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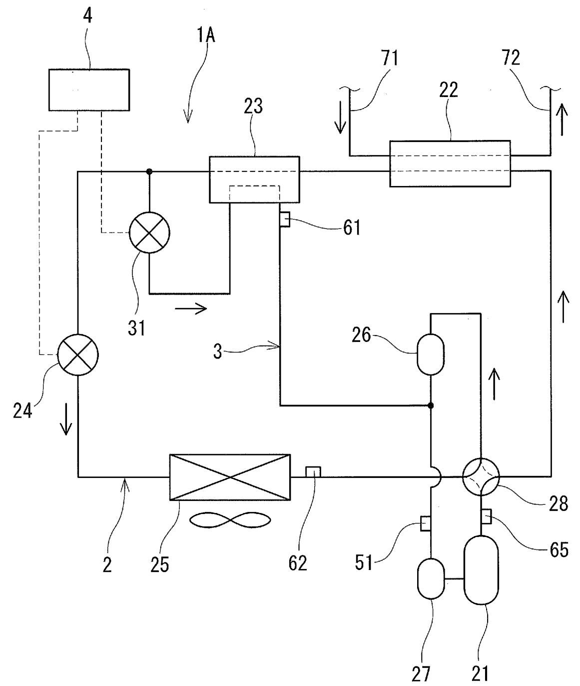
(54) **Refrigeration cycle apparatus and hot water heater**

(57) A refrigeration cycle apparatus 1A includes: a refrigerant circuit 2 provided with a subcooling heat exchanger 23; a bypass passage 3 extending through the subcooling heat exchanger 23; and a controller 4 for controlling a main expansion means 24 in the refrigerant circuit 2 and a bypass expansion means 31 in the bypass passage 3. The bypass expansion means 31 is controlled so that a bypass side outlet temperature conforms to a saturation temperature at a pressure of a refrigerant to be drawn into a compressor 21, and a degree of superheat at an outlet of an evaporator 25 calculated based on an evaporator outlet temperature is equal to or lower than a predetermined degree of superheat.

FIG.1




EP 2 320 165 A2

## Description

**[0001]** The present invention relates to a refrigeration cycle apparatus for subcooling a refrigerant that has flowed out of a condenser, and a hot water heater including the refrigeration cycle apparatus.

**[0002]** Conventionally, there is known a refrigeration cycle apparatus in which a subcooling heat exchanger is provided in a refrigerant circuit downstream of a condenser and an expanded refrigerant is made to flow into the subcooling heat exchanger so that the refrigerant that has flowed out of the condenser is subcooled. For example, JP 10(1998)-68553 A discloses a refrigeration cycle apparatus 100 as shown in FIG. 6.

**[0003]** The refrigeration cycle apparatus 100 includes a refrigerant circuit 110 in which a refrigerant circulates, and a bypass passage 120. The refrigerant circuit 110 includes a compressor 111, a condenser 112, a subcooling heat exchanger 113, a main expansion valve 114, and an evaporator 115 that are connected circularly. The bypass passage 120 is branched from the refrigerant circuit 110 between the condenser 112 and the subcooling heat exchanger 113, and extends through the subcooling heat exchanger 113 to join to the refrigerant circuit 110 between the evaporator 115 and the compressor 111. Abypass expansion valve 121 is provided in the bypass passage 120 upstream of the subcooling heat exchanger 113.

**[0004]** The refrigeration cycle apparatus 100 further includes: a pressure sensor 131 for detecting a pressure of the refrigerant to be drawn into the compressor 111; a temperature sensor 141 for detecting a temperature (an evaporator outlet temperature) Teo of the refrigerant that has flowed out of the evaporator 115; and a temperature sensor 142 for detecting a temperature (a bypass side outlet temperature) Tbo of the refrigerant that has flowed out of the subcooling heat exchanger 113 in the bypass passage 120.

**[0005]** JP 10(1998)-68553 A also describes that: with the pressure detected by the pressure sensor 131, a saturation temperature Ts at this pressure is calculated; the main expansion valve 114 is controlled so that a degree of superheat (Teo - Ts) at an outlet of the evaporator 115 conforms to a target degree of superheat; and the bypass expansion valve 121 is controlled so that a degree of superheat (Tbo - Ts) at an outlet of the subcooling heat exchanger 113 conforms to a target degree of superheat.

**[0006]** However, where the bypass expansion valve 121 is controlled so that the degree of superheat (Tbo - Ts) at the outlet of the subcooling heat exchanger 113 conforms to the target degree of superheat as described in JP 10(1998)-68553 A, the subcooling heat exchanger 113 cannot operate to its maximum capability because a larger amount of the refrigerant could be evaporated in the subcooling heat exchanger 113. More specifically, it is not possible to maximize the effect of increasing an enthalpy in the evaporator 115 owing to the heat exchange between the main flow refrigerant and the bypass flow refrigerant and the effect of reducing the pressure loss in a low pressure side refrigerant passage by bypassing the refrigerant. Moreover, if the refrigerant bypassing the evaporator 115 is superheated, not only the specific volume of the refrigerant to be drawn into the compressor 111 increases and the circulating amount of the refrigerant reduces, but also the discharge temperature of the compressor increases. Thus, when an outside air temperature is low, which requires a high heating capacity, it is not allowed to make the rotation speed of the compressor so high from the viewpoint of suppressing the discharge temperature and ensuring the reliability of the compressor. Thus, the heating capacity may be insufficient.

**[0007]** In view of the foregoing, the present invention is intended to provide a refrigeration cycle apparatus that is capable of maximizing the effect of increasing an enthalpy in an evaporator and the effect of reducing a pressure loss in a low pressure side refrigerant passage, and is capable of obtaining a sufficient heating capacity when an outside air temperature is low. The present invention is also intended to provide a hot water heater including the refrigeration cycle apparatus.

**[0008]** In order to solve the above-mentioned problems, the present invention provides a refrigeration cycle apparatus including: a refrigerant circuit including a compressor, a condenser, a subcooling heat exchanger, a main expansion means, and an evaporator that are connected circularly; a bypass passage that is branched from the refrigerant circuit between the condenser and the subcooling heat exchanger or between the subcooling heat exchanger and the main expansion means, and extends through the subcooling heat exchanger to join to the refrigerant circuit between the evaporator and the compressor; a bypass expansion means provided in the bypass passage upstream of the subcooling heat exchanger; a first temperature sensor for detecting a temperature of a refrigerant that has flowed out of the subcooling heat exchanger in the bypass passage; a second temperature sensor for detecting a temperature of the refrigerant that has flowed out of the evaporator in the refrigerant circuit; and a controller for controlling the bypass expansion means so that the temperature detected by the first temperature sensor conforms to a saturation temperature at a pressure of the refrigerant to be drawn into the compressor, and a degree of superheat at an outlet of the evaporator calculated based on the temperature detected by the second temperature sensor is equal to or lower than a predetermined degree of superheat.

**[0009]** The present invention also provides a hot water heater that performs heating by utilizing hot water produced by a heating means. The hot water heater includes the refrigeration cycle apparatus as the heating means.

**[0010]** In the above-mentioned configuration, since the temperature of the refrigerant that has flowed out of the subcooling heat exchanger in the bypass passage is maintained at the saturation temperature at the pressure of the refrigerant to be drawn into the compressor, the refrigerant that has flowed out of the subcooling heat exchanger can be maintained in a wet state or a saturated gaseous state. Moreover, since the degree of superheat at the outlet of the evaporator is suppressed to be equal to or lower than the predetermined degree of superheat, it is possible to prevent a situation in which the flow rate of the refrigerant flowing through the bypass passage increases excessively and thus a dryness fraction of the refrigerant to be drawn into the compressor (the refrigerant resulting from the merge of the refrigerant that has flowed through the bypass passage and the refrigerant that has passed through the evaporator) lowers excessively. Accordingly, the dryness fraction of the refrigerant to be drawn into the compressor can fall in a desired range (at least 0.8 but less than 1.0, for example). Thereby, it is possible to maximize the effect of increasing the enthalpy in the evaporator owing to the heat exchange between the main flow refrigerant and the bypass flow refrigerant, and the effect of reducing the pressure loss in the low pressure side refrigerant passage by bypassing the refrigerant. Moreover, since the discharge temperature of the compressor is suppressed, it is possible to increase the rotation speed of the compressor when the outside air temperature is low and to obtain a sufficient heating capacity.

**[0011]** FIG. 1 is a schematic configuration diagram of a refrigeration cycle apparatus according to Embodiment 1 of the present invention.

**[0012]** FIG. 2 is a Mollier diagram of the refrigeration cycle apparatus shown in FIG. 1.

**[0013]** FIG. 3 is a flow chart illustrating a control performed by a controller in Embodiment 1.

**[0014]** FIG. 4 is a schematic configuration diagram of a refrigeration cycle apparatus according to Embodiment 2 of the present invention.

**[0015]** FIG. 5 is a flow chart illustrating a control performed by a controller in Embodiment 2.

**[0016]** FIG. 6 is a schematic configuration diagram of a conventional refrigeration cycle apparatus.

(Embodiment 1)

**[0017]** FIG. 1 shows a refrigeration cycle apparatus 1A according to Embodiment 1 of the present invention. The refrigeration cycle apparatus 1A includes: a refrigerant circuit 2 in which a refrigerant circulates; a bypass passage 3; and a controller 4. Examples of the refrigerant include a zeotropic refrigerant mixture such as R407C, a nearly-azeotropic refrigerant mixture such as R410A, and a single refrigerant.

**[0018]** The refrigerant circuit 2 includes a compressor 21, a condenser 22, a subcooling heat exchanger 23, a main expansion valve (a main expansion means) 24, and an evaporator 25 that are connected circularly with a pipe. In the present embodiment, a sub accumulator 26 and a main accumulator 27 for performing gas-liquid separation are provided between the evaporator 25 and the compressor 21. The refrigerant circuit 2 is also provided with a four-way valve 28 for switching between a normal operation and a defrosting operation.

**[0019]** In the present embodiment, the refrigeration cycle apparatus 1A constitutes the heating means in the hot water heater that performs heating by utilizing hot water produced by the heating means, and the condenser 22 is a heat exchanger that heats water by exchanging heat between the water and the refrigerant. Specifically, a supply pipe 71 and a recovery pipe 72 are connected to the condenser 22, so that water is supplied to the condenser 22 through the supply pipe 71 and the water (hot water) heated in the condenser 22 is recovered through the recovery pipe 72. The hot water recovered through the recovery pipe 72 is sent to, for example, a heater such as a radiator, directly or through a hot water reservoir tank, and thereby heating is performed.

**[0020]** The bypass passage 3 is branched from the refrigerant circuit 2 between the subcooling heat exchanger 23 and the main expansion valves 24, and extends through the subcooling heat exchanger 23 to join to the refrigerant circuit 2 between the evaporator 25 and the compressor 21. In the present embodiment, the bypass passage 3 joins to the refrigerant circuit 2 between the sub accumulator 26 and the main accumulator 27. A bypass expansion valve (a bypass expansion means) 31 is provided in the bypass passage 3 upstream of the subcooling heat exchanger 23.

**[0021]** In the normal operation, the refrigerant discharged from the compressor 21 is sent to the condenser 22 through the four-way valve 28. In the defrosting operation, the refrigerant discharged from the compressor 21 is sent to the evaporator 25 through the four-way valve 28. In FIG. 1, the flowing directions of the refrigerant in the normal operation are indicated by arrows. Hereinafter, the state change of the refrigerant in the normal operation will be described.

**[0022]** The high pressure refrigerant discharged from the compressor 21 flows into the condenser 22 and radiates heat to the water passing through the condenser 22. The high pressure refrigerant that has flowed out of the condenser 22 flows into the subcooling heat exchanger 23 and is subcooled with the low pressure refrigerant decompressed by the bypass expansion valve 31. The high pressure refrigerant that has flowed out of the subcooling heat exchanger 23 is divided to flow separately to the main expansion valve 24 and the bypass expansion valve 31.

**[0023]** The high pressure refrigerant divided to flow to the main expansion valve 24 is decompressed and expanded by the main expansion valve 24, and then flows into the evaporator 25. The low pressure refrigerant that has flowed into the evaporator 25 absorbs heat from the air therein. On the other hand, the high pressure refrigerant divided to flow to the bypass expansion valve 31 is decompressed and expanded by the bypass expansion valve 31, and then flows into the subcooling heat exchanger 23. The low pressure refrigerant that has flowed into the subcooling heat exchanger 23 is heated with the high pressure refrigerant that has flowed out of the condenser 22. Thereafter, the low pressure refrigerant that has flowed out of the subcooling heat exchanger 23 is merged with the low pressure refrigerant that has flowed out of the evaporator 25 and the resulted refrigerant is drawn into the compressor 21 once again.

**[0024]** The refrigeration cycle apparatus 1A of the present embodiment is configured so as to prevent the situation in which when the outside air temperature is low, the pressure of the refrigerant to be drawn into the compressor 21 is lowered and the circulating amount of the refrigerant is reduced, and thus the heating capacity of the condenser 22 is lowered. In order to realize this configuration, it is important to increase an enthalpy difference in the evaporator 25 by subcooling the refrigerant, and to suppress the amount of the gaseous phase refrigerant having a low effect of absorbing heat flowing through a low pressure side of the refrigerant circuit 2 by bypassing the refrigerant with the bypass passage 3, and thereby reducing the pressure loss in the low pressure side of the refrigerant circuit 2. When the pressure loss in the low pressure side of the refrigerant circuit 2 is reduced, the pressure of the refrigerant to be drawn into the compressor 21 increases by the amount of the reduced pressure loss, reducing the specific volume of the refrigerant. Accordingly, the circulating amount of the refrigerant increases. Moreover, by increasing the enthalpy difference in the evaporator 25, it is possible to ensure the amount of heat absorption in the evaporator 25 even when the mass flow rate of the refrigerant passing through the evaporator 25 lowers due to the bypassing. More specifically, by maximizing the degree of subcooling the refrigerant and the bypassing amount of the refrigerant, it is possible to maximize the effect of enhancing the heating capacity of the condenser 22 and the effect of enhancing the COP (Coefficient of Performance) of the refrigeration cycle apparatus 1A.

**[0025]** In the present embodiment, the bypass expansion valve 31 is controlled so as to prevent the refrigerant flowing through the bypass passage 3 from being superheated in the subcooling heat exchanger 23, which will be described in detail later. Accordingly, the refrigerant that has flowed out of the subcooling heat exchanger 23 in the bypass passage 3 is in a saturated state of Point a shown in FIG. 2. In contrast, since the refrigerant is superheated in the evaporator 25, the refrigerant that has flowed out of the evaporator 25 is in the state of Point b shown in FIG. 2. The refrigerant to be drawn into the compressor 21 is in the state of Point c, which is between Point a and Point b, because it is the result of the merge of these refrigerants.

**[0026]** The bypass passage 3 is provided with a first temperature sensor 61 for detecting a temperature (a bypass side outlet temperature) Tbo of the refrigerant that has flowed out of the subcooling heat exchanger 23. In contrast, the refrigerant circuit 2 is provided with: a pressure sensor 51 for detecting a pressure (a suction pressure) Ps of the refrigerant to be drawn into the compressor 21; a discharge temperature sensor 65 for detecting a temperature (a discharge temperature) Td of the refrigerant that has been discharged from the compressor 21; and a second temperature sensor 62 for detecting a temperature (an evaporator outlet temperature) Teo of the refrigerant that has flowed out of the evaporator 25.

**[0027]** The controller 4 controls the rotation speed of the compressor 21, the switching of the four-way valve 28, and openings of the main expansion valve 24 and the bypass expansion valve 31, based on the detected values detected by the sensors 51, 61, 62, and 65, etc. In the present embodiment, the controller 4 controls the bypass expansion means 31 so that, in the normal operation, the bypass side outlet temperature Tbo detected by the first temperature sensor 61 conforms to a saturation temperature STs at the pressure of the refrigerant to be drawn into the compressor 21, and a degree of superheat SHe at an outlet of the evaporator 25 calculated based on the evaporator outlet temperature Teo detected by the second temperature sensor 62 is equal to or lower than a predetermined degree of superheat.

**[0028]** Next, the control performed by the controller 4 in the normal operation will be described in detail with reference to the flow chart shown in FIG. 3.

**[0029]** First, the controller 4 detects the discharge temperature Td with the discharge temperature sensor 65 (Step S1), and adjusts the opening of the main expansion valve 24 so that the discharge temperature Td conforms to a target value (Step S2).

**[0030]** Subsequently, the controller 4 detects the suction pressure Ps with the pressure sensor 51 and detects the bypass side outlet temperature Tbo with the first temperature sensor 61 (Step S3). Further, the controller 4 calculates, from the detected suction pressure Ps, the saturation temperature STs at the pressure of the refrigerant to be drawn into the compressor 21 (Step S4). The calculation of the saturation temperature STs is made using a refrigerant property formula. Thereafter, the controller 4 judges whether the bypass side outlet temperature Tbo is equal to the saturation temperature STs (Step S5).

**[0031]** If the bypass side outlet temperature Tbo is not equal to the saturation temperature STs (NO in Step S5), the controller 4 increases the opening of the bypass expansion valve 31 by a specified amount (Step S6) and returns to Step S1, under the assumption that a larger amount of refrigerant could have been evaporated in the subcooling heat exchanger 23.

**[0032]** In contrast, if the bypass side outlet temperature Tbo is equal to the saturation temperature STs (YES in Step S5), the controller 4 proceeds to a control for correcting the opening of the bypass expansion valve 31, under the assumption that the subcooling heat exchanger 23 operates to its maximum capability to evaporate the refrigerant.

**[0033]** More specifically, the controller 4 detects the evaporator outlet temperature Teo with the second temperature sensor 62 (Step S7), and calculates the degree of superheat SHe at the outlet of the evaporator 25 using a formula below (Step S8).

$$SHe = Teo - STs$$

**[0034]** Thereafter, the controller 4 judges whether the calculated degree of superheat SHe at the outlet of the evaporator 25 is equal to or lower than the predetermined degree of superheat (Step S9). If NO in Step S9, the controller 4 reduces the opening of the bypass expansion valve 31 by a specified amount (Step S 10) and returns to Step S1, under the assumption that Point c shown in FIG. 2 is too far on the right (the degree of superheat is excessively high because the flow rate of the refrigerant is insufficient), that is, Point a is too far on the left (the refrigerant is excessively wet because the flow rate is excessively high). In contrast, if YES in Step S9, the controller 4 returns to Step S1 without changing the opening of the bypass expansion valve 31, under the assumption that the opening is appropriate.

**[0035]** In the present embodiment, since the bypass side outlet temperature Tbo is maintained at the saturation temperature STs at the pressure of the refrigerant to be drawn into the compressor 21 as described above, the refrigerant that has flowed out of the subcooling heat exchanger 23 can be maintained in a wet state or in a saturated gaseous state. Moreover, since the degree of superheat SHe at the outlet of the evaporator is suppressed to be equal to or lower than the predetermined degree of superheat, it is possible to prevent a situation in which the flow rate of the refrigerant flowing through the bypass passage 3 increases excessively and thus a dryness fraction of the refrigerant to be drawn into the compressor 21 (the refrigerant resulted from the merge of the refrigerant that has flowed through the bypass passage 3 and the refrigerant that has passed through the evaporator 25) lowers excessively. Accordingly, the dryness fraction of the refrigerant to be drawn into the compressor 21 can fall in a desired range (at least 0.8 but less than 1.0, for example). Thereby, it is possible to maximize the effect of increasing the enthalpy in the evaporator 25 owing to the heat exchange between the main flow refrigerant and the bypass flow refrigerant, and the effect of reducing the pressure loss in a low pressure side refrigerant passage by bypassing the refrigerant. Moreover, since the discharge temperature Td of the compressor 21 is suppressed, it is possible to increase the rotation speed of the compressor 21 when the outside air temperature is low and to obtain a sufficient heating capacity.

**[0036]** As stated herein, the "predetermined degree of superheat" used in Step S9 preferably is a degree of superheat that allows the refrigerant to be drawn into the compressor 21 to have a dryness fraction of at least 0.8 but less than 1.0. Such a configuration makes it possible to operate the refrigeration cycle apparatus 1A in the most efficient state. The dryness fraction of the refrigerant to be drawn into the compressor 21 is calculated using a formula below.

$$X = (ha - hl) / (hv - hl)$$

**[0037]** where: X is the dryness fraction of the refrigerant to be drawn into the compressor 21; ha is an enthalpy of the refrigerant to be drawn into the compressor 21; hl is an enthalpy of the saturated gaseous refrigerant at the pressure of the refrigerant to be drawn into the compressor 21; and hv is an enthalpy of the saturated liquid refrigerant at the pressure of the refrigerant to be drawn into the compressor 21.

**[0038]** Moreover, the "predetermined degree of superheat" preferably is defined in accordance with an outside air temperature so that the dryness fraction of the refrigerant to be drawn into the compressor 21 reduces as the outside air temperature lowers. Such a configuration makes it possible to increase the rotation speed of the compressor 21 while suppressing the discharge temperature from rising beyond an appropriate range because of a decrease in an evaporating pressure caused by the lowering of the outside air temperature. As a result, a sufficient heating capacity can be obtained. In this case, the control may be performed while the outside air temperature is detected with an outside air temperature sensor.

**[0039]** Alternatively, the "predetermined degree of superheat" preferably is defined in accordance with a compression ratio of the refrigerant by the compressor 21 so that the dryness fraction of the refrigerant to be drawn into the compressor 21 reduces as the compression ratio increases. Such a configuration makes it possible to increase the rotation speed of the compressor 21 while suppressing an increase in the discharge temperature caused by the increase in the compression ratio. As a result, a sufficient heating capacity can be obtained. In this case, the control may be performed while a discharge pressure and the suction pressure of the compressor 21 are detected with pressure sensors.

**[0040]** From another aspect, the "predetermined degree of superheat" preferably is defined in accordance with the rotation speed of the compressor 21 so that the dryness fraction of the refrigerant to be drawn into the compressor 21 reduces as the rotation speed of the compressor 21 increases. Such a configuration makes it possible to increase the rotation speed of the compressor 21 while suppressing a decrease in the discharge temperature caused by the increase in the rotation speed. As a result, a sufficient heating capacity can be obtained.

<Modification>

**[0041]** In FIG. 1, the pressure sensor 51 is provided in the refrigerant circuit 2, between the main accumulator 27 and a position at which the bypass passage 3 joins to the refrigerant circuit 2. However, the pressure sensor 51 may be provided anywhere in the refrigerant circuit 2 as long as it is between the evaporator 25 and the compressor 21. Alternatively, the pressure sensor 51 may be provided in the bypass passage 3 downstream of the subcooling heat exchanger 23.

(Embodiment 2)

**[0042]** FIG. 4 shows a refrigeration cycle apparatus 1B according to Embodiment 2 of the present invention. In the present embodiment, the same components as those in Embodiment 1 are designated by the same reference numerals, and the descriptions thereof are omitted.

**[0043]** Also in the present embodiment, the controller 4 controls the bypass expansion means 31 so that, in the normal operation, the bypass side outlet temperature Tbo detected by the first temperature sensor 61 conforms to the saturation temperature STs at the pressure of the refrigerant to be drawn into the compressor 21, and the degree of superheat SHe at the outlet of the evaporator 25 calculated based on the evaporator outlet temperature Teo detected by the second temperature sensor 62 is equal to or lower than a predetermined degree of superheat, as in Embodiment 1. It should be noted, however, that the present embodiment is different from Embodiment 1 in that the controller 4 recognizes that the bypass side outlet temperature Tbo detected by the first temperature sensor 61 conforms to the saturation temperature STs at the pressure of the refrigerant to be drawn into the compressor 21 from the fact that the bypass side outlet temperature Tbo detected by the first temperature sensor 61 is approximately equal to a temperature detected by a third temperature sensor 63.

**[0044]** Specifically, as shown in Fig. 4, the pressure sensor 51 (see FIG. 1) is not provided in the refrigerant circuit 2 in the present embodiment. Instead, the third temperature sensor 63 for detecting a temperature (a bypass side inlet temperature) Tbi of the refrigerant to flow into the subcooling heat exchanger 23 is provided in the bypass passage 3.

**[0045]** Next, the control performed by the controller 4 in the normal operation will be described in detail with reference to the flow chart shown in FIG. 5.

**[0046]** First, the controller 4 detects the discharge temperature Td with the discharge temperature sensor 65 (Step S21), and adjusts the opening of the main expansion valve 24 so that the discharge temperature Td conforms to a target value (Step S22), as in Embodiment 1.

**[0047]** Subsequently, the controller 4 detects the bypass side outlet temperature Tbo with the first temperature sensor 61 and detects the bypass side inlet temperature Tbi with the third temperature sensor 63 (Step S23). Thereafter, the controller 4 judges whether the bypass side outlet temperature Tbo is approximately equal to the bypass side inlet temperature Tbi (Step S24). In reality, the bypass side outlet temperature Tbo is not completely equal to the bypass side inlet temperature Tbi because of the influence of the pressure loss. Thus, the term "approximately equal" is a concept taking this phenomenon into consideration. For example, in the case where the difference between the bypass side outlet temperature Tbo and the bypass side inlet temperature Tbi is 3K or less, it can be regarded as being approximately equal.

**[0048]** If the bypass side outlet temperature Tbo is not approximately equal to the bypass side inlet temperature Tbi (NO in Step S24), the controller 4 increases the opening of the bypass expansion valve 31 by a specified amount (Step S25) and returns to Step S21, under the assumption that a larger amount of refrigerant could have been evaporated in the subcooling heat exchanger 23.

**[0049]** In contrast, if the bypass side outlet temperature Tbo is approximately equal to the bypass side inlet temperature Tbi (YES in Step S24), the controller 4 proceeds to the control for correcting the opening of the bypass expansion valve 31, under the assumption that the subcooling heat exchanger 23 operates to its maximum capability to evaporate the refrigerant.

**[0050]** More specifically, the controller 4 detects the evaporator outlet temperature Teo with the second temperature sensor 62 (Step S26), and calculates the degree of superheat SHe at the outlet of the evaporator 25 using a formula below (Step S27).

$$SHe = Teo - Tbi$$

**[0051]** Thereafter, the controller 4 judges whether the calculated degree of superheat SHe at the outlet of the evaporator 25 is equal to or lower than the predetermined degree of superheat (Step S28). If NO in Step S28, the controller 4 decreases the opening of the bypass expansion valve 31 by a specified amount (Step S29) and returns to Step S21, under the assumption that Point c shown in FIG. 2 is too far on the right, that is, Point a shown is too far on the left. In contrast, if YES in Step S28, the controller 4 returns to Step S21 without changing the opening of the bypass expansion valve 31, under the assumption that the opening is appropriate.

**[0052]** Performing the control as in the present embodiment also makes it possible to obtain the same advantageous effects as in Embodiment 1.

<Modification>

**[0053]** Although the third temperature sensor 63 for detecting the bypass side inlet temperature Tbi is used in the present embodiment, the third temperature sensor in the present invention may be a temperature sensor for detecting a temperature (an evaporator inlet temperature) Tei of the refrigerant to flow into the evaporator 25 in the refrigerant circuit 2. The flow chart in this case is given by replacing the bypass side inlet temperature Tbi in the flow chart shown in FIG. 5 with the evaporator inlet temperature Tei. In Step S27, the degree of superheat SHe at the outlet of the evaporator 25 is calculated using a formula below.

$$SHe = Teo - Tei$$

(Other Embodiments)

**[0054]** In Embodiments 1 and 2, the main expansion valve 24 is controlled so that the discharge temperature Td conforms to a target value. However, the method of controlling the main control valve 24 is not limited to this. For example, the main expansion valve 24 may be controlled so that the pressure of the refrigerant discharged from the compressor 21 conforms to a target value. Alternatively, the main expansion valve 24 can be controlled based on a degree of superheat at an outlet of the compressor 21 or a degree of subcooling at an outlet of the condenser 22.

**[0055]** The bypass passage 3 does not necessarily have to be branched from the refrigerant circuit 2 between the subcooling heat exchanger 23 and the main expansion valves 24. It may be branched from the refrigerant circuit 2 between the condenser 22 and the subcooling heat exchanger 23.

**[0056]** Furthermore, the main expansion means and the bypass expansion means of the present invention do not necessarily have to be expansion valves. Each of them may be an expander that recovers power from the refrigerant expanding. In this case, the rotation speed of the expander may be controlled by, for example, changing the load by using a power generator connected to the expander.

**[0057]** The present invention is particularly useful for hot water heaters that produce hot water with a refrigeration cycle apparatus and perform heating by utilizing the hot water.

## Claims

**1.** A refrigeration cycle apparatus comprising:

a refrigerant circuit including a compressor, a condenser, a subcooling heat exchanger, a main expansion means, and an evaporator that are connected circularly;

a bypass passage that is branched from the refrigerant circuit between the condenser and the subcooling heat exchanger or between the subcooling heat exchanger and the main expansion means, and extends through the subcooling heat exchanger to join to the refrigerant circuit between the evaporator and the compressor;

a bypass expansion means provided in the bypass passage upstream of the subcooling heat exchanger;

a first temperature sensor for detecting a temperature of a refrigerant that has flowed out of the subcooling heat exchanger in the bypass passage;

a second temperature sensor for detecting a temperature of the refrigerant that has flowed out of the evaporator in the refrigerant circuit; and

a controller for controlling the bypass expansion means so that the temperature detected by the first temperature sensor conforms to a saturation temperature at a pressure of the refrigerant to be drawn into the compressor, and a degree of superheat at an outlet of the evaporator calculated based on the temperature detected by the second temperature sensor is equal to or lower than a predetermined degree of superheat.

**2.** The refrigeration cycle apparatus according to claim 1, further comprising a pressure sensor for detecting the pressure of the refrigerant to be drawn into the compressor,
wherein the controller calculates, from the pressure detected by the pressure sensor, the saturation temperature at the pressure of the refrigerant to be drawn into the compressor.

**3.** The refrigeration cycle apparatus according to claim 1, further comprising a third temperature sensor for detecting a temperature of the refrigerant to flow into the subcooling heat exchanger in the bypass passage, or for detecting a temperature of the refrigerant to flow into the evaporator in the refrigerant circuit,
wherein the controller recognizes that the temperature detected by the first temperature sensor conforms to the saturation temperature at the pressure of the refrigerant to be drawn into the compressor from the fact that the temperature detected by the first temperature sensor is approximately equal to the temperature detected by the third temperature sensor.

**4.** The refrigeration cycle apparatus according to any one of claims 1 to 3, wherein the predetermined degree of superheat is a degree of superheat that allows the refrigerant to be drawn into the compressor to have a dryness fraction of at least 0.8 but less than 1.0.

**5.** The refrigeration cycle apparatus according to claim 4, wherein the predetermined degree of superheat is defined in accordance with an outside air temperature so that the dryness fraction of the refrigerant to be drawn into the compressor reduces as the outside air temperature lowers.

**6.** The refrigeration cycle apparatus according to claim 4, wherein the predetermined degree of superheat is defined in accordance with a compression ratio of the refrigerant by the compressor so that the dryness fraction of the refrigerant to be drawn into the compressor reduces as the compression ratio increases.

**7.** The refrigeration cycle apparatus according to claim 4, wherein the predetermined degree of superheat is defined in accordance with a rotation speed of the compressor so that the dryness fraction of the refrigerant to be drawn into the compressor reduces as the rotation speed of the compressor increases.

**8.** The refrigeration cycle apparatus according to any one of claims 1 to 7, wherein the condenser is a heat exchanger that heats water by exchanging heat between the water and the refrigerant.

**9.** A hot water heater that performs heating by utilizing hot water produced by a heating means, comprising the refrigeration cycle apparatus according to claim 8 as the heating means.

FIG.1

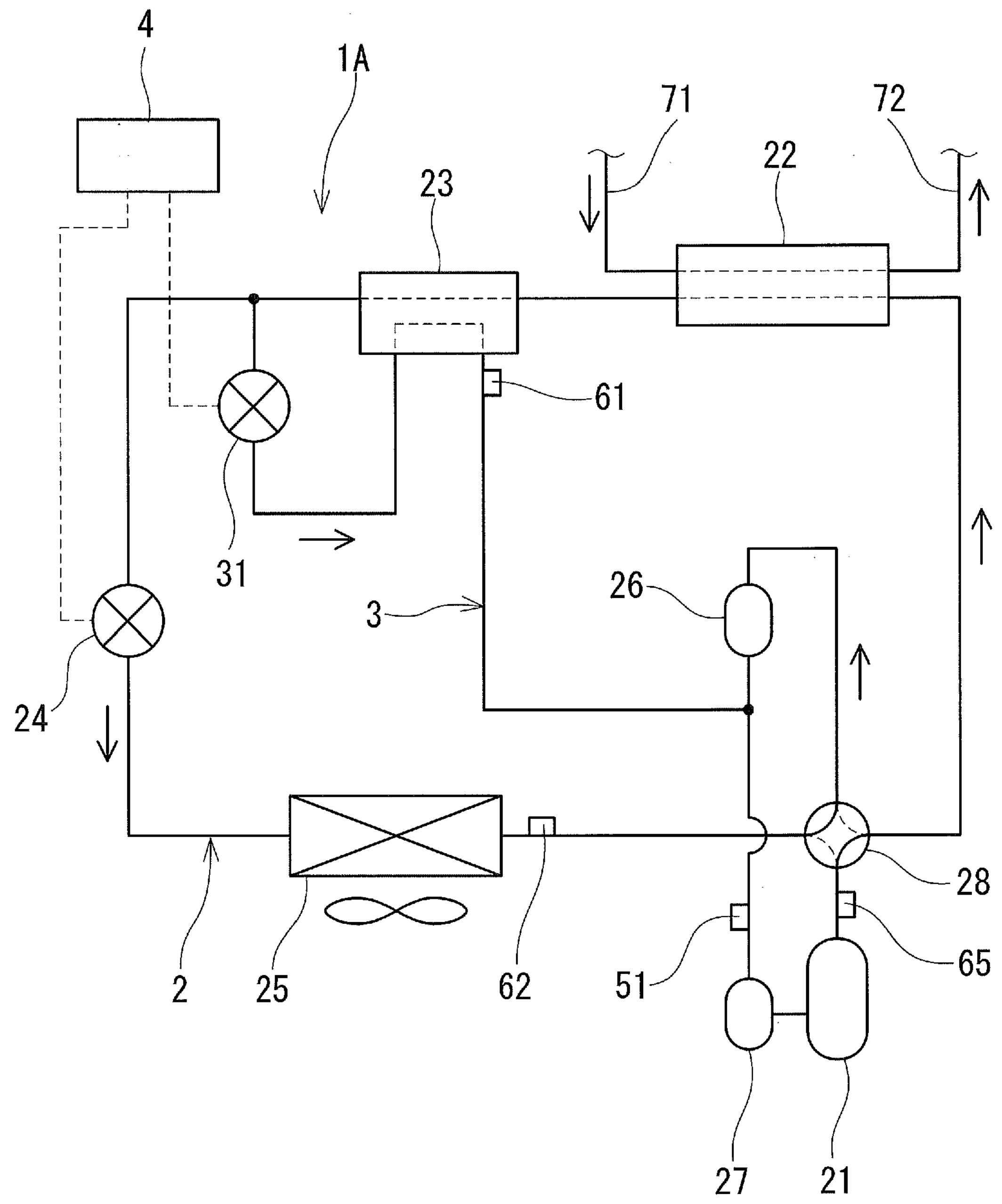


FIG.2

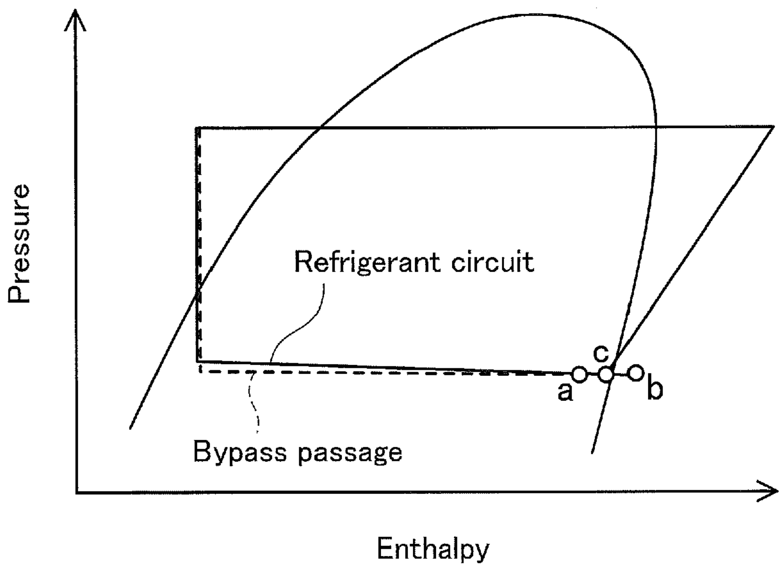

Pressure
Refrigerant circuit
c
a
b
Bypass passage
Enthalpy

FIG.3

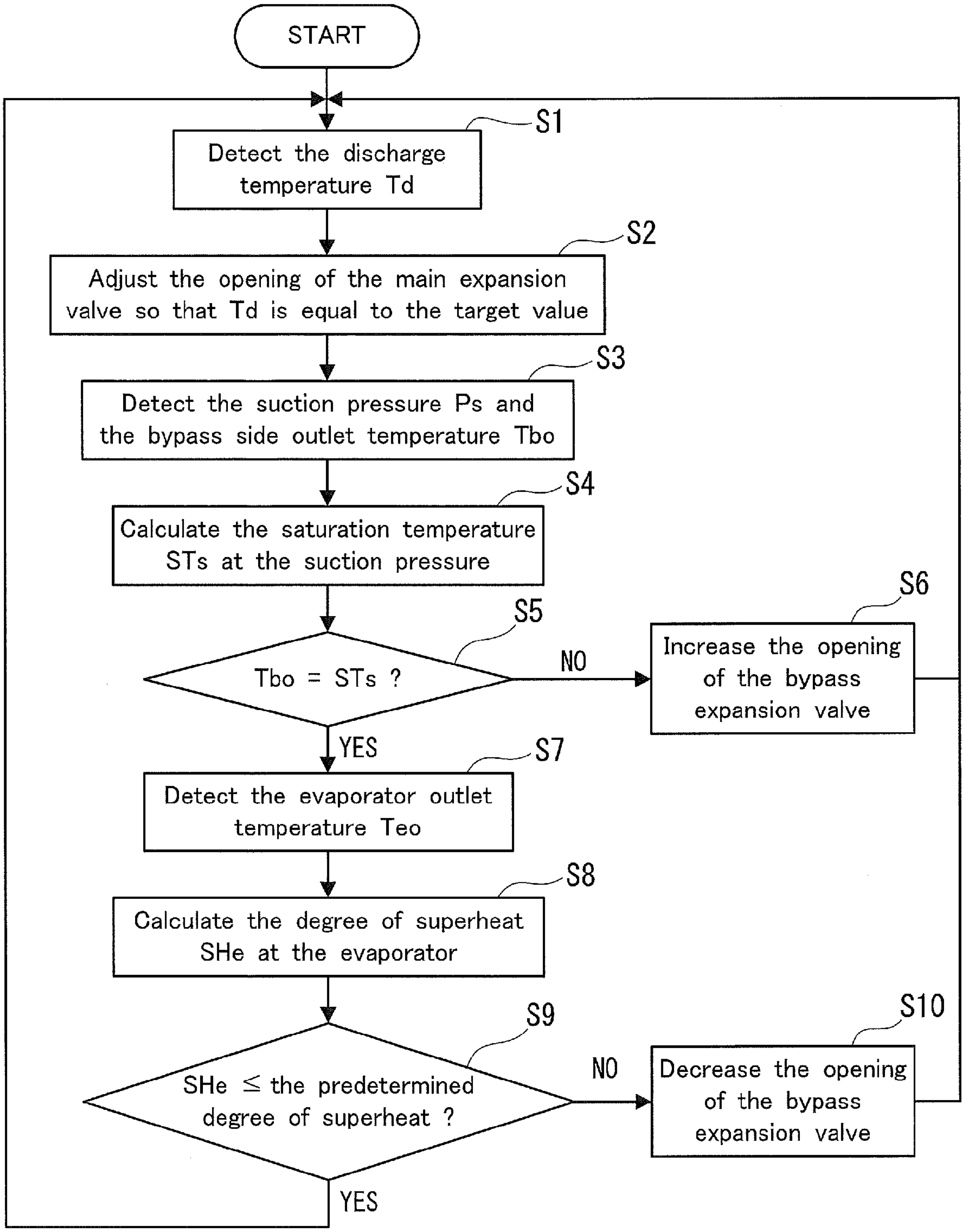

START
S1
Detect the discharge temperature Td
S2
Adjust the opening of the main expansion valve so that Td is equal to the target value
S3
Detect the suction pressure Ps and the bypass side outlet temperature Tbo
S4
Calculate the saturation temperature STs at the suction pressure
S5
Tbo = STs ?
NO
S6
Increase the opening of the bypass expansion valve
YES
S7
Detect the evaporator outlet temperature Teo
S8
Calculate the degree of superheat SHe at the evaporator
S9
SHe ≤ the predetermined degree of superheat ?
NO
S10
Decrease the opening of the bypass expansion valve
YES

FIG.4

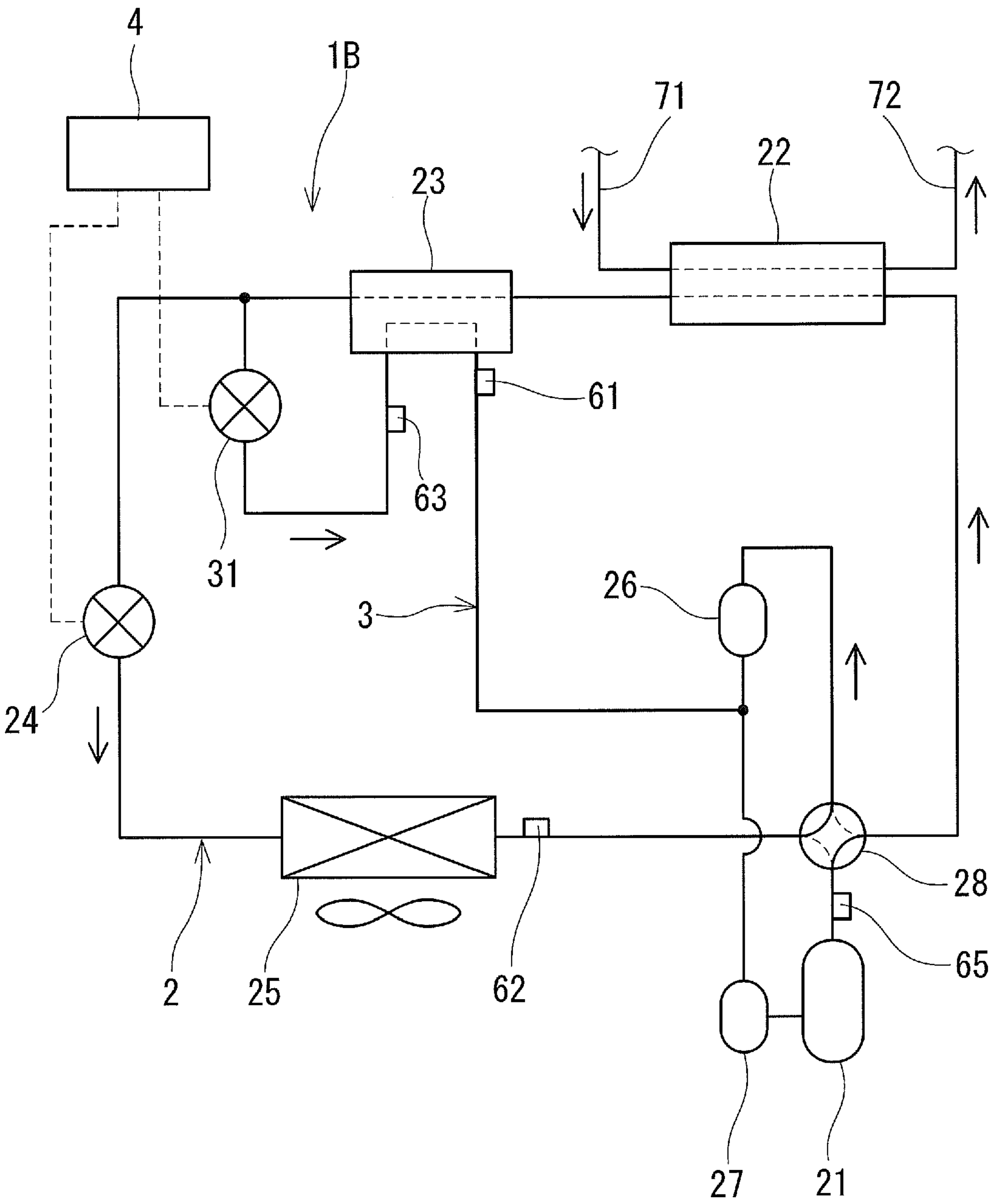


FIG.5

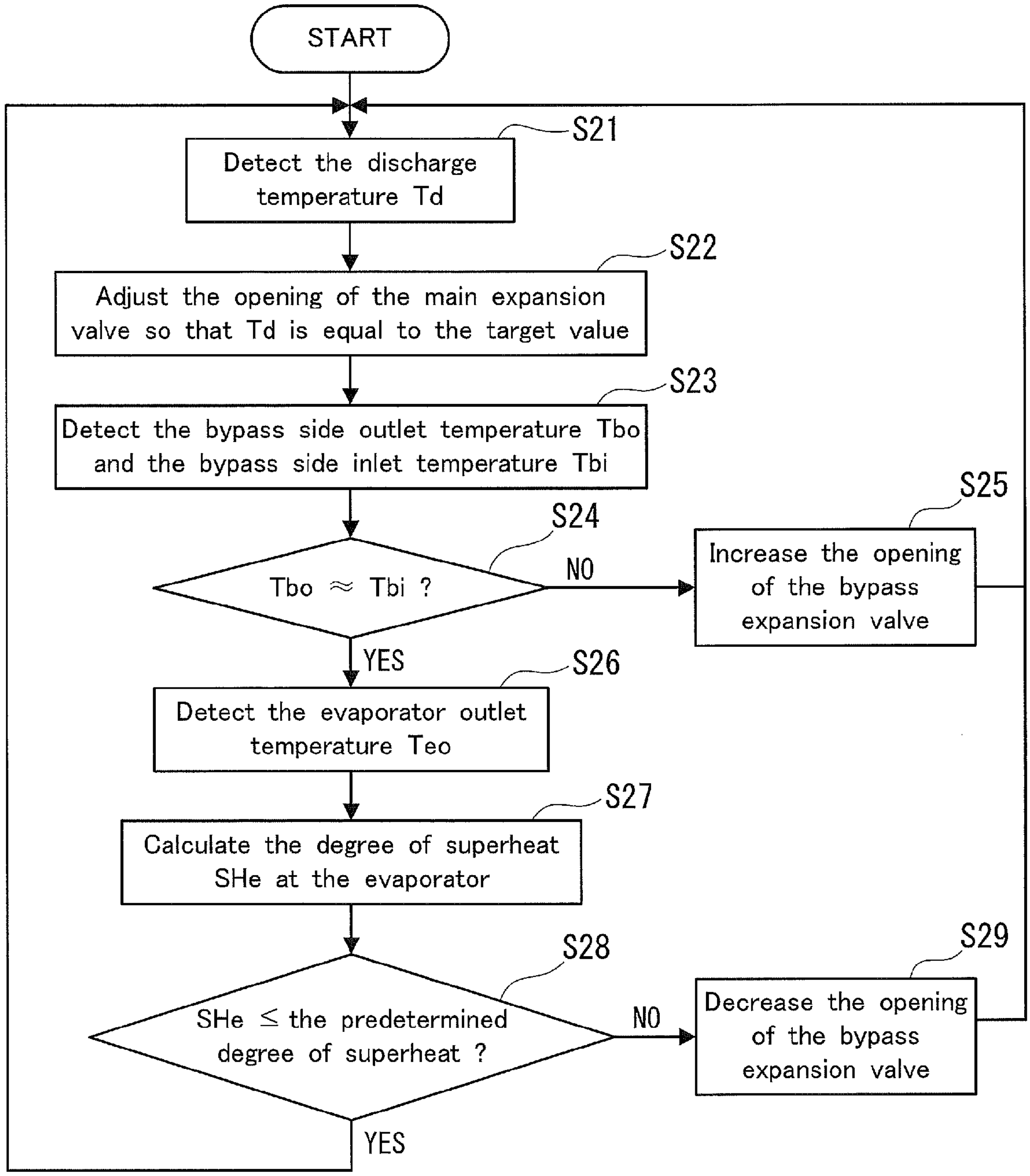
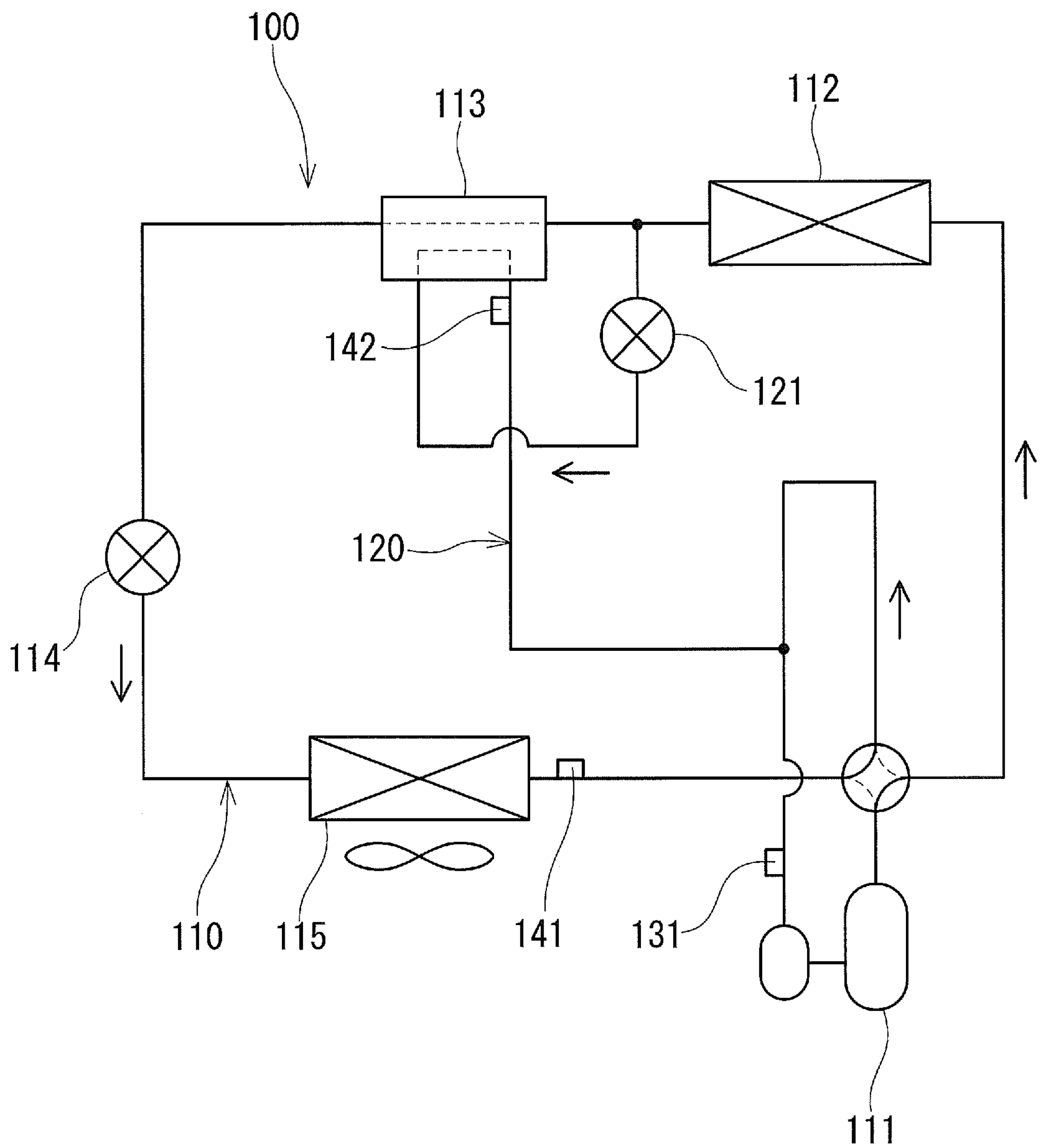

START
S21
Detect the discharge temperature Td
S22
Adjust the opening of the main expansion valve so that Td is equal to the target value
S23
Detect the bypass side outlet temperature Tbo and the bypass side inlet temperature Tbi
S24
Tbo ≈ Tbi ?
NO
S25
Increase the opening of the bypass expansion valve
YES
S26
Detect the evaporator outlet temperature Teo
S27
Calculate the degree of superheat SHe at the evaporator
S28
SHe ≤ the predetermined degree of superheat ?
NO
S29
Decrease the opening of the bypass expansion valve
YES

FIG.6



## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- JP 10068553 A **[0002] [0005] [0006]**