0008] One aspect of the present invention is a cascade refrigeration system including: a high-side refrigerant circuit containing a high-side compressor, a high-side heat exchanger configured to exchange heat with a heating medium, a high-side expansion mechanism, and a cascade heat exchanger sequentially connected by a refrigerant pipe and having a high-side first circulation path through which a high-side refrigerant circulates; a low-side refrigerant circuit containing a low-side compressor, the cascade heat exchanger, a low-side expansion mechanism, and a heat source-side heat exchanger sequentially connected by a refrigerant pipe, the low-side refrigerant circuit through which a low-side refrigerant circulates; and a controller configured to control the high-side refrigerant circuit and the low-side refrigerant circuit, in which the high-side refrigerant and the low-side refrigerant exchange heat in the cascade heat exchanger, and the high-side refrigerant circuit includes: a high-side second circulation path in which a discharge side and a suction side of the high-side compressor are connected by a high-side bypass path and the high-side refrigerant discharged from the high-side compressor circulates to the suction side of the high-side compressor through the high-side bypass path; and a high-side switching device configured to switch a circulation path such that the high-side refrigerant discharged from the high-side compressor circulates through the high-side first circulation path or the high-side second circulation path.

Advantageous Effects of Invention

[0009] The present invention can provide a cascade refrigeration system capable of promptly performing a start-up operation, and suppressing the decrease in reliability of the compressor and suppressing the increase in power consumption in the cascade refrigeration system.

Brief Description of Drawings

[0010]

FIG. 1 is a refrigeration circuit diagram of a cascade refrigeration system according to a first embodiment of the present invention;
FIG. 2 is a control flow diagram of the cascade refrigeration system according to the first embodiment of the present invention;
FIG. 3 is a refrigeration circuit diagram of a cascade refrigeration system according to a second embodiment of the present invention;
FIG. 4 is a control flow diagram of the cascade refrigeration system according to the second embodiment of the present invention;
FIG. 5 is a refrigeration circuit diagram of a cascade refrigeration system according to a third embodiment of the present invention; and
FIG. 6 is a control flow diagram of the cascade refrigeration system according to the third embodiment of the present invention.

Description of Embodiments

[0011] Hereinafter, embodiments of a cascade refrigeration system according to the present invention are described in detail based on the drawings. This invention is not limited by the embodiments.

[0012] FIG. 1 is a refrigeration circuit diagram of a cascade refrigeration system according to a first embodiment of the present invention. FIG. 2 is a control flow diagram of the cascade refrigeration system according to the first embodiment of the present invention.

EXAMPLES

[0013] A cascade refrigeration system 1, which is a first embodiment, is described with reference to FIG. 1. The cascade refrigeration system 1 is a refrigeration system usable for an operation of making high-temperature hot water or for a heating operation on a high-temperature side. Hereinafter, the hot water making operation and the heating operation are sometimes collectively referred to as a heating operation. This embodiment describes a cascade refrigeration system used for the heating operation. The cascade refrigeration system 1 includes a high-side refrigerant circuit 2, a low-side refrigerant circuit 3, and a controller 5, in which the controller 5 controls the cascade refrigeration system 1.

[0014] The high-side refrigerant circuit 2 has a high-side first circulation path 17. The high-side first circulation path 17 contains a high-side compressor 10, a high-side heat exchanger 11 exchanging heat with a heating medium, such as air or water, a high-side expansion valve 12 as a high-side expansion mechanism, and a cascade heat exchanger 13 sequentially connected by a refrigerant pipe 6, the high-side first circulation path 17 through which a high-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the high-side refrigerant flowing through the high-side refrigerant circuit 2 and a low-side refrigerant flowing through the low-side refrigerant circuit 3 exchange heat. In this embodiment, the high-side heat exchanger 11 is a heat exchanger exchanging heat with the high-side refrigerant and air as the heating medium through a ventilator (not illustrated). The high-side heat exchanger 11 is a heat exchanger where the high-side refrigerant and the air as the heating medium exchange heat, but may also be a heat exchanger exchanging heat with water as a heating medium flowing through a heating medium circuit (not illustrated), for example. The arrows in the high-side refrigerant circuit 2 indicate the flow of the high-side refrigerant in the heating operation.

[0015] In the high-side refrigerant circuit 2, a high-side four-way valve 14 is connected to a discharge side of the high-side compressor 10, the high-side four-way valve 14 which switches the flow of the high-side refrigerant discharged from the high-side compressor 10 between the flow to the side of the high-side heat exchanger 11 and the flow to the side of the cascade heat exchanger 13. This embodiment describes a case where the high-side four-way valve 14 sends the high-side refrigerant discharged from the high-side compressor 10 to the side of the high-side heat exchanger 11 (heating operation). Accordingly, in the high-side refrigerant circuit 2, the high-side refrigerant discharged from the high-side compressor 10 flows through the high-side heat exchanger 11, the high-side expansion valve 12, and the cascade heat exchanger 13 to be sucked into the high-side compressor 10.

[0016] The low-side refrigerant circuit 3 has a low-side first circulation path 23 and a low-side second circulation path 28. The low-side first circulation path 23 contains a low-side compressor 20, the cascade heat exchanger 13 connected to the high-side refrigerant circuit 2, a low-side expansion valve 21 as a low-side expansion mechanism, and a heat source-side heat exchanger 22 absorbing heat from the outside air sequentially connected by the refrigerant pipe 6, the low-side first circulation path 23 through which the low-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the low-side refrigerant and the high-side refrigerant flowing through the high-side refrigerant circuit 2 exchange heat. The arrows in the low-side refrigerant circuit 3 indicate the flow of the low-side refrigerant.

[0017] The low-side refrigerant circuit 3 has a low-side bypass path 25 connecting a discharge side of the low-side compressor 20 and a suction side of the low-side compressor 20. The low-side bypass path 25 is provided with a low-side opening and closing valve 26. The low-side opening and closing valve 26 opens and closes the low-side bypass path 25. A flow path where the low-side refrigerant circulates from the discharge side of the low-side compressor 20 to the suction side of the low-side compressor 20 through the low-side bypass path 25 serves as the low-side second circulation path 28. When the low-side opening and closing valve 26 is closed, the low-side refrigerant circulates through the low-side first circulation path 23. When the low-side opening and closing valve 26 is opened, most of the low-side refrigerants circulate through the low-side second circulation path 28 smaller in flow resistance than the low-side first circulation path 23. The low-side opening and closing valve 26 serves as a low-side switching device switching the circulation of the low-side refrigerant discharged from the low-side compressor 20 between the circulation to the low-side first circulation path 23 and the circulation to the low-side second circulation path 28 in the present invention. This embodiment uses the low-side opening and closing valve 26, which is an opening and closing valve, as the low-side switching device. However, the other device may be used as the low-side switching device. For example, it may be acceptable that a three-way valve is provided at one end or the other end of the low-side bypass path 25 and the three-way valve switches the circulation of the low-side refrigerant discharged from the low-side compressor 20 between the circulation to the low-side first circulation path 23 and the circulation to the low-side second circulation path 28.

[0018] In the low-side refrigerant circuit 3, a low-side four-way valve 27 is connected to the discharge side of the low-side compressor 20, the low-side four-way valve 27 which switches the flow of the low-side refrigerant discharged from the low-side compressor 20 between the flow to the side of the cascade heat exchanger 13 and the flow to the heat source-side heat exchanger 22. This embodiment describes a case where the low-side four-way valve 27 sends the low-side refrigerant discharged from the low-side compressor 20 to the side of the cascade heat exchanger 13 (heating operation). In this case, in the low-side refrigerant circuit 3, the low-side refrigerant discharged from the low-side compressor 20 flows through the cascade heat exchanger 13, the low-side expansion valve 21, and the heat source-side heat exchanger 22 to be sucked into the low-side compressor 20. In the low-side refrigerant circuit 3, the low-side compressor 20 is a configuration commonly used in the low-side first circulation path 23 and the low-side second circulation path 28.

[0019] In the first embodiment, the high-side refrigerant in the high-side refrigerant circuit 2 and the low-side refrigerant in the low-side refrigerant circuit 3 are the same refrigerant, but are not necessarily required to be the same, and a low-side refrigerant having a lower boiling point than that of a high-side refrigerant may be acceptable, for example .

[0020] Next, the control of the cascade refrigeration system 1 according to the first embodiment is described with reference to the control flow diagram illustrated in FIG. 2.

[0021] When the cascade refrigeration system 1 is activated, the controller 5 first activates the high-side compressor 10 (ST1), and then activates the low-side compressor 20 (ST2) . More specifically, the high-side compressor 10 and the low-side compressor 20 are almost simultaneously activated. Next, the low-side opening and closing valve 26 is opened (ST3) . By opening the low-side opening and closing valve 26, most of the low-side refrigerants at high temperatures and high pressures discharged from the low-side compressor 20 flow to the suction side of the low-side compressor 20 through the low-side bypass path 25 smaller in flow resistance than the low-side first circulation path 23. More specifically, the low-side refrigerant at a high temperature and a high pressure discharged from the low-side compressor 20 circulates through the low-side second circulation path 28. Next, it is determined whether the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of air as the heating medium exchanging heat in the high-side heat exchanger 11 (ST4). The temperature of the high-side refrigerant is detected by a temperature sensor (not illustrated) provided in a pipe connected to the discharge side of the high-side compressor 10. The temperature of the heating medium is detected by a temperature sensor (not illustrated) provided at a position where the temperature of the heating medium flowing into the high-side heat exchanger 11 is detected. When the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of the air as the heating medium exchanging heat in the high-side heat exchanger 11 (Yes in ST4), the low-side opening and closing valve 26 is closed (ST5) .

[0022] The cascade refrigeration system 1 of the first embodiment is characterized by the fact that the high-side compressor 10 is activated (ST1), the low-side compressor 20 is activated (ST2), the low-side opening and closing valve 26 is opened, and then the low-side refrigerant at a high temperature and a high pressure discharged from the low-side compressor 20 circulates through the low-side second circulation path 28. More specifically, most of the low-side refrigerants at high temperatures and high pressures discharged from the low-side compressor 20 circulate to the suction side of the low-side compressor 20 through the low-side bypass path 25 smaller in flow resistance than the low-side first circulation path 23. This reduces a difference between the pressure of the refrigerant discharged from the low-side compressor 20 and the pressure of the refrigerant suctioned into the low-side compressor 20. This makes it possible to suppress a rise in the pressure of the low-side refrigerant on the high-pressure side of the low-side refrigerant circuit 3 and makes it possible to continue the operation of the low-side compressor 20 even when the high-side refrigerant is unable to evaporate in the cascade heat exchanger 13 of the high-side refrigerant circuit 2. Further, by immediately warming the low-side compressor 20, stagnation when the outside air is low can be suppressed.

[0023] Next, a cascade refrigeration system 50 as a second embodiment is described with reference to FIG. 3. A difference between the cascade refrigeration system 50 of the second embodiment and the cascade refrigeration system 1 of the first embodiment is that the high-side refrigerant circuit 2 is provided with a high-side second circulation path 18 and the low-side refrigerant circuit 3 is not provided with the low-side second circulation path 28, and the other configurations are common. The same reference numerals are used for the common configurations.

[0024] FIG. 3 is a refrigerant circuit diagram of the cascade refrigeration system 50 of the second embodiment. The cascade refrigeration system 50 is a refrigeration system usable for the heating operation on the high temperature side. This embodiment describes a cascade refrigeration system used for the heating operation. The cascade refrigeration system 50 includes the high-side refrigerant circuit 2, the low-side refrigerant circuit 3, and the controller 5, in which the controller 5 controls the cascade refrigeration system 50.

[0025] The high-side refrigerant circuit 2 has the high-side first circulation path 17 and the high-side second circulation path 18. The high-side first circulation path 17 contains the high-side compressor 10, the high-side heat exchanger 11 exchanging heat with the heating medium, such as air or water, the high-side expansion valve 12 as the high-side expansion mechanism, and the cascade heat exchanger 13 sequentially connected by the refrigerant pipe 6, the high-side first circulation path 17 through which the high-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the high-side refrigerant flowing through the high-side refrigerant circuit 2 and the low-side refrigerant flowing through the low-side refrigerant circuit 3 exchange heat. In this embodiment, the high-side heat exchanger 11 is a heat exchanger exchanging heat with the high-side refrigerant and air as a heating medium through a ventilator (not illustrated) . The high-side heat exchanger 11 is a heat exchanger where the high-side refrigerant and the air as the heating medium exchange heat, but may also be a heat exchanger exchanging heat with water as a heating medium flowing through a heating medium circuit (not illustrated), for example. The arrows in the high-side refrigerant circuit 2 indicate the flow of the high-side refrigerant (heating operation).

[0026] The high-side refrigerant circuit 2 includes a high-side bypass path 15 connecting the discharge side of the high-side compressor 10 and a suction side of the high-side compressor 10. The high-side bypass path 15 is provided with a high-side opening and closing valve 16. The high-side opening and closing valve 16 opens and closes the high-side bypass path 15. A flow path where the high-side refrigerant circulates from the discharge side of the high-side compressor 10 to the suction side of the high-side compressor 10 through the high-side bypass path 15 serves as the high-side second circulation path 18. When the high-side opening and closing valve 16 is closed, the high-side refrigerant circulates through the high-side first circulation path 17. When the high-side opening and closing valve 16 is opened, most of the high-side refrigerants circulate through the high-side second circulation path 18 smaller in flow resistance than the high-side first circulation path 17. The high-side opening and closing valve 16 serves as a high-side switching device switching the circulation of the high-side refrigerant discharged from the high-side compressor 10 between the circulation to the high-side first circulation path 17 and the circulation to the high-side second circulation path 18 in the present invention. This embodiment uses the high-side opening and closing valve 16, which is an opening and closing valve, as the high-side switching device. However, the other device may be used as the high-side switching device. For example, it may be acceptable that a three-way valve is provided at one end or the other end of the high-side bypass path 15 and the three-way valve switches the circulation of the high-side refrigerant discharged from the high-side compressor 10 between the circulation to the high-side first circulation path 17 and the circulation to the high-side second circulation path 18.

[0027] In the high-side refrigerant circuit 2, a high-side four-way valve 14 is connected to the discharge side of the high-side compressor 10, the high-side four-way valve 14 which switches the flow of the high-side refrigerant discharged from the high-side compressor 10 between the flow to the side of the high-side heat exchanger 11 and the flow to the side of the cascade heat exchanger 13. This embodiment describes a case where the high-side four-way valve 14 sends the high-side refrigerant discharged from the high-side compressor 10 to the side of the high-side heat exchanger 11. Accordingly, in the high-side refrigerant circuit 2, the high-side refrigerant discharged from the high-side compressor 10 flows through the high-side heat exchanger 11, the high-side expansion valve 12, and the cascade heat exchanger 13 to be sucked into the high-side compressor 10. In the high-side refrigerant circuit 2, the high-side compressor 10 is a configuration commonly used in the high-side first circulation path 17 and the high-side second circulation path 18.

[0028] The low-side refrigerant circuit 3 has the low-side first circulation path 23. The low-side first circulation path 23 contains a low-side compressor 20, the cascade heat exchanger 13 connected to the high-side refrigerant circuit 2, a low-side expansion valve 21 as a low-side expansion mechanism, and a heat source-side heat exchanger 22 absorbing heat from the outside air sequentially connected by the refrigerant pipe 6, the low-side first circulation path 23 through which the low-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the low-side refrigerant and the high-side refrigerant flowing through the high-side refrigerant circuit 2 exchange heat. The arrows in the low-side refrigerant circuit 3 indicate the flow of the low-side refrigerant.

[0029] In the low-side refrigerant circuit 3, the low-side four-way valve 27 is connected to the discharge side of the low-side compressor 20, the low-side four-way valve 27 which switches the flow of the low-side refrigerant discharged from the low-side compressor 20 between the flow to the side of the cascade heat exchanger 13 and the flow to the heat source-side heat exchanger 22. This embodiment describes a case where the low-side four-way valve 27 sends the low-side refrigerant discharged from the low-side compressor 20 to the side of the cascade heat exchanger 13. Accordingly, in the low-side refrigerant circuit 3, the low-side refrigerant discharged from the low-side compressor 20 flows through the cascade heat exchanger 13, the low-side expansion valve 21, and the heat source-side heat exchanger 22 to be sucked into the low-side compressor 20.

[0030] In this embodiment, the high-side refrigerant in the high-side refrigerant circuit 2 and the low-side refrigerant in the low-side refrigerant circuit 3 are the same refrigerant, but are not necessarily required to be the same, and a low-side refrigerant having a lower boiling point than that of a high-side refrigerant may be acceptable, for example.

[0031] Next, the control of the cascade refrigeration system 50 according to the second embodiment is described with reference to the control flow diagram illustrated in FIG. 4.

[0032] When the cascade refrigeration system 50 is activated, the controller 5 first activates the high-side compressor 10 (ST10). Next, the high-side opening and closing valve 16 is opened (ST11). By opening the high-side opening and closing valve 16, most of the high-side refrigerants at high temperatures and high pressures discharged from the high-side compressor 10 circulate to the suction side of the high-side compressor 10 through the high-side bypass path 15 smaller in flow resistance than the high-side first circulation path 17. More specifically, the high-side refrigerant at a high temperature and a high pressure discharged from the high-side compressor 10 circulates through the high-side second circulation path 18. Next, it is determined whether the temperature of the high-side compressor 10 exceeds 60°C which is a predetermined value (ST12). The temperature of the high-side compressor 10 is detected by a temperature sensor (not illustrated) provided in a pipe connected to the discharge side of the high-side compressor 10. The predetermined value is such a value that, when the temperature of the high-side compressor 10 is equal to or larger than the value, a desired heat exchange amount with the heating medium is obtained in the high-side heat exchanger 11, and, when the temperature is reached, the high-side refrigerant can be sufficiently condensed in the high-side heat exchanger 11. When the temperature of the high-side compressor 10 exceeds 60°C which is the predetermined value (Yes in ST12), the high-side opening and closing valve 16 is closed (ST13) . When the temperature of the high-side compressor 10 does not exceed 60°C which is the predetermined value (No in ST12), the operation is continued. Next, it is determined whether the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of the air as the heating medium exchanging heat in the high-side heat exchanger 11 (ST14). The temperature of the heating medium is detected by a temperature sensor (not illustrated) provided at a position where the temperature of the heating medium flowing into the high-side heat exchanger 11 is detected. When the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of the air as the heating medium exchanging heat in the high-side heat exchanger 11 (Yes in ST14), the low-side compressor 20 is activated (ST15).

[0033] The cascade refrigeration system 1 of this embodiment is characterized by the fact that the high-side compressor 10 is activated (ST10), the high-side opening and closing valve 16 is opened, and then the high-side refrigerant at a high temperature and a high pressure discharged from the high-side compressor 10 circulates through the high-side second circulation path 18. More specifically, most of the high-side refrigerants at high temperatures and high pressures discharged from the high-side compressor 10 circulate to the suction side of the high-side compressor 10 through the high-side bypass path 15 smaller in flow resistance than the high-side first circulation path 17. This makes it possible to immediately raise the temperature of the high-side compressor 10 and suppress a stagnation operation when the outside air temperature is low. Further, a state where the refrigerant pressure of the high-side refrigerant is easily raised can be achieved, and therefore the high-side refrigerant exchange heat with the air which is the heating medium in the high-side heat exchanger 11, and thus can be condensed. This enables the high-side refrigerant to exchange heat with the low-side refrigerant in the cascade heat exchanger 13, which makes it possible to promptly start the activation of the low-side compressor 20.

[0034] Next, a cascade refrigeration system 51 as a third embodiment is described with reference to FIG. 5. A difference between the cascade refrigeration system 51 of the third embodiment and the cascade refrigeration system 1 of the first embodiment is that the high-side refrigerant circuit 2 is provided with the high-side second circulation path 18 and the low-side refrigerant circuit 3 is provided with the low-side second circulation path 28, and the other configurations are common. The same reference numerals are used for the common configurations.

[0035] FIG. 5 is a refrigerant circuit diagram of the cascade refrigeration system 51 of the third embodiment. The cascade refrigeration system 51 is a refrigeration system usable for storing frozen food or other items when used on the low temperature side, and usable for making high-temperature hot water or usable for the heating operation when used on the high temperature side. This embodiment describes a cascade refrigeration system used for the heating operation. The cascade refrigeration system 51 includes the high-side refrigerant circuit 2, the low-side refrigerant circuit 3, and the controller 5, in which the controller 5 controls the cascade refrigeration system 51.

[0036] The high-side refrigerant circuit 2 has the high-side first circulation path 17 and the high-side second circulation path 18. The high-side first circulation path 17 contains the high-side compressor 10, the high-side heat exchanger 11 exchanging heat with the heating medium, such as air or water, the high-side expansion valve 12 as the high-side expansion mechanism, and the cascade heat exchanger 13 sequentially connected by the refrigerant pipe 6, the high-side first circulation path 17 through which the high-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the high-side refrigerant flowing through the high-side refrigerant circuit 2 and the low-side refrigerant flowing through the low-side refrigerant circuit 3 exchange heat. In this embodiment, the high-side heat exchanger 11 is a heat exchanger exchanging heat with the high-side refrigerant and the air as the heating medium through a ventilator (not illustrated). The high-side heat exchanger 11 is a heat exchanger where the high-side refrigerant and the air as the heating medium exchange heat, but may also be a heat exchanger exchanging heat with water as a heating medium flowing through a heating medium circuit (not illustrated), for example. The arrows in the high-side refrigerant circuit 2 indicate the flow of the high-side refrigerant (heating operation).

[0037] The high-side refrigerant circuit 2 includes the high-side bypass path 15 connecting the discharge side of the high-side compressor 10 and the suction side of the high-side compressor 10. The high-side bypass path 15 is provided with the high-side opening and closing valve 16. The high-side opening and closing valve 16 opens and closes the high-side bypass path 15. A flow path where the high-side refrigerant circulates from the discharge side of the high-side compressor 10 to the suction side of the high-side compressor 10 through the high-side bypass path 15 serves as the high-side second circulation path 18. When the high-side opening and closing valve 16 is closed, the high-side refrigerant circulates through the high-side first circulation path 17. When the high-side opening and closing valve 16 is opened, most of the high-side refrigerants circulate through the high-side second circulation path 18 smaller in flow resistance than the high-side first circulation path 17. The high-side opening and closing valve 16 serves as the high-side switching device switching the circulation of the high-side refrigerant discharged from the high-side compressor 10 between the circulation to the high-side first circulation path 17 and the circulation to the high-side second circulation path 18 in the present invention. This embodiment uses the high-side opening and closing valve 16, which is an opening and closing valve, as the high-side switching device. However, the other device may be used as the high-side switching device. For example, it may be acceptable that a three-way valve is provided at one end or the other end of the high-side bypass path 15 and the three-way valve switches the circulation of the high-side refrigerant discharged from the high-side compressor 10 between the circulation to the high-side first circulation path 17 and the circulation to the high-side second circulation path 18.

[0038] In the high-side refrigerant circuit 2, the high-side four-way valve 14 is connected to the discharge side of the high-side compressor 10, the high-side four-way valve 14 which switches the flow of the high-side refrigerant discharged from the high-side compressor 10 between the flow to the side of the high-side heat exchanger 11 and the flow to the side of the cascade heat exchanger 13. This embodiment describes a case where the high-side four-way valve 14 sends the high-side refrigerant discharged from the high-side compressor 10 to the side of the high-side heat exchanger 11. Accordingly, in the high-side refrigerant circuit 2, the high-side refrigerant discharged from the high-side compressor 10 flows through the high-side heat exchanger 11, the high-side expansion valve 12, and the cascade heat exchanger 13 to be sucked into the high-side compressor 10. In the high-side refrigerant circuit 2, the high-side compressor 10 is a configuration commonly used in the high-side first circulation path 17 and the high-side second circulation path 18.

[0039] The low-side refrigerant circuit 3 has the low-side first circulation path 23 and the low-side second circulation path 28. The low-side first circulation path 23 contains the low-side compressor 20, the cascade heat exchanger 13 connected to the high-side refrigerant circuit 2, the low-side expansion valve 21 as the low-side expansion mechanism, and the heat source-side heat exchanger 22 absorbing heat from the outside air sequentially connected by the refrigerant pipe 6, the low-side first circulation path 23 through which the low-side refrigerant circulates. The cascade heat exchanger 13 is a heat exchanger where the low-side refrigerant and the high-side refrigerant flowing through the high-side refrigerant circuit 2 exchange heat. The arrows in the low-side refrigerant circuit 3 indicate the flow of the low-side refrigerant.

[0040] The low-side refrigerant circuit 3 has the low-side bypass path 25 connecting the discharge side of the low-side compressor 20 and the suction side of the low-side compressor 20. The low-side bypass path 25 is provided with the low-side opening and closing valve 26. The low-side opening and closing valve 26 opens and closes the low-side bypass path 25. A flow path where the low-side refrigerant circulates from the discharge side of the low-side compressor 20 to the suction side of the low-side compressor 20 through the low-side bypass path 25 serves as the low-side second circulation path 28. When the low-side opening and closing valve 26 is closed, the low-side refrigerant circulates through the low-side first circulation path 23. When the low-side opening and closing valve 26 is opened, most of the low-side refrigerants circulate through the low-side second circulation path 28 smaller in flow resistance than the low-side first circulation path 23. The low-side opening and closing valve 26 serves as the low-side switching device switching the circulation of the low-side refrigerant discharged from the low-side compressor 20 between the circulation to the low-side first circulation path 23 and the circulation to the low-side second circulation path 28 in the present invention. This embodiment uses the low-side opening and closing valve 26, which is an opening and closing valve, as the low-side switching device. However, the other device may be used as the low-side switching device. For example, it may be acceptable that a three-way valve is provided at one end or the other end of the low-side bypass path 25 and the three-way valve switches the circulation of the low-side refrigerant discharged from the low-side compressor 20 between the circulation to the low-side first circulation path 23 and the circulation to the low-side second circulation path 28.

[0041] In the low-side refrigerant circuit 3, the low-side four-way valve 27 is connected to the discharge side of the low-side compressor 20, the low-side four-way valve 27 which switches the flow of the low-side refrigerant discharged from the low-side compressor 20 between the flow to the side of the cascade heat exchanger 13 and the flow to the heat source-side heat exchanger 22. This embodiment describes a case where the low-side four-way valve 27 sends the low-side refrigerant discharged from the low-side compressor 20 to the side of the cascade heat exchanger 13. Accordingly, in the low-side refrigerant circuit 3, the low-side refrigerant discharged from the low-side compressor 20 flows through the cascade heat exchanger 13, the low-side expansion valve 21, and the heat source-side heat exchanger 22 to be sucked into the low-side compressor 20. In the low-side refrigerant circuit 3, the low-side compressor 20 is a configuration commonly used in the low-side first circulation path 23 and the low-side second circulation path 28.

[0042] In this embodiment, the high-side refrigerant in the high-side refrigerant circuit 2 and the low-side refrigerant in the low-side refrigerant circuit 3 are the same refrigerant, but are not necessarily required to be the same, and a low-side refrigerant having a lower boiling point than that of a high-side refrigerant may be acceptable, for example.

[0043] Next, the control of the cascade refrigeration system 51 according to the third embodiment is described with reference to the control flow diagram illustrated in FIG. 6.

[0044] When the cascade refrigeration system 51 is activated, the controller 5 first activates the high-side compressor 10, and then opens the high-side opening and closing valve 16 (ST20). By opening the high-side opening and closing valve 16, most of the high-side refrigerants at high temperatures and high pressures discharged from the high-side compressor 10 circulate to the suction side of the high-side compressor 10 through the high-side bypass path 15 smaller in flow resistance than the high-side first circulation path 17. More specifically, the high-side refrigerant at a high temperature and a high pressure discharged from the high-side compressor 10 circulates through the high-side second circulation path 18. Next, the low-side compressor 20 is activated, and then the low-side opening and closing valve 26 is opened (ST21). By opening the low-side opening and closing valve 26, most of the low-side refrigerants at high temperatures and high pressures discharged from the low-side compressor 20 circulate to the suction side of the low-side compressor 20 through the low-side bypass path 25 smaller in flow resistance than the low-side first circulation path 23. More specifically, the low-side refrigerant at a high temperature and a high pressure discharged from the low-side compressor 20 circulates through the low-side second circulation path 28. Next, it is determined whether the temperature of the high-side compressor 10 exceeds 60°C which is the predetermined value (ST22). The temperature of the high-side compressor 10 is detected by a temperature sensor (not illustrated) provided in a pipe connected to the discharge side of the high-side compressor 10. The predetermined value is such a value that a desired heat exchange amount with the heating medium is obtained in the high-side heat exchanger 11, and, when the temperature is reached, the high-side refrigerant can be sufficiently condensed in the high-side heat exchanger 11. When the temperature of the high-side compressor 10 exceeds 60°C which is the predetermined value (Yes in ST22), the high-side opening and closing valve 16 is closed (ST23). When the temperature of the high-side compressor 10 does not exceed 60°C which is the predetermined value (No in ST22), the operation is continued. Next, it is determined whether the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of the air as the heating medium exchanging heat in the high-side heat exchanger 11 (ST24). The temperature of the heating medium is detected by a temperature sensor (not illustrated) provided at a position where the temperature of the heating medium flowing into the high-side heat exchanger 11 is detected. When the temperature of the high-side refrigerant discharged from the high-side compressor 10 of the high-side refrigerant circuit 2 is higher than the temperature of the air as the heating medium exchanging heat in the high-side heat exchanger 11 (Yes in ST24), the low-side opening and closing valve 26 is closed (ST25).

[0045] In the cascade refrigeration system 51 of this embodiment is characterized that the high-side compressor 10 is activated and the high-side opening and closing valve 16 is opened, and the low-side compressor 20 is activated and the low-side opening and closing valve 26 is opened, the high-side refrigerant at a high temperature and a high pressure discharged from the high-side compressor 10 circulates through the high-side second circulation path 18, and the low-side refrigerant at a high temperature and a high pressure discharged from the low-side compressor 20 circulates through the low-side second circulation path 28. More specifically, most of the high-side refrigerants at high temperatures and high pressures discharged from the high-side compressor 10 circulate to the suction side of the high-side compressor 10 through the high-side bypass path 15 smaller in flow resistance than the high-side first circulation path 17. Most of the low-side refrigerants at high temperatures and high pressures discharged from the low-side compressor 20 circulate to the suction side of the low-side compressor 20 through the low-side bypass path 25 smaller in flow resistance than the low-side first circulation path 23. This makes it possible to immediately raise the temperature of the high-side compressor 10 and suppress a stagnation operation when the outside air temperature is low. Further, a state where the refrigerant pressure of the high-side refrigerant is easily raised can be achieved. Therefore, the high-side refrigerant can exchange heat with the air which is the heating medium in the high-side heat exchanger 11, and thus can be condensed. This enables the high-side refrigerant to exchange heat with the low-side refrigerant in the cascade heat exchanger 13, which makes it possible to promptly start the activation of the low-side compressor 20. Further, a rise in the high-pressure side of the low-side refrigerant in the low-side refrigerant circuit 3 can be suppressed. Accordingly, even when the high-side refrigerant is unable to evaporate in the cascade heat exchanger 13 of the high-side refrigerant circuit 2, the operation of the low-side compressor 20 can be continued. Further, by immediately warming the low-side compressor 20, stagnation when the outside air is low can be suppressed.

[0046] The description above is given with reference to the limited number of embodiments, but the scope of the present invention is not limited to thereto, and modifications of the embodiment based on the disclosure above are obvious to those skilled in the art.

Reference Signs List

[0047]

1 cascade refrigeration system
2 high-side refrigerant circuit
3 low-side refrigerant circuit
5 controller
6 refrigerant pipe
10 high-side compressor
11 high-side heat exchanger
12 high-side expansion valve
13 cascade heat exchanger
14 high-side four-way valve
15 high-side bypass path
16 high-side opening and closing valve
17 high-side first circulation path
18 high-side second circulation path
20 low-side compressor
21 low-side expansion valve
22 heat source-side heat exchanger
23 low-side first circulation path
25 low-side bypass path
26 low-side opening and closing valve
27 low-side four-way valve
28 low-side second circulation path
50 cascade refrigeration system
51 cascade refrigeration system

Claims

1. A cascade refrigeration system comprising:

a high-side refrigerant circuit containing a high-side compressor, a high-side heat exchanger configured to exchange heat with a heating medium, a high-side expansion mechanism, and a cascade heat exchanger sequentially connected by a refrigerant pipe and having a high-side first circulation path through which a high-side refrigerant circulates;

a low-side refrigerant circuit containing a low-side compressor, the cascade heat exchanger, a low-side expansion mechanism, and a heat-side heat exchanger sequentially connected by a refrigerant pipe, the low-side refrigerant circuit through which a low-side refrigerant circulates; and

a controller configured to control the high-side refrigerant circuit and the low-side refrigerant circuit, wherein

the high-side refrigerant and the low-side refrigerant exchange heat in the cascade heat exchanger, and

the high-side refrigerant circuit includes: a high-side second circulation path in which a discharge side and a suction side of the high-side compressor are connected by a high-side bypass path and the high-side refrigerant discharged from the high-side compressor circulates to the suction side of the high-side compressor through the high-side bypass path; and a high-side switching device configured to switch a circulation path such that the high-side refrigerant discharged from the high-side compressor circulates through the high-side first circulation path or the high-side second circulation path.

2. The cascade refrigeration system according to claim 1, wherein

the controller is configured to, in activating the cascade refrigeration system, activate the high-side compressor and control the high-side switching device such that the high-side refrigerant circulates through the high-side second circulation path,
when a discharge medium temperature of the high-side refrigerant exceeds a predetermined value, to switch the high-side switching device to the high-side first circulation path to circulate the high-side refrigerant through the high-side first circulation path, and
when the discharge medium temperature of the high-side refrigerant exceeds a temperature of the heating medium, to activate the low-side compressor.

3. A cascade refrigeration system comprising:

a high-side refrigerant circuit containing a high-side compressor, a high-side heat exchanger configured to exchange heat with a heating medium, a high-side expansion mechanism, and a cascade heat exchanger sequentially connected by a refrigerant pipe, the high-side refrigerant circuit through which a high-side refrigerant circulates;
a low-side refrigerant circuit containing a low-side compressor, the cascade heat exchanger, a low-side expansion mechanism, and a heat source-side heat exchanger sequentially connected by a refrigerant pipe and having a low-side first circulation path through which a low-side refrigerant circulates; and
a controller configured to control the high-side refrigerant circuit and the low-side refrigerant circuit, wherein
the high-side refrigerant and the low-side refrigerant exchange heat in the cascade heat exchanger, and
the low-side refrigerant circuit includes: a low-side second circulation path in which a discharge side and a suction side of the low-side compressor are connected by a low-side bypass path and the low-side refrigerant discharged from the low-side compressor circulates to the suction side of the low-side compressor through the low-side bypass path; and a low-side switching device configured to switch a circulation path such that the low-side refrigerant discharged from the low-side compressor circulates through the low-side first circulation path or the low-side second circulation path.

4. The cascade refrigeration system according to claim 3, wherein the controller is configured to, in activating the cascade refrigeration system, activate the high-side compressor and the low-side compressor and control the low-side switching device such that the low-side refrigerant circulates through the low-side second circulation path.

5. The cascade refrigeration system according to claim 4, wherein the controller is configured to, when a discharge medium temperature of the high-side refrigerant exceeds a temperature of the heating medium, switch the low-side switching device to the low-side first circulation path to circulate the low-side refrigerant through the low-side first circulation path.

6. A cascade refrigeration system comprising:

a high-side refrigerant circuit containing a high-side compressor, a high-side heat exchanger configured to exchange heat with a heating medium, a high-side expansion mechanism, and a cascade heat exchanger sequentially connected by a refrigerant pipe and having a high-side first circulation path through which a high-side refrigerant circulates;
a low-side refrigerant circuit containing a low-side compressor, the cascade heat exchanger, a low-side expansion mechanism, and a heat source-side heat exchanger sequentially connected by a refrigerant pipe and having a low-side first circulation path through which a low-side refrigerant circulates; and
a controller configured to control the high-side refrigerant circuit and the low-side refrigerant circuit, wherein
the high-side refrigerant and the low-side refrigerant exchange heat in the cascade heat exchanger,
the high-side refrigerant circuit includes: a high-side second circulation path in which a discharge side and a suction side of the high-side compressor are connected by a high-side bypass path and the high-side refrigerant discharged from the high-side compressor circulates to the suction side of the high-side compressor through the high-side bypass path; and a high-side switching device configured to switch a circulation path such that the high-side refrigerant discharged from the high-side compressor circulates through the high-side first circulation path or the high-side second circulation path, and
the low-side refrigerant circuit includes: a low-side second circulation path in which a discharge side and a suction side of the low-side

compressor are connected by a low-side bypass path and the low-side refrigerant discharged from the low-side compressor circulates to the suction side of the low-side compressor through the low-side bypass path; and a low-side switching device configured to switch a circulation path such that the low-side refrigerant discharged from the low-side compressor circulates through the low-side first circulation path or the low-side second circulation path.

7. The cascade refrigeration system according to claim 6, wherein

the controller is configured to, in activating the cascade refrigeration system, activate the high-side compressor and the low-side compressor, to control the high-side switching device such that the high-side refrigerant circulates through the high-side second circulation path, and
to control the low-side switching device such that the low-side refrigerant circulates through the low-side second circulation path.

8. The cascade refrigeration system according to claim 7, wherein

the controller is configured to, when a discharge medium temperature of the high-side refrigerant exceeds a predetermined value, switch the high-side switching device to the high-side first circulation path to circulate the high-side refrigerant through the high-side first circulation path, and
when the discharge medium temperature of the high-side refrigerant exceeds a temperature of the heating medium, to switch the low-side switching device to the low-side first circulation path to circulate the low-side refrigerant through the low-side first circulation path.

FIG. 1

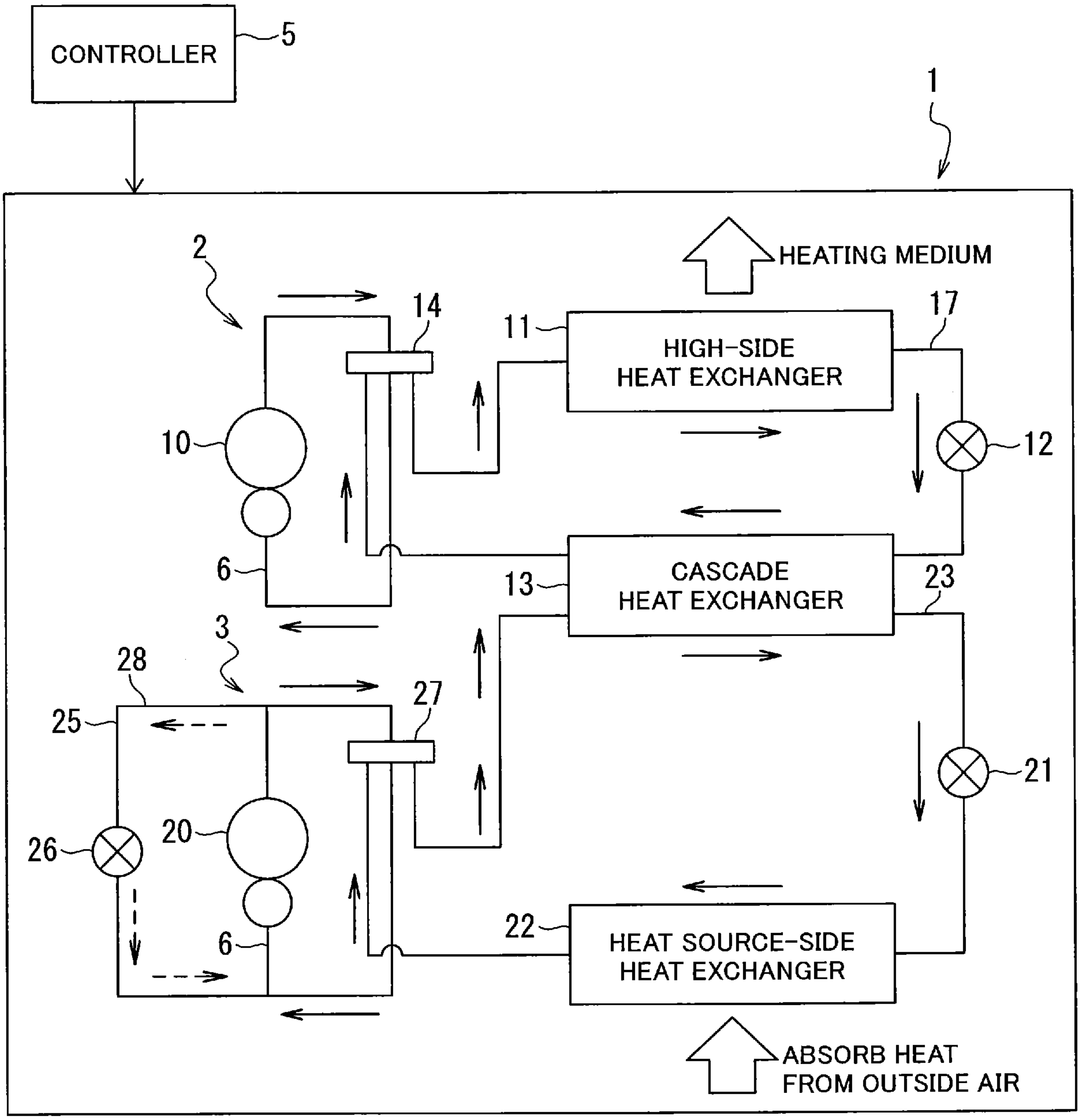

CONTROLLER
5
1
2
HEATING MEDIUM
14
11
HIGH-SIDE
HEAT EXCHANGER
17
10
12
6
13
CASCADE
HEAT EXCHANGER
23
3
28
27
25
20
21
26
22
HEAT SOURCE-SIDE
HEAT EXCHANGER
6
ABSORB HEAT
FROM OUTSIDE AIR

FIG. 2

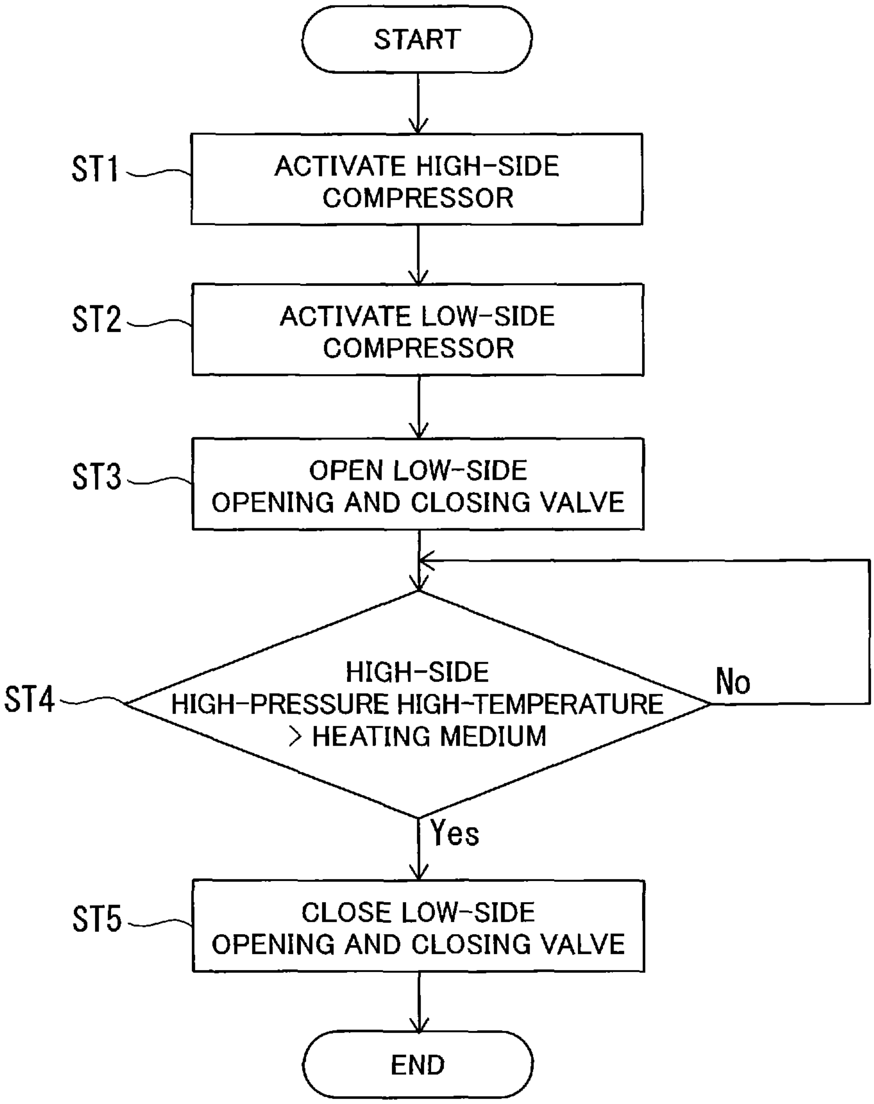

START
ST1
ACTIVATE HIGH-SIDE COMPRESSOR
ST2
ACTIVATE LOW-SIDE COMPRESSOR
ST3
OPEN LOW-SIDE OPENING AND CLOSING VALVE
ST4
HIGH-SIDE HIGH-PRESSURE HIGH-TEMPERATURE > HEATING MEDIUM
No
Yes
ST5
CLOSE LOW-SIDE OPENING AND CLOSING VALVE
END

FIG. 3

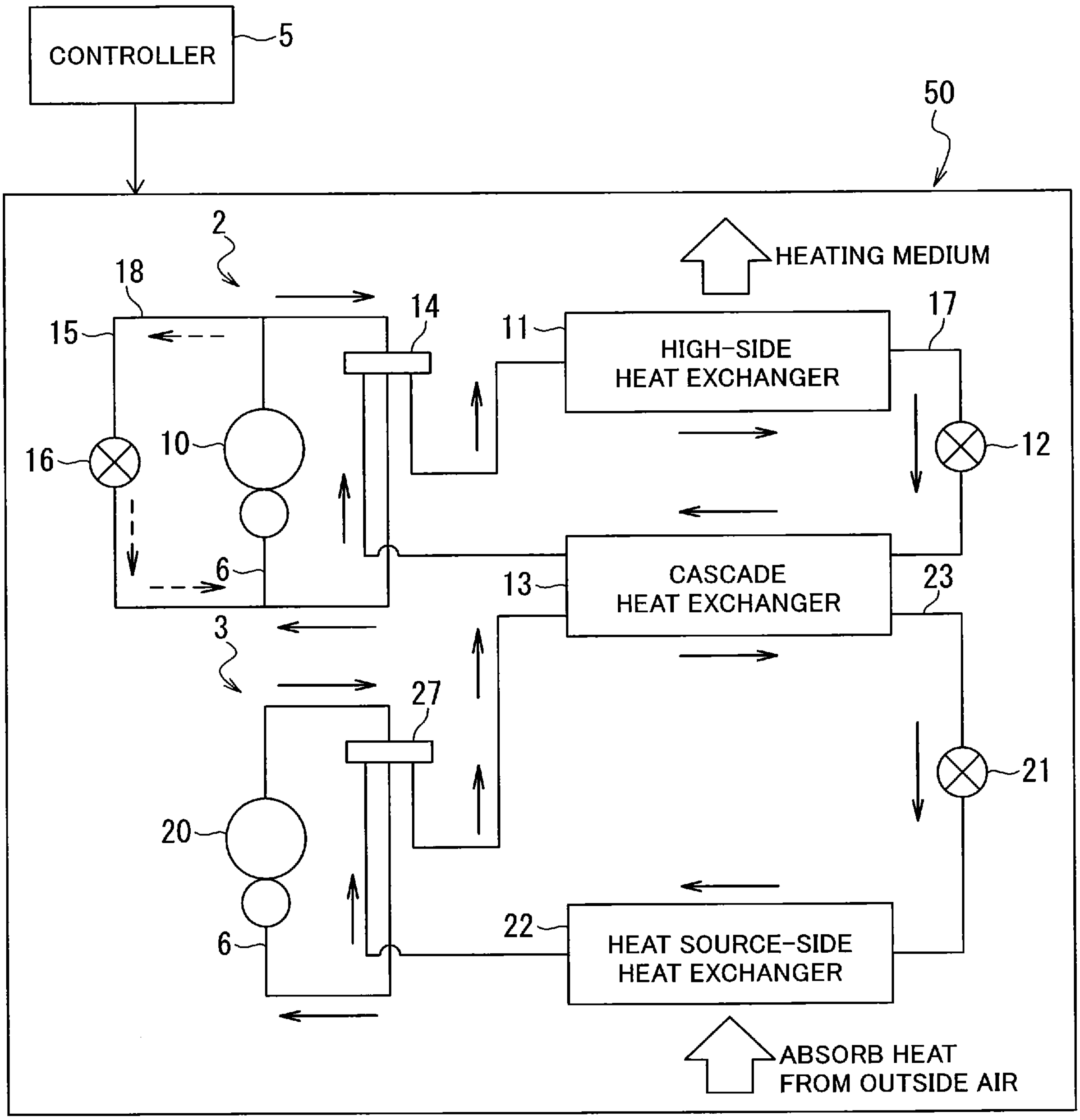

CONTROLLER
5
50
2
18
15
14
11
HEATING MEDIUM
HIGH-SIDE
HEAT EXCHANGER
17
16
10
12
6
CASCADE
HEAT EXCHANGER
13
23
3
27
21
20
22
6
HEAT SOURCE-SIDE
HEAT EXCHANGER
ABSORB HEAT
FROM OUTSIDE AIR

FIG. 4

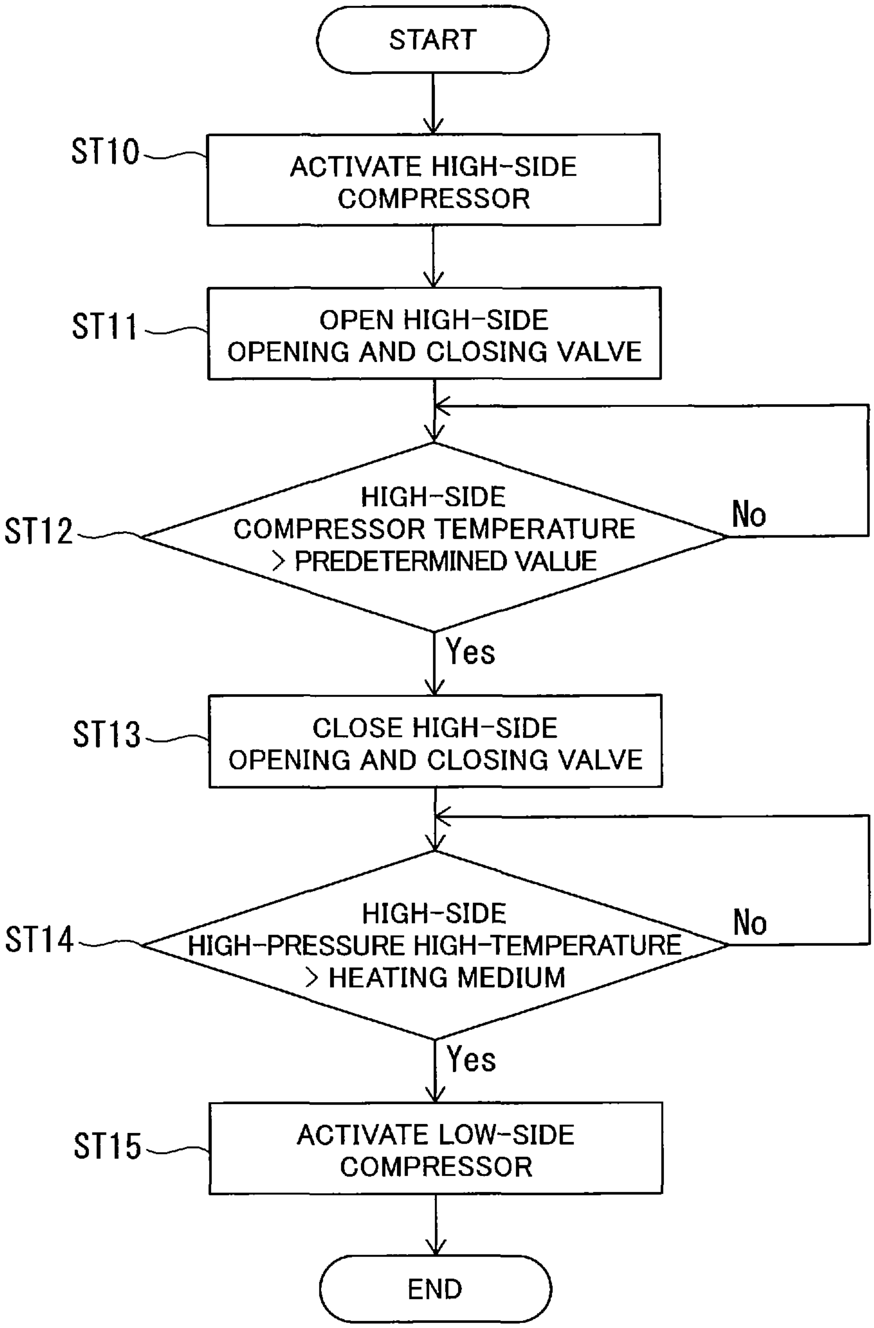

START
ST10
ACTIVATE HIGH-SIDE COMPRESSOR
ST11
OPEN HIGH-SIDE OPENING AND CLOSING VALVE
ST12
HIGH-SIDE COMPRESSOR TEMPERATURE > PREDETERMINED VALUE
No
Yes
ST13
CLOSE HIGH-SIDE OPENING AND CLOSING VALVE
ST14
HIGH-SIDE HIGH-PRESSURE HIGH-TEMPERATURE > HEATING MEDIUM
No
Yes
ST15
ACTIVATE LOW-SIDE COMPRESSOR
END

FIG. 5

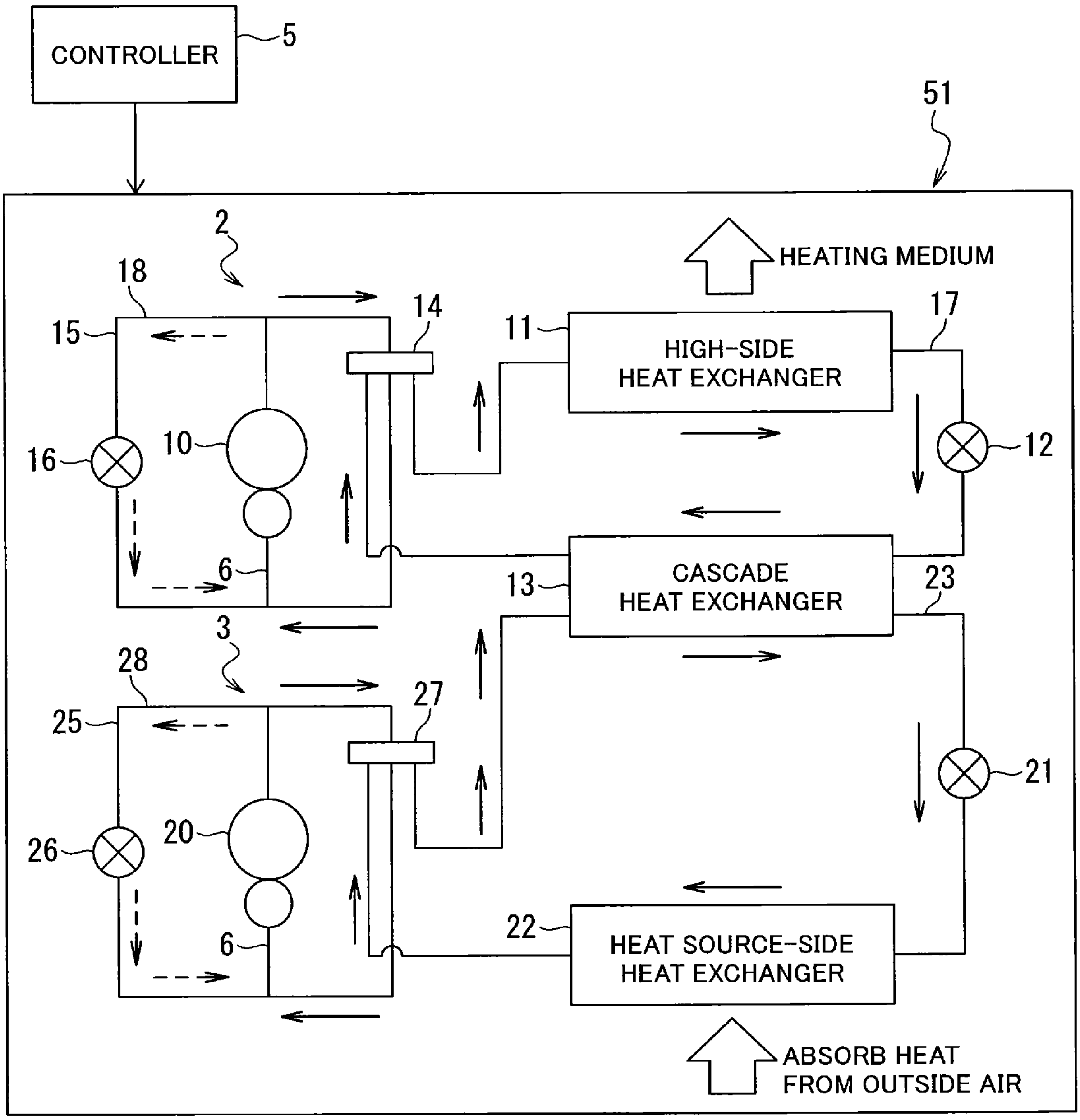
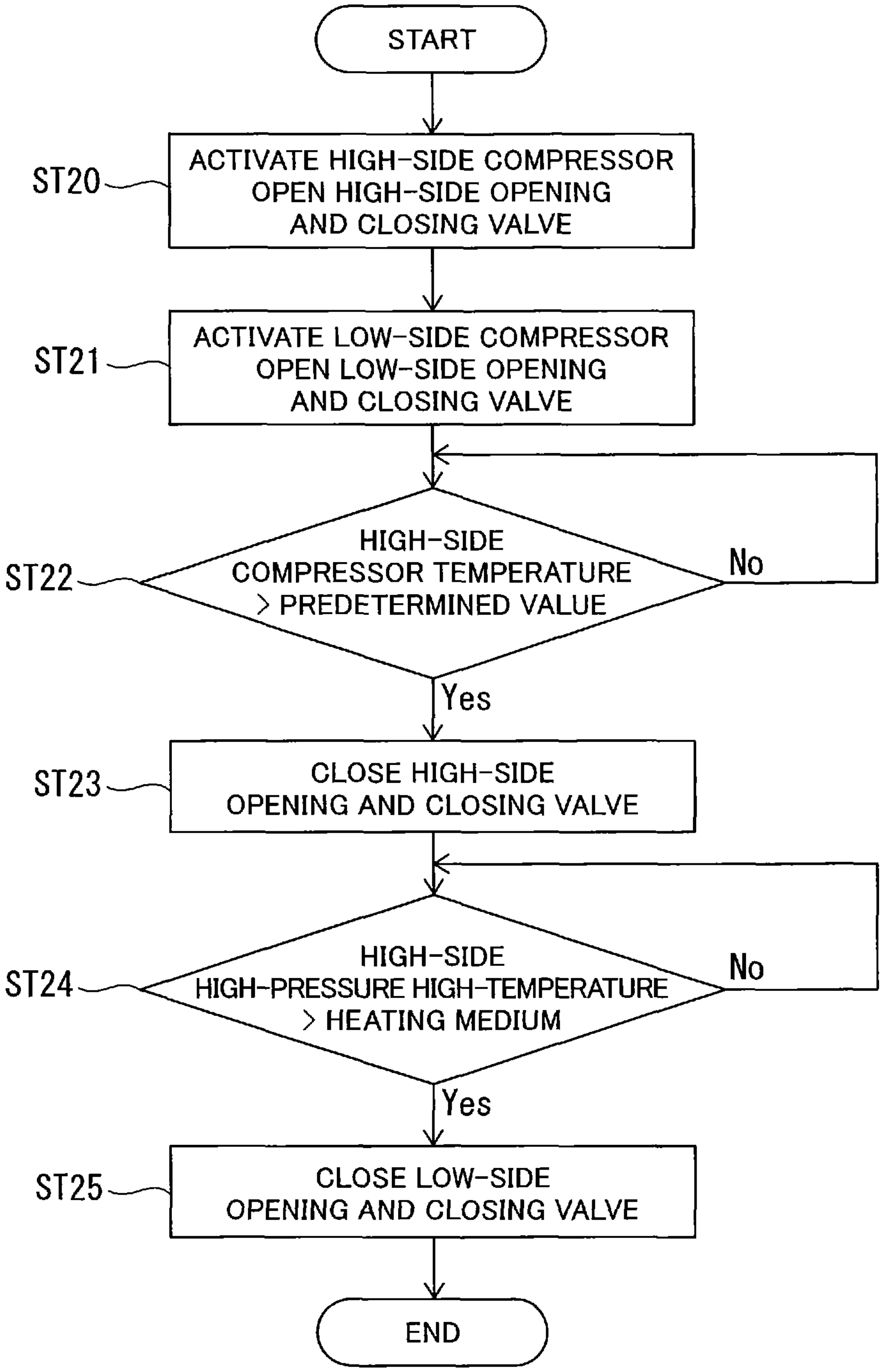

CONTROLLER
5
51
2
HEATING MEDIUM
18
14
11
17
15
HIGH-SIDE
HEAT EXCHANGER
16
10
12
6
CASCADE
HEAT EXCHANGER
13
23
3
28
27
25
21
20
26
6
22
HEAT SOURCE-SIDE
HEAT EXCHANGER
ABSORB HEAT
FROM OUTSIDE AIR

FIG. 6


START
ST20
ACTIVATE HIGH-SIDE COMPRESSOR
OPEN HIGH-SIDE OPENING
AND CLOSING VALVE
ST21
ACTIVATE LOW-SIDE COMPRESSOR
OPEN LOW-SIDE OPENING
AND CLOSING VALVE
ST22
HIGH-SIDE
COMPRESSOR TEMPERATURE
> PREDETERMINED VALUE
No
Yes
ST23
CLOSE HIGH-SIDE
OPENING AND CLOSING VALVE
ST24
HIGH-SIDE
HIGH-PRESSURE HIGH-TEMPERATURE
> HEATING MEDIUM
No
Yes
ST25
CLOSE LOW-SIDE
OPENING AND CLOSING VALVE
END

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2023/009142**

A. CLASSIFICATION OF SUBJECT MATTER

F25B 7/00(2006.01)i; ***F25B 1/00***(2006.01)i
FI: F25B7/00 E; F25B1/00 101Z; F25B1/00 101J; F25B1/00 351N

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

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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.
X A	WO 2014/112615 A1 (TOSHIBA CARRIER CORPORATION) 24 July 2014 (2014-07-24) paragraphs [0009]-[0013], [0016], [0022], [0031], [0039]-[0043], fig. 1, 3	1, 3-4, 6-7 2, 5, 8
X	JP 7-243711 A (DAIKIN IND LTD) 19 September 1995 (1995-09-19) paragraphs [0017]-[0021], [0025]-[0026], fig. 1	1, 3, 6
X A	JP 2004-177046 A (SANYO ELECTRIC CO LTD) 24 June 2004 (2004-06-24) paragraphs [0002], [0012], [0017]-[0020], fig. 1	1 2
X	WO 2016/147305 A1 (MITSUBISHI ELECTRIC CORPORATION) 22 September 2016 (2016-09-22) paragraphs [0009]-[0017], [0021]-[0023], [0032], [0041]-[0042], fig. 1	3

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

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 May 2023	**23 May 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/009142

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2014/112615 A1	24 July 2014	KR 10-2015-0096746 A CN 104937352 A	
JP 7-243711 A	19 September 1995	(Family: none)	
JP 2004-177046 A	24 June 2004	US 2004/0118145 A1 paragraphs [0002], [0052], [0057]-[0060], fig. 2	
WO 2016/147305 A1	22 September 2016	GB 2548309 A paragraphs [0009]-[0017], [0021]-[0023], [0032], [0041]-[0042], fig. 1	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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