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(54) **AIR CONDITIONER**

(57) The air conditioner includes: a refrigerant circuit (70) provided with a compressor (1), a condenser (5), an expansion valve (4), and an evaporator (3), and configured to circulate refrigerant; a suction temperature sensor (21) configured to detect a suction temperature of the refrigerant sucked into the compressor (1); and an outside air temperature sensor (11) configured to detect an outside air temperature. The refrigerant includes at least one of R290 and R1270. During a heating operation, when the difference between the suction temperature and the outside air temperature is smaller than (-2.0°C), the opening degree of the expansion valve (4) is decreased; and when the difference between the suction temperature and the outside air temperature is greater than (+0.6°C), the opening degree of the expansion valve (4) is increased.

FIG.8

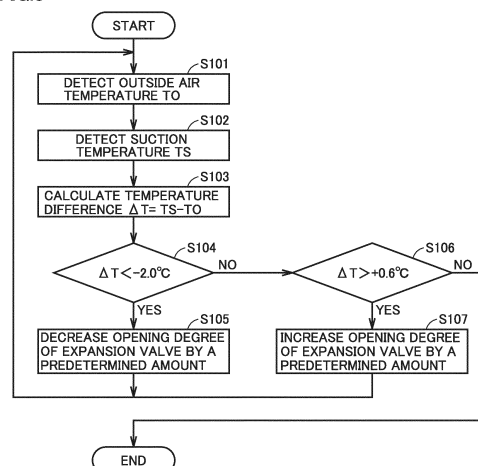
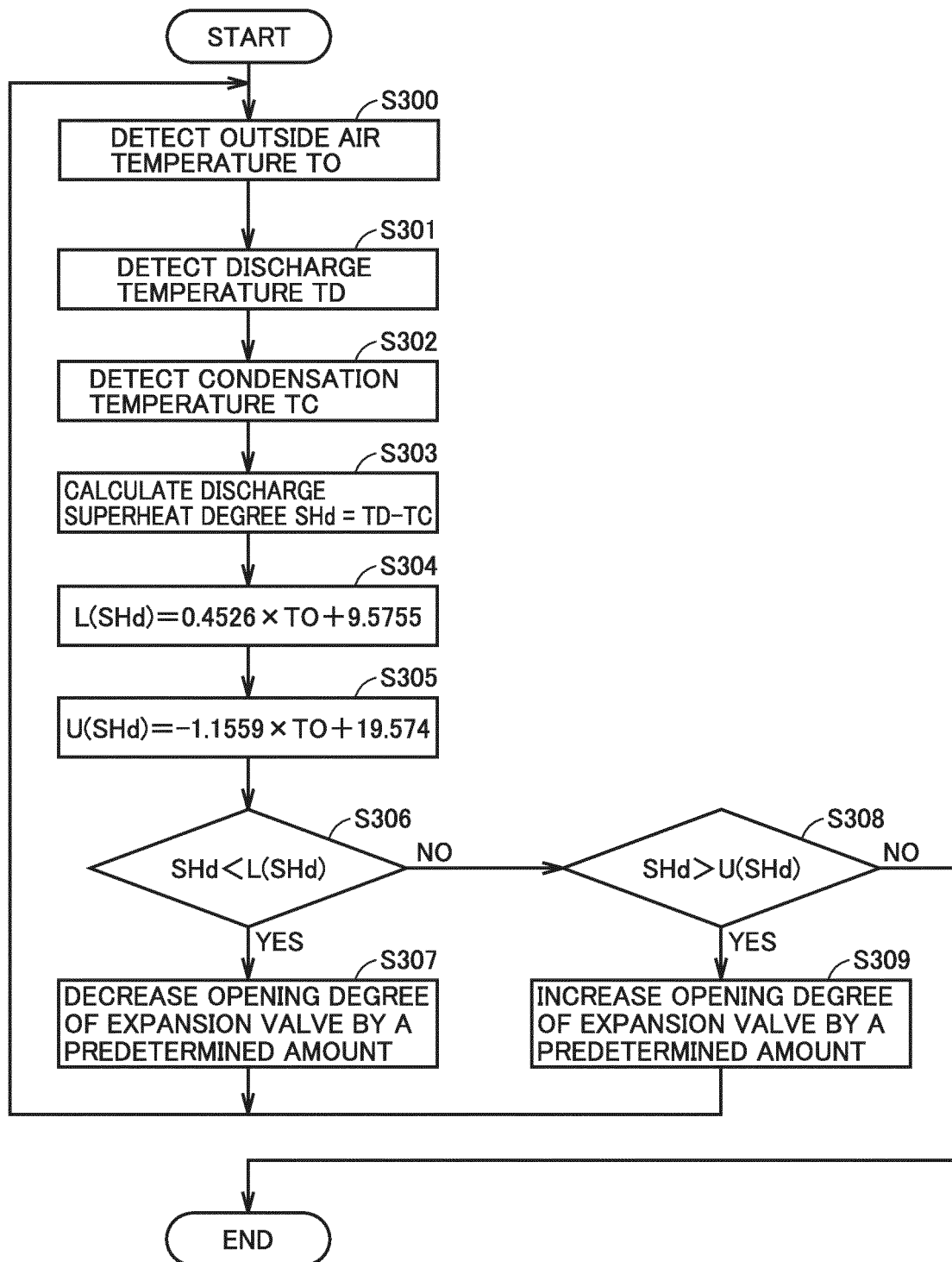


FIG.12



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to an air conditioner.

BACKGROUND ART

10 **[0002]** HC refrigerant is known as a refrigerant with a low global warming potential. PTL 1 (Japanese Patent Laying-Open No. 11-230626) describes a refrigeration cycle apparatus which uses a refrigerant mixture that includes the HC (hydrocarbon) refrigerant. PTL 1 describes that when the refrigerant mixture is used in the refrigeration cycle apparatus, in order to prevent the discharge temperature of the compressor from becoming too high, the opening degree of the expansion valve is adjusted so as to control the discharge temperature equal to or lower than a predetermined temperature.

15 CITATION LIST

PATENT LITERATURE

20 **[0003]** PTL 1: Japanese Patent Laying-Open No. 11-230626

SUMMARY OF INVENTION

TECHNICAL PROBLEM

25 **[0004]** However, as described in PTL 1, when the HC refrigerant is used in the refrigeration cycle apparatus and the discharge temperature is controlled equal to or lower than the predetermined temperature, the discharge superheat degree of the compressor may become excessively large while the suction temperature and the suction superheat degree of the compressor may become excessively small. As a result, when the HC refrigerant is used, the COP (Coefficient Of Performance) may become lower than that when an HFC (hydrofluorocarbon) refrigerant such as R32 is used.

30 **[0005]** Therefore, an object of the present invention is to provide an air conditioner capable of using HC refrigerant with a low global warming potential as a refrigerant and capable of increasing a COP when the HC refrigerant is used higher than that when R32 is used.

35 SOLUTION TO PROBLEM

[0006] The air conditioner of the present invention includes: a refrigerant circuit provided with a compressor, a condenser, an expansion valve, and an evaporator, and configured to circulate refrigerant; a first sensor configured to detect a suction temperature of the refrigerant sucked into the compressor; and a second sensor configured to detect an outside air temperature. The refrigerant includes at least one of R290 and R1270. During a heating operation, when a difference between the suction temperature and the outside air temperature is smaller than (-2.0°C), an opening degree of the expansion valve is decreased; and when the difference is greater than (+0.6°C), the opening degree of the expansion valve is increased.

45 ADVANTAGEOUS EFFECTS OF INVENTION

[0007] According to the present invention, the HC refrigerant with a low global warming potential may be used as a refrigerant, and the COP when the HC refrigerant is used may be made higher than that when R32 is used.

50 BRIEF DESCRIPTION OF DRAWINGS

[0008]

55 Fig. 1 is a diagram illustrating a configuration of an air conditioner according to a first embodiment;
 Fig. 2 is a diagram illustrating a control device 60 and components connected to the control device 60;
 Fig. 3 is a diagram illustrating the flow of refrigerant in a refrigerant circuit 70 during a cooling operation;
 Fig. 4 is a diagram illustrating the flow of refrigerant in the refrigerant circuit 70 during a heating operation;

Fig. 5 is a diagram illustrating a relationship between a suction superheat degree SHs and a theoretical COP;
 Fig. 6 is a diagram illustrating a relationship between an outside air temperature TO and a normalized COP;
 Figs. 7(a) to 7(c) are diagrams illustrating a relationship between a suction temperature TS and a normalized COP for R290 and R32;

Fig. 8 is a flowchart illustrating a control process on the air conditioner during the heating operation according to the first embodiment;

Fig. 9 is a flowchart illustrating a control process on the air conditioner during the heating operation according to a second embodiment;

Figs. 10(a) to 10(c) are diagrams illustrating a relationship between a discharge superheat degree SHd and a normalized COP for R290 and R32;

Fig. 11 is a diagram illustrating a range of discharge superheat degrees SHd in which the COP of R290 is higher than the COP of R32 and no liquid back phenomenon occurs in the compressor 1; and

Fig. 12 is a flowchart illustrating a control process on the air conditioner during the heating operation according to a third embodiment.

DESCRIPTION OF EMBODIMENTS

[0009] Hereinafter, embodiments will be described with reference to the drawings.

First Embodiment

[0010] Fig. 1 is a diagram illustrating a configuration of an air conditioner according to a first embodiment.

[0011] As illustrated in Fig. 1, the air conditioner includes an outdoor unit 50 and an indoor unit 51.

[0012] The outdoor unit 50 includes a compressor 1, a four-way valve 2, an outdoor heat exchanger 3, an expansion valve 4, an outdoor blower 6, an outdoor air temperature sensor 11, a discharge temperature sensor 23, a discharge pressure sensor 24, a suction pressure sensor 22, a suction temperature sensor 21, and a controller 60.

[0013] The compressor 1 sucks refrigerant, compresses the sucked refrigerant and discharges the compressed refrigerant thereafter.

[0014] The outdoor heat exchanger 3 functions as a condenser during a cooling operation. The outdoor heat exchanger 3 functions as an evaporator during a heating operation.

[0015] The expansion valve 4 expands the refrigerant. The expansion valve 4 is an electronic expansion valve, and is configured to change the opening degree (opening area) from zero (full close) to full open stepwise.

[0016] The outdoor blower 6 blows outdoor air (outside air) to the outdoor heat exchanger 3.

[0017] The outside air temperature sensor 11 is installed on the air suction side of the outdoor heat exchanger 3 at a position of several centimeters from the housing of the outdoor unit 50. The outside air temperature sensor 11 measures an outside air temperature TO.

[0018] The discharge temperature sensor 23 detects a discharge temperature TD of the refrigerant discharged from the compressor 1 (hereinafter referred to as the discharge temperature of the compressor 1).

[0019] The discharge pressure sensor 24 detects a discharge pressure PD of the refrigerant discharged from the compressor 1 (hereinafter referred to as the discharge pressure of the compressor 1). This pressure is the maximum pressure of the refrigerant in the refrigerant circuit 70.

[0020] The suction pressure sensor 22 detects a suction pressure PS of the refrigerant sucked into the compressor 1 (hereinafter referred to as the suction pressure of the compressor 1). This pressure is the minimum pressure of the refrigerant in the refrigerant circuit 70.

[0021] The suction temperature sensor 21 detects a suction temperature TS of the refrigerant sucked into the compressor 1 (hereinafter referred to as the suction temperature of the compressor 1).

[0022] The outdoor heat exchanger temperature sensor 35 measures an evaporation temperature TE of the refrigerant in the outdoor heat exchanger 3 during the heating operation. The outdoor heat exchanger temperature sensor 35 measures a condensation temperature of the refrigerant in the outdoor heat exchanger 3 during the cooling operation.

[0023] The indoor unit 51 includes an indoor heat exchanger 5 and an indoor blower 7.

[0024] The indoor heat exchanger 5 functions as an evaporator during the cooling operation. The indoor heat exchanger 5 functions as a condenser during the heating operation.

[0025] The indoor blower 7 blows indoor air to the indoor heat exchanger 5.

[0026] The indoor heat exchanger temperature sensor 25 measures a condensation temperature TC of the refrigerant in the indoor heat exchanger 5 during the heating operation. The indoor heat exchanger temperature sensor 25 measures an evaporation temperature of the refrigerant in the indoor heat exchanger 5 during the cooling operation.

[0027] The refrigerant circuit 70 includes therein the compressor 1, the four-way valve 2, the outdoor heat exchanger 3, the expansion valve 4, and the indoor heat exchanger 5.

[0028] The four-way valve 2 is a valve provided with four ports a, b, c and d.

[0029] The port a is connected to a discharge port of the compressor 1 via a pipe P1. The port b is connected to the outdoor heat exchanger 3 via a pipe P2. The port c is connected to a suction port of the compressor 1 via a pipe P3. The port d is connected to the indoor heat exchanger 5 via a pipe P4. The expansion valve 4 is connected to the indoor heat exchanger 5 via a pipe P5. The expansion valve 4 is connected to the outdoor heat exchanger 3 via a pipe P6.

[0030] Fig. 2 is a diagram illustrating the controller 60 and components connected to the controller 60.

[0031] The controller 60 receives a signal indicating a detected outside air temperature from the outside air temperature sensor 11. The controller 60 receives a signal indicating a detected discharge temperature from the discharge temperature sensor 23. The controller 60 receives a signal indicating a detected discharge pressure from the discharge pressure sensor 24. The controller 60 receives a signal indicating a detected suction pressure from the suction pressure sensor 22. The controller 60 receives a signal indicating a detected suction temperature from the suction temperature sensor 21. The controller 60 receives a signal indicating a detected temperature of the indoor heat exchanger 5 from the indoor heat exchanger temperature sensor 25.

[0032] The controller 60 sends a signal to the four-way valve 2 to instruct the switching thereof. The controller 60 sends a signal to the compressor 1 to instruct the start or stop, or a rotation speed thereof. The controller 60 sends a signal to the outdoor blower 6 to instruct the start or stop thereof. The controller 60 sends a signal to the indoor blower 7 to instruct the start or stop thereof. The controller 60 sends a signal to the expansion valve 4 to control the opening degree thereof.

[0033] The controller 60 is constructed by a processing circuit. When the processing circuit is dedicated hardware, the processing circuit may be, for example, a single circuit, a composite circuit, a programmed processor, ASIC (Application Specific Integrated Circuit), FPGA (Field Programmable Gate Array), or a combination thereof. When the processing circuit is a CPU, the function of the controller 60 is realized by software, firmware, or a combination of software and firmware. Software and firmware are written as programs and stored in a memory. The processing circuit realizes a function of the controller 60 by executing a program stored in the memory. In the present disclosure, the memory may be a nonvolatile or volatile semiconductor memory such as a RAM, a ROM, a flash memory, an EPROM or an EEPROM, or a magnetic disk, a flexible disk, an optical disk, a compact disk, a mini disk, a DVD, or the like. A part of each function of the controller 60 may be realized by dedicated hardware, and a part thereof may be realized by software or firmware.

[0034] First, how the refrigerant circuit 70 operates during the cooling operation will be described.

[0035] Fig. 3 is a diagram illustrating the flow of refrigerant in the refrigerant circuit 70 during the cooling operation.

[0036] During the cooling operation, the controller 60 switches the four-way valve 2 of the refrigerant circuit 70 to a first state. In the first state, the port a and the port b of the four-way valve 2 communicate with each other, and the port c and the port d of the four-way valve 2 communicate with each other. Thus, the refrigerant discharged from the indoor heat exchanger 5 flows into the compressor 1, and the refrigerant discharged from the compressor 1 flows into the outdoor heat exchanger 3. The controller 60 sets the number of cycles per minute of the compressor 1 and the opening degree of the expansion valve 4 to values suitable for the cooling operation, and starts the compressor 1. Thus, the refrigerant circuit 70 operates as follows.

[0037] The refrigerant is compressed in the compressor 1 into a vapor refrigerant with a high temperature and a high pressure, the high-temperature and high-pressure vapor refrigerant passes through the four-way valve 2 and flows into the outdoor heat exchanger 3. The outdoor heat exchanger 3 functions as a condenser that cools the high-temperature and high-pressure vapor refrigerant during the cooling operation. The high-temperature and high-pressure vapor refrigerant radiates heat to the outdoor air blown by the outdoor blower 6 to the outdoor heat exchanger 3, and thereby is condensed into a high-pressure liquid refrigerant.

[0038] Thereafter, the high-pressure liquid refrigerant passes through the expansion valve 4, and is depressurized and expanded into a low-temperature and low-pressure gas-liquid two-phase refrigerant, and flows into the indoor heat exchanger 5. The indoor heat exchanger 5 functions as an evaporator that absorbs heat from the depressurized and expanded refrigerant during the cooling operation. The low-temperature and low-pressure gas-liquid two-phase refrigerant absorbs heat from the indoor air blown by the indoor blower 7 to the indoor heat exchanger 5, and thereby is evaporated into a low-pressure vapor refrigerant. Thereafter, the low-pressure vapor refrigerant is sucked into the compressor 1 via the four-way valve 2.

[0039] Thereafter, the refrigerant is circulated in the refrigerant circuit 70 through the compressor 1, the outdoor heat exchanger 3, the expansion valve 4, and the indoor heat exchanger 5 in this order in the same procedure.

[0040] Next, how the refrigerant circuit 70 operates during the heating operation will be described.

[0041] Fig. 4 is a diagram illustrating the flow of refrigerant in the refrigerant circuit 70 during the heating operation.

[0042] During the heating operation, the controller 60 switches the four-way valve 2 of the refrigerant circuit 70 to a second state. In the second state, the port a and the port d of the four-way valve 2 communicate with each other, and the port b and the port c of the four-way valve 2 communicate with each other. When the four-way valve 2 is switched to the second state, the refrigerant discharged from the outdoor heat exchanger 3 flows into the compressor 1, and the refrigerant discharged from the compressor 1 flows into the indoor heat exchanger 5.

[0043] The controller 60 sets the number of cycles per minute of the compressor 1 and the opening degree of the expansion valve 4 respectively to a suitable value for the heating operation, and starts the compressor 1. Thus, the refrigerant circuit 70 operates as follows.

[0044] The refrigerant is compressed in the compressor 1 into a vapor refrigerant with a high temperature and a high pressure, the high-temperature and high-pressure vapor refrigerant passes through the four-way valve 2 and flows into the indoor heat exchanger 5. The indoor heat exchanger 5 functions as a condenser that cools the high-temperature and high-pressure vapor refrigerant during the heating operation. The high-temperature and high-pressure vapor refrigerant radiates heat to the indoor air blown by the indoor blower 7 to the indoor heat exchanger 5, and thereby is condensed into a high-pressure liquid refrigerant.

[0045] Thereafter, the high-pressure liquid refrigerant passes through the expansion valve 4, and is depressurized and expanded into a low-temperature and low-pressure gas-liquid two-phase refrigerant, and flows into the outdoor heat exchanger 3. The outdoor heat exchanger 3 functions as an evaporator that absorbs heat from the depressurized and expanded refrigerant during the heating operation. The low-temperature and low-pressure gas-liquid two-phase refrigerant absorbs heat from the outdoor air blown by the outdoor blower 6 to the outdoor heat exchanger 3, and thereby is evaporated into a low-pressure vapor refrigerant. Thereafter, the low-pressure vapor refrigerant is sucked into the compressor 1 via the four-way valve 2.

[0046] Thereafter, the refrigerant is circulated in the refrigerant circuit 70 through the compressor 1, the indoor heat exchanger 5, the expansion valve 4, and the outdoor heat exchanger 3 in this order in the same procedure.

[0047] During the heating operation, the controller 60 calculates a suction superheat degree SHs based on the suction temperature TS and the suction pressure PS. Further, during the heating operation, the controller 60 calculates the suction superheat degree SHs based on the suction temperature TS and the evaporation temperature TE of the refrigerant in the outdoor heat exchanger 3.

[0048] During the heating operation, the controller 60 calculates a discharge superheat degree SHd based on the discharge temperature TD and the discharge pressure Pd. During the heating operation, the controller 60 calculates the discharge superheat degree SHd based on the discharge temperature TD and the condensation temperature TC of the refrigerant in the indoor heat exchanger 4.

[0049] The controller 60 controls the number of cycles per minute of the compressor 1 and a rotation speed of the outdoor blower 6 based on the outside air temperature TO.

[0050] Next, the refrigerant to be used in the air conditioner of the present embodiment will be described.

[0051] Due to the influence on global warming, it is required to use a refrigerant with a low global warming potential. Therefore, in an air conditioner, it is expected to use an HC refrigerant such as R290 (GWP4) or R1270 instead of an HFC refrigerant such as R410A (GWP2088) or R32 (GWP675).

[0052] For example, R290 has a latent heat of condensation that is 1.2 times greater than R32, and has a larger refrigeration effect that is exhibited by an enthalpy difference between an inlet and an outlet of the condenser with respect to an increase in the suction superheat degree SHs. Therefore, if the suction superheat degree SHs is the same, the circulation amount of refrigerant R290 required to reach a certain capacity is only 0.8 times of the circulation amount of refrigerant R32. As a result, when R290 is used, the theoretical compression work of the compressor 1 becomes smaller, and thereby the theoretical COP becomes higher than the case when R32 is used.

[0053] Fig. 5 is a diagram illustrating the relationship between the suction superheat degree SHs and the theoretical COP.

[0054] As illustrated in Fig. 5, when the suction superheat degree SHs increases, the theoretical COP of the fluorocarbon-based refrigerant such as R32 and R410A decreases, but the theoretical COP of R290 increases. This is because when the suction superheat degree SHs increases, the refrigeration effect of R290 increases more than the reduction rate of the circulation amount of refrigerant than that of the fluorocarbon-based refrigerant.

[0055] Therefore, in the present embodiment, the refrigerant circulated in the refrigerant circuit 70 includes at least one of R290 and R1270, each of which is a flammable natural HC refrigerant with a low GWP. In other words, the refrigerant flowing in the refrigerant circuit 70 is R290 alone, R1270 alone, or a mixed refrigerant containing at least one of R290 and R1270 as a main component.

[0056] In a conventional air conditioner that uses R32, due to the characteristics of R32, the lubricating oil and the motor may be deteriorated by an increase in the discharge temperature of the compressor 1. Therefore, the conventional air conditioner that uses R32 is configured to operate while performing a control on the discharge temperature TD by reducing the suction superheat degree SHs of the compressor 1 so as to prevent the discharge temperature TD from increasing. However, in the case where R290 with a low global warming potential is used, if the same control as that of R32 is performed, the discharge superheat degree SHd may become excessively large, and the suction temperature TS and the suction superheat degree SHs may become excessively small, which may deteriorate the COP. In other words, although the theoretical COP of R290 is higher than that of R32, it is difficult to obtain a COP in the case where R290 is used equal to or higher than that in the case where R32 is used by the conventional control.

[0057] As a conventional lubricating oil for hydrocarbon refrigerants, paraffin-based hydrocarbons, naphthene-based

hydrocarbons, alkylbenzene alone, or a mixed oil thereof may be used, but because of their high compatibility, they are not suitable for strongly combustible refrigerant such as R290 or R1270 for the safety purpose according to the regulations on filling amount of refrigerant (IEC 60335-2-40). Further, these lubricating oils are not suitable for a typical high-pressure hermetic air conditioner because of their low viscosity.

[0058] In the present embodiment, an oil which has a density higher than that of the refrigerant, such as polyalkylene glycol-based PAG or polyvinyl ether-based PVE having an ether bond, or polyol ester-based POE having an ester bond is used as the lubricating oil of the compressor 1. Since PAG has low compatibility with R290, when R290 is used as the refrigerant, PAG is preferably used as the lubricating oil for R290.

[0059] The compressor 1, the four-way valve 2, and the expansion valve 4 are connected to each other by refrigerant pipes in a machine chamber of the outdoor unit 50. These components are covered with a front panel, side panels, a rear panel and partition plates, each of which is made of a metal plate, and are separated from the outside air. Therefore, due to the heat radiated from the compressor 1, the ambient air temperature in the machine chamber may be higher than the outside air temperature TO. Due to the overheating by the ambient air in the machine chamber and the heat absorbed from the refrigerant which is discharged from the four-way valve 2 at the discharge temperature TD, the suction temperature TS may be higher than the outside air temperature TO.

[0060] In Europe, in order to reduce energy consumption of room air conditioners, it is required that a SCOP (Seasonal Coefficient of Performance) determined from the COP at a desired outside air temperature must comply with the ErP directive Lot 10.

[0061] Fig. 6 is a diagram illustrating the relationship between an outside air temperature TO and a normalized COP.

[0062] The normalized COP represents a ratio of the COP at each temperature to the COP at an outside air temperature TO of 12°C.

[0063] As the outside air temperature TO increases, the load on the building and the room decreases, and thereby the COP increases. The SCOP is represented by the COP(A) at the outside air temperature TO of -7°C, the COP(B) at the outside air temperature TO of 2°C, the COP(C) at the outside air temperature TO of 7°C and the COP(D) at the outside air temperature TO of 12°C in the following formula:

$$\text{SCOP} = 0.17 \times \text{COP(A)} + 0.51 \times \text{COP(B)} + 0.23 \times \text{COP(C)} + 0.09 \times \text{COP(D)} \quad (1).$$

[0064] The COP(B) at the outside air temperature TO of 2°C and the COP(C) at the outside air temperature TO of 7°C contribute a greater part to the SCOP. The contribution of the COP(B) at the outside air temperature TO of 2°C and the COP(C) at the outside air temperature TO of 7°C to the SCOP is 74%. The contribution of the COP(B) at the outside air temperature TO of 2°C, the COP(C) at the outside air temperature TO of 7°C, and the COP(D) at the outside air temperature TO of 12°C to the SCOP is 83%.

[0065] As illustrated in Fig. 6, the COP of the air conditioner changes linearly in response to the outside air temperature TO. Thus, if the COP of the air conditioner at each of the three outside air temperatures TO is determined, the SCOP of the air conditioner is generally determined. However, since the heating operation in the case where the outside air temperature TO is below zero involves a defrosting operation, the actual COP may be different from the theoretical COP. Therefore, in the present embodiment, three outside air temperatures TO of 2°C, 7°C and 12°C among the outside air temperatures TO of -7°C, 2°C, 7°C and 12°C that are used to determine the SCOP will be discussed.

[0066] Figs. 7(a) to 7(c) are diagrams illustrating a relationship between the suction temperature TS and the normalized COP for R290 and R32. Figs. 7(a) to 7(c) illustrate the relationship between the suction temperature TS and the normalized COP when the suction superheat degree SHs for determining the SCOP changes from 0.1°C to 20°C at the outside air temperature TO of 2°C, 7°C, and 12°C, respectively. When the suction superheat degree SHs is 0.1°C, the suction temperature TS is minimum. When the suction superheat degree SHs is 20°C, the suction temperature TS is maximum. If the COP of R32 when the suction superheat degree SHs is 0.1°C is denoted by X, the normalized COP is represented by $(\text{COP}/X) \times 100$.

[0067] Horizontal straight lines L1, L2 and L3 in Figs. 7(a) to 7(c), respectively, indicate a lower limit of a COP so as to achieve an SCOP equivalent to the COP of R32 at another outside air temperature TO. In the present embodiment, when the outside air temperature TO is 2°C or 7°C, the lower limit represented by L1 and L2 is 97%; and when the outside air temperature TO is 12°C, the lower limit represented by L3 is 93%.

[0068] As illustrated in Fig. 7(a), when the outside air temperature TO is 2°C and the suction temperature TS is within the range of 0°C to 6.6°C, in other words, when ΔT is within the range of -2.0°C to +4.6°C, the COP of the air conditioner may be improved by using R290 instead of R32. When $\Delta T < -2^\circ\text{C}$, the suction temperature TS becomes smaller than 0°C, the suction pipe is frosted, which significantly reduces the COP.

[0069] As illustrated in Fig. 7(b), when the outside air temperature TO is 7°C and the suction temperature TS is within the range of 3.0°C to 7.6°C, in other words, ΔT is within the range of -4.0°C to +0.6°C, the COP of the air conditioner may be improved by using R290 instead of R32. When $\Delta T (=TS-TO) > 0.6^\circ\text{C}$, since the COP in the case where R290 is

used is smaller than the COP in the case where R32 is used, R290 should not be used in the air conditioner even though R290 has a theoretical COP higher than that of R32.

[0070] As illustrated in Fig. 7(c), when the outside air temperature T_O is 12°C and the suction temperature T_S is within the range of 9.4°C to 13.6°C, in other words, when ΔT is within the range of -2.6°C to +1.6°C, the COP of the air conditioner may be improved by using R290 instead of R32.

[0071] As described above, by controlling ΔT in response to the outside air temperature T_O , it is possible to use R290 instead of R32 in the air conditioner at a higher COP.

[0072] Further, by controlling ΔT ($=T_S - T_O$) within the range of -2.0°C to +0.6°C, it is possible to use R290 instead of R32 in the air conditioner at a higher COP despite the outside air temperature T_O .

[0073] As described above, in the present embodiment, the controller 60 controls the expansion valve 4 so that the difference ΔT ($=T_S - T_O$) between the suction temperature T_S and the outside air temperature T_O is within the range W (-2.0°C to +0.6°C) during the heating operation. Thus, during the heating operation, it is possible to use R290 as the refrigerant in the air conditioner at an SCOP equal to or more than that in the case where R32 is used. Although R290 has been described as an example in the above, the same effect may be achieved by using R1270 which has properties such as the boiling point and the operating pressure similar to that of R290.

[0074] Fig. 8 is a flowchart illustrating a control process during a heating operation of the air conditioner according to the first embodiment.

[0075] In step S301, the discharge temperature sensor 23 detects a discharge temperature T_D of the compressor 1. The controller 60 receives a signal indicating the discharge temperature T_D of the compressor 1 from the discharge temperature sensor 23.

[0076] In step S302, the suction temperature sensor 21 detects a suction temperature T_S of the compressor 1. The controller 60 receives a signal indicating the detected suction temperature T_S from the suction temperature sensor 21.

[0077] In step S103, the controller 60 calculates the temperature difference $\Delta T = T_S - T_O$.

[0078] If it is determined that the temperature difference ΔT is less than (-2.0°C) in step S104 (YES in S104), the process proceeds to step S105. If it is determined that the temperature difference ΔT is greater than (+0.6°C) in step S106 (YES in S106), the process proceeds to step S107. If it is determined that the temperature difference ΔT is not less than (-2.0°C) and not greater than (+0.6°C) (NO in S104 and NO in S106), the process ends.

[0079] In step S105, the controller 60 decreases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S101.

[0080] In step S107, the controller 60 increases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S101.

Second Embodiment

[0081] As illustrated in Figs. 7(a) to 7(c), when the outside air temperature T_O and the suction temperature T_S are controlled to be equal to each other, since the COP of R32 is maximum at a suction temperature T_S higher than the outside air temperature T_O due to the properties of the refrigerant, it cannot be used in the air conditioner at a higher COP, and however, R290 may be used in the air conditioner at a high COP.

[0082] In the present embodiment, the controller 60 controls the expansion valve 4 so as to make the suction temperature T_S equal to the outside air temperature T_O .

[0083] Fig. 9 is a flowchart illustrating a control process on the air conditioner during the heating operation according to a second embodiment.

[0084] In step S201, the outside air temperature sensor 11 detects an outside air temperature T_O . The controller 60 receives a signal indicating the outside air temperature T_O from the outside air temperature sensor 11.

[0085] In step S202, the suction temperature sensor 21 detects a suction temperature T_S of the compressor 1. The controller 60 receives a signal indicating the suction temperature T_S from the suction temperature sensor 21.

[0086] In step S203, the controller 60 calculates a temperature difference $\Delta T = T_S - T_O$.

[0087] If it is determined that the suction temperature T_S is lower than the outside air temperature T_O in step S203 (YES in S203), the process proceeds to step S204. If it is determined that the suction temperature T_S is greater than the outside air temperature T_O in step S205 (YES in S205), the process proceeds to step S206. If it is determined that the suction temperature T_S is equal to the outside air temperature T_O (NO in S203 and NO in S205), the process ends.

[0088] In step S204, the controller 60 decreases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S101.

[0089] In step S206, the controller 60 increases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S101.

[0090] According to the present embodiment, it is possible to operate the air conditioner at a high COP in response to a change in the outside air temperature T_O . Since the controller 60 controls the suction temperature T_S based on the detected outside air temperature T_O , the controller 60 controls the refrigerant sucked into the compressor 1 by turning

the refrigerant into superheated gas instead of controlling the suction superheat degree SHs. In other words, the air conditioner may be operated at an evaporation temperature TE that is lower than the outside air temperature TO, while in the present embodiment, the outside air temperature TO is controlled equal to the suction temperature TS, which means that the evaporation temperature TE is lower than the suction temperature TS. Thereby, it is ensured that the refrigerant sucked into the compressor 1 is converted into superheated gas. As a result, it is possible to prevent a liquid back phenomenon, which is a major cause of failure, from occurring in the compressor 1, which makes it possible to make the air conditioner operate stable. Further, since it is easy to prevent the air conditioner from operating at a suction temperature that is equal to or lower than 0°C, which prevents frost from being formed on the suction pipes, it is possible to prevent the recondensation of the refrigerant in the refrigerant pipe due to an increase in the thermal resistance caused by the frost.

Third Embodiment

[0091] Figs. 10(a) to 10(c) are diagrams illustrating the relationship between the discharge superheat degree SHd and the normalized COP for R290 and R32.

[0092] Figs. 10(a) to 10(c) illustrate the relationship between the discharge superheat degree SHd and the normalized COP at the outside air temperature TO of 2°C, 7°C, and 12°C, respectively, when the suction superheat degree SHs, which is used to determine the SCOP, changes from 0.1°C to 20°C. When the suction superheat degree SHs is 0.1°C, the discharge superheat degree SHd is minimum. When the suction superheat degree SHs is 20°C, the discharge superheat degree SHd is maximum. If the COP when the suction superheat degree SHs of R32 is 0.1°C is denoted by X, the normalized COP is represented by $(COP/X) \times 100$.

[0093] As illustrated in Figs. 10(a) to 10(c), at each outside air temperature TO, there is a range of discharge superheat degrees SHd in which the COP of R290 is higher than that of R32. The maximum value of the range is denoted by U(SHd).

[0094] As illustrated in Figs. 10(a) to 10(c), due to the difference in physical properties of refrigerants R290 and R32, the discharge superheat degree SHd of R290 having a COP higher than that of R32 at an outside air temperature TO is smaller than that of R32.

[0095] U(SHd) at an outside air temperature TO may be represented by the following formula:

$$U(SHd) = -1.1559 \times TO + 19.574 \quad (2).$$

[0096] On the other hand, if the lower limit of a range of discharge superheat degrees SHd in which no liquid back phenomenon occurs in the compressor 1 at an outside air temperature TO is denoted by L(SHd), L(SHd) may be represented by the following formula:

$$L(SHd) = -0.4526 \times TO + 9.5755 \quad (3).$$

[0097] Fig. 11 is a diagram illustrating a range of discharge superheat degrees SHd in which the COP of R290 is higher than the COP of R32 and no liquid back phenomenon occurs in the compressor 1.

[0098] In Fig. 11, the straight line R1 is expressed by the formula (2), and the straight line R2 is expressed by the formula (3). Within the range between the straight line R1 and the straight line R2 (including the straight lines R1 and R2), the COP of R290 is higher than the COP of R32, and no liquid back phenomenon occurs in the compressor 1. In Fig. 11, since the air conditioning load becomes smaller as the outside air temperature TO becomes higher, the range of discharge superheat degrees SHd in which the air conditioner may be operated at a higher COP when R290 is used becomes smaller than the range when R32 is used.

[0099] In the present embodiment, the controller 60 controls the opening degree of the expansion valve 4 based on the outside air temperature TO such that the discharge superheat degree SHd is equal to or greater than L(SHd) represented by the formula (3) and equal to or less than U(SHd) represented by the formula (2).

[0100] Fig. 12 is a flowchart illustrating a control process on the air conditioner during the heating operation according to a third embodiment.

[0101] In step S300, the outside air temperature sensor 11 detects an outside air temperature TO. The controller 60 receives a signal indicating the outside air temperature TO from the outside air temperature sensor 11.

[0102] In step S301, the outside air temperature sensor 11 detects an outside air temperature TO. The controller 60 receives a signal indicating the outside air temperature TO from the outside air temperature sensor 11.

[0103] In step S302, the indoor heat exchanger temperature sensor 25 detects a condensation temperature TC of the refrigerant in the indoor heat exchanger 5. The controller 60 receives a signal indicating the condensation temperature TC of the refrigerant from the indoor heat exchanger temperature sensor 25.

[0104] In step S303, the controller 60 calculates the discharge superheat degree SHd (=TD-TC) by subtracting TC from TD.

[0105] In step S304, the controller 60 calculates U(SHd) from the outside air temperature TO by the formula (2) mentioned in the above.

5 **[0106]** In step S304, the controller 60 calculates L(SHd) from the outside air temperature TO by the formula (3) mentioned in the above.

[0107] If it is determined that the discharge superheat degree SHd is less than L(SHd) in step S305 (YES in S305), the process proceeds to step S307. If it is determined that the discharge superheat degree SHd is greater than U(SHd) in step S308 (YES in S308), the process proceeds to step S309. If it is determined that the discharge superheat degree SHd is not less than L(SHd) and not greater than U(SHd) (NO in S305 and NO in S308), the process ends.

10 **[0108]** In step S307, the controller 60 decreases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S301.

[0109] In step S309, the controller 60 increases the opening degree of the expansion valve 4 by a predetermined amount. Thereafter, the process returns to step S301.

15 **[0110]** In the present embodiment, it is possible to use R290 instead of R32 in the air conditioner at a higher COP. In addition, since the control may be made finely in response to the change in the outside air temperature TO, more energy may be saved as compared with the conventional control on the discharge temperature. The same effect may be achieved by using R1270 which has properties such as the boiling point and the operating pressure similar to that of R290.

20 **[0111]** In the case where R290 is used as the refrigerant and PAG is used as the lubricating oil of the compressor 1 so as to control the discharge superheat degree SHd within the above-described range, the ratio of the refrigerant dissolved in the PAG may be limited to 30% or less. As a result, the refrigerant filling amount may be made equal to or less than an allowable refrigerant amount. The same effect may be achieved by using R1270 which has properties such as the boiling point and the operating pressure similar to that of R290.

25 (Modifications)

[0112] The present invention is not limited to the embodiments described above, and may include, for example, the following modifications.

30 (1) Control of expansion valve

[0113] In steps S105 and S107 of Fig. 8 according to the first embodiment, it is described that the controller adjusts the opening degree of the expansion valve by a predetermined amount, but the present invention is not limited thereto. The controller may be configured to adjust the opening degree of the expansion valve by an amount in proportion to the magnitude of the difference between ΔT and (-2.0) or the magnitude of the difference between ΔT and (+0.6).

35 **[0114]** Similarly, in steps S203 and S205 of Fig. 9 of the second embodiment, it is described that the controller adjusts the opening degree of the expansion valve by a predetermined amount, but the present invention is not limited thereto. The controller may be configured to adjust the opening degree of the expansion valve by an amount in proportion to the magnitude of the difference between TS and TO.

40 **[0115]** Similarly, in steps S306 and S308 of Fig. 12 of the third embodiment, it is described that the controller adjusts the opening degree of the expansion valve by a predetermined amount, but the present invention is not limited thereto. The controller may be configured to adjust the opening degree of the expansion valve by an amount in proportion to the magnitude of the difference between SHd and L(SHd) or the magnitude of the difference between SHd and U(SHd).

45 (2) Control in response to outside air temperature

[0116] The controller may be configured to control the expansion valve such that ΔT (=suction temperature TS-outside air temperature TO) is within the range W (-2.0°C to +4.6°C) when the outside air temperature TO is 2°C. In other words, if the outside air temperature TO is 2°C, the controller may decrease the opening degree of the expansion valve by a predetermined amount when ΔT is less than (-2.0), and increase the opening degree of the expansion valve by a predetermined amount when ΔT is greater than (+4.6).

50 **[0117]** The controller may be configured to control the expansion valve such that ΔT is within the range W (-4.0°C to +0.6°C) when the outside air temperature TO is 7°C. In other words, if the outside air temperature TO is 7°C, the controller may decrease the opening degree of the expansion valve by a predetermined amount when ΔT is less than (-4.0), and increase the opening degree of the expansion valve by a predetermined amount when ΔT is greater than (0.6).

55 **[0118]** The controller may be configured to control the expansion valve such that ΔT is within the range W (-2.6°C to +1.6°C) when the outside air temperature TO is 12°C.

[0119] In other words, if the outside air temperature TO is 12°C, the controller may decrease the opening degree of

the expansion valve by a predetermined amount when ΔT is less than (-2.6), and increase the opening degree of the expansion valve by a predetermined amount when ΔT is greater than (+1.6).

[0120] If the outside air temperature is a value other than 2°C, 7°C, or 12°C, the controller may determine an upper limit and a lower limit of the range W by linear interpolation.

[0121] It should be understood that the embodiments disclosed herein are merely by way of illustration and example but not limited in all aspects. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modifications within the meaning and scope equivalent to the terms of the claims.

REFERENCE SIGNS LIST

[0122] 1: compressor; 2: four-way valve; 3: outdoor heat exchanger; 4: expansion valve; 5: indoor heat exchanger; 6: outdoor blower; 7: indoor blower; 11: outside air temperature sensor; 21: suction temperature sensor; 22: suction pressure sensor; 23: discharge temperature sensor; 24: discharge pressure sensor; 25: indoor heat exchanger temperature sensor; 35: outdoor heat exchanger temperature sensor; 50: outdoor unit; 51: indoor unit; 60: controller; 70: refrigerant circuit; P4, P5, P6: pipe

Claims

1. An air conditioner comprising:

a refrigerant circuit provided with a compressor, a condenser, an expansion valve, and an evaporator, and configured to circulate refrigerant;

a first sensor configured to detect a suction temperature of the refrigerant sucked into the compressor; and a second sensor configured to detect an outside air temperature, the refrigerant including at least one of R290 and R1270, and

during a heating operation, when a difference between the suction temperature and the outside air temperature is smaller than (-2.0°C), an opening degree of the expansion valve being decreased; and when the difference is greater than (+0.6°C), the opening degree of the expansion valve being increased.

2. The air conditioner according to claim 1, wherein

during the heating operation, when the suction temperature is lower than the outside air temperature, the opening degree of the expansion valve is decreased; and when the suction temperature is higher than the outside air temperature, the opening degree of the expansion valve is increased.

3. An air conditioner comprising:

a refrigerant circuit provided with a compressor, a condenser, an expansion valve, and an evaporator, and configured to circulate refrigerant; and

a first sensor configured to detect a discharge temperature of the refrigerant discharged from the compressor, the refrigerant including at least one of R290 and R1270,

during a heating operation, when a discharge superheat degree of the refrigerant discharged from the compressor is smaller than a predetermined range, an opening degree of the expansion valve being decreased; and when the discharge superheat degree is greater than the predetermined range, the opening degree of the expansion valve being increased, and

in the predetermined range, a COP (Coefficient Of Performance) at which the refrigerant is circulated in the refrigerant circuit being higher than the COP at which R32 is circulated in the refrigerant circuit, and no liquid back phenomenon occurring in the compressor.

4. The air conditioner according to claim 3 further comprising:

a second sensor configured to detect an outside air temperature, wherein when the outside air temperature is denoted by TO, a lower limit L(SHd) of the predetermined range is represented by the following formula:

$$L(SHd) = -0.4526 \times TO + 9.5755 \quad (A1)$$

5. The air conditioner according to claim 3 further comprising:

a second sensor configured to detect an outside air temperature,
wherein when the outside air temperature is denoted by TO, an upper limit U(SHd) of the predetermined range
is represented by the following formula:

$$U(SHd) = -1.1559 \times TO + 19.574 \quad (A2).$$

6. The air conditioner according to claim 3 further comprising:

a second sensor configured to detect a condensation temperature,
wherein the discharge superheat degree is a difference between the discharge temperature and the condensation temperature.

7. The air conditioner according to claim 3, wherein
the compressor includes PGA as a lubricating oil.

FIG.1

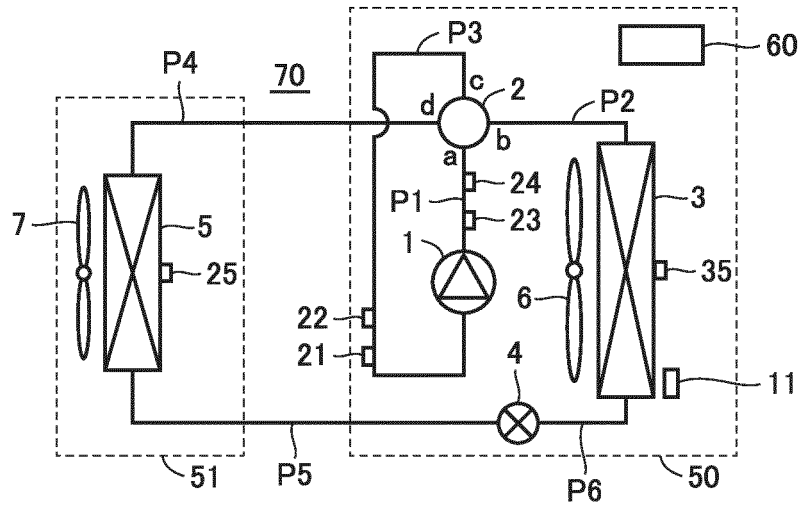


FIG.2

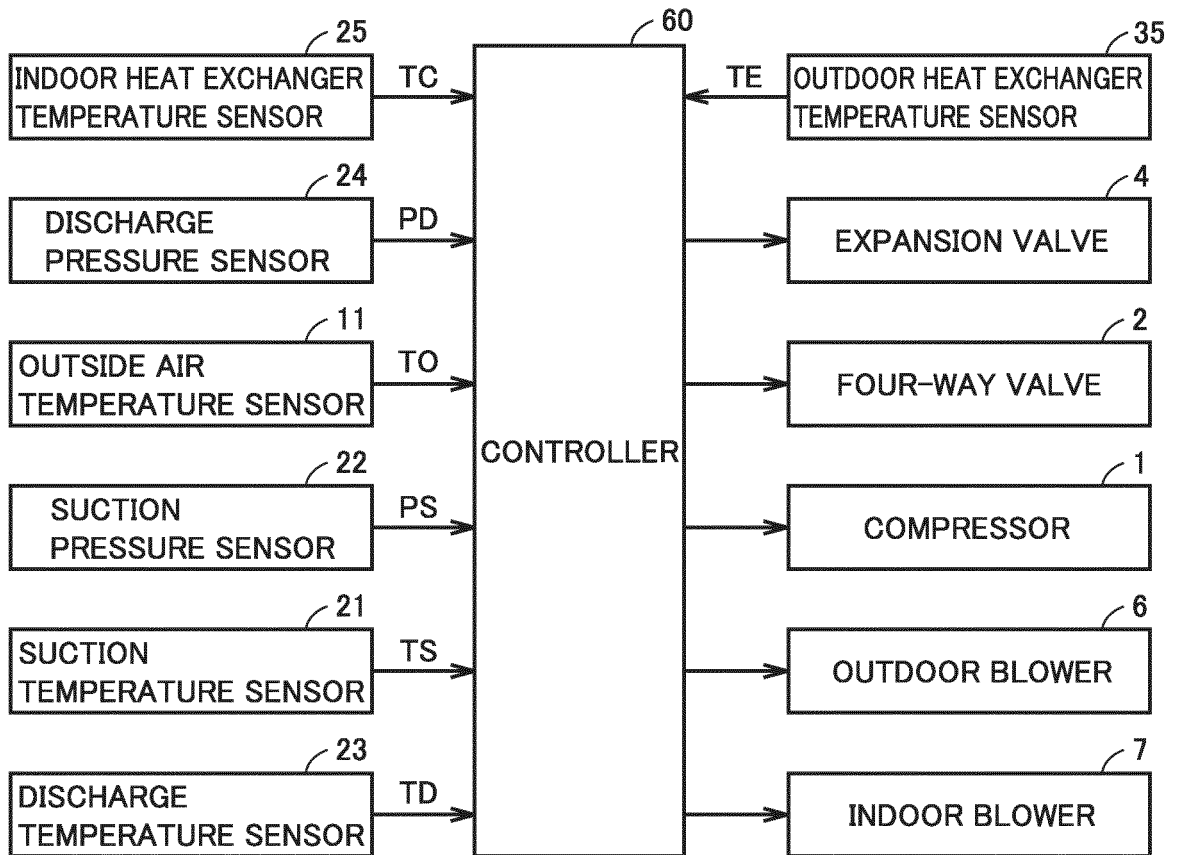


FIG.3

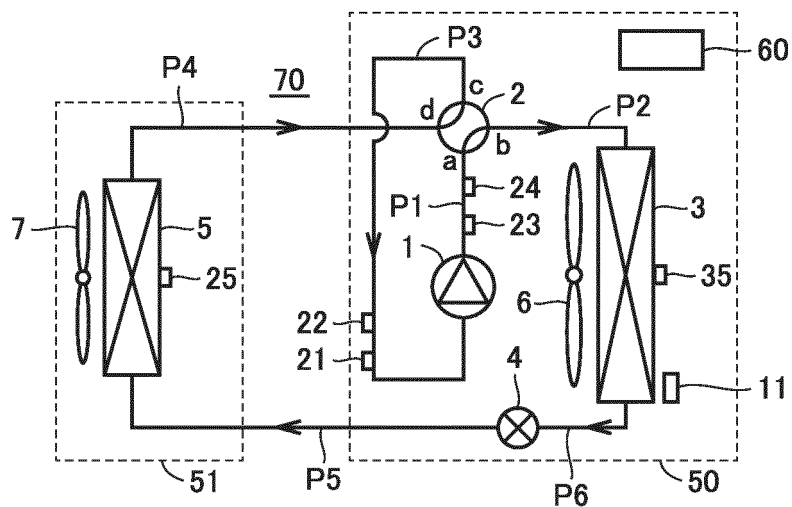


FIG.4

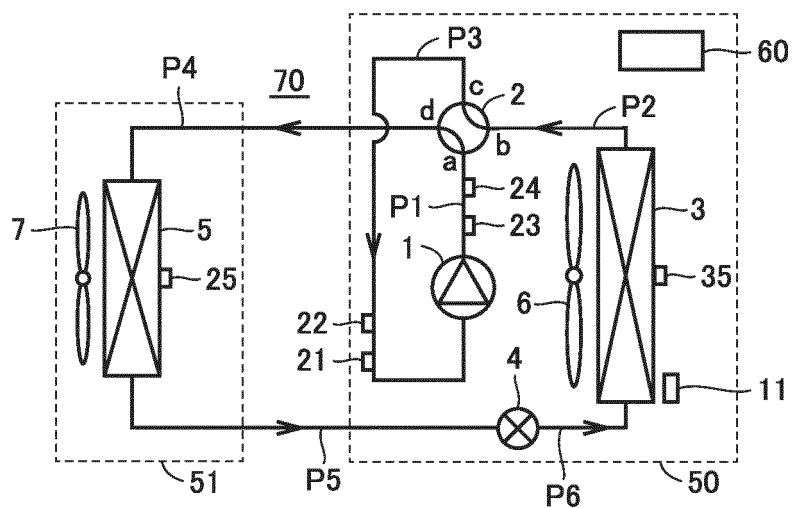


FIG.5

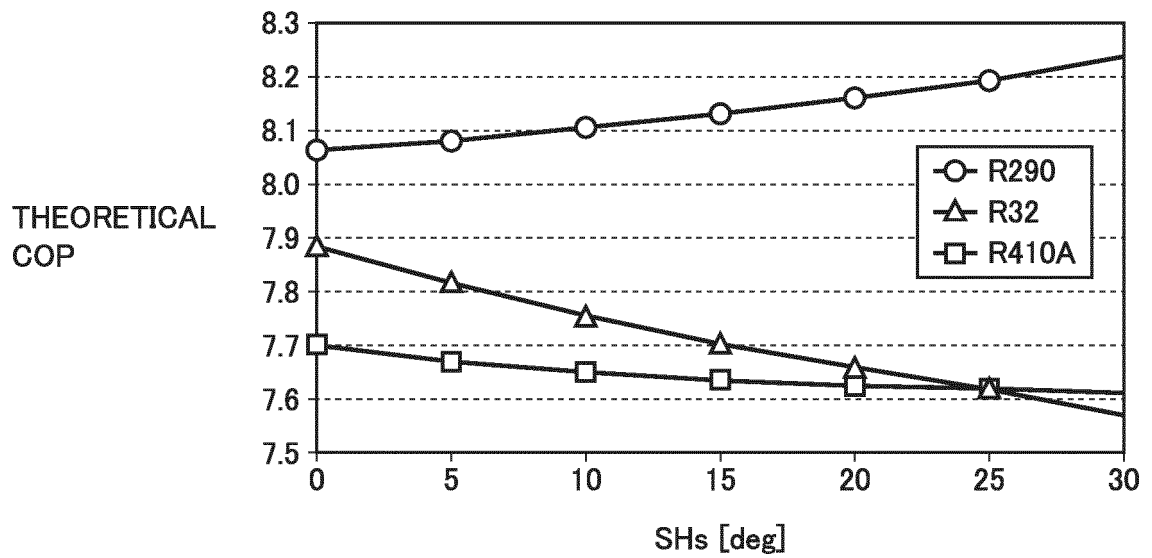


FIG.6

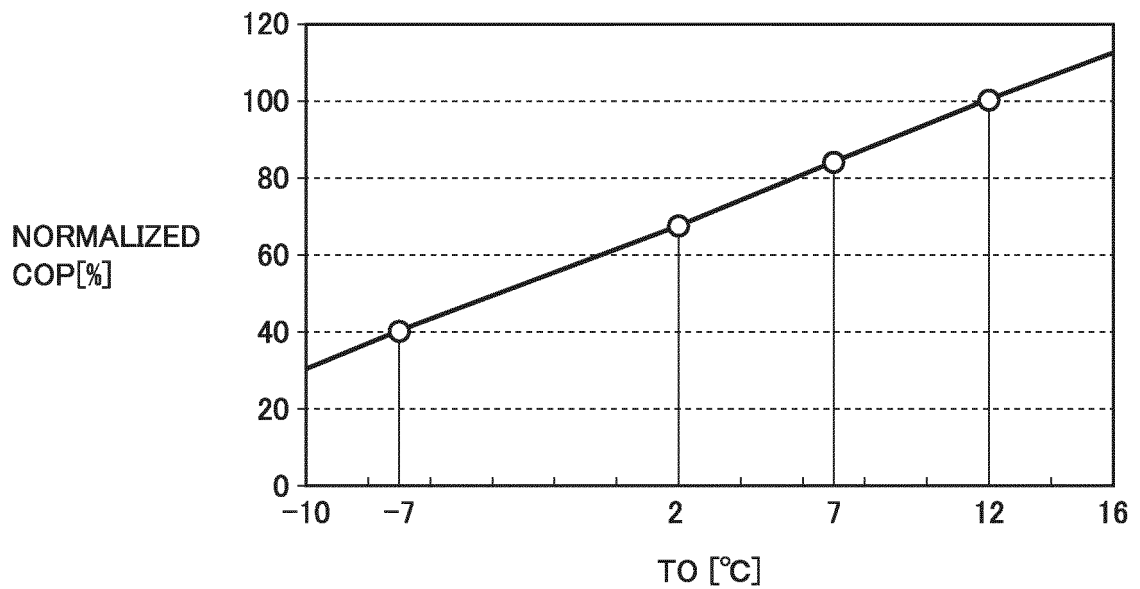
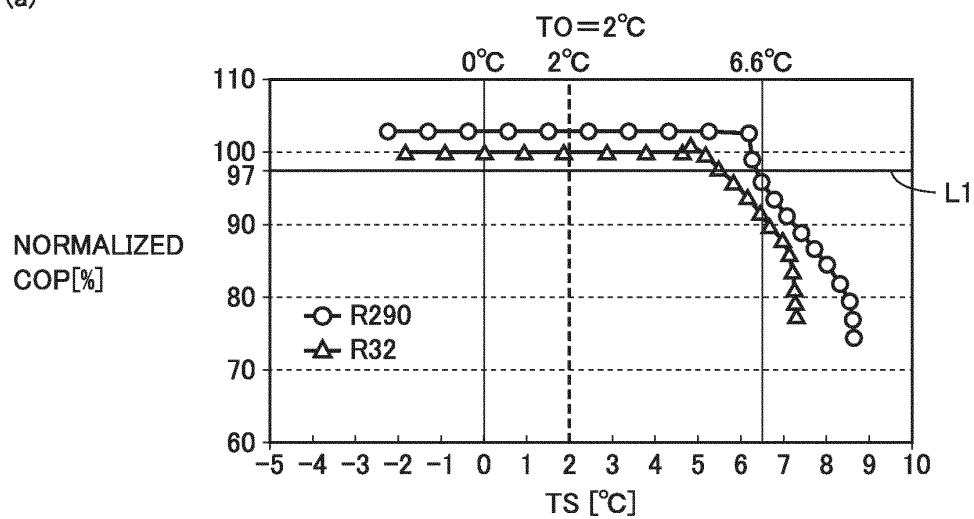
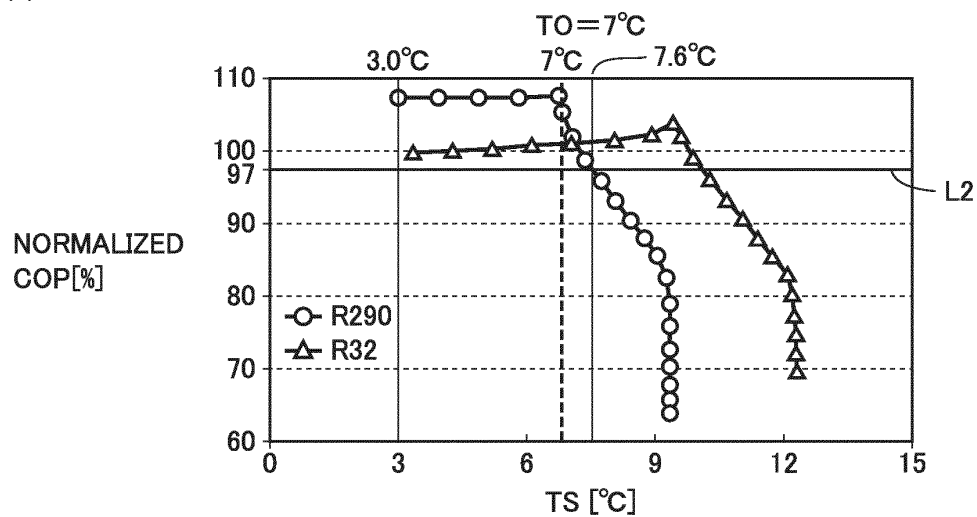


FIG. 7

(a)



(b)



(c)

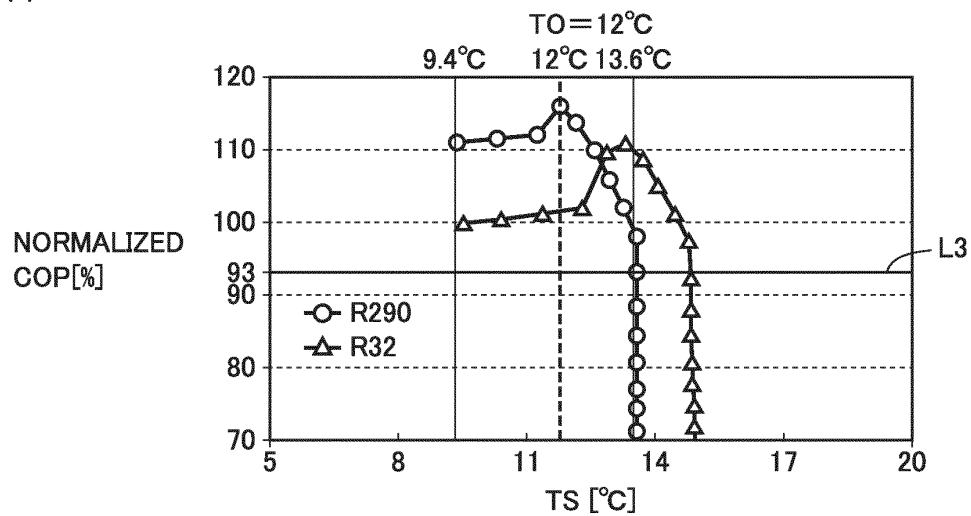


FIG.8

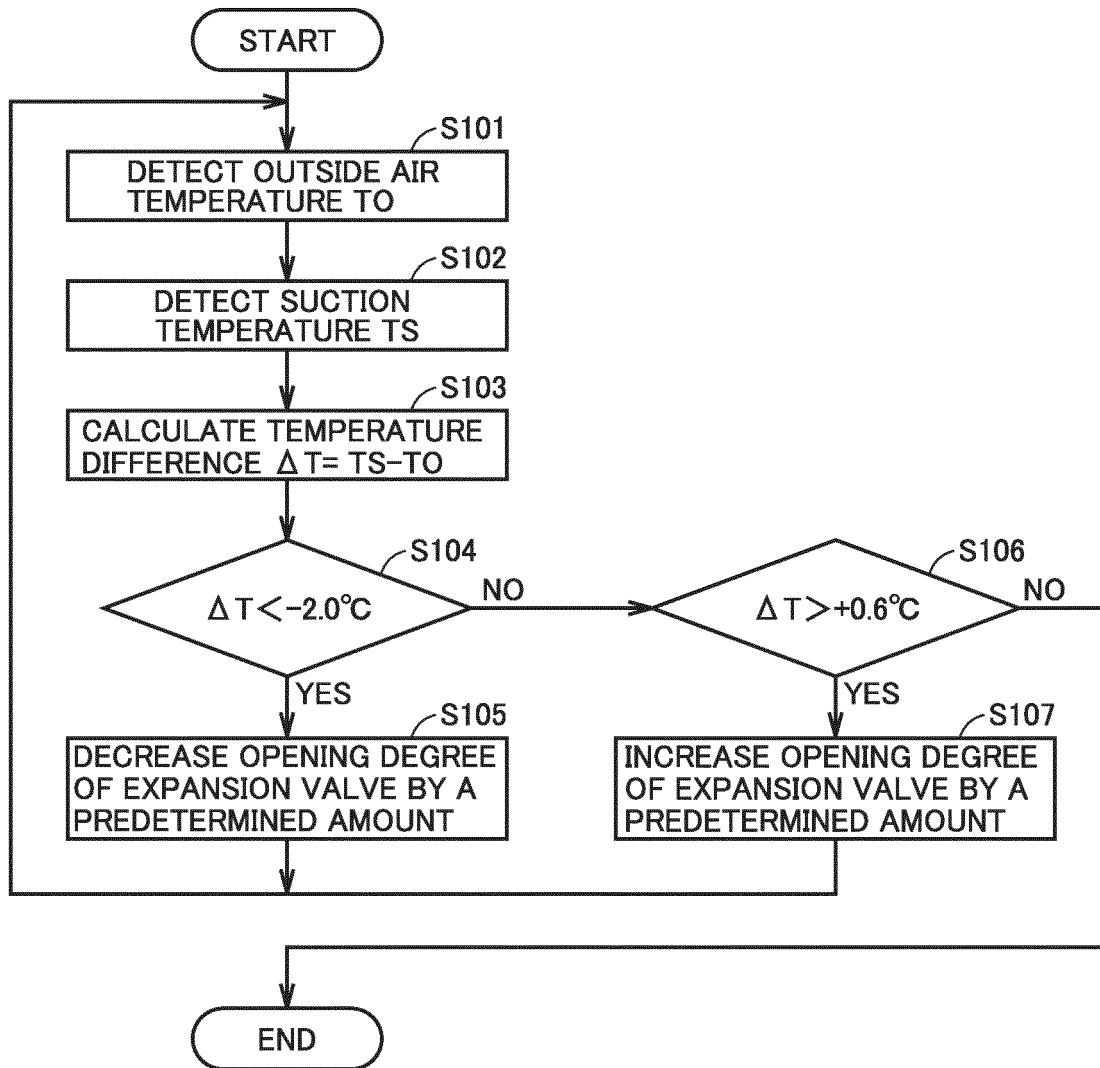


FIG.9

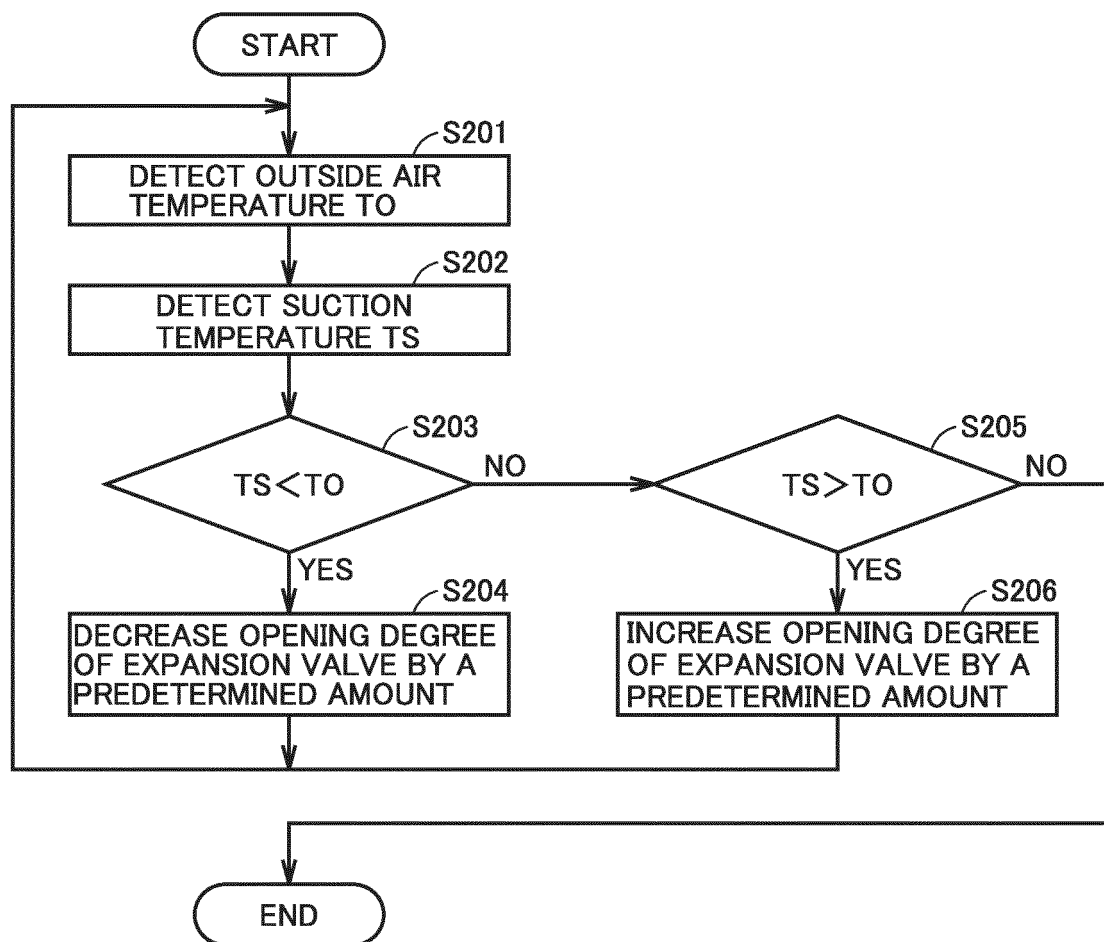
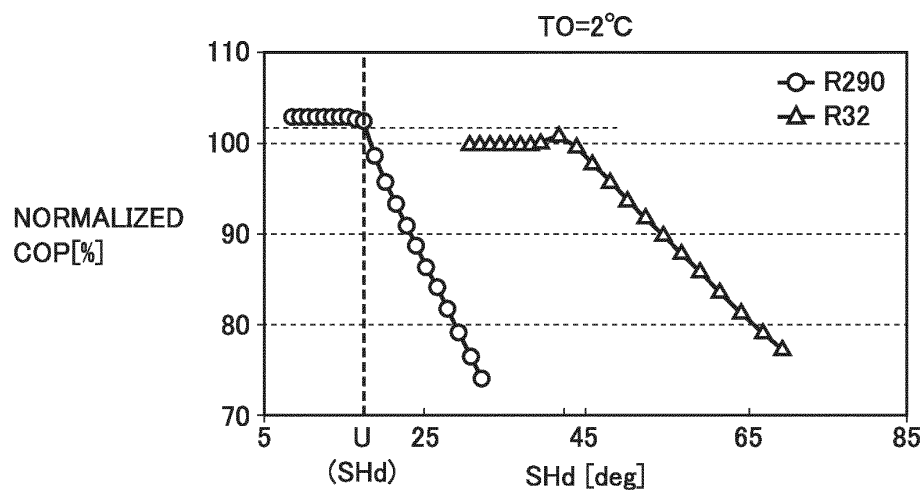
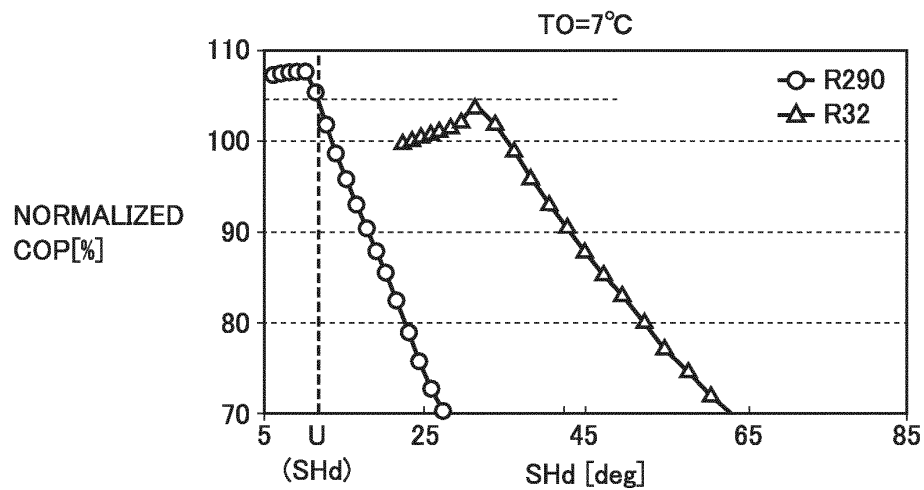


FIG.10

(a)



(b)



(c)

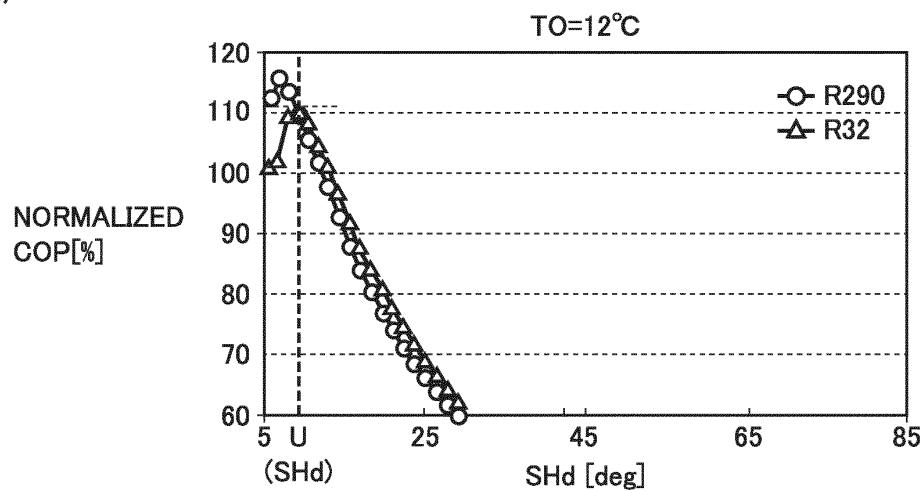


FIG.11

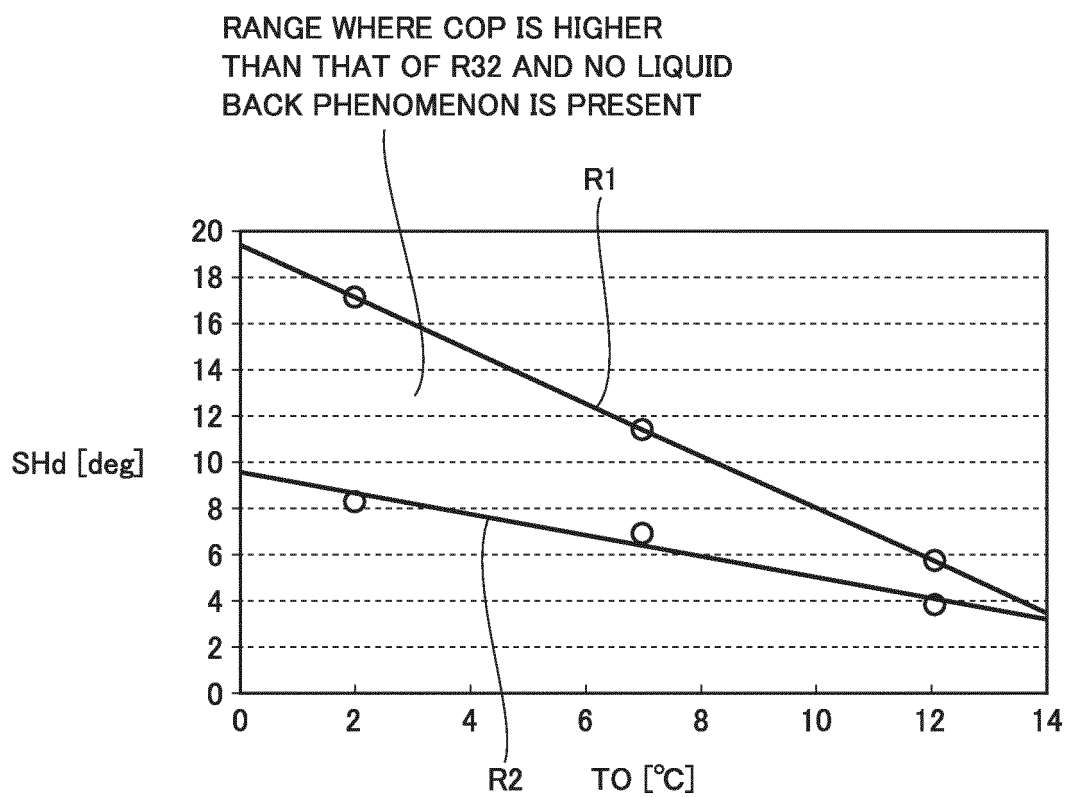
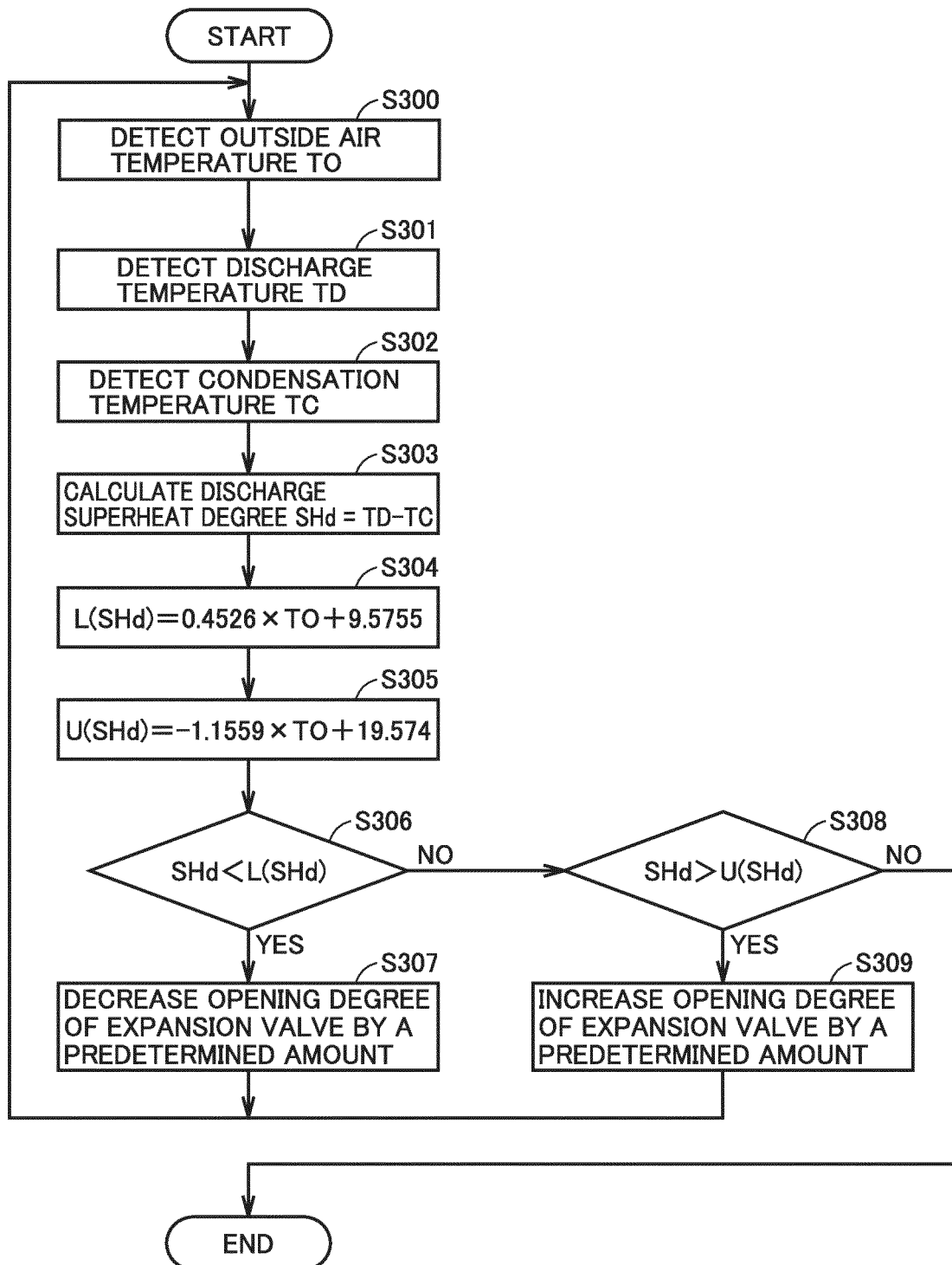


FIG.12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/042112

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. F25B1/00 (2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl. 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 1971-2019

Registered utility model specifications of Japan 1996-2019

Published registered utility model applications of Japan 1994-2019

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.
A	JP 2010-38463 A (PANASONIC CORP.) 18 February 2010, paragraphs [0046]-[0052], [0079]-[0087], [0118] (Family: none)	1-2
A	WO 2013/080244 A1 (MITSUBISHI ELECTRIC CORP.) 06 June 2013, paragraphs [0056], [0079] & US 2014/0290292 A1, paragraphs [0065], [0089] & EP 2787305 A1 & CN 103958986 A	3-7

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

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Date of the actual completion of the international search
08.01.2019Date of mailing of the international search report
22.01.2019Name and mailing address of the ISA/
Japan Patent Office
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Tokyo 100-8915, Japan

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Patent documents cited in the description

- JP 11230626 A [0002] [0003]