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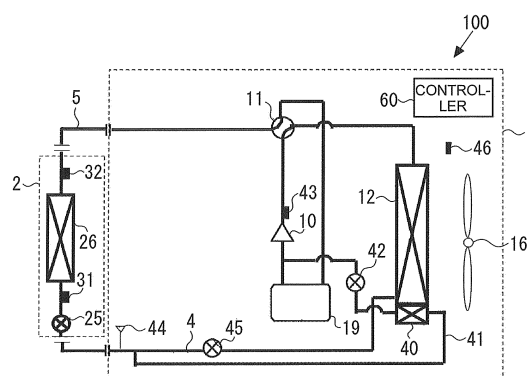
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(54) **AIR CONDITIONING DEVICE**

(57) An air-conditioning apparatus includes a first expansion device provided between a heat source-side heat exchanger and a load-side expansion device, a bypass pipe having one end connected between the first expansion device and the heat source-side heat exchanger, and allowing refrigerant flowing out of the first expansion device to flow through the bypass pipe, an auxiliary heat exchanger cooling refrigerant flowing through the bypass pipe and supplying the cooled refrigerant to a suction part of a compressor, a second expansion device regulating a flow rate of refrigerant allowed to flow into the suction part of the compressor from the auxiliary heat exchanger, a refrigerant flow switching device, and a controller configured to control an opening degree of the first expansion device and an opening degree of the second expansion device. When the heat source-side heat exchanger acts as a condenser or a gas cooler, the controller is configured to control the first expansion device and the second expansion device to allow high-pressure refrigerant to flow into the auxiliary heat exchanger. When the heat source-side heat exchanger acts as an evaporator, the controller is configured to control the first expansion device to allow medium-pressure refrigerant to flow into the auxiliary heat exchanger, and control the second expansion device to allow refrigerant cooled in the auxiliary heat exchanger to flow into the suction part of the compressor.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to an air-conditioning apparatus used as, for example, a multi-air-conditioning apparatus for buildings.

Background Art

10 **[0002]** Some of air-conditioning apparatuses known in related art, such as multi-air-conditioning apparatuses for buildings, have a refrigerant circuit in which, for example, an outdoor unit as a heat source unit disposed outside a building, and an indoor unit disposed inside the building are connected by pipes. Refrigerant circulates in the refrigerant circuit, and air is heated or cooled by utilizing the rejection or removal of heat by the refrigerant, thus heating or cooling the air-conditioned space. In recent years, air-conditioning apparatuses employing fluorocarbon refrigerants with low global warming potentials, such as an R32 refrigerant, have been considered for use in multi-air-conditioning apparatuses for buildings.

15 **[0003]** As opposed to an R410A refrigerant widely used in conventional air-conditioning apparatuses such as multi-air-conditioning apparatuses for buildings, an R32 refrigerant is characterized by its high discharge temperature of the compressor. The high discharge temperature causes problems such as degradation of the refrigerating machine oil, leading to damage to the compressor. Thus, to lower the discharge temperature of the compressor, the rotation speed of the compressor needs to be lowered to reduce the compression ratio. For this reason, it is impossible to increase the rotation speed of the compressor, leading to insufficient cooling capacity or insufficient heating capacity. The following approach is being proposed to address this problem. Refrigerant in a two-phase gas-liquid state is injected into a medium-pressure chamber that attains a medium pressure during the compression process of the compressor, thus lowering the discharge temperature of the compressor while the rotation speed of the compressor is increased (see, for example, Patent Literature 1).

Citation List

30 Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2008-138921 (Fig. 1, Fig. 2, and other descriptions)

35 Summary of Invention

Technical Problem

40 **[0005]** In the air-conditioning apparatus described in Patent Literature 1, when the saturation temperature of high-pressure refrigerant becomes equal to or higher than the temperature of the indoor or outdoor air after activation of the air-conditioning apparatus, the high-pressure refrigerant in a gaseous state liquefies as the refrigerant rejects heat to the indoor air or outdoor air. Then, refrigerant in a two-phase gas-liquid state and at a low quality (with a high liquid-phase content) is allowed to flow into the medium-pressure part of the compressor, thus lowering the discharge temperature of the compressor. This approach, however, lacks general applicability because the limiting of discharge temperature is possible only for compressors having a structure allowing refrigerant to flow into the medium-pressure part of the compressor. Such compressors with a structure allowing refrigerant to flow into the medium-pressure part of the compressor are more expensive than compressors with no such structure.

45 **[0006]** The air-conditioning apparatus according to Patent Literature 1 has a circuit configuration that allows injection to be performed also in cooling operation. Specifically, the air-conditioning apparatus according to Patent Literature 1 includes a bypass expansion device that controls the flow rate of refrigerant injected into the medium-pressure chamber of the compressor, and a refrigerant-to-refrigerant heat exchanger that cools the refrigerant flowing from the bypass expansion device. The flow rate of refrigerant flowing into the refrigerant-to-refrigerant heat exchanger is controlled by the expansion device to control the discharge temperature at which refrigerant is discharged from the compressor. This arrangement makes it impossible to individually control both the discharge temperature and the degree of subcooling at the outlet of the condenser by using different target values, making it impossible to properly control the discharge temperature while maintaining an appropriate degree of subcooling.

55 **[0007]** That is, if the outdoor unit and the indoor unit are connected by a long extension pipe, when the discharge temperature is controlled to become a target value, it is impossible to control the degree of subcooling at the outlet of

the outdoor unit to become a target value. For this reason, refrigerant to flow into the indoor unit can be brought into a two-phase gas-liquid state owing to the pressure loss along the extension pipe. If an expansion device is provided on the indoor unit side as in, for example, a multi-air-conditioning apparatus having a plurality of indoor units, entry of refrigerant in a two-phase gas-liquid state into the inlet side of the expansion device produces noise or causes unstable control, thus reducing the reliability of the system.

[0008] The present invention has been made to address the above-mentioned problem, and ensures the reliability of the system of an air-conditioning apparatus even when an inexpensive compressor is used rather than a compressor having a special structure.

Solution to Problem

[0009] An air-conditioning apparatus according to the present invention is an air-conditioning apparatus including a refrigeration cycle in which refrigerant circulates, the refrigeration cycle including a compressor, a refrigerant flow switching device, a heat source-side heat exchanger, a load-side expansion device, and a load-side heat exchanger connected by a refrigerant pipe, the air-conditioning apparatus including a first expansion device provided between the heat source-side heat exchanger and the load-side expansion device, a bypass pipe having one end connected between the first expansion device and the heat source-side heat exchanger, and allowing refrigerant flowing out of the first expansion device to flow through the bypass pipe, an auxiliary heat exchanger connected to another end of the bypass pipe and a suction part of the compressor, and cooling refrigerant flowing through the bypass pipe and supplying the cooled refrigerant to the suction part of the compressor, a second expansion device provided on a refrigerant outlet side of the auxiliary heat exchanger, and regulating a flow rate of refrigerant allowed to flow into the suction part of the compressor from the auxiliary heat exchanger, and a controller configured to control the refrigerant flow switching device to switch a flow path of refrigerant between a flow path in a case where the heat source-side heat exchanger acts as a condenser or a gas cooler and a flow path in a case where the heat source-side heat exchanger acts as an evaporator, and control an opening degree of the first expansion device and an opening degree of the second expansion device. When the heat source-side heat exchanger acts as the condenser or the gas cooler, the controller is configured to control the first expansion device and the second expansion device to allow high-pressure refrigerant to flow into the auxiliary heat exchanger. When the heat source-side heat exchanger acts as the evaporator, the controller is configured to control the first expansion device to allow medium-pressure refrigerant to flow into the auxiliary heat exchanger, and control the second expansion device to allow refrigerant cooled in the auxiliary heat exchanger to flow into the suction part of the compressor.

Advantageous Effects of Invention

[0010] With the air-conditioning apparatus according to the present invention, the state and flow rate of refrigerant flowing into the suction part of the compressor from the bypass pipe are controlled by using the auxiliary heat exchanger, the first expansion device, and the second expansion device under all operating conditions to limit a rise in the discharge temperature of refrigerant discharged from the compressor. This configuration improves the reliability of the system inexpensively without employing a special structure for the compressor.

Brief Description of Drawings

[0011]

[Fig. 1] Fig. 1 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 1 of the present invention.

[Fig. 2] Fig. 2 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling operation mode of the air-conditioning apparatus according to Embodiment 1 of the present invention.

[Fig. 3] Fig. 3 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating operation mode of the air-conditioning apparatus according to Embodiment 1 of the present invention.

[Fig. 4] Fig. 4 is a graph illustrating the relationship between the ratio of the heat transfer area of a heat source-side heat exchanger to the sum of the heat transfer area of the heat source-side heat exchanger and the heat transfer area of an auxiliary heat exchanger in the air-conditioning apparatus according to Embodiment 1 of the present invention, and COP, which is an index of the performance of the air-conditioning apparatus.

[Fig. 5] Fig. 5 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 2 of the present invention.

[Fig. 6] Fig. 6 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of the air-conditioning apparatus according to Embodiment 2 of the present invention.

[Fig. 7] Fig. 7 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling main operation mode of the air-conditioning apparatus according to Embodiment 2 of the present invention.

[Fig. 8] Fig. 8 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating only operation mode of the air-conditioning apparatus according to Embodiment 2 of the present invention.

[Fig. 9] Fig. 9 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating main operation mode of the air-conditioning apparatus according to Embodiment 2 of the present invention.

[Fig. 10] Fig. 10 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of an air-conditioning apparatus according to Embodiment 3 of the present invention.

[Fig. 11] Fig. 11 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of an air-conditioning apparatus according to a modification of Embodiment 3 of the present invention.

[Fig. 12] Fig. 12 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of an air-conditioning apparatus according to Embodiment 4 of the present invention.

[Fig. 13] Fig. 13 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of an air-conditioning apparatus according to Embodiment 5 of the present invention.

[Fig. 14] Fig. 14 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to the present invention in which a heat exchanger such as a plate heat exchanger that allows heat exchange between refrigerant and a heat medium such as water and brine is provided in a relay device as a load-side heat exchanger.

Description of Embodiments

Embodiment 1

[0012] Hereinafter, an air-conditioning apparatus according to the present invention will be described with reference to the drawings. Fig. 1 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of the air-conditioning apparatus according to Embodiment 1. An air-conditioning apparatus 100 illustrated in Fig. 1 includes an outdoor unit 1 and an indoor unit 2 that are connected by a main pipe 5. Although a single indoor unit 2 is connected to the outdoor unit 1 via the main pipe 5 in Fig. 1, this is not intended to limit the number of indoor units 2 to one. Alternatively, multiple indoor units 2 may be connected.

[Outdoor Unit 1]

[0013] In the outdoor unit 1, a compressor 10, a refrigerant flow switching device 11, a heat source-side heat exchanger 12, an accumulator 19, an auxiliary heat exchanger 40, a first expansion device 45, a second expansion device 42, and a bypass pipe 41 are connected by a refrigerant pipe 4, and are mounted together with a fan 16 that is an air-sending device.

[0014] The compressor 10 sucks and compresses refrigerant to bring the refrigerant into a high-temperature, high-pressure state. For example, the compressor 10 may be an inverter compressor or other compressors whose capacity can be controlled. The compressor 10 used is of, for example, one having a low-pressure shell structure in which a compression chamber is provided inside a hermetic container that is in a low refrigerant-pressure atmosphere to suck and compress the low-pressure refrigerant inside the hermetic container.

[0015] The refrigerant flow switching device 11 may be, for example, a four-way valve, and switches between the flow path of refrigerant in heating operation mode and the flow path of refrigerant in cooling operation mode. The heating operation mode refers to a time when the heat source-side heat exchanger 12 acts as a condenser or a gas cooler, and the heating operation mode refers to a time when the heat source-side heat exchanger 12 acts as an evaporator.

[0016] The heat source-side heat exchanger 12 functions as an evaporator in heating operation mode, and functions as a condenser in cooling operation mode. The heat source-side heat exchanger 12 allows heat to be exchanged between the air supplied from the fan 16 and the refrigerant. The accumulator 19 is provided at the suction part of the compressor 10, and accumulates the excess refrigerant resulting from the difference between the heating operation mode and the cooling operation mode or the excess refrigerant for transient changes in operation.

[0017] The auxiliary heat exchanger 40 functions as a condenser in both heating operation mode and cooling operation mode, and exchanges heat between the air supplied from the fan 16 and the refrigerant. Each structure of the heat source-side heat exchanger 12 and the auxiliary heat exchanger 40 is so that heat transfer tubes having different refrigerant flow paths are attached to the same heat transfer fins. Specifically, a plurality of heat transfer fins are arranged adjacent to each other to be oriented in the same direction, and a large number of heat transfer fins are inserted into a plurality of heat transfer tubes. The heat source-side heat exchanger 12 and the auxiliary heat exchanger 40 are provided integrally on the same heat transfer fins, with the heat transfer tubes being provided independently from each other. For example, the heat source-side heat exchanger 12 is disposed on the upper side, and the auxiliary heat exchanger 40 is disposed on the lower side, with adjacent heat transfer fins being shared by the two heat exchangers. Thus, the air

around the heat source-side heat exchanger 12 flows through both the heat source-side heat exchanger 12 and the auxiliary heat exchanger 40. The auxiliary heat exchanger 40 is disposed so that its heat transfer area is smaller than the heat transfer area of the heat source-side heat exchanger 12.

[0018] The first expansion device 45 may be, for example, a device with a variable opening degree, such as an electronic expansion valve. The first expansion device 45 is provided between the heat source-side heat exchanger 12 and a load-side expansion device 25. The first expansion device 45 raises the pressure of refrigerant between the first expansion device 45 and the indoor unit 2, and allows the refrigerant flowing into from the indoor unit 2 in heating operation mode to expand.

[0019] The bypass pipe 41 is connected between the first expansion device 45 and the heat source-side heat exchanger 12. Part of refrigerant flowing out of the first expansion device 45 flows through the bypass pipe 41. The bypass pipe 41 allows high-pressure or medium-pressure refrigerant to flow into the auxiliary heat exchanger 40, and allows liquid refrigerant condensed in the auxiliary heat exchanger 40 to flow into the suction part of the compressor 10 via the second expansion device 42. One end of the bypass pipe 41 is connected to the part of the refrigerant pipe 4 between the heat source-side heat exchanger 12 and the indoor unit 2, and the other end is connected to the part of the refrigerant pipe 4 between the compressor 10 and the accumulator 19.

[0020] The second expansion device 42 may be, for example, a device with a variable opening degree, such as an electronic expansion valve. The second expansion device 42 is located on the outflow side of the auxiliary heat exchanger 40. The second expansion device 42 regulates the flow rate of the liquid refrigerant to flow into the suction part of the compressor 10 after the refrigerant is condensed in the auxiliary heat exchanger 40.

[0021] Further, the outdoor unit 1 is provided with a discharge temperature sensor 43 that detects the temperature of high-temperature, high-pressure refrigerant discharged from the compressor 10. In the outdoor unit 1, an outside-air temperature sensor 46 that measures the temperature around the outdoor unit 1 is provided at the air inlet part of the heat source-side heat exchanger 12. The outdoor unit 1 is further provided with a pressure sensor 44 that detects the pressure of refrigerant between the first expansion device 45 and the indoor unit 2.

[Indoor Unit 2]

[0022] The indoor unit 2 has a load-side heat exchanger 26 and the load-side expansion device 25. The load-side heat exchanger 26 is connected to the outdoor unit 1 via the main pipe 5, and exchanges heat between air and the refrigerant to generate the heating air or cooling air that is to be supplied to the indoor space. Indoor air is sent to the load-side heat exchanger 26 from an air-sending device such as a fan (not illustrated). The load-side expansion device 25 may be, for example, a device with a variable opening degree, such as an electronic expansion valve. The load-side expansion device 25 functions as a pressure reducing valve or an expansion valve, and reduces the pressure of refrigerant to expand the refrigerant. In cooling only operation mode, the load-side expansion device 25 is located upstream of the load-side heat exchanger 26.

[0023] The indoor unit 2 is provided with an inlet-side temperature sensor 31 and an outlet-side temperature sensor 32 that may be thermistors or other sensors. The inlet-side temperature sensor 31 detects the temperature of refrigerant flowing into the load-side heat exchanger 26, and is provided in the pipe at the refrigerant inlet side of the load-side heat exchanger 26. The outlet-side temperature sensor 32 is located at the refrigerant outlet side of the load-side heat exchanger 26, and detects the temperature of refrigerant flowing out of the load-side heat exchanger 26.

[0024] A controller 60 may be a microcomputer or other devices. The controller 60 performs various operation modes described later by controlling, for example, the driving frequency of the compressor 10, the rotation speed of the air-sending device (including turning on and off of the air-sending device), the switching action of the refrigerant flow switching device 11, the opening degree of the first expansion device 45, the opening degree of the second expansion device 42, and the opening degree of the load-side expansion device 25, on the basis of information detected by the various sensors mentioned above and instructions from a remote controller. Although the controller 60 is illustrated to be provided in the outdoor unit 1, the controller 60 may be provided for each individual unit, or may be provided in the indoor unit 2.

[0025] Next, various operation modes performed by the air-conditioning apparatus 100 will be described. In the air-conditioning apparatus 100, a cooling operation mode and a heating operation mode are performed in each indoor unit 2 based on an instruction from the indoor unit 2. Operation modes performed by the air-conditioning apparatus 100 illustrated in Fig. 1 include cooling operation mode in which all of the indoor units 2 being driven perform cooling operation, and a heating operation mode in which all of the indoor units 2 being driven perform heating operation. Hereinafter, each of the operation modes will be described with reference to the corresponding flow of refrigerant.

[Cooling Operation Mode]

[0026] Fig. 2 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling operation mode of the air-conditioning apparatus 100. In Fig. 2, a cooling only operation mode will be described with reference to, for example, a

case where a cooling load is generated in the load-side heat exchanger 26. In Fig. 2, the direction of flow of refrigerant is indicated by solid arrows.

[0027] In Fig. 2, low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 flows into the heat source-side heat exchanger 12 via the refrigerant flow switching device 11. In the heat source-side heat exchanger 12, the refrigerant changes to high-pressure liquid refrigerant while rejecting heat to the outdoor air supplied from the fan 16. After flowing out of the heat source-side heat exchanger 12, the high-pressure refrigerant flows out of the outdoor unit 1 via the first expansion device 45 that is set to the full opening degree. The refrigerant then passes through the main pipe 5 to flow into the indoor unit 2.

[0028] In the indoor unit 2, the high-pressure refrigerant is expanded in the load-side expansion device 25, and changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. The refrigerant in a two-phase gas-liquid state flows into the load-side heat exchanger 26 acting as an evaporator where the refrigerant removes heat from the indoor air, thus changing to low-temperature, low-pressure gas refrigerant while cooling the indoor air. During this process, the opening degree of the load-side expansion device 25 is controlled by the controller 60 to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 and the temperature detected by the outlet-side temperature sensor 32. The gas refrigerant flowing out of the load-side heat exchanger 26 passes through the main pipe 5 to flow into the outdoor unit 1 again. The refrigerant flowing into the outdoor unit 1 passes through the refrigerant flow switching device 11 and the accumulator 19 and then is sucked into the compressor 10 again.

(Overview of Necessity and Effect of Injection in Cooling Only Operation Mode)

[0029] If the refrigeration cycle of the air-conditioning apparatus 100 uses, for example, a refrigerant such as an R32 refrigerant whose discharge temperature of the compressor 10 is higher than that of an R410A refrigerant (to be referred to as R410A hereinafter), it is necessary to lower the discharge temperature to prevent degradation of the refrigerating machine oil or burnout of the compressor 10. Thus, in cooling only operation mode, part of the high-pressure liquid refrigerant flowing out of the heat source-side heat exchanger 12 is allowed to flow into the auxiliary heat exchanger 40 via the bypass pipe 41, and the refrigerant that has changed to subcooled liquid in the auxiliary heat exchanger 40 is allowed to flow into the suction part of the compressor 10 via the second expansion device 42.

[0030] At this time, the controller 60 controls the first expansion device 45 and the second expansion device 42 so that high-pressure refrigerant flows into the auxiliary heat exchanger 40 from the bypass pipe 41. Then, in the auxiliary heat exchanger 40, the high-pressure liquid refrigerant changes to high-pressure subcooled liquid while rejecting heat to the outdoor air supplied from the fan 16, and the subcooled liquid refrigerant flows into the suction part of the compressor 10 via the second expansion device 42. Thus, the discharge temperature of refrigerant discharged from the compressor 10 can be lowered, ensuring safe use of the air-conditioning apparatus 100.

(Control of Second Expansion Device 42)

[0031] The following describes how the second expansion device 42 is controlled by the controller 60 in cooling operation mode. The controller 60 controls the opening degree of the second expansion device 42 on the basis of the discharge temperature of the compressor 10 detected by the discharge temperature sensor 43. That is, the discharge temperature of the compressor 10 drops when the amount of subcooled liquid refrigerant flowing into the suction part of the compressor 10 from the auxiliary heat exchanger 40 is increased by increasing the opening degree (opening area) of the second expansion device 42. By contrast, the discharge temperature of the compressor 10 rises when the amount of subcooled liquid refrigerant flowing into the suction part of the compressor 10 from the auxiliary heat exchanger 40 is decreased by decreasing the opening degree (opening area) of the second expansion device 42.

[0032] Thus, when the discharge temperature of the compressor 10 detected by the discharge temperature sensor 43 is equal to or lower than a discharge temperature threshold (for example, equal to or lower than 115 degrees C) at which burnout of the compressor 10 or degradation of the refrigerating machine oil occurs, the controller 60 controls the second expansion device 42 to fully close. Then, the flow path of refrigerant flowing into the suction part of the compressor 10 from the auxiliary heat exchanger 40 via the bypass pipe 41 is cut off. The discharge temperature threshold is set depending on the limit value of the discharge temperature of the compressor 10.

[0033] When the discharge temperature becomes higher than the discharge temperature threshold, the controller 60 controls the second expansion device 42 to open to allow the refrigerant subcooled in the auxiliary heat exchanger 40 to flow into the suction part of the compressor 10. During this process, the controller 60 regulates the opening degree (opening area) of the second expansion device 42 so that the discharge temperature becomes equal to or lower than the discharge temperature threshold. For example, a table or mathematical expression associating discharge temperature with the opening degree of the second expansion device 42 is stored in the controller 60, and the controller 60 controls

the opening degree of the second expansion device 42 on the basis of the discharge temperature. Then, low-pressure, low-temperature gas refrigerant flowing out of the accumulator 19, and the liquid refrigerant subcooled in the auxiliary heat exchanger 40 mix together, resulting in low-pressure, two-phase gas-liquid refrigerant at a high quality. This refrigerant is then sucked from the suction part of the compressor 10.

(Operation and Effect of Injection in Cooling Operation Mode)

[0034] As described above, the refrigerant flows into the suction part of the compressor 10 with its enthalpy at the inlet of the compressor 10 reduced, thus making it possible to limit an excessive rise in the discharge temperature of the compressor 10. As a result, degradation of the refrigerating machine oil can be minimized and damage to the compressor 10 can be prevented. Thus, the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting of an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

[0035] Furthermore, in cooling operation mode, the controller 60 causes part of the high pressure refrigerant flowing out of the heat source-side heat exchanger 12 to be subcooled in the auxiliary heat exchanger 40, thus ensuring that the refrigerant flowing into the second expansion device 42 be in a liquid state. This configuration prevents refrigerant from flowing into the second expansion device 42 in a two-phase state, thus preventing noise generation in the second expansion device 42 and unstable control of discharge temperature of the compressor 10 by the second expansion device 42.

[Heating Only Operation Mode]

[0036] Fig. 3 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating operation mode of the air-conditioning apparatus 100. In Fig. 3, a heating only operation mode will be described with reference to, for example, a case where a heating load is generated in the load-side heat exchanger 26. In Fig. 3, the direction of flow of refrigerant is indicated by solid arrows.

[0037] In Fig. 3, low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 passes through the refrigerant flow switching device 11 and then flows out of the outdoor unit 1. The high-temperature, high-pressure gas refrigerant flowing out of the outdoor unit 1 passes through the main pipe 5, and as the refrigerant rejects heat to the indoor air in the load-side heat exchanger 26, the refrigerant changes to liquid refrigerant while heating the indoor space. The liquid refrigerant flowing out of the load-side heat exchanger 26 is expanded in the load-side expansion device 25, changes to medium-temperature, medium-pressure refrigerant that is in a two-phase gas-liquid state, and then passes through the main pipe 5 to flow into the outdoor unit 1 again. The medium-temperature, medium-pressure refrigerant in a two-phase gas-liquid state flowing into the outdoor unit 1 changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state as the refrigerant passes through the first expansion device 45, and this refrigerant flows into the heat source-side heat exchanger 12. In the heat source-side heat exchanger 12, the refrigerant changes to low-temperature, low-pressure gas refrigerant while removing heat from the outdoor air. The refrigerant passes through the refrigerant flow switching device 11 and the accumulator 19 and then is sucked into the compressor 10 again.

(Overview of Necessity and Effect of Injection in Heating Operation Mode)

[0038] As in the cooling operation mode mentioned above, in heating operation mode, when the refrigerant used is, for example, a refrigerant that is discharged from the compressor 10 at a high temperature, such as R32, it is necessary to lower the discharge temperature to prevent degradation of the refrigerating machine oil or burnout of the compressor 10. Thus, in heating operation mode as well, part of the medium-temperature, medium-pressure refrigerant in a two-phase gas-liquid state flowing out of the load-side expansion device 25 is allowed to flow into the auxiliary heat exchanger 40 via the bypass pipe 41.

[0039] Specifically, in heating operation mode, the controller 60 controls the first expansion device 45 to allow medium-pressure refrigerant to flow into the auxiliary heat exchanger 40. Further, the controller 60 controls the first expansion device 45 and the second expansion device 42 so that the refrigerant cooled in the auxiliary heat exchanger 40 is allowed to flow into the flow path at the suction part of the compressor 10 or the compression chamber of the compressor 10. Then, in the auxiliary heat exchanger 40, the refrigerant changes to medium-pressure subcooled liquid while rejecting heat to the outdoor air supplied from the fan 16, and the liquid refrigerant flows into the suction part of the compressor 10 via the second expansion device 42. As a result, the temperature of the refrigerant discharged from the compressor 10 can be lowered to ensure safe use.

(Control of Second Expansion Device 42)

[0040] The following describes how the second expansion device 42 is controlled by the controller 60 in heating operation mode. The controller 60 controls the opening degree of the second expansion device 42 on the basis of the discharge temperature of the compressor 10 detected by the discharge temperature sensor 43. That is, the discharge temperature of the compressor 10 drops when the amount of subcooled liquid refrigerant to flow into the suction part of the compressor 10 from the auxiliary heat exchanger 40 is increased by increasing the opening degree (opening area) of the second expansion device 42. By contrast, the discharge temperature of the compressor 10 rises when the amount of subcooled liquid refrigerant to flow into the suction part of the compressor 10 from the auxiliary heat exchanger 40 is decreased by decreasing the opening degree (opening area) of the second expansion device 42.

[0041] Thus, when the discharge temperature of the compressor 10 detected by the discharge temperature sensor 43 is equal to or lower than a discharge temperature threshold (for example, equal to or lower than 115 degrees C) at which burnout of the compressor 10 or degradation of the refrigerating machine oil occurs, the controller 60 controls the second expansion device 42 to fully close. Then, the flow path of refrigerant flowing into the suction part of the compressor 10 from the auxiliary heat exchanger 40 via the bypass pipe 41 is cut off. The discharge temperature threshold is set depending on the limit value of the discharge temperature of the compressor 10.

[0042] On the other hand, in a case where, for example, the outdoor unit 1 is installed in a low temperature environment and the indoor unit 2 is installed in a high temperature environment in heating operation mode, a compression ratio between the high pressure at the discharge part of the compressor 10 and the low pressure at the suction part of the compressor 10 increases, causing an excessive rise in the discharge temperature of the compressor 10. When the discharge temperature becomes higher than a discharge temperature threshold, the controller 60 controls the second expansion device 42 to open so that the refrigerant passing through the auxiliary heat exchanger 40 flows to the suction part of the compressor 10. During this process, the controller 60 regulates the opening degree (opening area) of the second expansion device 42 so that the discharge temperature becomes equal to or lower than the discharge temperature threshold. For example, a table or mathematical expression associating discharge temperature with the opening degree of the second expansion device 42 is stored in the controller 60, and the controller 60 controls the opening degree of the second expansion device 42 on the basis of the discharge temperature.

[0043] Then, heat is exchanged in the auxiliary heat exchanger 40 between the air supplied from the fan 16, and medium-pressure, two-phase gas-liquid refrigerant that is at a saturation temperature higher than the temperature of air, resulting in subcooled medium-pressure liquid refrigerant. This refrigerant is then allowed to flow into the suction part of the compressor 10 via the second expansion device 42. At this time, low-pressure, low-temperature gas refrigerant flowing out of the accumulator 19, and the liquid refrigerant cooled in the auxiliary heat exchanger 40 mix together, resulting in low-pressure refrigerant that is in a two-phase gas-liquid state and at a high quality. That is, the refrigerant flows into the compressor 10 with its enthalpy at the inlet of the compressor 10 reduced, thus limiting an excessive rise in the discharge temperature of the compressor 10. Thus, it is possible to minimize degradation of the refrigerating machine oil and prevent damage to the compressor 10.

(Control of First Expansion Device 45)

[0044] In heating operation mode, to cool the medium-pressure, medium-temperature, two-phase gas-liquid refrigerant to flow into the auxiliary heat exchanger 40, it is necessary to raise the saturation temperature of the medium-pressure, medium-temperature, two-phase gas-liquid refrigerant above the temperature of the environment in which the outdoor unit 1 is installed. Thus, the controller 60 controls the first expansion device 45 so that the refrigerant is at a medium pressure upstream of the first expansion device 45, thus allowing the refrigerant at a medium pressure to flow into the auxiliary heat exchanger 40.

[0045] When the opening degree (opening area) of the first expansion device 45 is small, the amount of refrigerant flowing out of the first expansion device 45 decreases, and the amount of refrigerant in the part of the refrigerant pipe 4 between the load-side expansion device 25 and the first expansion device 45 increases. Thus, the pressure of the medium-pressure, medium-temperature refrigerant in a two-phase gas-liquid state to flow into the auxiliary heat exchanger 40 increases. By contrast, when the opening degree (opening area) of the first expansion device 45 is large, the amount of refrigerant flowing out of the first expansion device 45 increases, and the amount of refrigerant in the part of the refrigerant pipe 4 between the load-side expansion device 25 and the first expansion device 45 decreases. Thus, the pressure of the medium-pressure, medium-temperature refrigerant in a two-phase gas-liquid state to flow into the auxiliary heat exchanger 40 decreases.

[0046] Thus, the controller 60 calculates the saturation temperature of the medium-temperature, medium-pressure, two-phase gas-liquid refrigerant flowing out of the load-side expansion device 25, from the value detected by the pressure sensor 44. The controller 60 then regulates the opening degree (opening area) of the first expansion device 45 so that the calculated saturation temperature of the medium-temperature, medium-pressure refrigerant in a two-phase gas-

liquid state becomes sufficiently higher than a value detected by the outside-air temperature sensor 46 as a measurement of the ambient temperature of the outdoor unit 1. For example, the controller 60 regulates the opening degree of the first expansion device 45 so that the difference between the saturation temperature calculated from the value detected by the pressure sensor 44, and the value detected by the outside-air temperature sensor 46 approaches a temperature difference threshold (for example, 10 degrees C or higher, which ensures sufficient subcooling).

(Effect of Injection in Heating Operation Mode)

[0047] As described above, in heating operation mode, part of the medium-pressure, medium-temperature refrigerant flowing into the outdoor unit 1 from the indoor unit 2 is changed to subcooled liquid in the auxiliary heat exchanger 40, and the subcooled liquid is allowed to flow into the suction part of the compressor 10 to limit a rise in the discharge temperature of the compressor 10. This arrangement allows all of the high-pressure, high-temperature gas refrigerant discharged from the compressor 10 to be supplied to the indoor unit 2. Thus, the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting of an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

(Selection of Size of Auxiliary Heat Exchanger)

[0048] For stable control of the second expansion device 42, the refrigerant flowing out of the auxiliary heat exchanger 40 needs to be liquefied reliably. For this reason, the heat transfer area of the auxiliary heat exchanger 40 needs to be taken into consideration. A conceivable environment that necessitates limiting of a rise in the discharge temperature of the compressor 10 in heating operation mode is a case where the outdoor unit 1 is installed under an environment of low temperature (for example, at an environmental temperature of -10 degrees C or lower). In this case, the second expansion device 42 may be controlled as described above to raise the saturation temperature of the medium-pressure, medium-temperature refrigerant at a low quality that needs to be subcooled in the auxiliary heat exchanger 40, thus providing a large temperature difference from the environmental temperature.

[0049] A conceivable environment that necessitates limiting of a rise in the discharge temperature of the compressor 10 in cooling operation mode is a case where the outdoor unit 1 is installed under an environment of high temperature (for example, at an environmental temperature of 40 degrees C or higher). Under this environment, the difference between the temperature of high-pressure, low-temperature refrigerant cooled in the heat source-side heat exchanger 12 (for example, approximately 50 degrees C), the refrigerant temperature when the refrigerant cooled in the heat source-side heat exchanger 12 is further subcooled in the auxiliary heat exchanger 40, and the environmental temperature is small. Thus, for sufficient subcooling of refrigerant to occur in the auxiliary heat exchanger 40, the heat transfer area of the auxiliary heat exchanger 40 needs to be increased.

[0050] Thus, the heat transfer area of the auxiliary heat exchanger 40 may be selected to achieve a condition that maximizes the amount of subcooled liquid flowing into the suction part of the compressor 10 during the injection process in cooling operation mode. This condition depends on the environmental temperature at which the air-conditioning apparatus 100 can be operated. In this regard, the condition that gives the greatest difference between the pressure of refrigerant cooled in the heat source-side heat exchanger 12 and the pressure of refrigerant heated in the load-side heat exchanger 26 is the condition that causes the greatest rise in the temperature of the high-pressure, high-temperature refrigerant discharged from the compressor 10.

[0051] Thus, the heat transfer area of the auxiliary heat exchanger 40 is determined on an assumption of the environment under which the rise in the temperature of high-pressure, high-temperature refrigerant discharged from the compressor 10 is greatest. For example, when the environmental temperature at which the air-conditioning apparatus 100 can be operated is assumed so that the maximum value of the environmental temperature at which the outdoor unit 1 is installed is 43 degrees C, and the minimum value of the environmental temperature at which the indoor unit 2 is installed is 15 degrees C, this environment is the condition that causes the greatest rise in the discharge temperature of refrigerant discharged from the compressor 10. The heat transfer area of the auxiliary heat exchanger 40 is determined based on this condition.

[0052] First, in cooling operation mode, on an assumption that the maximum environmental temperature at which the outdoor unit 1 is installed is 43 degrees C, and the minimum environmental temperature at which the indoor unit 2 is installed is 15 degrees C, the flow rate (the amount of injection) of the subcooled liquid refrigerant that needs to flow into the suction part of the compressor 10 from the auxiliary heat exchanger 40 to make the discharge temperature of refrigerant discharged from the compressor 10 equal to or lower than a discharge temperature threshold (for example, equal to or lower than 115 degrees C) may be calculated from the energy conversation law as represented by Equation (1).

[0053] [Math. 1]

$$Gr_1h_1 + Gr_2h_2 = Grh \quad (1)$$

[0054] In Equation (1), Gr_1 (kg/h) and h_1 (kJ/kg) denote the flow rate and enthalpy of the low-temperature, low-pressure gas refrigerant that flows into the suction part of the compressor 10 from the accumulator 19, Gr_2 (kg/h) and h_2 (kJ/kg) denote the flow rate and enthalpy of the low-temperature, low-pressure liquid refrigerant injected from the auxiliary heat exchanger 40 to the suction part of the compressor 10 via the second expansion device 42 and the bypass pipe 41, and Gr (kg/h) and h (kJ/kg) denote the total refrigerant flow rate after the two streams of refrigerant merge at the suction part of the compressor 10, and the enthalpy after merging.

[0055] The enthalpy after merging, h (kJ/kg), which is calculated using Equation (1), is less than the enthalpy h_1 (kJ/kg) of the low-temperature, low-pressure gas refrigerant that flows into the suction part of the compressor 10 from the accumulator 19. Consequently, the discharge temperature of refrigerant discharged from the compressor 10 is lower in a case where refrigerant is injected from the auxiliary heat exchanger 40 than in a case where no liquid refrigerant is injected from the auxiliary heat exchanger 40.

[0056] In both a case where the refrigerant is compressed to a predetermined pressure from the enthalpy h_1 (kJ/kg) with the second expansion device 42 fully closed and a case where the refrigerant is compressed to a predetermined pressure when the second expansion device 42 is open and liquid is injected from the bypass pipe 41, the refrigerant is compressed to the same pressure with an equivalent adiabatic efficiency and by an equivalent displacement. Under this condition, the refrigerant flow rate Gr_2 at which the temperature of gas refrigerant discharged from the compressor 10 becomes equal to or less than a discharge temperature threshold (for example, equal to or lower than 115 degrees C) is derived from Equation (1).

[0057] Next, Q_1 (W) denotes the amount of heat exchange in the auxiliary heat exchanger 40, and h_3 (kJ/kg) denotes the enthalpy of the high-pressure, low-temperature refrigerant at the outlet side of the heat source-side heat exchanger 12 in cooling operation mode and also denotes the enthalpy of the refrigerant at the inlet side of the auxiliary heat exchanger 40, and thus the general form of the equation defining the amount of heat exchange due to a change in enthalpy represented by Equation (2) holds.

[0058] [Math. 2]

$$Q_1 = Gr_2 \times (h_3 - h_2) \quad (2)$$

[0059] Further, the amount of heat exchange in the auxiliary heat exchanger 40, Q_1 (W), can be represented by Equation (3) below that is the general form of the equation defining the amount of heat exchange due to heat transmission, where A_1 (m²) is the area in which the auxiliary heat exchanger 40 contacts the air of the environment under which the outdoor unit 1 is installed (to be referred to as total heat transfer area hereinafter), k (W/(m²·K)) is the overall heat transmission coefficient based on the side where the fins used in the auxiliary heat exchanger 40 and the outer surface of the heat transfer tubes contact the air of the environment of the installation location (to be referred to as "based on the tube's outer side" hereinafter), k (W/(m²·K)) also represents the ease with which heat is transmitted owing to the difference in temperature between refrigerant and air, and ΔT_m (K or degrees C) is the logarithmic mean temperature difference, which represents the temperature difference between refrigerant and air at each of the inlet and outlet of the auxiliary heat exchanger 40, with variations of temperature in the direction of flow taken into account.

[0060] [Math. 3]

$$Q_1 = A_1 \times k \times \Delta T_m \quad (3)$$

[0061] The overall heat transmission coefficient k based on the tube's outer side varies with changes in heat transfer coefficient due to changes in, for example, the specifications of the heat transfer tubes used in the auxiliary heat exchanger 40, which is a plate fin-tube heat exchanger, fin geometry, fan air velocity, or the operating state of the refrigeration cycle. For example, the overall heat transmission coefficient k is set to approximately 25 (W/(m²·K)), which is a value obtained by the results of a large number of cooling operation mode tests.

[0062] On an assumption that the auxiliary heat exchanger 40 employs the counterflow arrangement for heat exchange with air, the logarithmic mean temperature difference ΔT_m (K or degrees C) can be calculated as Equation (4) below, where T_1 (K or degrees C) is the temperature of refrigerant flowing into the heat transfer tubes of the auxiliary heat exchanger 40, T_2 (K or degrees C) is the temperature of refrigerant flowing out of the auxiliary heat exchanger 40, T_3 (K or degrees C) is the temperature of air flowing into the auxiliary heat exchanger 40, and T_4 (K or degrees C) is the temperature of air flowing out of the auxiliary heat exchanger 40.

[Math. 4]

$$\Delta T_m = \frac{(T_1 - T_4) - (T_2 - T_3)}{\ln \left(\frac{T_1 - T_4}{T_2 - T_3} \right)} \quad \cdot \cdot \cdot \quad (4)$$

[0063] The total heat transfer area A_1 of the auxiliary heat exchanger 40 can be calculated by using Equations (1) to (4) above. For example, the following describes how the total heat transfer area A_1 is calculated for the air-conditioning apparatus 100 having capacity equivalent to 10 horsepower that uses an R32 refrigerant as the refrigerant. For the air-conditioning apparatus 100 mentioned above, under the condition that the outdoor unit 1 is installed at an environmental temperature of approximately 43 degrees C, and the indoor unit 2 is installed at an environmental temperature of approximately 15 degrees C, the total refrigerant flow rate $Gr (= Gr_1 + Gr_2)$ in Equation (1) is approximately 340 (kg/h). Further, on an assumption that the temperature of saturated gas at the suction part of the compressor 10 is approximately zero degrees C, the enthalpy h_1 in Equation (1) is given as enthalpy $h_1 =$ approximately 515 (kJ/kg).

[0064] For sufficient subcooling, it is assumed that the degree of subcooling that is the difference in temperature between the refrigerant at the inlet side of the auxiliary heat exchanger 40 and the liquid refrigerant at the outlet side of the auxiliary heat exchanger 40 is set to approximately 9 degrees C, in the auxiliary heat exchanger 40, saturated liquid at 54 degrees C exchanges heat with air at approximately 43 degrees C, and saturated liquid at 45 degrees C flows into the suction part of the compressor 10. In this case, the enthalpy h_2 at the outlet of the auxiliary heat exchanger 40 is determined by the pressure calculated from the refrigerant saturation temperature of 54 degrees C, and the temperature of the liquid refrigerant at the outlet of the auxiliary heat exchanger 40. In the present case, the enthalpy h_2 is obtained as approximately 283 (kJ/kg).

[0065] The total refrigerant flow rate Gr and the enthalpies h_1 and h_2 in Equation (1) are determined on the basis of the above-mentioned condition under which the air-conditioning apparatus 100 can be operated or other conditions. When the adiabatic efficiency of the compressor 10 is 0.6, and refrigerant is compressed in the compressor 10 to a pressure corresponding to the saturation temperature of refrigerant in the heat source-side heat exchanger 12 of 54 degrees C, the refrigerant flow rate Gr_2 required to make the discharge temperature of the compressor 10 equal to or lower than the discharge temperature threshold (equal to or lower than 115 degrees C) is calculated from Equation (1) as refrigerant flow rate $Gr_2 =$ approximately 12 (kg/h).

[0066] Next, on an assumption that the saturation temperature of refrigerant cooled in the heat source-side heat exchanger 12 is 54 degrees C, and the refrigerant is cooled to saturated liquid at 54 degrees C in the heat source-side heat exchanger 12, the enthalpy h_3 of the saturated liquid at 54 degrees C is approximately 307 (kJ/kg). Thus, on the basis of the refrigerant flow rate Gr_2 and the enthalpies h_2 and h_3 , the amount of heat exchange Q_1 required for the auxiliary heat exchanger 40 is calculated from Equation (2) to be approximately 80 (W).

[0067] As described above, it is assumed that the temperature T_1 of refrigerant flowing into the heat transfer tubes of the auxiliary heat exchanger 40 is approximately 54 (degrees C), the temperature T_2 of refrigerant flowing out of the auxiliary heat exchanger 40 is 45 (degrees C), and the temperature T_3 of air flowing into the auxiliary heat exchanger 40 is 43 (degrees C). As for the temperature T_4 of air flowing out of the auxiliary heat exchanger 40, it is regarded that the temperature of air remains substantially unchanged owing to the small amount of heat exchange Q_1 in the auxiliary heat exchanger 40 of approximately 80 (W). Thus, the temperature T_4 is set as 44 (degrees C), on an assumption that the temperature of air rises by approximately one degree C from the temperature of incoming air. Then, the logarithmic mean temperature difference ΔT_m is calculated as approximately 4.97 (degrees C) from Equation (4). Thus, the total heat transfer area A_1 required for the auxiliary heat exchanger 40 is calculated from Equation (3) to be approximately 0.644 (m²).

[0068] When an R32 refrigerant is used for the air-conditioning apparatus 100 having capacity equivalent to 10 horsepower, the total heat transfer area A_2 required for the heat source-side heat exchanger 12 is approximately 141 (m²). When the auxiliary heat exchanger 40 is a part of the heat source-side heat exchanger 12, the ratio $A_1/(A_1 + A_2)$, which is the ratio of the total heat transfer area A_1 of the auxiliary heat exchanger 40 to the sum of the total heat transfer area A_2 required for the heat source-side heat exchanger 12 and the total heat transfer area A_1 required for the auxiliary heat exchanger 40, equals 0.644/141.644, which is equal to or higher than approximately 0.46%.

[0069] Although the total heat transfer area A_1 of the auxiliary heat exchanger 40 is calculated above for, by way of example, the air-conditioning apparatus 100 having capacity equivalent to 10 horsepower under a predetermined condition in which the air-conditioning apparatus 100 can be operated, the configuration is not limited to this configuration. For example, in a case where the air-conditioning apparatus 100 is configured so that even when the required cooling or heating capacity (horsepower) changes, the high-pressure/low-pressure operating state of refrigerant remains sub-

stantially unchanged with respect to the environmental temperature at which each of the outdoor unit 1 and the indoor unit 2 is installed, the cooling or heating capacity (horsepower) changes only with a change in the displacement of the compressor 10 (a change in total refrigerant flow rate Gr (kg/h)). Thus, the flow rate Gr_2 of refrigerant allowed to flow into the auxiliary heat exchanger 40 may be made to vary with the rate of change in the displacement of the compressor 10, and the total heat transfer area A_1 of the auxiliary heat exchanger 40 may be calculated from Equation (2) and Equation (3).

[0070] For example, the displacement of the compressor 10 required for the air-conditioning apparatus 100 having capacity equivalent to 14 horsepower is approximately 1.4 times greater than that required for an air-conditioning apparatus having capacity equivalent to 10 horsepower. Thus, the flow rate Gr_2 of refrigerant allowed to flow into the auxiliary heat exchanger 40 is approximately 16.8 (kg/h) (= 10-horsepower-equivalent Gr_2 of 12 (kg/h) $\times$ 1.4). On an assumption that the enthalpy of refrigerant at each of the inlet and outlet of the auxiliary heat exchanger 40 is substantially equal to that for the air-conditioning apparatus 100 having capacity equivalent to 10 horsepower, the amount of heat exchange Q_1 in the auxiliary heat exchanger 40 is calculated from Equation (2) to be approximately 112 (W). Because the overall heat transmission coefficient k and the logarithmic mean temperature difference ΔT_m can be also regarded as substantially equal to those for the air-conditioning apparatus 100 having capacity equivalent to 10 horsepower, from Equation (3), the total heat transfer area A_1 required for the auxiliary heat exchanger 40 equals 0.9016 (m^2), which is approximately 1.4 times the total heat transfer area A_1 of the auxiliary heat exchanger 40 for the air-conditioning apparatus having capacity equivalent to 10 horsepower. Likewise, on an assumption that the cooling or heating capacity (horsepower) changes only with a change in the displacement of the compressor 10 (a change in total refrigerant flow rate Gr (kg/h)), the total heat transfer area A_2 required for the heat source-side heat exchanger 12 can be also regarded as approximately 1.4 times greater than that required for the air-conditioning apparatus having capacity equivalent to 10 horsepower. That is, irrespective of the horsepower of the air-conditioning apparatus 100, the ratio $A_1/(A_1 + A_2)$, which is the ratio of the total heat transfer area A_1 of the auxiliary heat exchanger 40 to the sum of the total heat transfer area A_2 required for the heat source-side heat exchanger 12 and the total heat transfer area A_1 required for the auxiliary heat exchanger 40, is equal to or higher than approximately 0.46%.

[0071] If a part of the heat source-side heat exchanger 12 is used as the auxiliary heat exchanger 40, for example, the number of stages for the heat source-side heat exchanger 12 may not be able to increase owing to factors such as a constraint on the direction of height of the outdoor unit 1. If the auxiliary heat exchanger 40 constituting a part of the heat source-side heat exchanger 12 has an excessively large size in this case, the total heat transfer area A_1 of the heat source-side heat exchanger 12 decreases, resulting in deterioration of the performance of the heat source-side heat exchanger 12.

[0072] Fig. 4 is a graph illustrating the relationship between the ratio of the heat transfer area of the heat source-side heat exchanger 12 to the sum of the total heat transfer area A_2 of the heat source-side heat exchanger 12 and the total heat transfer area A_1 of the auxiliary heat exchanger 40 in the air-conditioning apparatus 100, and COP, which is an index of the performance of the air-conditioning apparatus 100. As illustrated in Fig. 4, to keep the decrease in COP within approximately 1.5%, the ratio $A_2/(A_1 + A_2)$ of the total heat transfer area A_2 of the heat source-side heat exchanger 12 to the sum $A_1 + A_2$ of the total heat transfer areas needs to be approximately 95%. Thus, that the corresponding ratio $A_1/(A_1 + A_2)$ for the total heat transfer area A_1 of the auxiliary heat exchanger 40 is equal to or less than 5%. Thus, it is desirable that the ratio $A_1/(A_1 + A_2)$ of the total heat transfer area A_1 of the auxiliary heat exchanger 40 to the sum $A_1 + A_2$ of the total heat transfer areas be equal to or less than approximately 5%. However, if the auxiliary heat exchanger 40 is installed not as a part of the heat source-side heat exchanger 12 but independently from the heat source-side heat exchanger 12, the ratio $A_1/(A_1 + A_2)$ does not need to be kept within approximately 5%. In this case, the ratio $A_1/(A_1 + A_2)$ may be any value equal to or higher than approximately 0.46%.

Embodiment 2

[0073] Fig. 5 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 2 of the present invention. An air-conditioning apparatus 200 will be described below with reference to Fig. 5. In Fig. 5, parts configured in the same manner as those in the air-conditioning apparatus 100 illustrated in Fig. 1 will be denoted by the same reference signs to omit a description of these parts.

[0074] The air-conditioning apparatus 200 illustrated in Fig. 5 has a single outdoor unit 201 that is a heat source unit, a plurality of indoor units 2a to 2d, and a relay device 3 including an opening and closing device provided between the outdoor unit 201 and each of the indoor units 2a to 2d. The outdoor unit 201 and the relay device 3 are connected by the main pipes 5 through which refrigerant flows, and the relay device 3 and the indoor units 2a to 2d are each connected by a branch pipe 6 through which refrigerant flows. The cooling energy or heating energy generated by the outdoor unit 1 is allowed to pass through each of the indoor units 2a to 2d via the relay device 3.

[0075] The outdoor unit 201 and the relay device 3 are connected by using two main pipes 5, and the relay device 3 and each of the indoor units 2 are connected by two branch pipes 6. Using two pipes to connect the outdoor unit 201

with the relay device 3, and each of the indoor units 2a to 2d with the relay device 3 in this way allows for easy installation.

[Outdoor Unit 201]

[0076] As in Embodiment 1, in the outdoor unit 201, the compressor 10, the refrigerant flow switching device 11 such as a four-way valve, the heat source-side heat exchanger 12, the auxiliary heat exchanger 40, the first expansion device 45, the second expansion device 42, the bypass pipe 41, and the accumulator 19 are connected by the refrigerant pipe 4, and are mounted together with the fan 16, which is an air-sending device.

[0077] Further, the outdoor unit 201 has a first connecting pipe 4a, a second connecting pipe 4b, and first backflow prevention devices 13a to 13d such as check valves or other devices. The first backflow prevention device 13a prevents high-temperature, high-pressure gas refrigerant from flowing backward from the first connecting pipe 4a to the heat source-side heat exchanger 12 in heating only operation mode and heating main operation mode. The first backflow prevention device 13b prevents high-pressure refrigerant that is in a liquid or two-phase gas-liquid state from flowing backward from the first connecting pipe 4a to the accumulator 19 in cooling only operation mode and cooling main operation mode. The first backflow prevention device 13c prevents high-pressure refrigerant that is in a liquid or two-phase gas-liquid state from flowing backward from the first connecting pipe 4a to the accumulator 19 in cooling only operation mode and cooling main operation mode. The first backflow prevention device 13d prevents high-temperature, high-pressure gas refrigerant from flowing backward from the flow path on the discharge side of the compressor 10 to the second connecting pipe 4b in heating only operation mode and heating main operation mode.

[0078] The provision of the first connecting pipe 4a, the second connecting pipe 4b, and the first backflow prevention devices 13a to 13d allows the refrigerant flowing into the relay device 3 to flow in a fixed direction irrespective of the operation required for the indoor unit 2. Although the first backflow prevention devices 13a to 13d are illustrated to be check valves, their configuration is not limited as long as backflow of refrigerant can be prevented. For example, the first backflow prevention devices 13a to 13d may be opening and closing devices or expansion devices capable of full closing.

[0079] In Fig. 5, one end of the bypass pipe 41 is connected to the part of the second connecting pipe 4b between the first expansion device 45 and the first backflow prevention device 13c, and the other end is connected to the part of the refrigerant pipe 4 between the compressor 10 and the accumulator 19. That is, in the air-conditioning apparatus 200 illustrated in Fig. 5 as well, the first expansion device 45 is connected between the heat source-side heat exchanger 12 and the indoor units 2a to 2d (load-side expansion devices 25a to 26d), and the bypass pipe 41 is connected between the first expansion device 45 and the heat source-side heat exchanger 12 so that the refrigerant flowing out of the first expansion device 45 flows through the bypass pipe 41.

[Indoor Units 2a to 2d]

[0080] The indoor units 2a to 2d have, for example, the same configuration, and respectively include load-side heat exchangers 26a to 26d, and the load-side expansion devices 25a to 25d. The load-side heat exchangers 26a to 26d are each connected to the outdoor unit 201 via the branch pipes 6, the relay device 3, and the main pipes 5. The load-side heat exchangers 26a to 26d allow heat to be exchanged between air supplied from an air-sending device such as a fan (not illustrated), and refrigerant to thereby generate the heating air or cooling air to be supplied to the indoor space. The load-side expansion devices 25a to 25d may each be, for example, a device with a variable opening degree, such as an electronic expansion valve. The load-side expansion devices 25a to 25d each function as a pressure reducing valve or expansion valve to cause refrigerant to be reduced in pressure and expand. The load-side expansion devices 25a to 25d are located upstream of the load-side heat exchangers 26a to 26d with respect to the flow of refrigerant in cooling only operation mode.

[0081] The indoor units 2 are provided with inlet-side temperature sensors 31 a to 31 d that each detect the temperature of refrigerant flowing into the corresponding load-side heat exchanger 26, and outlet-side temperature sensors 32a to 32d that each detect the temperature of refrigerant flowing out of the corresponding load-side heat exchanger 26. The inlet-side temperature sensor 31 a to 31 d and the outlet-side temperature sensor 32a to 32d may be, for example, thermistors or other sensors, and the detected inlet-side temperatures and outlet-side temperatures of the load-side heat exchangers 26a to 26d are sent to the controller 60.

[0082] Although four indoor units 2 are connected to the outdoor unit 201 via the relay device 3 and the refrigerant pipe 4 in Fig. 5, the number of indoor units 2 connected is not limited to four but may be any number equal to or greater than two.

[Relay Device 3]

[0083] The relay device 3 has a gas-liquid separator 14, a refrigerant-to-refrigerant heat exchanger 50, a third expansion device 15, a fourth expansion device 27, a plurality of first opening and closing devices 23a to 23d, a plurality of second

opening and closing devices 24a to 24d, a plurality of second backflow prevention devices 21 a to 21 d that are backflow prevention devices such as check valves and a plurality of third backflow prevention devices 22a to 22d that are backflow prevention devices such as check valves.

[0084] In cooling and heating mixed operation mode when there is a large cooling load, the gas-liquid separator 14 separates high-pressure, two-phase gas-liquid refrigerant generated in the outdoor unit 201 into liquid and gas. The liquid is allowed to flow into the pipe located on the lower side in Fig. 5 to supply cooling energy to the indoor unit 2, and the gas is allowed to flow into the pipe located on the upper side in Fig. 5 to supply heating energy to the indoor unit 2. The gas-liquid separator 14 is installed at the inlet of the relay device 3.

[0085] The refrigerant-to-refrigerant heat exchanger 50 may be, for example, a double-pipe heat exchanger or a plate heat exchanger. In cooling only operation mode, cooling main operation mode, and heating main operation mode, the refrigerant-to-refrigerant heat exchanger 50 allows heat to be exchanged between high-pressure or medium-pressure refrigerant and low-pressure refrigerant to provide a sufficient degree of subcooling for the liquid or two-phase gas-liquid refrigerant to be supplied to the load-side expansion device 25 of the indoor unit 2 in which a cooling load is generated. The flow path of high-pressure or medium-pressure refrigerant of the refrigerant-to-refrigerant heat exchanger 50 is connected between the third expansion device 15 and the second backflow prevention devices 21 a to 21 d. One end of the flow path of low-pressure refrigerant is connected between the second backflow prevention devices 21 a to 21 d, and the outlet side of the flow path of high-pressure or medium-pressure refrigerant of the refrigerant-to-refrigerant heat exchanger 50, and the other end communicates with the low-pressure pipe at the outlet side of the relay device 3 via the fourth expansion device 27 and the refrigerant-to-refrigerant heat exchanger 50.

[0086] The third expansion device 15 functions as a pressure reducing valve or an opening and closing valve, and reduces the pressure of liquid refrigerant to a predetermined pressure, or opens or closes the flow path of the liquid refrigerant. The third expansion device 15 may be, for example, a device with a variable opening degree, such as an electronic expansion valve. The third expansion device 15 is provided on the pipe to which the liquid refrigerant flowing out of the gas-liquid separator 14 flows.

[0087] The fourth expansion device 27 functions as a pressure reducing valve or an opening and closing valve. In heating only operation mode, the fourth expansion device 27 opens or closes the flow path of refrigerant, and in heating main operation mode, the fourth expansion device 27 regulates the flow rate of a bypass liquid depending on the indoor-side load. In cooling only operation mode, cooling main operation mode, and heating main operation mode, the fourth expansion device 27 allows refrigerant to flow into the refrigerant-to-refrigerant heat exchanger 50, and regulates the degree of subcooling of the refrigerant supplied to the load-side expansion device 25 of the indoor unit 2 in which a cooling load is generated. The fourth expansion device 27 may be, for example, a device with a variable opening degree, such as an electronic expansion valve. The fourth expansion device 27 is located in the flow path on the inlet side of low-pressure refrigerant of the refrigerant-to-refrigerant heat exchanger 50.

[0088] The number (four in this case) of first opening and closing devices 23a to 23d equal to the number of indoor units 2a to 2d to be installed are provided, individually for the corresponding indoor units 2a to 2d. The first opening and closing devices 23a to 23d may each be, for example, a solenoid valve or other devices, and open or close the flow path of the high-temperature, high-pressure gas refrigerant supplied to the corresponding indoor units 2a to 2d. The first opening and closing devices 23a to 23d are each connected to the gas-side pipe of the gas-liquid separator 14. The first opening and closing devices 23a to 23d are only required to be able to open and close a flow path, and may be expansion devices capable of full closing.

[0089] The number (four in this case) of second opening and closing devices 24a to 24d equal to the number of indoor units 2a to 2d to be installed are provided, individually for the corresponding indoor units 2a to 2d. The second opening and closing devices 24a to 24d may each be, for example, a solenoid valve or other devices, and open and close the flow path of the low-pressure, low-temperature gas refrigerant flowing out of the corresponding indoor units 2a to 2d. The second opening and closing devices 24a to 24d are each connected to the low-pressure pipe that communicates with the outlet side of the relay device 3. The second opening and closing devices 24a to 24d are only required to be able to open and close a flow path, and may be expansion devices capable of full closing.

[0090] The number (four in this case) of second backflow prevention devices 21 a to 21 d equal to the number of indoor units 2a to 2d to be installed are provided, individually for the corresponding indoor units 2a to 2d. The second backflow prevention devices 21 a to 21 d allow high-pressure liquid refrigerant to flow into the indoor units 2a to 2d in which cooling operation is being performed, and are each connected to the pipe at the outlet side of the third expansion device 15. In cooling main operation mode and heating main operation mode, this configuration is able to prevent medium-temperature, medium-pressure, liquid or two-phase gas-liquid refrigerant yet to attain a sufficient degree of subcooling that has flowed out of the load-side expansion device 25 of the indoor unit 2 that is performing heating operation, from flowing into the load-side expansion device 25 of the indoor unit 2 that is performing cooling operation. Although the second backflow prevention devices 21 a to 21 d are depicted as if the second backflow prevention devices 21 a to 21 d are check valves in Fig. 5, the second backflow prevention devices 21 a to 21 d used may be any devices capable of preventing backflow of refrigerant and may be opening and closing devices or expansion devices capable of

full closing.

[0091] The number (four in this case) of third backflow prevention devices 22a to 22d equal to the number of indoor units 2a to 2d to be installed are provided, individually for the corresponding indoor units 2a to 2d. The third backflow prevention devices 22a to 22d allow high-pressure liquid refrigerant to flow into the indoor unit 2 that is performing cooling operation, and are connected to the outlet pipe of the third expansion device 15. In cooling main operation mode and heating main operation mode, the third backflow prevention devices 22a to 22d prevent medium-temperature, medium-pressure, liquid or two-phase gas-liquid refrigerant yet to attain a sufficient degree of subcooling that has flowed out of the third expansion device 15, from flowing into the load-side expansion device 25 of the indoor unit 2 that is performing cooling operation. Although the third backflow prevention devices 22a to 22d are depicted as if the third backflow prevention devices 22a to 22d are check valves in Fig. 5, the third backflow prevention devices 22a to 22d used may be any devices capable of preventing backflow of refrigerant and may be opening and closing devices or expansion devices capable of full closing.

[0092] In the relay device 3, an inlet-side pressure sensor 33 is provided on the inlet side of the third expansion device 15, and an outlet-side pressure sensor 34 is provided on the outlet side of the third expansion device 15. The inlet-side pressure sensor 33 detects the pressure of high-pressure refrigerant. The outlet-side pressure sensor 34 detects, in cooling main operation mode, the intermediate pressure of liquid refrigerant at the outlet of the third expansion device 15.

[0093] The relay device 3 is further provided with a temperature sensor 51 that detects the temperature of the high-pressure or medium-pressure refrigerant flowing out of the refrigerant-to-refrigerant heat exchanger 50. The temperature sensor 51 is provided to the pipe at the outlet side of the flow path of high-pressure or medium-pressure refrigerant of the refrigerant-to-refrigerant heat exchanger 50, and may preferably be a thermistor or other sensors.

[0094] In the air-conditioning apparatus 200 illustrated in Fig. 5 as well, the controller 60 performs various operation modes described later by controlling, for example, the driving frequency of the compressor 10, the rotation speed of the air-sending device (including turning on and off of the air-sending device), the switching action of the refrigerant flow switching device 11, the opening degree of the first expansion device 45, the opening degree of the second expansion device 42, the opening degree of the load-side expansion device 25, and the opening and closing actions of the first opening and closing devices 23a to 23d, the second opening and closing devices 24a to 24d, the fourth expansion device 27, and the third expansion device 15, on the basis of information detected by the various sensors and instructions from a remote controller. The controller 60 may be provided for each individual unit, or may be provided in the outdoor unit 201 or the relay device 3.

[0095] Various operation modes performed by the air-conditioning apparatus 200 will be described. The air-conditioning apparatus 200 is capable of performing, on the basis of an instruction from each indoor unit 2, either cooling operation or heating operation in the corresponding indoor unit 2. That is, the air-conditioning apparatus 200 allows all of the indoor units 2 to perform the same operation, and also allows each individual indoor unit 2 to perform a different operation.

[0096] Of the operation modes performed by the air-conditioning apparatus 200, the cooling operation mode includes a cooling only operation mode, in which all of the indoor units 2 being driven perform cooling operation, and a cooling main operation mode that is a cooling and heating mixed operation mode in which the cooling load is comparatively greater, and the heating operation mode includes a heating only operation mode, in which all of the indoor units 2 being driven perform heating operation, and a heating main operation mode that is a cooling and heating mixed operation mode in which the heating load is comparatively greater. These operation modes will be described below.

[Cooling Only Operation Mode]

[0097] Fig. 6 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of the air-conditioning apparatus 200. In Fig. 6, pipes indicated by thick lines represent pipes through which refrigerant flows, and the direction of flow of refrigerant is indicated by solid arrows. In Fig. 6, the cooling only operation mode will be described with reference to, for example, a case where a cooling load is generated only in the load-side heat exchanger 26a and the load-side heat exchanger 26b. In cooling only operation mode illustrated in Fig. 6, the controller 60 switches the refrigerant flow switching device 11 of the outdoor unit 201 so that the refrigerant discharged from the compressor 10 is allowed to flow into the heat source-side heat exchanger 12.

[0098] First, low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 flows into the heat source-side heat exchanger 12 via the refrigerant flow switching device 11. In the heat source-side heat exchanger 12, the refrigerant changes to high-pressure liquid refrigerant as the refrigerant rejects heat to the outdoor air. The high-pressure liquid refrigerant flowing out of the heat source-side heat exchanger 12 passes through the first backflow prevention device 13a and flows out of the outdoor unit 201, and then flows into the relay device 3 through the main pipe 5.

[0099] After flowing into the relay device 3, the high-pressure liquid refrigerant passes through the gas-liquid separator 14 and the third expansion device 15 and then is sufficiently subcooled in the refrigerant-to-refrigerant heat exchanger

50. Then, most of the subcooled high-pressure refrigerant passes through the second backflow prevention devices 21 a and 21 b and the branch pipe 6, is expanded in the load-side expansion device 25, and changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. The remaining part of the high-pressure refrigerant is expanded in the fourth expansion device 27, and thus changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. Then, the low-temperature, low-pressure refrigerant in a two-phase gas-liquid state exchanges heat with the high-pressure liquid refrigerant in the refrigerant-to-refrigerant heat exchanger 50, changes to low-temperature, low-pressure gas refrigerant, and then flows into the low-pressure pipe at the outlet side of the relay device 3. During this process, the opening degree of the fourth expansion device 27 is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the outlet-side pressure sensor 34 into a saturation temperature, and the temperature detected by the temperature sensor 51.

[0100] Most of the streams of low-temperature, low-pressure refrigerant in a two-phase gas-liquid state flowing out of the load-side expansion devices 25a and 25b respectively flow into the load-side heat exchangers 26a and 26b acting as evaporators where the refrigerant removes heat from the indoor air, and changes to low-temperature, low-pressure gas refrigerant while cooling the indoor air. During this process, the opening degree of the load-side expansion device 25a is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 a and the temperature detected by the outlet-side temperature sensor 32a. Likewise, the opening degree of the load-side expansion device 25b is controlled to maintain a constant level of superheat calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 b and the temperature detected by the outlet-side temperature sensor 32b.

[0101] The gas refrigerant flowing out of each of the load-side heat exchangers 26a and 26b passes through the branch pipe 6 and the second opening and closing device 24, and merges with the gas refrigerant flowing out of the refrigerant-to-refrigerant heat exchanger 50. The merged refrigerant flows out of the relay device 3, and passes through the main pipe 5 to flow into the outdoor unit 201 again. The refrigerant flowing into the outdoor unit 201 passes through the first backflow prevention device 13d, the refrigerant flow switching device 11, and the accumulator 19 and then is sucked into the compressor 10 again.

[0102] No refrigerant needs to be allowed to pass through the load-side heat exchanger 26c and the load-side heat exchanger 26d where no cooling load exists, and thus the corresponding load-side expansion device 25c and load-side expansion device 25d are in their closed state. When a cooling load is generated in the load-side heat exchanger 26c or the load-side heat exchanger 26d, the load-side expansion device 25c or the load-side expansion device 25d opens to allow refrigerant to circulate. During this process, like the load-side expansion device 25a or the load-side expansion device 25b, the opening degree of the load-side expansion device 25c or the load-side expansion device 25d is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 and the temperature detected by the outlet-side temperature sensor 32.

[Cooling Main Operation Mode]

[0103] Fig. 7 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling main operation mode of the air-conditioning apparatus 200. In Fig. 7, the cooling main operation mode will be described with reference to, for example, a case where a cooling load is generated in the load-side heat exchanger 26a and a heating load is generated in the load-side heat exchanger 26b. In Fig. 7, pipes indicated by thick lines represent pipes through which refrigerant circulates, and the direction of flow of refrigerant is indicated by solid arrows. In cooling main operation mode illustrated in Fig. 7, in the outdoor unit 201, the refrigerant flow switching device 11 is switched to allow the heat source-side refrigerant discharged from the compressor 10 to flow into the heat source-side heat exchanger 12.

[0104] First, low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 flows into the heat source-side heat exchanger 12 via the refrigerant flow switching device 11. In the heat source-side heat exchanger 12, the gas refrigerant changes to two-phase gas-liquid refrigerant while rejecting heat to the outdoor air. The refrigerant flowing out of the heat source-side heat exchanger 12 passes through the first backflow prevention device 13a and the main pipe 5, and flows into the relay device 3.

[0105] After flowing into the relay device 3, the two-phase gas-liquid refrigerant is separated in the gas-liquid separator 14 into high-pressure gas refrigerant and high-pressure liquid refrigerant. The high-pressure gas refrigerant passes through the first opening and closing device 23b and the branch pipe 6, and flows into the load-side heat exchanger 26b acting as a condenser, where the high-pressure gas refrigerant rejects heat to the indoor air and thus changes to liquid refrigerant while heating the indoor space. During this process, the opening degree of the load-side expansion device 25b is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the inlet-side pressure sensor 33 into a saturation temperature, and the temperature detected by the inlet-side temperature sensor 31 b. The liquid refrigerant flowing out of the load-

side heat exchanger 26b is expanded in the load-side expansion device 25b, and then passes through the branch pipe 6 and the third backflow prevention device 22b.

[0106] Then, medium-pressure liquid refrigerant that has been expanded to a medium pressure in the third expansion device 15 after being separated in the gas-liquid separator 14, and the liquid refrigerant that has passed through the third backflow prevention device 22b merge. During this process, the opening degree of the third expansion device 15 is controlled to provide a predetermined pressure difference (for example, 0.3 MPa) between the pressure detected by the inlet-side pressure sensor 33, and the pressure detected by the outlet-side pressure sensor 34.

[0107] After the merged liquid refrigerant is sufficiently subcooled in the refrigerant-to-refrigerant heat exchanger 50, most of the subcooled refrigerant passes through the second backflow prevention device 21 a and the branch pipe 6, and is then expanded in the load-side expansion device 25a, and changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. The remaining part of the liquid refrigerant is expanded in the fourth expansion device 27, and thus changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. During this process, the opening degree of the fourth expansion device 27 is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the outlet-side pressure sensor 34 into a saturation temperature, and the temperature detected by the temperature sensor 51. Then, the low-temperature, low-pressure refrigerant in a two-phase gas-liquid state exchanges heat with the medium-pressure liquid refrigerant in the refrigerant-to-refrigerant heat exchanger 50, changes to low-temperature, low-pressure gas refrigerant, and then flows into the low-pressure pipe at the outlet side of the relay device 3.

[0108] The high-pressure liquid refrigerant separated in the gas-liquid separator 14 passes through the refrigerant-to-refrigerant heat exchanger 50 and the second backflow prevention device 21 a, and flows into the indoor unit 2a. Most of the refrigerant in a two-phase gas-liquid state expanded in the load-side expansion device 25a of the indoor unit 2a flows into the load-side heat exchanger 26a acting as an evaporator where the refrigerant removes heat from the indoor air, and changes to low-temperature, low-pressure gas refrigerant while cooling the indoor air. During this process, the opening degree of the load-side expansion device 25a is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 a and the temperature detected by the outlet-side temperature sensor 32b. The gas refrigerant flowing out of the load-side heat exchanger 26a passes through the branch pipe 6 and the second opening and closing device 24a and merges with the remaining part of the gas refrigerant that has flowed out of the refrigerant-to-refrigerant heat exchanger 50. The merged refrigerant then flows out of the relay device 3, and passes through the main pipe 5 to flow into the outdoor unit 201 again. The refrigerant flowing into the outdoor unit 201 passes through the first backflow prevention device 13d, the refrigerant flow switching device 11, and the accumulator 19 and then is sucked into the compressor 10 again.

[0109] No refrigerant needs to be allowed to pass through the load-side heat exchanger 26c and the load-side heat exchanger 26d where no thermal load exists, and thus the corresponding load-side expansion device 25c and load-side expansion device 25d are in their closed state. When a cooling load is generated in the load-side heat exchanger 26c or the load-side heat exchanger 26d, the load-side expansion device 25c or the load-side expansion device 25d opens to allow refrigerant to circulate. During this process, like the load-side expansion device 25a or the load-side expansion device 25b, the opening degree of the load-side expansion device 25c or the load-side expansion device 25d is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 and the temperature detected by the outlet-side temperature sensor 32.

[Heating Only Operation Mode]

[0110] Fig. 8 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating only operation mode of the air-conditioning apparatus 200. In Fig. 8, pipes indicated by thick lines represent pipes through which refrigerant flows, and the direction of flow of refrigerant is indicated by solid arrows. In Fig. 8, the heating only operation mode will be described with reference to, for example, a case where a cooling load is generated only in the load-side heat exchanger 26a and the load-side heat exchanger 26b. In heating only operation mode illustrated in Fig. 8, in the outdoor unit 201, the refrigerant flow switching device 11 is switched so that the heat source-side refrigerant discharged from the compressor 10 is allowed to flow into the relay device 3 without passing through the heat source-side heat exchanger 12.

[0111] First, low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 passes through the refrigerant flow switching device 11 and the first backflow prevention device 13b, and then flows out of the outdoor unit 201. The high-temperature, high-pressure gas refrigerant flowing out of the outdoor unit 201 flows into the relay device 3 through the main pipe 5.

[0112] After flowing into the relay device 3, the high-temperature, high-pressure gas refrigerant passes through the gas-liquid separator 14, the first opening and closing devices 23a and 23b, and the branch pipes 6, and flows into each of the load-side heat exchanger 26a and the load-side heat exchanger 26b that act as a condenser. The refrigerant flowing into each of the load-side heat exchanger 26a and the load-side heat exchanger 26b rejects heat to the indoor

air, and thus changes to liquid refrigerant while heating the indoor space. The refrigerant flowing out of the load-side heat exchanger 26a and the load-side heat exchanger 26b is respectively expanded in the load-side expansion devices 25a and 25b, passes through the branch pipes 6, the third backflow prevention devices 22a and 22b, the refrigerant-to-refrigerant heat exchanger 50, the fourth expansion device 27 controlled in its open state, and the main pipe 5, and flows into the outdoor unit 201 again. During this process, the opening degree of the load-side expansion device 25a is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the inlet-side pressure sensor 33 into a saturation temperature, and the temperature detected by the inlet-side temperature sensor 31 a. Likewise, the opening degree of the load-side expansion device 25b is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the inlet-side pressure sensor 33 into a saturation temperature, and the temperature detected by the inlet-side temperature sensor 31 b.

[0113] The refrigerant flowing into the outdoor unit 201 passes through the first backflow prevention device 13c, is expanded in the first expansion device 45 and changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state, and then changes to low-temperature, low-pressure gas refrigerant in the heat source-side heat exchanger 12 while removing heat from the outdoor air. The low-temperature, low-pressure gas refrigerant then passes through the refrigerant flow switching device 11 and the accumulator 19 and then is sucked into the compressor 10 again.

[0114] No refrigerant needs to be allowed to pass through the load-side heat exchanger 26c and the load-side heat exchanger 26d where no thermal load exists, and thus the corresponding load-side expansion device 25c and load-side expansion device 25d are in their closed state. When a cooling load is generated in the load-side heat exchanger 26c or the load-side heat exchanger 26d, the load-side expansion device 25c or the load-side expansion device 25d opens to allow refrigerant to circulate. During this process, like the load-side expansion device 25a or the load-side expansion device 25b, the opening degree of the load-side expansion device 25c or the load-side expansion device 25d is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 and the temperature detected by the outlet-side temperature sensor 32.

[Heating Main Operation Mode]

[0115] Fig. 9 is a refrigerant circuit diagram illustrating the flow of refrigerant in heating main operation mode of the air-conditioning apparatus 200. In Fig. 9, pipes indicated by thick lines represent pipes through which refrigerant circulates, and the direction of flow of refrigerant is indicated by solid arrows. In Fig. 9, the heating main operation mode will be described with reference to, for example, a case where a cooling load is generated in the load-side heat exchanger 26a, and a heating load is generated in the load-side heat exchanger 26b. In heating main operation mode illustrated in Fig. 9, in the outdoor unit 201, the refrigerant flow switching device 11 is switched so that the heat source-side refrigerant discharged from the compressor 10 is allowed to flow into the relay device 3 without passing through the heat source-side heat exchanger 12.

[0116] Low-temperature, low-pressure refrigerant is compressed by the compressor 10, and discharged from the compressor 10 as high-temperature, high-pressure gas refrigerant. The high-temperature, high-pressure gas refrigerant discharged from the compressor 10 passes through the refrigerant flow switching device 11 and the first backflow prevention device 13b, and then flows out of the outdoor unit 201. The high-temperature, high-pressure gas refrigerant flowing out of the outdoor unit 201 flows into the relay device 3 through the main pipe 5.

[0117] The high-temperature, high-pressure gas refrigerant flowing into the relay device 3 passes through the gas-liquid separator 14, the third expansion device 15, the first opening and closing device 23b, and the branch pipe 6, and flows into the load-side heat exchanger 26b acting as a condenser. The refrigerant flowing into the load-side heat exchanger 26b rejects heat to the indoor air, and thus changes to liquid refrigerant while heating the indoor space. The liquid refrigerant flowing out of the load-side heat exchanger 26b is expanded in the load-side expansion device 25b, passes through the branch pipe 6 and the third backflow prevention device 22b, and then is sufficiently subcooled in the refrigerant-to-refrigerant heat exchanger 50. Then, most of the subcooled refrigerant passes through the second backflow prevention device 21 a and the branch pipe 6, and is expanded in the load-side expansion device 25a, and changes to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. The remaining part of the liquid refrigerant is expanded in the fourth expansion device 27, which also serves as a bypass, and changes to medium-temperature, medium-pressure refrigerant that is in a two-phase or liquid state. This refrigerant then exchanges heat with the liquid refrigerant in the refrigerant-to-refrigerant heat exchanger 50 to change to low-temperature, medium-pressure refrigerant that is in a gaseous or two-phase gas-liquid state, and then flows into the low-pressure pipe at the outlet side of the relay device 3.

[0118] Most of the two-phase gas-liquid refrigerant expanded in the load-side expansion device 25a flows into the load-side heat exchanger 26a acting as an evaporator where the refrigerant removes heat from the indoor air, and changes to low-temperature, medium-pressure refrigerant that is in a two-phase gas-liquid state. The refrigerant in a two-phase gas-liquid state flowing out of the load-side heat exchanger 26a passes through the branch pipe 6 and the

second opening and closing device 24a, and merges with the remaining part of the gas refrigerant that has flowed out of the refrigerant-to-refrigerant heat exchanger 50. The merged refrigerant then flows out of the relay device 3, and passes through the main pipe 5 to flow into the outdoor unit 201 again. The refrigerant flowing into the outdoor unit 201 passes through the first backflow prevention device 13c, and is expanded in the first expansion device 45 to change to low-temperature, low-pressure refrigerant that is in a two-phase gas-liquid state. This refrigerant then changes to low-temperature, low-pressure gas refrigerant in the heat source-side heat exchanger 12 while removing heat from the outdoor air. The low-temperature, low-pressure gas refrigerant then passes through the refrigerant flow switching device 11 and the accumulator 19 and then is sucked into the compressor 10 again.

[0119] During this process, the opening degree of the load-side expansion device 25b is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the inlet-side pressure sensor 33 into a saturation temperature, and the temperature detected by the inlet-side temperature sensor 31 b. The opening degree of the load-side expansion device 25a is controlled to maintain a constant level of superheat (degree of superheat) calculated as the difference between the temperature detected by the inlet-side temperature sensor 31 a and the temperature detected by the outlet-side temperature sensor 32b.

[0120] The opening degree of the fourth expansion device 27 is controlled to maintain a constant level of subcooling (degree of subcooling) calculated as the difference between a value obtained by converting the pressure detected by the outlet-side pressure sensor 34 into a saturation temperature, and the temperature detected by the temperature sensor 51. For example, the opening degree of the fourth expansion device 27 is controlled to provide a predetermined pressure difference (for example, 0.3 MPa) between the pressure detected by the inlet-side pressure sensor 33, and the pressure detected by the outlet-side pressure sensor 34.

[0121] No refrigerant needs to be allowed to pass through the load-side heat exchanger 26c and the load-side heat exchanger 26d where no thermal load exists, and thus the corresponding load-side expansion device 25c and load-side expansion device 25d are in their closed state. When a thermal load is generated in the load-side heat exchanger 26c or the load-side heat exchanger 26d, the load-side expansion device 25c or the load-side expansion device 25d may be opened to allow refrigerant to circulate.

[0122] As in the air-conditioning apparatus 100 illustrated in Figs. 1 to 4, in the air-conditioning apparatus 200 illustrated in Figs. 5 to 9, refrigerant is injected into the suction part of the compressor 10 via the auxiliary heat exchanger 40 and the second expansion device 42 in cooling operation mode and heating operation mode. Thus, the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

[0123] In the air-conditioning apparatus 200, the calculation method for and the size of the required total heat transfer area A_1 (m^2), which represents the area in which the auxiliary heat exchanger 40 contacts the air of the environment under which the outdoor unit 201 is installed, are the same as those in Embodiment 1.

Embodiment 3

[0124] Fig. 10 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 3 and the flow of refrigerant in cooling only operation mode. The following description of Embodiment 3 will mainly focus on differences from Embodiment 2, and parts that are the same as those in Embodiment 2 will be denoted by the same reference signs. An air-conditioning apparatus 300 illustrated in Fig. 10 differs from the air-conditioning apparatus 200 illustrated in Figs. 5 to 9 in the configuration of an outdoor unit 301.

[0125] In the outdoor unit 301 of the air-conditioning apparatus 300, one end of the bypass pipe 41 is connected to a first diverging pipe 48 and a second diverging pipe 49. The bypass pipe 41 is thus diverged in two directions. One end of the first diverging pipe 48 is connected to the part of the second connecting pipe 4b between the first expansion device 45 and the first backflow prevention device 13c, and the other end is connected to the bypass pipe 41. One end of the second diverging pipe 49 is connected to the part of the refrigerant pipe 4 between the merging point of the first backflow prevention device 13a and the first connecting pipe 4a, and the main pipe 5, and the other end is connected to the bypass pipe 41. An opening and closing device 47 is provided in the second diverging pipe 49. Operation of the opening and closing device 47 is controlled by the controller 60. The opening and closing device 47 is only required to be able to open and close a flow path, and may be an expansion device capable of full closing.

[0126] In cooling operation mode (cooling only operation mode and cooling main operation mode), to limit a rise in the discharge temperature of refrigerant discharged from the compressor 10, the controller 60 controls the first expansion device 45 to be fully closed, and controls the opening and closing device 47 to be open. Then, part of the high-pressure refrigerant flowing out of the heat source-side heat exchanger 12 flows into the auxiliary heat exchanger 40, via the second diverging pipe 49, the opening and closing device 47 controlled to open, and the bypass pipe 41. In the auxiliary heat exchanger 40, the refrigerant changes to high-pressure subcooled liquid while rejecting heat to the outdoor air

supplied from the fan 16. The subcooled liquid flows into the suction part of the compressor 10 via the second expansion device 42. As a result, the discharge temperature of refrigerant discharged from the compressor 10 can be lowered.

[0127] In heating operation mode (heating only operation mode and heating main operation mode), the opening and closing device 47 is controlled to be closed by the controller 60 to limit a rise in the discharge temperature of refrigerant discharged from the compressor 10. The operation and control of the air-conditioning apparatus 300 when the opening and closing device 47 is closed are substantially the same as those in the air-conditioning apparatus 200. Further, the effect of the circuit configuration of the air-conditioning apparatus 300 is also similar to that of the air-conditioning apparatus 200.

[0128] Fig. 11 is a refrigerant circuit diagram illustrating the flow of refrigerant in cooling only operation mode of the air-conditioning apparatus according to a modification of Embodiment 3 of the present invention. In the outdoor unit 301 illustrated in Fig. 10, a backflow prevention device 13g is provided in the first diverging pipe 48. When high-pressure gas refrigerant flows into the auxiliary heat exchanger 40 in heating operation mode (heating only operation mode and heating main operation mode), the backflow prevention device 13g prevents the high-pressure gas refrigerant discharged from the compressor 10 from flowing backward to the second connecting pipe 4b, which is a flow path of low-pressure refrigerant. With the circuit configuration employed, for example, in heating only operation mode and heating main operation mode, the opening and closing device 47 is controlled to open, allowing high-pressure gas refrigerant to flow into the auxiliary heat exchanger 40 from the second diverging pipe 49.

[0129] For example, in a case where a medium pressure is difficult to be generated in the first expansion device 45 at the start of the heating only operation mode or at the start of the heating main operation mode, the controller 60 controls the opening and closing device 47 to open, thus allowing high-pressure gas refrigerant to flow into the auxiliary heat exchanger 40 from the first connecting pipe 4a. As a result, refrigerant that has been changed to subcooled liquid in the auxiliary heat exchanger 40 can be allowed to flow into the suction part of the compressor 10, thus making it possible to limit an excessive rise in the discharge temperature of the compressor 10. The backflow prevention device 13g may be any device capable of preventing backflow of refrigerant, and may be an opening and closing device or an expansion device capable of full closing.

[0130] Although the foregoing description is directed to a case where the backflow prevention device 13g is installed in the first diverging pipe 48, a first diverging-pipe opening and closing device, such as an opening and closing device and an expansion device capable of full closing that can open and close a flow path, may be provided instead of the backflow prevention device 13g. In a case where an excessive rise in the discharge temperature of the compressor 10 does not need to be limited, the controller 60 may control the first diverging-pipe opening and closing device and the opening and closing device 47 to close, and control the second expansion device 42 to a small opening degree just short of full closure. This configuration can minimize stagnation of refrigeration in the bypass pipe 41 and the auxiliary heat exchanger 40. Further, when an excessive rise in the discharge temperature of the compressor 10 needs to be limited, the above configuration prevents an excessive amount of liquid refrigerant from flowing into the suction part of the compressor 10 from the second expansion device 42, thus preventing damage to the compressor 10 due to excessive liquid return to the compressor 10.

[0131] As described above, in the air-conditioning apparatus 300 illustrated in Figs. 10 and 11 as well, refrigerant is injected into the suction part of the compressor 10 via the auxiliary heat exchanger 40 and the second expansion device 42, and thus the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

[0132] In the air-conditioning apparatus 300, the calculation method for and the size of the required total heat transfer area A_1 (m^2), which represents the area in which the auxiliary heat exchanger 40 contacts the air of the environment under which the outdoor unit 201 is installed, are the same as those in Embodiment 1.

Embodiment 4

[0133] Fig. 12 is a schematic circuit configuration diagram illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 4, and the flow of refrigerant in cooling operation mode. The following description of Embodiment 4 will mainly focus on differences from Embodiments mentioned above, and parts that are the same as those in Embodiment 1 will be denoted by the same reference signs. An air-conditioning apparatus 400 illustrated in Fig. 12 differs from the air-conditioning apparatus 100 in the configuration of an outdoor unit 401.

[0134] That is, in the outdoor unit 401 of the air-conditioning apparatus 400, one end of the bypass pipe 41 is diverged in two directions into the first diverging pipe 48 and the second diverging pipe 49. One end of the first diverging pipe 48 is connected to the part of the refrigerant pipe 4 between the first expansion device 45 and the load-side expansion device 25, and the other end of the first diverging pipe 48 merges with the second diverging pipe 49 via the backflow prevention device 13g and is connected to the bypass pipe 41.

[0135] When high-pressure gas refrigerant is to be allowed to flow into the auxiliary heat exchanger 40 in cooling only operation mode and cooling main operation mode, the backflow prevention device 13g prevents the high-pressure gas refrigerant discharged from the compressor 10 from flowing backward to the refrigerant pipe 4, which is a flow path of high-pressure, liquid or two-phase gas-liquid refrigerant flowing out of the heat source-side heat exchanger 12. One end of the second diverging pipe 49 is connected to the part of the refrigerant pipe 4 between the flow path on the discharge side of the compressor 10 and the refrigerant flow switching device 11. The second diverging pipe 49 is provided with the opening and closing device 47. The other end of the second diverging pipe 49 merges with the first diverging pipe 48 via the opening and closing device 47, and is connected to the bypass pipe 41.

[0136] In the air-conditioning apparatus 400, when a rise in the discharge temperature of refrigerant discharged from the compressor 10 is to be limited in cooling operation mode, part of the high-pressure gas refrigerant discharged from the compressor 10 is allowed to flow into the auxiliary heat exchanger 40, via the second diverging pipe 49, the opening and closing device 47 controlled to open, and the bypass pipe 41. The refrigerant then changes to high-pressure subcooled liquid in the auxiliary heat exchanger 40 while rejecting heat to the outdoor air supplied from the fan 16, and the high-pressure subcooled liquid refrigerant flows into the suction part of the compressor 10 via the second expansion device 42. As a result, the discharge temperature of refrigerant discharged from the compressor 10 can be lowered.

[0137] In heating operation mode, the opening and closing device 47 is controlled to be closed, and other operation and control of the air-conditioning apparatus 400 are similar to those of the air-conditioning apparatus 100. Further, the effect of the circuit configuration of the air-conditioning apparatus 400 is also similar to that of the air-conditioning apparatus 100. Although the backflow prevention device 13g is depicted as if the backflow prevention device 13g is a check valve, the backflow prevention device 13g may be any device capable of preventing backflow of refrigerant, and may be an opening and closing device or an expansion device capable of full closing. Further, the opening and closing device 47 is only required to be able to open and close a flow path, and may be an expansion device capable of full closing.

[0138] Although the air-conditioning apparatus 400 is provided with the backflow prevention device 13g, a first diverging-pipe opening and closing device, such as an opening and closing device and an expansion device capable of full closing that can open and close a flow path, may be provided instead of the backflow prevention device 13g. In a case where an excessive rise in the discharge temperature of the compressor 10 does not need to be limited, the first diverging-pipe opening and closing device and the opening and closing device 47 may be controlled to be closed, and the second expansion device 42 may be controlled to a small opening degree just short of full closure. This configuration can minimize stagnation of refrigeration in the bypass pipe 41 and the auxiliary heat exchanger 40. When an excessive rise in the discharge temperature of the compressor 10 needs to be limited, the above configuration prevents an excessive amount of liquid refrigerant from flowing into the suction part of the compressor 10 from the second expansion device 42, thus preventing damage to the compressor 10 due to excessive liquid return to the compressor 10.

[0139] As described above, in the air-conditioning apparatus 400 illustrated in Fig. 12 as well, refrigerant is injected into the suction part of the compressor 10, and thus the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

[0140] In the air-conditioning apparatus 400, the calculation method for and the size of the required total heat transfer area A_1 (m^2), which represents the area in which the auxiliary heat exchanger 40 contacts the air of the environment under which the outdoor unit 201 is installed, are the same as those in Embodiment 1.

Embodiment 5

[0141] Fig. 13 is a schematic circuit configuration diagram, illustrating an exemplary circuit configuration of an air-conditioning apparatus according to Embodiment 5, and the flow of refrigerant in cooling only operation mode. The following description of Embodiment 5 will mainly focus on differences from Embodiment 2, and parts that are the same as those in Embodiment 2 will be denoted by the same reference signs. An air-conditioning apparatus 500 illustrated in Fig. 13 differs from the air-conditioning apparatus 200 in the configuration of an outdoor unit 501.

[0142] That is, in the air-conditioning apparatus 500, one end of the bypass pipe 41 is diverged in two directions into the first diverging pipe 48 and the second diverging pipe 49. One end of the first diverging pipe 48 is connected to the part of the second connecting pipe 4b between the first expansion device 45 and the first backflow prevention device 13c, and the other end merges with the second diverging pipe 49 and is connected to the bypass pipe 41. One end of the second diverging pipe 49 is connected to the part of the refrigerant pipe 4 between the flow path on the discharge side of the compressor 10 and the refrigerant flow switching device 11, and the other end merges with the first diverging pipe 48 via the opening and closing device 47 and is connected to the bypass pipe 41. The opening and closing device 47 is only required to be able to open and close a flow path, and may be an expansion device capable of full closing.

[0143] In the air-conditioning apparatus 500, when a rise in the discharge temperature of refrigerant discharged from the compressor 10 is to be limited in cooling only operation mode and cooling main operation mode, the first expansion

device 45 is controlled by the controller 60 to be fully closed, and part of the high-pressure gas refrigerant discharged from the compressor 10 is allowed to flow into the auxiliary heat exchanger 40, via the second diverging pipe 49, the opening and closing device 47 controlled to open, and the bypass pipe 41. In this way, after the refrigerant changes to high-pressure subcooled liquid in the auxiliary heat exchanger 40 while rejecting heat to the outdoor air supplied from the fan 16, the resulting refrigerant is allowed to flow into the suction part of the compressor 10 via the second expansion device 42, thus allowing the discharge temperature of refrigerant discharged from the compressor 10 to be lowered.

[0144] When a rise in the discharge temperature of refrigerant discharged from the compressor 10 is to be limited in heating only operation mode and heating main operation mode, the opening and closing device 47 is controlled by the controller 60 to be closed, and other operation and control of the air-conditioning apparatus 500 are similar to those of the air-conditioning apparatus 200. Further, the effect of the circuit configuration of the air-conditioning apparatus 500 is also similar to that of the air-conditioning apparatus 200.

[0145] In the air-conditioning apparatus 500, further, the first diverging pipe 48 is provided with the backflow prevention device 13g. The function of the backflow prevention device 13g is to prevent the high-pressure gas refrigerant discharged from the compressor 10 from flowing backward to the second connecting pipe 4b, which is a flow path of low-pressure refrigerant, when high-pressure gas refrigerant is allowed to the auxiliary heat exchanger 40 in heating only operation mode and heating main operation mode. Further, the circuit configuration is employed so that, for example, in heating only operation mode and heating main operation mode, the controller 60 controls the opening and closing device 47 to open, allowing high-pressure gas refrigerant to flow into the auxiliary heat exchanger 40 from the second diverging pipe 49.

[0146] Thus, in a case where a medium pressure is difficult to be generated in the first expansion device 45 at the start of the heating only operation mode or at the start of the heating main operation mode, the high-pressure gas refrigerant from the first connecting pipe 4a is allowed to flow into the auxiliary heat exchanger 40, and in the auxiliary heat exchanger 40, the high-pressure gas refrigerant is changed to subcooled liquid and is allowed to flow into the suction part of the compressor 10 to thereby limit an excessive rise in the discharge temperature of the compressor 10. The backflow prevention device may be any device capable of preventing backflow of refrigerant, and may be an opening and closing device or an expansion device capable of full closing.

[0147] If the air-conditioning apparatus 500 is to be provided with a backflow prevention device, a first diverging-pipe opening and closing device, such as an opening and closing device and an expansion device capable of full closing that can open and close a flow path, may be provided instead of such a backflow prevention device. In a case where an excessive rise in the discharge temperature of the compressor 10 does not need to be limited, the first diverging-pipe opening and closing device and the opening and closing device 47 may be controlled to be closed, and the second expansion device 42 may be controlled to a small opening degree just short of full closure, thus minimizing stagnation of refrigerant in the bypass pipe 41 and the auxiliary heat exchanger 40. When an excessive rise in the discharge temperature of the compressor 10 needs to be limited, this configuration prevents an excessive amount of liquid refrigerant from flowing into the suction part of the compressor 10 from the second expansion device 42, thus preventing damage to the compressor 10 due to excessive liquid return to the compressor 10.

[0148] As in the air-conditioning apparatus 200 illustrated in Figs. 5 to 9, in the air-conditioning apparatus 500 illustrated in Fig. 13, refrigerant is injected into the suction part of the compressor 10 via the auxiliary heat exchanger 40 and the second expansion device 42 in cooling operation mode and heating operation mode, and thus the reliability of the system is ensured even when an inexpensive compressor is used rather than a compressor having a special structure. Further, limiting an excessive rise in the discharge temperature of the compressor 10 allows for an increase in the rotation speed of the compressor 10 to ensure sufficient heating capacity, thus minimizing a decrease in user comfort.

[0149] In the air-conditioning apparatus 500, the calculation method for and the size of the required total heat transfer area A_1 (m^2), which represents the area in which the auxiliary heat exchanger 40 contacts the air of the environment under which the outdoor unit 201 is installed, are the same as those in Embodiment 1.

[0150] Although the air-conditioning apparatus 500 illustrated in Fig. 13 employs the outdoor unit 201 as in Embodiment 2, the air-conditioning apparatus 500 may employ the outdoor unit 301 illustrated in Figs. 10 and 11.

[0151] Embodiments of the present invention are not limited to Embodiments mentioned above, and various modifications can be made. For example, although the foregoing description is directed to a case where the discharge temperature threshold is 115 degrees C in cooling operation mode and heating operation mode, the discharge temperature threshold may be any value determined depending on the limit value of the discharge temperature of the compressor 10. For example, if the limit value of the discharge temperature of the compressor 10 is 120 degrees C, the operation of the compressor 10 is controlled by the controller 60 so that the discharge temperature does not exceed this value. Specifically, when the discharge temperature exceeds 110 degrees C, the controller 60 lowers the frequency of the compressor 10 to lower the rotation speed of the compressor 10. Thus, if the discharge temperature of the compressor 10 is to be lowered by performing the above-mentioned injection, the discharge temperature threshold is preferably set to a temperature between 100 degrees C and 110 degrees C (for example, 105 degrees C), slightly lower than the temperature threshold of 110 degrees C at which the frequency of the compressor 10 is to be lowered. If, for example, the frequency of the compressor 10 is not lowered at the discharge temperature of 110 degrees C, the discharge

temperature threshold at which the injection is to be performed to lower the discharge temperature may be set to a value between 100 degrees C and 120 degrees C (for example, 115 degrees C).

[0152] Further, like, for example, an R32 refrigerant, other than an R32 refrigerant, a refrigerant mixture (zeotropic refrigerant mixture) of an R32 refrigerant and a refrigerant such as HFO1234yf and HFO1234ze, which is a tetrafluoropropene-based refrigerant having a low global warming potential and represented by the chemical formula $\text{CF}_3\text{CF}=\text{CH}_2$, may be used as the refrigerant. When R32 is used as the refrigerant, in particular, the discharge temperature under the same operating condition is higher by approximately 20 degrees C than the discharge temperature in a case where R410A is used. Thus, the discharge temperature needs to be lowered, and the effect of the above-mentioned injection is significant in this respect. The effect of the above-mentioned injection is particularly significant when a refrigerant with a comparatively high discharge temperature is used.

[0153] For a refrigerant mixture of an R32 refrigerant and HFO1234yf, when the mass fraction of R32 is equal to or higher than 62% (62 wt%), the discharge temperature is higher by three degrees C or more than the discharge temperature in a case where an R410A refrigerant is used. Thus, the effect of lowering discharge temperature through the above-mentioned injection is high. For a refrigerant mixture of R32 and HFO1234ze, when the mass fraction of R32 is equal to or higher than 43% (43 wt%), the discharge temperature is higher by three degrees C or more than the discharge temperature in a case where an R410A refrigerant is used. Thus, the effect of lowering discharge temperature through injection in the air-conditioning apparatuses 100 to 500 mentioned above is high. The kinds of refrigerant present in a refrigerant mixture are not limited to the above. Use of a refrigerant mixture containing a small amount of one or more other refrigerant components does not significantly affect discharge temperature and thus provides the same effect. The configuration employed may be used also for, for example, a refrigerant mixture containing R32, HFO1234yf, and a small amount of one or more other refrigerants. For any refrigerant whose discharge temperature is higher than that of R410A, there is a need to lower the discharge temperature, and thus the same effect can be obtained.

[0154] Further, for situations where a refrigerant whose high-pressure side operates under supercritical conditions, such as CO_2 (R744), needs to be used as the refrigerant in each of Embodiments 1 to 5 above to lower the discharge temperature, employing the refrigerant circuit configuration according to Embodiments can lower the discharge temperature.

[0155] Although Embodiments 1 to 5 are directed to a case where the auxiliary heat exchanger 40 and the heat source-side heat exchanger 12 are integrated, the auxiliary heat exchanger 40 may be disposed as an independent component. In another alternative configuration, the auxiliary heat exchanger 40 may be disposed on the upper side. Although the foregoing description is directed to a case where the auxiliary heat exchanger 40 is located on the lower side of the fins, and the heat source-side heat exchanger 12 is located on the upper side of the heat transfer fins, the auxiliary heat exchanger 40 may be located on the upper side, and the heat source-side heat exchanger 12 may be located on the lower side.

[0156] Although the air-conditioning apparatus capable of concurrent cooling and heating operation according to each of Embodiments 2, 3 and 5 above employs a pipe connection in which two main pipes 5 are used to connect the outdoor unit 201 and the relay device 3, the pipe connection is not limited to this configuration but various known methods may be used. For example, an excessive rise in the temperature of high-pressure, high-temperature gas refrigerant discharged from the compressor 10 can be limited as in Embodiment 2 mentioned above also when the air-conditioning apparatus capable of concurrent cooling and heating operation is configured so that the outdoor unit 1 and the relay device 3 are connected by using three main pipes 5.

[0157] Although the foregoing description is directed to a case where a low-pressure shell compressor is used as the compressor 10 according to Embodiments, the same effect can be obtained when, for example, a high-pressure shell compressor is used.

[0158] Although the foregoing description is directed to a case where a compressor that does not have a structure for allowing refrigerant to flow into its medium-pressure part is used as the compressor 10, the present invention is also applicable to compressors including an injection port for allowing refrigerant to flow into the medium-pressure part of the compressor.

[0159] Although it is common to attach an air-sending device to the heat source-side heat exchanger 12 and the load-side heat exchangers 26a to 26d to blow air through the heat exchangers to promote condensation or evaporation of refrigerant, the present invention is not limited to this configuration. For example, devices such as panel heaters that utilize radiation may be also used as the load-side heat exchangers 26a to 26d. The heat source-side heat exchanger 12 used may be a water-cooled heat exchanger that uses a fluid such as water and antifreeze to exchange heat. Any heat exchanger that allows refrigerant to reject heat or remove heat may be used. If a water-cooled heat exchanger is to be used, for example, a water-to-refrigerant heat exchanger, such as a plate heat exchanger and a double-pipe heat exchanger, may be installed for use as the auxiliary heat exchanger 40, or alternatively, a controller-cooling heat exchanger with a fan mounted to cool the controller 60 may be used.

[0160] Further, although the foregoing description is directed to use of a direct-expansion air-conditioning apparatus in which the outdoor unit 1 and the indoor unit 2, or the outdoor unit 1, the relay device 3, and the indoor unit 2 are

connected by pipes to circulate refrigerant, the present invention is not limited to this configuration. For example, an alternative configuration as illustrated in Fig. 14 may be employed, in which the relay device 3 is connected between the outdoor unit 1 and the indoor unit 2, heat exchangers that allow heat exchange between refrigerant and a heat medium such as water and brine, such as plate heat exchangers, are provided inside the relay device 3 as the load-side heat exchangers 26a and 26b, and heat exchangers 29a to 29d are respectively provided in the indoor units 2a to 2d. The present invention is also applicable to an air-conditioning apparatus in which refrigerant is circulated in an intervening area A between the outdoor unit and the relay unit, a heat medium such as water and brine is circulated in an intervening area B between the relay unit and the heat exchangers (load-side heat exchangers) provided in the indoor units 2, and the refrigerant and the heat medium are allowed to exchange heat in the relay device 3 for air conditioning.

Reference Signs List

[0161]

1,201,301,401,501 outdoor unit 2, 2a to 2d indoor unit 3 relay device 4 refrigerant pipe 4a first connecting pipe 4b second connecting pipe 5 main pipe 6 branch pipe 10 compressor 11 refrigerant flow switching device 12 heat source-side heat exchanger 13a to 13d first backflow prevention device 13g backflow prevention device 14 gas-liquid separator 15 third expansion device 16 fan 19 accumulator 21a to 21d second backflow prevention device 22a to 22d third backflow prevention device 23a to 23d first opening and closing device 24a to 24d second opening and closing device 25, 25a to 25d load-side expansion device 26, 26a to 26d load-side heat exchanger 27 fourth expansion device 28a heat exchanger 29a to 29d load-side heat exchanger 31, 31 a, 31 b inlet-side temperature sensor 32, 32a, 32b outlet-side temperature sensor 33 inlet-side pressure sensor 34 outlet-side pressure sensor 40 auxiliary heat exchanger 41 bypass pipe 42 second expansion device 43 discharge temperature sensor 44 pressure sensor 45 first expansion device 46 outside-air temperature sensor 47 opening and closing device 48 first diverging pipe 49 second diverging pipe 50 refrigerant-to-refrigerant heat exchanger 51 temperature sensor 60 controller 100, 200, 300, 400, 500 air-conditioning apparatus A_1 total heat transfer area A_2 total heat transfer area B intervening area G_r total refrigerant flow rate G_{r2} refrigerant flow rate Q_1 amount of heat exchange T_1 temperature T_2 temperature T_4 temperature h, h_1, h_2, h_3 enthalpy k overall heat transmission coefficient ΔT_m logarithmic mean temperature difference

Claims

1. An air-conditioning apparatus including a refrigeration cycle in which refrigerant circulates, the refrigeration cycle including a compressor, a refrigerant flow switching device, a heat source-side heat exchanger, a load-side expansion device, and a load-side heat exchanger connected by a refrigerant pipe, the air-conditioning apparatus comprising:
 - a first expansion device provided between the heat source-side heat exchanger and the load-side expansion device;
 - a bypass pipe having one end connected between the first expansion device and the heat source-side heat exchanger, and allowing refrigerant flowing out of the first expansion device to flow through the bypass pipe;
 - an auxiliary heat exchanger connected to an other end of the bypass pipe and a suction part of the compressor, and cooling refrigerant flowing through the bypass pipe and supplying the cooled refrigerant to the suction part of the compressor;
 - a second expansion device provided on a refrigerant outlet side of the auxiliary heat exchanger, and regulating a flow rate of refrigerant allowed to flow into the suction part of the compressor from the auxiliary heat exchanger; and
 - a controller configured to control the refrigerant flow switching device to switch a flow path of refrigerant between a flow path in a case where the heat source-side heat exchanger acts as a condenser or a gas cooler and a flow path in a case where the heat source-side heat exchanger acts as an evaporator, and control an opening degree of the first expansion device and an opening degree of the second expansion device, when the heat source-side heat exchanger acts as the condenser or the gas cooler, the controller being configured to control the first expansion device and the second expansion device to allow high-pressure refrigerant to flow into the auxiliary heat exchanger, and when the heat source-side heat exchanger acts as the evaporator, the controller being configured to control the first expansion device to allow medium-pressure refrigerant to flow into the auxiliary heat exchanger, and

control the second expansion device to allow refrigerant cooled in the auxiliary heat exchanger to flow into the suction part of the compressor.

2. The air-conditioning apparatus of claim 1, further comprising a discharge temperature sensor detecting a discharge temperature of refrigerant discharged from the compressor, wherein, when the discharge temperature detected by the discharge temperature sensor is higher than a discharge temperature threshold, the controller is configured to regulate the opening degree of the second expansion device to make the discharge temperature equal to or lower than the discharge temperature threshold.

3. The air-conditioning apparatus of claim 2, wherein a settable upper limit of the discharge temperature threshold is 115 degrees C.

4. The air-conditioning apparatus of any one of claims 1 to 3, further comprising:

a pressure sensor detecting a pressure of refrigerant flowing into the bypass pipe; and an outside-air temperature sensor detecting a temperature of air around the heat source-side heat exchanger, wherein, when the heat source-side heat exchanger acts as the evaporator, the controller is configured to calculate a saturation temperature based on the pressure of refrigerant detected by the pressure sensor, and regulate the opening degree of the first expansion device so that a difference between the calculated saturation temperature and the temperature detected by the outside-air temperature sensor approaches a temperature difference threshold.

5. The air-conditioning apparatus of claim 4, wherein a settable lower limit of the temperature difference threshold is 10 degrees C.

6. The air-conditioning apparatus of any one of claims 1 to 5, wherein the heat source-side heat exchanger and the auxiliary heat exchanger include heat transfer tubes having different refrigerant flow paths attached to same heat transfer fins, wherein air around the heat source-side heat exchanger flows through both the heat source-side heat exchanger and the auxiliary heat exchanger, and wherein the auxiliary heat exchanger has a heat transfer area smaller than a heat transfer area of the heat source-side heat exchanger.

7. The air-conditioning apparatus of claim 6, wherein a ratio $A_1/(A_1 + A_2)$ is from 0.46% to 5%, where A_1 is an area in which the auxiliary heat exchanger contacts air, and A_2 is an area in which the heat source-side heat exchanger contacts air.

8. The air-conditioning apparatus of any one of claims 1 to 7, wherein the bypass pipe is connected to a first diverging pipe and a second diverging pipe, the first diverging pipe having one end connected between the first expansion device and the load-side expansion device and having an other end connected to an inflow side of the auxiliary heat exchanger, the second diverging pipe having one end connected to the first diverging pipe and having an other end connected to a discharge side of the compressor, and wherein the second diverging pipe is provided with an opening and closing device regulating a flow rate of refrigerant flowing into the bypass pipe.

9. The air-conditioning apparatus of claim 8, wherein the first diverging pipe is provided with a backflow prevention device to prevent backflow.

10. The air-conditioning apparatus of claim 8 or 9, wherein, when the heat source-side heat exchanger acts as the condenser or the gas cooler, the controller is configured to control the opening and closing device to allow part of refrigerant discharged from the compressor to flow into the bypass pipe from the second diverging pipe, and, when the heat source-side heat exchanger acts as the evaporator, the controller is configured to control the opening and closing device to be closed.

11. The air-conditioning apparatus of any one of claims 1 to 10, wherein the compressor, the refrigerant flow switching device, and the heat source-side heat exchanger are installed in an outdoor unit, wherein the load-side expansion device and the load-side heat exchanger are installed in an indoor unit, and

wherein the outdoor unit and the indoor unit are connected to circulate refrigerant via a relay device.

12. The air-conditioning apparatus of claim 11,
wherein the bypass pipe is connected to a first diverging pipe and a second diverging pipe, the first diverging pipe
having one end connected between the first expansion device and the heat source-side heat exchanger and having
an other end connected to an inflow side of the auxiliary heat exchanger, the second diverging pipe having one end
connected to the first diverging pipe and having an other end connected to a flow path between the heat source-
side heat exchanger and an inlet-side flow path of the relay device, and
wherein the second diverging pipe is provided with an opening and closing device regulating a flow rate of refrigerant
flowing into the bypass pipe.
13. The air-conditioning apparatus of claim 12, wherein the first diverging pipe is provided with a backflow prevention
device to prevent backflow.
14. The air-conditioning apparatus of claim 12 or 13, wherein, when the heat source-side heat exchanger acts as the
condenser or the gas cooler, the controller is configured to control the opening and closing device to allow part of
refrigerant discharged from the compressor to flow into the bypass pipe from the second diverging pipe, and, when
the heat source-side heat exchanger acts as the evaporator, the controller is configured to control the opening and
closing device to be closed.
15. The air-conditioning apparatus of any one of claims 1 to 14, wherein the heat source-side heat exchanger or the
auxiliary heat exchanger is a water-to-refrigerant heat exchanger exchanging heat between water and refrigerant.

FIG. 1

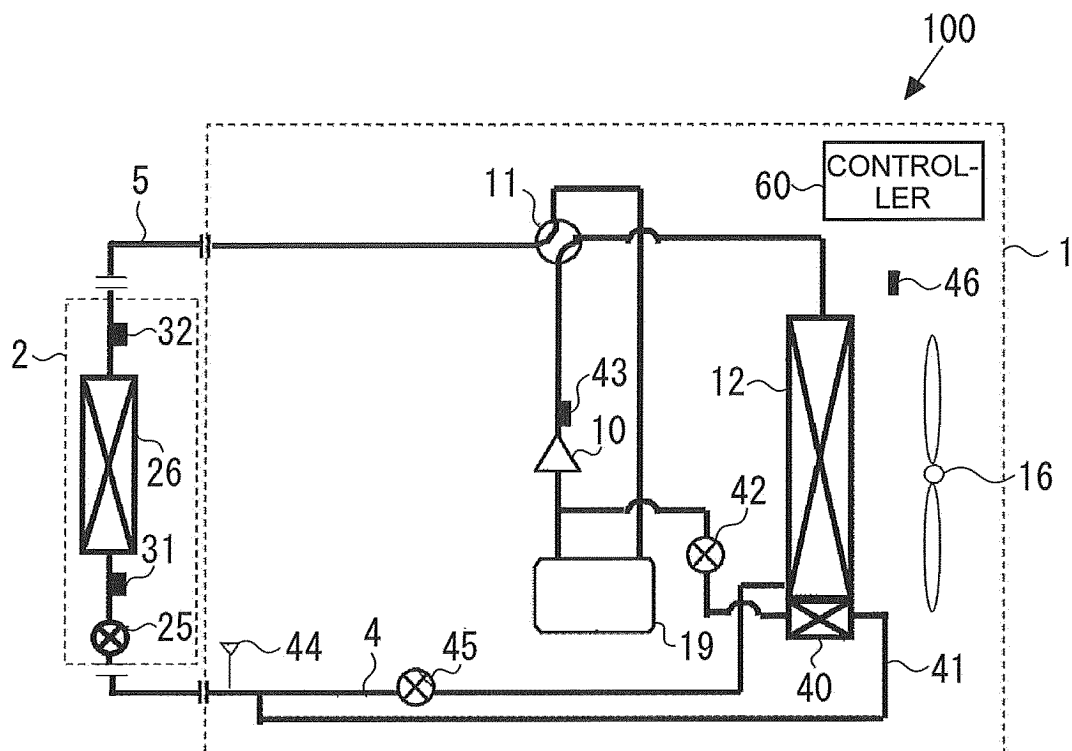


FIG. 2

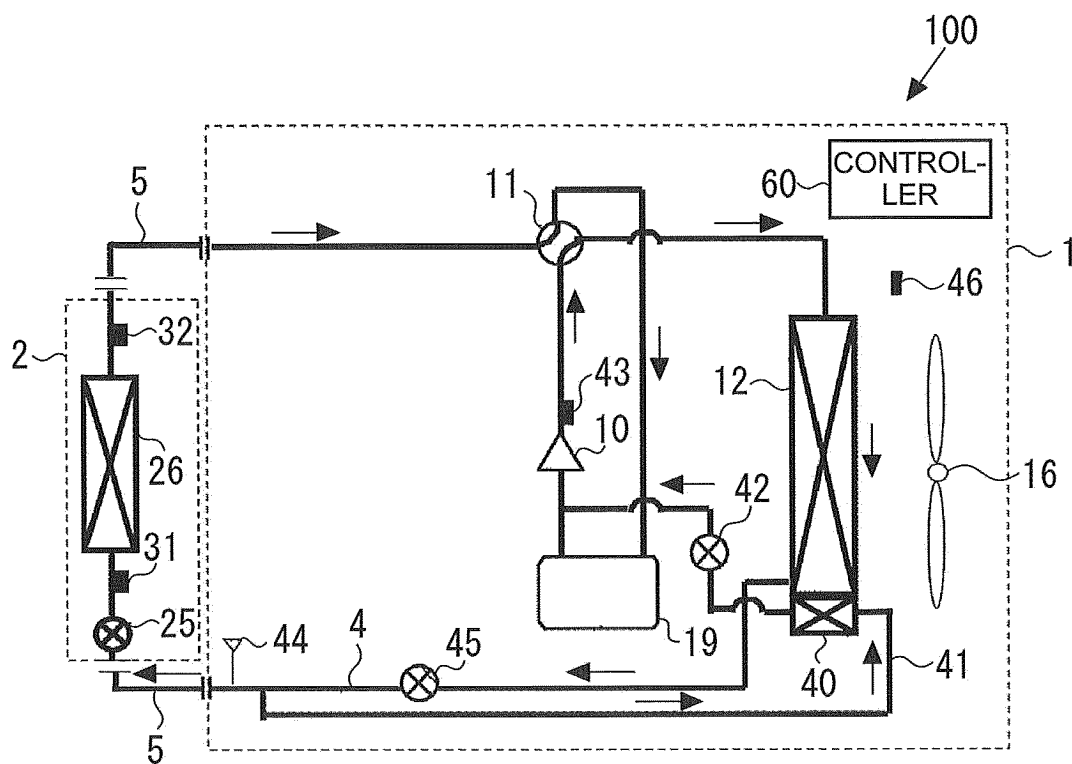


FIG. 3

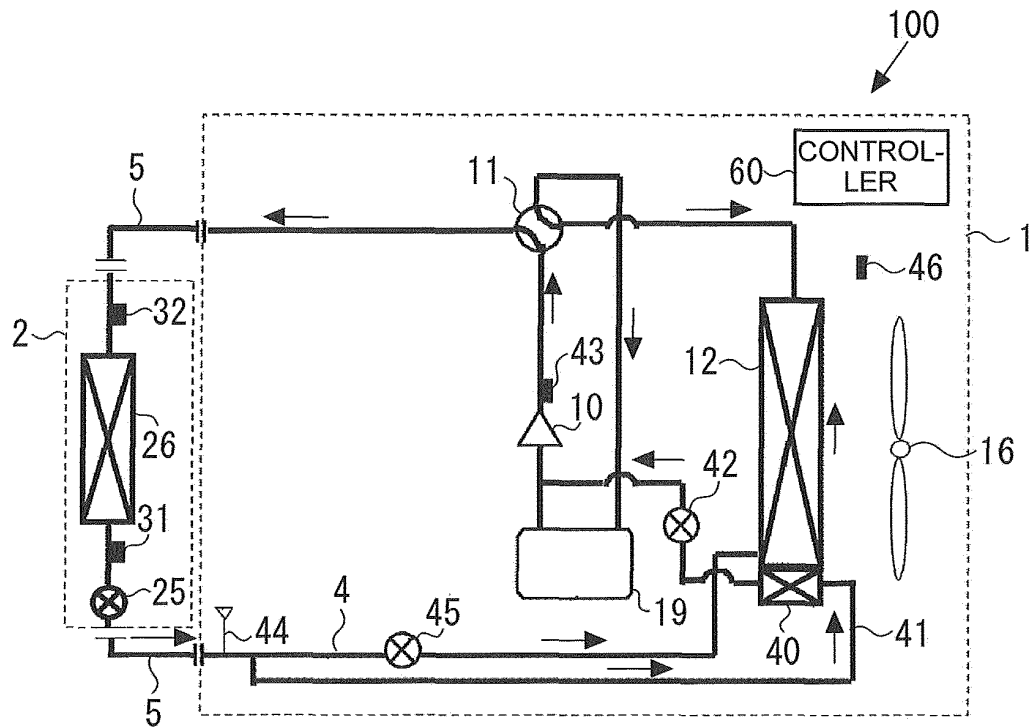


FIG. 4

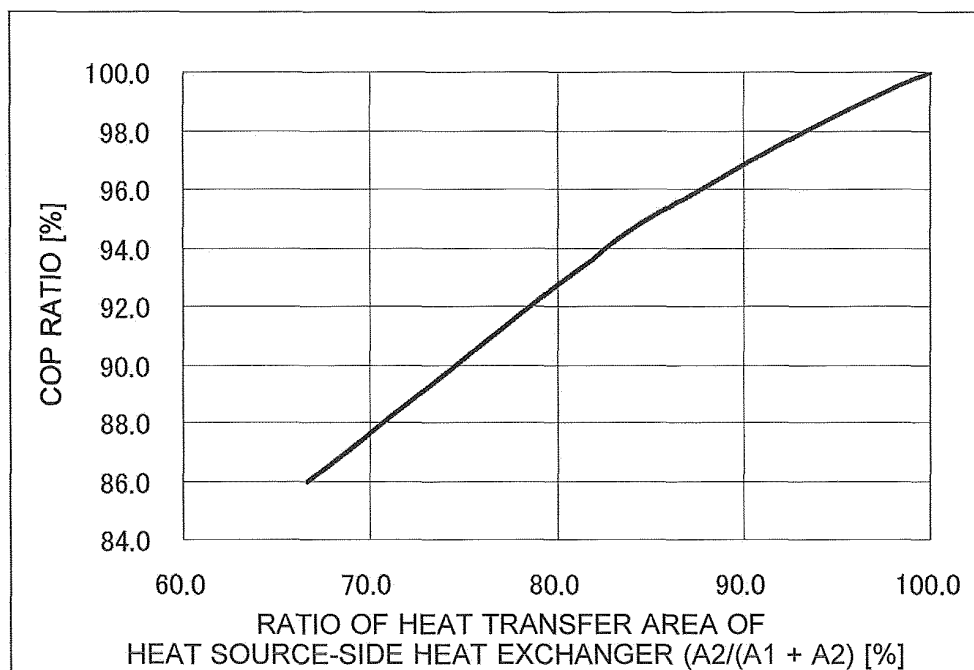


FIG. 5

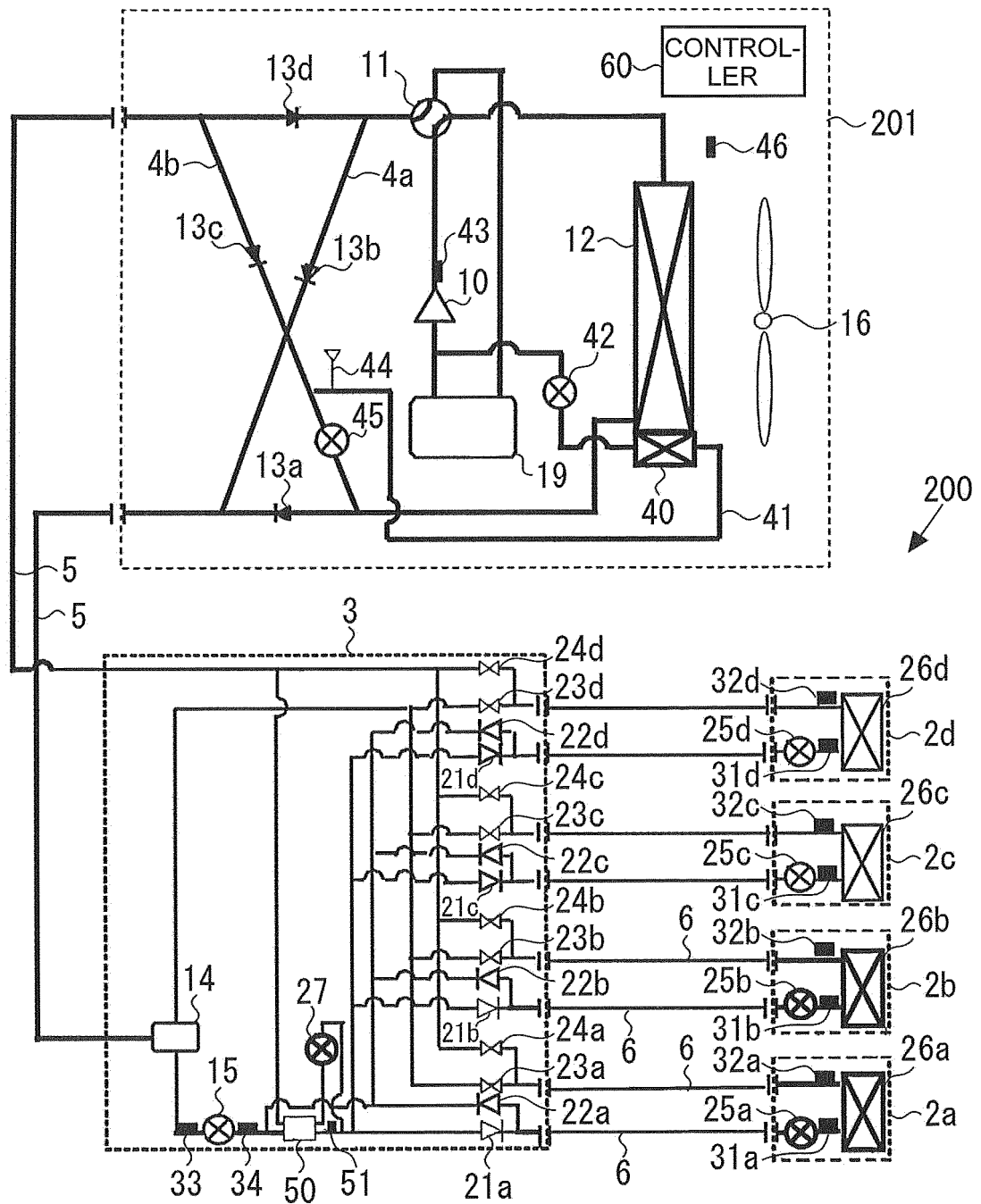


FIG. 6

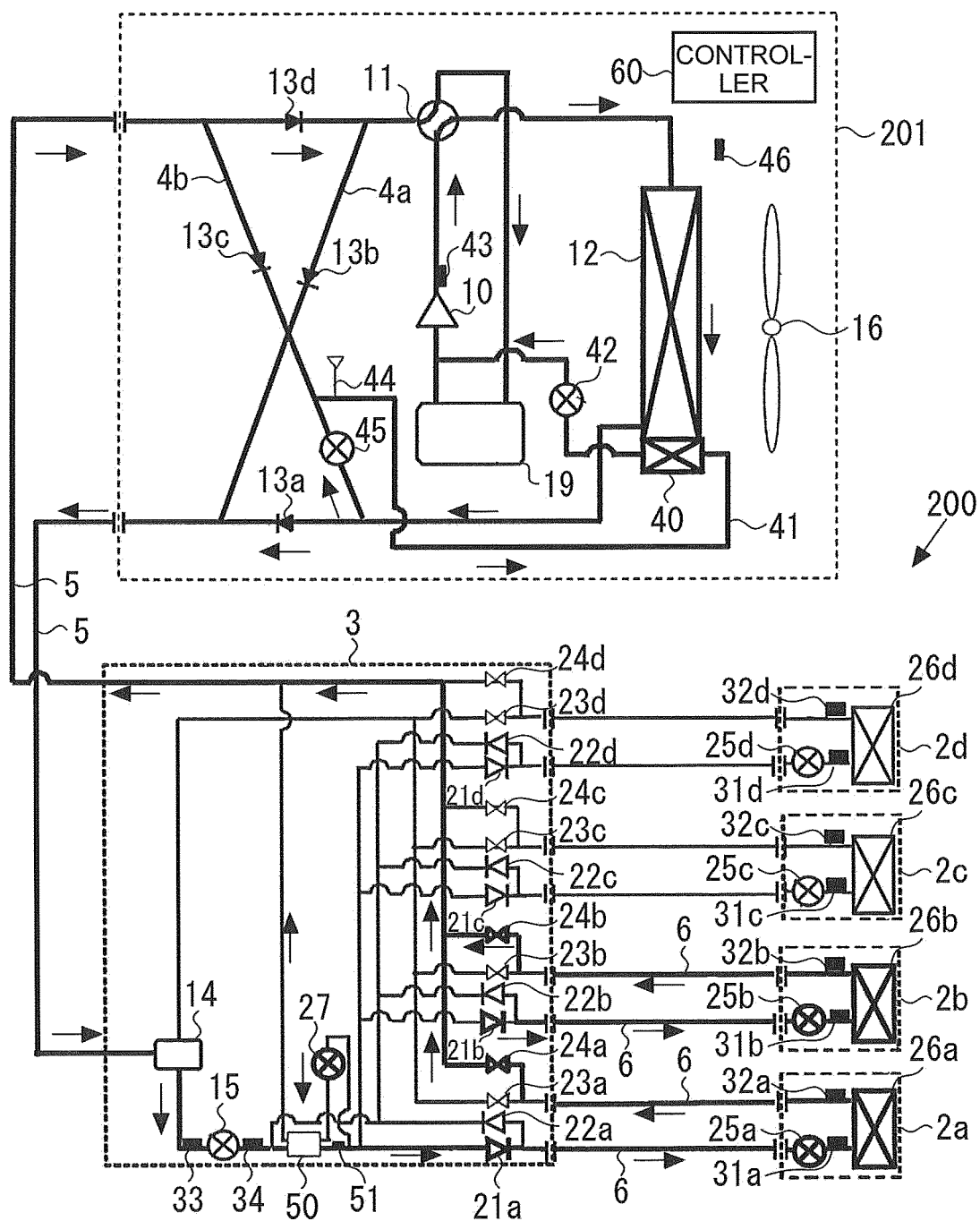


FIG. 7

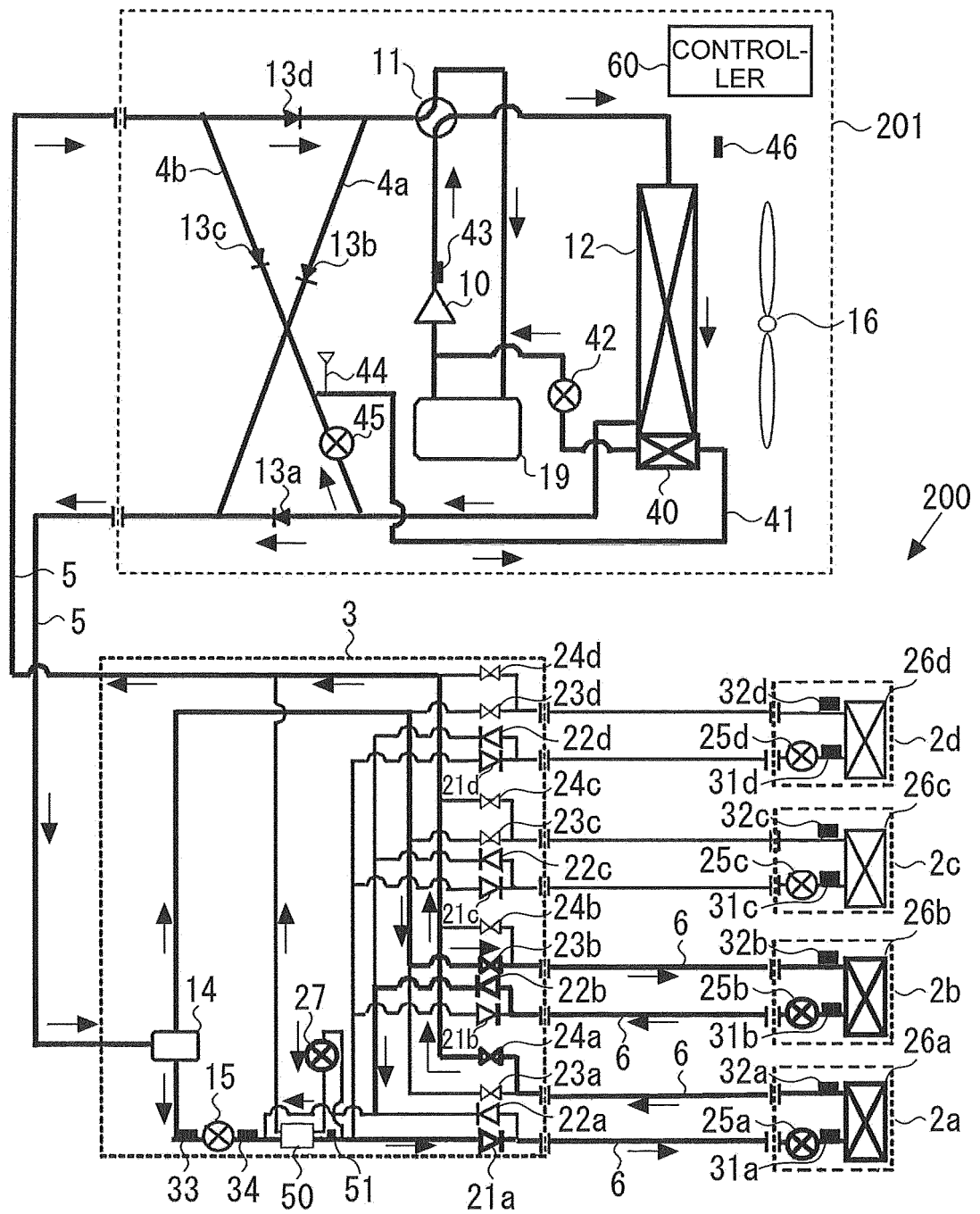


FIG. 8

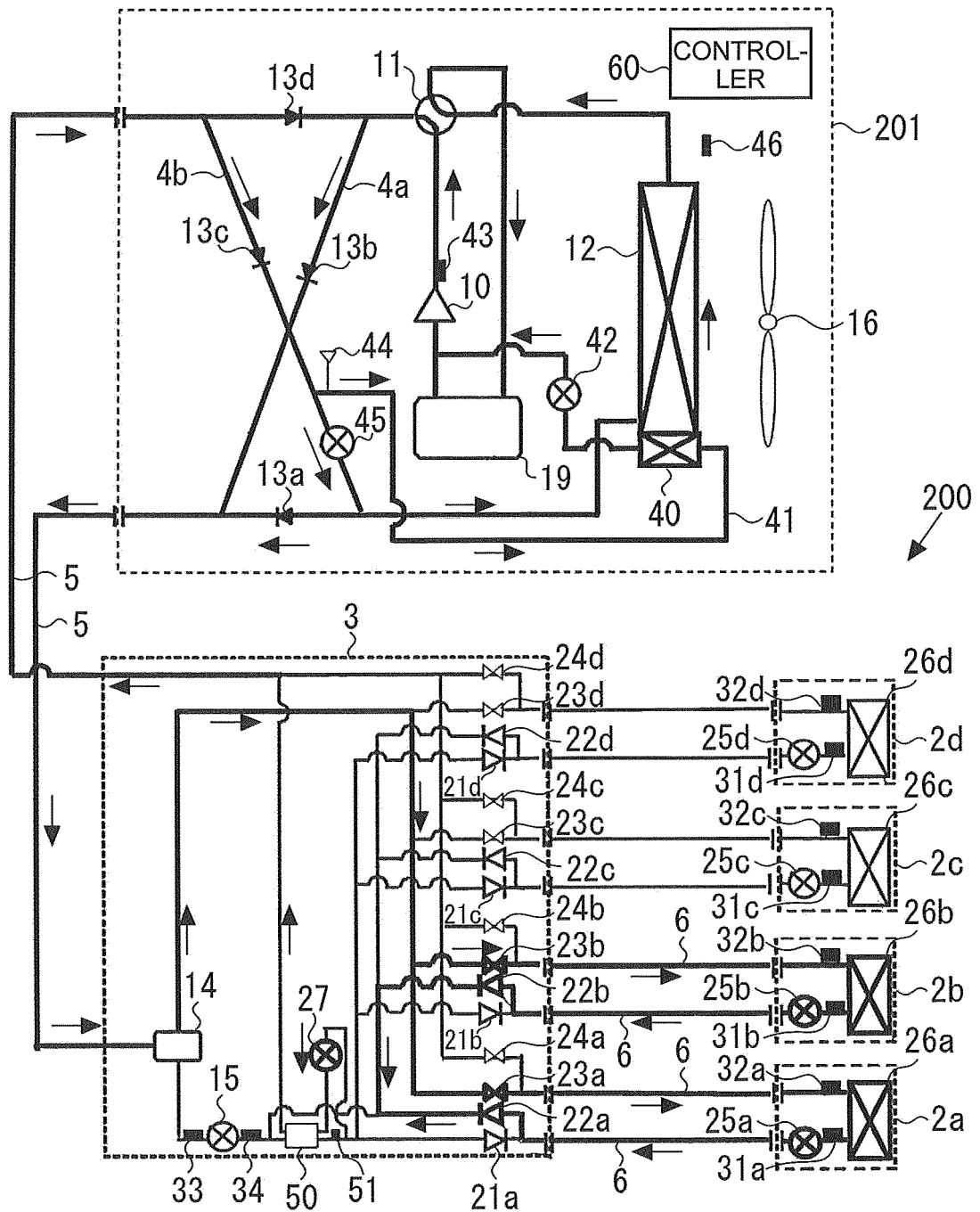


FIG. 9

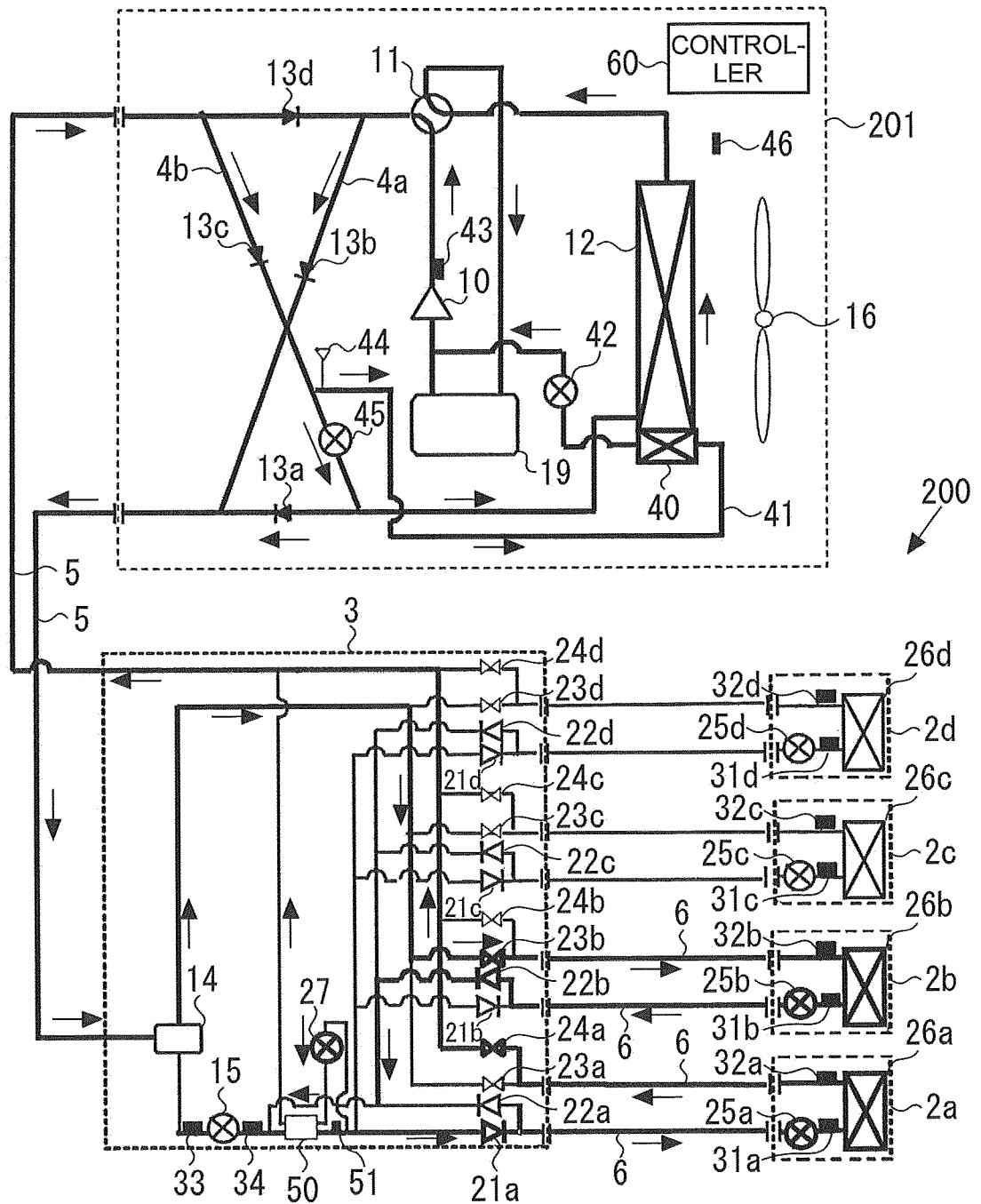


FIG. 10

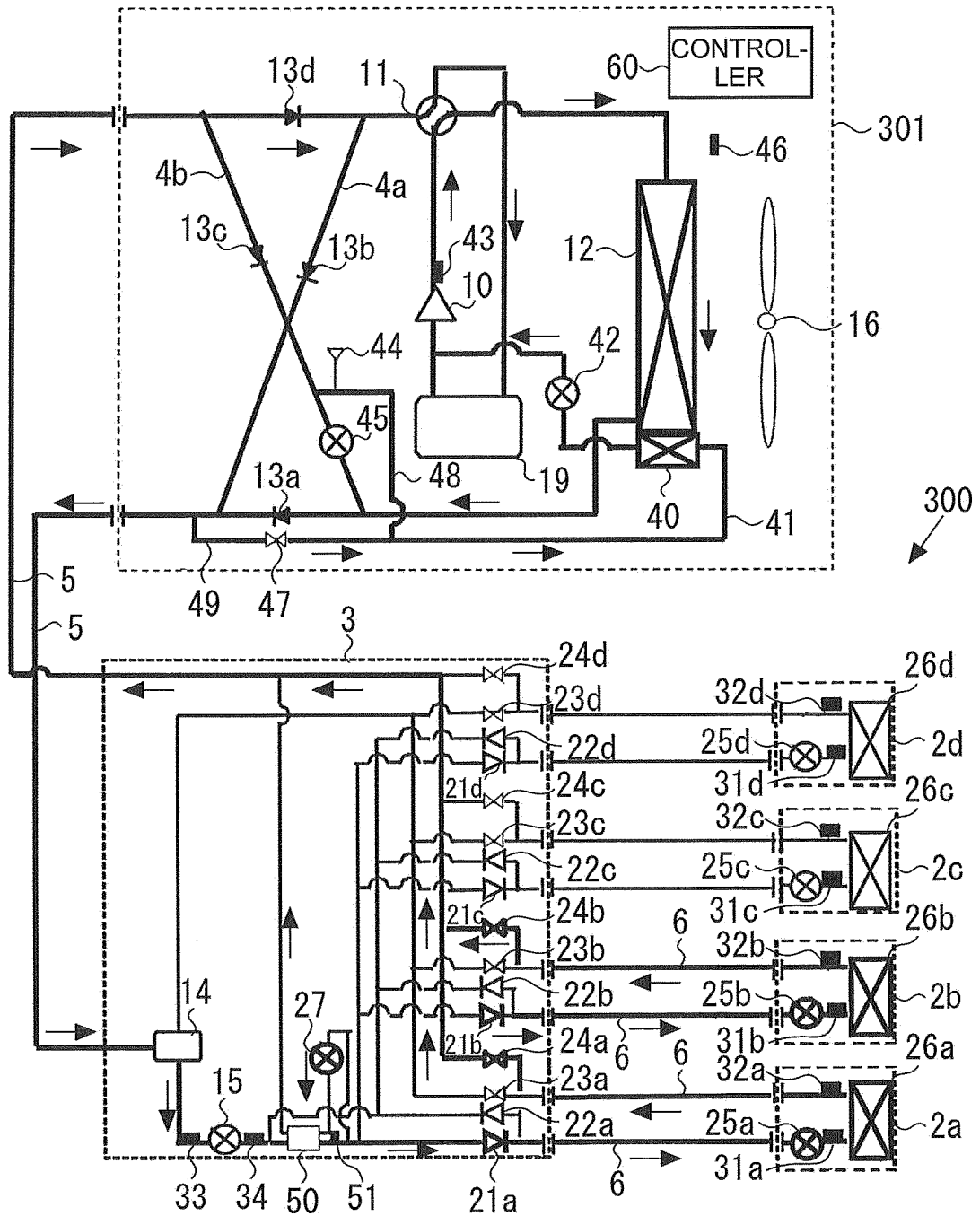


FIG. 11

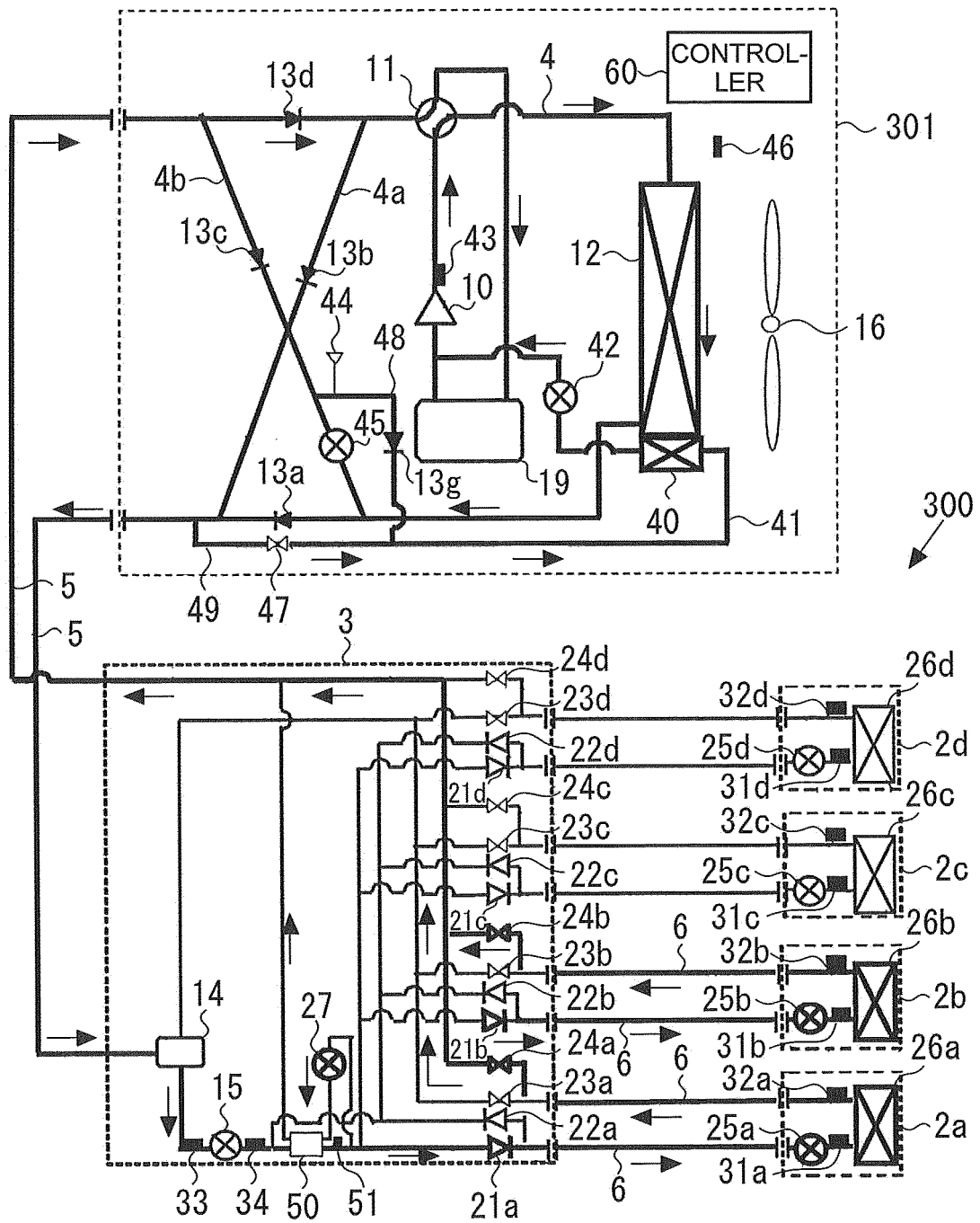


FIG. 12

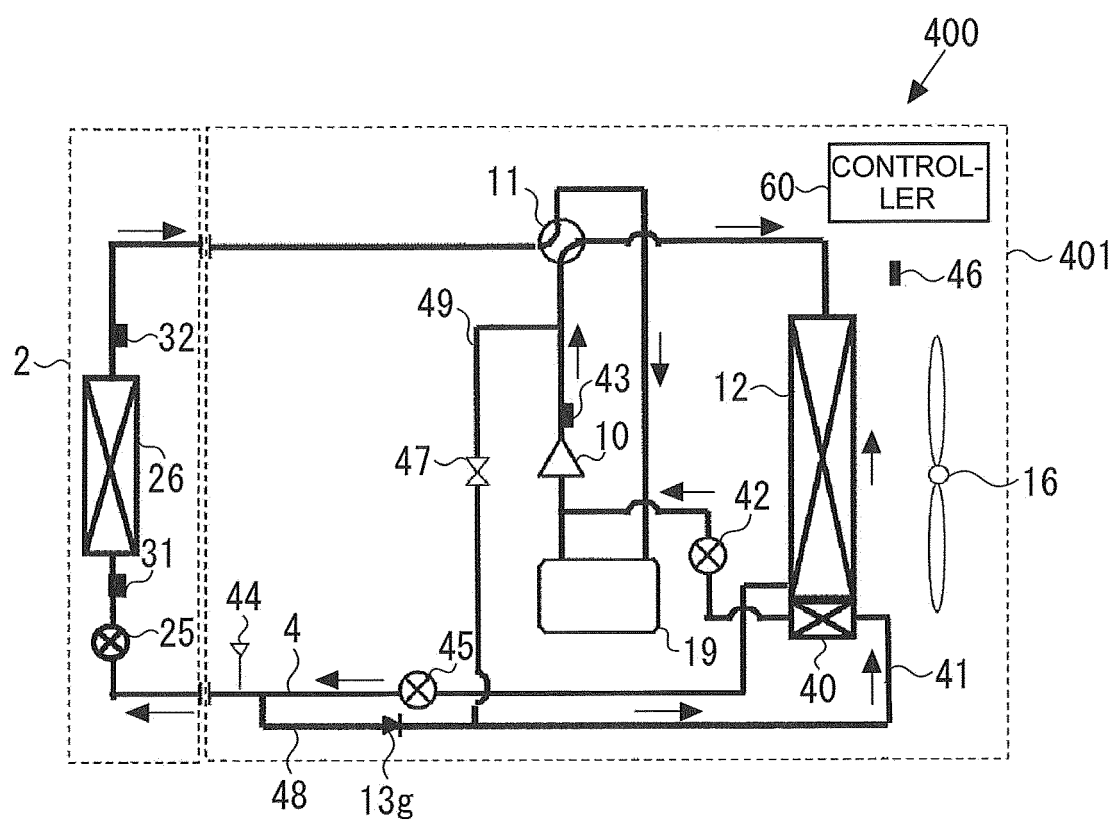


FIG. 13

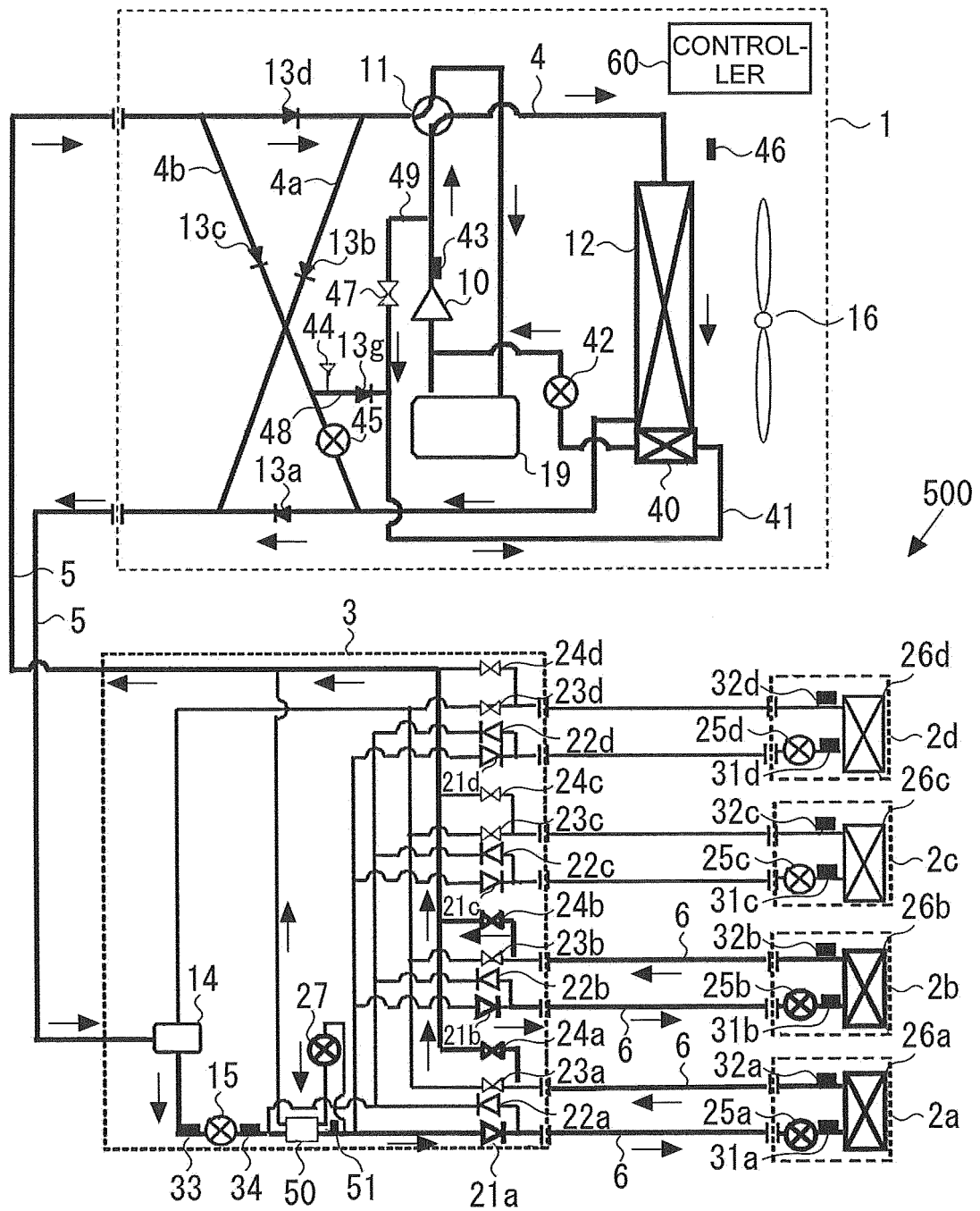
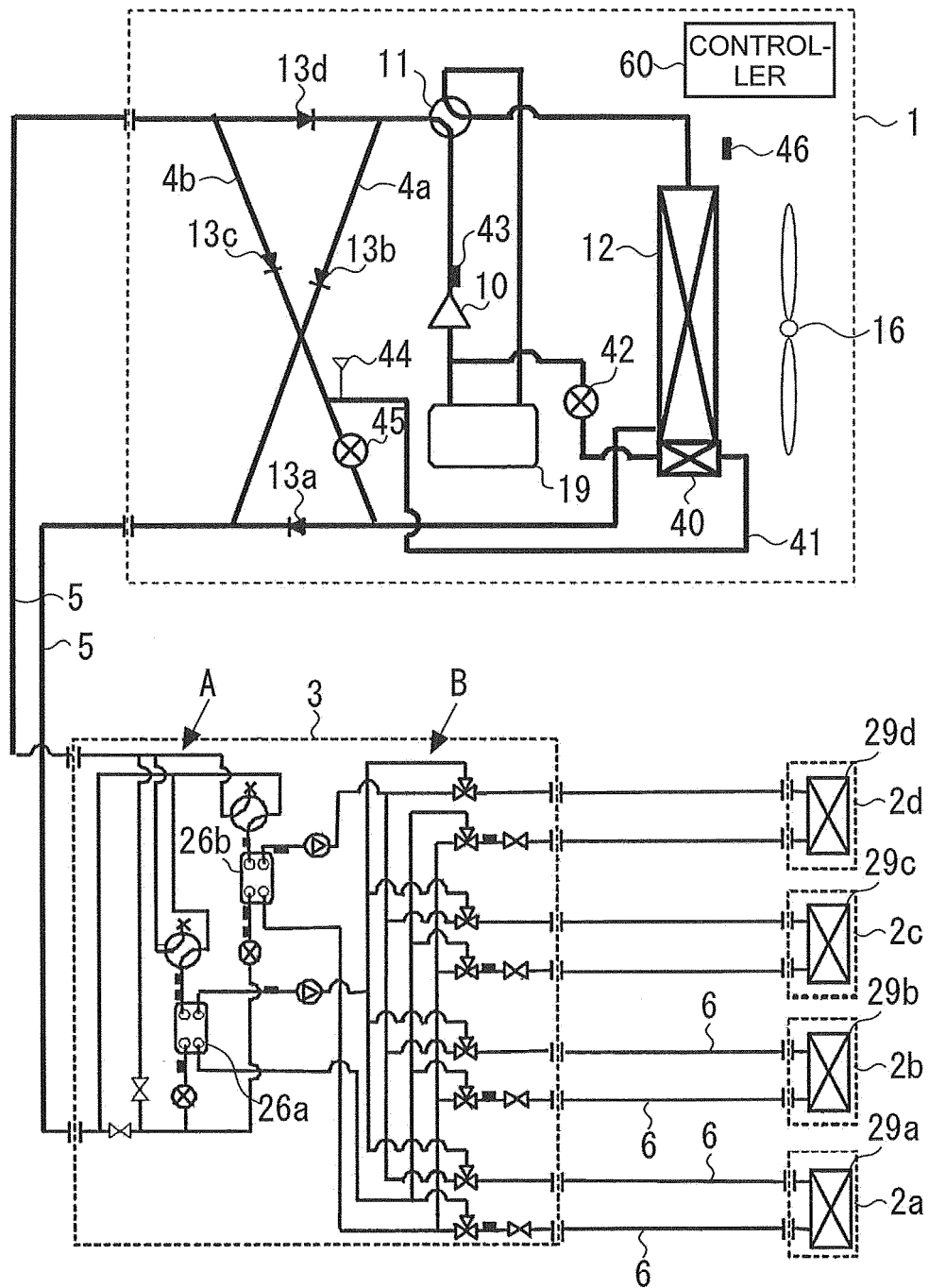


FIG. 14



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/053809

A. CLASSIFICATION OF SUBJECT MATTER

F25B1/00(2006.01)i, F24F11/02(2006.01)i, F25B13/00(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)

F25B1/00, F24F11/02, F25B13/00

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2014

Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

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 2009-228979 A (Mitsubishi Electric Corp.), 08 October 2009 (08.10.2009), paragraphs [0040] to [0046]; fig. 4 (Family: none)	1-15
A	JP 56-32862 Y2 (Matsushita Electric Industrial Co., Ltd.), 04 August 1981 (04.08.1981), column 2, lines 4 to 21; fig. 2, 3 (Family: none)	1-15
A	JP 2573028 B2 (Sanyo Electric Co., Ltd.), 16 January 1997 (16.01.1997), column 3, line 38 to column 4, line 13; fig. 1 (Family: none)	1-15

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

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search
12 May, 2014 (12.05.14)Date of mailing of the international search report
27 May, 2014 (27.05.14)Name and mailing address of the ISA/
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INTERNATIONAL SEARCH REPORT

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PCT/JP2014/053809

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4-27465 B2 (Sanyo Electric Co., Ltd.), 11 May 1992 (11.05.1992), column 4, line 42 to column 5, line 26; fig. 2 (Family: none)	1-15

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2008138921 A [0004]