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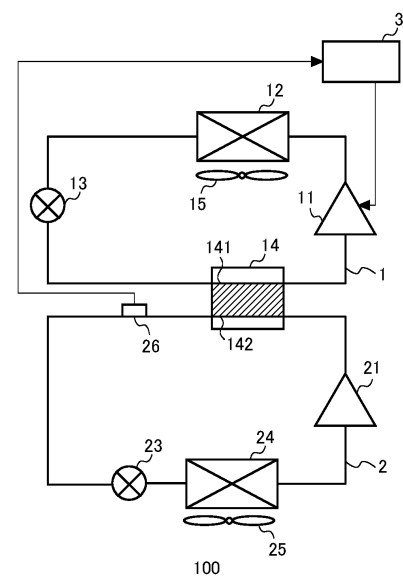
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(54) **REFRIGERATION CIRCUIT DEVICE AND CONTROL METHOD FOR REFRIGERATION CIRCUIT DEVICE**

(57) A refrigeration cycle apparatus includes: a high-stage circuit through which a high-stage refrigerant circulates, the high-stage circuit including a first compressor, a condenser, a first expansion device, and a cascade heat exchanger; and a low-stage circuit through which a low-stage refrigerant circulates, the low-stage circuit including a second compressor, the cascade heat exchanger, a second expansion device, and an evaporator, wherein the cascade heat exchanger is configured to exchange heat between the high-stage refrigerant and the low-stage refrigerant, the low-stage refrigerant is a zeotropic refrigerant mixture, and pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor is maintained to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable.

FIG. 1



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Description

Technical Field

[0001] The present disclosure relates to a refrigeration cycle apparatus provided with a two-stage refrigeration cycle, and also relates to a method for controlling the refrigeration cycle apparatus.

Background Art

[0002] As a conventional refrigeration cycle apparatus provided with a two-stage refrigeration cycle, a refrigeration apparatus including a low-stage circuit through which a low-stage refrigerant circulates, a high-stage circuit through which a high-stage refrigerant circulates, and a cascade condenser configured to exchange heat between the low-stage refrigerant and the high-stage refrigerant has been known (for example, Patent Literature 1).

Citation List

Patent Literature

[0003] Patent Literature 1: International Publication No. WO 2014030236

Summary of Invention

Technical Problem

[0004] In the refrigeration cycle apparatus disclosed in Patent Literature 1, a zeotropic refrigerant mixture is used as a low-stage refrigerant that circulates in the low-stage circuit. In this case, during a stop of operation of the low-stage circuit, refrigerant having a low-boiling-point contained in the zeotropic refrigerant mixture is gasified and remains in the low-stage circuit in its entirety, which may vary the composition of liquid refrigerant. Particularly, in a case where the low-stage circuit includes a welding portion of pipes, if the gasified refrigerant leaks from the welding portion, the leakage leads to significant variations in the composition of the liquid refrigerant. When refrigerant having a high-boiling-point contained in the zeotropic refrigerant mixture is flammable, the variations in the composition of the refrigerant lead to an increase in flammability of the liquid refrigerant, and accordingly an increase in the risk due to the flammability at the time of refrigerant leakage.

[0005] The present disclosure has been made to solve the above problems, and it is an object of the present disclosure to provide a refrigeration cycle apparatus and a method for controlling the refrigeration cycle apparatus that can reduce variations in composition of refrigerant after stopping operation of a low-stage circuit.

Solution to Problem

[0006] A refrigeration cycle apparatus according to one embodiment of the present disclosure includes: a high-stage circuit through which a high-stage refrigerant circulates, the high-stage circuit including a first compressor, a condenser, a first expansion device, and a cascade heat exchanger; and a low-stage circuit through which a low-stage refrigerant circulates, the low-stage circuit including a second compressor, the cascade heat exchanger, a second expansion device, and an evaporator, wherein the cascade heat exchanger is configured to exchange heat between the high-stage refrigerant and the low-stage refrigerant, the low-stage refrigerant is a zeotropic refrigerant mixture, and pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor is maintained to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable.

[0007] A method for controlling a refrigeration cycle apparatus according to another embodiment of the present disclosure is a method for controlling a refrigeration cycle apparatus, the refrigeration cycle apparatus including a high-stage circuit through which a high-stage refrigerant circulates and a low-stage circuit through which a low-stage refrigerant circulates, the high-stage circuit including a first compressor, a condenser, a first expansion device, and a cascade heat exchanger, the low-stage circuit including a second compressor, the cascade heat exchanger, a second expansion device, and an evaporator, the cascade heat exchanger being configured to exchange heat between the high-stage refrigerant and the low-stage refrigerant, the low-stage refrigerant being a zeotropic refrigerant mixture, the method including maintaining pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable.

Advantageous Effects of Invention

[0008] According to the embodiments of the present disclosure, the pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor is maintained to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable, so that it is possible to reduce variations in composition of the refrigerant after stopping operation of the low-stage circuit.

Brief Description of Drawings

[0009]

[Fig. 1] Fig. 1 is a schematic configuration diagram of a refrigeration cycle apparatus according to Embodiment 1.

[Fig. 2] Fig. 2 is a graph illustrating a relationship

between flammability and a pressure P of a low-stage refrigerant.

[Fig. 3] Fig. 3 is a flowchart illustrating operation of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 4] Fig. 4 is a flowchart illustrating operation of the refrigeration cycle apparatus according to Embodiment 2.

[Fig. 5] Fig. 5 is a schematic configuration diagram of a refrigeration cycle apparatus according to Modification 1.

[Fig. 6] Fig. 6 is a schematic configuration diagram of a refrigeration cycle apparatus according to Modification 2.

Description of Embodiments

[0010] Hereinafter, embodiments will be described based on the drawings. Note that in the drawings below, the same reference signs denote the same or equivalent components. In addition, the relationship of sizes of the components in the drawings described below may differ from that of actual ones. Furthermore, the level of temperature, pressure, and other factors in the descriptions below is not particularly determined in relation to an absolute value, but is determined relative to the conditions, operation, or other factors of the system, device, or the like.

Embodiment 1

[0011] A refrigeration cycle apparatus 100 according to Embodiment 1 is described below. The refrigeration cycle apparatus 100 is provided with a two-stage refrigeration cycle in which refrigerant circulates independently in each refrigerant cycle. The refrigeration cycle apparatus 100 is used for various purposes such as freezing, refrigeration, hot-water supply, or air-conditioning. In the present embodiment, an example is described in which the refrigeration cycle apparatus 100 is used as a refrigeration apparatus configured to cool a freezer compartment or the like.

[0012] Fig. 1 is a schematic configuration diagram of the refrigeration cycle apparatus 100 according to Embodiment 1. As illustrated in Fig. 1, the refrigeration cycle apparatus 100 in the present embodiment includes a high-stage circuit 1, a low-stage circuit 2, and a controller 3. The high-stage circuit 1 is a high-temperature circuit through which a high-stage refrigerant circulates. The low-stage circuit 2 is a low-temperature circuit through which a low-stage refrigerant circulates. The low-stage refrigerant has a boiling point lower than that of the high-stage refrigerant. The high-stage circuit 1 and the low-stage circuit 2 include a cascade heat exchanger 14 that is shared between them. Through the cascade heat exchanger 14, the high-stage refrigerant circulating in the high-stage circuit 1 exchanges heat with the low-stage refrigerant circulating in the low-stage circuit 2.

[0013] The high-stage circuit 1 includes a first compressor 11, a condenser 12, a first expansion device 13, and the cascade heat exchanger 14. The first compressor 11, the condenser 12, the first expansion device 13, and the cascade heat exchanger 14 are connected in this order by pipes. Examples of the high-stage refrigerant circulating in the high-stage circuit 1 include an HFC-based single refrigerant such as R134a, R32, or R410A, a refrigerant mixture thereof, an HFO-based single refrigerant such as HFO-1234yf, and a refrigerant mixture thereof.

[0014] The first compressor 11 is, for example, an inverter-type compressor whose capacity is controllable. The first compressor 11 suctions a high-stage refrigerant, compresses the suctioned high-stage refrigerant into a high-temperature high-pressure state, and discharges the compressed high-stage refrigerant to be circulated in the high-stage circuit 1.

[0015] The condenser 12 is, for example, a fin-and-tube heat exchanger. The condenser 12 is configured to exchange heat between air and a high-stage refrigerant, and condense and liquefy the high-stage refrigerant. The refrigeration cycle apparatus 100 includes a first fan 15 for supplying air to the condenser 12. Examples of the first fan 15 include a propeller fan and a cross flow fan whose airflow volume is controllable. Note that the condenser 12 may be, for example, a plate heat exchanger configured to exchange heat between water or brine and the high-stage refrigerant. In this case, the first fan 15 may be omitted.

[0016] The first expansion device 13 is, for example, an electronic expansion valve whose opening degree is controllable. The first expansion device 13 is connected to the condenser 12 to reduce a pressure of the high-stage refrigerant flowing out from the condenser 12 and expand the high-stage refrigerant. Note that the first expansion device 13 may be a capillary tube or a thermostatic expansion valve.

[0017] The cascade heat exchanger 14 is, for example, a plate heat exchanger. The cascade heat exchanger 14 includes a high-stage flow passage 141 connected to the high-stage circuit 1, and a low-stage flow passage 142 connected to the low-stage circuit 2. The cascade heat exchanger 14 is configured to exchange heat between the high-stage refrigerant flowing through the high-stage flow passage 141 and the low-stage refrigerant flowing through the low-stage flow passage 142. The high-stage flow passage 141 in the cascade heat exchanger 14 serves as an evaporator to evaporate and gasify the high-stage refrigerant. The low-stage flow passage 142 in the cascade heat exchanger 14 serves as a condenser to condense and liquefy the low-stage refrigerant.

[0018] The low-stage circuit 2 includes a second compressor 21, the cascade heat exchanger 14, a second expansion device 23, and an evaporator 24. The second compressor 21, the cascade heat exchanger 14, the second expansion device 23, and the evaporator 24 are connected in this order by pipes. The low-stage refrigerant

circulating in the low-stage circuit 2 is a zeotropic refrigerant mixture having a boiling point lower than that of the high-stage refrigerant. A lower evaporating temperature can be obtained by using the zeotropic refrigerant mixture, compared to the evaporating temperature obtained by using a single refrigerant. In the present embodiment, a zeotropic refrigerant mixture containing CO₂ and R290 (propane) is used as the low-stage refrigerant. CO₂ is refrigerant having a low-boiling-point, while R290 is refrigerant having a high-boiling-point whose boiling point is higher than that of CO₂. It is possible to decrease an environmental load by using natural refrigerants such as CO₂ and R290. Mixing CO₂ into the low-stage refrigerant leads to an improvement in the cooling capacity, while mixing R290 into the low-stage refrigerant leads to an improvement in COP and to a decrease in triple point of CO₂, which allows applications in low temperature.

[0019] The second compressor 21 is, for example, an inverter-type compressor whose capacity is controllable. The second compressor 21 suctions the low-stage refrigerant, compresses the suctioned low-stage refrigerant into a high-temperature high-pressure state, and discharges the compressed low-stage refrigerant to be circulated in the low-stage circuit 2.

[0020] The second expansion device 23 is, for example, an electronic expansion valve whose opening degree is controllable. The second expansion device 23 is connected to the low-stage flow passage 142 in the cascade heat exchanger 14 to reduce the pressure of the low-stage refrigerant flowing out from the low-stage flow passage 142 and expand the low-stage refrigerant. Note that the second expansion device 23 may be a capillary tube or a thermostatic expansion valve.

[0021] The evaporator 24 is, for example, a fin-and-tube heat exchanger. The evaporator 24 is configured to exchange heat between air and the low-stage refrigerant, and evaporate and gasify the low-stage refrigerant. The refrigeration cycle apparatus 100 includes a second fan 25 configured to supply air to the evaporator 24. Examples of the second fan 25 include a propeller fan and a cross flow fan whose airflow volume is controllable. Note that the evaporator 24 may be, for example, a plate heat exchanger configured to exchange heat between water or brine and the low-stage refrigerant. In this case, the second fan 25 may be omitted.

[0022] The refrigeration cycle apparatus 100 includes a pressure sensor 26 configured to detect a pressure P of the low-stage refrigerant in the low-stage circuit 2 during a stop of operation of the low-stage circuit 2. Since the pressure P of the low-stage refrigerant during a stop of operation of the low-stage circuit 2 is substantially uniform in the low-stage circuit 2, the pressure sensor 26 is provided at any location in the low-stage circuit 2. In the example illustrated in Fig. 1, the pressure sensor 26 is provided on a pipe connecting the low-stage flow passage 142 in the cascade heat exchanger 14 and the second expansion device 23. The pressure P of the low-stage refrigerant detected by the pressure sensor 26 is

transmitted to the controller 3.

[0023] Note that in place of the pressure sensor 26, the refrigeration cycle apparatus 100 may include a sensor configured to detect any other physical quantity (for example, condensing temperature) that is convertible to the pressure P of the low-stage refrigerant, such that the controller 3 converts the detected physical quantity to the pressure P. The refrigeration cycle apparatus 100 may further include various types of sensors (not illustrated) such as an outside-air temperature sensor configured to detect an outside-air temperature, a room temperature sensor configured to detect a temperature in the freezer compartment, or a sensor configured to detect a refrigerant temperature or pressure at any location in the high-stage circuit 1 and the low-stage circuit 2.

[0024] The controller 3 controls operation of the refrigeration cycle apparatus 100 in its entirety. The controller 3 is constituted by a processing device including a memory configured to store data and programs necessary for controlling the operation, and a CPU configured to execute the programs, or is constituted by dedicated hardware such as ASIC or FPGA or by both the processing device and the dedicated hardware. The controller 3 in the present embodiment controls the high-stage circuit 1 based on the pressure P of the low-stage refrigerant detected by the pressure sensor 26 when operation of the low-stage circuit 2 is stopped. The controller 3 controls the respective devices in the high-stage circuit 1 and the low-stage circuit 2 as well as the first fan 15 and the second fan 25 based on the information received from the various types of sensors and an operating instruction given by a user.

[0025] Operation of the refrigeration cycle apparatus 100 in the present embodiment is described below based on a flow of refrigerant circulating in each refrigerant circuit. First, operation of the high-stage circuit 1 is described. The first compressor 11 and the second compressor 21 are driven upon receiving an instruction to start operation of the refrigeration cycle apparatus 100. The first compressor 11 in the high-stage circuit 1 suctions the high-stage refrigerant, compresses the suctioned high-stage refrigerant into a high-temperature high-pressure state, and discharges the compressed high-stage refrigerant. The high-stage refrigerant discharged from the first compressor 11 flows into the condenser 12. The condenser 12 is configured to exchange heat between air supplied by the first fan 15 and the high-stage refrigerant, and condenses and liquefies the high-stage refrigerant.

[0026] The high-stage refrigerant condensed and liquefied through the condenser 12 passes through the first expansion device 13. The first expansion device 13 reduces the pressure of the condensed and liquefied high-stage refrigerant. The high-stage refrigerant with its pressure reduced by the first expansion device 13 flows into the high-stage flow passage 141 in the cascade heat exchanger 14. The high-stage refrigerant flowing into the high-stage flow passage 141 exchanges heat with the

low-stage refrigerant flowing through the low-stage flow passage 142 in the cascade heat exchanger 14, and is thus evaporated and gasified. The high-stage refrigerant evaporated and gasified through the cascade heat exchanger 14 is suctioned into the first compressor 11 again.

[0027] Next, operation of the low-stage circuit 2 is described. The second compressor 21 in the low-stage circuit 2 suctions the low-stage refrigerant, compresses the suctioned low-stage refrigerant into a high-temperature high-pressure state, and discharges the compressed low-stage refrigerant. The low-stage refrigerant discharged from the second compressor 21 flows into the low-stage flow passage 142 in the cascade heat exchanger 14. The low-stage refrigerant flowing into the low-stage flow passage 142 exchanges heat with the high-stage refrigerant flowing through the high-stage flow passage 141 in the cascade heat exchanger 14, and is thus condensed and liquefied.

[0028] The low-stage refrigerant condensed and liquefied through the cascade heat exchanger 14 passes through the second expansion device 23. The second expansion device 23 reduces the pressure of the low-stage refrigerant. The low-stage refrigerant with its pressure reduced by the second expansion device 23 flows into the evaporator 24. The evaporator 24 is configured to exchange heat between air supplied by the second fan 25 and the low-stage refrigerant, and evaporates and gasifies the low-stage refrigerant. At this time, the low-stage refrigerant removes heat from the air, so that the freezer compartment is cooled. The low-stage refrigerant evaporated and gasified through the evaporator 24 is suctioned into the second compressor 21 again.

[0029] Upon receiving an instruction to stop operation of the refrigeration cycle apparatus 100, the first compressor 11 and the second compressor 21 is deactivated, and refrigerant stops circulating in the high-stage circuit 1 and the low-stage circuit 2. At this time, the refrigerant having a low-boiling-point contained in the low-stage refrigerant in the low-stage circuit 2 in its entirety is gasified, which varies the composition of liquid refrigerant in the low-stage circuit 2. For example, as described in the present embodiment, when a zeotropic refrigerant mixture of CO₂ and R290 is used as the low-stage refrigerant, CO₂ having a lower boiling point than R290 is gasified, and consequently the ratio of R290 that is a flammable refrigerant increases in the liquid refrigerant.

[0030] The evaporator 24 in the low-stage circuit 2 is located in a room such as a freezer compartment and connected to the second compressor 21 by an extension pipe. Due to this structure, on the suction side of the second compressor 21, a welding portion connected to the extension pipe is provided. If the CO₂ gas leaks from the welding portion when the operation of the low-stage circuit 2 is stopped, the ratio of R290 that is a flammable refrigerant further increases in the liquid refrigerant in the low-stage circuit 2. This results in an increase in the flammability of the low-stage refrigerant in the low-stage circuit 2, and accordingly an increase in the risk due to the flammability at the time of refrigerant leakage.

cuit 2, and accordingly an increase in the risk due to the flammability at the time of refrigerant leakage.

[0031] In view of that, the controller 3 in the present embodiment continues operation of the high-stage circuit 1 even after stopping the operation of the low-stage circuit 2, and controls the capacity of the high-stage circuit 1 to cause the pressure P of the low-stage refrigerant to be equal to or lower than a pressure value at or below which the low-stage refrigerant is non-flammable. Fig. 2 is a graph illustrating the relationship between flammability and the pressure P of the low-stage refrigerant. Fig. 2 is a graph when the low-stage refrigerant is a zeotropic refrigerant mixture in which refrigerant having a higher-boiling-point is flammable as described in the present embodiment. As illustrated in Fig. 2, as the pressure P of the low-stage refrigerant increases, the flammability of the low-stage refrigerant increases. In view of that, the pressure P of the low-stage refrigerant needs to be equal to or lower than a threshold P_T to maintain the low-stage refrigerant to be non-flammable. The threshold P_T is uniquely determined by physical properties of refrigerants that constitute the low-stage refrigerant. In the present embodiment, the threshold P_T is set in advance appropriate to the low-stage refrigerant and stored in the controller 3. The controller 3 controls the capacity of the high-stage circuit 1 such that the pressure P of the low-stage refrigerant detected by the pressure sensor 26 is equal to or lower than the threshold P_T.

[0032] Fig. 3 is a flowchart illustrating operation of the refrigeration cycle apparatus 100 according to Embodiment 1. When receiving an instruction from a user or other information to start operation of the refrigeration cycle apparatus 100, the controller 3 drives the first compressor 11 and the second compressor 21 (S1). This causes the high-stage refrigerant to circulate in the high-stage circuit 1, and causes the low-stage refrigerant to circulate in the low-stage circuit 2, so that the freezer compartment is cooled.

[0033] The controller 3 determines whether to stop operation of the refrigeration cycle apparatus 100 based on an instruction from a user or other information (S2). When the controller 3 does not stop operation of the refrigeration cycle apparatus 100 (S2: NO), the controller 3 continues operation of the high-stage circuit 1 and the low-stage circuit 2 until receiving an instruction to stop operation of the refrigeration cycle apparatus 100.

[0034] In contrast, when the controller 3 stops operation of the refrigeration cycle apparatus 100 (S2: YES), the controller 3 deactivates the second compressor 21 (S3). This causes the low-stage refrigerant to stop circulating in the low-stage circuit 2. Note that at this time, operation of the first compressor 11 is continued.

[0035] The pressure sensor 26 detects the pressure P of the low-stage refrigerant (S4). The controller 3 determines whether the pressure P of the low-stage refrigerant detected by the pressure sensor 26 is equal to or lower than the threshold P_T (S5). When the pressure P of the low-stage refrigerant is equal to or lower than the thresh-

old P_T (S5: YES), the controller 3 shifts to step S7, while maintaining the capacity of the high-stage circuit 1. In contrast, when the pressure P of the low-stage refrigerant is higher than the threshold P_T (S5: NO), the controller 3 increases the capacity of the high-stage circuit 1 (S6). The controller 3 may increase the operating frequency of the first compressor 11 by a predetermined constant value, or may increase it by a value corresponding to a difference between the pressure P of the low-stage refrigerant and the threshold P_T .

[0036] As the capacity of the high-stage circuit 1 is increased, the temperature of the high-stage refrigerant flowing through the high-stage flow passage 141 in the cascade heat exchanger 14 is decreased. With this decrease, the temperature of the low-stage refrigerant that exchanges heat with the high-stage refrigerant through the cascade heat exchanger 14 is decreased, and accordingly the pressure P of the low-stage refrigerant is decreased. As the pressure P of the low-stage refrigerant is decreased, the density of the gas in the low-stage circuit 2 is decreased, and accordingly the mass of the gas refrigerant in the low-stage circuit 2 is reduced. That is, as the pressure P of the low-stage refrigerant is decreased, a gas amount of the refrigerant (CO_2) having the low-boiling-point in the low-stage circuit 2 in its entirety after stopping operation of the low-stage circuit 2 is reduced. This can minimize variations in the composition of the liquid refrigerant in the low-stage circuit 2.

[0037] The controller 3 determines whether to start operation of the refrigeration cycle apparatus 100 based on an instruction from a user or other information (S7). When the controller 3 does not start operation of the refrigeration cycle apparatus 100 (S7: NO), the controller 3 returns to step S4 to repeat the subsequent processes. When the controller 3 starts operation of the refrigeration cycle apparatus 100 (S7: YES), the controller 3 shifts to step S1 to drive the second compressor 21 to cause the low-stage refrigerant to circulate in the low-stage circuit 2.

[0038] As described above, in the refrigeration cycle apparatus 100 in the present embodiment, operation of the high-stage circuit 1 is continued even after stopping operation of the low-stage circuit 2, and the high-stage circuit 1 is controlled such that the pressure P of the low-stage refrigerant is equal to or lower than the threshold P_T at or below which the low-stage refrigerant is non-flammable. This can reduce variations in the composition of the low-stage refrigerant in the low-stage circuit 2 after stopping operation of the low-stage circuit 2. As a result of this, even when a zeotropic refrigerant mixture containing a flammable refrigerant is used as the low-stage refrigerant, it is still possible to suppress the increase in risk due to the flammability at the time of refrigerant leakage. When a refrigerant mixture containing CO_2 is used as the low-stage refrigerant as described in the present embodiment, the freezing point of CO_2 can be decreased. This makes it possible to achieve cooling even at the freezing point (-56 degrees C) or lower.

Embodiment 2

[0039] The refrigeration cycle apparatus 100 according to Embodiment 2 is described below. Fig. 4 is a flow-chart illustrating operation of the refrigeration cycle apparatus 100 according to Embodiment 2. In the present embodiment, the refrigeration cycle apparatus 100 operates differently from the operation in Embodiment 1. The configuration of the refrigeration cycle apparatus 100 is the same as that in Embodiment 1.

[0040] As illustrated in Fig. 4, when receiving an instruction from a user or other information to start operation of the refrigeration cycle apparatus 100, the controller 3 drives the first compressor 11 and the second compressor 21 (S11). This causes the high-stage refrigerant to circulate in the high-stage circuit 1, and causes the low-stage refrigerant to circulate in the low-stage circuit 2.

[0041] The controller 3 determines whether to stop operation of the refrigeration cycle apparatus 100 based on an instruction or the like from a user (S12). When the controller 3 does not stop operation of the refrigeration cycle apparatus 100 (S12: NO), the controller 3 continues operation of the high-stage circuit 1 and the low-stage circuit 2 until receiving an instruction to stop operation of the refrigeration cycle apparatus 100.

[0042] In contrast, when the controller 3 stops operation of the refrigeration cycle apparatus 100 (S12: YES), the controller 3 performs pump-down operation of the low-stage circuit 2 (S13). Specifically, the controller 3 fully closes the second expansion device 23, while continuing operation of the second compressor 21. Since the second expansion device 23 is closed, the low-stage refrigerant in the low-stage circuit 2 is collected on a high-pressure side of the low-stage circuit 2. The high-pressure side of the low-stage circuit 2 is between a discharge port of the second compressor 21 and a refrigerant inlet of the second expansion device 23. This generates a negative pressure (equal to or lower than the atmospheric pressure) on a low-pressure side of the low-stage circuit 2. The low-pressure side of the low-stage circuit 2 is between a refrigerant outlet of the second expansion device 23 and a suction port of the second compressor 21.

[0043] Thereafter, the controller 3 deactivates the second compressor 21 (S14). This causes the low-stage refrigerant to stop circulating in the low-stage circuit 2. Note that a solenoid valve may be provided between the low-stage flow passage 142 in the cascade heat exchanger 14 and the second expansion device 23 to perform the pump-down operation by closing the solenoid valve. A pressure sensor configured to detect a low pressure of the low-stage refrigerant may be provided on the low-pressure side of the low-stage circuit 2, that is, between the refrigerant outlet of the second expansion device 23 and the suction port of the second compressor 21. When the low pressure of the low-stage refrigerant is equal to or lower than the atmospheric pressure, the controller 3 may deactivate the second compressor 21. This can prevent a fault or other problems caused by continuously

driving the second compressor 21 even after there is no refrigerant left on the low-pressure side of the low-stage circuit 2.

[0044] The subsequent processes in steps S15 to S18 are the same as those in steps S4 to S7 in Embodiment 1. The high-stage circuit 1 is controlled such that the pressure P of the low-stage refrigerant is equal to or lower than the threshold P_T . However, in the present embodiment, the pressure sensor 26 is configured to detect the pressure P of the low-stage refrigerant collected on the high-pressure side of the low-stage circuit 2. That is, the pressure sensor 26 is provided between the discharge port of the second compressor 21 and the refrigerant inlet of the second expansion device 23.

[0045] The refrigeration cycle apparatus 100 in the present embodiment performs pump-down operation after stopping operation of the low-stage circuit 2, and can thereby generate a negative pressure on the low-pressure side of the low-stage circuit 2. This can prevent gas refrigerant from leaking from the welding portion provided on the low-pressure side of the low-stage circuit 2. As a result, it is possible to further reduce variations in the composition of the liquid refrigerant in the low-stage circuit 2 during a stop of operation of the refrigeration cycle apparatus 100.

[0046] While the embodiments have been described above, the present disclosure is not limited to the embodiments described above, and can be variously modified or combined without departing from the scope of the present disclosure. For example, the low-stage refrigerant is not limited to the zeotropic refrigerant mixture of CO_2 and R290, but may be other zeotropic refrigerant mixtures. However, when the low-stage refrigerant is the zeotropic refrigerant mixture containing CO_2 and a flammable refrigerant, the effects achieved by the above embodiments can be particularly obtained.

[0047] In the above embodiments, the refrigeration cycle apparatus 100 has the configuration in which the controller 3 controls the refrigeration cycle apparatus 100 in its entirety. However, the controller 3 may be provided in each of the high-stage circuit 1 and the low-stage circuit 2, such that the controllers 3 individually control operation of the high-stage circuit 1 and operation of the low-stage circuit 2.

[0048] In the above embodiments, the refrigeration cycle apparatus 100 has the configuration in which the controller 3 controls the operating frequency of the first compressor 11 to thereby control the capacity of the high-stage circuit 1. However, the refrigeration cycle apparatus 100 is not limited to having this configuration. For example, instead of, or in addition to, the operating frequency of the first compressor 11, the controller 3 may control the opening degree of the first expansion device 13 in the high-stage circuit 1 or the rotation speed of the first fan 15 to thereby control the capacity of the high-stage circuit 1. In this case, when the pressure P of the low-stage refrigerant is higher than the threshold P_T , the controller 3 increases the opening degree of the first ex-

pansion device 13 or the rotation speed of the first fan 15 to thereby increase the capacity of the high-stage circuit 1.

[0049] The low-stage circuit 2 in the refrigeration cycle apparatus 100 may include a receiver 22. Fig. 5 is a schematic configuration diagram of a refrigeration cycle apparatus 100A according to Modification 1. As illustrated in Fig. 5, the low-stage circuit 2 in the refrigeration cycle apparatus 100A includes the receiver 22 between the cascade heat exchanger 14 and the second expansion device 23. The receiver 22 is configured to temporarily accumulate therein the low-stage refrigerant flowing out from the low-stage flow passage 142 in the cascade heat exchanger 14. Surplus refrigerant generated due to variations in cooling load is accumulated in the receiver 22.

[0050] Even when the refrigeration cycle apparatus 100A includes the receiver 22, operation of the high-stage circuit 1 is continued after stopping operation of the low-stage circuit 2, and the high-stage circuit 1 is controlled such that the pressure P of the low-stage refrigerant is equal to or lower than the threshold P_T at or below which the low-stage refrigerant is non-flammable. When the refrigeration cycle apparatus 100A includes the receiver 22, the high-stage circuit 1 may be controlled such that a high pressure of the low-stage refrigerant is equal to or lower than the threshold P_T at or below which the low-stage refrigerant is non-flammable, even during operation of the low-stage circuit 2.

[0051] In the above embodiments, the refrigeration cycle apparatus 100 has the configuration in which the controller 3 controls the high-stage circuit 1 based on the pressure P of the low-stage refrigerant detected by the pressure sensor 26 after stopping operation of the low-stage circuit 2. However, the refrigeration cycle apparatus 100 is not limited to having this configuration. For example, the controller 3 may control the high-stage circuit 1 based on the temperature of a low-stage refrigerant associated with the pressure P of the low-stage refrigerant. Alternatively, the low-stage circuit 2 may be provided with a pressure relief device configured to be opened when the pressure or temperature increases to a reference value, and the pressure relief device may be used to maintain the pressure P of the low-stage refrigerant in the low-stage circuit 2 to be equal to or lower than a pressure value at or below which the low-stage refrigerant is non-flammable.

[0052] Fig. 6 is a schematic configuration diagram of a refrigeration cycle apparatus 100B according to Modification 2. As illustrated in Fig. 6, the refrigeration cycle apparatus 100B includes a pressure relief device 27. The pressure relief device 27 is provided at any location in the low-stage circuit 2. Note that in a case where the pump-down operation is performed as described in Embodiment 2, the pressure relief device 27 is provided on the high-pressure side of the low-stage circuit 2. The pressure relief device 27 is a pressure relief valve or a fusible plug. When the pressure P or temperature of the low-stage refrigerant is equal to or higher than the thresh-

old P_T , the valve or the plug is opened, so that gas refrigerant is discharged to the outside, and consequently the pressure P of the low-stage refrigerant decreases. The threshold P_T refers to a pressure value or a temperature at or below which the low-stage refrigerant is non-flammable, similarly to the above embodiments. This helps maintain the pressure P of the low-stage refrigerant to be equal to or lower than the pressure value at or below which the low-stage refrigerant is non-flammable even after stopping operation of the low-stage circuit 2. Note that in the present modification, after stopping operation of the low-stage circuit 2, operation of the high-stage circuit 1 may be stopped. Alternatively, even after stopping operation of the low-stage circuit 2, the high-stage circuit 1 may still be continuously operated, and a pressure control using the pressure relief device 27 may be executed in combination with a control of the high-stage circuit 1 based on the pressure P of the low-stage refrigerant.

Reference Signs List

[0053] 1: high-stage circuit, 2: low-stage circuit, 3: controller, 11: first compressor, 12: condenser, 13: first expansion device, 14: cascade heat exchanger, 15: first fan, 21: second compressor, 22: receiver, 23: second expansion device, 24: evaporator, 25: second fan, 26: pressure sensor, 27: pressure relief device, 100, 100A, 100B: refrigeration cycle apparatus, 141: high-stage flow passage, 142: low-stage flow passage

Claims

1. A refrigeration cycle apparatus comprising:

a high-stage circuit through which a high-stage refrigerant circulates, the high-stage circuit including a first compressor, a condenser, a first expansion device, and a cascade heat exchanger; and

a low-stage circuit through which a low-stage refrigerant circulates, the low-stage circuit including a second compressor, the cascade heat exchanger, a second expansion device, and an evaporator, wherein

the cascade heat exchanger is configured to exchange heat between the high-stage refrigerant and the low-stage refrigerant,

the low-stage refrigerant is a zeotropic refrigerant mixture, and

pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor is maintained to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable.

2. The refrigeration cycle apparatus of claim 1, further comprising a controller, wherein

the controller is configured to control the high-stage circuit such that pressure of the low-stage refrigerant in the low-stage circuit after deactivating the second compressor is equal to or lower than a threshold, and the threshold is a pressure at or below which the low-stage refrigerant is non-flammable.

3. The refrigeration cycle apparatus of claim 2, wherein the controller increases a capacity of the high-stage circuit when the pressure of the low-stage refrigerant is higher than the threshold.

4. The refrigeration cycle apparatus of claim 2 or 3, wherein the controller increases an operating frequency of the first compressor when the pressure of the low-stage refrigerant is higher than the threshold.

5. The refrigeration cycle apparatus of any one of claims 2 to 4, wherein the controller performs pump-down operation of the low-stage circuit before deactivating the second compressor.

6. The refrigeration cycle apparatus of claim 1, wherein

the low-stage circuit includes a pressure relief device configured to be opened when the pressure of the low-stage refrigerant in the low-stage circuit is equal to or higher than a threshold, and the threshold is a pressure at or below which the low-stage refrigerant is non-flammable.

7. The refrigeration cycle apparatus of any one of claims 1 to 6, wherein the low-stage refrigerant is a zeotropic refrigerant mixture containing CO_2 and a flammable refrigerant.

8. A method for controlling a refrigeration cycle apparatus,

the refrigeration cycle apparatus comprising a high-stage circuit through which a high-stage refrigerant circulates and a low-stage circuit through which a low-stage refrigerant circulates, the high-stage circuit including a first compressor, a condenser, a first expansion device, and a cascade heat exchanger, the low-stage circuit including a second compressor, the cascade heat exchanger, a second expansion device, and an evaporator, the cascade heat exchanger being configured to exchange heat between the high-stage refrigerant and the low-stage refrigerant, the low-stage refrigerant being a zeotropic refrigerant mixture, the method comprising maintaining pressure of the low-stage refrigerant in the low-stage circuit after deactivating the

second compressor to be equal to or lower than a pressure at or below which the low-stage refrigerant is non-flammable.

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FIG. 1

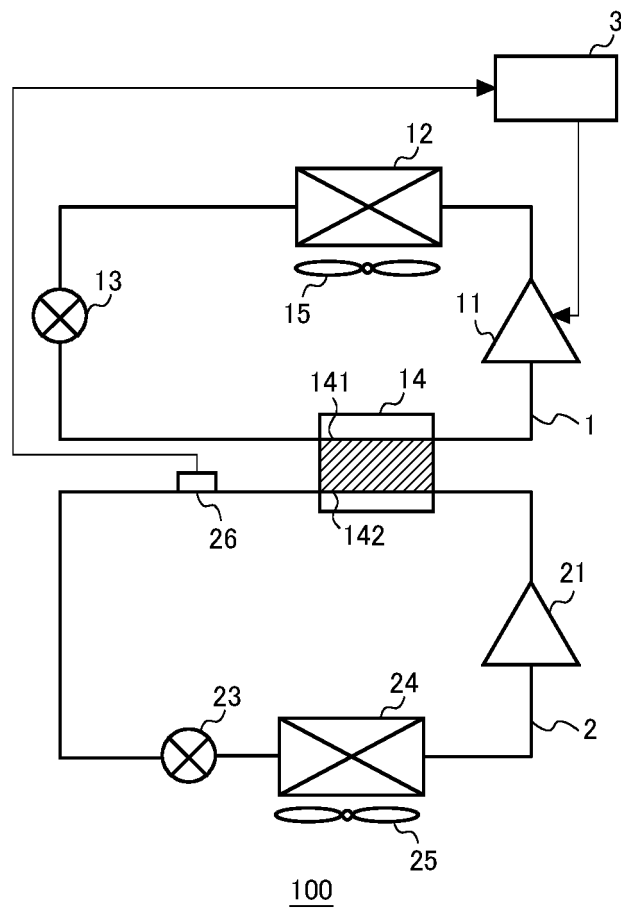


FIG. 2

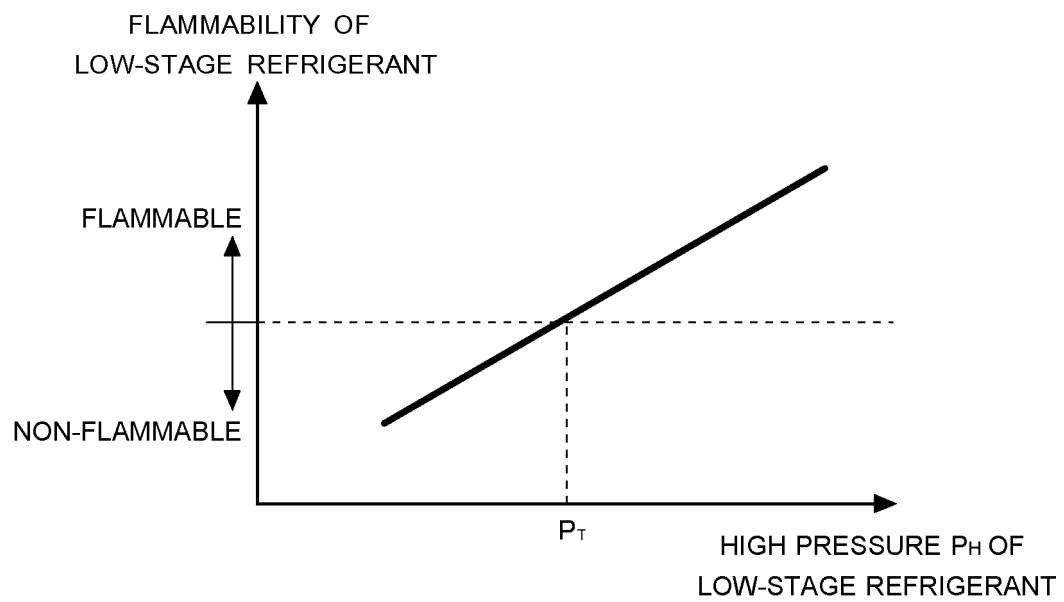


FIG. 3

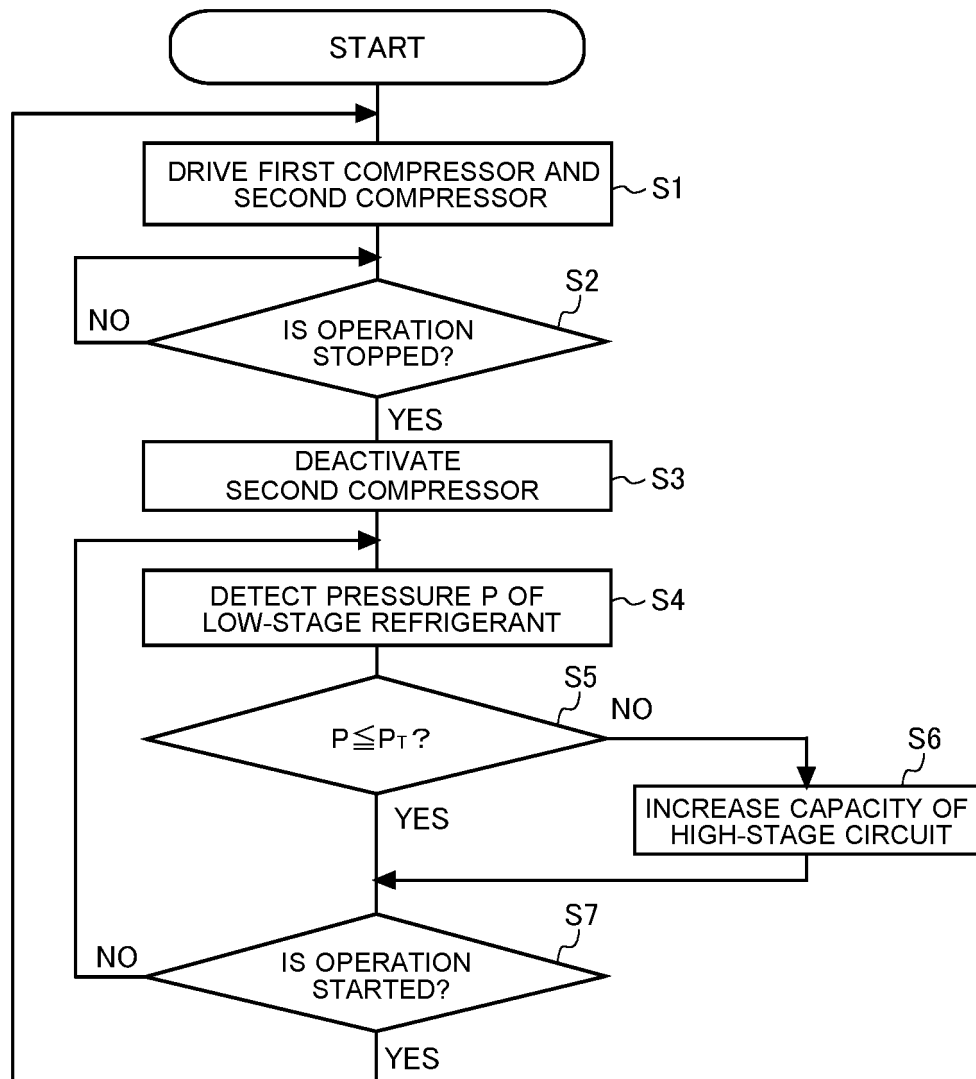


FIG. 4

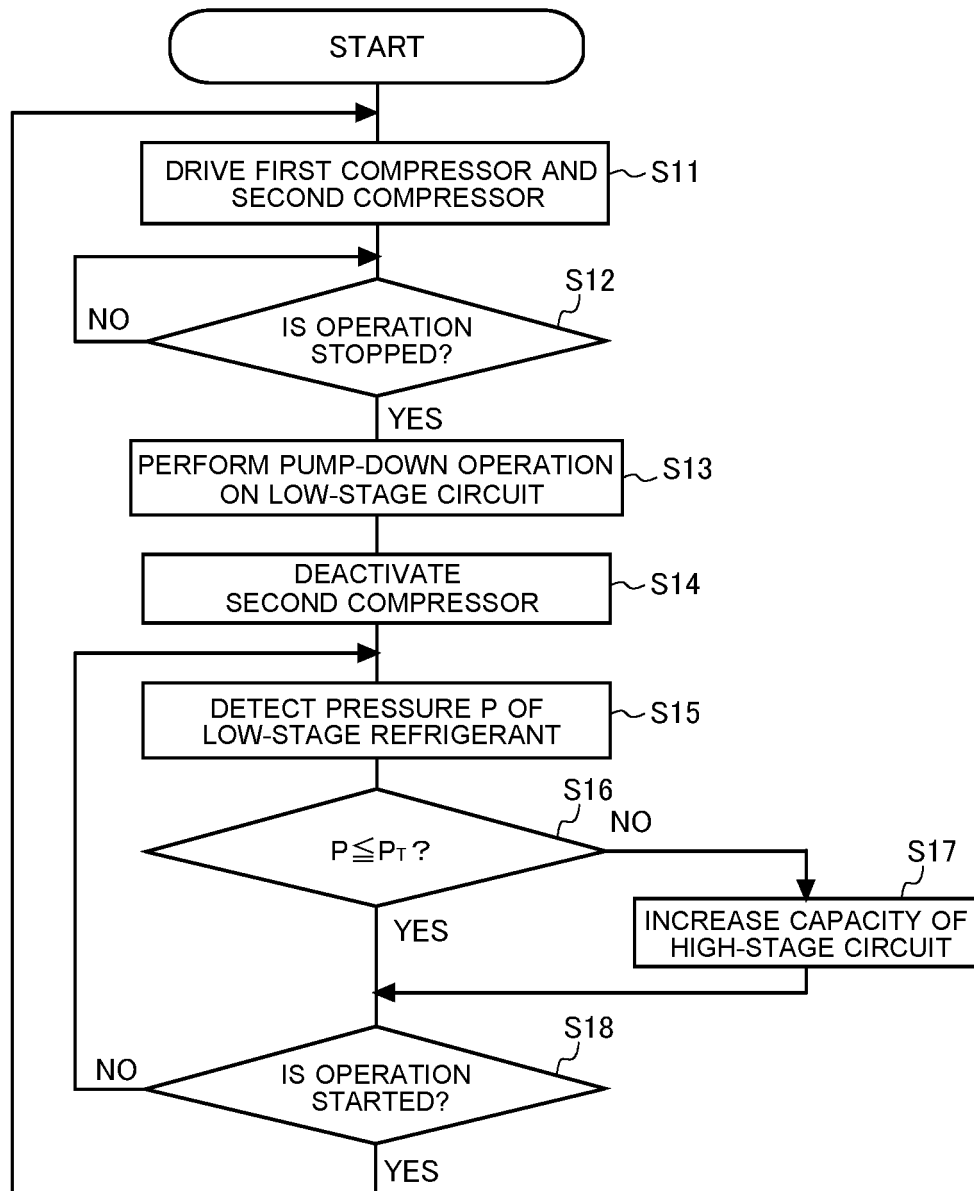


FIG. 5

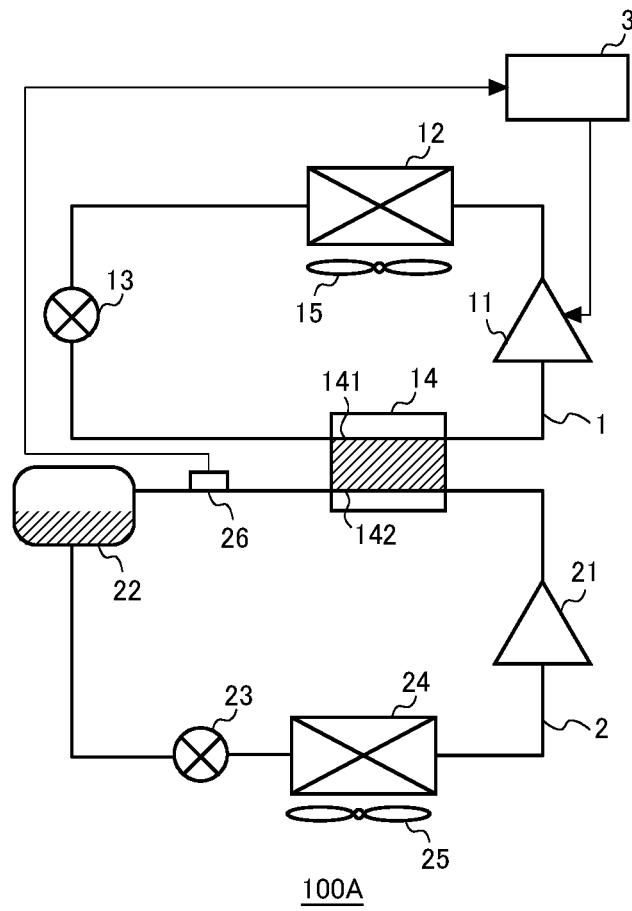
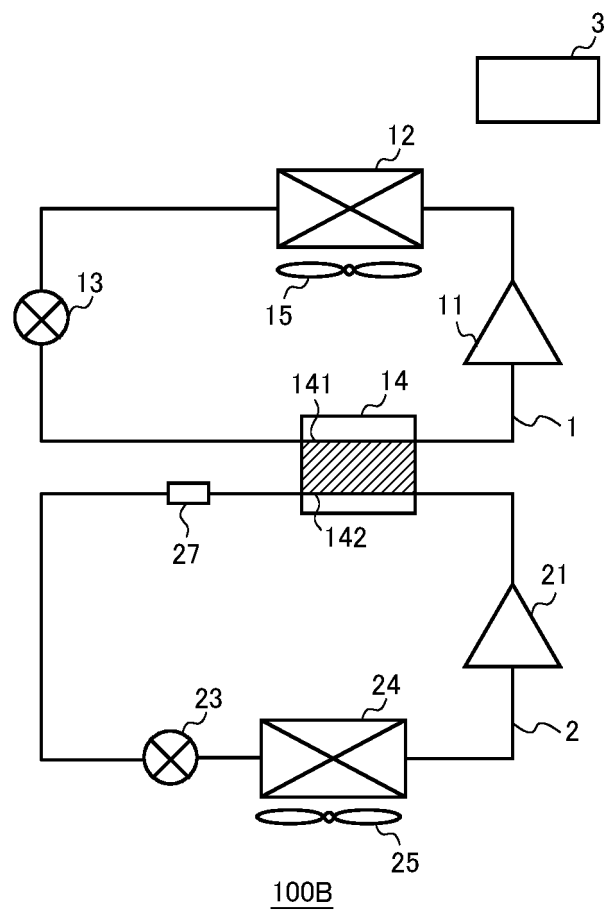


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/029053

A. CLASSIFICATION OF SUBJECT MATTER F25B 1/00 (2006.01)i; F25B 7/00 (2006.01)i FI: F25B7/00 E; F25B7/00 A; F25B1/00 396B; F25B1/00 396D; F25B1/00 396E 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 Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2021 Registered utility model specifications of Japan 1996-2021 Published registered utility model applications of Japan 1994-2021 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																								
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>WO 2015/140873 A1 (MITSUBISHI ELECTRIC CORP.) 24 September 2015 (2015-09-24) paragraphs [0013]-[0047], fig. 1-5</td> <td>1-4, 6, 8</td> </tr> <tr> <td>Y</td> <td>paragraphs [0013]-[0047], fig. 1-5</td> <td>5, 7</td> </tr> <tr> <td>Y</td> <td>JP 2013-083407 A (MITSUBISHI ELECTRIC CORP.) 09 May 2013 (2013-05-09) paragraphs [0011], [0047], [0050], fig. 1</td> <td>5</td> </tr> <tr> <td>Y</td> <td>WO 2015/045354 A1 (PANASONIC HEALTHCARE CO., LTD.) 02 April 2015 (2015-04-02) paragraph [0038], fig. 1, 3</td> <td>7</td> </tr> <tr> <td>Y</td> <td>JP 2008-215672 A (MAC CORP.) 18 September 2008 (2008-09-18) paragraph [0013], fig. 1</td> <td>7</td> </tr> <tr> <td>A</td> <td>WO 2018/198203 A1 (MITSUBISHI ELECTRIC CORP.) 01 November 2018 (2018-11-01) entire text, all drawings</td> <td>1-8</td> </tr> <tr> <td>A</td> <td>WO 2014/045400 A1 (MITSUBISHI ELECTRIC CORP.) 27 March 2014 (2014-03-27) entire text, all drawings</td> <td>1-8</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	WO 2015/140873 A1 (MITSUBISHI ELECTRIC CORP.) 24 September 2015 (2015-09-24) paragraphs [0013]-[0047], fig. 1-5	1-4, 6, 8	Y	paragraphs [0013]-[0047], fig. 1-5	5, 7	Y	JP 2013-083407 A (MITSUBISHI ELECTRIC CORP.) 09 May 2013 (2013-05-09) paragraphs [0011], [0047], [0050], fig. 1	5	Y	WO 2015/045354 A1 (PANASONIC HEALTHCARE CO., LTD.) 02 April 2015 (2015-04-02) paragraph [0038], fig. 1, 3	7	Y	JP 2008-215672 A (MAC CORP.) 18 September 2008 (2008-09-18) paragraph [0013], fig. 1	7	A	WO 2018/198203 A1 (MITSUBISHI ELECTRIC CORP.) 01 November 2018 (2018-11-01) entire text, all drawings	1-8	A	WO 2014/045400 A1 (MITSUBISHI ELECTRIC CORP.) 27 March 2014 (2014-03-27) entire text, all drawings	1-8
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/029053

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Information on patent family members

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